TECHNICAL GUIDANCE MANUAL FOR THE IMPLEMENTATION OF THE HAWAI'I STATE CONTINGENCY PLAN

State of Hawai'i
Department of Health
Office of Hazard Evaluation and Emergency Response
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SECTION 1
HAZARD EVALUATION AND EMERGENCY RESPONSE OFFICE AUTHORITIES, RESPONSIBILITIES, AND ORGANIZATION

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SECTION 1 ACRONYMS AND ABBREVIATIONS

ARAR	Applicable or relevant and appropriate requirements
CAB	Clean Air Branch
CAO	Compliance Assistance Office
CERCLA	Comprehensive Environmental Response, Compensation & Liability Act (also known as the Federal Superfund Law)
CWB	Clean Water Branch
DoD	United States Department of Defense
DSMOA	DoD State Memorandum of Agreement
EAL	Environmental Action Level
EHSD	Environmental Health Services Division
EMD	Environmental Management Division
EP&R	HEER Office Emergency Preparedness and Response Section
EPCRA	Emergency Planning and Community Right-to-know Act
EPO	Environmental Planning Office
ERO	Environmental Resources Office
HAR	Hawai'i Administrative Rules
Hawai'i SCP	Hawai'i State Contingency Plan (HAR, Title 11, Chapter 451)
HCIF	Hawai'i Chemical Inventory Form
HDOH	Hawai'i Department of Health
HEER Office	Hazard Evaluation and Emergency Response Office
HEPCRA	Hawai'i Emergency Planning and Community Right-to-Know Act (HRS, Chapter 128E)
HERL	Hawai'i Environmental Response Law (HRS, Chapter 128D)
HRS	Hawai'i Revised Statutes
HSERC	Hawai'i State Emergency Response Commission
LEPC	Local Emergency Planning Committees
LOC	Letter of Completion
NCP	National Contingency Plan
OPA	Oil Pollution Act of 1990
RPM	Remedial Project Manager
SCP	Hawai'i State Contingency Plan
SDAR	HEER Office Site Discovery, Assessment and Remediation Section
SDWB	Safe Drinking Water Branch
SHWB	HDOH Solid and Hazardous Waste Branch
SOSC	State On-Scene Coordinator
TGM	Technical Guidance Manual
UECA	Uniform Environmental Covenants Act (HRS, Chapter 508C)
UIPA	Uniform Information Practices Act
USEPA	United States Environmental Protection Agency
UST	Underground Storage Tank
VRP	HEER Office Voluntary Response Program
WWB	Wastewater Branch

1.0 HAZARD EVALUATION AND EMERGENCY RESPONSE OFFICE AUTHORITIES, RESPONSIBILITIES, AND ORGANIZATION

The Hawai‘i Department of Health (HDOH) Office of Hazard Evaluation and Emergency Response (HEER Office) has responsibility and legal authority to respond to releases, threats of releases, or discoveries of hazardous substances, including oil, that present a substantial endangerment to public health or the environment. Responses may require:

1. Emergency response (see Subsection 2.3), and/or
2. Longer-term (non-emergency) environmental cleanup (see Subsection 2.4).

For information and guidance relating to emergency responses, see Subsection 2.3 and Subsection 20.1. All emergencies involving hazardous substance releases (e.g. recent hazardous substance spills, or identification of containers of hazardous substances that have spilled/leaked or present an imminent spill/leak hazard) should be reported immediately, as detailed in Subsection 2.3.1.1 (Release Notification). This Technical Guidance Manual (TGM) primarily provides information and guidance to address non-emergency environmental cleanups. See Subsection 2.4 (Environmental Cleanups) for a brief overview of non-emergency environmental cleanups and other TGM sections for details. This includes guidance on the cleanup process, site assessment, sampling strategies, data quality control, analyses of samples, environmental hazard evaluations, cleanup technologies, reporting requirements, and other relevant information.

1.1 HEER OFFICE LEGAL AUTHORITIES

Although a number of laws may be available to assist in carrying out responsibilities and action, the HEER Office derives authority for the main activities discussed in this TGM from the following statutes or rules:

- Hawai'i Environmental Response Law (HERL) - Hawai'i Revised Statutes (HRS) Chapter 128D;
- Hawai'i State Contingency Plan (Hawai'i SCP) - Hawai'i Administrative Rules (HAR), Title 11, Chapter 451
- Uniform Environmental Covenants Act (UECA) -HRS, Chapter 508C
- Hawai'i Emergency Planning and Community Right-to-Know Act (HEPCRA) - HRS, Chapter 128E

Each of these documents is discussed briefly in the following sections

1.1.1 THE HAWAI'I ENVIRONMENTAL RESPONSE LAW (HERL), HAWAI'I REVISED STATUTES (HRS) CHAPTER 128D

The primary state-level enabling legislation for the HEER Office is Chapter 128D, HRS, which is referred to as Hawai'i's Environmental Response Law (HRS 128D). This statute, which became effective in 1990, establishes authority at the state level to respond to releases of hazardous substances. It is fashioned after the 1980 Comprehensive Environmental Response, Compensation & Liability Act (CERCLA), commonly known as the Federal Superfund Law, which grants authority to the United States Environmental Protection Agency (USEPA). The HERL grants certain authority and responsibility to the HDOH to respond to both emergency and non-emergency hazardous substance releases or threats of releases.

A release is defined as any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing of any hazardous substance, pollutant, or contaminant into the environment. Certain exclusions from the definition of a release are also identified in HRS 128D-1 (definition of release).

The HERL includes the definition of a hazardous substance, which is a compilation of specific hazardous substances listed in various federal environmental protection laws such as the Clean Water Act, CERCLA, the Solid Waste Disposal Act, the Clean Air Act, and the Toxic Substances Control Act. However, hazardous substances addressed under HERL also include oil and trichloropropane (this is a major difference from CERCLA). Consequently, the HEER Office is also involved in oil spill prevention planning, preparedness, and response activities as required under the federal Oil Pollution Act (OPA) of 1990.

Part II of the HERL (128D-31 through 128D-41) was adopted through amendments in 1997, and addresses the Voluntary Response Program (VRP). The VRP encourages owners and purchasers to voluntarily investigate and cleanup property that may be contaminated. More detailed information on the VRP is provided in Subsection 20.3.

1.1.2 HAWAI'I STATE CONTINGENCY PLAN (HAWAI'I SCP), HAWAI'I ADMINISTRATIVE RULES (HAR) TITLE 11, CHAPTER 451

The procedures by which HDOH responds to hazardous substance releases under the HERL is described more fully in a set of administrative rules known as the Hawai'i State Contingency Plan (Hawai'i SCP) (HAR, 1995). These state administrative rules are based upon (but not the same as) the USEPA CERCLA-related administrative rules called the National Contingency Plan (NCP).

Among other things, the Hawai'i SCP explains:

- What hazardous substances are, and when parties are required to report releases of hazardous substances
- The process by which HDOH will oversee investigation and cleanup of releases and select cleanup remedies
- How the public will be kept informed and afforded the opportunity to participate in cleanup decisions

The site discovery, site investigation and site cleanup processes that are described under the Hawai'i SCP rules are described in more detail in Section 2.

1.1.3 THE UNIFORM ENVIRONMENTAL COVENANTS ACT (UECA), HAWAI'I REVISED STATUTES CHAPTER 508C

The UECA (HRS, 508C), enacted in July 2006, provides a statutory framework for imposing certain conditions on environmental response projects. These "institutional controls," as they are called, are used in situations where it is not feasible or necessary to remove all contamination. The UECA provides a regulatory mechanism for recording institutional controls and requires the creation of a publicly accessible, web-based registry to identify properties utilizing this mechanism.

The UECA creates an "environmental covenant", which specifies the conditions for a property. The environmental covenant is recorded on the official land records to assure that current and subsequent owners of the property are subject to the conditions until the covenant is amended or terminated. The UECA operates only in conjunction with other environmental laws and does not itself prescribe any cleanup processes or standards. An environmental covenant recorded under UECA is used only as part of an environmental response project. UECA is not limited to use by HDOH. Any two parties can enter into a UECA environmental covenant.

1.1.4 THE HAWAI'I EMERGENCY PLANNING AND COMMUNITY RIGHT-TO-KNOW ACT, (HEPCRA), HAWAI'I REVISED STATUTES CHAPTER 128E

The Hawai'i Emergency Planning and Community Right-To-Know Act of 1993 (HEPCRA), established planning, reporting, emergency notification, and public information access requirements related to hazardous chemicals (HRS 128E). HEPCRA is modeled after the federal Emergency Planning and Community Right-to-know Act (EPCRA). The act also created the Hawai'i State Emergency Response Commission (HSERC), established within the HDOH, as well as Local Emergency Planning Committees (LEPC) located on O'ahu, Maui, Hawai'i, and Kaua'i Islands to implement emergency response planning and related actions.

Under HEPCRA, facilities that have spilled hazardous substances, or that store, use, or release certain chemicals are subject to various reporting requirements. All of this information is made publicly available so that interested parties may become informed about potentially dangerous chemicals in their community. Facilities must report annually (using the Hawai'i Chemical Inventory Form – HCIF – sometimes referred to as Tier II reports) on hazardous substances stored on their premises, if the amounts stored exceed specified threshold planning quantities.

For additional information and guidance relating to hazardous chemicals, emergency planning, and emergency response, see Subsection 2.3 and Subsection 20.1.

1.1.5 AUTHORITY TO REQUEST SITE INFORMATION

The HERL also grants HDOH the authority to require any person to submit information regarding a hazardous substance release. This authority is contained in Chapter 128D-4(b). Chapter 128D-8, provides authority to enforce orders that are issued by HDOH with penalties up to $50,000 for each separate violation.

1.1.6 AUTHORITY TO CONDUCT SITE INSPECTIONS AND COLLECT DATA

The HERL, Chapter 128D-4 also grants HDOH extensive authority to conduct its own inspections and investigations. HERL Chapter 128D-4(b)(3) requires responsible parties (upon notice) to grant HDOH access to a facility/property at all reasonable times for inspections or to obtain copies of documents/records.

1.1.7 AUTHORITY TO REQUIRE RESPONSIBLE PARTY-LEAD ACTIONS

HERL Chapter 128D-4(a)(1) grants HDOH the authority to require that responsible parties investigate and clean up hazardous substance releases. If parties fail to comply with HDOH orders, HDOH may perform the work, sue the parties to recover its costs and impose punitive penalties and legal interest [128D-5(a)]. However, HDOH prefers to work cooperatively with responsible parties to address hazardous substance releases as provided for in HERL Chapter 128D-4(a)(3).

1.1.8 AUTHORITY TO CONDUCT STATE-LED ACTIONS

Situations may arise when the party responsible for a hazardous substance release is either unable or unwilling to take appropriate action. In such cases, Chapter 128D-4(a)(4) grants HDOH the authority to conduct state-led response actions. This authority includes any investigation that is necessary, as well as the actual cleanup action. Responsible parties that refuse to cooperate with HDOH are subject to "cost recovery" and may also be required to pay punitive penalties, as discussed in Subsection 1.1.9.

1.1.9 AUTHORITY TO RECOVER COSTS

Chapter 128D emphasizes that responsible parties should report and clean up releases of hazardous substances. When responsible parties do not act, HDOH may take action and recover its costs as prescribed in Chapter 128D-5. In addition to recovering its cost, in some cases HDOH may sue the responsible party for punitive fines known as civil penalties for up to three

times the cost of investigation and cleanup, or fines of up to $50,000 for each separate violation 128D-8(a),(b). These severe penalties are designed to encourage voluntary cleanup of releases.

1.2 HEER OFFICE RESPONSIBILITIES UNDER HRS 128D AND HAR 11-451

The Hawai'i Environmental Response Law (HRS 128D) and related administrative rules (HAR 11-451) define specific responsibilities to ensure responsible parties, consultants, the public, and the legislature have access to regularly updated information regarding environmental cleanup and emergency response actions under the oversight of the HEER Office. These responsibilities are described below.

1.2.1 LISTING OF SITES

The HDOH maintains a "site list" identifying sites that are subject to HRS 128D and the Hawai'i SCP (i.e., HAR 11-451). The purpose of the site list is to identify sites that require or may require a response action to address a release or suspected release of a hazardous substance. Lists are maintained in a database by the HEER Office, periodically updated, and contain important site information, such as name, location, staff assigned, and status. The database listing is posted on the HEER Office website under the heading Public Records.

The lists maintained by the HEER Office include release sites under the emergency response section, as well as sites of interest under the non-emergency environmental cleanup section (these are cumulative lists covering multiple years). In addition, a list of the past years completed sites activity, as well as a list of sites planned for action in the current year are provided separately, with detail on name, location, staff assigned, status, etc

A summary of HEER Office activities, including lists of sites overseen by the emergency response section and the non-emergency environmental cleanup section, are also provided in an annual HEER Office report to the Legislature.

1.2.2 PROVISION OF ACCESS TO SITE RECORDS

The HEER Office maintains detailed individual records/files on sites that are or have been under investigation/cleanup oversight for hazardous substances. These records are public information and subject to review and/or copying by the public upon request.

1.2.2.1 PUBLIC RECORDS ACCESS IN GENERAL (HRS 92F)

Access to government records in Hawai'i is intended to be as open as possible under the Uniform Information Practices Act (UIPA), HRS Chapter 92F. UIPA encourages agencies to provide timely access to complete records on request by the public, allowing access unless disclosure would constitute a clearly unwarranted invasion of personal privacy, confidential business information, or a protected trade secret. Doubts regarding disclosure of a record are typically resolved in favor of access.

Requests are generally required in writing, and an appointment is made to review the records during regular business hours. Fees may be charged to cover copying of records, if requested. The HEER office, depending on workload, usually takes a minimum of 10 working days to produce records for public review.

1.2.2.2 ACCESS TO SITE ADMINISTRATIVE RECORDS (HAR 11-451-19)

The Hawai'i SCP details requirements for the establishment and content of, and access to, HEER Office administrative records relating to individual facility/site hazardous substance response activities (HAR 11-451-19). Administrative records are established and maintained by facility identification numbers within the HEER Office, and typically contain documents such as consultant reports, correspondence between the site representative and the HEER Office, and decision documents relating to site assessment and/or site remediation actions. These records are available for inspection and/or copying. Submit a written request to the HEER Office to gain access to the records. The form, "Request to Access a Government Record" is available on the HEER Office website under the Public Records section. This form can be printed out, completed, and then faxed, e-mailed, or mailed to the HEER Office to request an appointment to review a site's Administrative Record. Since many of the records are lengthy, it may be expeditious to contact the assigned project manager to narrow the scope of the record review.

Requests to review site documents may be submitted at any time. Such reviews are often encouraged as part of the public participation process when a draft document proposes a specific removal or remedial response action for a given site. See Subsection 2.4.6 for additional discussion of the public participation process and access to records for environmental cleanups.

1.2.3 DOCUMENTATION OF HEER OFFICE DECISIONS ON SITES

Decision documents on the oversight of assessment and/or response actions for hazardous substance releases are provided in writing and included in the administrative records for individual facility/site locations. These documents are available upon request to the HEER Office. These decision documents may include letters of interest, VRP applications, VRP agreement approvals, report review letters, response action memorandums, removal action reports, no further action letters, and letters of completion.

1.3 HEER OFFICE ORGANIZATION

The mission of the HEER Office is to protect human health, public welfare, and the environment and provide state leadership, support and partnership in preventing, planning for, responding to, and enforcing environmental laws relating to releases or threats of releases of hazardous substances, pollutants or contaminants. The HEER Office is one of seven division-level offices organized under the Environmental Health Administration of the HDOH. These seven division-level offices are described in Subsection 1.4. To help accomplish its mission, the HEER Office is divided into four primary technical sections that are listed below and described in the following sections (also see Functional Areas Chart in Appendix 1-A).

- Emergency Preparedness & Response (EP&R) Section
- Site Discovery, Assessment, and Remediation (SDAR) Section
- Hazard Evaluation Section
- Planning Section

1.3.1 EMERGENCY PREPAREDNESS & RESPONSE (EP&R) SECTION

The EP&R Section is responsible for planning and preparing for, and responding to hazardous substance releases that may cause immediate and substantial threats to human health or the environment. EP&R has authority given in the HERL (HRS 128D), the Hawai'i SCP (HAR 11-451), and the HEPCRA (HRS 128E) to provide for or coordinate timely and effective hazardous substance release response and hazardous substance reporting.

This section of the HEER Office also focuses on emergency preparedness training exercises for emergency response actions. The EP&R Section's State On-Scene Coordinators (SOSCs) work closely with first responders, State Civil Defense, and other federal, state, and county agencies to help strengthen the state's ability to respond to hazardous substance release emergencies. EP&R staff also provide administrative support and/or technical assistance for the Hawai'i State Emergency Response Commission (HSERC) and the Local (county level) Emergency Planning Committees (LEPCs). The annual Tier II reports (and fees) required under HEPCRA for facilities that exceed specified threshold planning quantities of covered hazardous substances are collected and documented by the EP&R staff. Emergency Preparedness and Response activities of the HEER Office are described in additional detail in Subsections 2.3 and 20.1.

1.3.2 SITE DISCOVERY, ASSESSMENT, AND REMEDIATION (SDAR) SECTION

The largest section within the HEER Office is SDAR; most of the guidance described in this TGM is carried out under the oversight of the SDAR Section. This section has responsibility for oversight of all sites identified through release notification, sites in voluntary cleanup programs, or sites discovered through any other means - after any initial emergency response has been completed. The section's oversight responsibilities include the review of site assessments and draft/final site remediation documents by responsible parties to ensure that the environmental work meets legal requirements and results in site conditions that will be protective of human health and the environment. The section's staff is composed of Remedial Project Managers (RPMs) working on sites within six separate programs, which are described below. Individual RPMs may work on sites in one or a number of these programs.

1.3.2.1 SITE DISCOVERY PROGRAM

The Site Discovery Program identifies and assesses sites that are contaminated or potentially contaminated, and managed under HEER Office jurisdiction. . Discovery of new sites may occur from various initiatives including:

- Targeted sampling of suspect contaminated sites to determine presence or absence of significant contamination
- Assessment and site inspections funded by and coordinated with USEPA under the federal CERCLA program
- Investigations generated by release reporting.
- Investigations of public reports or media reports regarding hazardous substances
- Sites where owners/operators apply for and/or participate in voluntary investigation or cleanup programs such as Fast Track Cleanup (see Section 15) or the Voluntary Response Program (see Subsection 20.3).
- Follow-up on referrals from other government agencies

1.3.2.2 STATE SITES PROGRAM

Many of the sites overseen by the SDAR section fall in the "State Sites" category: non-military sites, including those participating in a specific voluntary cleanup program such as the Fast Track Cleanup Program, Brownfields Program, or the Voluntary Response Program (described below). The RPMs in this program generally request and receive voluntary cooperation of the responsible party for the site. RPMs typically request that a site assessment be conducted, and then evaluate the site assessment report. If significant contamination is found through the site assessment (e.g. hazardous substance levels exceeding the HEER Office Environmental Action Levels (EALs), then follow-up work is requested to conduct further assessment or develop and carry out site cleanup.

1.3.2.3 FAST TRACK CLEANUP PROGRAM

The Fast Track Cleanup Program enables owners/operators of certain contaminated sites or potentially contaminated sites to conduct voluntary investigation or removal cleanups under an agreement with the HEER Office. Participants can move forward to investigation summaries or cleanup actions without the submittal of multiple work plans and interim report submittals, thereby streamlining and expediting site closures for removal action sites. Project status reviews and updates are generally conducted with HDOH through meetings or presentations, as needed.

Those interested in participating in the Fast Track Cleanup Program must first be screened for eligibility and attend a "scoping" meeting. Participation officially begins with the completion of an application and agreement form. See Section 15 for full details regarding the Fast Track Cleanup Program.

1.3.2.4 BROWNFIELDS PROGRAM

The Brownfields Program helps to facilitate voluntary assessment, cleanup, and redevelopment of brownfields properties. These are properties that are abandoned or underutilized due to real or perceived environmental issues associated with the property.

The RPMs in this program provide:

- Oversight of site assessments and cleanup of brownfields sites.
- Technical assistance to brownfields developers regarding cleanup options.
- Support for non-profits and state/county agencies in applying for USEPA brownfields grants.
- Assistance to the counties to develop an inventory of brownfields sites.

See Subsection 20.2 for additional information on the Brownfields Program .

1.3.2.5 VOLUNTARY RESPONSE PROGRAM

The Voluntary Response Program (VRP) encourages voluntary cleanup of contaminated properties. The HERL was amended in 1997 to include this voluntary program for the state of Hawai‘i. Under the law, HDOH has the authority to grant prospective purchasers or developers an exemption from future hazardous substance liability if cleanup is performed to HEER Office specifications under this program. Past, current, or future property owners can participate in the VRP, however liability exemptions can only be given to prospective purchasers or tenants. RPMs working in this program provide oversight for the site assessments and remediation activities, with completion documented via a Letter of Completion (LOC) issued by HDOH and a UECA covenant noted to the property deed, if necessary.

The cost of the HEER Office oversight (charge for hours of RPM oversight) is borne by the responsible party under the terms of the VRP Agreement. VRP sites are normally given a dedicated RPM who is required to respond to investigation and remediation reports in less than 30 days. Subsection 20.3 provides more detailed information on the VRP. Information regarding the VRP can also be found on the HEER Office website.

1.3.2.6 DOD STATE MEMORANDUM OF AGREEMENT PROGRAM (DSMOA)

RPMs working in the DSMOA program provide oversight for assessments and cleanups of Department of Defense (DoD) sites. Although the DoD is the lead responsible agency for cleanup decisions on CERCLA-regulated sites under the agreement, DoD funds the DSMOA program RPM positions to provide:

- Technical review, comments, and recommendations on DoD documents.
- Identification and explanation of State applicable or relevant and appropriate requirements (ARARs).
- Oversight and decisions on DoD sites involving petroleum contamination only (regulated under the Hawai‘i SCP)
- Site visits; involvement in public education and participation activities; and participation in technical review committees.

Subsection 20.4 gives additional detail on the DSMOA program

1.3.3 HAZARD EVALUATION SECTION

The Hazard Evaluation Section of the HEER Office provides human health and ecological risk assessment evaluation and support for the HEER Office as well as other sections within the Environmental Management Division. Hazard Evaluation staff also provide toxicological assessments of chemical threats to human health, establish appropriate cleanup levels for chemical contamination, and assist the public with information concerning the health effects of chemicals. This section works on a variety of specific studies and projects related to chemical hazards in Hawai‘i, including the responsibility for collecting and monitoring reports of pesticide and heavy metal poisoning under Title 11, Chapter 5, HAR, Environmentally-Related Illness and Injury Reporting.

1.3.4 PLANNING SECTION

The Planning Section within the HEER Office serves to support the entire office in the areas of long-term planning, program development, financial reporting, data management, logistical support, and legislative expertise. The Planning Section assists in identifying resource and training needs to ensure that HEER Office staff have appropriate tools and training to perform their jobs. A major objective of the Planning Section is to assist the other sections, and to have in place regulations, policies, databases, and procedures for responding to information requests or reports of releases of hazardous substances, pollutants, or contaminants.

1.4 ENVIRONMENTAL HEALTH ADMINISTRATION DIVISIONS

The Environmental Health Administration of the HDOH is organized into seven division-level offices, one of which is the HEER Office. The HEER Office frequently works closely with other divisions/programs within Environmental Health Administration to help address the range of environmental issues that may occur on a specific site. The divisions of the Environmental Health Administration are described in the sections below:

1.4.1 HAZARD EVALUATION & EMERGENCY RESPONSE OFFICE

The HEER Office mission is to protect human health, public welfare, and the environment and provide state leadership, support and partnership in preventing, planning for, responding to, and enforcing environmental laws relating to releases or threats of releases of hazardous substances, pollutants or contaminants. The organization and function of the HEER Office is described in Subsection 1.3.

1.4.2 ENVIRONMENTAL MANAGEMENT DIVISION (EMD)

The EMD is responsible for implementing and maintaining statewide programs for controlling air, water and wastewater pollution, assuring safe drinking water, and for the proper management of solid and hazardous waste. The EMD is organized into five branches, as follows:

- Solid and Hazardous Waste Branch (SHWB)—administers the following sections:
  - Solid Waste Management Program provides permitting and enforcement for municipal solid waste management as well as special waste management and alternative waste management.
  - Hazardous Waste Management Program provides inspection and enforcement for facilities that generate, store, transport or treat hazardous wastes.
  - Underground Storage Tank Management Program (UST Management Program) provides inspection and enforcement for design and operation of USTs, as well as oversight of leaking UST cleanup.

  Programs within the SHWB operate under specific authorities/regulations; sites that have overlapping regulatory issues may need to work with multiple program representatives within the branch.

- Safe Drinking Water Branch (SDWB)-administers federal and state safe drinking water regulations for public water systems in the state to assure water served by these systems meets state and federal standards.
- Clean Water Branch (CWB)-administers and enforces federal and state water pollution control laws and regulations. Services include permitting of point sources, compliance monitoring, inspections, investigations of complaints, and ambient water quality monitoring.
- Clean Air Branch (CAB)-responsible for implementing a statewide air pollution control program through services that include engineering analysis and permitting, monitoring and investigations, and enforcement of federal and state air pollution control laws and regulations.
- Wastewater Branch (WWB)-implements construction of County wastewater facilities and is involved in related regulatory and financing issues.

1.4.3 ENVIRONMENTAL HEALTH SERVICES DIVISION (EHSD)

The Environmental Health Services Division (EHSD) implements and maintains statewide programs to assure safety of food and drugs, control noise and radiation, and improve air quality. They are also responsible for lead and asbestos abatement programs, sanitation, and vector control. The EHSD is organized into four branches, as follows:

- Noise, Radiation and Indoor Air Quality Branch-responsible for statewide programs of community noise and radiation control through services including inspections, education, consultation, and enforcement. They also work to ensure air conditioning and ventilation rules are enforced, and the public is protected from exposure to lead and asbestos.
- Food and Drug Branch-ensures food, drugs, cosmetics, medical devices, and related consumer products are safe, effective and properly labeled, while also providing education and consultation for food handlers.

- Sanitation Branch-enforces sanitation laws and rules relating to food and service establishments, public swimming pools, housing, milk, recreational trailer camps, and tattoo artists. They also oversee licensing for sanitarians, mortuaries, cemeteries, and embalmers.
- Vector Control Branch-prevents or suppresses outbreaks of vector-borne diseases and vector nuisance by maintaining vector populations below disease or nuisance causing levels.

1.4.4 ENVIRONMENTAL PLANNING OFFICE

The Environmental Planning Office (EPO) develops strategic plans, supports land use reviews and helps get new programs underway. They are also involved in coordinating watershed management projects and the polluted runoff control program.

1.4.5 COMPLIANCE ASSISTANCE OFFICE

The Compliance Assistance Office (CAO) is a one-stop, non-regulatory office that helps small business understand and comply with environmental regulations.

1.4.6 ENVIRONMENTAL RESOURCES OFFICE

The Environmental Resources Office (ERO) handles many grant and administrative responsibilities, primarily implementing administration changes, establishing new positions, and assisting programs in obtaining funding from the USEPA.

1.4.7 STATE LABORATORIES DIVISION

The State Laboratories Division (SLD) administers a statewide program which conducts analytical testing services in support of environmental health and communicable disease control activities, as well as public health emergency preparedness and response efforts. SLD provides consultative and other related laboratory services to departmental programs, health care providers, institutions, and various federal, state, county, and city agencies including the certification of certain types of laboratories, and the licensing of clinical laboratory personnel and medical review officers. SLD participates in environmental and public health training, research, exercises, and investigations.

SECTION 1 REFERENCES

Citation references for this TGM Section denoted with an “a”, “b”, “c”, etc… after the year of publication may not appear in sequence as these refer to the order placed in the Master References List for the entire TGM.

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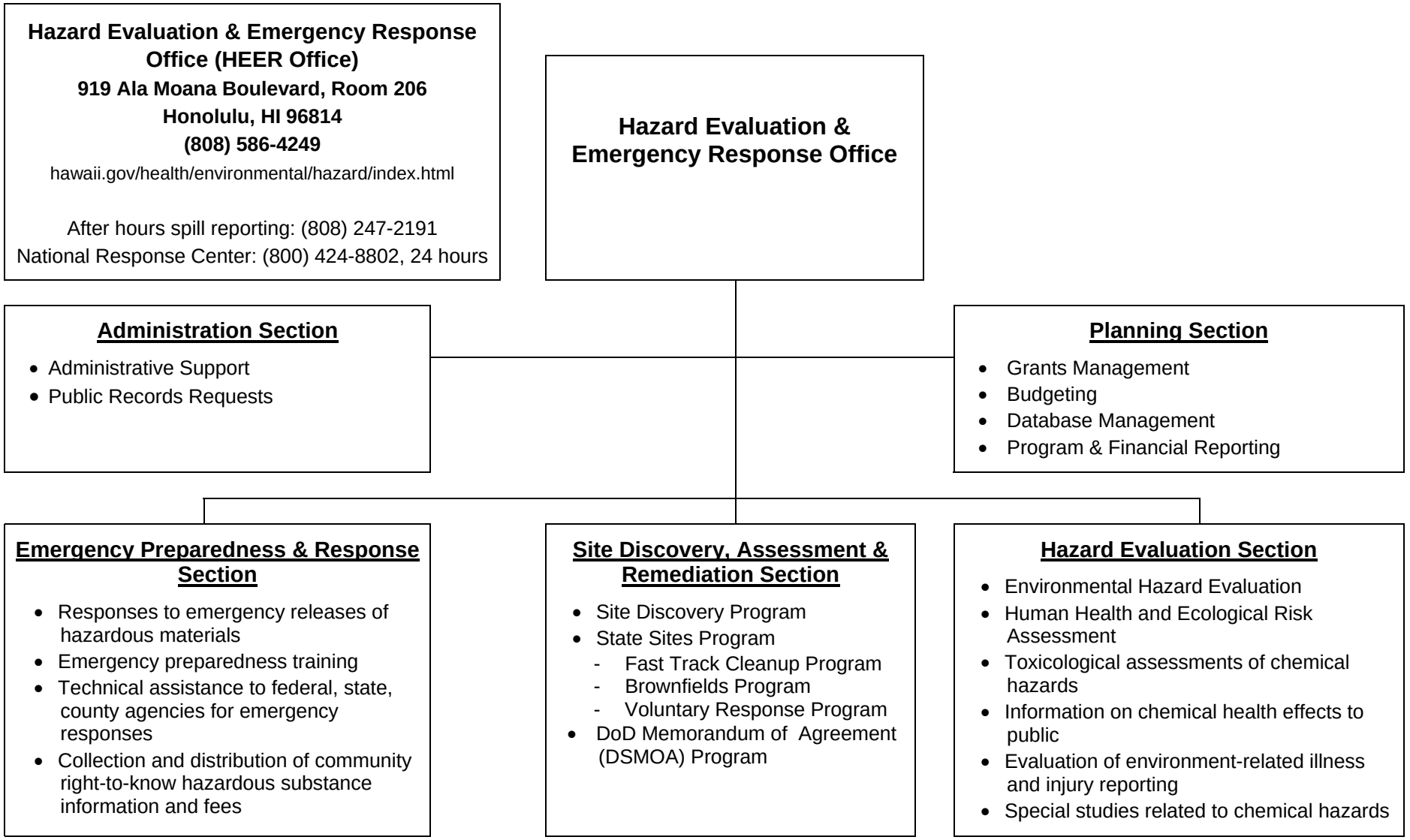
Appendix 1-A
OFFICE OF HAZARD EVALUATION AND EMERGENCY RESPONSE FUNCTIONAL AREAS CHART

(see PDF file)

APPENDIX 1-A

OFFICE OF HAZARD EVALUATION AND EMERGENCY RESPONSE FUNCTIONAL AREAS CHART

Appendix 1-A
HEER Office Functional Areas Chart



SECTION 2
EMERGENCY RESPONSE AND THE SITE DISCOVERY, INVESTIGATION, AND CLEANUP PROCESS UNDER HAWAIʻI ADMINISTRATIVE RULES CHAPTER 11-451, THE STATE CONTINGENCY PLAN

Interim Final-November 12, 2008

State of Hawaiʻi
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SECTION 2 ACRONYMS AND ABBREVIATIONS

CAS	Chemical Abstract Service
CERCLA	Comprehensive Environmental Response, Compensation & Liability Act (also known as the Federal Superfund Law)
Draft RAM	Draft Response Action Memorandum
EAL	Environmental Action Level
EHE	Environmental Hazard Evaluation
EP&R	HEER Office Emergency Preparedness and Response Section
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
Final RAM	Final Response Action Memorandum
HAR	Hawai'i Administrative Rules
Hawai'i SCP	Hawai'i State Contingency Plan (HAR, Title 11, Chapter 451)
HDOH	Hawai'i Department of Health
HEER Office	Hazard Evaluation and Emergency Response Office
HRS	Hawai'i Revised Statutes
LEPC	Local Emergency Planning Committees
LOC	Letter of Completion
NFA	No Further Action
NRC	National Response Center
OEQC	HDOH Office of Environmental Quality Control
RAA	Remedial alternatives analysis
RAR	Removal Action Report
RI	Remedial Investigation
SDAR	HEER Office Site Discovery, Assessment and Remediation Section
TCLP	Toxicity characteristic leaching procedure
USEPA	United States Environmental Protection Agency
VRP	HEER Office Voluntary Response Program

2.0 EMERGENCY RESPONSE AND THE SITE DISCOVERY, INVESTIGATION, AND CLEANUP PROCESS

This section provides details of the state rules and processes used by the Hawai‘i Department of Health (HDOH) Office of Hazard Evaluation and Emergency Response (HEER Office) to address both Emergency Responses and longer term Environmental Cleanups of hazardous substance releases (or threats of releases) under Hawai‘i Administrative Rules – Chapter 11-451 the State Contingency Plan. Steps in this process include initial discovery of sites followed by immediate action to address and close most Emergency Response scenarios. For longer term Environmental Cleanups, steps also typically include listing and prioritizing a site, followed by site assessment, response actions and public participation (as appropriate), and finally site closure.

2.1 STATE CONTINGENCY PLAN

The process for environmental cleanup or remediation of hazardous substance releases in Hawai‘i is guided by a set of administrative rules adopted and periodically revised by HDOH. These administrative rules, which became effective in August 1995, are referred to as the Hawai‘i State Contingency Plan (Hawai‘i SCP) or Hawai‘i Administrative Rules (HAR), Title 11, Chapter 451 (HAR, 1995). The Hawai‘i SCP was written to implement, administer, and enforce Chapter 128D of the Hawai‘i Revised Statutes (HRS), also called the Hawai‘i Environmental Response Law, which was established by the Hawai‘i Legislature effective June 1991 (HRS 128D).

A hazardous substance release is defined as any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing of any hazardous substance, pollutant, or contaminant into the environment. Note: seven specific exclusions from the definition of a release are provided in HAR 11-451-3. Sources that identify many specific hazardous substances are provided in the Hawai‘i SCP. The Hawai‘i SCP establishes regulatory authorities, responsibilities and guidelines for the discovery, investigation, and cleanup of hazardous substances in Hawai‘i. Cleanup of a variety of waste, accidentally spilled substances, abandoned materials, soil, groundwater, surface water, air, and leaking underground tanks may be addressed through the Hawai‘i SCP.

In some cases, such as during emergency responses and responses to contaminated surface water, drinking water, outdoor air, soil vapor, or leaking underground tanks, the HEER Office may refer cases to or work closely with other HDOH branches within the Environmental Health Administration (or other state, county, or federal personnel for emergency responses) to ensure appropriate assessment and cleanup is accomplished.

2.2 SITE DISCOVERY

The HEER Office becomes aware of a site where a hazardous substance release has or may have occurred through the process of site discovery. Sites may be discovered through a number of means, such as:

- Calls from county or state agencies regarding emergencies
- Notification required for a release of a hazardous substance that meets or exceeds a "reportable quantity" as specified under the Hawai'i SCP (see Subsection 2.3.1.1, Release Notification, below))
- Investigations by other government agencies, universities, private and non-profit organizations
- State-led site discovery efforts
- Reports of contaminants in environmental assessments conducted by consultants for private or public parties (e.g. Phase I or Phase II Environmental Site Assessments)
- Sites where owners/operators are participating in voluntary investigation and/or cleanup programs such as Fast Track Cleanup (see Section 15) or the Voluntary Response Program (see Section 20)
- Public observations or complaints

Once the HEER Office is aware of a hazardous substance release or potential release site, all situations determined to be emergency responses are acted upon immediately or as appropriate by the Emergency Preparedness and Response Section (EP&R) staff of the HEER Office. These are typically "recent" hazardous substance releases or recent discoveries of abandoned containers that may present a significant threat of release. Hazardous substance releases or suspected releases judged not to require emergency response are assigned to the Site Discovery, Assessment, and Remediation Section (SDAR) of the HEER Office for evaluation and action. These non-emergency releases are typically "historic" hazardous substance releases, or releases where an initial emergency response action has been completed.

2.3 EMERGENCY RESPONSE

The HEER Office EP&R is responsible for planning, preparing for, and responding to hazardous substance releases that may cause immediate and substantial threats to human health or the environment. The EP&R Section has authority given in the Environmental Response Law (HRS 128D) and the State Contingency Plan (HAR 11-451) to provide for or coordinate timely and effective hazardous substance release response. Emergency preparedness training exercises for emergency response actions are also a primary focus of the HEER Office EP&R Section. The EP&R Section works closely with individual county hazmat, fire, and police personnel as well as other federal, state, and county agencies to help strengthen the state's ability to respond to hazardous substance release emergencies.

The EP&R staff cover calls related to hazardous substance releases 24 hours a day, and initiate actions to provide appropriate state resources for emergency response actions. The EP&R staff can be contacted at the numbers below:

Telephone (Business Hours):	(808) 586-4249
Telephone (After Hours):	(808) 247-2191
Facsimile:	((808) 586-7537

This may involve referrals and support to county, state and federal agencies involved in emergency response actions, as well as assignments to a private contractor to assist in emergency response cleanups.

An emergency situation exists if there is a release, or threat of a release, of a hazardous substance that may pose an imminent and substantial danger to human health and the environment. Most commonly, the HEER Office and/or County Hazmat/Fire Department will determine if an emergency situation exists; however, in some cases, such as sites under federal jurisdiction, other agencies (e.g., U.S. Coast Guard, U.S. Department of Defense) will make the determination that an emergency exists.

County first responders may transfer a site to the HEER Office EP&R Section after the emergency situation is stabilized, if necessary for further evaluation and action.

Due to the nature of emergency responses and importance of expedient actions, procedures for handling these releases are quite different from procedures used for non-emergency environmental cleanups (see Subsection 2.4). Emergency response implies immediate evaluation and appropriate action (including Removal Action); sufficient time is typically not available to allow for detailed site assessment activities, multiple site reports, and public participation activities generally conducted for non-emergency environmental cleanups.

EP&R staff may issue responsible parties (or potentially responsible parties) for hazardous substance releases one or more of several types of letters as part of the response process to help ensure appropriate cleanup is accomplished, necessary reports are provided, and/or to establish responsibility for cost recovery of state resources expended in the cleanup. These letters include:

- Failure to Notify - for a reportable quantity release
- Notice of Interest in a Release or Threatened Release - used to request follow-up information or action on a specific site.
- Notice of Improper Response Action in a Release or Threatened Release - used to inform responsible party that appropriate action has not yet been completed, and to request action be completed.
- Notice of Undertaking in a Release or Threatened Release - used to inform the responsible party the state is conducting or involved in the response action due to the urgency of the situation or lack of previous appropriate response, and as applicable, cost recovery for the state's actions will be sought.

In some cases, the potentially responsible party may already be conducting an emergency response at the time of release notification. In some cases the emergency response cleanup is performed without delay, perhaps at state expense, and details of responsibility and cost reimbursement are worked out after the incident has been appropriately handled or stabilized.

A "Removal Action Report" (RAR) is typically required to document the emergency response cleanup at a site. The RAR may require confirmation sampling to demonstrate that the actions taken were responsive to the emergency condition(s) and there is

no longer an immediate danger to human health or the environment (see Sections 14 and 18 for more information on Removal Actions and report contents, respectively).

If the emergency response can be shown to have addressed all threats posed by the hazardous substance release, then EP&R may make a "No Further Action" determination for the entire release. However, if the emergency response has addressed only the immediate threats posed by the release and significant long-term threats may remain at the site, EP&R would make an "emergency response resolved" determination and transfer oversight of the release to the Site Discovery, Assessment, and Remediation Section (SDAR) Section for a non-emergency environmental cleanup (see Subsection 2.4 below). This includes identifying and transferring all documentation and reports generated by the release, and providing rationale for the transfer of oversight.

2.3.1 EMERGENCY RESPONSE ACTIONS

Specific actions that must be taken during an emergency response are outlined in this section. Emergency response is activated when there is a release or threat of release that may pose an immediate threat of exposure to hazardous substances. These are generally recent spills/releases of hazardous substances, or the discovery of abandoned containers of suspected hazardous substances that may have leaked or have the potential to leak into the environment. The EP&R Section staff has oversight for emergency response actions.

The following are examples of hazardous substance releases or threats of release requiring emergency response

- Release notification
- Discovery and report of abandoned drums of suspected hazardous materials
- A potential public health threat, such as a report of people being sickened or affected by exposure to noxious fumes or contaminants, whether or not the source has been identified
- A hazardous substance reported to be spilled/released as a result of operator error during transfer (e.g., oil product)
- Hazardous substances observed being improperly disposed into the soil
- A report of a hazardous substance release to the environment due to an equipment malfunction at an industrial or commercial facility
- Abandoned gas cylinder (unlabelled) washing ashore

Hazardous substance release notification requirements mandated under the Hawai‘i Environmental Response Law (HRS 128D) and the Hawai‘i SCP are intended to ensure discovery of recent hazardous substance releases into the environment, and to initiate emergency responses, as appropriate, to prevent exposures to hazardous substances that could be harmful.

2.3.1.1 RELEASE NOTIFICATION

Immediate notification to the HEER Office, your County Fire Department, your local County Emergency Planning Committee (LEPC), and the National Response Center (NRC) is required by the Hawai‘i SCP if spills or releases of hazardous substances exceed a threshold quantity referred to as the "reportable quantity" (see Appendix 2A, Appendix 2B, Appendix 2C, and Appendix 2D).

Failure to report a hazardous substance release exceeding the applicable reportable quantity to the HEER Office immediately upon knowledge of the release may result in a civil penalty in an amount up to $10,000 for each day of failure to report (HRS 128D-3c).

The purpose of the notification (and penalty for not reporting) is to ensure quick evaluation of the release by local, state, or federal government personnel, and to determine appropriate response actions. Evaluating these releases often involves the collaboration of local and state government emergency response personnel, with the federal government providing support as requested. Releases discovered through notification are typically recent hazardous substance releases. All notifications are evaluated by the EP&R of the HEER Office to determine if response action is warranted.

2.3.1.2 WHEN AND HOW TO NOTIFY ON RELEASES OF HAZARDOUS SUBSTANCES

Any person in charge of a facility or vessel is required to phone the HEER Office, their local Fire Department, their County Local Emergency Planning Committee, and the National Response Center (NRC) immediately to notify them regarding a hazardous substance release that is equal to or exceeds the reportable quantity criteria (see Subsection 2.3.1.3) in any 24-hour period. However, notification to NRC is not required for releases of oil or for releases of trichloropropane, which are not Comprehensive Environmental Response, Compensation & Liability Act (CERCLA) hazardous substances. For releases of oil and trichloropropane, only the Hawai‘i state/county reporting requirements apply. Phone and addresses for the agency contacts are provided in Appendix 2A.

When you provide initial notice of a hazardous substance release, specific information is requested to help those evaluating the release identify:

- Chemical information
- Incident information
- Contact informatioHealth information

A list of the information requested in the initial (immediate) phone notices of hazardous substance releases is provided in Appendix 2B.

A written follow-up notice regarding the release is also required to be sent to the state/county contacts noted above, postmarked no later than 30 days after initial discovery of the release. A written follow-up report is not required to be sent to the NRC. The information request form in Appendix 2B can be used to provide the written follow-up notice.

2.3.1.3 REPORTABLE QUANTITIES OF HAZARDOUS SUBSTANCES

Sources that list many hazardous substances and their corresponding reportable quantities are provided in the Hawai'i SCP. Most of these sources were last updated in July 1993. The reportable quantities list [numerical order by Chemical Abstract Number (CAS)] can be found in Appendix 2C, while Appendix 2D presents an alphabetical list by chemical name).

Oil is considered a hazardous substance in the Hawai'i rules, but has some more specific criteria for notification:

- Any amount of oil causing a sheen to appear on surface water or any navigable water of the State (sheens resulting from discharge of oil from a properly functioning vessel engine are exempt)
- Any free product that appears on groundwater
- Any amount of oil greater than 25 gallons released to the environment
- Any amount of oil less than 25 gallons released to the environment and not contained and remediated within 72 hours.

Note: Incidental drips of oil/fuel from properly maintained vehicles and oil-containing equipment would not require release notification. Also see exemptions listed in Subsection 2.3.1.6.

2.3.1.4 RELEASES OF MIXTURES OR SOLUTIONS OF HAZARDOUS SUBSTANCES

Notification for releases of mixtures or solutions containing a hazardous substance or substances are required only when a component hazardous substance of the mixture or solution is released in a quantity equal to or greater than its reportable quantity. However, if the exact concentration of all the hazardous substance components in the mixture or solution is not known, notification is required if the entire amount of the mixture or solution released equals or exceeds the reportable quantity of any of the hazardous substances it contains.

2.3.1.5 RELEASES OF HAZARDOUS WASTE

Hazardous waste may also be considered a hazardous substance if it exhibits any of the characteristics of ignitability, corrosivity, reactivity, or toxicity (include these terms in definitions). Notification for hazardous waste release is required as follows:

- Hazardous waste does not exhibit toxicity characteristics when tested with the Toxicity Characteristic Leaching Procedure (TCLP) test, but exhibits ignitability, corrosivity, or reactivity characteristics: reportable quantity is 100 pounds.
- Hazardous waste does exhibit toxicity characteristics in the TCLP test: reportable quantities are listed in Appendices 2-C or 2-D.
- Hazardous waste exhibits toxicity characteristics of more than one hazardous substance in the TCLP test: reportable quantity is the lowest quantity listed in Appendices 2-C or 2-D, for those hazardous substances on which the toxicity characteristic is based.
- Hazardous waste exhibits toxicity characteristics and the waste has one or more of the other hazard characteristics (ignitability, corrosivity, or reactivity): reportable quantity will be the lowest of the applicable reportable quantities (the reportable quantity for hazardous waste exhibiting ignitability, corrosivity, or reactivity characteristics is 100 pounds)..

Note: The reportable quantities for hazardous waste described above apply to the weight of the entire amount of waste material released, not just to the hazardous substance component of the waste.

The EPA has determined that some specific wastes are hazardous by definition. These wastes are incorporated into lists published by the EPA. Listed hazardous wastes are organized into three categories:

- The F-list (non-specific source wastes). This list identifies wastes from common manufacturing and industrial processes, such as solvents that have been used in cleaning or degreasing operations.
- The K-list (source-specific wastes). This list includes certain wastes from specific industries, such as petroleum refining or pesticide manufacturing.
- The P-list and the U-list (discarded commercial chemical products). These lists include specific commercial chemical products in an unused form.

All listed wastes (codes F, K, U, and P) are considered hazardous wastes.

2.3.1.6 EXEMPTIONS FOR RELEASE NOTIFICATION

The following types of releases are exempt from notification:

- Releases of hazardous substances from bituminous pavement, landscaping materials, or building materials that are in good repair and serving their original intended use
- Releases of gasoline or diesel fuel that result from the rupture of the fuel tank of a passenger vehicle as a result of an accident
- Sheens resulting from discharges of oil from a properly functioning vessel engine
- Releases of radionuclides regulated by United States Environmental Protection Agency (USEPA))
- Releases of hazardous substances that are discharged or emitted from an outfall, stack, or other point source, or as fugitive emissions, if regulated under a valid permit, license, or approval, and/or operating under a valid registration, order, or guideline issued under a federal or state statute or regulation (unless the release exceeds the permitted/allowed amount or may pose a substantial endangerment to public health or the environment).

2.4 NON-EMERGENCY ENVIRONMENTAL CLEANUPS

In contrast to Emergency Responses, non-emergency Environmental Cleanup actions generally occur over a longer time frame, allowing for detailed site assessments to help determine whether and to what extent sites are contaminated, identify environmental hazards, and determine if response actions are necessary to remediate hazardous substances. In some cases complex environmental cleanups involving multiple contaminants and both soil and groundwater contamination can involve years of effort before the site is adequately cleaned up and closed.

Environmental cleanups conducted for non-emergency hazardous substance releases are often responding to historic or suspect past releases rather than to observable recent evidence, such as leaking containers, spilled materials, or other obvious sources of contamination at the site. Examples of historic releases include:

- Containers of leaking hazardous substances and stained surface soils are discovered and removed during an emergency response, but some sub-soil or groundwater contamination still remains
- Groundwater contamination discovered in a non-drinking groundwater aquifer located below a former gasoline service station
- A Phase II Environmental Site Assessment required by a financial institution reveals soil or groundwater contaminated with a hazardous substance above HEER Office Environmental Action Levels
- Soil pesticide residue above HEER Office Environmental Action Levels is documented in a former agricultural field. Note: where owners/operators can document that pesticides were legally applied under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), an exemption from the definition of a release may apply (i.e., HRS 128D-1, definition of a "release"); however, the HEER Office would still be interested to ensure the potential risk was evaluated to determine if any response action is appropriate to protect public health or the environment.

Historic releases generally do not present immediate threats needing an emergency response, because they have typically aged, weathered, absorbed, or dispersed into the soil, or diluted in groundwater to the point that the contamination present does not pose a significant short-term hazard. However, they may commonly represent long-term hazards to human health or the environment. The SDAR staff of the HEER Office oversees these types of releases. A hazardous substance release could start out as an emergency response cleanup action under the oversight of the EP&R Section, and then be transferred over to the SDAR Section for follow through on cleanup of contamination that was not addressed in the emergency response cleanup. Examples of these "non-historic" releases resulting in longer-term environmental cleanups include;

- Sub-surface soil contamination from a diesel line rupture (after EP&R provided oversight of the surface soil removal)
- A release from an above-ground storage tank resulting in both surface and subsurface soil contamination
- Drums of hazardous chemicals and surface soil are removed under EP&R oversight, but where soil staining or sampling data indicated the potential for remaining subsurface or groundwater contamination

An overview of the discovery, assessment, and cleanup steps for non-emergency hazardous substance releases established under the Hawai‘i SCP is provided in Figure 2-1, and described below.

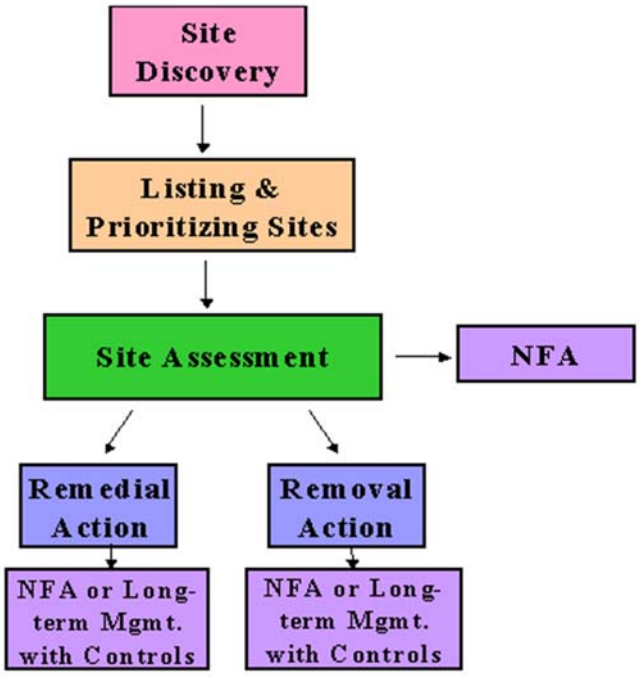


Figure 2-1. Overview of the Site Discovery, Investigation and Cleanup Process for Non-emergency Environmental Cleanups

2.4.1 SITE DISCOVERY FOR ENVIRONMENTAL CLEANUPS

The SDAR Section discovers sites that need evaluation or environmental cleanups through the following means:

- Reports of contaminants in environmental assessments conducted by environmental consultants for private or public parties (e.g., Phase I or II Environmental Site Assessments)
- State-led site discovery efforts
- Referrals from the HEER Office EP&R Section for follow through on cleanup of contamination that was not addressed in an initial emergency response cleanup
- Investigations by other government agencies, universities, private and non-profit organizations
- Observations or complaints provided by the public

It is common for banks or lending institutions to require environmental assessments of properties before they may be considered as security for a loan, as well as to seek written assurance from the HEER Office that sites have been evaluated appropriately and found free from human health or environmental hazards.

The HEER Office considers sites where environmental contaminant concentrations exceed relevant HDOH HEER Office Tier 1 Environmental Action Levels (EALs) to be sites where hazardous substances may present an unacceptable risk or substantial endangerment to health or the environment.

Exceedances of the Tier 1 EALs do not automatically mean that unacceptable risks exist. Tier 1 EAL exceedances do mean a site needs to be evaluated further to determine if the level of risk at the site is acceptable or unacceptable, and if cleanup actions are appropriate. Historic releases are usually identified when environmental samples (typically soil and/or groundwater) are collected at a site, and sample analysis shows Tier 1 EAL exceedances. These exceedances are an indicator that a health or environmental threat may exist and should be addressed or evaluated further (e.g., additional site investigation or site-specific risk assessment).

2.4.2 SITE LISTING

The HEER Office maintains a list of sites that have been identified for attention under the Hawai‘i SCP. The site list is updated on a regular basis, and is available to the public for review. The HEER Office site listing includes sites that have been

discovered through a variety of means, including mandatory release notification (emergency responses are included in the site listing database), HEER Office site discovery actions, and voluntary reporting. The list includes sites where a responsible party may or may not have been identified, sites in compliance with enforceable agreements or those in compliance through voluntary actions, as well as sites where hazardous substances have not been adequately characterized yet.

Sites are placed on the HEER Office site list based on information regarding actual or probable environmental hazards from hazardous substance releases, including actual or probable releases to:

- Groundwater that is a drinking water supply
- Surface water that is a drinking water supply
- Groundwater or surface water that is not a drinking water supply
- Air that poses a threat to public health
- Soil that may pose a direct exposure or other hazard

In addition, sites may be listed for other actual or probable concerns, including:

- Uncontrolled hazardous substances, such as leaking containers or impoundments
- Soil, soil gas, indoor air, groundwater, or surface water that has contamination levels exceeding HDOH Tier 1 EALs
- Adverse impacts to natural resources
- Imminent danger of fire or explosion
- A determination by the Director of a substantial endangerment to public health or the environment

2.4.3 SITE PRIORITIZATION

Sites that are not considered emergencies (e.g., historic releases) and sites that may have been stabilized but not entirely cleaned up following emergency response actions are prioritized by the HEER Office SDAR Section for evaluation and/or response action (HAR 11-451-9(d)). The priority categories include:

1. High priority sites
2. Medium priority sites
3. Low priority sites

Sites are categorized based on the number and/or severity of any potential environmental hazard concerns listed in Subsection 2.4.2, as well as other relevant factors identified through site assessment activities. New or additional site assessment data may result in a re-evaluation and re-categorization of the site priority for future response action. Review of site assessment data may also result in a site being identified/categorized as a "no further action" (NFA) site (see Subsection 2.5).

2.4.4 SITE ASSESSMENT

Site Assessment is broadly defined in the Hawai‘i SCP as activities that involve the collection of environmental data for decision-making purposes. The goal of a site assessment is to identify and remediate contaminated soil and groundwater that poses unacceptable environmental hazards, either under current site conditions or under uncontrolled, future conditions. The site assessment process can be divided into three stages:

1. Site Investigation - determine the extent and magnitude of contamination
2. Environmental Hazard Evaluation - determine the presence or absence of potential environmental hazards
3. Response Action - determine appropriate actions to address the identified hazards

The purpose of the Site Investigation is to determine if the site is contaminated and, if so, the extent and magnitude of contamination above levels of potential concern. The investigation is carried out by the collection and analysis of samples of soil, groundwater, soil gas, surface water, sediment, air and/or other media as needed (see 4 through 11). The HDOH Tier 1 EALs may be used to identify contamination "above levels of potential concern." The investigation of contamination below the EALs is generally not necessary.

The presence of a contaminant at concentrations above the Tier 1 EALs indicates a potential environmental hazard. The nature and magnitude of tentatively identified hazards are described in the Environmental Hazard Evaluation (EHE) (see Section 13). In a very basic EHE, the presence or absence of potential hazards may simply be identified and the contaminated soil or groundwater quickly remediated without further assessment. In cases where remedial costs could be significant or the contamination cannot otherwise be easily remediated, a more advanced evaluation of specific environmental hazards (e.g., more detailed site-specific action level calculations) may be desired or even necessary (see Section 13 and Evaluation of

Environmental Hazards at Sites with Contaminated Soil and Groundwater, HDOH, 2016). This will help make the final EHE more site-specific and ensure that the resulting response actions are as efficient and effective as possible.

HEER Office SDAR staff review the Site Investigation and EHE reports to make one of the following decisions:

- The site does not pose a substantial threat to public health or the environment, and a No Further Action (NFA) letter will be issued
- The site needs additional assessment to provide reliable data to make a decision whether a threat exists
- The site poses a substantial threat to public health or the environment and response is necessary (either removal action or remedial action)

The Site Investigation and EHE reports are important decision-making documents and typically provide recommendations for additional actions. It is recommended that environmental consultants conducting site investigation and hazard evaluation activities work closely with HEER Office SDAR staff, as necessary, when developing site objectives and sampling plans, to review draft documents, and/or to consult on critical planning or implementation details. Good coordination between environmental consultants and SDAR staff providing oversight of the site activities may significantly improve the quality and timeliness of the site assessment actions.

The nature of any Response Action is generally very site-specific (see Sections 14, 15, and 16). For sites where the extent of contamination is very limited and/or time is of the essence, aggressive remediation of the contamination may be most cost-beneficial (e.g., excavation and disposal of contaminated soil). In other cases, it may be appropriate to aggressively remediate contamination that is causing immediate environmental hazards (e.g., free product discharging into a surface water body or vapor intrusion into a building) and prepare an Environmental Hazard Management Plan to address long-term management of contamination that must be left in place. See Section 19 for a discussion of implications of the various types of site closure.

The investigation, evaluation and response action process is iterative, with the need for additional data and closer evaluation of identified hazards continually re-evaluated as a better understanding of site conditions is gained. Understanding how the three stages of the site assessment process are linked and interdependent is crucial for ensuring that the project proceeds smoothly. As discussed in Section 3, the use of systematic planning in preparation and implementation of the site-investigation stage of the process is the first step.

2.4.5 RESPONSE ACTIONS

If a hazardous substance release poses a substantial endangerment to public health or the environment, an appropriate response action is required.

The Hawai‘i SCP defines two response action processes: the removal action process and the remedial action process. Due to the urgency of the threats posed and the need for prompt action, emergency responses are typically conducted under the removal action process, which is also used for most responses to historic releases. However, in a smaller number of cases, where the HEER Office determines that a more intensive level of review and scrutiny is needed or removal actions may be impractical, the remedial action process is used.

2.4.5.1 RESPONSE ACTION DETERMINATION AND RESPONSE OPTIONS

The HEER Office SDAR Section determines or approves whether a response action for environmental cleanups will be conducted as a removal action or a remedial action based on data provided in the site investigation and environmental hazard evaluation reports or additional assessment that may have been required.

Removal and remedial actions are not clearly distinguishable based on specific on-site activities. However, there are very real differences in the Hawai‘i SCP requirements associated with these two response action options – these requirements are summarized below in Figures 2-2 and 2-3:

Differences in Required Documentation for Response Action Optionsumentation for Response Action Options	
Removal Action	**Remedial Action**
Removal Action Report	Remedial Investigation Report
	Remedial Alternatives Analysis Report (RAA)
	Draft Response Action Memorandum (Draft RAM)
	Final Response Action Memorandum (Final RAM)

	Remedial Design/Remedial Action Workplan
	Remedial Design/Remedial Action Report

Figure 2-2. Differences in Required Documentation for Response Action Options

Differences in Required Public Participation for Response Action Options	
Removal Action	**Remedial Action**
Public notice and comment **only required if:** • Significant concern expressed/ likely • HEER Office decides in public interest • HDOH-lead and >$25,000 spent	Public Notice and Comment **Always Required**
Must be published no later than **60** days after initiation of on-site removal activity	Must be published at least **30** days prior to final remedial action selection

Figure 2-3. Differences in Public Participation for Response Action Options

Note: Voluntary Response Program (VRP) sites must follow the public participation steps of the remedial action process – see Subsection 20.3.

The Hawai‘i SCP established two separate response action processes in order to provide site-specific flexibility in balancing two distinct needs in the release response process. In deciding when and how to respond to a particular hazardous substance release, the HEER Office must balance the need to act quickly against the need to require more detailed evaluation, analysis, and public participation.

Fires, explosions, acute exposures, and other situations that pose an imminent and substantial threat require quick response to prevent, minimize, and mitigate the damage being caused or threatened by hazardous substance release. Removal actions provide a streamlined process to quickly address these time-sensitive releases. Removal actions are also typically effective where site assessment activities have clearly documented that significant contamination in soil is limited in extent, and within the reach of common excavation equipment.

In other situations, where the relative effectiveness, technological and administrative feasibility, and cost of different cleanup methods may be less clear, a remedial action option may be more appropriate. Remedial actions may depend on the collection and analysis of site-specific and release-specific information that is complex, difficult or time-consuming to obtain, and subject to uncertainty and variation in interpretation. In addition, there may be significant community impacts and/or community concerns associated with more complex cleanups. In these cases, remedial actions offer a methodical, explicitly documented, step-by-step approach, including public notice and comment, to ensure that relevant questions and issues are identified and addressed prior to the selection of a final cleanup approach.

The Hawai‘i SCP states that in deciding whether a response action should be a removal action or a remedial action, HDOH may consider factors including but not limited to:

- Immediacy of the threat
- Planning time
- Implementation time
- Risk to public health and the environment
- Cost
- Community interest
- Site complexity
- Availability of other response mechanisms
- Other situations or factors that may pose an imminent and substantial endangerment

2.4.5.2 REMOVAL ACTIONS

The Hawai‘i SCP notes that removal actions are intended to:

- Address all immediate threats
- Permanently and completely address threats posed by entire site
- Contribute to efficient performance of any anticipated remedial action that also may be necessary at the site

The HEER Office will determine if sufficient data is available in the site investigation and environmental hazard evaluation reports or additional site investigation documents to warrant a removal action decision. If inadequate data exists for this decision, additional site investigation will be required.

Removal actions are documented in a Removal Action Report (RAR) containing the following minimum elements:

- Location of release or threat
- Cause of release or threat
- Site history
- General site geology, hydrology, groundwater status, adjacent land uses
- Distance to surface water bodies
- Situation preceding decision to conduct removal
- Efforts by Dept. to obtain response by other parties, if appropriate
- The removal action and alternatives considered
- Resources expended
- Sampling methods and data on confirmation testing of removal action
- Description of hazardous substances remaining on site

Where practical, the RAR is completed before initiation of the removal action. Typically, completion is practical before initiation of a removal action selected for environmental cleanups, but not in the case of emergency responses. In the case of removal actions selected for environmental cleanups, the "resources expended" and "description of hazardous substances remaining on site" report elements are added after the cleanup has been completed. For emergency responses, the RAR may be required after the emergency response has been completed. A very important component of any RAR includes a summary and analysis of confirmation testing conducted to demonstrate the removal action has been successful.

When a removal action option has been selected for environmental cleanups, the HEER Office has the option to require a public notice to be issued as well as a public comment period to allow review and comment on the response selection. The HEER Office initiates this notice and public comment if significant public concern has been expressed or is likely to be expressed, or it is decided to be in the public's interest. In these cases, any public comment received would be carefully considered and addressed before making a final decision on the appropriate response action.

See Section 14 for details on Removal Response Actions and Section 15 for details on Fast Track Cleanup, a voluntary program for expedited investigation and cleanup for removal responses.

2.4.5.3 REMEDIAL ACTIONS

Remedial response actions are intended to:

- Eliminate, reduce, prevent, minimize, mitigate or control risks to public health or environment
- Provide for efficient, cost effective, and long-term reliable solutions, which are protective

The HEER Office will review the existing site investigation, environmental hazard evaluation report, and any other relevant site investigation reports to determine if adequate data exists to support selection of a remedial action option and to develop the required reports under the remedial action option.

Because remedial response actions are typically more complex than removal response actions, it is not uncommon for additional site investigation to be required to support appropriate decisions in the following required reports:

- Remedial Investigation and Environmental Hazard Evaluation
- Remedial Alternatives Analysis (RAA)
- Draft Response Action Memorandum (DRAFT RAM)

Additional site investigation might focus on more sampling to further delineate contaminant distribution on the site, identify likely remedial action options and applicable technologies (including presumptive remedies - remedies demonstrated to work well in other similar circumstances), or fill other data gaps related to remedial alternatives that are important for decision-making. This additional site investigation for remedial action responses is generally included in a Remedial Investigation (RI) Report.

The RAA Report provides a comparison of various remedial strategies to clean up contamination on the site. Typically, at least 5 different strategies (one of which is a "no action" strategy) are initially selected and analyzed, with at least 3 of the strategies judged most appropriate then presented and compared in detail in the RAA report. Primary considerations in weighing the strengths and weaknesses of remedial alternatives include:

- Effectiveness
- Technological and administrative feasibility
- Cost

Based on these considerations, comparisons, and associated information a preferred or preliminary remedial alternative is selected for the site and documented in the RAA Report.

The Draft RAM is a concise summary of site investigation and environmental hazard data, supplemental remedial investigation data (if obtained), the remedial alternatives analysis, and the preliminary remedial alternative selected for the site. The Draft RAM is intended for review and public comment. A public notice regarding availability of the Draft RAM, and a minimum 30-day comment period are provided for review. In most cases additional public scoping actions such as providing fact sheets and mailings are conducted, and in some cases public meetings are held to encourage review and comment on the Draft RAM (see Subsection 2.4.6, Public Participation).

A Final RAM, documenting the final site remedial alternative approved by the HEER Office is provided after completion of the public comment period on the Draft RAM. All public comments received are taken into consideration and addressed in the Response Summary section of the Final RAM. Review and consideration of public comments may result in a different remedial alternative being selected, or additional details on a remedial alternative being specified. The Final RAM is also made available for public review.

A remedial design/remedial action work plan is typically required for the site to ensure that the selected remedial alternative will be appropriately implemented and evaluated for effectiveness. A Remedial Design/Remedial Action Report documents the implementation and final evaluation of the selected remedial alternative (on complex sites this may be a series of reports over time).

See Section16 for details on Remedial Response Actions.

2.4.6 PUBLIC PARTICIPATION

Significant differences in public participation requirements for removal or remedial action options specified in the Hawai‘i SCP were discussed in Subsection 2.4.5.1, Response Action Determination and Response Options. In general, public participation activities for removal response actions are at the discretion of the HEER Office, except for the unusual circumstance of a state-funded removal action anticipated to cost in excess of $25,000. In addition, the public notice and comment period (at least 30 days) for removal action activities, if provided at the discretion of the HEER Office, is not required to be completed prior to implementation of the removal action itself, but within 60 days of initiation of the on-site removal activity.

For remedial response actions, public notice and a minimum 30-day public comment period to review the Draft RAM and associated documents and provide comment are required under the Hawai‘i SCP. This public notice and comment period must be completed prior to adopting the Final RAM and implementing the selected remedial alternative. A public meeting may also be held to review and discuss the Draft RAM, at the discretion of the HEER Office. Voluntary Response Program (VRP) sites must follow the public participation steps of the remedial action process (see Subsection 20.3, VRP).

See Sections 14 and 16 for additional detail on Public Participation requirements for Removal and Remedial Response Actions, respectively.

2.4.6.1 PUBLIC NOTICES

Public notices, where required or provided at the discretion of the HEER Office, primarily advertise the availability of the administrative record for a particular site, the proposed response action, and the opportunity to review the record and submit public comment on the proposed response action within a specified comment period (at least 30 days). When a decision has been made by the HEER Office to hold a public meeting regarding the proposed response action, the meeting is also advertised in the public notice. Generally, public notices would provide the following type of information:

- Location and size of site
- Hazardous substances and media being addressed
- Availability of key site documents such as the Draft RAR for a proposed removal action or a Draft RAM for a remedial response action - these key documents are made available in a local library, on the HEER Office website, and/or at the HEER Office in Honolulu
- Availability of the full administrative record for the site in the Honolulu HEER Office
- Availability of a "fact sheet" or an executive summary document containing concise summary information on the site and response action proposed, with contact number/e-mail to request
- Solicitation of written or oral comments on the proposed response action within the specified public comment period of at least 30 days, the address and e-mail to send comments; who to call for questions
- If a public meeting scheduled - date, time, and location of the meeting

Note: Publication date of the public notice is the official start of the public comment period (at least 30 calendar days).

Public notices are typically posted for one or two days in the "Public Notices" section of a general circulation newspaper in the county affected by the response action.

The HEER Office project manager for the site will also send a copy of the public notice to the HDOH Office of Environmental Quality Control (OEQC) bulletin editor for publication in The Environmental Notice. The OEQC publishes this bulletin every two weeks to inform the public of all projects being proposed in the State that are subject to public review and comment

In some cases, the HEER Office project manager may also elect to send or request notice information be sent via direct mail or e-mail to inform known interested parties directly about the proposed response action, and to solicit their review and input. If this approach is taken, a letter is typically sent from the HEER Office that contains information similar to what is published in the public notice, and a brief fact sheet or executive summary from the Draft RAM or Draft RAR as an enclosure/attachment. The letter or e-mail would then be sent to target groups or individuals such as:

- Known community groups in the site area (e.g. community/neighborhood associations or councils)
- Property owners surrounding the site
- Political representatives of the site area (i.e. City or County Council member(s), Legislative Senator/Representative from the site area)
- Public interest groups, if known and likely to have interest
- Other interested parties, if known

2.4.6.2 PUBLIC MEETINGS

If the HEER Office determines there is sufficient public interest, a public meeting is scheduled to provide information about and seek comment on a proposed response action at a particular site. Public meetings are typically set up with the following provisions:

- The meeting is typically held in the evening on a weekday at a well known public location near the site, and/or coordinated with local community group meetings
- The public meeting is scheduled to be held in about the middle of the public comment period to allow time for interested parties to review materials before the meeting, and to provide time for comments sometime after the public meeting is held
- The meeting is conducted by the HEER office (often with the participation of the site owner and/or their environmental consultant), a sign in sheet is provided to document attendance, and minutes or a transcript of the meeting is required (these minutes are made part of site file and available for review on request)
- Site maps, photos, or other relevant information can be posted on walls of meeting room for review by public
- Copies of a site fact sheet and/or the Draft RAM or Draft RAR are on hand for distribution at the public meeting
- The HEER Office project manager and/or site environmental consultant generally provides an opening presentation summarizing the site, nature of contamination, remedial options considered, and the preliminary remedial option selected for public review (e.g. briefly summarize information contained in the Draft RAM or Draft RAR)
- The HEER Office project manager, risk assessor, and site environmental consultants should be available to answer questions during and/or after the presentation on the site
- Public comment on the proposed response action is solicited during the meeting and documented. The HEER Office reiterates the dates that public comment will be accepted and notes that all public comment will be addressed during development of the Final RAM or Final RAR (i.e. final response plan could change as a result of public comment)
- Comment "forms" can be provided to those at the public meeting to fill out and leave at end of meeting or to mail in during the public comment period

2.4.6.3 RESPONSE TO PUBLIC COMMENTS

Based on public comments received during the comment period on the Draft RAM or the Draft RAR, the HEER Office project manager will reassess appropriateness of the preliminary response action, make a final decision on the remedial or removal action, and document the decision in the record. The Final RAM or Final RAR, which addresses public comments received and provides supporting analysis, is made available for public inspection and copying in the affected county prior to start of the response action.

The HEER Office will generally consider comments submitted by interested persons after the close of the public comment period only to the extent the comments contain significant information not contained elsewhere in the record which could not have been submitted during the public comment period and which substantially supports the need to significantly alter the response action.

If new information is made available before the Draft RAM or Draft RAR is finalized that fundamentally changes the response action from the original proposal, the HEER Office will seek additional public comment on a revised Draft RAM or Draft RAR that explains the fundamental changes from the original, or will provide a discussion in the Final RAM/Final RAR of the fundamental changes if the HEER Office determines such changes could be reasonably anticipated by the public based of the alternatives and other information in the record.

After a response action decision document has been finalized, the following record requirements apply:

- The HEER Office may add documents to the administrative record after the decision document has been finalized - if the documents concern a portion of the response action decision that the decision document does not address or defers to be decided at a later date
- The HEER Office may hold additional public comment periods or extend the time of comment on any issues concerning selection of the response action after the decision document has been finalized

2.5 SITE CLOSURE

Sites are no longer subject to response actions under the Hawai'i SCP when the HEER Office determines no further action (NFA) is necessary based on a review of all information that is available in the record for the site. Section 19 provides a detailed discussion of site closures; however, primary considerations include:

- Has evaluation of site data relating to minimum hazard criteria shown any of these criteria to be exceeded? (see Subsection 2.4.2, Site Listing) Note: This evaluation must be based on defensible site characterization data and other supportive evidence documented in the file. If minimum hazard criteria are not exceeded, taking response action is not appropriate.
- If response actions have been taken, were they sufficient to address the release or threat of release?

Once the HEER Office decides that no further action is necessary for a specific release or suspect release site, a NFA letter will be sent to the responsible party(s). The NFA determination may be made after review of site assessment reports that demonstrate a release or threat of release does not exist. NFA letters may also be issued after appropriate response action (either removal or remedial action) has been successfully completed and documented. The NFA letter typically:

- Summarizes the release or suspect release scenario briefly
- Indicates all pertinent information and data regarding the site assessment and/or response actions have been reviewed
- States that no further action appears necessary for the release
- Notes that if new information indicates that contamination is present at levels of concern, the HEER Office may require additional assessment and cleanup work (as necessary) to be performed

In some cases, a response action may address the threat posed by a hazardous substance release by containing the hazardous substances on site so that exposure to the public and the environment is prevented. For example, a barrier cover might be used to prevent direct contact with contaminated soil at a site. To ensure the continued effectiveness of controls preventing public exposure at a site, HDOH may place conditions on the site's NFA letter to require monitoring and reporting of site conditions, placement of an environmental covenant on the property title, or other long-term management actions. If these controls are not adequately maintained, HDOH may revoke the NFA letter and initiate additional site assessment or response actions (see Section 19, Site Closures).

As noted in Subsection 2.3, Emergency Response, an NFA letter regarding completion of an emergency response action may be qualified as pertaining only to the emergency response action, and may not necessarily address contamination that may remain at the site (e.g., in the subsurface soil or groundwater). In these instances, the NFA letter will indicate that the emergency response has been appropriately concluded and the site stabilized, but the site has been referred for additional environmental evaluation and remains an active (listed) environmental cleanup site.

Voluntary Response Program (VRP) sites receive a specialized NFA letter called a Letter of Completion (LOC), which also includes an exemption from future liability for the specific contaminants and media that were cleaned up (see Subsection 20.3, VRP).

Sites receiving NFA letters are removed from the "list of sites" (at the end of the yearly reporting period) that are required to be identified for assessment or potential cleanup action under HRS 128-D and the Hawai'i SCP (see Subsection 2.4.2, Site Listing.

Finally, under HEER Office guidance for Long-Term Management of Petroleum-Contaminated Soil and Groundwater, responsible parties may request the HEER Office to issue a determination that "No Further Active Remediation" is required for a site. Although short of a NFA letter (a No Further Active Remediation determination is not considered a type of site closure), this letter clearly defines the remaining environmental hazards, and consequently the environmental liabilities posed by the release, and the site conditions under which such hazards would be posed. This determination may be helpful to site owners, financial institutions, and potential purchasers to establish the "environmental liability" of a site with remaining contamination prior to formal site closure.

SECTION 2 REFERENCES

Citation references for this TGM Subsection denoted with an “a”, “b”, “c”, etc… after the year of publication may not appear in sequence as these refer to the order placed in the Master References List for the entire TGM.

HAR 11-451. Hawai'i Administrative Rules, Department of Health. Title 11, Chapter 451, State Contingency Plan (SCP). Local Copy (2.2mb). August 2, 1995.

HDOH, 2016. Hawai'i Department of Health, Office of Hazard Evaluation and Emergency Response. Screening for Environmental Concerns at Sites with Contaminated Soil and Groundwater. Website URL: http://eha-web.doh.hawaii.gov/eha-cma/Leaders/HEER/EALs. Summer 2016 (and updates).

HRS 128D. Hawai'i Revised Statutes. Hawai'i Environmental Response Law (HERL), Chapter 128D. Website URL: https://www.capitol.hawaii.gov/hrscurrent/Vol03_Ch0121-0200D/HRS0128D/.

HRS 128E. Hawai'i Revised Statutes. Hawai'i Emergency Planning and Community Right-To-Know Act, Chapter 128E. Website URL: https://www.capitol.hawaii.gov/hrscurrent/Vol03_Ch0121-0200D/HRS0128E/.

HRS 508C. Hawai'i Revised Statutes. Uniform Environmental Covenants Act (UECA), Chapter 508C. Website URL: https://www.capitol.hawaii.gov/hrscurrent/Vol12_Ch0501-0588/HRS0508C/. Local Copy (20kb).

APPENDIX 2-A
HAZARDOUS SUBSTANCE RELEASE NOTIFICATION AND INVENTORY GUIDELINE

(see PDF file)

APPENDIX 2-B
HAZARDOUS SUBSTANCE RELEASE NOTIFICATION GUIDELINE

(see PDF file)

APPENDIX 2-C
REPORTABLE QUANTITIES
(SORTED BY CHEMICAL ABSTRACT NUMBER)

(see PDF file)

APPENDIX 2-D
REPORTABLE QUANTITIES
(SORTED BY CHEMICAL NAME)

(see PDF file)

APPENDIX 2A

HAZARDOUS SUBSTANCE RELEASE NOTIFICATION AND INVENTORY GUIDELINE

Appendix 2-A (Continued)

Hawaii State Department of Health Hazard Evaluation and Emergency Response Office (HEER) Addresses of HEER Office and Local Emergency Planning Committee (LEPCs)

Emergency Planning and Community Right to Know Act of 1986 §302, §304, §311, §312 and §313
Hawaii Emergency Planning and Community Right to Know Act §128E-6, §128E-7, §128E-9 and Title 11 Chapter 453 Hawaii Administrative Rules § 11-453
The State Contingency Plan, Title 11 Chapter 451 Hawaii Administrative Rules §11-451-7
Comprehensive Environmental Response Compensation and Liability Act §103

The Hawaii State Emergency Response Commission (HSERC), the Local Emergency Planning Committee (LEPC), local Fire Department and the National Response Center (NRC) must receive the appropriate notification upon a covered chemical release and/or for routine inventories at the addresses and phone numbers listed in the table below.

County	HSERC	LEPC	Fire Department	NRC
C & C of Honolulu	Hawaii State Department of Health 919 Ala Moana Blvd., Room 206 Honolulu, Hawaii 96814-4912 Attn: EPCRA Data Manager Phone: (808) 586-4249 Fax: (808) 586-7537 After Hours: (808) 247-2191 **sharon.leonida@doh.hawaii.gov**	Honolulu LEPC Department of Emergency Management 650 South King St. Honolulu, Hawaii 96813 Phone: (808) 723-8960 After Hours: 911 Fax: 524-3439	Manuel Neves, Fire Chief Honolulu Fire Department 636 South St. Honolulu, Hawaii 96813-5007 Phone: Fire Chief (808) 723-7101 Fax: (808) 723-7111	1 (800) 424-8802
Hawaii	Hawaii State Department of Health Same address and phone numbers statewide.	Gerald Kosaki Hawaii County LEPC Co-Chair Hawaii State District Health Office 1582 Kamehameha Ave. Hilo, Hawaii 96720 (808) 936-8181/(808) 443-4150 Henry Silva, LEPC Co-Chair Phone: (808) 895-7318	Darren Rosario, Fire Chief Hawaii Fire Department 25 Aupuni St., Suite 2501 Hilo, Hawaii 96720 Phone: (808) 932-2903	Same number nationwide.

Appendix 2-A (Continued)

Kauai	Hawaii State Department of Health Same address and phone numbers statewide.	Albert Kaui Kauai Fire Department 4444 Rice St., Suite 315 Lihue, Hawaii 96766 Phone: (808) 634-0310 After Hours: (Dispatch) (808) 241-1711 Fax: (808) 241-6508	Robert Westerman, Chief Kauai Fire Department 4444 Rice St., Suite 315 Lihue, Hawaii 96766 Phone: (808) 241-4975 Fax: (808) 241-6508	Same number nationwide.
Maui	Hawaii State Department of Health Same address and phone numbers statewide.	Jeffrey Kihune Maui County Fire Department 200 Dairy Rd. Kahului, Hawaii 96732 Phone: (808) 870-7404 (primary and after hours) Alternate: (808) 270-7911 Fax: (808) 270-7917	Jeff Murray, Chief Maui County Fire Department 200 Dairy Rd. Kahului, Hawaii 96732 Phone: (808) 270-7561 Fax: (808) 270-7919	Same number nationwide.

Appendix 2-A (Continued)

HEER Hazardous Substance Release Notification and Inventory Guideline Summary Implementation Table

Statute or Regulation Section Number	List of Lists(7/1/93) Column Heading	Who must Provide Information	Information to Provide	To Whom Information Goes	When to Submit Information
§302 §128E-6	Sec. 302 (EHS) TPQ	All who store in excess of the TPQ.	Letter stating that you are regulated.	HSERC, LEPC	Information due within 60 days of receipt of Extremely Hazardous Substance at a facility.
§304 §128E-7 §11-451-7 §103	EHS RQ CERCLA RQ and 10 pound RQ for TCP and Oil under the listed circumstances.*	Those who release above the RQ in a 24 hour period.	Release Notification and Written Follow-up.	HSERC, LEPC	Release Notification due immediately. Written follow-up due as soon as possible within 30 days.
§103	CERCLA RQ	Those who release above the RQ.	Release Notification	NRC	Immediately.
§311 §128E-6(2)(A)	Sec. 302 (EHS) TPQ and 10,000 pound TPQ for OSHA Hazardous Chemicals.	Those who store above the TPQ.	List of MSDS Chemicals and Hazard Categories for Each.	HSERC, LEPC, Fire Department	Due annually by March 1 for preceding calendar year inventory.

Appendix 2-A (Continued)

Statute or Regulation Section Number	List of Lists(7/1/93) Column Heading	Who must Provide Information	Information to Provide	To Whom Information Goes	When to Submit Information
§312 §128E- 6(2)(B)&(C)	Sec. 302 (EHS) TPQ and 10,000 pound TPQ for OSHA Hazardous Chemicals.	Those who store above the TPQ.	Hawaii Chemical Inventory Form (Tier II) and Site Map.	HSERC, LEPC, Fire Department	Due annually by March 1 for preceding calendar year inventory.
§128E-9		Those who submit an HCIF.	Filing Fee - $100 per facility.	HSERC	Due annually with HCIF.
§313	Sec 313	Manufacturing facilities in specified SIC Codes, with more than 10 employees, that manufacture or process more than 25,000 pounds or otherwise use more than 10,000 pounds of the listed chemicals.	TRI Form R		Due annually by July 1 for preceding calendar year inventory.

Notes:
* (A) Any amount of oil which when released into the environment causes a sheen to appear on surface water, or any navigable water of the State;
(B) Any free product that appears on groundwater;
(C) Any amount of oil released to the environment greater than 25 gallons; and
(D) Any amount of oil released to the environment which is less than 25 gallons, but which is not contained and remediated within 72 hours.

APPENDIX 2-B

HAZARDOUS SUBSTANCE RELEASE NOTIFICATION GUIDELINE

Appendix 2-B

Hazardous Substance Release Notification Guideline
Hawai`i Department of Health (HDOH)
Office of Hazard Evaluation and Emergency Response (HEER Office)

This guideline is general in nature and is provided to assist in complying with HEPCRA and the SCP in Hawaii and does not have the force and effect of law. To ensure full compliance under the law, persons affected should review the appropriate Federal and State statutes and regulations. Failure to report a release under these laws and regulations may prompt EPA or State enforcement action including penalties not to exceed fines of $25,000 per day per violation or imprisonment. Copies of the laws and regulations may be obtained by contacting the HSERC/HEER at (808) 586-4249 or on the HEER website.

Overview of Requirements

In Hawaii, owners or operators of facilities or vessels reporting releases of hazardous substances are subject to state notification requirements under Chapter 128D, Hawaii Revised Statutes, the Environmental Response Law, Chapter 128E, Hawaii Revised Statutes, the Hawaii Emergency Planning and Community Right-to-Know Act (HEPCRA) and Title 11, Chapter 451, Hawaii Administrative Rules, the State Contingency Plan (SCP).

In general, the owner or operator of a facility or vessel **must immediately notify** the Hawaii State Emergency Response Commission (HSERC/HEER) ((808) 586-4249 or (808) 247-2191 after work hours) and the Local Emergency Planning Committee (LEPC) (telephone numbers are listed on a separate sheet) of the appropriate jurisdiction after the release of:

1. A listed hazardous substance designated under section 11-451-5(b), in quantities equal to or exceeding the reportable quantity criteria in section 11-451-6(b) in any 24-hour period; or

2. An unlisted hazardous substance designated under section 11-451-5(c), in quantities equal to or exceeding the reportable quantity criteria in section 11-451-6(c) in any 24-hour period.

Note: The HSERC/HEER are listed together because the Hawaii State Department of Health Hazard Evaluation and Emergency Response Office is the administrative contact for the Hawaii State Emergency Response Commission.

An exception from immediate notification is provided for releases of oil of less than 25 gallons in any 24-hour period which is not contained and remedied within 72 hours. Such releases must be reported in written form only within 30 days of the discovery of the release.

The owner or operator of the facility or vessel must also provide a written follow-up notice within 30 days of the discovery of the release. If a release of a hazardous substance poses an imminent or immediate threat to public health or the environment, dial 911 to request fire, police, or emergency medical service personnel response.

Immediate Notification Contents

A reportable quantity of a hazardous substance is a trigger to notify the appropriate government agencies. This is necessary so that government personnel such as the State On-Scene Coordinators can evaluate the need for a response action and ensure that any necessary response actions are undertaken in a timely manner.

Immediate verbal notification shall be provided to the HSERC/HEER and LEPC either via telephone or in person. HEER/HSERC will not accept **initial notification** via fax or e-mail. In addition, unless it is specifically stated that a verbal notification is being given to a State On-Scene Coordinator (SOSC) on scene during an incident, the presence of a SOSC does not constitute a notification.

Provide the following information to the extent known at the time of the notice so long as no delay in responding to the emergency results. It is expected that notification occur within 20 minutes of discovery of the release. (Do not delay due to incomplete notification information related to the release):

1. Name and telephone number of the caller.
2. Name and telephone number of a contact person, (if different from the caller) that can provide timely information as the incident is occurring.
3. Name (trade and chemical), of the hazardous substance which has been released.
4. Approximate quantity of the hazardous substance which has been released.
5. Location of the incident.
6. Date and time of spill, release, or threatened release.
7. Description of what happened (source and cause of the release).
8. Immediate danger or threat posed by the release.
9. Name, address, and telephone number of the responsible party or potentially responsible party.
10. Measures taken or proposed to be taken in response to the release as of the time of the notification.
11. Any known injuries or advice regarding medical attention necessary for exposed individuals.
12. The names and phone numbers of other federal, state, or local government agencies that have been notified of the release.
13. Any other information that may help emergency personnel respond to the incident.

Once the information has been provided, the caller will be provided with a HEER Incident Case Number, which shall be referenced in any future correspondence including the written notification submittal.

Federal Requirements under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Oil Pollution Act (OPA)

Releases of Reportable Quantities (RQ) of CERCLA hazardous substances and releases of oil which causes a sheen on water must also be reported to the National Response Center at 1(800) 424-8802.

Written Follow-Up Notification Contents

Notice, including all information provided in the verbal notification described above and any other pertinent information not previously provided, shall also be made in writing to the HSERC/HEER. This written notification shall be sent to HSERC/HEER no later than thirty (30) days after initial discovery of a release. The written notification can be sent by certified mail, faxed, hand-delivered, or another means which provides proof of delivery. Photos should be included to document the incident. A suggested Written Follow-up Notification Form is provided.

Hawaii Hazardous Substance Written Follow-Up Notification Form

PLEASE PROVIDE THE FOLLOWING INFORMATION

Incident Case No.: _____

Contact Information

Caller's Information

Name: _____

Address: _____

City: _____ State _____ Zip _____

Telephone number: _____

Owner's Information

Name: _____

Title: _____

Company: _____

Address: _____

City: _____ State _____ Zip _____

Telephone number: _____

Operator's Information

Name: _____

Title: _____

Company: _____

Address: _____

City: _____ State _____ Zip _____

Telephone number: _____

Name of a contact person at the facility or vessel where the release has occurred: _____

_____

Telephone number: _____

Hazardous Substance Released:

Name (trade and chemical) of the hazardous substance which has been released: _____

_____

Chemical Abstract Service (CAS) Number (if applicable):_____

Approximate quantity of the hazardous substance released: _____

Incident Information

Location of the release:_____

_____

A brief description of the release: _____

_____

Media into which the release occurred or is likely to occur (Indicate all those that apply):

☐ Air ☐ Soil ☐ Groundwater ☐ Concrete ☐ Asphalt ☐ Stream ☐ Ocean ☐ Other

Cause of the release: _____

_____

Date of the release: _____

Time of the release: _____

Duration of the release: _____

Date: _____

Time that the person in charge of the facility or vessel where the release occurred obtained knowledge of the release: _____

Source of the release: _____

_____

Response Information

Response measures taken thus far: _____

_____

Any appropriate information relating to the ability of the owner or operator of the facility or vessel where the release has occurred to pay for or perform any proposed or required response actions: _____

_____

_____

The names of other federal, state, or local government agencies that have been notified of the release: _____

_____

Health Information

Known or anticipated acute health risks: _____

_____

Known or anticipated chronic health risks: _____

_____

Advice regarding medical attention necessary for exposed individuals: _____

_____

Potential impacts to public health or welfare: _____

_____

Potential impacts to the environment: _____

_____

"I certify under penalty of law that I have personally examined and am familiar with the information submitted and believe the submitted info is true, accurate, and complete."

Signature: _____ Date: _____

Printed Name: _____

Title: _____

Company: _____

APPENDIX 2-C

REPORTABLE QUANTITIES

(SORTED BY CHEMICAL ABSTRACT NUMBER)

Appendix 2-C
Reportable Quantities (Sorted by Chemical Abstract Number)

Chemical Abstract Number (CAS)	NAME	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid$^{\Delta}$ (Gallons)
0	Antimony Compounds		**	
0	Arsenic Compounds		**	
0	Beryllium Compounds		**	
0	Cadmium Compounds		**	
0	Chlordane (Technical Mixture and Metabolites)		**	
0	Chlorinated Benzenes		**	
0	Chlorinated Ethanes		**	
0	Chlorinated Naphthalene		**	
0	Chlorinated Phenols		**	
0	Chloroalkyl Ethers		**	
0	Chlorophenols		**	
0	Chromium Compounds		**	
0	Cobalt Compounds		*	
0	Coke Oven Emissions		1	
0	Copper Compounds		**	
0	Cyanide Compounds		**	
0	DDT and Metabolites		**	
0	Dichlorobenzidine		**	
0	Diphenylhydrazine		**	
0	Endosulfan and Metabolites		**	
0	Endrin and Metabolites		**	
0	Fine mineral fibers		*	
0	Glycol Ethers		*	
0	Haloethers		**	
0	Halomethanes		**	
0	Heptachlor and Metabolites		**	
0	Hexachlorocyclohexane (all isomers) CAS 608-73-1		**	
0	Lead Compounds		**	
0	Manganese Compounds		*	
0	Manganese Compounds		*	
0	Mercury Compounds		**	
0	Nickel Compounds		**	
0	Nitrophenols		**	
0	Nitrosamines		**	
0	Organorhodium Complex (PMN-82-147)		1	
na	Oil		Ψ	
0	Phthalate Esters		**	
0	Polycyclic organic matter		*	
0	Polynuclear Aromatic Hydrocarbons		**	
0	Selenium Compounds		**	
0	Silver Compounds		**	
0	Thallium Compounds		**	
0	Zinc Compounds		**	

Chemical Abstract Number (CAS)	NAME	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
50000	Formaldehyde	U122	100	na
50077	Mitomycin C	U010	10	na
50146	Ergocalciferol		1	na
50180	Cyclophosphamide	U058	10	na
50293	DDT	U061	1	na
50328	Benzo[a]pyrene	U022	1	na
50555	Reserpine	U200	5000	na
51218	Fluorouracil		1	na
51285	"2,4-Dinitrophenol"	P048	10	na
51434	Epinephrine	P042	1000	na
51752	Mechlorethamine		1	0.11
51796	"Carbamic acid, ethyl ester"	U238	100	na
51796	Ethyl carbamate	U238	100	na
51796	Urethane	U238	100	na
51832	Carbachol chloride		1	na
52686	Trichlorfon		100	na
52857	Famphur	P097	1000	na
53703	"Dibenz[a,h]anthracene"	U063	1	na
53963	2-Acetylaminofluorene	U005	1	na
54115	Nicotine	P075	100	11.88
54115	Nicotine and salts	P075	100	11.88
54115	"Pyridine, 3-(1-methyl-2-pyrrolidinyl)-,(S)-"	P075	100	11.87
54626	Aminopterin		1	na
55185	N-Nitrosodiethylamine	U174	1	na
55630	Nitroglycerin	P081	10	0.75
55914	Diisopropylfluorophosphate	P043	100	11.37
55914	Isofluorphate	P043	100	11.37
56042	Methylthiouracil	U164	10	na
56235	Carbon tetrachloride	U211	10	0.75
56257	Cantharidin		1	na
56382	Parathion	P089	10	0.95
56495	3-Methylcholanthrene	U157	10	na
56531	Diethylstilbestrol	U089	1	na
56553	Benz[a]anthracene	U018	10	na
56724	Coumaphos		10	na
57125	Cyanides (soluble salts and complexes) [hydrogen]	P030	10	1.72
57125	Cyanides (soluble salts and complexes) [sodium]		10	na
57125	Cyanides (soluble salts and complexes) [potassium]		10	na
57147	"1,1-Dimethyl hydrazine"	U098	10	1.53
57147	Dimethylhydrazine	U098	10	1.53
57147	"Hydrazine, 1,1-dimethyl-"	U098	10	1.53
57249	Strychnine	P108	10	na
57249	"Strychnine, and salts"	P108	10	na
57476	Physostigmine		1	na
57578	beta-Propiolactone		10	1.04
57647	"Physostigmine, salicylate (1:1)"		1	na

Chemical Abstract Number (CAS)	NAME	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
57749	Chlordane	U036	1	0.07
57976	"7,12-Dimethylbenz[a]anthracene"	U094	1	na
58366	"Phenoxarsine, 10,10'-oxydi-"		1	na
58899	Hexachlorocyclohexane (gamma isomer)	U129	1	na
58899	Lindane	U129	1	na
58902	"2,3,4,6-Tetrachlorophenol"	U212	10	na
59507	p-Chloro-m-cresol	U039	5000	na
59881	Phenylhydrazine hydrochloride		1	na
59892	N-Nitrosomorpholine		1	na
60004	Ethylenediamine-tetraacetic acid (EDTA)		5000	na
60117	4-Dimethylaminoazobenzene	U093	10	na
60117	Dimethylaminoazobenzene	U093	10	na
60297	Ethyl ether	U117	100	16.81
60344	Methyl hydrazine	P068	10	1.38
60355	Acetamide		100	na
60413	"Strychnine, sulfate"		10	na
60515	Dimethoate	P044	10	na
60571	Dieldrin	P037	1	na
61825	Amitrole	U011	10	na
62384	Phenylmercuric acetate	P092	100	na
62384	Phenylmercury acetate	P092	100	na
62442	Phenacetin	U187	100	na
62500	Ethyl methanesulfonate	U119	1	0.10
62533	Aniline	U012	5000	586.79
62555	Thioacetamide	U218	10	na
62566	Thiourea	U219	10	na
62737	Dichlorvos		10	0.85
62748	"Fluoroacetic acid, sodium salt"	P058	10	na
62748	Sodium fluoroacetate	P058	10	na
62759	"Methanamine, N-methyl-N-nitroso-"	P082	10	1.19
62759	N-Nitrosodimethylamine	P082	10	1.19
62759	Nitrosodimethylamine	P082	10	1.19
63252	Carbaryl		100	na
64006	"Phenol, 3-(1-methylethyl)-, methylcarbamate"		1	na
64186	Formic acid	U123	5000	495.47
64197	Acetic acid		5000	571.41
64675	Diethyl sulfate		10	1.02
64868	Colchicine		1	na
65305	Nicotine sulfate		100	na
65850	Benzoic acid		5000	na
66751	Uracil mustard	U237	10	na
66819	Cycloheximide		1	na
67561	Methanol	U154	5000	757.93
67641	Acetone	U002	5000	763.04
67663	Chloroform	U044	10	0.80
67721	Hexachloroethane	U131	100	na
68122	Dimethylformamide		10	1.27
70257	"Guanidine, N-methyl-N'-nitro-N-nitroso-"	U163	10	na

Chemical Abstract Number (CAS)	NAME	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
70304	Hexachlorophene	U132	100	na
70699	"Propiophenone, 4'-amino"		1	na
71363	n-Butyl alcohol	U031	5000	740.15
71432	Benzene	U019	10	1.36
71556	Methyl chloroform	U226	1000	89.64
71556	"1,1,1-Trichloroethane"	U226	1000	89.64
71636	Digitoxin		1	na
72208	Endrin	P051	1	na
72435	Methoxychlor	U247	1	na
72548	DDD	U060	1	na
72559	DDE		1	na
72571	Trypan blue	U236	10	na
74839	Bromomethane	U029	1000	na
74839	Methyl bromide	U029	1000	na
74873	Chloromethane	U045	100	na
74873	Methyl chloride	U045	100	na
74884	Methyl iodide	U138	100	5.26
74895	Monomethylamine		100	13.29
74908	Hydrocyanic acid	P063	10	na
74908	Hydrogen cyanide	P063	10	na
74931	Methyl mercaptan	U153	100	na
74931	Thiomethanol	U153	100	na
74953	Methylene bromide	U068	1000	48.02
75003	Chloroethane		100	4.80
75003	Ethyl chloride		100	4.80
75014	Vinyl chloride	U043	1	na
75047	Monoethylamine		100	na
75058	Acetonitrile	U003	5000	763.04
75070	Acetaldehyde	U001	1000	na
75092	Dichloromethane	U080	1000	90.46
75092	Methylene chloride	U080	1000	90.46
75150	Carbon disulfide	P022	100	9.49
75207	Calcium carbide		10	na
75218	Ethylene oxide	U115	10	na
75218	Oxirane	U115	10	na
75252	Bromoform	U225	100	4.14
75252	Tribromomethane	U225	100	4.14
75274	Dichlorobromomethane		5000	304.17
75343	"1,1-Dichloroethane"	U076	1000	101.96
75354	"1,1-Dichloroethylene"	U078	100	9.88
75354	Vinylidene chloride	U078	100	9.88
75365	Acetyl chloride	U006	5000	543.04
75445	Phosgene	P095	10	na
75503	Trimethylamine		100	na
75558	"Aziridine, 2-methyl"	P067	1	0.15
75558	Propyleneimine	P067	1	0.15
75569	Propylene oxide		100	14.45
75605	Cacodylic acid	U136	1	na

Chemical Abstract Number (CAS)	NAME	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
75649	tert-Butylamine		1000	172.28
75694	CFC-11	U121	5000	na
75694	Trichlorofluoromethane [CFC-11]	U121	5000	na
75694	Trichloromonofluoromethane	U121	5000	na
75718	CFC-12	U075	5000	na
75718	Dichlorodifluoromethane [CFC-12]	U075	5000	na
75741	Tetramethyllead		1	na
75774	Trimethylchlorosilane		1	0.14
75785	Dimethyldichlorosilane		1	0.11
75796	Methyltrichlorosilane		1	0.09
75865	Acetone cyanohydrin	P069	10	1.29
75876	"Acetaldehyde, trichloro-"	U034	5000	396.48
75990	"2,2-Dichloropropionic acid"		5000	na
76017	Pentachloroethane	U184	10	0.71
76028	Trichloroacetyl chloride		1	0.07
76448	Heptachlor	P059	1	na
77474	Hexachlorocyclopentadiene	U130	10	0.70
77781	Dimethyl sulfate	U103	100	9.00
77816	Tabun		1	0.11
78002	Tetraethyl lead	P110	10	0.72
78342	Dioxathion		1	0.10
78535	Amiton		1	0.11
78591	Isophorone		5000	649.60
78717	"Oxetane, 3,3-bis(chloromethyl)-"		1	na
78795	Isoprene		100	17.74
78819	iso-Butylamine		1000	165.61
78820	Isobutyronitrile		1	0.16
78831	Isobutyl alcohol	U140	5000	747.53
78875	"1,2-Dichloropropane"	U083	1000	103.74
78875	"Propane 1,2-dichloro-"	U083	1000	103.74
78886	"2,3-Dichloropropene"		100	9.96
78933	Methyl ethyl ketone	U159	5000	744.75
78933	Methyl ethyl ketone (MEK)	U159	5000	744.75
78944	Methyl vinyl ketone		1	0.14
78977	Lactonitrile		1	0.12
78999	"1,1-Dichloropropane"		1000	105.92
79005	"1,1,2-Trichloroethane"	U227	100	8.32
79016	Trichloroethylene	U228	100	8.20
79061	Acrylamide	U007	5000	na
79094	Propionic acid		5000	603.53
79107	Acrylic acid	U008	5000	565.59
79118	Chloroacetic acid		100	na
79196	Thiosemicarbazide	P116	100	na
79210	Peracetic acid		1	0.10
79221	Methyl chloroformate	U156	1000	98.04
79312	iso-Butyric acid		5000	632.41
79345	"1,1,2,2-Tetrachloroethane"	U209	100	7.52
79447	Dimethylcarbamyl chloride	U097	1	0.10

Chemical Abstract Number (CAS)	NAME	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
79469	2-Nitropropane	U171	10	1.21
80159	Cumene hydroperoxide	U096	10	1.17
80159	"Hydroperoxide, 1-methyl-1-phenylethyl-"	U096	10	1.17
80626	Methyl methacrylate	U162	1000	127.15
80637	Methyl 2-chloroacrylate		1	0.10
81072	Saccharin (manufacturing)	U202	100	na
81072	Saccharin and salts	U202	100	na
81812	Warfarin	P001	100	na
81812	"Warfarin, & salts, conc.>0.3%"	P001	100	na
82666	Diphacinone		1	na
82688	PCNB	U185	100	na
82688	Pentachloronitrobenzene	U185	100	na
82688	Quintozene	U185	100	na
83329	Acenaphthene		100	na
84662	Diethyl phthalate	U088	1000	107.25
84742	n-Butyl phthalate	U069	10	1.15
84742	Dibutyl phthalate	U069	10	1.15
85007	Diquat		1000	na
85018	Phenanthrene		5000	na
85449	Phthalic anhydride	U190	5000	na
85687	Butyl benzyl phthalate		100	10.90
86306	N-Nitrosodiphenylamine		100	na
86500	Azinphos-methyl		1	na
86500	Guthion		1	na
86737	Fluorene		5000	na
86884	Antu	P072	100	na
86884	"Thiourea, 1-naphthalenyl-"	P072	100	na
87650	"2,6-Dichlorophenol"	U082	100	na
87683	"Hexachloro-1,3-butadiene"	U128	1	0.07
87683	Hexachlorobutadiene	U128	1	0.07
87865	PCP	U242	10	na
87865	Pentachlorophenol	U242	10	na
88051	"Aniline, 2,4,6-trimethyl-"		1	0.12
88062	"2,4,6-Trichlorophenol"	U231	10	na
88722	o-Nitrotoluene		1000	103.10
88755	2-Nitrophenol		100	na
88857	Dinoseb	P020	1000	na
90040	o-Anisidine		100	10.98
91087	"Toluene-2,6-diisocyanate"		100	9.79
91203	Naphthalene	U165	100	na
91225	Quinoline		5000	550.02
91587	2-Chloronaphthalene	U047	5000	na
91598	beta-Naphthylamine	U168	10	na
91667	"N,N-Diethylaniline"		1000	127.83
91805	Methapyrilene	U155	5000	na
91941	"3,3'-Dichlorobenzidine"	U073	1	na
92524	Biphenyl		100	na
92671	4-Aminobiphenyl		1	na

Chemical Abstract Number (CAS)	NAME	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid$^{\Delta}$ (Gallons)
92875	Benzidine	U021	1	na
92933	4-Nitrobiphenyl		10	na
93721	"Silvex (2,4,5-TP)"	U233	100	na
93765	"2,4,5-T acid"	U232	1000	na
93798	"2,4,5-T esters"		1000	na
94111	"2,4-D Esters"		100	na
94586	Dihydrosafrole	U090	10	na
94597	Safrole	U203	100	10.95
94757	"2,4-D"	U240	100	na
94757	"2,4-D Acid"	U240	100	na
94757	"2,4-D, salts and esters"	U240	100	na
94791	"2,4-D Esters"		100	na
94804	"2,4-D Esters"		100	na
95476	"Benzene, o-dimethyl-"	U239	1000	133.67
95476	o-Xylene	U239	1000	133.67
95487	o-Cresol	U052	100	na
95501	o-Dichlorobenzene	U070	100	9.18
95501	"1,2-Dichlorobenzene"	U070	100	9.18
95534	o-Toluidine	U328	100	11.90
95578	2-Chlorophenol	U048	100	9.66
95807	"2,4-Diaminotoluene"		10	na
95943	"1,2,4,5-Tetrachlorobenzene"	U207	5000	na
95954	"2,4,5-Trichlorophenol"	U230	10	na
96093	Styrene oxide		100	11.42
96128	DBCP	U066	1	0.06
96128	"1,2-Dibromo-3-chloropropane"	U066	1	0.06
96184	1,2,3-Trichloropropane (TCP)		10	na
96457	Ethylene thiourea	U116	10	na
97632	Ethyl methacrylate	U118	1000	131.26
98011	Furfural	U125	5000	517.27
98055	Benzenearsonic acid		1	na
98077	Benzoic trichloride	U023	10	0.87
98077	Benzotrichloride	U023	10	0.87
98099	Benzenesulfonyl chloride	U020	100	8.66
98135	Trichlorophenylsilane		1	0.09
98168	"Benzenamine, 3-(trifluoromethyl)-"		1	0.09
98828	Cumene	U055	5000	695.50
98862	Acetophenone	U004	5000	583.99
98873	Benzal chloride	U017	5000	477.44
98884	Benzoyl chloride		1000	98.38
98953	Nitrobenzene	U169	1000	100.25
99081	m-Nitrotoluene		1000	103.63
99354	"1,3,5-Trinitrobenzene"	U234	10	na
99558	5-Nitro-o-toluidine	U181	100	na
99650	m-Dinitrobenzene		100	na
99989	Dimethyl-p-phenylenediamine		1	na
99990	p-Nitrotoluene		1000	na
100016	p-Nitroaniline	P077	5000	na

Chemical Abstract Number (CAS)	NAME	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
100027	p-Nitrophenol	U170	100	na
100027	4-Nitrophenol	U170	100	na
100141	"Benzene, 1-(chloromethyl)-4-nitro-"		1	na
100254	p-Dinitrobenzene		100	na
100414	Ethylbenzene		1000	138.30
100425	Styrene		1000	132.56
100447	Benzyl chloride	P028	100	10.90
100470	Benzonitrile		5000	593.58
100754	N-Nitrosopiperidine	U179	10	1.13
101144	MBOCA	U158	10	na
101144	"4,4'-Methylenebis(2-chloroaniline)"	U158	10	na
101553	4-Bromophenyl phenyl ether	U030	100	8.44
101688	MBI		5000	na
101688	Methylenebis(phenylisocyanate)		5000	na
101779	"4,4'-Methylenedianiline"		10	na
102363	"Isocyanic acid, 3,4-dichlorophenyl ester"		1	na
103855	Phenylthiourea	P093	100	na
105464	sec-Butyl acetate		5000	687.52
105602	Caprolactam		5000	na
105679	"2,4-Dimethylphenol"	U101	100	na
106423	"Benzene, p-dimethyl-"	U239	100	13.93
106423	p-Xylene	U239	100	13.93
106445	p-Cresol	U052	100	na
106467	"1,4-Dichlorobenzene"	U072	100	na
106478	p-Chloroaniline	P024	1000	na
106490	p-Toluidine	U353	100	na
106503	p-Phenylenediamine		5000	na
106514	p-Benzoquinone	U197	10	na
106514	Quinone	U197	10	na
106887	"1,2-Butylene oxide"		100	14.45
106898	Epichlorohydrin	U041	100	10.14
106934	"1,2-Dibromoethane"	U067	1	0.06
106934	Ethylene dibromide	U067	1	0.06
106967	Propargyl bromide		1	0.09
106990	"1,3-Butadiene"		10	na
107028	Acrolein	P003	1	0.14
107051	Allyl chloride		1000	127.83
107062	"1,2-Dichloroethane"	U077	100	9.57
107062	Ethylene dichloride	U077	100	9.57
107073	Chloroethanol		1	0.10
107108	n-Propylamine	U194	5000	836.15
107119	Allylamine		1	0.16
107120	Ethyl cyanide	P101	10	1.53
107120	Propionitrile	P101	10	1.53
107131	Acrylonitrile	U009	100	14.85
107153	Ethylenediamine		5000	666.87
107164	Formaldehyde cyanohydrin		1	0.11
107186	Allyl alcohol	P005	100	14.04

Chemical Abstract Number (CAS)	NAME	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
107197	Propargyl alcohol	P102	1000	126.48
107200	Chloroacetaldehyde	P023	1000	97.01
107211	Ethylene glycol		5000	537.45
107302	Chloromethyl methyl ether	U046	10	1.13
107448	Sarin		1	0.11
107493	Tepp	P111	10	1.01
107493	Tetraethyl pyrophosphate	P111	10	1.01
107926	Butyric acid		5000	625.80
108054	Vinyl acetate monomer		5000	641.88
108054	Vinyl acetate		5000	641.88
108101	Methyl isobutyl ketone	U161	5000	751.47
108236	Isopropyl chloroformate		1	0.11
108247	Acetic anhydride		5000	555.11
108316	Maleic anhydride	U147	5000	na
108383	"Benzene, m-dimethyl-"	U239	100	13.81
108383	m-Xylene	U239	100	13.81
108394	m-Cresol	U052	100	11.60
108463	Resorcinol	U201	5000	na
108601	Bis(2-chloro-1-methylethyl)ether	U027	1000	108.02
108601	Dichloroisopropyl ether	U027	1000	108.02
108883	Toluene	U220	1000	138.30
108907	Chlorobenzene	U037	100	10.84
108918	Cyclohexylamine		1	0.14
108941	Cyclohexanone	U057	5000	633.07
108952	Phenol	U188	1000	na
108985	Benzenethiol	P014	100	11.17
108985	Thiophenol	P014	100	11.17
109068	2-Picoline	U191	5000	635.76
109615	Propyl chloroformate		1	0.11
109739	Butylamine		1000	161.81
109773	Malononitrile	U149	1000	na
109897	Diethylamine		100	16.95
109999	"Furan, tetrahydro-"	U213	1000	135.33
110009	Furan	U124	100	12.81
110167	Maleic acid		5000	na
110178	Fumaric acid		5000	na
110190	iso-Butyl acetate		5000	685.95
110543	Hexane		5000	915.58
110576	"Trans-1,4-dichlorobutene"		1	0.10
110758	2-Chloroethyl vinyl ether	U042	1000	114.41
110805	"Ethanol, 2-ethoxy-"	U359	1000	128.79
110805	2-Ethoxyethanol	U359	1000	128.79
110827	Cyclohexane	U056	1000	153.92
110861	Pyridine	U196	1000	122.11
110894	Piperidine		1	0.14
111422	Diethanolamine		100	na
111444	Bis(2-chloroethyl) ether	U025	10	0.98
111444	Dichloroethyl ether	U025	10	0.98

Chemical Abstract Number (CAS)	NAME	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
111546	"Ethylenebisdithiocarbamic acid, salts & esters"	U114	5000	na
111693	Adiponitrile		1	0.13
111911	Bis(2-chloroethoxy) methane	U024	1000	97.48
114261	Propoxur		100	na
115026	Azaserine	U015	1	na
115219	Trichloroethylsilane		1	0.10
115264	Dimefox		1	0.11
115297	Endosulfan	P050	1	na
115322	Dicofol		10	na
115902	Fensulfothion		1	na
116063	Aldicarb	P070	1	na
117806	Dichlone		1	na
117817	Bis(2-ethylhexyl)phthalate	U028	100	12.32
117817	DEHP	U028	100	12.32
117817	Di(2-ethylhexyl) phthalate	U028	100	12.32
117840	n-Dioctylphthalate	U107	5000	613.01
117840	Di-n-octyl phthalate	U107	5000	613.01
118741	Hexachlorobenzene	U127	10	na
119380	Isopropylmethylpyrazolyl dimethylcarbamate		1	0.11
119904	"3,3'-Dimethoxybenzidine"	U091	100	na
119937	"3,3'-Dimethylbenzidine"	U095	10	na
119937	o-Tolidine	U095	10	na
120127	Anthracene		5000	na
120581	Isosafrole	U141	100	10.71
120809	Catechol		100	na
120821	"1,2,4-Trichlorobenzene"		100	8.19
120832	"2,4-Dichlorophenol"	U081	100	na
121142	"2,4-Dinitrotoluene"	U105	10	na
121211	Pyrethrins		1	0.08
121299	Pyrethrins		1	0.12
121448	Triethylamine		5000	823.52
121697	"N,N-Dimethylaniline"		100	12.54
121755	Malathion		100	9.93
122098	"Benzeneethanamine, alpha,alpha-dimethyl-"	P046	5000	na
122145	Fenitrothion		1	0.09
122394	Diphenylamine		100	na
122667	"1,2-Diphenylhydrazine"	U109	10	na
122667	"Hydrazine, 1,2-diphenyl-"	U109	10	na
122667	Hydrazobenzene	U109	10	na
123319	Hydroquinone		100	na
123331	Maleic hydrazide	U148	5000	na
123386	Propionaldehyde		1000	150.44
123626	Propionic anhydride		5000	590.66
123637	Paraldehyde	U182	1000	120.87
123739	"Crotonaldehyde, (E)-"	U053	100	13.97
123864	Butyl acetate		5000	679.73
123911	"1,4-Dioxane"	U108	100	11.61
123922	iso-Amyl acetate		5000	684.38

Chemical Abstract Number (CAS)	NAME	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid$^{\Delta}$ (Gallons)
124049	Adipic acid		5000	na
124403	Dimethylamine	U092	1000	na
124414	Sodium methylate		1000	na
124481	Chlorodibromomethane		100	4.89
124652	Sodium cacodylate		1	na
124878	Picrotoxin		1	na
126727	"Tris(2,3-dibromopropyl) phosphate"	U235	10	0.53
126987	Methacrylonitrile	U152	1000	149.88
126998	Chloroprene		100	12.49
127184	Perchloroethylene	U210	100	7.39
127184	Tetrachloroethylene	U210	100	7.39
127822	Zinc phenolsulfonate		5000	na
129000	Pyrene		5000	na
129066	Warfarin sodium		100	na
130154	"1,4-Naphthoquinone"	U166	5000	na
131113	Dimethyl phthalate	U102	5000	503.80
131748	Ammonium picrate	P009	10	na
131895	"2-Cyclohexyl-4,6-Dinitrophenol"	P034	100	na
132649	Dibenzofuran		100	na
133062	Captan		10	na
133904	Chloramben		100	na
134327	alpha-Naphthylamine	U167	100	na
137268	Thiram	U244	10	na
140294	Benzyl cyanide		1	0.12
140761	"Pyridine, 2-methyl-5-vinyl-"		1	0.12
140885	Ethyl acrylate	U113	1000	129.77
141662	Dicrotophos		1	0.10
141786	Ethyl acetate	U112	5000	670.23
142289	"1,3-Dichloropropane"		1000	100.93
142712	Cupric acetate		100	na
142847	Dipropylamine	U110	5000	812.36
143339	Sodium cyanide (Na(CN))	P106	10	na
143500	Kepone	U142	1	na
144490	Fluoroacetic acid		1	na
145733	Endothall	P088	1000	na
148823	Melphalan	U150	1	na
149746	Dichloromethylphenylsilane		1	0.10
151382	Methoxyethylmercuric acetate		1	na
151508	Potassium cyanide	P098	10	na
151564	Aziridine	P054	1	0.15
151564	Ethyleneimine	P054	1	0.15
152169	"Diphosphoramide, octamethyl-"	P085	100	11.00
156605	"1,2-Dichloroethylene"	U079	1000	95.39
156627	Calcium cyanamide		1000	na
189559	"Dibenz[a,i]pyrene"	U064	10	na
191242	Benzo[ghi]perylene		5000	na
193395	"Indeno(1,2,3-cd)pyrene"	U137	100	na
205992	Benzo[b]fluoranthene		1	na

Chemical Abstract Number (CAS)	NAME	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid$^{\Delta}$ (Gallons)
206440	Fluoranthene	U120	100	na
207089	Benzo(k)fluoranthene		5000	na
208968	Acenaphthylene		5000	na
218019	Chrysene	U050	100	na
225514	Benz[c]acridine	U016	100	na
297789	Isobenzan		1	na
297972	"O,O-Diethyl O-pyrazinyl phosphorothioate"	P040	100	9.96
297972	Thionazin	P040	100	9.96
298000	Methyl parathion	P071	100	na
298000	Parathion-methyl	P071	100	na
298022	Phorate	P094	10	1.00
298044	Disulfoton	P039	1	na
300629	Amphetamine		1	0.13
300765	Naled		10	na
301042	Lead acetate	U144	5000	na
302012	Hydrazine	U133	1	0.12
303344	Lasiocarpine	U143	10	na
305033	Chlorambucil	U035	10	na
309002	Aldrin	P004	1	na
311455	Diethyl-p-nitrophenyl phosphate	P041	100	9.41
314409	Bromacil		100	na
315184	Mexacarbate		1000	na
316427	"Emetine, dihydrochloride"		1	na
319846	alpha-BHC		10	na
319857	beta-BHC		1	na
319868	delta-BHC		1	na
327980	Trichloronate		1	0.09
329715	"2,5-Dinitrophenol"		10	na
330541	Diuron		100	na
330552	Linuron		100	na
333415	Diazinon		1	na
334883	Diazomethane		100	na
353424	Boron trifluoride compound with methyl ether (1:1)		1	0.10
353504	Carbonic difluoride	U033	1000	na
357573	Brucine	P018	100	na
359068	Fluoroacetyl chloride		1	0.09
371620	Ethylene fluorohydrin		1	0.11
379793	Ergotamine tartrate		1	na
460195	Cyanogen	P031	100	na
463581	Carbonyl sulfide		100	na
465736	Isodrin	P060	1	na
470906	Chlorfenvinfos		1	0.09
492808	Auramine	U014	100	na
492808	C.I. Solvent Yellow 34	U014	100	na
494031	Chlornaphazine	U026	100	na
496720	Diaminotoluene	U221	10	na
502396	Methylmercuric dicyanamide		1	na
504245	4-Aminopyridine	P008	1000	na

Chemical Abstract Number (CAS)	NAME	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
504245	"Pyridine, 4-amino-"	P008	1000	na
504609	"1,3-Pentadiene"	U186	100	17.56
505602	Mustard gas		1	0.09
506616	Potassium silver cyanide	P099	1	na
506649	Silver cyanide	P104	1	na
506683	Cyanogen bromide	U246	1000	na
506774	Cyanogen chloride	P033	10	na
506785	Cyanogen iodide		1	na
506876	Ammonium carbonate		5000	na
506967	Acetyl bromide		5000	360.51
509148	Tetranitromethane	P112	10	0.75
510156	Chlorobenzilate	U038	10	na
513495	sec-Butylamine		1000	165.61
514738	Dithiazanine iodide		1	na
528290	o-Dinitrobenzene		100	na
532274	2-Chloroacetophenone		100	na
534076	Bis(chloromethyl) ketone		1	na
534521	Dinitrocresol	P047	10	na
534521	"4,6-Dinitro-o-cresol"	P047	10	na
534521	"4,6-Dinitro-o-cresol and salts"	P047	10	na
535897	Crimidine		1	na
538078	Ethylbis(2-chloroethyl)amine		1	0.11
540738	"Hydrazine, 1,2-dimethyl-"	U099	1	0.12
540841	"2,2,4-Trimethylpentane"		1000	173.27
540885	tert-Butyl acetate		5000	695.50
541093	Uranyl acetate		100	na
541253	Lewisite		1	0.06
541537	Dithiobiuret	P049	100	na
541731	"1,3-Dichlorobenzene"	U071	100	9.31
542621	Barium cyanide	P013	10	na
542756	"1,3-Dichloropropene"	U084	1000	98.28
542756	"1,3-Dichloropropylene"	U084	1000	98.28
542767	3-Chloropropionitrile	P027	1000	104.81
542767	"Propionitrile, 3-chloro-"	P027	1000	104.81
542881	Bis(chloromethyl) ether	P016	10	0.92
542881	Chloromethyl ether	P016	10	0.92
542881	Dichloromethyl ether	P016	10	0.92
542905	Ethylthiocyanate		1	0.12
543908	Cadmium acetate		10	na
544183	Cobaltous formate		1000	na
544923	Copper cyanide	P029	10	na
554847	m-Nitrophenol		100	na
555771	Tris(2-chloroethyl)amine		1	na
556616	Methyl isothiocyanate		1	na
556649	Methyl thiocyanate		1	0.11
557197	Nickel cyanide	P074	10	na
557211	Zinc cyanide	P121	10	na
557346	Zinc acetate		1000	na

Chemical Abstract Number (CAS)	NAME	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid$^{\Delta}$ (Gallons)
557415	Zinc formate		1000	na
558258	Methanesulfonyl fluoride		1	0.08
563122	Ethion		10	0.98
563417	Semicarbazide hydrochloride		1	na
563688	Thallium(I) acetate	U214	100	na
573568	"2,6-Dinitrophenol"		10	na
584849	"Toluene-2,4-diisocyanate"		100	9.79
591082	1-Acetyl-2-thiourea	P002	1000	na
592018	Calcium cyanide	P021	10	na
592041	Mercuric cyanide		1	na
592858	Mercuric thiocyanate		10	na
592870	Lead thiocyanate		100	na
593602	Vinyl bromide		100	na
594423	Perchloromethylmercaptan		100	6.96
594423	Trichloromethanesulfenyl chloride		100	6.96
597648	Tetraethyltin		1	0.10
598312	Bromoacetone	P017	1000	73.56
606202	"2,6-Dinitrotoluene"	U106	100	na
608935	Pentachlorobenzene	U183	10	na
609198	"3,4,5-Trichlorophenol"		10	na
610399	"3,4-Dinitrotoluene"		10	na
614788	"Thiourea, (2-methylphenyl)-"		1	na
615532	N-Nitroso-N-methylurethane	U178	1	na
621647	N-Nitrosodi-n-propylamine	U111	10	1.31
621647	Di-n-propylnitrosamine	U111	10	1.31
624839	Methyl isocyanate	P064	10	1.25
625161	tert-Amyl acetate		5000	685.95
626380	sec-Amyl acetate		5000	697.12
627112	Chloroethyl chloroformate		1	0.09
628637	Amyl acetate		5000	684.38
628864	Mercury fulminate	P065	10	na
630104	Selenourea	P103	1000	na
630206	"Ethane, 1,1,1,2-tetrachloro-"	U208	100	7.72
630604	Ouabain		1	na
631618	Ammonium acetate		5000	na
636215	o-Toluidine hydrochloride	U222	100	na
639587	Triphenyltin chloride		1	na
640197	Fluoroacetamide	P057	100	na
644644	Dimetilan		1	na
675149	Cyanuric fluoride		1	na
676971	Methyl phosphonic dichloride		1	na
680319	Hexamethylphosphoramide		1	0.12
684935	N-Nitroso-N-methylurea	U177	1	na
692422	Diethylarsine	P038	1	na
696286	Dichlorophenylarsine	P036	1	0.07
696286	Phenyl dichloroarsine	P036	1	0.07
732116	Phosmet		1	na
757584	Hexaethyl tetraphosphate	P062	100	9.28

Chemical Abstract Number (CAS)	NAME	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
759739	N-Nitroso-N-ethylurea	U176	1	na
760930	Methacrylic anhydride		1	0.12
764410	"2-Butene, 1,4-dichloro-"	U074	1	0.11
765344	Glycidylaldehyde	U126	10	1.12
786196	Carbophenothion		1	0.09
814493	Diethyl chlorophosphate		1	0.10
814686	Acrylyl chloride		1	0.11
815827	Cupric tartrate		100	na
822060	"Hexamethylene-1,6-diisocyanate"		100	11.53
823405	Diaminotoluene	U221	10	na
824113	Trimethylolpropane phosphite		1	na
900958	"Stannane, acetoxytriphenyl-"		1	na
919868	Demeton-S-methyl		1	0.10
920467	Methacryloyl chloride		1	0.11
924163	N-Nitrosodi-n-butylamine	U172	10	1.33
930552	N-Nitrosopyrrolidine	U180	1	0.11
933755	"2,3,6-Trichlorophenol"		10	na
933788	"2,3,5-Trichlorophenol"		10	na
944229	Fonofos		1	na
947024	Phosfolan		1	na
950107	Mephosfolan		1	0.08
950378	Methidathion		1	na
959988	alpha - Endosulfan		1	na
991424	Norbormide		1	na
998301	Triethoxysilane		1	0.14
999815	Chlormequat chloride		1	na
1024573	Heptachlor (and epoxide)	D031	1	na
1031078	Endosulfan sulfate		1	na
1031476	Triamiphos		1	na
1066304	Chromic acetate		1000	na
1066337	Ammonium bicarbonate		5000	na
1066451	Trimethyltin chloride		1	na
1072351	Lead stearate		5000	na
1111780	Ammonium carbamate		5000	na
1116547	N-Nitrosodiethanolamine	U173	1	0.09
1120714	"1,3-Propane sultone"	U193	10	na
1120714	Propane sultone	U193	10	na
1122607	Nitrocyclohexane		1	0.11
1124330	"Pyridine, 4-nitro-, 1-oxide"		1	na
1129415	Metolcarb		1	na
1185575	Ferric ammonium citrate		1000	na
1194656	Dichlobenil		100	na
1300716	Xylenol		1000	na
1303282	Arsenic pentoxide	P011	1	na
1303328	Arsenic disulfide		1	na
1303339	Arsenic trisulfide		1	na
1306190	Cadmium oxide		1	na
1309644	Antimony trioxide		1000	na

Chemical Abstract Number (CAS)	NAME	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid$^{\Delta}$ (Gallons)
1310583	Potassium hydroxide		1000	na
1310732	Sodium hydroxide		1000	na
1314325	Thallic oxide	P113	100	na
1314563	Phosphorus pentoxide		1	na
1314621	Vanadium pentoxide	P120	1000	na
1314803	Sulfur phosphide	U189	100	na
1314847	Zinc phosphide (conc. > 10%)	P122	100	na
1314847	Zinc phosphide	P122	100	na
1314847	Zinc phosphide (conc. <= 10%)	U249	100	na
1314870	Lead sulfide		5000	na
1319728	"2,4,5-T amines"		5000	na
1319773	Cresol (mixed isomers)	U052	100	11.53
1320189	"2,4-D Esters"		100	11.02
1321126	Nitrotoluene		1000	na
1327522	Arsenic acid	P010	1	0.06
1327533	Arsenic trioxide	P012	1	na
1327533	Arsenous oxide	P012	1	na
1330207	Xylene (mixed isomers)	U239	100	13.91
1332076	Zinc borate		1000	na
1332214	Asbestos (friable)		1	na
1333831	Sodium bifluoride		100	na
1335326	Lead subacetate	U146	100	na
1336216	Ammonium hydroxide		1000	133.97
1336363	PCBs		1	0.09
1336363	Polychlorinated biphenyls		1	0.09
1338234	Methyl ethyl ketone peroxide	U160	10	na
1338245	Naphthenic acid		100	11.60
1341497	Ammonium bifluoride		100	na
1397940	Antimycin A		1	na
1420071	Dinoterb		1	na
1464535	"2,2'-Bioxirane"	U085	10	1.08
1464535	Diepoxybutane	U085	10	1.08
1558254	Trichloro(chloromethyl)silane		1	0.08
1563662	Carbofuran		10	na
1582098	Trifluralin		10	na
1600277	Mercuric acetate		1	na
1615801	"Hydrazine, 1,2-diethyl-"	U086	10	na
1622328	"Ethanesulfonyl chloride, 2-chloro-"		1	0.08
1634044	Methyl tert-butyl ether		1000	161.81
1642542	Diethylcarbamazine citrate		1	na
1746016	"2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD)"		1	na
1752303	Acetone thiosemicarbazide		1	na
1762954	Ammonium thiocyanate		5000	na
1863634	Ammonium benzoate		5000	na
1888717	Hexachloropropene	U243	1000	67.93
1910425	Paraquat		1	na
1918009	Dicamba		1000	na
1928387	"2,4-D Esters"		100	na

Chemical Abstract Number (CAS)	NAME	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
1928478	"2,4,5-T esters"		1000	na
1928616	"2,4-D Esters"		100	na
1929733	"2,4-D Esters"		100	na
1982474	Chloroxuron		1	na
2001958	Valinomycin		1	na
2008460	"2,4,5-T amines"		5000	na
2032657	Mercaptodimethur		10	na
2032657	Methiocarb		10	na
2074502	Paraquat methosulfate		1	na
2097190	Phenylsilatrane		1	na
2104645	EPN		1	na
2223930	Cadmium stearate		1	na
2231574	Thiocarbazide		1	na
2238075	Diglycidyl ether		1	0.10
2275185	Prothoate		1	na
2303164	Diallate	U062	100	na
2312358	Propargite		10	1.11
2497076	Oxydisulfoton		1	0.10
2524030	Dimethyl phosphorochloridothioate		1	na
2540821	Formothion		1	na
2545597	"2,4,5-T esters"		1000	na
2570265	Pentadecylamine		1	na
2587908	"Phosphorothioic acid, O,O-dimethyl-5-(2-(methylthio)ethyl)es"		1	0.10
2631370	Promecarb		1	na
2636262	Cyanophos		1	0.10
2642719	Azinphos-ethyl		1	na
2665307	"Phosphonothioic acid, methyl-, O-(4-nitrophenyl) O-phenyl es"		1	na
2703131	"Phosphonothioic acid, methyl-, O-ethyl O-(4-(methylthio)phen"		1	na
2757188	Thallous malonate		1	na
2763964	5-(Aminomethyl)-3-isoxazolol	P007	1000	na
2763964	Muscimol	P007	1000	na
2764729	Diquat		1000	na
2778043	Endothion		1	na
2921882	Chlorpyrifos		1	na
2944674	Ferric ammonium oxalate		1000	na
2971382	"2,4-D Esters"		100	na
3012655	"Ammonium citrate, dibasic"		5000	na
3037727	"Silane, (4-aminobutyl)diethoxymethyl-"		1	0.13
3164292	Ammonium tartrate		5000	na
3165933	"4-Chloro-o-toluidine, hydrochloride"	U049	100	na
3251238	Cupric nitrate		100	na
3254635	"Phosphoric acid, dimethyl 4-(methylthio) phenyl ester"		1	0.09
3288582	"O,O-Diethyl S-methyl dithiophosphate"	U087	5000	na
3486359	Zinc carbonate		1000	na

Chemical Abstract Number (CAS)	NAME	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid$^{\Delta}$ (Gallons)
3547044	DDE		1000	na
3569571	"Sulfoxide, 3-chloropropyl octyl"		1	na
3615212	"Benzimidazole, 4,5-dichloro-2-(trifluoromethyl)-"		1	na
3689245	Sulfotep	P109	100	9.99
3689245	Tetraethyldithiopyrophosphate	P109	100	na
3691358	Chlorophacinone		1	na
3734972	Amiton oxalate		1	na
3735237	Methyl phenkapton		1	na
3813147	"2,4,5-T amines"		5000	na
3878191	Fuberidazole		1	na
4044659	Bitoscanate		1	na
4098719	Isophorone diisocyanate		1	0.11
4104147	Phosacetim		1	na
4170303	Crotonaldehyde	U053	100	14.17
4301502	Fluenetil		1	na
4418660	"Phenol, 2,2'-thiobis[4-chloro-6-methyl-"		1	na
4549400	N-Nitrosomethylvinylamine	P084	10	na
4835114	"Hexamethylenediamine, N,N'-dibutyl-"		1	0.15
5344821	"Thiourea, (2-chlorophenyl)-"	P026	100	na
5836293	Coumatetralyl		1	na
5893663	Cupric oxalate		100	na
5972736	Ammonium oxalate		5000	na
6009707	Ammonium oxalate		5000	na
6369966	"2,4,5-T amines"		5000	na
6369977	"2,4,5-T amines"		5000	na
6533739	Thallium(I) carbonate	U215	100	na
6533739	Thallous carbonate	U215	100	na
6923224	Monocrotophos		1	na
7005723	4-Chlorophenyl phenyl ether		5000	498.52
7421934	Endrin aldehyde		1	na
7428480	Lead stearate		5000	na
7439921	Lead	D008	1	na
7439976	Mercury	U151	1	0.01
7440020	Nickel		100	na
7440224	Silver	D011	1000	na
7440235	Sodium		10	na
7440280	Thallium		1000	na
7440360	Antimony		5000	na
7440382	Arsenic	D004	1	na
7440417	Beryllium	P015	10	na
7440439	Cadmium	D006	10	na
7440473	Chromium		5000	na
7440508	Copper		5000	na
7440666	Zinc (fume or dust)		1000	na
7440666	Zinc		1000	na
7446084	Selenium dioxide		10	na
7446095	Sulfur dioxide		1	na

Chemical Abstract Number (CAS)	NAME	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid$^{\Delta}$ (Gallons)
7446119	Sulfur trioxide		1	0.06
7446142	Lead sulfate		100	na
7446186	Thallium(I) sulfate	P115	100	na
7446186	Thallous sulfate	P115	100	na
7446277	Lead phosphate	U145	1	na
7447394	Cupric chloride		10	na
7487947	Mercuric chloride		1	na
7488564	Selenium sulfide	U205	10	na
7550450	Titanium tetrachloride		100	6.95
7558794	"Sodium phosphate, dibasic"		5000	na
7580678	Lithium hydride		1	na
7601549	"Sodium phosphate, tribasic"		5000	na
7631892	Sodium arsenate		1?	na
7631905	Sodium bisulfite		5000	na
7632000	Sodium nitrite		100	na
7637072	Boron trifluoride		1	na
7645252	Lead arsenate		1	na
7646857	Zinc chloride		1000	na
7647010	Hydrochloric acid		5000	na
7647010	Hydrogen chloride (gas only)		5000	na
7647189	Antimony pentachloride		1000	52.13
7664382	Phosphoric acid		5000	355.80
7664393	Hydrofluoric acid	U134	100	na
7664393	Hydrogen fluoride	U134	100	na
7664417	Ammonia		100	na
7664939	Sulfuric acid		1000	65.17
7681494	Sodium fluoride		1000	na
7681529	Sodium hypochlorite		100	9.92
7697372	Nitric acid		1000	86.70
7699458	Zinc bromide		1000	na
7705080	Ferric chloride		1000	na
7718549	Nickel chloride		100	na
7719122	Phosphorus trichloride		1000	76.37
7720787	Ferrous sulfate		1000	na
7722647	Potassium permanganate		100	na
7722841	Hydrogen peroxide (Conc.> 52%)		1	0.09
7723140	Phosphorus		1	na
7723140	Phosphorus (yellow or white)		1	na
7726956	Bromine		1	0.04
7733020	Zinc sulfate		1000	na
7738945	Chromic acid		10	na
7758294	"Sodium phosphate, tribasic"		5000	na
7758943	Ferrous chloride		100	na
7758954	Lead chloride		100	na
7758987	Cupric sulfate		10	na
7761888	Silver nitrate		1	na
7773060	Ammonium sulfamate		5000	na
7775113	Sodium chromate		10	na

Chemical Abstract Number (CAS)	NAME	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid$^{\Delta}$ (Gallons)
7778394	Arsenic acid	P010	1	na
7778441	Calcium arsenate		1	na
7778509	Potassium bichromate		10	na
7778543	Calcium hypochlorite		10	na
7779864	Zinc hydrosulfite		1000	na
7779886	Zinc nitrate		1000	na
7782414	Fluorine	P056	10	na
7782492	Selenium	D010	100	na
7782505	Chlorine		10	na
7782630	Ferrous sulfate		1000	na
7782823	Sodium selenite		100	na
7782867	Mercurous nitrate		10	na
7783008	Selenious acid	U204	10	na
7783064	Hydrogen sulfide	U135	100	na
7783075	Hydrogen selenide		1	na
7783359	Mercuric sulfate		10	na
7783462	Lead fluoride		100	na
7783495	Zinc fluoride		1000	na
7783508	Ferric fluoride		100	na
7783564	Antimony trifluoride		1000	na
7783600	Sulfur tetrafluoride		1	na
7783702	Antimony pentafluoride		1	0.04
7783804	Tellurium hexafluoride		1	na
7784341	Arsenous trichloride		1	0.06
7784409	Lead arsenate		1	na
7784410	Potassium arsenate		1	na
7784421	Arsine		1	na
7784465	Sodium arsenite		1	na
7785844	"Sodium phosphate, tribasic"		5000	na
7786347	Mevinphos		10	0.97
7786814	Nickel sulfate		100	na
7787475	Beryllium chloride		1	na
7787497	Beryllium fluoride		1	na
7787555	Beryllium nitrate		1	na
7788989	Ammonium chromate		10	na
7789006	Potassium chromate		10	na
7789062	Strontium chromate		10	na
7789095	Ammonium bichromate		10	na
7789426	Cadmium bromide		10	na
7789437	Cobaltous bromide		1000	na
7789619	Antimony tribromide		1000	na
7790945	Chlorosulfonic acid		1000	68.40
7791120	Thallium chloride TlCl	U216	100	na
7791120	Thallous chloride	U216	100	na
7791233	Selenium oxychloride		1	0.05
7803512	Phosphine	P096	100	na
7803556	Ammonium vanadate	P119	1000	na
8001352	Camphechlor	P123	1	na

Chemical Abstract Number (CAS)	NAME	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid$^{\Delta}$ (Gallons)
8001352	"Camphene, octachloro-"	P123	1	na
8001352	Toxaphene	P123	1	na
8001589	Creosote	U051	1	0.11
8003198	Dichloropropane - Dichloropropene (mixture)		100	9.99
8003347	Pyrethrins		1	0.14
8014957	Sulfuric acid (fuming)		1000	62.61
8065483	Demeton		1	0.11
10022705	Sodium hypochlorite		100	na
10025737	Chromic chloride		1	na
10025873	Phosphorus oxychloride		1000	72.67
10025919	Antimony trichloride		1000	na
10026116	Zirconium tetrachloride		5000	na
10026138	Phosphorus pentachloride		1	na
10028156	Ozone		1	na
10028225	Ferric sulfate		1000	na
10031591	Thallium sulfate		100	na
10039324	"Sodium phosphate, dibasic"		5000	na
10043013	Aluminum sulfate		5000	na
10045893	Ferrous ammonium sulfate		1000	na
10045940	Mercuric nitrate		10	na
10049055	Chromous chloride		1000	na
10099748	Lead nitrate		100	na
10101538	Chromic sulfate		1000	na
10101630	Lead iodide		100	na
10101890	"Sodium phosphate, tribasic"		5000	na
10102064	Uranyl nitrate		100	na
10102188	Sodium selenite		100	na
10102202	Sodium tellurite		1	na
10102439	Nitric oxide	P076	10	na
10102440	Nitrogen dioxide	P078	10	na
10102451	Thallium(I) nitrate	U217	100	na
10102484	Lead arsenate		1	na
10108642	Cadmium chloride		10	na
10124502	Potassium arsenite		1	na
10124568	"Sodium phosphate, tribasic"		5000	524.51
10140655	"Sodium phosphate, dibasic"		5000	na
10140871	"Ethanol, 1,2-dichloro-, acetate"		1	0.09
10192300	Ammonium bisulfite		5000	na
10196040	Ammonium sulfite		5000	na
10210681	Cobalt carbonyl		1	na
10265926	Methamidophos		1	na
10294345	Boron trichloride		1	na
10311849	Dialifor		1	na
10361894	"Sodium phosphate, tribasic"		5000	na
10380297	"Cupric sulfate, ammoniated"		100	na
10415755	Mercurous nitrate		10	na
10421484	Ferric nitrate		1000	na
10476956	Methacrolein diacetate		1	na

Chemical Abstract Number (CAS)	NAME	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid$^{\Delta}$ (Gallons)
10544726	Nitrogen dioxide		10	0.83
10588019	Sodium bichromate		10	na
11096825	Aroclor 1260		1	0.08
11097691	Aroclor 1254		1	0.08
11104282	Aroclor 1221		1	0.10
11115745	Chromic acid		10	na
11141165	Aroclor 1232		1	0.10
12002038	Cupric acetoarsenite		1	na
12002038	Paris green		1	na
12039520	"Selenious acid, dithallium(1+) salt"	P114	1000	na
12054487	Nickel hydroxide		10	na
12108133	"Manganese, tricarbonyl methylcyclopentadienyl"		1	0.09
12125018	Ammonium fluoride		100	na
12125029	Ammonium chloride		5000	na
12135761	Ammonium sulfide		100	11.99
12672296	Aroclor 1248		1	0.09
12674112	Aroclor 1016		1	0.09
12771083	Sulfur monochloride		1000	71.37
13071799	Terbufos		1	0.11
13171216	Phosphamidon		1	0.10
13194484	Ethoprophos		1	0.11
13410010	Sodium selenate		1	na
13450903	Gallium trichloride		1	na
13463393	Nickel carbonyl	P073	10	0.92
13463406	"Iron, pentacarbonyl-"		1	0.08
13494809	Tellurium		1	na
13560991	"2,4,5-T salts"		1000	na
13597994	Beryllium nitrate		1	na
13746899	Zirconium nitrate		5000	na
13765190	Calcium chromate	U032	10	na
13814965	Lead fluoborate		100	6.85
13826830	Ammonium fluoborate		5000	na
13952846	sec-Butylamine		1000	165.38
14017415	Cobaltous sulfamate		1000	na
14167181	Salcomine		1	na
14216752	Nickel nitrate		100	9.75
14258492	Ammonium oxalate		5000	na
14307358	Lithium chromate		10	na
14307438	Ammonium tartrate		5000	na
14639975	Zinc ammonium chloride		1000	na
14639986	Zinc ammonium chloride		1000	na
14644612	Zirconium sulfate		5000	na
15271417	"Bicyclo[2.2.1]heptane-2-carbonitrile, 5-chloro-6-((((methyla"		1	na
15699180	Nickel ammonium sulfate		100	na
15739807	Lead sulfate		100	na
15950660	"2,3,4-Trichlorophenol"		10	na
16721805	Sodium hydrosulfide		5000	na

Chemical Abstract Number (CAS)	NAME	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
16752775	"Ethanimidothioic acid, N-[[methylamino) carbonyl]"	P066	100	na
16752775	Methomyl	P066	100	na
16871719	Zinc silicofluoride		5000	na
16919190	Ammonium silicofluoride		1000	na
16923958	Zirconium potassium fluoride		1000	na
17702419	Decaborane(14)		1	na
17702577	Formparanate		1	na
18883664	"D-Glucose, 2-deoxy-2-[[(methylnitrosoamino) -carbo"	U206	1	na
19287457	Diborane		1	na
19624227	Pentaborane		1	0.20
20816120	Osmium oxide OsO4 (T-4)-	P087	1000	na
20816120	Osmium tetroxide	P087	1000	na
20830755	Digoxin		1	na
20830813	Daunomycin	U059	10	na
20859738	Aluminum phosphide	P006	100	na
21548323	Fosthietan		1	0.09
21609905	Leptophos		1	na
21908532	Mercuric oxide		1	na
21923239	Chlorthiophos		1	0.09
22224926	Fenamiphos		1	na
23135220	Oxamyl		1	na
23422539	Formetanate hydrochloride		1	na
23505411	Pirimifos-ethyl		1	0.11
23950585	"Benzamide,3,5-dichloro-N-(1,1-dimethyl-2-propyn yl"	U192	5000	na
24017478	Triazofos		1	0.10
24934916	Chlormephos		1	0.10
25154545	Dinitrobenzene (mixed isomers)		100	na
25154556	Nitrophenol (mixed isomers)		100	na
25155300	Sodium dodecylbenzenesulfonate		1000	na
25167822	Trichlorophenol		10	na
25168154	"2,4,5-T esters"		1000	na
25168267	"2,4-D Esters"		100	na
25321146	Dinitrotoluene (mixed isomers)		10	na
25321226	Dichlorobenzene		100	9.22
25321226	Dichlorobenzene (mixed isomers)		100	9.22
25376458	Diaminotoluene (mixed isomers)	U221	10	na
25376458	Toluenediamine	U221	10	na
25550587	Dinitrophenol		10	na
26264062	Calcium dodecylbenzenesulfonate		1000	na
26419738	"Carbamic acid, methyl-, O-(((2,4-dimethyl-1, 3-dithiolan-2-y"		1	na
26471625	Toluenediisocyanate (mixed isomers)	U223	100	9.83
26628228	Sodium azide (Na(N3))	P105	1000	na
26638197	Dichloropropane		1000	103.37
26952238	Dichloropropene		100	na

Chemical Abstract Number (CAS)	NAME	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid$^{\Delta}$ (Gallons)
27137855	Trichloro(dichlorophenyl)silane		1	0.08
27176870	Dodecylbenzenesulfonic acid		1000	99.92
27323417	Triethanolamine dodecylbenzene sulfonate		1000	na
27774136	Vanadyl sulfate		1000	na
28300745	Antimony potassium tartrate		100	na
28347139	Xylylene dichloride		1	na
28772567	Bromadiolone		1	na
30525894	Paraformaldehyde		1000	na
30674807	Methacryloyloxyethyl isocyanate		1	0.11
32534955	"2,4,5-TP esters"		100	na
33213659	beta - Endosulfan		1	na
36478769	Uranyl nitrate		100	na
37211055	Nickel chloride		100	na
39196184	Thiofanox	P045	100	na
42504461	Isopropanolamine dodecylbenzene sulfonate		1000	na
50782699	"Phosphonothioic acid, methyl-, S-(2-(bis(1-methylethyl)amino"		1	0.12
52628258	Zinc ammonium chloride		1000	na
52652592	Lead stearate		5000	na
52740166	Calcium arsenite		1	na
53467111	"2,4-D Esters"		100	na
53469219	Aroclor 1242		1	0.09
53558251	Pyriminil		1	na
55488874	Ferric ammonium oxalate		1000	na
56189094	Lead stearate		5000	na
58270089	"Zinc, dichloro(4,4-dimethyl-5((((methylamino) carbonyl)oxy)im"		1	na
61792072	"2,4,5-T esters"		1000	na
62207765	"Cobalt, ((2,2'-(1,2-ethanediylbis (nitrilomethylidyne))bis(6-"		1	na
	Radionuclides (including radon)		β	na
	Multi Source Leachate		1	na
	Unlisted hazardous wastes characteristic of ignitability	D001	100	na
	Unlisted hazardous wastes characteristic of corrosivity	D002	100	na
	Unlisted hazardous wastes characteristic of reactivity	D003	100	na
	Spent Halogenated Solvents used in Degreasing	F001	10	na
	Spent halogenated solvents:	F002	10	na
	Spent non-halogenated solvents:	F003	100	na
	Spent non-halogenated solvents and still bttm. from cresol\nitrobenzene recovery	F004	100	na
	cresol\nitrobenzene recovery	F004	100	na
	Spent non-halogenated solvents(still bttm.) toluene\methyl ethyl ketone recovery	F005	100	na
	Wastewater treatment sludges from electroplating operations	F006	10	na

Chemical Abstract Number (CAS)	NAME	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid$^{\Delta}$ (Gallons)
	Spent cyanide plating bath solns. from electroplating	F007	10	na
	Plating bath residues from electroplating where cyanides are used		10	na
	Spent stripping/cleaning bath solns. from electroplating where cyanides are used	F009	10	na
	Quenching bath residues from metal heat treating where cyanides are used	F010	10	na
	Spent cyanide soln. from salt bath pot cleaning from metal heat treating	F011	10	na
	Quenching wastewater sludges from metal heat treating where cyanides are used	F012	10	na
	Wastewater treatment sludges from chemical conversion of aluminum coating	F019	10	na
	Wastes from prod. or use of tri/tetrachlorophenol or derivatives	F020	1	na
	Wastes from prod. or use of pentachlorophenol or intermediates	F021	1	na
	Wastes from use of tetra/penta/hexachlorobenzenes	F022	1	na
	Wastes from mat. prod. on equip. which prev. used tri\tetrachlorophenol	F023	1	na
	Wastes from prod. of chlorinated aliphatic hydrocarbons (C1-C5)	F024	1	na
	"Lights ends, filters from prod. of chlorinated aliphatic hydrocarbons(C1-C5)"	F025	1	na
	Waste from equipment previously used to prod. tetra/penta/hexachlorobenzenes	F026	1	na
	Discarded wastes containing tetra/penta/hexachlorobenzenes or derivatives	F027	1	na
	"Residues from incineration of contaminated soils:	F020,F021, F022,F023, F026,F027, F028	1	na
	"Wastewaters, process residuals from wood preserving using chlorophenolic solns."	F032	1	na
	"Wastewaters, process residuals from wood preserving using creosote formulations"	F034	1	na
	"Wastewaters, process residuals from wood preserving usingarsenic or chromium"	F035	1	na
	Petroleum refinery primary oil/water/solids separation sludge	F037	1	na
				na
	Petroleum refinery secondary (emulsified) oil/water/solids separation sludge	F038	1	na

Chemical Abstract Number (CAS)	NAME	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
	F069	F069	10	na
	Wastewater treatment sludge from creosote or pentachlorophenol wood preserving	K001	1	na
	Wastewater treatment sludge from prod. of chrome yellow and orange pigments	K002	1	na
	Wastewater treatment sludge from prod. of molybdate orange pigments	K003	1	na
	Wastewater treatment sludge from prod. of zinc yellow pigments	K004	10	na
	Wastewater treatment sludge from prod. of chrome green pigments	K005	1	na
	Wastewater treatment sludge from prod. of chrome oxide green pigments anyhydrous	K006	10	na
	Wastewater treatment sludge from prod. of iron blue pigments	K007	10	na
	Oven residue from prod. of chrome oxide green pigments	K008	10	na
	Dist. bottoms from prod. of acetaldehyde from ethylene	K009	10	na
	Dist. side cuts from prod. of acetaldehyde from ethylene	K010	10	na
	Bottom stream from wastewater stripper in acrylonitrile prod.	K011	10	na
	Bottom stream from acetonitrile column in acrylonitrile prod.	K013	10	na
	Bottoms from acetonitrile purification column in acrylonitrile prod.	K014	5000	na
	Still bottoms from the dist. of benzyl chloride	K015	10	na
	Heavy ends or dist. residues from prod. of carbon tetrachloride	K016	1	na
	Heavy ends from the purification column in epichlorohydrin prod.	K017	10	na
	Heavy ends from the fractionation column in ethyl chloride prod.	K018	1	na
	Heavy ends from the dist. of ethylene dichloride during its prod.	K019	1	na
	Heavy ends from the dist. of vinyl chloride during prod. of the monomer	K020	1	na
	Aqueous spent antimony catalyst waste from fluoromethanes prod.	K021	10	na
	Dist. bottom tars from prod. of phenol/acetone from cumene	K022	1	na
	Dist. light ends from prod. of phthalic anhydride fromnaphthalene	K023	5000	na
	Dist. bottoms from prod. of phthalic anhydride from naphthalene	K024	5000	na
	Dist. bottoms from prod. of nitrobenzene by nitration of benzene	K025	10	na

Chemical Abstract Number (CAS)	NAME	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
	Stripping still tails from the prod. of methyl ethyl pyridines	K026	1000	na
	Centrifuge/dist. residues from toluene diisocyanate prod.	K027	10	na
	"Spent catalyst from hydrochlorinator reactor in prod. of 1,1,1-trichloroethane"	K028	1	na
	"Waste from product steam stripper in prod. of 1,1,1-trichloroethane"	K029	1	na
	Column bottoms(heavy ends) from prod. of trichloroethylene and perchloroethylene	K030	1	na
	By-product salts generated in the prod. msma and cacodylic acid	K031	1	na
	Wastewater treatment sludge from the prod. of chlordane	K032	10	na
	Wastewaster/scrubwater from chlorination during prod. of chlordane	K033	10	na
	Filter solids from filtration of hexachlorocyclopentadiene in chlordane prod.	K034	10	na
	Wastewater treatment sludges from the prod. of creosote	K035	1	na
	Still bottoms from toluene reclamation distillation in disulfoton prod.	K036	1	na
	Wastewater treatment sludges from the prod. of disulfoton	K037	1	na
	Wastewater from the washing and stripping of phorate production	K038	10	na
	Filter cake from filtration during prod. of phorate	K039	10	na
	Wastewater treatment sludge from the prod. of phorate	K040	10	na
	Wastewater treatment sludge from the prod. of toxaphene	K041	1	na
	"Heavy ends from dist. of tetrachlorobenzene in the prod. of 2,4,5-T"	K042	10	na
	"2,6-Dichlorophenol waste from the prod. of 2,4-D"	K043	10	na
	Wastewater treatment sludge from manuf. and processing of explosives	K044	10	na
	Spent carbon from treatment of wastewater containing explosives	K045	10	na
	"Wastewater sludge from manuf.,formulating,loading of lead-based initiating compd"	K046	100	na
	Pink/red water from TNT operations	K047	10	na
	Dissolved air flotation (DAF) float from the petroleum refining industry	K048	1	na
	Slop oil emulsion solids from the petroleum refining industry	K049	1	na

Chemical Abstract Number (CAS)	NAME	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid$^{\Delta}$ (Gallons)
	Heat exchanger bundle cleaning sludge from petroleum refining industry	K050	10	na
	API separator sludge from the petroleum refining industry	K051	1	na
	Tank bottoms (leaded) from the petroleum refining industry	K052	10	na
	Ammonia still lime sludge from coking operations	K060	1	na
	Emission control dust/sludge from primary prod. of steel in electric furnaces	K061	1	na
	Spent pickle liquor generated by steel finishing: (SIC codes 331 and 332)	K062	1	na
	Acid plant blowdown sludge from blowdown slurry from primary copper prod.	K064	1	na
	Surface impoundment solids at primary lead smelting facilities	K065	1	na
	Sludge from treatment of wastewater(acid plant blowdown) fromprimary zinc prod.	K066	1	na
	Emission Control Dust/Sludge from secondary lead smelting	K069	1	na
	Brine purification muds from mercury cell process in chlorine production	K071	1	na
	Chlorinated hydrocarbon waste in chlorine production	K073	10	na
	Distillation bottoms from aniline extraction	K083	100	na
	Wastewater sludges from prod. of veterinary pharm. from arsenic compds.	K084	1	na
	Distillation or fractionation column bottoms in prod. of chlorobenzenes	K085	10	na
	Wastes/sludges from prod. of inks from chromium and lead compds.	K086	1	na
	Decanter tank tar sludge from coking operations	K087	100	na
	Spent potliners from primary aluminum reduction	K088	10	na
	Emission control dust/sludge from ferrochromiumsilicon prod.	K090	10	na
	Emission control dust/sludge from ferrochromium prod.	K091	10	na
	Dist. light ends from prod. of phthalic anhydride by ortho-xylene	K093	5000	na
	Dist. bottoms in prod. of phthalic anhydride by ortho-xylene	K094	5000	na
	"Distillation bottoms in prod. of 1,1,1-trichloroethane"	K095	100	na
	"Heavy ends from dist. column in prod. of 1,1,1-trichloroethane"	K096	100	na
	Vacuum stripper discharge from the chlordane chlorinator in prod. of chlordane	K097	1	na
	Untreated process wastewater from the prod. of toxaphene	K098	1	na

Chemical Abstract Number (CAS)	NAME	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid$^{\Delta}$ (Gallons)
	"Untreated wastewater from the prod. of 2,4-D"	K099	10	na
	Waste leaching soln. from acid leaching of emission dust in 2nd lead smelting	K100	1	na
	Dist. tar residue from aniline in prod. of veterinary pharm. from arsenic compd.	K101	1	na
	Residue from activated carbon in prod. of veterinary pharm. from arsenic compds.	K102	1	na
	Process residues from aniline extraction from the prod. of aniline	K103	100	na
	Combined wastewater streams generated from prod. of nitrobenzene/aniline	K104	10	na
	Aqueous stream from washing in prod. of chlorobenzenes	K105	10	na
	Wastewater treatment sludge from mercury cell process in chlorine prod.	K106	1	na
	Column bottoms from separation in prod. of UDMH from carboxylic acid hydrazides	K107	10	na
	Condensed column overheads and vent gas from prod. of UDMH from -COOH hydrazides	K108	10	na
	Spent filter catridges from purif. of UDMH prod. from carboxylic acid hydrazides	K109	10	na
	Condensed column overheads from prod. of UDMH from carboxylic acid hydrazides	K110	10	na
	Product washwaters from prod. of dinitrotoluene via nitration of benzene	K111	10	na
	Reaction by-product water from drying of toluenediamine during its prod.	K112	10	na
	Condensed liquid light ends from purification of toluenediamine during its prod.	K113	10	na
	Vicinals from purification of toluenediamine during its prod.	K114	10	na
	Heavy ends from purification of toluenediamine during its prod.	K115	10	na
	Organic condensate solvent recovery system in prod. of toluene diisocyanate	K116	10	na
	Wastewater from vent gas scrubber in prod. of ethylene bromide prod. from ethene	K117	1	na
	Spent absorbant solids in purification of ethylene dibromide manuf. from ethene	K118	1	na
	K119	K119	100	na
	K120	K120	100	na
	K121	K121	100	na
	Process waterwater from the prod. of ethylenebisdithiocarbamic acid and salts	K123	10	na
	Reactor vent scubber water from prod of ethylenebisdithiocarbamic acid and salts	K124	10	na
	Solids formed in the prod. of ethylenebisdithiocarbamic acid and salts	K125	10	na

Chemical Abstract Number (CAS)	NAME	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid$^{\Delta}$ (Gallons)
	Dust/sweepings from the prod. of ethylenebisdithiocarbamicacid and salts	K126	10	na
	Wastewater and spent sulfuric acid from the prod. of methyl bromide	K131	100	na
	Spent absorbent and waste water from the prod. of methyl bromide	K132	1000	na
	Still bottoms from purification of ethylene dibromide manuf. from ethene	K136	1	na
	K141	K141	1	na
	K142	K142	1	na
	K143	K143	1	na
	K144	K144	1	na
	K145	K145	1	na
	K147	K147	1	na
	K148	K148	1	na
	Distillation bottoms from the production of chlorinated toluenes	K149	10	na
	Organic residuals of Cl gas and HCl from production of chlorinated toluenes	K150	10	na
	Wastewater treatment sludge from production of chlorinated toluenes	K151	10	na

Note:

RQ Reportable Quantity.

* Indicates that the EPA was considering several options for the CERCLA reporting requirements that would apply to these broad generic categories of hazardous air pollutants.

** Indicates that no RQ is being assigned to the generic or broad class.

Δ RQ is presented in gallons for materials that are in liquid form when at room temperature and standard pressure.

Ψ Oil released under the listed circumstances is considered as the RQ:
(1) Any amount of oil which when released into the environment causes a sheen to appear on surface water, or any navigable water of the State.
(2) Any free product that appears on groundwater.
(3) Any amount of oil released to the environment greater than 25 gallons.
(4) Any amount of oil released to the environment which is less than 25 gallons, but which is not contained

β Appendix B of Section 302.4 as it appears in the CFR published on July 1, 1993.

na Not Applicable

APPENDIX 2-D

REPORTABLE QUANTITIES

(SORTED BY CHEMICAL NAME)

Appendix 2-D
Reportable Quantities (Sorted by Chemical Name)

NAME	Chemical Abstract Number (CAS)	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
"1,1,1-Trichloroethane"	71556	U226	1000	89.64
"1,1,2,2-Tetrachloroethane"	79345	U209	100	7.52
"1,1,2-Trichloroethane"	79005	U227	100	8.32
"1,1-Dichloroethane"	75343	U076	1000	101.96
"1,1-Dichloroethylene"	75354	U078	100	9.88
"1,1-Dichloropropane"	78999		1000	105.92
"1,1-Dimethyl hydrazine"	57147	U098	10	1.53
"1,2,4,5-Tetrachlorobenzene"	95943	U207	5000	na
"1,2,4-Trichlorobenzene"	120821		100	8.19
"1,2-Butylene oxide"	106887		100	14.45
"1,2-Dibromo-3-chloropropane"	96128	U066	1	0.06
"1,2-Dibromoethane"	106934	U067	1	0.06
"1,2-Dichlorobenzene"	95501	U070	100	9.18
"1,2-Dichloroethane"	107062	U077	100	9.57
"1,2-Dichloroethylene"	156605	U079	1000	95.39
"1,2-Dichloropropane"	78875	U083	1000	103.74
"1,2-Diphenylhydrazine"	122667	U109	10	na
"1,3,5-Trinitrobenzene"	99354	U234	10	na
"1,3-Butadiene"	106990		10	na
"1,3-Dichlorobenzene"	541731	U071	100	9.31
"1,3-Dichloropropane"	142289		1000	100.93
"1,3-Dichloropropene"	542756	U084	1000	98.28
"1,3-Dichloropropylene"	542756	U084	1000	98.28
"1,3-Pentadiene"	504609	U186	100	17.56
"1,3-Propane sultone"	1120714	U193	10	na
"1,4-Dichlorobenzene"	106467	U072	100	na
"1,4-Dioxane"	123911	U108	100	11.61
"1,4-Naphthoquinone"	130154	U166	5000	na
"2,2,4-Trimethylpentane"	540841		1000	173.27
"2,2'-Bioxirane"	1464535	U085	10	1.08
"2,2-Dichloropropionic acid"	75990		5000	na
"2,3,4,6-Tetrachlorophenol"	58902	U212	10	na
"2,3,4-Trichlorophenol"	15950660		10	na
"2,3,5-Trichlorophenol"	933788		10	na
"2,3,6-Trichlorophenol"	933755		10	na
"2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD)"	1746016		1	na
"2,3-Dichloropropene"	78886		100	9.96
"2,4,5-T acid"	93765	U232	1000	na
"2,4,5-T amines"	1319728		5000	na
"2,4,5-T amines"	2008460		5000	na
"2,4,5-T amines"	3813147		5000	na
"2,4,5-T amines"	6369966		5000	na
"2,4,5-T amines"	6369977		5000	na
"2,4,5-T esters"	93798		1000	na
"2,4,5-T esters"	1928478		1000	na

NAME	Chemical Abstract Number (CAS)	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
"2,4,5-T esters"	2545597		1000	na
"2,4,5-T esters"	25168154		1000	na
"2,4,5-T esters"	61792072		1000	na
"2,4,5-T salts"	13560991		1000	na
"2,4,5-TP esters"	32534955		100	na
"2,4,5-Trichlorophenol"	95954	U230	10	na
"2,4,6-Trichlorophenol"	88062	U231	10	na
"2,4-D Acid"	94757	U240	100	na
"2,4-D Esters"	1320189		100	11.02
"2,4-D Esters"	94111		100	na
"2,4-D Esters"	94791		100	na
"2,4-D Esters"	94804		100	na
"2,4-D Esters"	1928387		100	na
"2,4-D Esters"	1928616		100	na
"2,4-D Esters"	1929733		100	na
"2,4-D Esters"	2971382		100	na
"2,4-D Esters"	25168267		100	na
"2,4-D Esters"	53467111		100	na
"2,4-D"	94757	U240	100	na
"2,4-D, salts and esters"	94757	U240	100	na
"2,4-Diaminotoluene"	95807		10	na
"2,4-Dichlorophenol"	120832	U081	100	na
"2,4-Dimethylphenol"	105679	U101	100	na
"2,4-Dinitrophenol"	51285	P048	10	na
"2,4-Dinitrotoluene"	121142	U105	10	na
"2,5-Dinitrophenol"	329715		10	na
"2,6-Dichlorophenol waste from the prod. of 2,4-D"	na	K043	10	na
"2,6-Dichlorophenol"	87650	U082	100	na
"2,6-Dinitrophenol"	573568		10	na
"2,6-Dinitrotoluene"	606202	U106	100	na
"2-Butene, 1,4-dichloro-"	764410	U074	1	0.11
"2-Cyclohexyl-4,6-Dinitrophenol"	131895	P034	100	na
"3,3'-Dichlorobenzidine"	91941	U073	1	na
"3,3'-Dimethoxybenzidine"	119904	U091	100	na
"3,3'-Dimethylbenzidine"	119937	U095	10	na
"3,4,5-Trichlorophenol"	609198		10	na
"3,4-Dinitrotoluene"	610399		10	na
"4,4'-Methylenebis(2-chloroaniline)"	101144	U158	10	na
"4,4'-Methylenedianiline"	101779		10	na
"4,6-Dinitro-o-cresol and salts"	534521	P047	10	na
"4,6-Dinitro-o-cresol"	534521	P047	10	na
"4-Chloro-o-toluidine, hydrochloride"	3165933	U049	100	na
"7,12-Dimethylbenz[a]anthracene"	57976	U094	1	na
"Acetaldehyde, trichloro-"	75876	U034	5000	396.48
"Ammonium citrate, dibasic"	3012655		5000	na
"Aniline, 2,4,6-trimethyl-"	88051		1	0.12
"Aziridine, 2-methyl"	75558	P067	1	0.15

NAME	Chemical Abstract Number (CAS)	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
"Benzamide,3,5-dichloro-N-(1,1-dimethyl-2-propyn yl"	23950585	U192	5000	na
"Benzenamine, 3-(trifluoromethyl)-"	98168		1	0.09
"Benzene, 1-(chloromethyl)-4-nitro-"	100141		1	na
"Benzene, m-dimethyl-"	108383	U239	100	13.81
"Benzene, o-dimethyl-"	95476	U239	1000	133.67
"Benzene, p-dimethyl-"	106423	U239	100	13.93
"Benzeneethanamine, alpha,alpha-dimethyl-"	122098	P046	5000	na
"Benzimidazole, 4,5-dichloro-2-(trifluoromethyl)-"	3615212		1	na
"Bicyclo[2.2.1]heptane-2-carbonitrile, 5-chloro-6-((((methyla"	15271417		1	na
"Camphene, octachloro-"	8001352	P123	1	na
"Carbamic acid, ethyl ester"	51796	U238	100	na
"Carbamic acid, methyl-, O-(((2,4-dimethyl-1, 3-dithiolan-2-y"	26419738		1	na
"Cobalt, ((2,2'-(1,2-ethanediylbis (nitrilomethylidyne))bis(6-"	62207765		1	na
"Crotonaldehyde, (E)-"	123739	U053	100	13.97
"Cupric sulfate, ammoniated"	10380297		100	na
"D-Glucose, 2-deoxy-2-[[(methylnitrosoamino) -carbo"	18883664	U206	1	na
"Dibenz[a,h]anthracene"	53703	U063	1	na
"Dibenz[a,i]pyrene"	189559	U064	10	na
"Diphosphoramide, octamethyl-"	152169	P085	100	11.00
"Distillation bottoms in prod. of 1,1,1-trichloroethane"	na	K095	100	na
"Emetine, dihydrochloride"	316427		1	na
"Ethane, 1,1,1,2-tetrachloro-"	630206	U208	100	7.72
"Ethanesulfonyl chloride, 2-chloro-"	1622328		1	0.08
"Ethanimidothioic acid, N-[[methylamino) carbonyl]"	16752775	P066	100	na
"Ethanol, 1,2-dichloro-, acetate"	10140871		1	0.09
"Ethanol, 2-ethoxy-"	110805	U359	1000	128.79
"Ethylenebisdithiocarbamic acid, salts & esters"	111546	U114	5000	na
"Fluoroacetic acid, sodium salt"	62748	P058	10	na
"Furan, tetrahydro-"	109999	U213	1000	135.33
"Guanidine, N-methyl-N'-nitro-N-nitroso-"	70257	U163	10	na
"Heavy ends from dist. column in prod. of 1,1,1-trichloroethane"	na	K096	100	na
"Heavy ends from dist. of tetrachlorobenzene in the prod. of 2,4,5-T"	na	K042	10	na
"Hexachloro-1,3-butadiene"	87683	U128	1	0.07
"Hexamethylene-1,6-diisocyanate"	822060		100	11.53
"Hexamethylenediamine, N,N'-dibutyl-"	4835114		1	0.15
"Hydrazine, 1,1-dimethyl-"	57147	U098	10	1.53
"Hydrazine, 1,2-diethyl-"	1615801	U086	10	na
"Hydrazine, 1,2-dimethyl-"	540738	U099	1	0.12

NAME	Chemical Abstract Number (CAS)	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
"Hydrazine, 1,2-diphenyl-"	122667	U109	10	na
"Hydroperoxide, 1-methyl-1-phenylethyl-"	80159	U096	10	1.17
"Indeno(1,2,3-cd)pyrene"	193395	U137	100	na
"Iron, pentacarbonyl-"	13463406		1	0.08
"Isocyanic acid, 3,4-dichlorophenyl ester"	102363		1	na
"Lights ends, filters from prod. of chlorinated aliphatic hydrocarbons(C1-C5)"	na	F025	1	na
"Manganese, tricarbonyl methylcyclopentadienyl"	12108133		1	0.09
"Methanamine, N-methyl-N-nitroso-"	62759	P082	10	1.19
"N,N-Diethylaniline"	91667		1000	127.83
"N,N-Dimethylaniline"	121697		100	12.54
"O,O-Diethyl O-pyrazinyl phosphorothioate"	297972	P040	100	9.96
"O,O-Diethyl S-methyl dithiophosphate"	3288582	U087	5000	na
"Oxetane, 3,3-bis(chloromethyl)-"	78717		1	na
"Phenol, 2,2'-thiobis[4-chloro-6-methyl-"	4418660		1	na
"Phenol, 3-(1-methylethyl)-, methylcarbamate"	64006		1	na
"Phenoxarsine, 10,10'-oxydi-"	58366		1	na
"Phosphonothioic acid, methyl-, O-(4-nitrophenyl) O-phenyl es"	2665307		1	na
"Phosphonothioic acid, methyl-, O-ethyl O-(4-(methylthio)phen"	2703131		1	na
"Phosphonothioic acid, methyl-, S-(2-(bis(1-methylethyl)amino"	50782699		1	0.12
"Phosphoric acid, dimethyl 4-(methylthio) phenyl ester"	3254635		1	0.09
"Phosphorothioic acid, O,O-dimethyl-5-(2-(methylthio)ethyl)es"	2587908		1	0.10
"Physostigmine, salicylate (1:1)"	57647		1	na
"Propane 1,2-dichloro-"	78875	U083	1000	103.74
"Propionitrile, 3-chloro-"	542767	P027	1000	104.81
"Propiophenone, 4'-amino"	70699		1	na
"Pyridine, 2-methyl-5-vinyl-"	140761		1	0.12
"Pyridine, 3-(1-methyl-2-pyrrolidinyl)-,(S)-"	54115	P075	100	11.87
"Pyridine, 4-amino-"	504245	P008	1000	na
"Pyridine, 4-nitro-, 1-oxide"	1124330		1	na
"Residues from incineration of contaminated soils:	na	F020,F021, F022,F023, F026,F027, F028	1	na
"Selenious acid, dithallium(1+) salt"	12039520	P114	1000	na
"Silane, (4-aminobutyl)diethoxymethyl-"	3037727		1	0.13
"Silvex (2,4,5-TP)"	93721	U233	100	na
"Sodium phosphate, dibasic"	7558794		5000	na
"Sodium phosphate, dibasic"	10039324		5000	na
"Sodium phosphate, dibasic"	10140655		5000	na

NAME	Chemical Abstract Number (CAS)	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
"Sodium phosphate, tribasic"	10124568		5000	524.51
"Sodium phosphate, tribasic"	7601549		5000	na
"Sodium phosphate, tribasic"	7758294		5000	na
"Sodium phosphate, tribasic"	7785844		5000	na
"Sodium phosphate, tribasic"	10101890		5000	na
"Sodium phosphate, tribasic"	10361894		5000	na
"Spent catalyst from hydrochlorinator reactor in prod. of 1,1,1-trichloroethane"	na	K028	1	na
"Stannane, acetoxytriphenyl-"	900958		1	na
"Strychnine, and salts"	57249	P108	10	na
"Strychnine, sulfate"	60413		10	na
"Sulfoxide, 3-chloropropyl octyl"	3569571		1	na
"Thiourea, (2-chlorophenyl)-"	5344821	P026	100	na
"Thiourea, (2-methylphenyl)-"	614788		1	na
"Thiourea, 1-naphthalenyl-"	86884	P072	100	na
"Toluene-2,4-diisocyanate"	584849		100	9.79
"Toluene-2,6-diisocyanate"	91087		100	9.79
"Trans-1,4-dichlorobutene"	110576		1	0.10
"Tris(2,3-dibromopropyl) phosphate"	126727	U235	10	0.53
"Untreated wastewater from the prod. of 2,4-D"	na	K099	10	na
"Warfarin, & salts, conc.>0.3%"	81812	P001	100	na
"Waste from product steam stripper in prod. of 1,1,1-trichloroethane"	na	K029	1	na
"Wastewater sludge from manuf.,formulating,loading of lead-based initiating compound"	na	K046	100	na
"Wastewaters, process residuals from wood preserving using chlorophenolic solns."	na	F032	1	na
"Wastewaters, process residuals from wood preserving using creosote formulations"	na	F034	1	na
"Wastewaters, process residuals from wood preserving usingarsenic or chromium"	na	F035	1	na
"Zinc, dichloro(4,4-dimethyl-5((((methylamino) carbonyl)oxy)im"	58270089		1	na
1-Acetyl-2-thiourea	591082	P002	1000	na
2-Acetylaminofluorene	53963	U005	1	na
2-Chloroacetophenone	532274		100	na
2-Chloroethyl vinyl ether	110758	U042	1000	114.41
2-Chloronaphthalene	91587	U047	5000	na
2-Chlorophenol	95578	U048	100	9.66
2-Ethoxyethanol	110805	U359	1000	128.79
2-Nitrophenol	88755		100	na
2-Nitropropane	79469	U171	10	1.21
2-Picoline	109068	U191	5000	635.76
3-Chloropropionitrile	542767	P027	1000	104.81
3-Methylcholanthrene	56495	U157	10	na
4-Aminobiphenyl	92671		1	na
4-Aminopyridine	504245	P008	1000	na

NAME	Chemical Abstract Number (CAS)	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
4-Bromophenyl phenyl ether	101553	U030	100	8.44
4-Chlorophenyl phenyl ether	7005723		5000	498.52
4-Dimethylaminoazobenzene	60117	U093	10	na
4-Nitrobiphenyl	92933		10	na
4-Nitrophenol	100027	U170	100	na
5-(Aminomethyl)-3-isoxazolol	2763964	P007	1000	na
5-Nitro-o-toluidine	99558	U181	100	na
Acenaphthene	83329		100	na
Acenaphthylene	208968		5000	na
Acetaldehyde	75070	U001	1000	na
Acetamide	60355		100	na
Acetic acid	64197		5000	571.41
Acetic anhydride	108247		5000	555.11
Acetone	67641	U002	5000	763.04
Acetone cyanohydrin	75865	P069	10	1.29
Acetone thiosemicarbazide	1752303		1	na
Acetonitrile	75058	U003	5000	763.04
Acetophenone	98862	U004	5000	583.99
Acetyl bromide	506967		5000	360.51
Acetyl chloride	75365	U006	5000	543.04
Acid plant blowdown sludge from blowdown slurry from primary copper prod.	na	K064	1	na
Acrolein	107028	P003	1	0.14
Acrylamide	79061	U007	5000	na
Acrylic acid	79107	U008	5000	565.59
Acrylonitrile	107131	U009	100	14.85
Acrylyl chloride	814686		1	0.11
Adipic acid	124049		5000	na
Adiponitrile	111693		1	0.13
Aldicarb	116063	P070	1	na
Aldrin	309002	P004	1	na
Allyl alcohol	107186	P005	100	14.04
Allyl chloride	107051		1000	127.83
Allylamine	107119		1	0.16
alpha - Endosulfan	959988		1	na
alpha-BHC	319846		10	na
alpha-Naphthylamine	134327	U167	100	na
Aluminum phosphide	20859738	P006	100	na
Aluminum sulfate	10043013		5000	na
Aminopterin	54626		1	na
Amiton	78535		1	0.11
Amiton oxalate	3734972		1	na
Amitrole	61825	U011	10	na
Ammonia	7664417		100	na
Ammonia still lime sludge from coking operations	na	K060	1	na
Ammonium acetate	631618		5000	na
Ammonium benzoate	1863634		5000	na
Ammonium bicarbonate	1066337		5000	na

NAME	Chemical Abstract Number (CAS)	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
Ammonium bichromate	7789095		10	na
Ammonium bifluoride	1341497		100	na
Ammonium bisulfite	10192300		5000	na
Ammonium carbamate	1111780		5000	na
Ammonium carbonate	506876		5000	na
Ammonium chloride	12125029		5000	na
Ammonium chromate	7788989		10	na
Ammonium fluoborate	13826830		5000	na
Ammonium fluoride	12125018		100	na
Ammonium hydroxide	1336216		1000	133.97
Ammonium oxalate	5972736		5000	na
Ammonium oxalate	6009707		5000	na
Ammonium oxalate	14258492		5000	na
Ammonium picrate	131748	P009	10	na
Ammonium silicofluoride	16919190		1000	na
Ammonium sulfamate	7773060		5000	na
Ammonium sulfide	12135761		100	11.99
Ammonium sulfite	10196040		5000	na
Ammonium tartrate	3164292		5000	na
Ammonium tartrate	14307438		5000	na
Ammonium thiocyanate	1762954		5000	na
Ammonium vanadate	7803556	P119	1000	na
Amphetamine	300629		1	0.13
Amyl acetate	628637		5000	684.38
Aniline	62533	U012	5000	586.79
Anthracene	120127		5000	na
Antimony	7440360		5000	na
Antimony Compounds	0		**	
Antimony pentachloride	7647189		1000	52.13
Antimony pentafluoride	7783702		1	0.04
Antimony potassium tartrate	28300745		100	na
Antimony tribromide	7789619		1000	na
Antimony trichloride	10025919		1000	na
Antimony trifluoride	7783564		1000	na
Antimony trioxide	1309644		1000	na
Antimycin A	1397940		1	na
Antu	86884	P072	100	na
API separator sludge from the petroleum refining industry	na	K051	1	na
Aqueous spent antimony catalyst waste from fluoromethanes prod.	na	K021	10	na
Aqueous stream from washing in prod. of chlorobenzenes	na	K105	10	na
Aroclor 1016	12674112		1	0.09
Aroclor 1221	11104282		1	0.10
Aroclor 1232	11141165		1	0.10
Aroclor 1242	53469219		1	0.09
Aroclor 1248	12672296		1	0.09

NAME	Chemical Abstract Number (CAS)	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
Aroclor 1254	11097691		1	0.08
Aroclor 1260	11096825		1	0.08
Arsenic	7440382	D004	1	na
Arsenic acid	1327522	P010	1	0.06
Arsenic acid	7778394	P010	1	na
Arsenic Compounds	0		**	
Arsenic disulfide	1303328		1	na
Arsenic pentoxide	1303282	P011	1	na
Arsenic trioxide	1327533	P012	1	na
Arsenic trisulfide	1303339		1	na
Arsenous oxide	1327533	P012	1	na
Arsenous trichloride	7784341		1	0.06
Arsine	7784421		1	na
Asbestos (friable)	1332214		1	na
Auramine	492808	U014	100	na
Azaserine	115026	U015	1	na
Azinphos-ethyl	2642719		1	na
Azinphos-methyl	86500		1	na
Aziridine	151564	P054	1	0.15
Barium cyanide	542621	P013	10	na
Benz[a]anthracene	56553	U018	10	na
Benz[c]acridine	225514	U016	100	na
Benzal chloride	98873	U017	5000	477.44
Benzene	71432	U019	10	1.36
Benzenearsonic acid	98055		1	na
Benzenesulfonyl chloride	98099	U020	100	8.66
Benzenethiol	108985	P014	100	11.17
Benzidine	92875	U021	1	na
Benzo(k)fluoranthene	207089		5000	na
Benzo[a]pyrene	50328	U022	1	na
Benzo[b]fluoranthene	205992		1	na
Benzo[ghi]perylene	191242		5000	na
Benzoic acid	65850		5000	na
Benzoic trichloride	98077	U023	10	0.87
Benzonitrile	100470		5000	593.58
Benzotrichloride	98077	U023	10	0.87
Benzoyl chloride	98884		1000	98.38
Benzyl chloride	100447	P028	100	10.90
Benzyl cyanide	140294		1	0.12
Beryllium	7440417	P015	10	na
Beryllium chloride	7787475		1	na
Beryllium Compounds	0		**	
Beryllium fluoride	7787497		1	na
Beryllium nitrate	7787555		1	na
Beryllium nitrate	13597994		1	na
beta - Endosulfan	33213659		1	na
beta-BHC	319857		1	na
beta-Naphthylamine	91598	U168	10	na

NAME	Chemical Abstract Number (CAS)	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
beta-Propiolactone	57578		10	1.04
Biphenyl	92524		100	na
Bis(2-chloro-1-methylethyl)ether	108601	U027	1000	108.02
Bis(2-chloroethoxy) methane	111911	U024	1000	97.48
Bis(2-chloroethyl) ether	111444	U025	10	0.98
Bis(2-ethylhexyl)phthalate	117817	U028	100	12.32
Bis(chloromethyl) ether	542881	P016	10	0.92
Bis(chloromethyl) ketone	534076		1	na
Bitoscanate	4044659		1	na
Boron trichloride	10294345		1	na
Boron trifluoride	7637072		1	na
Boron trifluoride compound with methyl ether (1:1)	353424		1	0.10
Bottom stream from acetonitrile column in acrylonitrile prod.	na	K013	10	na
Bottom stream from wastewater stripper in acrylonitrile prod.	na	K011	10	na
Bottoms from acetonitrile purification column in acrylonitrile prod.	na	K014	5000	na
Brine purification muds from mercury cell process in chlorine production	na	K071	1	na
Bromacil	314409		100	na
Bromadiolone	28772567		1	na
Bromine	7726956		1	0.04
Bromoacetone	598312	P017	1000	73.56
Bromoform	75252	U225	100	4.14
Bromomethane	74839	U029	1000	na
Brucine	357573	P018	100	na
Butyl acetate	123864		5000	679.73
Butyl benzyl phthalate	85687		100	10.90
Butylamine	109739		1000	161.81
Butyric acid	107926		5000	625.80
By-product salts generated in the prod. msma and cacodylic acid	na	K031	1	na
C.I. Solvent Yellow 34	492808	U014	100	na
Cacodylic acid	75605	U136	1	na
Cadmium	7440439	D006	10	na
Cadmium acetate	543908		10	na
Cadmium bromide	7789426		10	na
Cadmium chloride	10108642		10	na
Cadmium Compounds	0		**	
Cadmium oxide	1306190		1	na
Cadmium stearate	2223930		1	na
Calcium arsenate	7778441		1	na
Calcium arsenite	52740166		1	na
Calcium carbide	75207		10	na
Calcium chromate	13765190	U032	10	na
Calcium cyanamide	156627		1000	na
Calcium cyanide	592018	P021	10	na

NAME	Chemical Abstract Number (CAS)	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
Calcium dodecylbenzenesulfonate	26264062		1000	na
Calcium hypochlorite	7778543		10	na
Camphechlor	8001352	P123	1	na
Cantharidin	56257		1	na
Caprolactam	105602		5000	na
Captan	133062		10	na
Carbachol chloride	51832		1	na
Carbaryl	63252		100	na
Carbofuran	1563662		10	na
Carbon disulfide	75150	P022	100	9.49
Carbon tetrachloride	56235	U211	10	0.75
Carbonic difluoride	353504	U033	1000	na
Carbonyl sulfide	463581		100	na
Carbophenothion	786196		1	0.09
Catechol	120809		100	na
Centrifuge/dist. residues from toluene diisocyanate prod.	na	K027	10	na
CFC-11	75694	U121	5000	na
CFC-12	75718	U075	5000	na
Chloramben	133904		100	na
Chlorambucil	305033	U035	10	na
Chlordane	57749	U036	1	0.07
Chlordane (Technical Mixture and Metabolites)	0		**	
Chlorfenvinfos	470906		1	0.09
Chlorinated Benzenes	0		**	
Chlorinated Ethanes	0		**	
Chlorinated hydrocarbon waste in chlorine production	na	K073	10	na
Chlorinated Naphthalene	0		**	
Chlorinated Phenols	0		**	
Chlorine	7782505		10	na
Chlormephos	24934916		1	0.10
Chlormequat chloride	999815		1	na
Chlornaphazine	494031	U026	100	na
Chloroacetaldehyde	107200	P023	1000	97.01
Chloroacetic acid	79118		100	na
Chloroalkyl Ethers	0		**	
Chlorobenzene	108907	U037	100	10.84
Chlorobenzilate	510156	U038	10	na
Chlorodibromomethane	124481		100	4.89
Chloroethane	75003		100	4.80
Chloroethanol	107073		1	0.10
Chloroethyl chloroformate	627112		1	0.09
Chloroform	67663	U044	10	0.80
Chloromethane	74873	U045	100	na
Chloromethyl ether	542881	P016	10	0.92
Chloromethyl methyl ether	107302	U046	10	1.13
Chlorophacinone	3691358		1	na

NAME	Chemical Abstract Number (CAS)	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
Chlorophenols	0		**	
Chloroprene	126998		100	12.49
Chlorosulfonic acid	7790945		1000	68.40
Chloroxuron	1982474		1	na
Chlorpyrifos	2921882		1	na
Chlorthiophos	21923239		1	0.09
Chromic acetate	1066304		1000	na
Chromic acid	7738945		10	na
Chromic acid	11115745		10	na
Chromic chloride	10025737		1	na
Chromic sulfate	10101538		1000	na
Chromium	7440473		5000	na
Chromium Compounds	0		**	
Chromous chloride	10049055		1000	na
Chrysene	218019	U050	100	na
Cobalt carbonyl	10210681		1	na
Cobalt Compounds	0		*	
Cobaltous bromide	7789437		1000	na
Cobaltous formate	544183		1000	na
Cobaltous sulfamate	14017415		1000	na
Coke Oven Emissions	0		1	
Colchicine	64868		1	na
Column bottoms from separation in prod. of UDMH from carboxylic acid hydrazides	na	K107	10	na
Column bottoms(heavy ends) from prod. of trichloroethylene and perchloroethylene	na	K030	1	na
Combined wastewater streams generated from prod. of nitrobenzene/aniline	na	K104	10	na
Condensed column overheads and vent gas from prod. of UDMH from ‑COOH hydrazides	na	K108	10	na
Condensed column overheads from prod. of UDMH from carboxylic acid hydrazides	na	K110	10	na
Condensed liquid light ends from purification of toluenediamine during its prod.	na	K113	10	na
Copper	7440508		5000	na
Copper Compounds	0		**	
Copper cyanide	544923	P029	10	na
Coumaphos	56724		10	na
Coumatetralyl	5836293		1	na
Creosote	8001589	U051	1	0.11
Cresol (mixed isomers)	1319773	U052	100	11.53
cresol\nitrobenzene recovery	na	F004	100	na
Crimidine	535897		1	na
Crotonaldehyde	4170303	U053	100	14.17
Cumene	98828	U055	5000	695.50
Cumene hydroperoxide	80159	U096	10	1.17
Cupric acetate	142712		100	na
Cupric acetoarsenite	12002038		1	na

NAME	Chemical Abstract Number (CAS)	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
Cupric chloride	7447394		10	na
Cupric nitrate	3251238		100	na
Cupric oxalate	5893663		100	na
Cupric sulfate	7758987		10	na
Cupric tartrate	815827		100	na
Cyanide Compounds	0		**	
Cyanides (soluble salts and complexes) [hydrogen]	57125	P030	10	1.72
Cyanides (soluble salts and complexes) [potassium]	57125		10	na
Cyanides (soluble salts and complexes) [sodium]	57125		10	na
Cyanogen	460195	P031	100	na
Cyanogen bromide	506683	U246	1000	na
Cyanogen chloride	506774	P033	10	na
Cyanogen iodide	506785		1	na
Cyanophos	2636262		1	0.10
Cyanuric fluoride	675149		1	na
Cyclohexane	110827	U056	1000	153.92
Cyclohexanone	108941	U057	5000	633.07
Cycloheximide	66819		1	na
Cyclohexylamine	108918		1	0.14
Cyclophosphamide	50180	U058	10	na
Daunomycin	20830813	U059	10	na
DBCP	96128	U066	1	0.06
DDD	72548	U060	1	na
DDE	72559		1	na
DDE	3547044		1000	na
DDT	50293	U061	1	na
DDT and Metabolites	0		**	
Decaborane(14)	17702419		1	na
Decanter tank tar sludge from coking operations	na	K087	100	na
DEHP	117817	U028	100	12.32
delta-BHC	319868		1	na
Demeton	8065483		1	0.11
Demeton-S-methyl	919868		1	0.10
Di(2-ethylhexyl) phthalate	117817	U028	100	12.32
Dialifor	10311849		1	na
Diallate	2303164	U062	100	na
Diaminotoluene	496720	U221	10	na
Diaminotoluene	823405	U221	10	na
Diaminotoluene (mixed isomers)	25376458	U221	10	na
Diazinon	333415		1	na
Diazomethane	334883		100	na
Dibenzofuran	132649		100	na
Diborane	19287457		1	na
Dibutyl phthalate	84742	U069	10	1.15
Dicamba	1918009		1000	na
Dichlobenil	1194656		100	na

NAME	Chemical Abstract Number (CAS)	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
Dichlone	117806		1	na
Dichlorobenzene	25321226		100	9.22
Dichlorobenzene (mixed isomers)	25321226		100	9.22
Dichlorobenzidine	0		**	
Dichlorobromomethane	75274		5000	304.17
Dichlorodifluoromethane [CFC-12]	75718	U075	5000	na
Dichloroethyl ether	111444	U025	10	0.98
Dichloroisopropyl ether	108601	U027	1000	108.02
Dichloromethane	75092	U080	1000	90.46
Dichloromethyl ether	542881	P016	10	0.92
Dichloromethylphenylsilane	149746		1	0.10
Dichlorophenylarsine	696286	P036	1	0.07
Dichloropropane	26638197		1000	103.37
Dichloropropane - Dichloropropene (mixture)	8003198		100	9.99
Dichloropropene	26952238		100	na
Dichlorvos	62737		10	0.85
Dicofol	115322		10	na
Dicrotophos	141662		1	0.10
Dieldrin	60571	P037	1	na
Diepoxybutane	1464535	U085	10	1.08
Diethanolamine	111422		100	na
Diethyl chlorophosphate	814493		1	0.10
Diethyl phthalate	84662	U088	1000	107.25
Diethyl sulfate	64675		10	1.02
Diethylamine	109897		100	16.95
Diethylarsine	692422	P038	1	na
Diethylcarbamazine citrate	1642542		1	na
Diethyl-p-nitrophenyl phosphate	311455	P041	100	9.41
Diethylstilbestrol	56531	U089	1	na
Digitoxin	71636		1	na
Diglycidyl ether	2238075		1	0.10
Digoxin	20830755		1	na
Dihydrosafrole	94586	U090	10	na
Diisopropylfluorophosphate	55914	P043	100	11.37
Dimefox	115264		1	0.11
Dimethoate	60515	P044	10	na
Dimethyl phosphorochloridothioate	2524030		1	na
Dimethyl phthalate	131113	U102	5000	503.80
Dimethyl sulfate	77781	U103	100	9.00
Dimethylamine	124403	U092	1000	na
Dimethylaminoazobenzene	60117	U093	10	na
Dimethylcarbamyl chloride	79447	U097	1	0.10
Dimethyldichlorosilane	75785		1	0.11
Dimethylformamide	68122		10	1.27
Dimethylhydrazine	57147	U098	10	1.53
Dimethyl-p-phenylenediamine	99989		1	na
Dimetilan	644644		1	na
Dinitrobenzene (mixed isomers)	25154545		100	na

NAME	Chemical Abstract Number (CAS)	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
Dinitrocresol	534521	P047	10	na
Dinitrophenol	25550587		10	na
Dinitrotoluene (mixed isomers)	25321146		10	na
Di-n-octyl phthalate	117840	U107	5000	613.01
Dinoseb	88857	P020	1000	na
Dinoterb	1420071		1	na
Di-n-propylnitrosamine	621647	U111	10	1.31
Dioxathion	78342		1	0.10
Diphacinone	82666		1	na
Diphenylamine	122394		100	na
Diphenylhydrazine	0		**	
Dipropylamine	142847	U110	5000	812.36
Diquat	85007		1000	na
Diquat	2764729		1000	na
Discarded wastes containing tetra/penta/hexachlorobenzenes or derivatives	na	F027	1	na
Dissolved air flotation (DAF) float from the petroleum refining industry	na	K048	1	na
Dist. bottom tars from prod. of phenol/acetone from cumene	na	K022	1	na
Dist. bottoms from prod. of acetaldehyde from ethylene	na	K009	10	na
Dist. bottoms from prod. of nitrobenzene by nitration of benzene	na	K025	10	na
Dist. bottoms from prod. of phthalic anhydride from naphthalene	na	K024	5000	na
Dist. bottoms in prod. of phthalic anhydride by ortho-xylene	na	K094	5000	na
Dist. light ends from prod. of phthalic anhydride by ortho-xylene	na	K093	5000	na
Dist. light ends from prod. of phthalic anhydride fromnaphthalene	na	K023	5000	na
Dist. side cuts from prod. of acetaldehyde from ethylene	na	K010	10	na
Dist. tar residue from aniline in prod. of veterinary pharm. from arsenic compd.	na	K101	1	na
Distillation bottoms from aniline extraction	na	K083	100	na
Distillation bottoms from the production of chlorinated toluenes	na	K149	10	na
Distillation or fractionation column bottoms in prod. of chlorobenzenes	na	K085	10	na
Disulfoton	298044	P039	1	na
Dithiazanine iodide	514738		1	na
Dithiobiuret	541537	P049	100	na
Diuron	330541		100	na
Dodecylbenzenesulfonic acid	27176870		1000	99.92
Dust/sweepings from the prod. of ethylenebisdithiocarbamicacid and salts	na	K126	10	na

NAME	Chemical Abstract Number (CAS)	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
Emission control dust/sludge from ferrochromium prod.	na	K091	10	na
Emission control dust/sludge from ferrochromiumsilicon prod.	na	K090	10	na
Emission control dust/sludge from primary prod. of steel in electric furnaces	na	K061	1	na
Emission Control Dust/Sludge from secondary lead smelting	na	K069	1	na
Endosulfan	115297	P050	1	na
Endosulfan and Metabolites	0		**	
Endosulfan sulfate	1031078		1	na
Endothall	145733	P088	1000	na
Endothion	2778043		1	na
Endrin	72208	P051	1	na
Endrin aldehyde	7421934		1	na
Endrin and Metabolites	0		**	
Epichlorohydrin	106898	U041	100	10.14
Epinephrine	51434	P042	1000	na
EPN	2104645		1	na
Ergocalciferol	50146		1	na
Ergotamine tartrate	379793		1	na
Ethion	563122		10	0.98
Ethoprophos	13194484		1	0.11
Ethyl acetate	141786	U112	5000	670.23
Ethyl acrylate	140885	U113	1000	129.77
Ethyl carbamate	51796	U238	100	na
Ethyl chloride	75003		100	4.80
Ethyl cyanide	107120	P101	10	1.53
Ethyl ether	60297	U117	100	16.81
Ethyl methacrylate	97632	U118	1000	131.26
Ethyl methanesulfonate	62500	U119	1	0.10
Ethylbenzene	100414		1000	138.30
Ethylbis(2-chloroethyl)amine	538078		1	0.11
Ethylene dibromide	106934	U067	1	0.06
Ethylene dichloride	107062	U077	100	9.57
Ethylene fluorohydrin	371620		1	0.11
Ethylene glycol	107211		5000	537.45
Ethylene oxide	75218	U115	10	na
Ethylene thiourea	96457	U116	10	na
Ethylenediamine	107153		5000	666.87
Ethylenediamine-tetraacetic acid (EDTA)	60004		5000	na
Ethyleneimine	151564	P054	1	0.15
Ethylthiocyanate	542905		1	0.12
F069	na	F069	10	na
Famphur	52857	P097	1000	na
Fenamiphos	22224926		1	na
Fenitrothion	122145		1	0.09
Fensulfothion	115902		1	na

NAME	Chemical Abstract Number (CAS)	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
Ferric ammonium citrate	1185575		1000	na
Ferric ammonium oxalate	2944674		1000	na
Ferric ammonium oxalate	55488874		1000	na
Ferric chloride	7705080		1000	na
Ferric fluoride	7783508		100	na
Ferric nitrate	10421484		1000	na
Ferric sulfate	10028225		1000	na
Ferrous ammonium sulfate	10045893		1000	na
Ferrous chloride	7758943		100	na
Ferrous sulfate	7720787		1000	na
Ferrous sulfate	7782630		1000	na
Filter cake from filtration during prod. of phorate	na	K039	10	na
Filter solids from filtration of hexachlorocyclopentadiene in chlordane prod.	na	K034	10	na
Fine mineral fibers	0		*	
Fluenetil	4301502		1	na
Fluoranthene	206440	U120	100	na
Fluorene	86737		5000	na
Fluorine	7782414	P056	10	na
Fluoroacetamide	640197	P057	100	na
Fluoroacetic acid	144490		1	na
Fluoroacetyl chloride	359068		1	0.09
Fluorouracil	51218		1	na
Fonofos	944229		1	na
Formaldehyde	50000	U122	100	na
Formaldehyde cyanohydrin	107164		1	0.11
Formetanate hydrochloride	23422539		1	na
Formic acid	64186	U123	5000	495.47
Formothion	2540821		1	na
Formparanate	17702577		1	na
Fosthietan	21548323		1	0.09
Fuberidazole	3878191		1	na
Fumaric acid	110178		5000	na
Furan	110009	U124	100	12.81
Furfural	98011	U125	5000	517.27
Gallium trichloride	13450903		1	na
Glycidylaldehyde	765344	U126	10	1.12
Glycol Ethers	0		*	
Guthion	86500		1	na
Haloethers	0		**	
Halomethanes	0		**	
Heat exchanger bundle cleaning sludge from petroleum refining industry	na	K050	10	na
Heavy ends from purification of toluenediamine during its prod.	na	K115	10	na
Heavy ends from the dist. of ethylene dichloride during its prod.	na	K019	1	na

NAME	Chemical Abstract Number (CAS)	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
Heavy ends from the dist. of vinyl chloride during prod. of the monomer	na	K020	1	na
Heavy ends from the fractionation column in ethyl chloride prod.	na	K018	1	na
Heavy ends from the purification column in epichlorohydrin prod.	na	K017	10	na
Heavy ends or dist. residues from prod. of carbon tetrachloride	na	K016	1	na
Heptachlor	76448	P059	1	na
Heptachlor (and epoxide)	1024573	D031	1	na
Heptachlor and Metabolites	0		**	
Hexachlorobenzene	118741	U127	10	na
Hexachlorobutadiene	87683	U128	1	0.07
Hexachlorocyclohexane (all isomers) CAS 608-73-1	0		**	
Hexachlorocyclohexane (gamma isomer)	58899	U129	1	na
Hexachlorocyclopentadiene	77474	U130	10	0.70
Hexachloroethane	67721	U131	100	na
Hexachlorophene	70304	U132	100	na
Hexachloropropene	1888717	U243	1000	67.93
Hexaethyl tetraphosphate	757584	P062	100	9.28
Hexamethylphosphoramide	680319		1	0.12
Hexane	110543		5000	915.58
Hydrazine	302012	U133	1	0.12
Hydrazobenzene	122667	U109	10	na
Hydrochloric acid	7647010		5000	na
Hydrocyanic acid	74908	P063	10	na
Hydrofluoric acid	7664393	U134	100	na
Hydrogen chloride (gas only)	7647010		5000	na
Hydrogen cyanide	74908	P063	10	na
Hydrogen fluoride	7664393	U134	100	na
Hydrogen peroxide (Conc.> 52%)	7722841		1	0.09
Hydrogen selenide	7783075		1	na
Hydrogen sulfide	7783064	U135	100	na
Hydroquinone	123319		100	na
iso-Amyl acetate	123922		5000	684.38
Isobenzan	297789		1	na
iso-Butyl acetate	110190		5000	685.95
Isobutyl alcohol	78831	U140	5000	747.53
iso-Butylamine	78819		1000	165.61
iso-Butyric acid	79312		5000	632.41
Isobutyronitrile	78820		1	0.16
Isodrin	465736	P060	1	na
Isofluorphate	55914	P043	100	11.37
Isophorone	78591		5000	649.60
Isophorone diisocyanate	4098719		1	0.11
Isoprene	78795		100	17.74
Isopropanolamine dodecylbenzene sulfonate	42504461		1000	na

NAME	Chemical Abstract Number (CAS)	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
Isopropyl chloroformate	108236		1	0.11
Isopropylmethylpyrazolyl dimethylcarbamate	119380		1	0.11
Isosafrole	120581	U141	100	10.71
K119	na	K119	100	na
K120	na	K120	100	na
K121	na	K121	100	na
K141	na	K141	1	na
K142	na	K142	1	na
K143	na	K143	1	na
K144	na	K144	1	na
K145	na	K145	1	na
K147	na	K147	1	na
K148	na	K148	1	na
Kepone	143500	U142	1	na
Lactonitrile	78977		1	0.12
Lasiocarpine	303344	U143	10	na
Lead	7439921	D008	1	na
Lead acetate	301042	U144	5000	na
Lead arsenate	7645252		1	na
Lead arsenate	7784409		1	na
Lead arsenate	10102484		1	na
Lead chloride	7758954		100	na
Lead Compounds	0		**	
Lead fluoborate	13814965		100	6.85
Lead fluoride	7783462		100	na
Lead iodide	10101630		100	na
Lead nitrate	10099748		100	na
Lead phosphate	7446277	U145	1	na
Lead stearate	1072351		5000	na
Lead stearate	7428480		5000	na
Lead stearate	52652592		5000	na
Lead stearate	56189094		5000	na
Lead subacetate	1335326	U146	100	na
Lead sulfate	7446142		100	na
Lead sulfate	15739807		100	na
Lead sulfide	1314870		5000	na
Lead thiocyanate	592870		100	na
Leptophos	21609905		1	na
Lewisite	541253		1	0.06
Lindane	58899	U129	1	na
Linuron	330552		100	na
Lithium chromate	14307358		10	na
Lithium hydride	7580678		1	na
Malathion	121755		100	9.93
Maleic acid	110167		5000	na
Maleic anhydride	108316	U147	5000	na
Maleic hydrazide	123331	U148	5000	na
Malononitrile	109773	U149	1000	na

NAME	Chemical Abstract Number (CAS)	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
Manganese Compounds	0		*	
Manganese Compounds	0		*	
MBI	101688		5000	na
MBOCA	101144	U158	10	na
m-Cresol	108394	U052	100	11.60
m-Dinitrobenzene	99650		100	na
Mechlorethamine	51752		1	0.11
Melphalan	148823	U150	1	na
Mephosfolan	950107		1	0.08
Mercaptodimethur	2032657		10	na
Mercuric acetate	1600277		1	na
Mercuric chloride	7487947		1	na
Mercuric cyanide	592041		1	na
Mercuric nitrate	10045940		10	na
Mercuric oxide	21908532		1	na
Mercuric sulfate	7783359		10	na
Mercuric thiocyanate	592858		10	na
Mercurous nitrate	7782867		10	na
Mercurous nitrate	10415755		10	na
Mercury	7439976	U151	1	0.01
Mercury Compounds	0		**	
Mercury fulminate	628864	P065	10	na
Methacrolein diacetate	10476956		1	na
Methacrylic anhydride	760930		1	0.12
Methacrylonitrile	126987	U152	1000	149.88
Methacryloyl chloride	920467		1	0.11
Methacryloyloxyethyl isocyanate	30674807		1	0.11
Methamidophos	10265926		1	na
Methanesulfonyl fluoride	558258		1	0.08
Methanol	67561	U154	5000	757.93
Methapyrilene	91805	U155	5000	na
Methidathion	950378		1	na
Methiocarb	2032657		10	na
Methomyl	16752775	P066	100	na
Methoxychlor	72435	U247	1	na
Methoxyethylmercuric acetate	151382		1	na
Methyl 2-chloroacrylate	80637		1	0.10
Methyl bromide	74839	U029	1000	na
Methyl chloride	74873	U045	100	na
Methyl chloroform	71556	U226	1000	89.64
Methyl chloroformate	79221	U156	1000	98.04
Methyl ethyl ketone	78933	U159	5000	744.75
Methyl ethyl ketone (MEK)	78933	U159	5000	744.75
Methyl ethyl ketone peroxide	1338234	U160	10	na
Methyl hydrazine	60344	P068	10	1.38
Methyl iodide	74884	U138	100	5.26
Methyl isobutyl ketone	108101	U161	5000	751.47
Methyl isocyanate	624839	P064	10	1.25

NAME	Chemical Abstract Number (CAS)	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
Methyl isothiocyanate	556616		1	na
Methyl mercaptan	74931	U153	100	na
Methyl methacrylate	80626	U162	1000	127.15
Methyl parathion	298000	P071	100	na
Methyl phenkapton	3735237		1	na
Methyl phosphonic dichloride	676971		1	na
Methyl tert-butyl ether	1634044		1000	161.81
Methyl thiocyanate	556649		1	0.11
Methyl vinyl ketone	78944		1	0.14
Methylene bromide	74953	U068	1000	48.02
Methylene chloride	75092	U080	1000	90.46
Methylenebis(phenylisocyanate)	101688		5000	na
Methylmercuric dicyanamide	502396		1	na
Methylthiouracil	56042	U164	10	na
Methyltrichlorosilane	75796		1	0.09
Metolcarb	1129415		1	na
Mevinphos	7786347		10	0.97
Mexacarbate	315184		1000	na
Mitomycin C	50077	U010	10	na
m-Nitrophenol	554847		100	na
m-Nitrotoluene	99081		1000	103.63
Monocrotophos	6923224		1	na
Monoethylamine	75047		100	na
Monomethylamine	74895		100	13.29
Multi Source Leachate	na		1	na
Muscimol	2763964	P007	1000	na
Mustard gas	505602		1	0.09
m-Xylene	108383	U239	100	13.81
Naled	300765		10	na
Naphthalene	91203	U165	100	na
Naphthenic acid	1338245		100	11.60
n-Butyl alcohol	71363	U031	5000	740.15
n-Butyl phthalate	84742	U069	10	1.15
n-Dioctylphthalate	117840	U107	5000	613.01
Nickel	7440020		100	na
Nickel ammonium sulfate	15699180		100	na
Nickel carbonyl	13463393	P073	10	0.92
Nickel chloride	7718549		100	na
Nickel chloride	37211055		100	na
Nickel Compounds	0		**	
Nickel cyanide	557197	P074	10	na
Nickel hydroxide	12054487		10	na
Nickel nitrate	14216752		100	9.75
Nickel sulfate	7786814		100	na
Nicotine	54115	P075	100	11.88
Nicotine and salts	54115	P075	100	11.88
Nicotine sulfate	65305		100	na
Nitric acid	7697372		1000	86.70

NAME	Chemical Abstract Number (CAS)	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
Nitric oxide	10102439	P076	10	na
Nitrobenzene	98953	U169	1000	100.25
Nitrocyclohexane	1122607		1	0.11
Nitrogen dioxide	10544726		10	0.83
Nitrogen dioxide	10102440	P078	10	na
Nitroglycerin	55630	P081	10	0.75
Nitrophenol (mixed isomers)	25154556		100	na
Nitrophenols	0		**	
Nitrosamines	0		**	
Nitrosodimethylamine	62759	P082	10	1.19
Nitrotoluene	1321126		1000	na
N-Nitrosodiethanolamine	1116547	U173	1	0.09
N-Nitrosodiethylamine	55185	U174	1	na
N-Nitrosodimethylamine	62759	P082	10	1.19
N-Nitrosodi-n-butylamine	924163	U172	10	1.33
N-Nitrosodi-n-propylamine	621647	U111	10	1.31
N-Nitrosodiphenylamine	86306		100	na
N-Nitrosomethylvinylamine	4549400	P084	10	na
N-Nitrosomorpholine	59892		1	na
N-Nitroso-N-ethylurea	759739	U176	1	na
N-Nitroso-N-methylurea	684935	U177	1	na
N-Nitroso-N-methylurethane	615532	U178	1	na
N-Nitrosopiperidine	100754	U179	10	1.13
N-Nitrosopyrrolidine	930552	U180	1	0.11
Norbormide	991424		1	na
n-Propylamine	107108	U194	5000	836.15
Oil	na		Ψ	
o-Anisidine	90040		100	10.98
o-Cresol	95487	U052	100	na
o-Dichlorobenzene	95501	U070	100	9.18
o-Dinitrobenzene	528290		100	na
o-Nitrotoluene	88722		1000	103.10
Organic condensate solvent recovery system in prod. of toluene diisocyanate	na	K116	10	na
Organic residuals of Cl gas and HCl from production of chlorinated toluenes	na	K150	10	na
Organorhodium Complex (PMN-82-147)	0		1	
Osmium oxide OsO4 (T-4)-	20816120	P087	1000	na
Osmium tetroxide	20816120	P087	1000	na
o-Tolidine	119937	U095	10	na
o-Toluidine	95534	U328	100	11.90
o-Toluidine hydrochloride	636215	U222	100	na
Ouabain	630604		1	na
Oven residue from prod. of chrome oxide green pigments	na	K008	10	na
Oxamyl	23135220		1	na
Oxirane	75218	U115	10	na
Oxydisulfoton	2497076		1	0.10

NAME	Chemical Abstract Number (CAS)	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
o-Xylene	95476	U239	1000	133.67
Ozone	10028156		1	na
Paraformaldehyde	30525894		1000	na
Paraldehyde	123637	U182	1000	120.87
Paraquat	1910425		1	na
Paraquat methosulfate	2074502		1	na
Parathion	56382	P089	10	0.95
Parathion-methyl	298000	P071	100	na
Paris green	12002038		1	na
p-Benzoquinone	106514	U197	10	na
PCBs	1336363		1	0.09
p-Chloroaniline	106478	P024	1000	na
p-Chloro-m-cresol	59507	U039	5000	na
PCNB	82688	U185	100	na
PCP	87865	U242	10	na
p-Cresol	106445	U052	100	na
p-Dinitrobenzene	100254		100	na
Pentaborane	19624227		1	0.20
Pentachlorobenzene	608935	U183	10	na
Pentachloroethane	76017	U184	10	0.71
Pentachloronitrobenzene	82688	U185	100	na
Pentachlorophenol	87865	U242	10	na
Pentadecylamine	2570265		1	na
Peracetic acid	79210		1	0.10
Perchloroethylene	127184	U210	100	7.39
Perchloromethylmercaptan	594423		100	6.96
Petroleum refinery primary oil/water/solids separation sludge	na	F037	1	na
Petroleum refinery secondary (emulsified) oil/water/solids separation sludge	na	F038	1	na
Phenacetin	62442	U187	100	na
Phenanthrene	85018		5000	na
Phenol	108952	U188	1000	na
Phenyl dichloroarsine	696286	P036	1	0.07
Phenylhydrazine hydrochloride	59881		1	na
Phenylmercuric acetate	62384	P092	100	na
Phenylmercury acetate	62384	P092	100	na
Phenylsilatrane	2097190		1	na
Phenylthiourea	103855	P093	100	na
Phorate	298022	P094	10	1.00
Phosacetim	4104147		1	na
Phosfolan	947024		1	na
Phosgene	75445	P095	10	na
Phosmet	732116		1	na
Phosphamidon	13171216		1	0.10
Phosphine	7803512	P096	100	na
Phosphoric acid	7664382		5000	355.80
Phosphorus	7723140		1	na

NAME	Chemical Abstract Number (CAS)	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
Phosphorus (yellow or white)	7723140		1	na
Phosphorus oxychloride	10025873		1000	72.67
Phosphorus pentachloride	10026138		1	na
Phosphorus pentoxide	1314563		1	na
Phosphorus trichloride	7719122		1000	76.37
Phthalate Esters	0		**	
Phthalic anhydride	85449	U190	5000	na
Physostigmine	57476		1	na
Picrotoxin	124878		1	na
Pink/red water from TNT operations	na	K047	10	na
Piperidine	110894		1	0.14
Pirimifos-ethyl	23505411		1	0.11
Plating bath residues from electroplating where cyanides are used	na		10	na
p-Nitroaniline	100016	P077	5000	na
p-Nitrophenol	100027	U170	100	na
p-Nitrotoluene	99990		1000	na
Polychlorinated biphenyls	1336363		1	0.09
Polycyclic organic matter	0		*	
Polynuclear Aromatic Hydrocarbons	0		**	
Potassium arsenate	7784410		1	na
Potassium arsenite	10124502		1	na
Potassium bichromate	7778509		10	na
Potassium chromate	7789006		10	na
Potassium cyanide	151508	P098	10	na
Potassium hydroxide	1310583		1000	na
Potassium permanganate	7722647		100	na
Potassium silver cyanide	506616	P099	1	na
p-Phenylenediamine	106503		5000	na
Process residues from aniline extraction from the prod. of aniline	na	K103	100	na
Process waterwater from the prod. of ethylenebisdithiocarbamic acid and salts	na	K123	10	na
Product washwaters from prod. of dinitrotoluene via nitration of benzene	na	K111	10	na
Promecarb	2631370		1	na
Propane sultone	1120714	U193	10	na
Propargite	2312358		10	1.11
Propargyl alcohol	107197	P102	1000	126.48
Propargyl bromide	106967		1	0.09
Propionaldehyde	123386		1000	150.44
Propionic acid	79094		5000	603.53
Propionic anhydride	123626		5000	590.66
Propionitrile	107120	P101	10	1.53
Propoxur	114261		100	na
Propyl chloroformate	109615		1	0.11
Propylene oxide	75569		100	14.45
Propyleneimine	75558	P067	1	0.15

NAME	Chemical Abstract Number (CAS)	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
Prothoate	2275185		1	na
p-Toluidine	106490	U353	100	na
p-Xylene	106423	U239	100	13.93
Pyrene	129000		5000	na
Pyrethrins	121211		1	0.08
Pyrethrins	121299		1	0.12
Pyrethrins	8003347		1	0.14
Pyridine	110861	U196	1000	122.11
Pyriminil	53558251		1	na
Quenching bath residues from metal heat treating where cyanides are used	na	F010	10	na
Quenching wastewater sludges from metal heat treating where cyanides are used	na	F012	10	na
Quinoline	91225		5000	550.02
Quinone	106514	U197	10	na
Quintozene	82688	U185	100	na
Radionuclides (including radon)	na		β	na
Reaction by-product water from drying of toluenediamine during its prod.	na	K112	10	na
Reactor vent scubber water from prod of ethylenebisdithiocarbamic acid and salts	na	K124	10	na
Reserpine	50555	U200	5000	na
Residue from activated carbon in prod. of veterinary pharm. from arsenic compds.	na	K102	1	na
Resorcinol	108463	U201	5000	na
Saccharin (manufacturing)	81072	U202	100	na
Saccharin and salts	81072	U202	100	na
Safrole	94597	U203	100	10.95
Salcomine	14167181		1	na
Sarin	107448		1	0.11
sec-Amyl acetate	626380		5000	697.12
sec-Butyl acetate	105464		5000	687.52
sec-Butylamine	13952846		1000	165.38
sec-Butylamine	513495		1000	165.61
Selenious acid	7783008	U204	10	na
Selenium	7782492	D010	100	na
Selenium Compounds	0		**	
Selenium dioxide	7446084		10	na
Selenium oxychloride	7791233		1	0.05
Selenium sulfide	7488564	U205	10	na
Selenourea	630104	P103	1000	na
Semicarbazide hydrochloride	563417		1	na
Silver	7440224	D011	1000	na
Silver Compounds	0		**	
Silver cyanide	506649	P104	1	na
Silver nitrate	7761888		1	na
Slop oil emulsion solids from the petroleum refining industry	na	K049	1	na

NAME	Chemical Abstract Number (CAS)	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
Sludge from treatment of wastewater(acid plant blowdown) fromprimary zinc prod.	na	K066	1	na
Sodium	7440235		10	na
Sodium arsenate	7631892		1?	na
Sodium arsenite	7784465		1	na
Sodium azide (Na(N3))	26628228	P105	1000	na
Sodium bichromate	10588019		10	na
Sodium bifluoride	1333831		100	na
Sodium bisulfite	7631905		5000	na
Sodium cacodylate	124652		1	na
Sodium chromate	7775113		10	na
Sodium cyanide (Na(CN))	143339	P106	10	na
Sodium dodecylbenzenesulfonate	25155300		1000	na
Sodium fluoride	7681494		1000	na
Sodium fluoroacetate	62748	P058	10	na
Sodium hydrosulfide	16721805		5000	na
Sodium hydroxide	1310732		1000	na
Sodium hypochlorite	7681529		100	9.92
Sodium hypochlorite	10022705		100	na
Sodium methylate	124414		1000	na
Sodium nitrite	7632000		100	na
Sodium selenate	13410010		1	na
Sodium selenite	7782823		100	na
Sodium selenite	10102188		100	na
Sodium tellurite	10102202		1	na
Solids formed in the prod. of ethylenebisdithiocarbamic acid and salts	na	K125	10	na
Spent absorbant solids in purification of ethylene dibromide manuf. from ethene	na	K118	1	na
Spent absorbent and waste water from the prod. of methyl bromide	na	K132	1000	na
Spent carbon from treatment of wastewater containing explosives	na	K045	10	na
Spent cyanide plating bath solns. from electroplating	na	F007	10	na
Spent cyanide soln. from salt bath pot cleaning from metal heat treating	na	F011	10	na
Spent filter catridges from purif. of UDMH prod. from carboxylic acid hydrazides	na	K109	10	na
Spent Halogenated Solvents used in Degreasing	na	F001	10	na
Spent halogenated solvents:	na	F002	10	na
Spent non-halogenated solvents and still bttm. from cresol\nitrobenzene recovery	na	F004	100	na
Spent non-halogenated solvents(still bttm.) toluene\methyl ethyl ketone recovery	na	F005	100	na
Spent non-halogenated solvents:	na	F003	100	na
Spent pickle liquor generated by steel finishing: (SIC codes 331 and 332)	na	K062	1	na

NAME	Chemical Abstract Number (CAS)	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
Spent potliners from primary aluminum reduction	na	K088	10	na
Spent stripping/cleaning bath solns. from electroplating where cyanides are used	na	F009	10	na
Still bottoms from purification of ethylene dibromide manuf. from ethene	na	K136	1	na
Still bottoms from the dist. of benzyl chloride	na	K015	10	na
Still bottoms from toluene reclamation distillation in disulfoton prod.	na	K036	1	na
Stripping still tails from the prod. of methyl ethyl pyridines	na	K026	1000	na
Strontium chromate	7789062		10	na
Strychnine	57249	P108	10	na
Styrene	100425		1000	132.56
Styrene oxide	96093		100	11.42
Sulfotep	3689245	P109	100	9.99
Sulfur dioxide	7446095		1	na
Sulfur monochloride	12771083		1000	71.37
Sulfur phosphide	1314803	U189	100	na
Sulfur tetrafluoride	7783600		1	na
Sulfur trioxide	7446119		1	0.06
Sulfuric acid	7664939		1000	65.17
Sulfuric acid (fuming)	8014957		1000	62.61
Surface impoundment solids at primary lead smelting facilities	na	K065	1	na
Tabun	77816		1	0.11
Tank bottoms (leaded) from the petroleum refining industry	na	K052	10	na
Tellurium	13494809		1	na
Tellurium hexafluoride	7783804		1	na
Tepp	107493	P111	10	1.01
Terbufos	13071799		1	0.11
tert-Amyl acetate	625161		5000	685.95
tert-Butyl acetate	540885		5000	695.50
tert-Butylamine	75649		1000	172.28
Tetrachloroethylene	127184	U210	100	7.39
Tetraethyl lead	78002	P110	10	0.72
Tetraethyl pyrophosphate	107493	P111	10	1.01
Tetraethyldithiopyrophosphate	3689245	P109	100	na
Tetraethyltin	597648		1	0.10
Tetramethyllead	75741		1	na
Tetranitromethane	509148	P112	10	0.75
Thallic oxide	1314325	P113	100	na
Thallium	7440280		1000	na
Thallium chloride TlCl	7791120	U216	100	na
Thallium Compounds	0		**	
Thallium sulfate	10031591		100	na
Thallium(I) acetate	563688	U214	100	na
Thallium(I) carbonate	6533739	U215	100	na

NAME	Chemical Abstract Number (CAS)	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
Thallium(I) nitrate	10102451	U217	100	na
Thallium(I) sulfate	7446186	P115	100	na
Thallous carbonate	6533739	U215	100	na
Thallous chloride	7791120	U216	100	na
Thallous malonate	2757188		1	na
Thallous sulfate	7446186	P115	100	na
Thioacetamide	62555	U218	10	na
Thiocarbazide	2231574		1	na
Thiofanox	39196184	P045	100	na
Thiomethanol	74931	U153	100	na
Thionazin	297972	P040	100	9.96
Thiophenol	108985	P014	100	11.17
Thiosemicarbazide	79196	P116	100	na
Thiourea	62566	U219	10	na
Thiram	137268	U244	10	na
Titanium tetrachloride	7550450		100	6.95
Toluene	108883	U220	1000	138.30
Toluenediamine	25376458	U221	10	na
Toluenediisocyanate (mixed isomers)	26471625	U223	100	9.83
Toxaphene	8001352	P123	1	na
Triamiphos	1031476		1	na
Triazofos	24017478		1	0.10
Tribromomethane	75252	U225	100	4.14
Trichlorfon	52686		100	na
Trichloro(chloromethyl)silane	1558254		1	0.08
Trichloro(dichlorophenyl)silane	27137855		1	0.08
Trichloroacetyl chloride	76028		1	0.07
Trichloroethylene	79016	U228	100	8.20
Trichloroethylsilane	115219		1	0.10
Trichlorofluoromethane [CFC-11]	75694	U121	5000	na
Trichloromethanesulfenyl chloride	594423		100	6.96
Trichloromonofluoromethane	75694	U121	5000	na
Trichloronate	327980		1	0.09
Trichlorophenol	25167822		10	na
Trichlorophenylsilane	98135		1	0.09
Triethanolamine dodecylbenzene sulfonate	27323417		1000	na
Triethoxysilane	998301		1	0.14
Triethylamine	121448		5000	823.52
Trifluralin	1582098		10	na
Trimethylamine	75503		100	na
Trimethylchlorosilane	75774		1	0.14
Trimethylolpropane phosphite	824113		1	na
Trimethyltin chloride	1066451		1	na
Triphenyltin chloride	639587		1	na
Tris(2-chloroethyl)amine	555771		1	na
Trypan blue	72571	U236	10	na
Unlisted hazardous wastes characteristic of corrosivity	na	D002	100	na

NAME	Chemical Abstract Number (CAS)	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
Unlisted hazardous wastes characteristic of ignitability	na	D001	100	na
Unlisted hazardous wastes characteristic of reactivity	na	D003	100	na
Untreated process wastewater from the prod. of toxaphene	na	K098	1	na
Uracil mustard	66751	U237	10	na
Uranyl acetate	541093		100	na
Uranyl nitrate	10102064		100	na
Uranyl nitrate	36478769		100	na
Urethane	51796	U238	100	na
Vacuum stripper discharge from the chlordane chlorinator in prod. of chlordane	na	K097	1	na
Valinomycin	2001958		1	na
Vanadium pentoxide	1314621	P120	1000	na
Vanadyl sulfate	27774136		1000	na
Vicinals from purification of toluenediamine during its production	na	K114	10	na
Vinyl acetate	108054		5000	641.88
Vinyl acetate monomer	108054		5000	641.88
Vinyl bromide	593602		100	na
Vinyl chloride	75014	U043	1	na
Vinylidene chloride	75354	U078	100	9.88
Warfarin	81812	P001	100	na
Warfarin sodium	129066		100	na
Waste from equipment previously used to prod. tetra/penta/hexachlorobenzenes	na	F026	1	na
Waste leaching soln. from acid leaching of emission dust in 2nd lead smelting	na	K100	1	na
Wastes from mat. prod. on equip. which prev. used tri\tetrachlorophenol	na	F023	1	na
Wastes from prod. of chlorinated aliphatic hydrocarbons (C1-C5)	na	F024	1	na
Wastes from prod. or use of pentachlorophenol or intermediates	na	F021	1	na
Wastes from prod. or use of tri/tetrachlorophenol or derivatives	na	F020	1	na
Wastes from use of tetra/penta/hexachlorobenzenes	na	F022	1	na
Wastes/sludges from prod. of inks from chromium and lead compds.	na	K086	1	na
Wastewaster/scrubwater from chlorination during prod. of chlordane	na	K033	10	na
Wastewater and spent sulfuric acid from the prod. of methyl bromide	na	K131	100	na
Wastewater from the washing and stripping of phorate production	na	K038	10	na

NAME	Chemical Abstract Number (CAS)	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid[Δ] (Gallons)
Wastewater from vent gas scrubber in prod. of ethylene bromide prod. from ethene	na	K117	1	na
Wastewater sludges from prod. of veterinary pharm. from arsenic compds.	na	K084	1	na
Wastewater treatment sludge from creosote or pentachlorophenol wood preserving	na	K001	1	na
Wastewater treatment sludge from manuf. and processing of explosives	na	K044	10	na
Wastewater treatment sludge from mercury cell process in chlorine prod.	na	K106	1	na
Wastewater treatment sludge from prod. of chrome green pigments	na	K005	1	na
Wastewater treatment sludge from prod. of chrome oxide green pigments anyhydrous	na	K006	10	na
Wastewater treatment sludge from prod. of chrome yellow and orange pigments	na	K002	1	na
Wastewater treatment sludge from prod. of iron blue pigments	na	K007	10	na
Wastewater treatment sludge from prod. of molybdate orange pigments	na	K003	1	na
Wastewater treatment sludge from prod. of zinc yellow pigments	na	K004	10	na
Wastewater treatment sludge from production of chlorinated toluenes	na	K151	10	na
Wastewater treatment sludge from the prod. of chlordane	na	K032	10	na
Wastewater treatment sludge from the prod. of phorate	na	K040	10	na
Wastewater treatment sludge from the prod. of toxaphene	na	K041	1	na
Wastewater treatment sludges from chemical conversion of aluminum coating	na	F019	10	na
Wastewater treatment sludges from electroplating operations	na	F006	10	na
Wastewater treatment sludges from the prod. of creosote	na	K035	1	na
Wastewater treatment sludges from the prod. of disulfoton	na	K037	1	na
Xylene (mixed isomers)	1330207	U239	100	13.91
Xylenol	1300716		1000	na
Xylylene dichloride	28347139		1	na
Zinc	7440666		1000	na
Zinc (fume or dust)	7440666		1000	na
Zinc acetate	557346		1000	na
Zinc ammonium chloride	14639975		1000	na
Zinc ammonium chloride	14639986		1000	na
Zinc ammonium chloride	52628258		1000	na
Zinc borate	1332076		1000	na

NAME	Chemical Abstract Number (CAS)	RCRA Code	State RQ (Pounds)	Approximate Quantity of Liquid$^{\Delta}$ (Gallons)
Zinc bromide	7699458		1000	na
Zinc carbonate	3486359		1000	na
Zinc chloride	7646857		1000	na
Zinc Compounds	0		**	
Zinc cyanide	557211	P121	10	na
Zinc fluoride	7783495		1000	na
Zinc formate	557415		1000	na
Zinc hydrosulfite	7779864		1000	na
Zinc nitrate	7779886		1000	na
Zinc phenolsulfonate	127822		5000	na
Zinc phosphide	1314847	P122	100	na
Zinc phosphide (conc. <= 10%)	1314847	U249	100	na
Zinc phosphide (conc. > 10%)	1314847	P122	100	na
Zinc silicofluoride	16871719		5000	na
Zinc sulfate	7733020		1000	na
Zirconium nitrate	13746899		5000	na
Zirconium potassium fluoride	16923958		1000	na
Zirconium sulfate	14644612		5000	na
Zirconium tetrachloride	10026116		5000	na

Note:

RQ Reportable Quantity.

* Indicates that the EPA was considering several options for the CERCLA reporting requirements that would apply to these broad generic categories of hazardous air pollutants.

** Indicates that no RQ is being assigned to the generic or broad class.

Δ RQ is presented in gallons for materials that are in liquid form when at room temperature and standard pressure.

Ψ Oil released under the listed circumstances is considered as the RQ:
(1) Any amount of oil which when released into the environment causes a sheen to appear on surface water, or any navigable water of the State.
(2) Any free product that appears on groundwater.
(3) Any amount of oil released to the environment greater than 25 gallons.
(4) Any amount of oil released to the environment which is less than 25 gallons, but which is not contained

β Appendix B of Section 302.4 as it appears in the CFR published on July 1, 1993.

na Not Applicable

SECTION 3
SITE INVESTIGATION DESIGN AND IMPLEMENTATION

Interim Final - August, 2016

State of Hawai'i
Department of Health
Office of Hazard Evaluation and Emergency Response
919 Ala Moana Boulevard, Room 206
Honolulu, Hawai'i 96814

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Appendix

3-A Guidance for the Evaluation of Imported and Exported Fill Material, Including Contaminant Characterization of Stockpiles

SECTION 3 ACRONYMS AND ABBREVIATIONS

%	Percent
ASTM	American Society for Testing and Materials
CFR	Code of Federal Regulations
COPC	Chemicals (or Contaminants) of Potential Concern
CSM	Conceptual Site Model
Dioxins	Polychlorinated dibenzodioxins
DQA	Data Quality Assessment
DQO	Data Quality Objective
DU	Decision Unit
EAL	Environmental Action Level
EHE	Environmental Hazard Evaluation
FID	Flame Ionization Detector
ft^2	Square feet
Furans	Polychlorinated dibenzofurans
HAR	Hawai'i Administrative Rules
HASP	Health and Safety Plan
HAZWOPER	Hazardous Waste Operations and Emergency Response
HDOH	Hawai'i Department of Health
HEER Office	Hazard Evaluation and Emergency Response Office
HIOSH	Hawai'i Occupational Safety and Health
HRS	Hawai'i Revised Statutes
mg/kg	Milligrams per kilogram
OSHA	Occupational Safety and Health Administration
PAH	Polynuclear Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
PID	Photo Ionization Detector
PQL	Practical Quantitation Limit
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QC	Quality Control
RL	Reporting Limit
RSD	Relative standard deviation
SAP	Sampling and Analysis Plan
SCP	Hawai'i State Contingency Plan
SPLP	Synthetic Precipitation Leaching Procedure
TCLP	Toxicity characteristic leaching procedure
TGM	Technical Guidance Manual
UCL	Upper Confidence Level
USEPA	United States Environmental Protection Agency
VSP	Visual Sample Plan
XRF	X-Ray Fluorescence

yd^3	Cubic Yard

3.0 SITE INVESTIGATION DESIGN AND IMPLEMENTATION

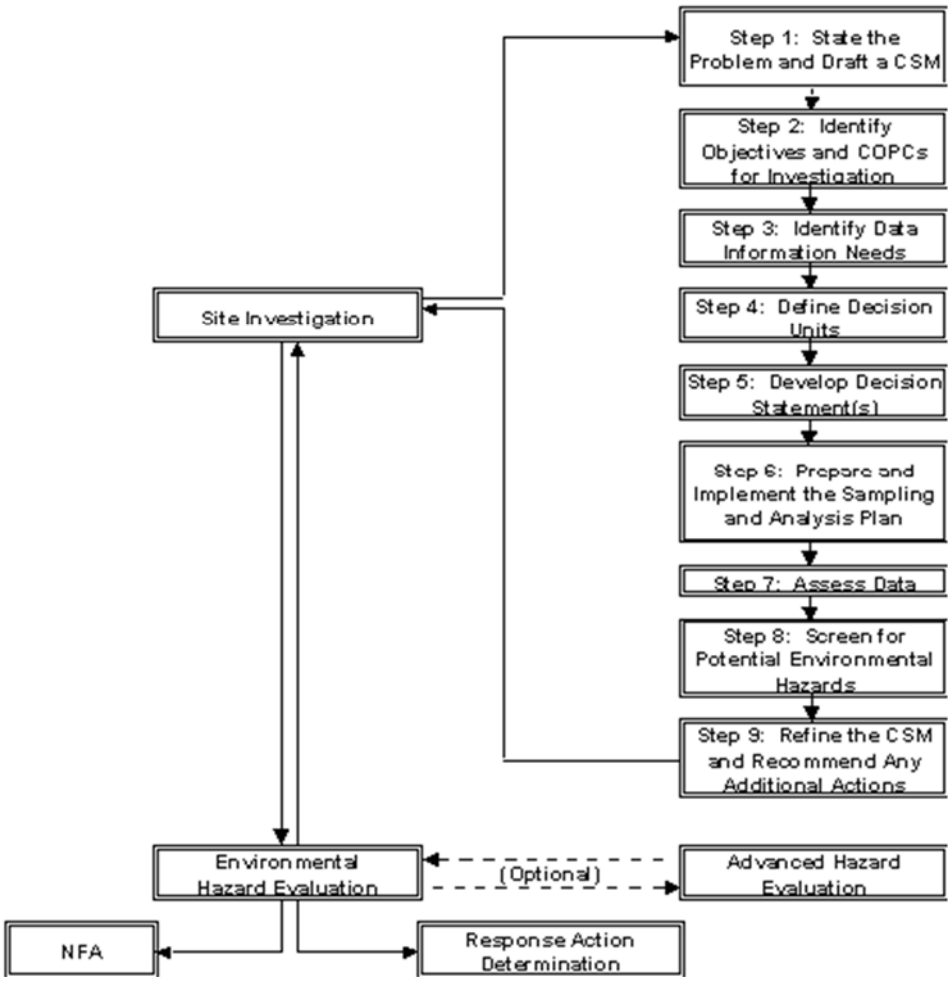


Figure 3-1. Expanded Overview of the Site Assessment Process

No Further Action (NFA) letter recommended, which may be requested from HEER Office if site data passes the EHE. Coordination with the HEER Office and Response Action Determination required if site data fail the EHE.

This Section of the Technical Guidance Manual (TGM) provides an overview of the Site Investigation element of the site assessment process (Figure 3-1; refer also to Figure 2-1 in Section 2).

The steps outlined above for implementation of a site investigation are discussed in Subsection 3.2. A site investigation is conducted in order to collect environmental data, evaluate the extent and magnitude of site contamination ("How bad is it?") and support decision-making ("What needs to be done?"). Site investigations can be carried out at different stages of the State Contingency Plan (SCP) process (refer to Subsection 2.1) in order to answer key questions, such as:

- Has a hazardous substance release occurred at the site?
- What is the extent and magnitude of contamination caused by the release?

- Does the release pose an environmental hazard under current or potential future site conditions?
- What method should be used to remediate this site?
- Has the cleanup eliminated the environmental hazard?

The scope and detail of the site investigation will vary from site to site, depending on the questions the investigation is intended to answer and the site complexity. A **systematic planning approach** is recommended to ensure that the data collected during the site investigation are of the type and quality needed to meet the overall site assessment objectives. In addition, the Site Investigation and Environmental Hazard Evaluation (EHE, see Section 13) stages of the site assessment process are necessarily interlinked and iterative (refer to Figure 3-1). The EHE is continually updated as additional site investigation data are obtained. These updates are used to guide and support further site investigation as needed.

For example, detection of high levels of tetrachloroethylene in groundwater during a site investigation could suggest vapor intrusion as a potential environmental hazard (e.g., groundwater action level for vapor intrusion exceeded). This could trigger the collection of soil gas samples in the source area as well as beneath and nearby existing buildings. Under some circumstances the resulting data could trigger the need for indoor air data and/or a review of the building ventilation system. This could then lead to the need to seal floors in order to prevent the potential intrusion of vapors into the building.

Linking the Site Investigation and Environmental Hazard Evaluation stages of the process in this manner from the very beginning of the project improves the effectiveness and efficiency of the overall site assessment process. This in turn helps to expedite completion of the project, minimize disruptions in site use and delays in site redevelopment.

3.1 SITE INVESTIGATION SCOPING

The first step of a **systematic planning approach** to site investigations is the effective scoping of available information and current site conditions in order to identify potential environmental problems at a property and develop an initial, Conceptual Site Model (CSM) (see Figure 3-1). This includes:

- Review applicable regulations and guidance (see Sections 1 and 2);
- Review site history and existing data;
- Consult with stakeholders.

The information is used to develop a preliminary CSM (see Subsections 3.2.1 and 3.3), identify potential environmental problems and develop the site investigation approach, all of which are essential components of the Sampling and Analysis Plan (see Subsections 3.2.1 and 3.6).

3.1.1 REVIEW SITE HISTORY AND EXISTING DATA

Existing reports and other records can provide significant information about site characteristics and environmental issues. Previously prepared Phase I and Phase II environmental site assessments (ESAs) may be of significant value. Phase I ESAs are designed to identify potential environmental issues at a site based on field inspections, interviews, and a review of existing documentation. These reports are often required by legal and financial institutions to support property sales or other transactions (e.g., refinancing or facility expansions). Phase II ESAs are conducted to follow up on Phase I findings through the collection, analysis and evaluation of soil, groundwater, soil gas or other types of environmental samples (e.g., lead and asbestos testing of building material). Phase I reports are often confidential and may not be available in public files for the property. Phase II reports might also be confidential, especially if prepared by a perspective purchaser rather than the building owner or operator.

If a Phase I ESA is not available for the site, or if one is available but out-of-date, then a review of site records that follows the Standards for Conducting All Appropriate Inquiries 40 CFR Part 312 (also described in American Society of Testing and Materials [ASTM] E1527-13(ASTM, 2013) should be carried out. The types of records described by 40 CFR Part 312 include:

- Physical setting sources (e.g., topographic maps and area-wide descriptions of geology, soil types, topography, and groundwater conditions);
- Historical use sources (e.g., aerial photographs, Sanborn fire insurance maps, street directories, title information, and newspaper archives);
- Federal, state, tribal and local government records or databases; and other environmental record sources as available (e.g., prior investigation reports, hazardous material and waste inventories, spill records, permits, etc.)

The detail and scope of the Phase I report depends in part on the needs of the requesting party as well as the experience of the preparer. The type and usefulness of information available for a property will vary. Information is more likely to be readily available for urban areas in comparison to rural areas, and for post-1970 time periods in comparison to earlier periods. Preparation of an adequate Phase I report is likely to require significantly more information than available in HEER Office public files for the property.

For example, site investigation scoping for identification of a suspected pesticide mixing area and other former agricultural operations at high risk for contamination might include the following elements:

- Review of historical Sanborn fire insurance maps (see Figure 3-2) produced between late 1800s to 1970s, available at UH-Manoa library and other sources;
- Review of historical aerial photos (for example, R.M. Towill Corp collection) (see Figure 3-3);
- Review of archives for former sugar plantations (for example, UH-Manoa library and Hawai‘i Agricultural Research Center);

- Interviews with people who worked at the facility or are otherwise familiar with the area;
- Inspection and photo documentation of identified, suspect sites.

Refer to TGM Section 9 for more information on pesticide mixing areas and former agricultural operations.

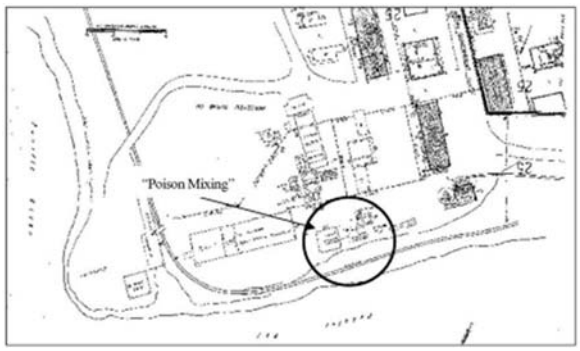


Figure 3-2. Portion of Sanborn Fire Insurance Map of Former Sugar Mill Operation

Location of "Poison Mixing" area is identified, indicating potential pesticide contamination (e.g. arsenic). Sugarcane seed dipping vats generally are not indicated, which may have potential mercury or other fungicide contamination.

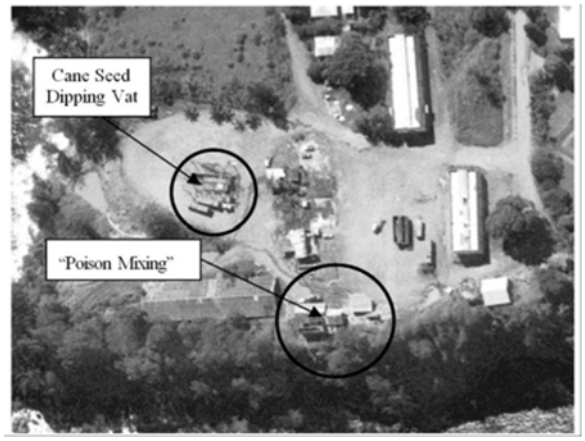


Figure 3-3. Historical Aerial Photo of Former Sugar Mill Operation

Location of pesticide mixing area is identified as well as a sugarcane seed dipping vat. This is the same former sugar mill operation as shown in Figure 3-2.

3.1.2 CONSULT WITH STAKEHOLDERS

Stakeholders are individuals or organizations who are affected by, who can affect, or who otherwise have interest, in the site (e.g., current and past owners, operators and employees; government agencies; nearby residents; developers; lenders; etc.). Stakeholders can be a valuable source of site information. For example, current or former employees can help document historical uses of the property, including locations of hazardous substance storage and disposal areas and point out other potentially important site features.

It is critical to consult with stakeholders early in the investigation scoping process to aid in an understanding of site issues. Early consultation with stakeholders, especially with the HEER Office, will help ensure that information collected during this stage of the environmental assessment process is sufficient to proceed to next steps. Avoidance of limitations on future use of the site should also be considered, for example by remediation of contaminated areas to meet unrestricted land use cleanup levels even though the property is currently used for commercial purposes (refer to HDOH, 2016).

3.1.3 DEVELOP THE OVERALL SITE INVESTIGATION APPROACH

The overall site investigation approach is broadly defined and progressively developed during the initial scoping stage of the assessment process. This can include a compilation of chemicals of potential concern, potential environmental hazards posed by the chemicals, the locations and types of media to be sampled and the general analyses to be performed.

Developing a general idea of the investigation approach facilitates systematic planning. Ultimately a more refined approach is developed and incorporated into the Sampling and Analysis Plan.

3.2 SYSTEMATIC PLANNING OF SITE INVESTIGATION

Environmental data must be of the appropriate type, quantity and quality to manage uncertainty and reach a defensible decision on appropriate response actions. The HEER Office recommends that the site investigation be developed using a **systematic planning approach** to ensure that data obtained during a site investigation are adequate to identify or negate the presence of potential environmental hazards. This approach emphasizes using straightforward, clear questions to design and guide the site investigation.

Systematic planning involves a series of well-thought-out steps that help ensure investigation results are adequate to characterize potential environmental hazards posed by contamination and provide sufficient information to develop response actions (refer to Figure 3-1). For the purposes of this guidance, these steps are summarized as follows (Figure 3-4):

STEP 1 – State the Problem: Draft a Conceptual Site Model (CSM)	
Activities • Assemble, review, and evaluate existing data (e.g. Phase 1 ESA, other) • Develop a preliminary CSM	Outputs • Concise description of documented or potential contaminant issues on site • Initial CSM
STEP 2 – Identify the Objectives and Chemicals of Potential Concern (COPCs)	
Activities • Identify questions to be answered • Identify site characteristics • Identify COPCs • Identify potential outcomes	Outputs • Questions to be answered • General description of the site • List of COPCs • List of potential outcomes
STEP 3 – Identify Data Information Needs	
Activities • Identify existing valid environmental data • Perform a data gaps analysis • Identify additional types and sources of information needed • Identify media of concern • Identify potential environmental hazards posed by COPCs • Identify sampling approach and lab methods to be used • Specify contaminant(s) to be measured and action level to be used for making the decision	Outputs • List of types of information to be collected, and potential sources • Description of media and environmental hazards of concern • Sampling approach and analytical methods to be used • Table including target contaminants, primary environmental hazard, lab analytical method and reporting limits, and applicable HDOH EALs
STEP 4 – Define Decision Units (DU)	
Activities • Define the geographic boundaries of the area of interest	Outputs • Definition of the project boundaries • Description and rationale for selection of Dus

• Identify temporal issues/sampling components for groundwater or ecological risk evaluations • Specify DU type, size, location, and shape (includes depth of soil DUs) • Identify particle size of interest and if surface organic matter will be sampled (for soil investigations) • Identify practical constraints (resources, accessibility, etc.)	• Description of soil particle size to be collected and if leaves, roots and other surface organic matter should or should not be included in the samples • Description of constraints on selection and investigation of DUs
STEP 5 – Develop Decision Statement(s)	
Activities	Outputs
• Develop a detailed "if… then…if not.." decision statement(s) • Determine statistical test and confidence level to be used	• A detailed "if… then…if not…" decision statement regarding the parameter, based on the action level • Description of the statistical test and confidence level for data analyses
STEP 6 – Develop and Implement the Sampling and Analysis Plan	
Activities	Outputs
• Summarize site background • Specify investigation objectives • Identify scope of work • Specify sampling and analysis methods and tools • Develop work plan and schedule	• Sampling and analysis plan • Work assignments and schedules • Tools / equipment list • Quality assurance project plan • Safety and health plan • Sample collection documentation
STEP 7 – Assess Data Quality	
Activities	Outputs
• Validate and determine adequacy of site data • Statistical evaluation of data • Interpret data and draw conclusions • Identify data gaps	• Data validation evaluation • Determination if data met DQO • Data tables, summary, and maps
STEP 8 – Identify Potential Environmental Hazards	
Activities	Outputs
• Compare site data to HDOH Tier 1 EALs (or approved, equivalent action levels) • Identify specific, potential environmental hazards if Tier 1 EAL for target contaminant exceeded.	• Site Investigation Report • Environmental Hazard Evaluation report (separate report or included with other reports as appropriate)
STEP 9 – Refine the CSM and Recommend Further Actions	
Activities	Outputs
• Review site conditions, data collected, and environmental hazards • Identify additional site investigation actions needed • Assess Removal or Remediation alternatives for contaminants above Action Levels	• Final CSM • Recommend additional site investigation actions (if needed) • Recommend advanced evaluation of identified environmental hazards (if needed)

• Develop engineering or administrative controls for contaminants remaining on site	• Develop Draft Removal or Remediation Action Plans, as appropriate • Develop EHMP if contaminants above Action Limits will remain on site

Figure 3-4. Nine Steps of the Systematic Planning Approach

Steps 1 through 3 identify the objectives of the site investigation and establish the type of information needed to determine if contamination at the site poses unacceptable environmental hazards. Site investigation activities are developed and carried out in Steps 4 through 6. Information gained from the investigation is evaluated and summarized in Steps 7 through 9.

The steps above are similar to the concept of *Data Quality Objectives* (DQOs) published in some guidance documents (Robbat, 1997, USEPA, 2000; USEPA, 2001; Tindall, 2006; USEPA, 2006; Triad, 2007). This term is retained for use in this Manual. Early DQO guidance focused on data quality needs with respect to laboratory analysis performance, however, rather than the quality of the data in terms of field representativeness. The DQO steps are modified and expanded in this guidance in order to incorporate the concepts of "decision units" and the collection of representative samples at the beginning of the process. This more comprehensively reflects the typical progression of environmental investigations at sites with contaminated soil and groundwater.

Preparing DQOs prior to the initiation of field activities should be an essential part of all site investigations. Decision Units and Decision Statements are established up front to reflect the desired end use of the data. The data quality assessment is carried out to determine if the DQOs have been met. This process is essential to ensure that the objectives of the site investigation are well thought out and that all samples to be collected are tied to clear decision statements. This will help avoid debate over interpretation of the resulting data and minimize the collection of data that are unnecessary or unreliable.

The level of detail needed to adequately incorporate the systematic planning approach into a site investigation, as well as formal report preparation and submittal requirements, will vary from site to site. Many of these steps may be combined at relatively simple sites where the risk to public health is low and the extent of environmental impacts well confined. This will allow cleanup actions to be conducted quickly and effectively. A more formal review process with greater regulatory oversight will be required for larger or more complex sites where there is greater public health risk or environmental impact, significant public interest, or where site investigation and response activities will be drawn out over a long time period.

Each of the steps noted above are discussed in more detail in the remainder of this Section.

3.2.1 OVERVIEW OF SYSTEMATIC PLANNING STEPS

A **systematic planning approach** is recommended to ensure that data collected during the site investigation are of the type and quality needed to meet the overall site assessment objectives. The nine-step systematic planning approach recommended by HDOH was summarized in the previous subsection. Additional detail is provided below and in Subsections 3.3 through 3.9 (refer also to Figure 3-1).

Step 1—State the Problem – Draft a Conceptual Site Model (CSM)

Summarize past or ongoing activities at the site that could have led to environmental contamination and will require additional investigation. Phase 1 Environmental Site Assessment documents are a good example of the type and level of detail useful to help summarize past and/or ongoing site activities. Summary information is then framed in terms of a CSM. The CSM is a comprehensive representation of the current understanding of site environmental conditions with respect to recognized or potential environmental hazards and is a necessary part of an Environmental Hazard Evaluation (See Section 13).

The CSM serves to summarize the current understanding of a site and identify gaps where additional data are needed. This then forms the basis of the site investigation. A detailed discussion of CSMs is provided in Subsection 3.3. The CSM is maintained and updated throughout the project as new data and information are obtained. To begin developing the CSM, a concise description of the site and potential problem(s) to be studied is prepared.

Issues to consider in Step 1 include:

a. What types of past or ongoing activities at the site could have led to environmental contamination?

b. What environmental conditions are identified in Phase I Environmental Site Assessment Reports (Recognized Environmental Conditions, including identified spill areas, storage areas, underground storage tanks, etc.)?

c. Can other sources of geologic or hydrologic conditions relevant to the site be identified (e.g. geotechnical reports, borings, etc.)?

d. Do preliminary data indicate the presence of contaminants in soil, groundwater or other environmental media greater than the HDOH Tier 1 Environmental Action Levels (EALs), and therefore the presence of potential environmental hazards?

e. Are data available from similar sites that may be useful for evaluating the site?

f. What are the regulatory requirements for reporting and investigating suspected releases of hazardous substances at the site?

Step 2—Identify the Objectives and Chemicals of Potential Concern (COPCs)

The primary objective of the Site Investigation is to collect data necessary to understand the presence and nature of potential environmental hazards at a site (e.g., direct exposure, vapor intrusion, leaching to groundwater, etc.). The site investigation must be designed to meet this objective, as well as to provide any additional information necessary to develop a response action to mitigate confirmed environmental hazards.

A list of site-specific questions is developed based on the initial CSM. These questions are framed so that their answers will be clear. Examples of typical site investigation questions are:

- Is soil in the vicinity of the former pesticide storage area contaminated above EALs over an area large enough to pose an environmental hazard?
- Does lead contamination in soil pose a direct exposure risk to residents?
- Is the size of the benzene plume in groundwater increasing, stable or shrinking?
- Does the contamination at the site extend beyond the property boundaries?

At this stage, questions are not specific enough to use in designing the sampling plan, but they roughly outline concerns at the site.

Potential outcomes – actions to be taken based on answers to the questions – should be identified. For example, if the question is "Does the mean concentration of lead in the DU surface soil exceed the action level?", then potential outcomes of the investigation might be: (1) Yes; additional cleanup is needed; (2) No; no further actions are needed.

Issues to review and consider in Step 2 include:

- What are the important geologic and hydrologic characteristics of the site and adjacent areas?
- What existing surface and subsurface structures occupy the site?
- Are there sensitive ecological habitats on the site, or nearby?
- What areas of the site may require additional investigation?
- What COPCs may be in each area?
- What is the appropriate size and location of DUs for the site?

Steps involved in addressing these issues initially include:

- Identify known or potential sources of chemical releases, including underground and aboveground tanks, piping networks, storage areas, disposal areas, etc.
- Complete an initial, screening level evaluation of potential environmental hazards and determine the need for additional site data.
- Develop a description of general surface and subsurface characteristics, including paved versus unpaved areas, soil type, presence of debris or fill material, location of utilities, depth to and use of groundwater, location and types of other manmade structures, etc.

- Identify nearby water supply wells, bodies of surface water and other potentially sensitive ecological habitats that could be threatened by the contamination.

The following actions may also apply:

- Collect data necessary to evaluate emergency response actions.
- Identify short-term containment and/or stabilization issues that may be immediately necessary to prevent exposure of on-site receptors to contaminants and to prevent the off-site migration of contaminants while response actions are being evaluated.
- Identify data necessary to evaluate the ecological impacts of the contaminants.
- Identify potential spill areas and/or exposure areas for detailed characterization.

The target COPCs should be identified early in the process based on the known or suspected past history of the site and be specific to the site under investigations. The list of target chemicals will likely be narrowed down substantially prior to investigation based on the Phase I review of the site history and other pertinent information. Testing for lengthy, multiple suites of contaminants is rarely required.

The rationale for including a chemical as a COPC should be clearly stated. A chemical should not be listed as a COPC simply because it is included in a default suite of chemicals reported for a specific laboratory method. For example, if lead and arsenic are target COPCs for a site due to historical operations then they should be specifically referenced, rather than listing the full "RCRA 8" suite of metals typically reported by the laboratory (i.e.., arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver). This helps to ensure that the rationale for the selection of target COPCs is clearly discussed and minimizes the use of resources on unnecessary testing. Section 9 provides supplemental guidance regarding the selection of COPCs for several specific types of releases. Refer also to common contaminants listed in the HDOH Tier 1 EAL lookup tables found in *Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater* (HDOH, 2016).

Step 3—Identify Data Needs

Understanding and collecting the information needed to answer the questions posed in Steps 1 and 2 is a critical part of the site investigation process. Data gaps are identified by an evaluation of existing site data and a determination of the need for additional data to meet site investigation objectives. Additional data may be needed for site characterization, health and safety planning, advanced evaluation of potential environmental hazards (e.g., need for a detailed, human health risk assessment) and the development of remedial alternatives (refer to Section 13). If additional data are needed, the intended use of the data should be clearly identified. Data needs should be continually re-evaluated and refined as more information about the site is gained and potential environmental hazards are identified.

Step 3 involves considering chemicals of potential concern and pathways that need to be investigated to determine the following:

- Can some groups of COPCs be eliminated from further consideration and testing based on data from previous investigations?
- What are the potential environmental hazards posed by targeted COPCs?
- What types of media should be collected and analyzed (e.g., soil, soil gas, groundwater, surface water, etc.) based on areas and types of potential contamination?
- For groundwater, how often will sampling need to be repeated, and how will samples for specific contaminants be collected/analyzed (e.g. total and/or dissolved metals)?
- How can representative concentrations of contaminants be best determined (e.g. Multi Increment sampling)?
- Will surface soil DU-MIS samples suffice, or will sub-surface DU-MIS soil samples be required as well?
- Will additional, non-traditional data potentially be needed to support the Environmental Hazard Evaluation or response action based on the results of initial data collected (e.g., bioaccessible arsenic data, batch test leaching data)?

Identify the optimal laboratory analytical method for the target COPCs and the media to be tested. Issues to consider in selecting lab analytical methods include:

- Is more than one laboratory method available for a target group of chemicals?

- If more than one lab method is available, is one method considered more accurate for the target COPC?
- Are reporting limits for each method sufficiently low to meet Tier 1 EALs for the COPC and, if not, are they within the generally acceptable range for commercial laboratories?
- Is prescreening using field equipment or a less rigorous lab method desirable to help refine the final analytical method? (refer to Section 8)

Samples collected during a site investigation may need to be split and sent to several laboratories for testing, based on the types of analyses required. All laboratories should have adequate internal QA/QC procedures to ensure sufficient data quality to satisfy the requirements of the DQO. Also, consider laboratory certification credentials during the lab selection process.

Less sensitive laboratory analytical methods may be necessary for samples that are known or suspected to be heavily contaminated. For example, Method 8280 (or equivalent) is considered to be adequate for testing of dioxins in soil. Testing of soil using an ultrasensitive, trace analysis test such as Method 8290 is not generally required to achieve reporting limits adequate for comparison to HDOH action levels (refer to Section 9). This will help avoid damage to laboratory equipment due to testing of highly contaminated samples.

Field screening may also be used as a screening tool to guide site investigations, but it is generally not acceptable to document the absence of contaminants. Examples of field screening equipment include photo ionization detectors (PIDs), flame ionization detectors (FIDs), and portable X-Ray Fluorescence (XRF) instruments. Additional information on use of field screening methods is provided in Section 8.

Data collected for targeted COPCs should be compared to action levels specific to the media tested. This is one of the primary uses of the HDOH Tier 1 Environmental Action Levels (Tier 1 EALs, refer also to Step 7). Use of the Tier 1 EALs is discussed in more detail in Section 13. Note that the HDOH EALs, as well as USEPA Regional Screening Levels (USEPA, 2014) and similar criteria, are not intended for comparison to individual, discrete sample data. The EALs instead are to be applied to the mean contaminant concentration within the targeted, decision unit.

In general, contaminants in soil, water, soil gas or indoor air at concentrations below the Tier 1 EALs do not pose a significant threat to human health and the environment. The presence of contaminants above the Tier 1 EALs does not necessarily indicate that significant environmental hazards exist, only that additional evaluation is warranted. Incorporation of the Tier 1 EALs in the site investigation work plan provides a useful endpoint for those tasked to carry out the fieldwork, and can reduce the need for remobilization and additional data collection.

The use of alternative action levels to help define the extent of contamination that may be of potential concern is acceptable but should be approved by the HEER Office in advance of the site investigation, or as part of a follow-up, site-specific Environmental Hazard Evaluation. Site-specific action levels must comprehensively address all potential environmental hazards posed by the chemical. Comparison to action levels that focus on a single potential concern, such as the USEPA Regional Screening Levels (RSLs) for direct-exposure (USEPA, 2014), may not be adequate. The presence of other potential hazards such as leaching, vapor intrusion, gross contamination and ecotoxicity concerns must also be evaluated using additional action levels specific to each hazard. As discussed in Section 13, action levels for each of these environmental hazards are incorporated into the HDOH Tier 1 EALs. Unlike the USEPA RSLs, this allows the HDOH EALs to be used as a stand-alone screening tool at most sites.

Environmental hazards that could be posed by targeted COPCs should ultimately be reflected in the Sampling and Analysis Plan. For example, a potential environmental hazard posed by volatile chemicals is the intrusion of vapors into existing or future buildings. The need to collect soil gas data should be evaluated at sites where releases of volatile contaminants have occurred. If heavy contamination is suspected or has been identified at a site, it may be prudent to include the collection of soil gas samples.

Concurrent collection of groundwater data should be considered at sites where soils are grossly contaminated with highly mobile contaminants (e.g., gasoline) or the type of contaminants present could otherwise pose significant leaching and groundwater contamination hazards (e.g., herbicides, such as atrazine). In other cases, additional laboratory tests may be run on split samples to better evaluate a specific hazard that is identified in initial site data.

Examples include:

- Collection of soil gas data at sites where initial soil and/or groundwater data indicate potential vapor intrusion hazards.
- Analysis of soil samples that exceed 24 milligrams per kilogram (mg/kg) total arsenic for bioaccessible arsenic in order to more closely evaluate potential direct-exposure hazards (see Section 9).

- Use of Synthetic Precipitation Leaching Procedure (SPLP) batch tests to better evaluate contaminant mobility in soil samples with reported concentrations of contaminants above action levels for leaching hazards. The SPLP batch test is used to evaluate the potential leaching of contaminants from soil under natural site conditions (refer to Section 13).

- Use of Toxicity Characteristic Leaching Procedure (TCLP) batch tests on contaminated soil that is to be disposed of in a landfill. The TCLP batch test uses more acidic conditions to simulate changing conditions over time in a landfill setting. TCLP data are used to determine if contaminated soil can be disposed of in a municipal landfill or instead must be sent to a permitted, hazardous waste landfill. Soil designated for disposal is considered to be a hazardous waste if TCLP data exceed regulatory limits found in HAR §11-261-24 and cannot be disposed of in a municipal landfill. (Note that soil is not generally considered to be a "waste" unless it has been excavated and a decision made for offsite disposal.)

A hazardous waste determination could require a separate sampling and analysis plan in order to address landfill disposal requirements (see Subsection 5.10). Contact the landfill for specific requirements. Consider the inclusion of additional sample collection and analysis in the original SAP in order address disposal needs prior to the initiation of site activities.

Step 4—Define the Decision Units

Steps 1-3 above will help to make a judgment call on how to best establish decision units (DUs) on the investigation site. A DU is a well-defined area of a site where a decision is to be made regarding the potential for contaminants to pose an environmental hazard, as defined in the HDOH Environmental Hazard Evaluation (EHE) guidance (HDOH, 2016). Put simply, a DU is the area and more specifically the volume of the targeted media (e.g., soil, sediment or water) that would be collected and analyzed as a single unit if possible. This is rarely if ever feasible and a representative sample (or samples) of the targeted media must instead be collected and submitted to a laboratory for analysis. In some cases, an entire site can be defined as a single decision unit; however, it is more typical to divide a site into multiple decision units based on known or suspected spill areas or areas where workers or residents are exposed to soil on a regular basis. A more detailed discussion of the selection of decision units is provided in Subsection 3.4.

The size and shape of a decision unit will depend on the specific, potential environmental hazards posed by the target COPCs, the intended use of the site and proposed response actions. Known or suspected spill areas should in general be treated as individual decision units. Spill area DUs are typically very small, ranging from a few hundred square feet to a few thousand square feet in area. This is especially important if the target contaminant is highly leachable from the soil and could pose a threat to groundwater resources or is highly volatile and could pose potential vapor intrusion hazards for buildings (e.g., water-soluble pesticides, solvents, light-end petroleum fuels, etc.). For relatively non-mobile contaminants the driving environmental hazard is often direct exposure, rather than leaching and groundwater protection (e.g., arsenic, lead, PCBs, polychlorinated dibenzodioxins and polychlorinated dibenzofurans "dioxins", etc.). If specific spill areas cannot be identified then the appropriate DU size is the current or anticipated exposure area(s) for the site, such as an entire residential yard or the outdoor work area(s) of a commercial or industrial site. Exposure area DUs typically cover areas of several thousand square feet but could be smaller or larger depending on site-specific circumstances.

Points to consider include:

- What are the primary environmental hazards posed by the target COPCs?

- How should the decision units be defined to evaluate these potential hazards and associated risks?

- Do the selected DUs provide sufficient coverage of targeted spill areas and/or exposure areas on the site?

- What is the optimal area and depth of the DUs to evaluate potential exposure, leaching, vapor intrusion and/or gross contamination concerns?

- What is the optimal area and depth of the DUs to optimize potential remedial actions?

- What soil particle size will be collected for analyses?

As discussed in Section 4, testing of a large number of points within a targeted DU (e.g., >30) is generally required to obtain a representative concentration of targeted COPCs for the DU as a whole.

Establishing DUs early in the investigation will also help integrate the field investigation with the evaluation of potential environmental hazards, as well as the preparation of site remedial action plans and long-term management plans. The designation of DUs and development of clear decision statements prior to the initiation of activities in the field is necessary for all investigations, including cases where discrete samples are collected.

Step 5—Develop decision statement(s)

Develop decision statements using sampling information identified in Step 3 and the decision unit boundaries defined in Step 4. Specify contaminants to be measured and action levels to be used for making the decision.

Decision statements are often phrased in the form:

> IF the concentration of [chemical] for the targeted decision unit based on [Multi Increment sampling methods] and analyzed using [analytical method] exceeds [value] THEN [action necessary]. IF NOT, then [outcome]."

Such as:

> IF the mean concentration of total lead in soil from DU #1, collected using Multi Increment sampling as per the Sampling and Analysis Plan (SAP) dated (day/month/year), and analyzed using USEPA SW-846 Method 6020, exceeds 200 mg/kg, THEN it will be concluded that the soil in DU #1 could pose a potential direct exposure hazard to residents and additional assessment or cleanup will be needed. IF NOT, then it will be concluded that the soil in DU #1 does not pose a potential hazard and no further action is needed.
>
> Or
>
> If the mean concentration of total arsenic in the soil in DU #1 exceeds the Tier 1 action level of 24 mg/kg, then an arsenic bioaccessibility test will be carried out on the soil. IF NOT, then it will be concluded that the soil in DU #1 does not pose a potential hazard and no further action is needed.

If the data on which the decision will be based consists of multiple values, then the statistic to be used for decision-making must be specified. The most commonly-used statistics are (see Subsection 4.2.5):

- The arithmetic mean contaminant concentration in the DU or
- The 95% Upper Confidence Level (UCL) of the mean.

Step 6—Develop and Implement the Sampling and Analysis Plan

The Sampling and Analysis Plan (SAP) should be designed to enable the investigation objectives to be achieved within acceptable uncertainty limits. Additional information on preparing a Sampling and Analysis Plan is provided in Subsection 3.6. A suggested format is provided in Section 18.

As described in Section 4, HDOH strongly encourages the use of Multi Increment and decision unit strategies to enhance sample representativeness in the investigation of contaminated soil (Jenkins et al. 2005; Ramsey and Hewitt, 2005). Field studies have demonstrated that error associated with discrete soil sample data can be significant, including underestimation of both the extent of contamination present and the mean contaminant concentration for a targeted area (e.g., HDOH, 2014). Multi Increment samples can significantly increase the representativeness of contaminant concentrations for targeted areas. Selection of decision units is discussed in Step 4, as well as in Subsection 3.4. A comparison of discrete versus Multi Increment soil sampling approaches is provided in Section 4. Soil sampling tools and techniques are discussed in Section 5.

Issues to consider in developing the SAP for soil, groundwater, soil gas and other targeted media include:

- How can sample collection be optimized to achieve site investigation objectives in a cost-effective manner?
- Should resources be focused on an investigation of a specific COPC or environmental hazard?
- Are adequate maps of the site available and if not what level of surveying or mapping will be required?
- Will rights of entry be required?
- Will utility clearance be required?
- Are geotechnical or other types of testing also necessary and if so can this be combined with the site investigation?
- How much total sample mass (of the designated maximum particle size, if soil) will be necessary to run all the COPC analyses planned?
- How many field replicates are required to determine overall representativeness of sample data and precision of estimated mean concentrations, given the targeted DUs and COPCs?
- Is the lab familiar with, and does it have protocols for representative laboratory sub-sampling of field samples (required for Multi Increment samples)?
- Should additional lab sub-sampling replicates be included to further examine the precision of the lab sub-sampling/lab analysis compared to the field replicate data?

- For soil, has the lab taken steps to reduce Fundamental Error by determining and using a digestion/analysis mass that is based on the maximum particle size in the sample (e.g., ten gram minimum subsample mass recommended for metals analyses of <2 mm particle size soil)?
- Have laboratory quality control criteria been met?
- How many soil gas samples are required to adequately assess potential vapor intrusion hazards?
- Is the collection of sorbent tube samples for TO-17 analysis required to test for long-chain hydrocarbons at petroleum release sites?
- Given the expected subsurface conditions, what is the minimal well size needed to collect the necessary amount of groundwater for sample analyses, given the site geology (e.g., micro-wells may not allow the collection of adequate sample volumes in tight soils)?
- What are the optimal tools for collecting samples for analyses by the methods identified in Step 3?
- Will field screening be carried out and if so, how will it be utilized and compared to laboratory data?
- Are the investigation areas accessible using the proposed tools and drilling equipment?

Soil and sediment sample collection methods are discussed in Sections 4 and 5. The collection of groundwater samples is discussed in Section 6. Soil gas and indoor air sampling is discussed in Section 7.

The reporting limit/practical quantitation limit (RL or PQL) a lab expects to achieve for a particular method generally should be low enough to determine if the analyte is present at or above the Tier 1 EALs or designated alternate value that meets the site investigation objectives. This will be a factor in selecting both the method(s) and the laboratory. If the reporting level achievable using standard laboratory methods is greater than the target action level then the reporting limit can be used for screening purposes (refer to Section 13 and EHE guidance, HDOH, 2016).

If soil/particulate samples are being collected and analyzed, the laboratory should be employing a representative laboratory sub-sampling procedure when processing the samples and preparing lab replicates (see Section 4). Such sub-sampling procedures include use of a sectoral splitter or hand Multi Increment sampling (USEPA, 2003b). Representative sub-sampling in the lab is generally considered the most important factor in reducing overall laboratory error.

After selecting analytical methods based on data needs, the next step is to specify the data quality performance and acceptance criteria the data will need to achieve. Uncertainty limits and performance data are developed in more detail in the Quality Assurance Project Plan (see Subsection 3.7). Both field and laboratory data quality considerations should be included in setting overall data quality and acceptance criteria. Providing limits on decision errors provides limits on the uncertainty in the data (USEPA, 2006b). Uncertainty limits are site-specific, and include considerations such as precision, accuracy, completeness, and comparability parameters.

Exceeding Tier 1 action levels for some contaminants may indicate a need for additional (contingent) analyses. For example, if total arsenic is found to be present in soil above 24 mg/kg then the laboratory should be asked to carry out or subcontract for bioaccessible arsenic tests on the sample or on selected samples if multiple samples were collected (see Section 9). If contaminants are detected in soil above action levels for leaching hazards and the soil is to be left in place, then the laboratory should be instructed to carry out a batch test (i.e. SPLP testing) on the samples to better evaluate contaminant mobility and the threat to groundwater. These possible outcomes should be identified in advance under Step 3 and contingencies made in the project budget to cover additional, potential laboratory costs, as appropriate.

It is important for the team tasked with preparing and carrying out the site investigation to visit the site prior to finalization of the *Sampling and Analysis Plan*. Final selection of decision units and collection of samples is dependent on a multitude of site-specific factors, including the location of buildings and other structures, the presence or absence of pavement, traffic, access, need for clearing prior to sample collection, suitability of tools to collect media targeted, etc.

An integral part of all SAPs is a site-specific Health and Safety Plan. The Health and Safety plan should be prepared and reviewed with field staff before initiating investigation activities at the site. Although the HEER Office will confirm that a SAP contains a site-specific Health and Safety Plan, workplace safety and health issues are under the jurisdiction of the Hawai‘i Occupational Safety and Health Division (HIOSH). HIOSH should be contacted regarding any safety and health compliance or consultation matters.

Issues to consider in developing the Health and Safety Plan include:

- What hazards could the targeted contaminants of potential concern or other chemicals that may be present pose to field staff at the anticipated or potential concentrations in soil, soil gas and groundwater?
- What physical site conditions could pose hazards to field staff and what type of personal equipment is necessary to protect field staff (e.g., for heavy equipment, confined spaces, trip and fall hazards, etc.)?
- What other environmental factors could pose hazards to field staff (e.g., heat, sunburn, poisonous plants or insects, wild animals, etc.)

Once the SAP has been finalized and, if required, reviewed and approved by the HEER Office, the site investigation should be implemented. The HEER Office should be notified at least two weeks prior to commencement of field activities.

Issues to consider while implementing the SAP include:

- Has all necessary sampling equipment been gathered and mobilized?
- Have field team members been made aware of potential chemical, biological and physical hazards that they may encounter at the investigation site?
- Can the collection of samples be accomplished in the proposed, allotted time?
- Do unanticipated field conditions warrant a change in sample collection approaches or sample point locations?
- What modifications will be required for the SAP if a new spill area is discovered, or a new contaminant of concern is identified?
- Do reported or field-detected levels of contaminants warrant additional laboratory tests on the samples?
- Do apparent environmental hazards identified in the field warrant an expansion of the investigation area, the collection of additional types of data, or the use of alternative laboratory analytical tests?

Unforeseen events and conditions are common, so it is important to allow flexibility in fieldwork. Unexpected field conditions such as very hard soils or unexpected rocks, pavement or debris below sample point locations could necessitate the use of heavier equipment or an alternative sampling strategy (see Section 5). Interim findings may indicate a (contingent) need for additional analyses; these should be part of the SAP in case they are needed.

Staff tasked with carrying out the field investigation should have a basic understanding of the Environmental Hazard Evaluation process (Step 8; refer also to Section 13). This helps ensure that DUs appropriate for the targeted COPC are designated and ensure that the appropriate amount and type of sample data are collected during the investigation. Major variations from a HDOH approved SAP should be discussed with the HEER Office project manager prior to implementation.

Step 7—Assess Data Quality

Data Quality Assessment starts with the sampling design (Step 3) and is also closely linked with the follow-up site investigation planning steps (Steps 4 through 6). The key focus of the sampling design is to control heterogeneity. The sampling design must be representative (e.g., Multi Increment sampling for soil) and in most cases will include field replicates in order to determine if the data are adequately representative, as well as determine sample variance from the mean. Good professional judgment is essential when selecting decision units for the site investigation. After the environmental data are collected, the data must be validated in accordance with the Quality Assurance Project Plan (QAPP; see Subsection 3.7) to determine quality (e.g., precision, reliability, etc.) and for comparison to relevant EALs. This assessment will determine if the data are sufficient to answer DQOs and address decision statements (Step 5) with the desired level of confidence.

Issues to consider in data validation and data quality assessment include:

- Did we follow the SAP? Were there any mistakes?
- Was the lab able to complete all analyses?
- How will samples outside lab acceptance criteria be further evaluated or handled?
- If samples were split and analyzed by multiple labs, how do the results compare?
- Did the laboratory re-analyze or provide appropriate interpretation data for samples that did not meet the sub-sampling or analysis QC criteria?

- Do the data come from the right decision unit?
- Are the sample data acceptable based on the field and laboratory QC data and acceptance criteria?
- Is there sample bias due to bad sample handling, transport, preparation, etc.?
- Are field replicate data used to assess precision appropriate for the subject data set?
- Are lab replicate and other lab QC measures used to assess the precision and accuracy of laboratory samples appropriate for the subject data set?

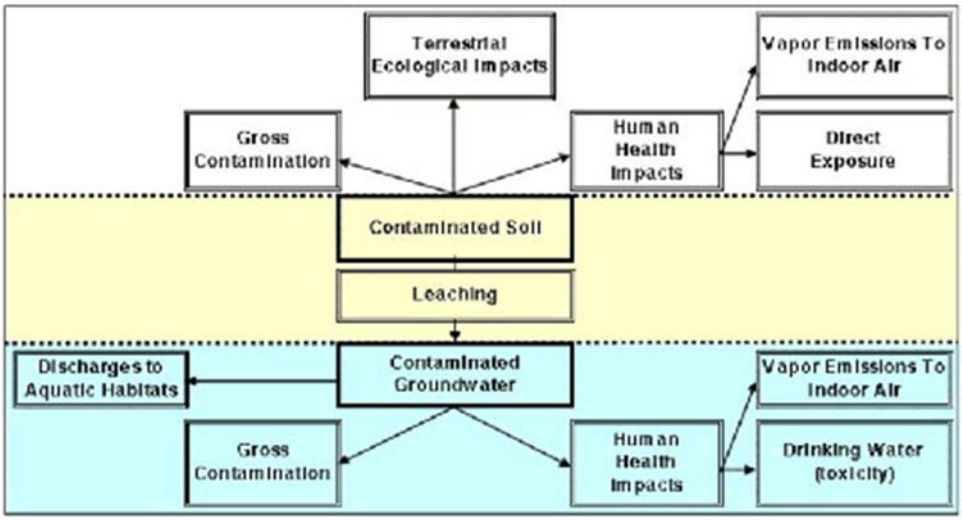


Figure 3-5. Summary of Environmental Hazards Considered in a Typical Environmental Hazard Evaluation

Additional detail on data validation and data quality assessment is provided in Subsections 3.7 and 3.8.

Step 8—Screen for Potential Environmental Hazards

Once the data assessment is complete, data judged appropriate for decision-making are compared to HDOH EALs to screen for potential environmental hazards or evaluated in a site-specific, Environmental Hazard Evaluation (see Section 13). The latter could include a site-specific, human health risk assessment although other potential environmental concerns must also be evaluated.

A summary of common environmental hazards posed by contaminated soil and groundwater is provided in Figure 3-5. Site investigations and Environmental Hazard Evaluations are iterative processes. Identifying potential hazards early on during site investigation activities, even at a cursory level, will help design and guide the progression of fieldwork and reduce the need for remobilization for additional sampling.

The default Conceptual Site Model used to develop the HDOH Tier 1 EALs assumes that each of these hazards could exist at a site given high enough contaminant concentrations and the absence of engineered or institutional controls. An evaluation of each of these potential environmental hazards must be considered in more site-specific Conceptual Site Models. Additional hazards may need to be considered on a site-by-site basis (e.g., uptake of contaminants in produce, etc.).

Issues to consider when screening for potential environmental hazards include:

- Do reported concentrations of target COPCS exceed Tier 1 EALs and indicate the presence of potential environmental hazards?
- Are additional data needed to fully define the horizontal and vertical extent of contamination exceeding Tier 1 EALs?
- What are the specific, potential environmental hazards posed by contaminants that exceed the Tier 1 EALs?

- Is additional testing of the samples needed to better evaluate potential environmental hazards (e.g., bioaccessible arsenic data or SPLP batch test data)?
- Are alternative laboratory analyses needed to better evaluate potential environmental hazards?

Issues to consider when interpreting the data and evaluating hazards include:

- Do current field conditions indicate an existing environmental hazard (e.g., exposed vs. capped areas of contaminated soil)?
- Could the removal of existing controls (e.g., pavement, buildings, site use, etc.) lead to actual environmental hazards?
- Is the collection of additional site data needed?

A basic understanding of the Environmental Hazard Evaluation by those tasked with carrying out the field investigation is critical to the accomplishment of the site investigation objectives. Field staff must ensure that the appropriate amount and type of sample data are collected during the investigation to allow completion of the Environmental Hazard Evaluation and formulate appropriate response actions. Current and anticipated (future) site conditions must be clearly documented and considered.

An overview of the Environmental Hazard Evaluation process and the use of Tier 1 EALs to screen site data for potential hazards is provided in Subsection 3.10 and Section 13. Use of the HDOH EAL Surfer to screen site data is strongly recommended.

Note that HDOH EALs are *not* intended for direct comparison to individual, discrete sample data. The EALs are intended for comparison to the *mean* concentration of a COPC in the target media (e.g., soil, air or water) over a specified area and volume of that media. The latter, referred to as the decision unit, is tied in part to the specific environmental hazard under investigation (Subsection 3.4; e.g., soil direct exposure area for evaluation of risk to human health).

Step 9—Refine the CSM and Provide Recommendations for Additional Actions

The CSM should be continually updated as site conditions and potential environmental hazards are better understood (refer to Subsection 3.3). The refined CSM should be used to identify data gaps and determine the scope of work needed to complete the site investigation.

Issues to consider when refining the CSM include:

- Do site conditions or sample data indicate the presence of previously unanticipated environmental hazards, or the absence of previously suspected hazards?
- Do reported concentrations of COPCs in soil present potential exposure hazards and warrant further analyses of the soil samples (e.g., direct exposure hazards for total arsenic and follow-up bioaccessible arsenic analysis; see Subsection 9.1.3.2)?
- Do reported concentrations of COPCs in soil present potential leaching hazards, indicating a need for soil leaching tests to evaluate contaminant mobility (HDOH, 2007, 2016) and/or the collection of groundwater data (Section 6)?
- Do reported concentrations of COPCs in soil or groundwater data present potential vapor intrusion concerns, indicating the need for soil gas or indoor air sampling data (Section 7)?
- Do reported levels of volatile COPCs in soil gas present potential explosive subsurface conditions, indicating the need for an expansion of the health and safety plan to address subsurface drilling or excavation activities?
- Do high levels of contaminants in groundwater indicate potential impacts to nearby aquatic habitats, suggesting the need to collect additional groundwater, sediment or surface water data?
- Do high levels of COPCs in soil and groundwater pose a threat to offsite migration which could lead to contamination of adjacent properties?

The revised CSM is used to make recommendations for additional actions necessary to complete the site investigation and direct appropriate response actions.

Additional site investigation may be necessary to fill identified data gaps, provide enhanced evaluation of specific environmental hazards, and develop clean-up or long-term management options, etc. Subsection 3.3 provides additional information about using CSMs to update and prepare site investigation plans.

Potential issues when considering additional site investigation actions include:

- Are the existing data adequate to address the objectives of the site investigation, as well as to prepare the Environmental Hazard Evaluation?
- Are additional data necessary for preparation of removal or remedial alternatives, or potential engineering or administrative controls?
- Do site conditions warrant emergency response actions to address conditions that pose an immediate endangerment to human or ecological receptors?

As discussed in the previous steps, site investigation is a dynamic and iterative process. Persons carrying out the site investigation should continually consult with those tasked with evaluating potential environmental hazards and those involved in developing response action plans. This will help to ensure that the additional data collected are adequate to fulfill the needs of subsequent stages of the project. Keeping these lines of communication open facilitates quick workplan changes when unexpected site conditions are discovered, reducing the need to remobilize field staff in the future and expediting completion of the project.

3.3 CONCEPTUAL SITE MODELS

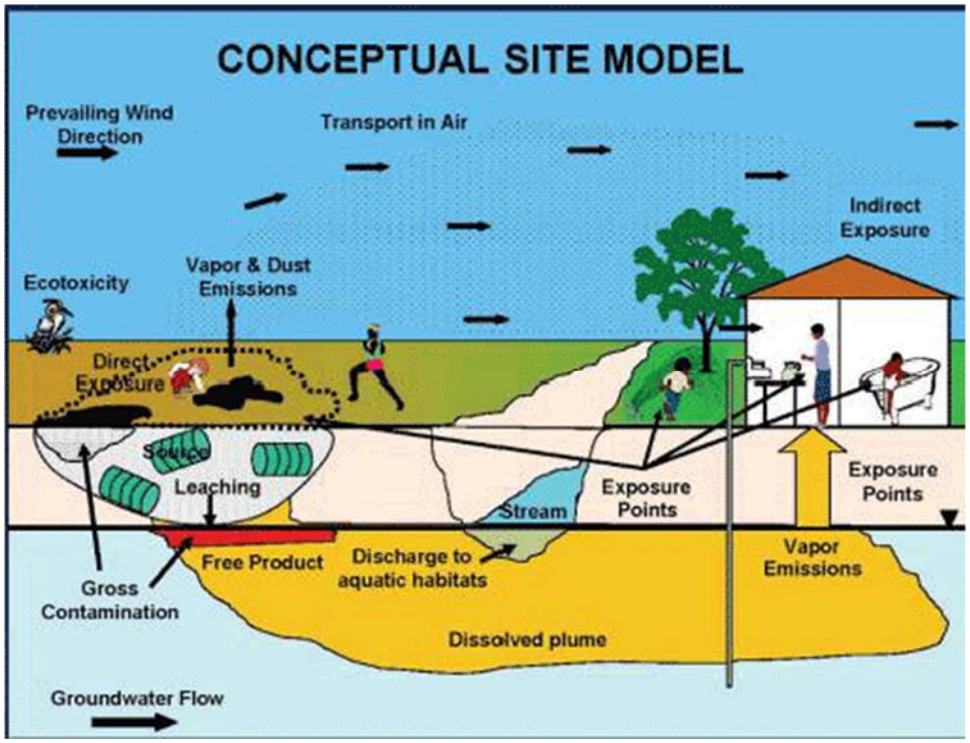


Figure 3-6. Pictorial Conceptual Site Model

Depiction of common environmental hazards associated with contaminated soil and groundwater as well as potential exposure pathways for human and ecological receptors.

The CSM prepared during the first step of the systematic planning is a comprehensive representation of site environmental conditions with respect to recognized or potential environmental hazards. CSMs are also a necessary starting point for preparation of an Environmental Hazard Evaluation. The CSM is presented in a series of figures that depict current and future site conditions in three dimensions, with textual explanations of the figures, as needed. There are a number of ways to present a CSM. Figure 3-6 is a pictorial depiction of environmental hazards associated with contaminated soil and groundwater (see also Figure 3-5). Exposure pathways to human and ecological receptors are also indicated (e.g., incidental ingestion, dermal absorption, and inhalation). These types of depictions are useful for those not well versed in Environmental Hazard Evaluation or human health and ecological risk assessment. Additional examples of CSMs are presented in Section 13.

3.3.1 SUMMARIZE KNOWN SITE CONDITIONS

The first step in the preparation of a CSM is to summarize current site conditions. At the most basic level, this includes a summary of the known or suspected extent and magnitude of soil and groundwater contamination. In addition, site conditions such as land use, groundwater use, potential onsite and offsite receptors, exposure or isolation of contaminated soil, etc., are identified, as are specific environmental hazards that may be posed by the identified contamination. The CSM is continually updated as the site investigation proceeds and site conditions are better understood.

3.3.2 SCREEN FOR POTENTIAL ENVIRONMENTAL HAZARDS

A basic understanding of potential environmental hazards in terms of the environmental fate and transport of COPCs targeted for a site is important for development of a CSM and subsequent stages of an investigation. As discussed in Subsection 3.4, the designation of DUs is intricately tied to the type of environmental hazard(s) posed by the COPC. Common environmental hazards associated with contaminated soil and groundwater (Figures 3-5 and 3-6) include:

Contaminated Soil:

- Direct/indirect exposure to impacted soil (ingestion, dermal absorption, inhalation of vapors and dust in outdoor air);
- Emission of subsurface vapors to building interiors;
- Leaching and contamination of groundwater resources;
- Impacts to terrestrial habitats (terrestrial ecotoxicity);
- Gross contamination conditions (explosive subsurface vapor conditions, odors, general resource degradation, etc.);

Contaminated Groundwater:

- Contamination of drinking water resources (toxicity, taste and odors);
- Emission of subsurface vapors to building interiors;
- Discharges of contaminated groundwater to surface water aquatic habitats (aquatic ecotoxicity or gross contamination conditions);
- Gross contamination conditions (generation of explosive vapors from free product, odors, sheens, general resource degradation, etc.).

Additional environmental hazards also may require evaluation on a site-by-site basis (e.g., uptake of contaminants in produce, runoff of contaminated soil into surface water bodies, etc.). A more detailed discussion of these and other potential environmental hazards is provided later in this Section and in Section 13 (Environmental Hazard Evaluation), as well as the HEER Office document *Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater* (HDOH 2016).

These environmental hazards form the basis of the default CSM used to develop the HDOH Tier 1 EALs. The applicability of each hazard for a given COPC should be reviewed on a site-by-site basis, depending on the nature of the contaminant (e.g., volatile vs. nonvolatile) and site characteristics (e.g., presence or absence of significant ecological habitat). For example, potential environmental hazards flagged based on a comparison of site data to HDOH EALs may in fact not be present under current site conditions but could pose a threat under future conditions (e.g., potential vapor intrusion hazards identified but no buildings currently on site; refer to Section 13 and HDOH 2016)

3.3.3 DEFAULT CONCEPTUAL SITE MODELS

Located within 150m of surface water body or sensitive aquatic habitat?	Groundwater is a current or potential drinking water resource	Groundwater is NOT a current or potential drinking water resource
Yes	Default CSM A	Default CSM C
No	Default CSM B	Default CSM D

Figure 3-7. Four Default Conceptual Site Models Provided in the HDOH Tier 1 EALs

The HDOH Tier 1 EALs are based on an assumption that the environmental hazards noted above (as applicable to the specific contaminant) could exist at a site given adequately high contaminant concentrations within targeted DU areas and the absence of engineered or institutional controls (see Section 13). Four default CSMs or site scenarios are provided for in the Tier 1 EALs,

depending on groundwater utility and location of a subject site with respect to nearby surface water bodies and aquatic habitats (Figure 3-7; HDOH 2016):

The default site scenarios reflect the basic CSMs used to develop and compile the Tier 1 EALs and serve as the starting point for preparation of an Environmental Hazard Evaluation (see Section 13). Only surface water bodies that are hydraulically connected to groundwater are considered to be potentially threatened by contaminated groundwater. This could include streams, drainage ways, or even leaky storm sewers that lead to a surface water body. Given their direct and potential rapid link to aquatic habitats, storm sewers in direct hydraulic connection with contaminated groundwater are considered to represent a "surface water body" for initial screening purposes. Measuring the piping invert in relation to the groundwater table at high-high tides and the presence or absence of free product at the discharge point of a storm drain can help determine if it serves as a pathway to a surface water body.

Data for a site are screened against Tier 1 EALs for the default CSMs most appropriate to the subject site. Preparation of a more site-specific CSM is not required, but may be useful or even necessary for sites with extensive contamination and/or significant public interest. One of the four default CSMs should, however, serve as the starting point for more site-specific CSMs. The default CSMs can also be depicted in a more classical "risk assessment" format, as presented for the default CSM in Figure 3-8.

Figure 3-8. Default Conceptual Site Model Default Conceptual Site Model used to develop Tier 1 EALs for sites that overlie a source of drinking water and are within 150m of a surface water body; assumes impacted soil exposed at surface.

Primary Sources	Primary Release Mechanism	Secondary Sources	[1]Potential Environmental Hazards		[2]Hazard Present Under Current or Future Site Conditions?	Comments
					Current	
					Future	
ASTs, USTs, pipelines, drums, disposal areas, etc.	Spills, leaks, improper disposal	Soil	[3]Risk to Human Health	Direct Exposure	YES	
					YES	
				Vapor Intrusion into Buildings	YES	
					YES	
			[4]Risk to Terrestrial Ecological Habitats		YES	
					YES	
			[5]Leaching		YES	
					YES	
			[6]Gross Contamination		YES	
					YES	
		Groundwater	[7]Risk to Human Health	Direct Exposure	YES	
					YES	
				Vapor Intrusion into Buildings	YES	
					YES	
			[8]Risk to Aquatic Ecological Habitats		YES	
					YES	
			[9]Gross Contamination		YES	
					YES	

Notes (Figure 3-8):

1. Refer to Section 13 for discussion of specific environmental hazards. Tier 1, default conceptual site model can be modified on a site-by-site basis as needed.
2. All noted hazards assumed present or potentially present under current or future site conditions. Exposure pathways assumed complete for toxicity-related hazards.
3. Human health hazards include direct exposure to contaminated soil or vapors & dust from soil as well as the intrusion of vapors into overlying buildings.
4. Assumes a significant terrestrial, ecological habitat is impacted by the contamination with resulting toxicity to flora and fauna.
5. Assumes potential leaching of contaminants from soil and impacts to underlying groundwater.
6. Gross contamination hazards for soil include potential explosive hazards, odors, interference with construction work (e.g., soil reuse and disposal) and related concerns.
7. Human health hazards based on ingestion of contaminated groundwater as well as exposure via dermal absorption and vapors during showering and other water use.
8. Assumes discharge of contaminated groundwater into an aquatic habitat. Contaminants in groundwater screened using chronic, aquatic toxicity action levels for sites <150m from a surface water body (acute toxicity action levels applied if >150m from surface water body).
9. Gross contamination hazards for groundwater include potential taste & odors concerns for drinking water, presence of free product, explosive hazards, odors, sheens, interference with construction work (e.g., dewatering) and other related concerns.

3.3.4 ADVANCED CONCEPTUAL SITE MODELS

The default CSMs used to develop the HDOH Tier 1 EALs are intentionally designed to be very conservative. The appropriate default CSM should be used to initially screen sites and, where appropriate, clear the site for unrestricted land use with minimal additional effort.

Site-specific CSMs can be prepared by modifying the default CSMs to more closely evaluate potential environmental hazards under current and anticipated future site conditions, as needed. A more detailed CSM is generally warranted at sites where cleanup costs could be significant, or at sites where long-term management of contaminated soil or groundwater will be required. A closer evaluation of current and future risks to human or ecological receptors will be particularly important. These types of CSMs will typically identify sources of contaminant releases, types of contaminated media, migration pathways, exposure pathways, and human and/or ecological receptors.

Figure 3-9. Expanded Conceptual Site Model

Primary Sources	**Primary Release Mechanism**	**Secondary Sources**	**[1]PotentialEnvironmental Hazards**	**[2]Hazard Present Under Current or Future Site Conditions?**					
							Receptors		
				Exposure Type	Secondary Release Mechanism	Exposure Route	On-Site Workers	Offsite Residents	Construction Workers
							Current Future	Current Future	Current Future
UST	Spills, leaks, improper disposal	Soil	[3]Risk to Human Health	Direct Exposure	none	Ingestion	*No *No	*No *No	Yes Yes
						Dermal	*No *No	*No *No	Yes Yes
					Dust/ Vapors	Inhalation	*No *No	*No *No	Yes Yes
				[4]Vapor Intrusion into Buildings	Vapors	Inhalation	Yes Yes	No No	na
			[5]Risk to Terrestrial Ecological Habitats	Current -No (no habitat or receptors) Future – No (no habitat or receptors)					
			[6]Leaching	Current -Yes (soil in contact with groundwater) Future - Yes					
			[7]Gross Contamination	Current - Yes (potential explosive vapors) Future – Yes (potential explosive vapors)					
			[8]Risk to Human Health				Receptors		

				Exposure Type	Secondary Release Mechanism	Exposure Route	On-Site Workers	Offsite Residents	Construction Workers
							Current Future	Current Future	Current Future
		Ground-water		Direct Exposure	none	Ingestion	No No	No No	Yes Yes
						Dermal	No No	No No	Yes Yes
						Inhalation	No No	No No	Yes Yes
				[4]Vapor Intrusion into Buildings	Vapors	Inhalation;	Yes Yes	No No	na
			[9]Risk to Aquatic Ecological Habitats	Current - *No (monitoring shows plume not migrating) Future - *No (monitoring shows plume not migrating)					
			[10]Gross Contamination	Current - Yes (free product present) Future – Yes (while free product present)					

Notes (Figure 3-9):

1. Summary of default environmental hazards to be initially evaluated at all contaminated sites.
2. Hazard evaluation results based on assumption that contaminated soil is capped with pavement and contaminated groundwater is not migrating (naturally or via storm sewers, dewatering, etc.). *Long-term management of contamination must be addressed in an *Environmental Hazard Management Plan* in the absence of cleanup.
3. Exposure pathways for daily workers not complete *provided site remains paved. Potential exposure of construction workers during future subsurface activities.
4. Recommend collection of soil gas data to further evaluate potential explosive hazards and vapor intrusion hazards.
5. No significant terrestrial, ecological habitat located on site or threatened by contamination.
6. Assumes contaminated soil is in direct contact with groundwater. Used to support collection of groundwater data for further evaluation.
7. Recommend remediation of gross contamination at a minimum to reduce vapor concerns.
8. Assumes groundwater is not used as a water supply and monitoring indicates that plume is not likely to migrate offsite under natural conditions.
9. Threat to aquatic habitats assumed insignificant *provided plume is not allowed to migrate offsite. Contaminants screened using acute, aquatic toxicity action levels.
10. Recommend removal of free product to extent practicable to reduce vapor concerns and continued source of contaminants to groundwater.

Figure 3-9 presents a more site-specific CSM for a hypothetical commercial/industrial site contaminated with petroleum. The CSM includes the following site assumptions:

- Contamination is restricted to the site boundaries;
- Area of contaminated soil is paved;
- Underlying groundwater is not a current or potential source of drinking water;
- Site is located more than 150m from the nearest surface water body.

A "Yes" in a cell under "Receptors" indicates that the noted exposure route is complete or potentially complete. This is important information for development of short-term or long-term response actions to address human health or ecological risk concerns.

The example CSM documents that the ingestion, dermal absorption and inhalation pathways for direct exposure to the contaminated soil are incomplete for daily on-site workers. Although the inhalation pathway could in theory still be complete, the presence of the pavement can reasonably be assumed to make this pathway insignificant. For construction workers, however, all of the direct-exposure pathways are considered complete because their work may involve removing pavement and disturbing contaminated soil.

The example CSM also indicates that the pathway for leaching of contaminants from soil and contamination of groundwater is complete, because contaminated soil is in direct contact with groundwater, even though the area is assumed to be capped with pavement. This is used to support the collection of groundwater data to more directly evaluate impacts and potential concerns. Removal of pavement could also exacerbate leaching and groundwater contamination due to infiltrating rain or irrigation water. This could require the maintenance of an impermeable cap over the contaminated soil under a long-term management plan prepared for the site (discussed below).

It is important to note that environmental response actions must identify and address all environmental hazards posed by a release, based on both current use and reasonably expected future use scenarios. In many cases, based on the current use of the site and the presence of existing engineered controls, an Environmental Hazard Evaluation might conclude that no current hazards exist (e.g., sites currently used for commercial purposes, with contaminated soil covered by existing buildings and pavements and no vapor intrusion concerns). Contaminant concentrations at the site could, however, indicate a potential hazard under land use scenarios that could lead to completed exposure pathways (e.g., redevelopment for residential use with open areas of exposed soil).

The more detailed CSM may be used to support a conclusion that contaminated soil and groundwater does not pose unacceptable environmental hazards under current site conditions. Depending on site conditions and planned uses, active remediation to eliminate future environmental hazards under any potential land use condition could be recommended or required. If active remediation is not practicable due to site conditions and/or financial constraints, the assumptions used in the CSM to support an absence of potential hazard under current site conditions can be used to develop an Environmental Hazard Management Plan (EHMP; Section 18; see also HDOH 2016). In the example, the EHMP would require that the area of contaminated soil remain capped, that a health and safety plan and soil and groundwater management measures be developed prior to any subsurface construction activities at the site, and that the need for long-term monitoring of groundwater be further evaluated. Actions related to restricted-use site closure, and the preparation of Environmental Hazard Management Plans, are discussed in more detail in Section 19.

A basic understanding of contaminant migration pathways and exposure pathways is necessary to formulate a CSM and guide site investigation and response actions, including preparation of an EHMP. Preparing and submitting a formal, detailed CSM, however, is generally only required at sites where significant contamination exists and cleanup and/or Environmental Hazard Management Plan activities are anticipated to take more than a year to complete.

Additional information on the development of CSMs is available in USEPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (USEPA, 1988) and USEPA's *Data Quality Objectives Process for Hazardous Waste Site Investigations* (USEPA, 2000). Note that examples of CSMs in these guidance documents often focus on human health or ecological risk assessment concerns and may not consider other potential environmental hazards, including leaching and potential contamination of groundwater (refer to Figure 3-5; see also Section 13). As discussed in Sections 2, 3 and 13, assessments of risk to human and ecological receptors are important parts of a more comprehensive Environmental Hazard Evaluation. Site-specific human health and ecological risk assessments do not replace Environmental Hazard Evaluations, however, and it is important to ensure that all potential hazards at a site are adequately evaluated.

3.3.5 MAINTAINING AND UPDATING THE CONCEPTUAL SITE MODEL

The CSM should be maintained and updated as needed throughout the life of the site activities. As appropriate based on additional site information, refine the CSM to more accurately identify known or suspected sources of contamination, types and concentrations of contaminants detected at the site, potentially contaminated media, potential environmental hazards, potential exposure and migration pathways, potential human and environmental receptors, and related information.

Information that should be used to maintain and continuously update the CSM includes (along with other relevant information):

- Additional soil, soil vapor or groundwater data;
- Location of existing monitoring wells and past soil borings;
- Soil contamination summary figures with areas above EALs highlighted (preferably based on decision unit and Multi Increment sample data);
- Groundwater contamination summary figures with areas above EALs highlighted;
- Soil gas survey summary figures with areas above EALs highlighted;
- Direction of groundwater flow, depth to groundwater;
- Cross sections that depict the site stratigraphy as well as the lateral and vertical extent of contamination; etc.

- Identification of existing buildings, structures, infrastructure changes that might affect subsurface conditions or preferential pathways (e.g., addition of underground piping), roads, surface water bodies, neighboring property operations and land uses, geographical features, etc.;
- Review of sources, exposure pathways, and potential receptors (see example in Figure 3-8);
- Advanced evaluations of specific environmental hazards.

Significant changes to the CSM may necessitate updates to decision statements (Step 5 of systematic planning), the sampling and analysis plan (Step 6 of systematic planning) and/or the Environmental Hazard Management Plan (see Section 19).

3.4 SELECTION OF DECISION UNITS

A decision unit (DU) is an area where a decision is to be made regarding the extent and magnitude of contaminants with respect to potential environmental hazards and associated risks to human health and the environment, as described in Section 13. A DU is necessarily a volume as well as area of soil. Decision units are designated in terms of size and location in a manner that ensures the objectives of the site investigation will be accomplished.

An important goal of a site investigation is to estimate the mean concentration of a contaminant for a designated DU volume of soil. A DU can be thought of as "The entire volume of soil that you would send to a laboratory for testing if this was indeed possible." Tested as a single sample, the concentration of the contaminant reported by the laboratory would represent the true mean for the DU volume of soil as a whole. This is usually not feasible given the large volume of soil assigned to a DU. A representative sample or samples of the soil must instead be collected and tested. As discussed in Section 5 while this can in theory be accomplished using discrete samples, Multi Increment samples are far more reliable and ultimately more cost efficient.

The designation of DUs is, importantly, independent of the sampling method used to characterize the area targeted. Practitioners new to sampling theory and Multi Increment sampling methods (Subsection 4.2) are often concerned about potential “dilution” of contaminated areas “hot spots” in comparison to traditional, discrete soil sampling methods (refer to Subsection 4.3). This is addressed through the designation of well-thought-out DUs that establish the desired resolution of the investigation. Although not directly referred to, the concept of “DUs” was an inherent part of past, discrete soil sample investigations. Discrete soil sample collection points were typically designated based on a desire to characterize contamination in one area versus another. As discussed in the subsections below, the area intended to be represented by a single, discrete sample point (or cluster of sample points) is designated as a separate DU for characterization. A large-mass, Multi Increment sample is then collected from multiple (e.g., 30-75+) locations within this area rather than reliance on a small, discrete soil sample collected from a single location. The number of DUs designated for a particular investigation not coincidentally often corresponds with the number of discrete soil samples or clusters of samples that might have been collected under past approaches.

Decision units can be designated for characterization of surface soils and/or subsurface soils. Designation of DUs for surface soil is described in Subsections 3.4.2 and 3.4.3. Designation of DUs for subsurface soils is discussed in Subsection 3.4.4.

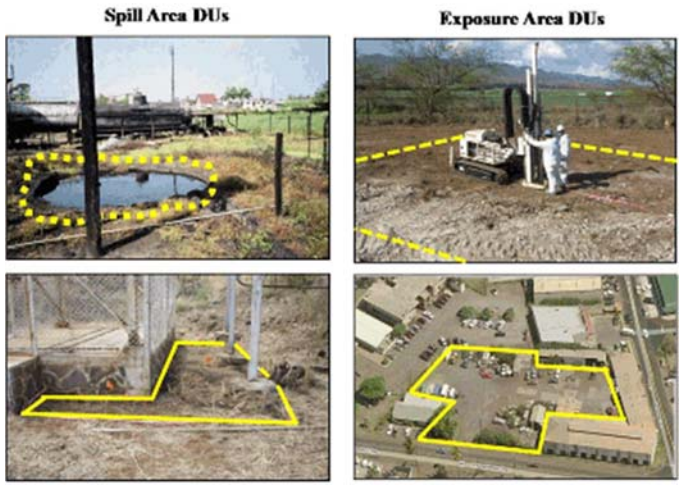


Figure 3-10. Example Spill Area and Exposure Area Decision Units

Establishing clear site investigation objectives and designating DUs to achieve these objectives early in the site investigation design helps develop an effective sampling approach to characterize a site. This ensures that adequate data are available to prepare an Environmental Hazard Evaluation (EHE, see Section 13), develop removal or remedial options, or carry out further

investigation. A discussion of DU investigation strategies in the context of EHEs is also included in the HDOH guidance document *Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater* (HDOH, 2016).

3.4.1 DECISION UNIT DESIGNATION

The designation of DUs for characterization is unique to each site and depends in part on the specific type of environmental hazard under investigation (see Step 8 in Subsection 3.2 and Section 13). Decision units generally fall into two categories (Figure 3-10): 1) Spill Areas, and 2) Exposure Areas. As the name implies, a Spill Area DU represents a specific area where releases of hazardous substances are known or suspected.

Example Spill Area DUs might include former waste storage or disposal areas, the area (and volume) of contaminated soil under and around a leaking underground tank or an area of a site where contaminated fill material is suspected to have been placed. Identification and characterization of such areas is a common objective of an environmental investigation.

An Exposure Area DU is an area where receptors, human or ecological, routinely access and could be exposed to hazardous substances. Example Exposure Area DUs might include the yard of a residence or an unpaved area of exposed soil at a commercial or industrial facility. Exposure Area DUs might include isolated (unknown) spill areas, but as described below determination of the exact location of such areas is not required for assessment of potential direct-exposure risk, provided that the sample (or samples) collected from the DU is representative of mean contaminant concentration for the DU as a whole. Large Exposure Area DUs initially anticipated to be clean might be divided up into small DUs for re-characterization if they are found to be contaminated, in order to help optimize removal or remedial actions. The need for smaller decision units for future response actions should in general be considered up front, however, in order to minimize the time and cost required to resample an area.

The appropriate type, size, shape and number of DUs for a given project is necessarily site-specific and must take into consideration the historical, current and future use of the site. A strong understanding of the historical use of a site is critical to the designation of DUs (see Subsection 3.1.1). Historical site plans, insurance maps, historical aerial photos and discussions with past or current workers are very useful for determining initial DU areas. Obvious or suspected spill areas should normally be investigated as separate DUs. This includes structural remnants of potential hazardous substance storage or disposal areas, suspect pits and trenches, stained areas and low points where runoff could have collected.

Investigation objectives and approaches can vary over time as the project proceeds and alternate DUs may need to be established to assist in response actions or long-term management of sites. For example, DUs established for site characterization purposes may need to be refined for the removal or remedial phase of the project to better isolate high-priority areas and optimize resources available for cleanup.

When contamination poses multiple, potential environmental hazards then the smallest DU area and depth (i.e., highest resolution) should be selected to characterize the area. DUs for different media (e.g. soil vs. groundwater vs. soil gas vs. indoor air) should in most cases be treated separately, even if they are investigated concurrently. DUs for different media could overlap but may have different decisions associated with them.

3.4.2 EXPOSURE AREA DECISION UNITS

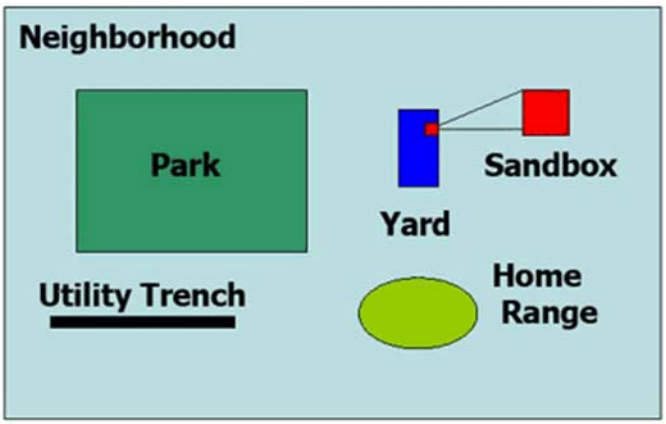


Figure 3-11. Example Exposure Area Decision Units

Figure shows areas where residents or workers may be exposed to contaminants in soil on a regular basis. For

ecological receptors, an example exposure area is the *home range*. The size & shape of exposure area decision units depends on the targeted receptor and the desired scale of the evaluation.

In the absence of a known or suspect spill area, the most appropriate Decision Unit for relatively immobile contaminants that primarily pose direct-exposure, toxicity-based hazards (e.g., lead, arsenic, dioxins, polychlorinated biphenyls [PCBs], polynuclear aromatic hydrocarbons [PAHs], etc.) is the assumed exposure area for the site receptor(s). "Exposure areas" are areas frequented by residents or workers or wildlife that may come in contact with contaminants in soil on a regular basis (see Section 13). Examples include residential yards, schoolyards, playgrounds, gardens, open areas on commercial/industrial properties, home range, etc. (refer to Figure 3-11). For exposure area DUs, the primary question is "What is the mean concentration of the target contaminant across the exposure area as a whole?" Exposure area DUs can be based on current land use (e.g., an open area of a commercial or industrial site) and/or future use of the area (e.g., proposed residential lots).

The top two to six inches of soil is generally considered for surface soil DUs, depending on the site-specific DQOs (USEPA 2011d; CalEPA 2013). The top 0-6 or 0-4 inches of soil are commonly selected for surface soil Dus in Hawaiian Islands investigations. Exposure area DUs for residential properties typically encompass the entire yard, but could also focus on play areas or other areas of the yard that are frequented most. DUs for apartment complexes should focus on open common areas. For future redevelopment projects that involve single-family homes, the size of a hypothetical residential lot is generally assumed to be 5,000 ft^2 (see Subsection 3.5).

The location and size of exposure area DUs for commercial or industrial sites is necessarily site specific. DUs should be based on the location of exposed areas of soil and use of the site by workers. As a default and especially for undeveloped properties, exposure areas should be initially limited to half an acre or approximately 20,000 ft^2. When possible, designate DUs and investigate the site in a manner that allows future, unrestricted land use (i.e., residential land use, see Section 13). This will minimize the need for restrictions on future site use or delays in redevelopment.

Recall that soil EALs are *not* intended for direct comparison to individual, discrete sample data, although this may be useful for general screening purposes (refer to Step 8 in Subsection 3.2.1). The EALs are intended for comparison to the *mean* concentration of a contaminant in soil within the designated DU. Soil action levels for direct exposure risks, for example, are intended to address long-term, "chronic" exposure to very low concentrations of contaminants in soil. Exposure is assessed in terms of random exposure to contaminants in soil throughout the DU area over a period of many years (see Section 13).

It is not necessary and indeed not practical to attempt to identify the "maximum" and "minimum" concentration of a contaminant within the DU. If a contaminant is present, then at some, minute mass of soil the concentration of the contaminant will necessarily be 100%, or 1,000,000 mg/kg. It is also highly likely that the contaminant is entirely absent in scattered, small masses of soil within the same area. Estimation of the representative, mean concentration of a contaminant for a DU requires that a representative proportion of both higher and lower contaminant concentration areas be included in the sample data. As discussed in more detail in Section 4, this is best accomplished by the collection of a Multi Increment (versus discrete) sample from the DU. Replicate field samples are routinely collected from DUs to evaluate the precision of the original sample data.

Examples of DUs based on exposure areas are included in Subsection 3.5. Decision units based on exposure areas can also be established for ecological risk assessments. Additional guidance on decision units for ecological risk assessments will be included in the TGM in the future.

3.4.3 SPILL AREA DECISION UNITS

For use in this guidance, a "spill area" is defined as a discernable area of elevated contamination in soil that can be mapped with respect to surrounding areas. Examples include areas with obviously contaminated and stained soils, unpaved areas used to store or mix hazardous chemicals, known waste disposal areas, areas immediately adjacent to transformer pads or other types of equipment that may have contained hazardous chemicals, releases from pipelines, etc.

The isolation and evaluation of individual spill areas is generally necessary to evaluate environmental hazards associated with soil leaching, vapor intrusion and gross contamination hazards (see Step 8 in Subsection 3.2 and Section 13). This applies to most releases of petroleum, solvents and highly mobile pesticides like atrazine and ametryn. In these cases, the appropriate question is "What is the mean concentration of the contaminant(s) within the volume of soil impacted by the spill"? Spill area DUs are sometimes recognizable based on surface staining but this is not always the case (e.g., PCP-related dioxins and arsenic). Typical spill area DUs are a few hundred to a few thousand feet in area and can extend to varying depths, depending on the nature of the contaminant released (see Subsection 3.5). For stockpiles, a default DU volume of twenty cubic yards is recommended for testing of soil stockpiles impacted by contaminants that could pose potential leaching concerns (HDOH 2011b).

If the target contaminant at the site poses leaching, vapor intrusion and gross contamination hazards, then the spill area should be designated as a separate DU for characterization. For example, a spill area associated with a petroleum release around an aboveground storage tank should be identified as a separate DU and appropriately investigated. This is because petroleum contamination can pose multiple environmental hazards, including leaching of contamination to subsurface groundwater resources, intrusion of vapors into overlying buildings and nuisance or even explosion hazards associated with grossly contaminated soil. It is inappropriate to incorporate data outside of the spill area in the evaluation of these types of hazards.

It may also become useful to identify and isolate small spill areas within a larger exposure area DU if the mean concentration of the target contaminant exceeds action levels and remediation is required. For example, isolating and remediating spill areas at a site heavily contaminated with arsenic can help optimize remedial actions to reduce average exposure concentrations (see Subsection 4.2.9 and 4.3.3). The cost-benefit of subdividing an initially larger DU into smaller DUs for additional, more detailed characterization is necessarily site-specific. The need for smaller DUs and a better resolution of contaminant distribution should ideally be taken into account as part of the initial designation of DUs at the site. Careful planning ahead of time will allow decisions to be made based on the original set of data collected and avoid the added time and expense of additional investigation.

Isolation and remediation of spill areas within an exposure area DU may also be necessary to prevent localized but heavily contaminated soil from being spread out across a larger area during future construction activities. For example, PCB-contaminated soil in the immediate vicinity of a transformer pad may not in itself pose direct exposure hazards to workers or even future residents given the assumed exposure area. However, under a future redevelopment scenario, the soil could be excavated and spread out over a much larger area. This could result in a dramatic increase in the average concentration of a contaminant across the DU(s). Decision units for these types of spill areas as well as other examples are described in Subsection 3.5.

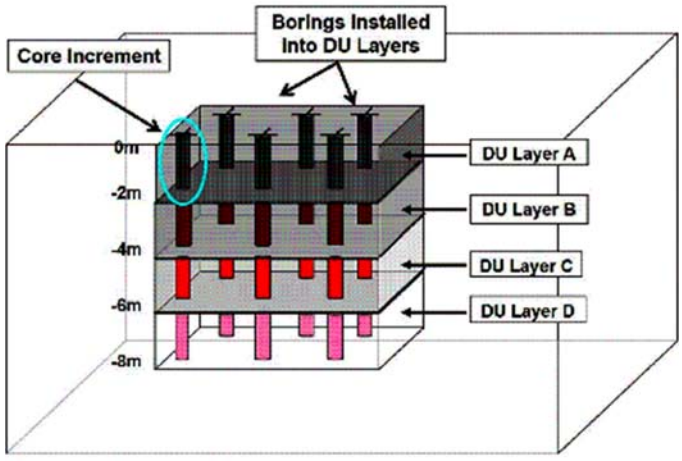


Figure 3-12. Designation of DU Layers for Characterization as Part of a Subsurface Investigation

3.4.4 SUBSURFACE DECISION UNITS

A similar approach should be followed for designation of subsurface DUs (e.g., review of site history and initial field observations). An investigation of the vertical extent of contamination is typically required for releases of liquids or other chemicals that could migrate downwards and contaminate deeper soil or groundwater. A subsurface investigation may also be required to further delineate contamination documented at the surface, determine the depth of buried contamination, or the extent of contaminated fill material.

A small number (e.g., <30) of *Exploratory Borings* are usually advantageous during the initial stages of an investigation, similar to initial field inspections of surface soils to identify potential spill areas. The resulting information can be used to identify obviously contaminated intervals (e.g., visual observation of petroleum contamination, ash layers, elevated PID readings, etc.) and assist in designation of subsurface, DU Layers for more detailed characterization.

Designated depth intervals should be targeted for characterization, (Figure 3-12). A subsurface investigation of suspected deeper contamination might, for example, include DU layers designated from 0.5'-1.0', 1.0'-2.0'; 2.0-5.0' and 5.0-10' below ground surface. This is necessarily site specific and dependent on the contaminants and objectives of the investigation. Subsurface DU Layers might, for example, be designated in a manner that allows optimal resolution of contaminant distribution

and mass for *in situ* remedial actions. Subsurface DU layers might also be designated in a manner that allows for optimization of *ex situ* removal or remedial actions, including segregation of contaminated soil that may require expensive treatment or disposal from otherwise clean areas of soil. Refer to the examples provided later in this Section.

Subsurface DU layers are ideally characterized to the same level of detail as carried out for exposed, surface soil DU, with 30-50+ increments collected and combined to form a bulk, MI sample. This will require the installation of borings through the overlying soil to access the targeted layer below and/or the collection of samples from pits or trenches (see Section 5).

As discussed in Section 4, characterization of subsurface DU Layers using Multi Increment sampling approaches is recommended. The collection of discrete samples from targeted depth points in a core (e.g., every five feet) is unreliable for characterization of subsurface soils. This is due to potential, small-scale, random variability of contaminant concentrations in soil at the scale of a discrete sample and/or the subsample mass tested by the laboratory (see also Schumacher and Minnich, 2000, Feenstra, 2003, HDOH, 2014). In Figure 3-12, the section of the core extracted from a DU layer represents an "increment" under a Multi Increment sampling approach (refer to Section 4). Core increments extracted from targeted DU layers are normally subsampled and combined in the field to prepare bulk MI samples in order to reduce the total mass of soil submitted to the laboratory for processing and analysis.

The thickness of subsurface DUs could vary between boring locations. For example, it may be desirable to determine the mean concentration of lead in an irregular, subsurface layer of fill material or debris across a site. In one area the layer might be a few inches thick, while in other areas the layer might be several feet thick. The mass of soil collected from increments extracted from the layer should be weighted in order to collect a representative sample. This can be done by collecting a fixed mass of soil from a fixed spacing of soil plugs extracted from the core (e.g., five-gram subsamples collected every two inches).

For samples to be analyzed for VOCs, collect regularly spaced (for example every two to six inches) 5 gram plugs from the targeted core interval or DU layer and place them in a sampling container with methanol while in the field. If this option is not feasible (e.g., due to methanol shipping constraints), individual subsample plugs can be collected in small gas-tight coring devices (e.g. Core-N'-One® or Encore®-type containers) and immediately frozen for shipment to the laboratory (see Section 11). The laboratory should be instructed to combine the increments in methanol prior to extraction and analysis.

In some cases it may be desirable or otherwise necessary to use an individual borehole as a DU for decision making. The borehole itself can be a "DU" if this is the scale at which a decision will be made. For example, single boreholes might be used to determine the depth to the bottom of contaminated fill at specific locations within a site in order to assist in remedial plans (Figure 3-13). In other cases, obstructions and other site factors may limit the number of borings that can be installed at a site to estimate the lateral extent of contamination. Investigations of active gas stations with suspected, leaking underground storage tanks (USTs) or small USTs associated with boilers or generators are a common example (Figure 3-13). The installation of a number of borings adequate to collect proper MI samples at such sites (e.g., 30+) is often impractical. The objective of the investigation might instead be to simply determine the presence or absence of contamination at depth at a specific location within the facility. Limited sampling objectives such as these could be carried out with a smaller number of borings, especially for contaminants such as petroleum that are easily identifiable in the field.



Figure 3-13. Example Gas Station and Former Boiler UST Sites Where Single Borehole DUs Might be Used.

These example sites show where single borehole DUs might be used for investigating the lateral and/or vertical extent of contamination. The hypothetical borehole locations are noted by red circles. This is adequate to determine presence or absence of the contaminant(s) only.

Data from a single or otherwise small number of borings will not be adequate to estimate the mean concentration of the contaminant in the area of the boring, but limited objectives for an investigation may be achieved. Narrow fingering of contamination into otherwise clean areas of soil could, however, cause the full extent of contamination to be underestimated. This approach is not reliable for contaminants and/or targeted contaminant layers that are not easily recognizable in the field.

The use of Laser Induced Fluorescence or Membrane Interface Probe methods for near-continuous readings of subsurface conditions can assist in providing higher quality data (refer to Section 8).

The collection of traditional discrete samples from targeted depths within borings is strongly discouraged, again due to the potential for significant, small-scale variability and resulting "false negatives" and unreliability of data interpolation between sample points. Designation and testing of targeted, DU Layers are especially important if decisions are to be made on data from a single boring. This might include the interval observed or suspected to have the highest probability of being contaminated (e.g., staining, odors, field XRF, debris, etc.). Intervals below and above this zone would be designated as separate, "perimeter" DU Layers to verify anticipated clean soil (see following Section).

For example, Figure 3-14 depicts boring locations and DU Layers for a hypothetical gas station with both lead-contaminated fill material and a leaking underground storage tank. The fill material is marked by pieces of wire, melted glass, burned wood and a distinct lead signature using a field XRF. Soil contaminated by the leaking tank is marked by a distinct, gasoline odor, staining and elevated PID readings.

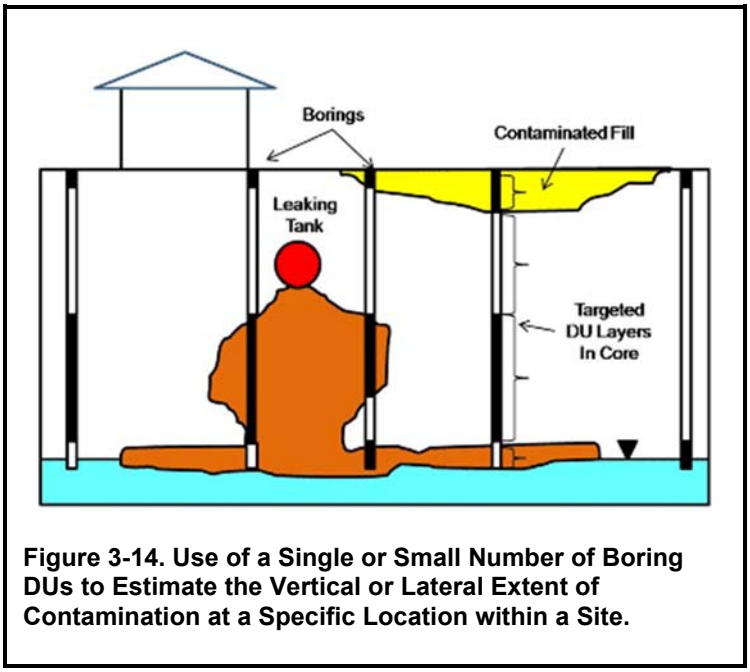


Figure 3-14. Use of a Single or Small Number of Boring DUs to Estimate the Vertical or Lateral Extent of Contamination at a Specific Location within a Site.

This method can be used with the entire targeted core interval or a representative subsample of the interval submitted to lab for processing and testing. Submitting the entire DU layer to the laboratory for processing and analysis is preferable, since this eliminates potential field error (see also Subsection 3.5.6). This is referred to as "direct inference" (AAFCO, 2015),

Borings are installed to estimate the lateral and vertical extent of contaminated soil associated with the two scenarios. Where encountered in a boring, intervals of fill material and/or gasoline-contaminated soil are designated as separate DU layers for characterization. The core in between these intervals is designated as a "perimeter" (or "confirmation") DU layer and likewise targeted for characterization. Similar DU layers are designated outside of the apparent margins of contamination in order to confirm that the same interval of soil is now clean. For example, this might include testing of the upper two feet in borings to verify the absence of contaminated fill material, the interval of vadose-zone soils previously identified to be contaminated by the tank release and soil at capillary fringe zone at the water table. Including a core interval across the capillary fringe is especially useful, since this has the highest chance of catching the presence of contamination that has reached the water table (see Figure 3-14).

Such core intervals might be considered "discrete" samples in that they are to be independently processed and tested. Reference to the samples as "core intervals" is preferable, however. This will help to avoid confusion with traditional and less reliable "discrete" samples collected from a single depth point within a core.

The installation of a large enough number of borings to estimate the mean concentration of termiticides in soil under an existing building slab likewise may not be practical (e.g., Technical Chlordane or aldrin-dieldrin). In such cases the HEER Office recommends that soil be collected and combined from a minimum of three borings through the slab. The resulting bulk sample should be processed in the same manner as done for a traditional, MI sample and the presence or absence of termiticides noted. The reported concentration of termiticides in the soil should not be relied upon for final decision making purposes.

As discussed in Sections 4 and 5, if the volume of soil in a boring for a targeted interval is small enough (e.g.1-3kgs), then the entire interval should again be submitted to the laboratory for processing and testing in the same manner as carried out for MI samples. If soil is to be tested for volatile organic chemicals (e.g., TPHg and BTEX) then subsampling of the targeted interval in the field and placement in methanol or gas-tight individual containers will be required (see Section 5). Note that plugs of soil removed from the core are not "increments" in the sense of MI samples. They are instead subsamples of core increments. The spacing and number of plugs necessary to collect a representative subsample of the core increment will vary based on anticipated, small-scale heterogeneity of the target contaminant in the core as well as the total, desired mass of soil to be collected from the targeted DU layer as a whole. This is discussed in more detail in Section 5.

The use of limited borings to estimate the lateral and vertical extent of subsurface contamination can be very useful and cost-effective for design of initial remedial actions. A more detailed characterization will normally be required for final decision making purposes (unless preliminary data will already be used to assume a potential environmental hazard exists) or to confirm the effectiveness of cleanup actions.

3.4.5 PERIMETER DECISION UNITS

"Perimeter DUs" are established immediately outside an area of suspected heavy contamination in order to confirm the lateral extent of contamination. Perimeter DUs can also be used to delineate the extent of contamination adjacent to any exposure area DU that has been found to exceed the applicable HDOH EALs. Soil contamination is typically delineated out to levels that fall below HDOH EALs, even if this involves crossing property borders (assuming property access is granted by the neighboring property owner). The number and design of perimeter DUs is necessarily site-specific and based in part on the confidence that the DUs will be placed in areas that are unlikely to be contaminated. For example, avoid letting a small area of contamination cause a much larger perimeter DU to fail action levels and require additional investigation.

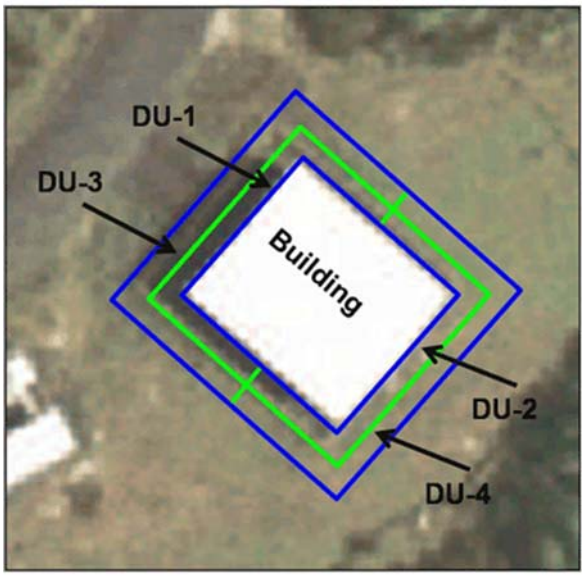


Figure 3-15. Primary (DU-1 and DU-2) and Perimeter DUs (DU-3 and DU-4) Designated Around a Building with Suspected Lead and Termiticide Contamination

Perimeter DUs should also be designated and used to collect confirmation samples adjacent to and below areas of excavated soil (Figure 3-16; after ITRC, 2012).

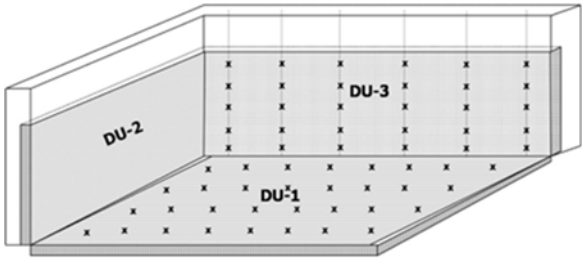


Figure 3-16. Perimeter DUs Designated Around a Planned Soil Excavation Area

Samples to confirm clean boundaries ideally collected prior to soil removal to avoid need for remobilization (after ITRC, 2012)

In Figure 3-15, DU-1 and DU-2 represent hypothetical spill area DUs designated around the perimeter of a building to test for the presence of lead and termiticides in soil. These DUs are bordered by the perimeter DUs 3 and 4, which are anticipated to be outside of impacts above EALs.

Note that samples can be collected either before or after actual excavation (Figure 3-16). The confirmation of clean perimeter DUs prior to excavation is optimal, since this will negate the need for sample collection afterward and minimize concerns about the potential need for repeated over excavation. No further sampling is required if data for perimeter DUs indicate impacts below applicable action levels and soil within the DUs is completely removed.

3.4.6 STOCKPILE DECISION UNITS

Decision unit designation and sampling strategies specific to stockpiles is provided in the HEER Office document *Guidance for the Evaluation of Imported and Exported Fill Material* (HDOH, 2017d; included as Appendix 3-A; see also Subsection 4.2.8.3 and Subsection 5.5). Background information on a stockpile should be compiled to the extent possible and used to support the sampling approach proposed in the SAP. Fill material that is imported to or exported from sites where significant environmental contamination has been identified or where cleanup projects are underway could pose multiple environmental hazards if not appropriately characterized and managed.

Special considerations for selecting DUs for sampling soil stockpiles include (see HDOH, 2017d):

Table 3-1. Default DU Volumes for Stockpiles

Receiving Site Land Use	Default DU Volume	Comments
Unrestricted Use (includes single-family homes)	100 yd^3	Assumes 5,000 ft^2 reuse exposure area and six-inch placement thickness.
Schools and High-Density Residential Developments	400 yd^3	Assumes 0.5-acre exposure area and six-inch placement thickness.
Commercial or Industrial use only (formerly developed fill source)	400 yd^3	Assumes 0.5-acre exposure area and six-inch placement thickness.
Commercial or Industrial use only (agricultural field fill source)	400 yd^3 or 18 DUs	Stockpile divided into minimum 18 DUs for characterization if >7,200 yd^3.

Notes (Table 3-1):

1. See guidance in Appendix 3-A for additional options and recommendations (HDOH, 2011e).

- The source of the soil in the stockpile;
- How the stockpile was created (over time, if applicable);
- How best to access the pile for sampling, especially if it is large and or unstable;
- Target contaminants.

Large stockpiles could be broken or segregated into separate DUs for characterization. Default DU volumes for testing of stockpiles (or sources of fill material) are summarized in Table 3-1. Division of the stockpile should be based on soil type, source, potential for contamination, potential environmental concerns based on targeted contaminants (e.g., direct exposure vs leaching) and volume limits based on proposed reuse.

Larger DU volumes are appropriate for testing of stockpiles for reuse at high-density residential developments or schools. For example, a 400cy DU represents the approximate volume of soil necessary to cover the default, commercial/industrial exposure area of 20,000 ft^2 to a depth of six inches. A similar DU volume serves as a good starting point for testing of stockpiled soil to be used for fill material at a commercial or industrial site.

Assumed exposure areas of one-acre or more and thicknesses of one foot or more might also be appropriate for beach replenishment using dredged material not otherwise suspected to contain significantly elevated levels of contaminants. This would yield DU volumes of several thousand cubic yards. Testing of larger volumes can also be appropriate for screening of large stockpiles that are not anticipated to include contaminated soil but where some level of verification data is desired (e.g., soil from previously tested agricultural fields).

Larger DU volumes might also be acceptable for general screening purposes if other lines of evidence support a low risk of contamination based on the known source of the soil. Smaller DU volumes (e.g., 20 yd^3; see HDOH, 2017d) are recommended for soil that might contain pockets of highly leaching contaminants (e.g., triazine herbicides) or contaminants that might pose potential gross contamination concerns (e.g., petroleum). Such high-resolution testing of stockpiled soil for potential reuse is likely to be cost-prohibitive, however.

Disposal of the soil with suspected pockets of highly leachable contaminants or gross contamination at a municipal landfill or long-term management at the source under an EHMP might be the most prudent option. Fill material characterization, sources of fill that should be considered suspect for contamination and other considerations are described in further detail in *Guidance for the Evaluation of Imported and Exported Fill Material, Including Contaminant Characterization of Stockpiles* (Appendix 3-A). Note that a hazardous waste determination is required for disposal of soil at a landfill (see Subsection 5.10). This could require additional sampling and analysis. Contact the landfill for specific information. Consider the inclusion of any additional testing methods and requirements in the original SAP in order address disposal needs prior to the initiation of site activities.

3.4.7 SEDIMENT DECISION UNITS

Detailed guidance on the designation of decision units for sediment investigations is forthcoming. Sediment is defined as unconsolidated material that is currently under water (e.g., harbor bottom sediment) or otherwise associated with deposition in an aquatic environment (e.g., tidal flats, ephemeral stream beds, flood plains, etc.). Factors that affect the lateral and vertical distribution of contaminants in sediments include:

- The nature of the source area (e.g., periodic vs continuous release),
- Proximity to contaminant source,
- Sediment geochemistry,
- Size distribution of sediment particles,
- Water flow rate and volume,
- Location of depositional areas,
- Local features (natural or artificial),
- Resuspension and deposition during subsequent flood events or other disturbances,
- Vertical stratification over time,
- Seasonal fluctuations, and
- Bioturbation effects

Stratification can affect the nature of contamination at the water-sediment interface, necessitating seasonal sampling and leading to significant and abrupt vertical variability in contaminant concentrations over short distances.

These factors necessitate careful planning and thought in designation of DUs for characterization. Initial DU designation should focus on migration pathways from suspected source areas to depositional areas. Decision unit sizes and boundaries should be adjusted to address ecological impact concerns and optimization of potential remedial actions as appropriate for the investigation. Vertical designation of DUs layers might focus on the uppermost, active benthic zone, past layers of suspected high contamination, or depth intervals targeted for future dredging.

Samples will typically need to be collected from the biotic zone (e.g., the 0 to 4-inch interval) at the sediment-water interface. Deeper samples might be necessary to delineate the vertical extent of contamination to address other site-specific receptors, or characterize layers of contaminated sediment deposited in the past. If a contamination release is not recent, it is possible that later events could have resulted in deposition of a new, possibly much less contaminated sediment layer above the sediment of concern. Surface samples could result in an incomplete characterization of the DU area. Contaminated sediments currently isolated at depth could pose a threat due to storms or other erosional events or disturbance by future dredging. Conversely, clean sediment of sufficient thickness in an overall constant depositional environment may act as a cap over underlying contamination and indicate that the exposure pathway is incomplete.

Although detailed data are less available, small-scale, random variability of contaminant distribution in sediment in a lateral direction may be less dramatic than for soil in some depositional areas due to mixing during sediment transport and deposition (refer to discussion in Section 4). This could include depositional areas from runoff of agricultural, industrial or urban areas, or

aquatic areas impacted by long-term discharges of industrial waste water. If this is the case, replicate field samples could document adequate sample precision with less individual increments per DU than typically utilized for soil sampling sites.

Potential distinct boundaries between clean and contaminated sediment may be anticipated with depth in areas near past contaminant source locations. This requires close consideration of the vertical resolution of a sediment investigation in terms of targeted, DU layers.

3.4.8 INVESTIGATION OF LARGE AREAS

The guidance in this Subsection applies to characterization of soil in large open areas, where based on a thorough Phase I Environmental Site Assessment, localized spill areas are not anticipated, or have been identified and will be separately characterized. Examples include former agricultural fields, golf courses, and munitions ranges. The guidance does not directly apply to previously developed commercial, industrial, or residential areas. Characterization of these areas, as well as known or suspect spill areas within the types large areas noted above, should follow DU designation guidance presented in Subsection 3.4.

Optimal methods of employing a DU-MIS strategy for very large areas are a subject of on-going research by various organizations, and refinements of the recommendations provided below will be made in the future, as may be appropriate.

3.4.8.1 CHARACTERIZATION FOR BASELINE INVESTIGATIONS

Baseline investigations of large areas, including agricultural fields, golf courses, and former munitions ranges might be necessary as part of a property transaction, potential redevelopment project or an evaluation of area-wide contamination. These areas can be up to hundreds or thousands of acres with dramatic changes in terrain and historical use. While still challenging logistically in the field, adhering to the same Systematic Planning process described earlier (see Subsection 3.2) will help ensure that investigation objectives are clearly defined and that meaningful data are collected.

The objective of a baseline investigation is to establish environmental impacts under current site conditions. This might include estimation of the mean concentration of residual pesticides in soil at a former golf course or in a large field that was formerly used to produce sugarcane. Other examples include assessment of soil impacts from dispersal of munitions-related contaminants across a former military target range.

The first step in this process should include completion of a thorough Phase I Environmental Site Assessment (Phase 1 ESA) covering the site history and current operations (refer to Subsection 3.1.1). The compilation and review of existing information for a former agricultural site might, for example, include the following:

- Crop history;
- Current and past pesticide use;
- Historic aerial photographs;
- Historic Sanborn Fire Insurance maps, topographical maps, or other maps;
- Interviews with former employees;
- Existing soil investigation reports (including investigations of adjacent or nearby fields using lot-size DUs);
- Review of other published, historic information (journals, etc.); and
- Field inspection (current operations, former buildings, suspect dump areas, etc.).

Decision units should be designated to characterize the site. Areas of suspected or known heavy contamination should be identified separately from anticipated less impacted areas (see Subsection 3.4.3). For example, these might include former pesticide mixing areas, storage areas, rail lines, and plantation camps for agricultural sites, and burn pits or areas immediately surrounding low-order detonations at a firing range impact zone. Designate DUs for non-suspect areas based on more localized factors including crop history, soil type, drainage patterns, etc., appropriate for the site investigation objectives and based on the information gained in the Phase I ESA. In the case of golf courses, older sections of the course where different types of pesticides were used might be characterized separately from more recent additions, and fairways might be separated from putting greens.

The total number and size of DUs will necessarily be site-specific. Use of even a single DU might be adequate to accomplish investigation objectives, although this is less likely as the size of the site increases. Past experience has suggested that 10-15 DUs are typically adequate for baseline characterization of very large areas, based on past use history, soil types, drainage patterns, etc. A better resolution of mean contaminant concentration within a single area might also be desirable, for example to

verify historic information gathered on past use of the site. A Multi Increment sample should be collected to characterize each DU, with triplicate samples collected from a minimum 10% of DUs (see Section 4). See Section 9 for COPCs for pesticides. Refer to the HDOH Environmental Action Level guidance for a list of potential munitions-related COPCs (HDOH 2016).

Note that the baseline investigation approach also requires a thorough walkthrough of the entire site. This walkthrough will assist in identifying areas suspected of elevated contamination, including previously unknown dumping sites, waste pits, former plantation camp areas, pesticide mixing or storage areas, etc. that might otherwise be missed.

The results of the baseline investigation can be used to estimate the general extent and magnitude of soil contamination within the targeted area at the scale of the DUs designated. This information, in conjunction with a thorough, Phase I ESA review of the site might be adequate for the entity overseeing the investigation and their consultant to draw initial conclusions regarding redevelopment of the site for residential or other purposes. As discussed below, however, a more detailed investigation might be required for a formal site closure determination by HDOH, depending in part on the anticipated land use. For example, a baseline assessment including a strong Phase 1 report might be adequate for concurrence with future commercial/industrial use of the area, while more detailed higher-resolution data will normally be required for residential development.

3.4.8.2 CHARACTERIZATION OF VERY LARGE AREAS FOR REDEVELOPMENT

Table 3-2. Recommendations for Investigation of Large Areas

Project Classification	Area	Recommendations
Category 1	≤59 Acres	• Phase 1 ESA • One DU per acre
Category 2	>59 to ≤118 Acres	• Phase 1 ESA • 59 randomly located, one-acre DUs
Category 3	>118 to ≤590 Acres	• Phase 1ESA • Baseline Investigation • 59 randomly located, one-acre DUs
Category 4	>590 Acres	• Phase 1 ESA • Baseline Investigation • 90 randomly located, one-acre DUs

Recommendations provided below apply to both residential and commercial/industrial redevelopment. Characterization of very large areas for redevelopment can be challenging. Such projects can cover hundreds or thousands of acres and include hundreds or thousands of individual residential lots. The primary environmental hazard is direct exposure of future residents and workers to residual pesticides, or other contaminants such as metals in the soil. Localized contamination of highly mobile chemicals (e.g. explosives residues) can also pose potential leaching threats to groundwater that might be used to serve the redevelopment in the future.

A default Exposure Area DU size of one-acre is considered acceptable for characterization of large areas where no localized areas of potentially heavy contamination are identified as part of a thorough Phase I ESA (i.e., suspect Spill Areas; refer to Subsection 3.4.3). Variability of mean contaminant concentrations within this default DU size (i.e. at the scale of potentially smaller exposure areas) is assumed to be relatively low based on investigations of former golf courses and agricultural field areas where detailed data has been collected (e.g., refer to studies referenced in Section 9 appendices). Restriction of the default exposure area size to one-acre also helps to ensure that unanticipated, small but heavily contaminated spill areas are captured by DU data (e.g., a former pesticide mixing area). Note that if a thorough Phase 1 ESA has not been completed, the default one-acre Exposure Area DU size may be judged inadequate for evaluation (this applies to all categories of large area sites discussed below).

Table 3-2 summarizes the recommended strategy for characterization of large parcels of land where localized spill areas are not known or anticipated. Division of the site into adjacent, one-acre DUs is recommended for areas 59-acres or less in size (**Category 1, <59 acres**). Designation of DUs should reflect information garnered during the Phase I ESA to the extent practical (e.g., land-use history, terrain, soil type, etc.).

Random placement of 59, one-acre DUs is recommended for moderately large sites where the DUs will cover at least 50% of the total area (**Category 2, ≤118 Acres**). Testing of 59 of the total number of potential, one-acre DUs within the project area allows 95% confidence that the mean contaminant concentration in 95% of one-acre DUs at the entire site will be lower than the highest concentration reported in the one-acre DUs that were tested (USEPA, 1989b). DUs should be placed in a systematic random distribution, and with consideration to adequately represent variability associated with land-use history, pesticide use, soil type, topography and other key factors gained from the Phase I ESA investigation. Note that the 95% confidence criteria will not be met if the highest mean concentration of just one of the 59 decision units exceeds the applicable target action level. Additional sampling would typically be required to adequately identify and address areas of the site with elevated contamination. Consultation with the HEER Office to discuss potential options is recommended.

Inclusion of baseline investigation data as described above is recommended for sites where 59, one-acre DUs will cover less than 50% but at least 10% of the total project area (**Category 3, >118 to ≤590 Acres**). The baseline investigation should be conducted first, and will help to identify large-scale variance within the subject site and assist in subsequent DU placement and decision making. DUs should again be placed in a systematic random distribution, and with consideration to adequately represent variability associated with land-use history, pesticide use, soil type, topography and other key factors gained from the Phase I ESA investigation and the baseline investigation. For example, the baseline study might identify somewhat higher but still potentially acceptable levels of arsenic contamination in a portion of a field that was already under sugarcane production in the 1920s and 1930s (see pesticide discussion Section 9). Placement of one-acre DUs within this area or even separate characterization of this area would be warranted. Including a baseline investigation also provides some level of data for the entire project area (in addition to the 59 one-acre DUs), and helps address concerns of prospective residents who understandably might ask about soil testing data for their area.

Confidence in the representativeness of data decreases as the total area encompassed by the one-acre DUs decreases. An increase in the number of one-acre DUs to 90 in addition to a baseline assessment is recommended for projects where less than 10% of the land will be covered by the DUs (**Category 4; >590 acres**). This provides a 99% confidence that the mean contaminant concentration in 95% of one-acre DUs at the entire site will be lower than the highest concentration reported in the one-acre DUs that were tested (USEPA, 1989b).

The configuration of DUs across very large areas with respect to the planned redevelopment might also be desirable, although this could complicate usage of the data should redevelopment plans change in the future (see example in Subsection 3.5.6). HDOH feels that these recommendations are manageable in terms of the overall cost of large-scale, redevelopment projects. Alternative approaches should be discussed with HDOH on a case-by-case basis.

Decision Units should be placed in a systematic random fashion, and with consideration to adequately represent variations in site characteristics (e.g., land-use history, terrain, soil type, etc.).

3.4.9 EVALUATION OF DECISION UNIT DATA

As discussed in Section 5, Multi Increment samples are considered to be more reliable for characterization of the mean concentration of a contaminant within a targeted DU. The evaluation of data collected from DUs is discussed in Section 13 of this guidance as well as the accompanying guidance *Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater* (HDOH, 2016). When using a Decision Unit strategy, the entire area of a Decision Unit is acted upon as a single entity based on the average contaminant data collected from that Decision Unit. If the decision outcome is "contaminated," then the entire area of the DU is treated as being contaminated. If the data indicate that remediation is required, this applies to the entire Decision Unit. If the outcome is "not contaminated," then the entire area of the DU is treated as being not contaminated. As discussed above, this makes the designation of Decision Units very important to ensure that appropriate exposure areas and/or spill areas are identified, and areas of obvious heavy contamination are segregated into separate DUs to reduce the volume of soil that is identified as "contaminated" and requires treatment.

3.5 EXAMPLE DECISION UNITS

This Section provides example decision units for commercial/ industrial, residential, school, large area, subsurface, stockpile, and sediment sites. Examples of both exposure area and spill area decision units are included. A mixture of both types of decision units is often appropriate. The examples provided are based in part on site investigations in Hawai´i, although the placement of DUs noted in the figures has been modified to reflect lessons learned or emphasize specific points discussed in the text.

3.5.1 COMMERCIAL & INDUSTRIAL SITES

Figure 3-17 depicts a simple spill area DU placed around a former transformer pad. The purpose of the decision unit is to investigate the presence or absence of PCB-contaminated soil in the immediate vicinity of the pad. An area extending approximately 3 feet out from the pad was selected as the DU. The pad appeared to drain to the side of the DU shown. A second DU of similar shape and size was placed on the other side of the pad. Triplicate Multi Increment samples were collected within the DU (i.e., three separate Multi Increment samples, refer to Section 4). The flags denote the location of increments collected for the first sample (approximately 30 increments per Multi Increment sample). Samples were to be tested for PCBs.



Figure 3-17. Decision Unit Designated to Investigate PCB Contamination Beside Former Transformer Pad

DU extended outward three feet from stained side of pad. Flags denote location of increments collected for Multi Increment sample.

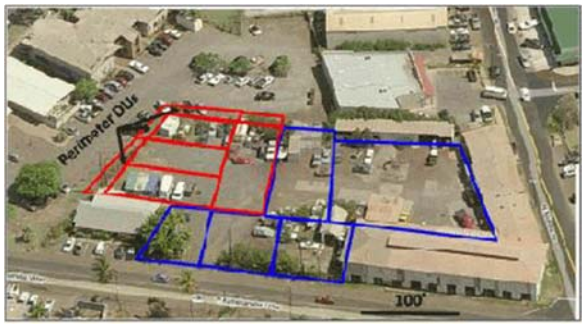


Figure 3-18. Designation of Spill Area (red) and Exposure Area (blue) DUs at a Former Electrical Power Plant to Determine the Magnitude and Extent of PCB-Contaminated Soil.

Former Transformer Storage and Repair Operations Located in Upper Left Area of the Property

Figure 3-18 depicts DUs designated for a former electric power plant. A review of historical data and previous discrete sample data suggested potential significant contamination of soil with PCBs in the area of the property where transformers were formerly stored and repaired. Relatively small DUs are designated across this area. This provides a high resolution for the distribution of PCBs across the area in order to maximize removal or remedial options. Small, perimeter DUs are designated around this area in hopes of confirming an outer boundary of clean soil. The remainder of the property where significant PCB contamination is not anticipated is divided into somewhat larger, Exposure Area DUs appropriate for the current, commercial use of the property.

Decision units designated for a former agricultural, pesticide storage and mixing area are depicted in Figure 3-19. Relatively small (100-2,000 ft^2), Spill Area DUs are designated in the former mixing tank area to evaluate potential leaching hazards posed by the triazine herbicides ametryn and atrazine (depicted in red, Figure 3-19). The DUs are designated based on obvious or suspected areas of high contamination. For example, obvious or suspected spill areas were identified on the ground under elevated mixing and storage tanks, under the floor or the storage building and in a low lying drainage area adjacent to the tanks and building (Figure 3-20). The use of small DUs helps to better assess potential leaching hazards from this area as well as optimize future remediation actions by minimizing the volume of potentially clean soil included in the DUs.

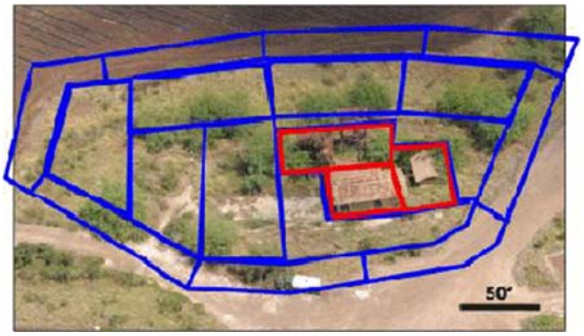


Figure 3-19. Example Spill Area (red), Exposure Area (blue), and Perimeter Area (blue, outside ring) Decision Units for a Former Pesticide Mixing and Storage Area

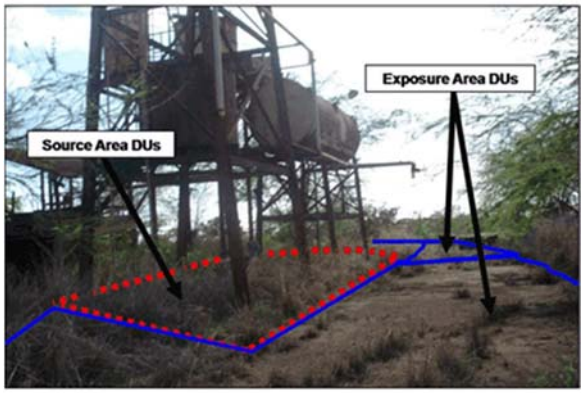


Figure 3-20. Spill Area Decision Units Designated Beneath Pesticide Mixing and Storage Tank

The remainder of the area is known from previous investigations to be contaminated with arsenic and pentachlorophenol-related dioxins with no known localized spill areas. This area was divided into eight 5,000 ft^2 Exposure Area DUs representing hypothetical, residential lots (see Figures 3-19 and 3-20). Two rings of lot-size, perimeter DUs were then designated around the site to establish a clean boundary and ensure that contamination associated with the pesticide mixing area has been adequately defined (refer to Figure 3-19). Decision units in the outer ring (not depicted) are tested as needed if samples from an inner ring DU failed action levels.

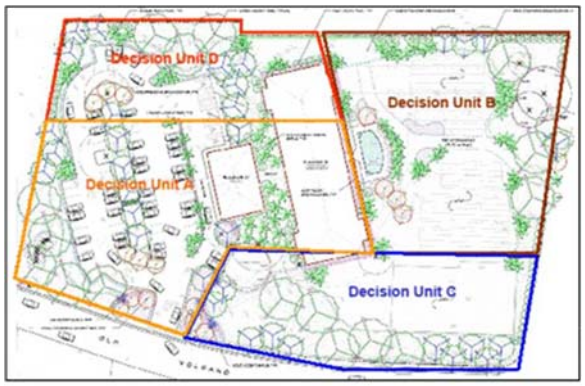


Figure 3-21. Decision Units to Investigate a Proposed, Four-Acre Hotel Site

DUs A through C represent exposure areas based on the proposed hotel design. DU-D represents a suspected spill area identified during initial site investigation actions



Figure 3-22. Example Designation of DUs Around House Perimeter and Yard

Multi Increment soil samples are collected in each DU (with triplicate samples collected in two of the DUs) and are used to evaluate direct exposure hazards and leaching hazards. The full suite of COPCs is tested for in each sample. The results of the investigation and a summary of the subsequent Environmental Hazard Evaluation are carried forward as an example in Section 13.

Figure 3-21 depicts Decision Units for a proposed commercial development on a four-acre site known to be contaminated with arsenic. The property was divided into four DUs. DUs A through C represent exposure areas. DU-D represents a suspected spill area identified during initial site investigation actions. This was an attempt to isolate the most heavily-contaminated soil on the property to as small an area as possible in order to minimize future remediation and long-term management costs.

3.5.2 SINGLE FAMILY HOMES

Soil contamination concerns for residential properties are normally limited to the presence of lead-based paint residue and organochlorine termiticides (e.g., Technical Chlordane) in soil surrounding the perimeters of wooden homes constructed prior to the mid 1970s. Termiticides could also be present beneath a building slab or in soil exposed in a crawl space, or less commonly in open areas in the yard.

Figure 3-22 depicts typical decision unit designations to investigate these potential concerns. A narrow DU (or DUs) is designated around the immediate perimeter of the home, typically within three to five feet of the foundation. The perimeter could be divided into separate DUs for testing if there is a reason to think that these areas could be different (e.g., more recent utility work or landscaping along one side of the home). The remainder of the yard or different sections of the yard can then be characterized separately as single or multiple Exposure Area DUs.

3.5.3 HIGH-DENSITY HOUSING

The investigation of large, high-density residential areas for potential soil contamination concerns is approached in a similar manner as done for individual homes. Suspect spill areas are targeted as separate DUs for characterization (e.g., lead-based paint and termiticides around building perimeters).

The identification and management of lead-contaminated soil or soil treated with organochlorine termiticides can be a significant challenge for the redevelopment of large housing complexes. Detailed characterization around and beneath each building is often not practical (e.g., redevelopment of military or public housing complexes where dozens or hundreds of buildings will be demolished or renovated).

As an alternative, detailed characterization can be conducted for a select number of buildings (e.g., 10%) constructed during the same time period and by the same builder, with the assumption that the use of lead-based paint or termiticides around the buildings would be similar. The results could then be applied to the remainder of the buildings in order to prepare initial soil management plans. Stockpiled soil following home demolition should be tested prior to reuse or disposal if past treatment with termiticides is possible.



Figure 3-23. Example Designation of DUs for Investigation Pesticide-Contaminated Soil at a Public Housing Complex

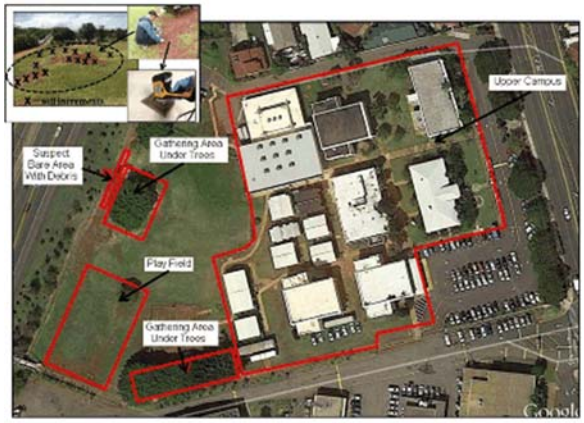


Figure 3-24. DUs Designated to Test for the Potential Presence of Lead-Contaminated Soil at a School

As discussed in Subsection 3.4.4, the presence of termiticide-treated soil under building pads can be evaluated by the collection of soil samples from a small number of borings through the building slab. The combined sample is processed and tested in the same manner as done for a MI sample. Although the resulting data will not be reliable for estimation of mean termiticide concentrations under the slab, the presence or absence of the chemicals can be used to prepare initial soil management plans for the complex as a whole.

Open areas planned for use by residents can also be tested separately as Exposure Area DUs. This can include play areas or lawns used for recreational activities. Exposure Area DUs can also be designated for yards located in suspect areas of the property where the specific location of potential spill areas is not known.

Figure 3-23 depicts DUs designated for a public housing complex suspected of being constructed in an area where pesticide mixing and storage may have taken place in the past. Relatively small (100s to a few 1,000 ft^2) DUs were designated for

characterization in areas of highest concern. Designated DUs included small backyards, large open areas and playground areas. The DUs reflect exposure areas appropriate for the housing complex and also provide good resolution of mean pesticide concentrations in soil across the site.

3.5.4 SCHOOLS

Designation of DUs for characterization of potential soil contamination at schools typically represents a combination of approaches used for commercial/industrial facilities and high-density residential complexes. Potential spill areas should be characterized separately with DUs sized to reflect the suspected extent of contamination, as well as to optimize anticipated removal or remedial actions. These could include maintenance yards, suspected termiticide-treated soil around buildings perimeters, garden areas where persistent pesticides may have been used in the past, and other areas of bare soil where children or staff may have periodic exposure.

Figure 3-24 depicts DUs designated for a school to test for the presence of lead-contaminated soil associated with dumping prior to construction of the campus. The DUs largely reflect easily recognizable exposure areas. This might include playgrounds or other gathering areas as well as gardens or open areas between buildings.

In this example a focus was made on barren areas of soil exposed in otherwise thick lawns including soil along walkways, under outdoor tables and in areas of high foot traffic. Field screening of samples from barren areas within the main campus was carried out using a portable XRF (see Figure 3-24). Soil from subareas of the upper campus was ultimately combined and tested as a single MI sample after field screening indicated similar low levels of lead within the preliminary DU as a whole.

3.5.5 LARGE AREAS

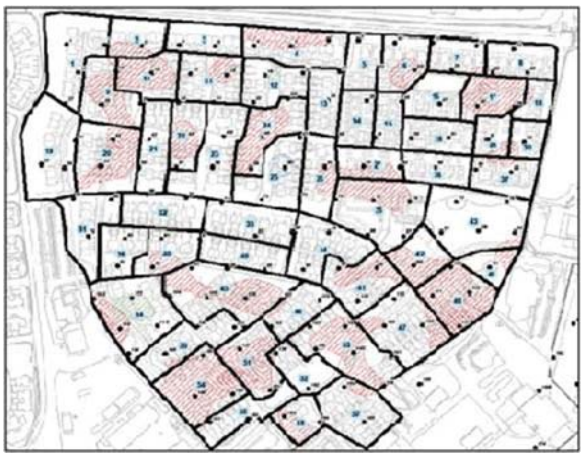


Figure 3-25. Grouped Lots for Decision Units at a Proposed Residential Site

Exposure area DUs for a former golf course based on clusters of planned houses. Red cross-hatched areas indicate suspected arsenic-contaminated soil as determined by field-based XRF.



Figure 3-26. Apparent leak under valve of large fuel tank designated as a small DU in order to document the presence of a release.

The configuration of DUs with respect to the planned redevelopment might also be desirable, although this could complicate usage of the data should redevelopment plans change in the future. An example is depicted in Figure 3-25. In this case, a former 100+-acre golf course, the property was known to contain elevated concentrations of arsenic that would require partial removal. Development plans were used to divide the property into DUs that consisted of four to five housing units each. Each DU was then tested separately for arsenic. A backhoe was used at each increment location to collect samples at depth. This allowed a three-dimensional image of soil that exceeded cleanup levels to be developed and incorporated into the site grading and soil removal plan.

3.5.6 SMALL AREAS

Characterization of DUs as small as a few square feet and/or a very small volume of soil or sediment might be required under some circumstances. Examples include testing of upper few inches of soil under a leaking tank valve to document the presence of a release (Figure 26) or testing of sediment in a storm sewer vault to assess runoff from a known or suspect, contaminated area (Figure 3-27). Another example includes the desire to test a small, easily accessible portion of a suspected much larger spill area, for example the rapid collection of a soil sample from an illegal dump site (Figure 3-28). This might be done in order to

document the presence of a release, identify specific contaminants of concern and establish the relative magnitude of potential contamination within the larger area as a whole.



Figure 3-27. Stormwater drainage vault designated as a DU for testing of sediment runoff from a contaminated property.

Representative sample or entire volume of sediment is collected and submitted to the laboratory for processing and analysis.



Figure 3-28. Designation of small, targeted DU within a suspected much larger area of contamination at an illegal dump site in order to document presence of contamination and identify potential contaminants of concern.

The size of DU will necessarily be site specific but should be made large enough to minimize “false negatives” and collection of a sample from a single and inadvertently clean location (e.g., three feet-by-three feet or approximately one-square meter). This is similar to the concept of “judgmental,” “biased” or “subjective” sampling under past, discrete sample collection methodologies. The data collected in judgmental sampling is only representative of the specific DU area tested, however, and while it can be used to initiate the need for a larger-scale investigation it cannot be used to quantitatively assess overall risk posed by the release.

In such cases it is important to specifically designate a DU and associated DQOs for characterization and to collect the sample in a nonbiased, “probabilistic” or “statistical” manner that ensures the resulting data will be representative of the targeted soil or sediment (refer to Section 4). This includes the need to collect a minimum, 1-2 kg of material in order to address Fundamental Error and to collect the sample from multiple, random locations within the DU in order to capture and represent random, small-scale heterogeneity (see Subsection 4.2.5). The sample must be processed for analysis at the laboratory in accordance with Multi Increment protocols again in order to address Fundamental Error (e.g., dried, sieved and subsampled; see Subsection 4.2.6). If the soil is to be tested for volatile chemicals then multiple increments from the DU can be placed into methanol in the field and submitted to the laboratory for analysis (minimum 300g recommended; see Subsection 4.2.8.1).

This approach achieves the same objectives as traditional, judgmental or “grab” discrete samples but provides much more defensible data for decision making. The potential for “false negatives,” where a small mass of unrepresentatively clean soil is inadvertently collected and/or tested by the laboratory, is also minimized (refer to Subsection 4.3).

In some cases collection of the entire DU volume of soil or sediment as a single sample might be feasible. Examples include small volumes of sediment in stormwater sumps being tested to assess contaminant runoff from a property (Figure 3-27). This ideal scenario, referred to as to as "direct inference" (AAFCO, 2015), negates the need for the collection of a Multi Increment sample (and replicates) and eliminating potential field error (e.g., <2kg of material present). Importantly, the sample must be processed and subsampled for analysis at the laboratory in accordance with Multi Increment protocols in order for the data to be considered representative (refer to Subsection 4.2.6).

The concept of very small DUs also applies to targeted “DU Layer” of soil or sediment in a core where decisions are to be made on data for single boreholes (see Subsection 3.4.4). If the targeted interval of the core is less than a few feet in length then it is usually practical and even desirable to submit the entire core interval to the laboratory for processing and testing. In other cases subsampling of the core will be required to reduce the sample to a manageable mass (see Subsection 4.2.8.2 and Section 5).

3.5.7 SUBSURFACE DECISION UNITS

Figure 3-29 depicts designation of a thin horizon that represents the top of a former dump area as a subsurface DU for characterization. The area was covered by clean fill material following closure of the dump. Subsequently, buried debris was removed as part of a redevelopment project. Soil around the perimeter of the former dump was tested for the presence of heavy metals and dioxins to determine if additional excavation was required.

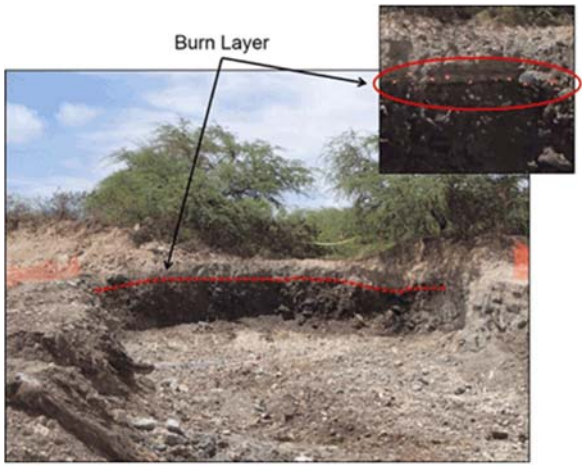


Figure 3-29. Subsurface Burn Layer Targeted for MI Sample Collection Following Excavation of Former Dump Area

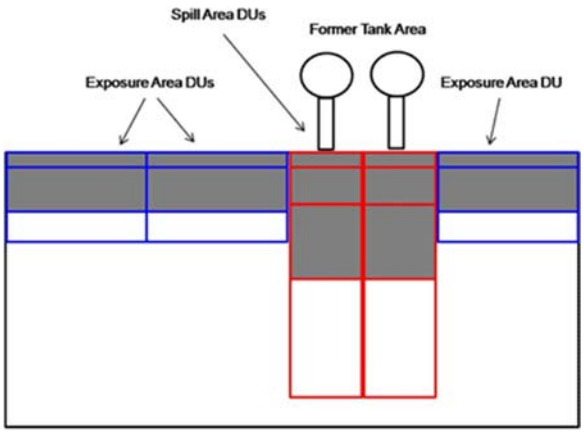


Figure 3-30. Cross Section of Subsurface DU Layers Designated at Former Pesticide Mixing Area Facility (white indicates anticipated clean soil)

The pesticide mixing area depicted in Figures 3-19 and 3-20 is used to depict a more detailed designation of DU layers for vertical characterization of the extent and magnitude of contamination. The resulting data might, for example, be used to estimate the volume and mass of soil that require excavation and disposal or the total mass of a contaminant present in soil for design of in situ treatment. Both the area and volume of DUs should be summarized in investigation work plans.

Refer again to Figure 3-19. Eight DUs of approximately 5,000 ft^2 each were designated for the outer area known to be contaminated by arsenic and dioxins. These contaminants primarily pose direct-exposure concerns. The DU area reflects the default size recommended for a hypothetical, single-family home residential lot. Three DUs are designated for the inner area contaminated with triazine herbicides (ametryn and atrazine), ranging in area from approximately 1,000 ft^2 to 2,000 ft^2. These areas primarily pose leaching and groundwater impact hazards.

Subsurface DU layers designated for the site are depicted in Figure 3-30. The thicknesses and depths of DU layers are assigned based on the anticipated depth of contamination and the desired resolution of the site investigation in terms of soil volumes for development of a remedial action plan. A higher resolution (i.e., smaller DU layer areas and volumes) increases the cost of the investigation but helps to minimize the inclusion of clean soil in treatment or removal plans. Maximum DU volumes of a few hundred cubic yards are recommended for contaminants that primarily pose direct exposure hazards (refer to Clean Fill Guidance; HDOH, 2017d). Maximum DU volumes of a few tens of yards are recommended for contaminants that pose significant leaching hazards.

In this example, arsenic and dioxin contamination in the outer part of the mixing area is assumed to be largely surficial due to the lack of distinct spill areas. Three vertical DU layers were designated (see Figure 3-30): 1) 0 to 0.5 feet, 2) 0.5 to 2.0 feet, and 3) 2.0 feet to 3.0 feet. The volumes of soil associated with the respective layers in each of the 5,000 ft^2 DUs are approximately 90 cubic yards, 280 cubic yards and 185 cubic yards, respectively. It is anticipated that the upper two layers will require removal. The lowermost layer is anticipated to be clean. This resolution was determined to be acceptable for development of a followup remedial action plan for this area.

Soil below a depth of two feet is divided into two DU layers in order to better assess the depth (and volume) of contamination by triazine herbicides. This is accomplished in this example by the use of smaller DUs in comparison to the arsenic- and dioxin-contaminated area. Four vertical DU layers were designated (see Figure 3-30): 1) 0 to 0.5 feet, 2) 0.5 to 2.0 feet, 3) 2.0 feet to 5.0 feet, and 4) 5.0 feet to 10.0 feet. The volumes of soil associated with the respective layers range from 20 to 50 cubic yards in shallow DU layers anticipated to be most heavily contaminated up to 185 to 370 cubic yards in deeper DU layers anticipated to be relatively clean. Contamination is anticipated to be concentrated in the upper three layers.

As discussed in Section 5, characterization of the DU layers can be accomplished by trenching and/or the installation of multiple borings. Trenching and testing of DU layers exposed in sidewalls was used to estimate depth of contamination in the outer areas. Trenching in this area was also desired to determine the presence or absence of burial pits common to these types of

sites that might have been missed in previous investigations. Borings were installed in the triazine spill area, with core increments from each targeted layer collected, subsampled, and combined to produce a bulk MI sample for each layer. Triplicate samples could be collected from alternative boring locations for all or select DU layers.

3.5.8 STOCKPILE DECISION UNITS

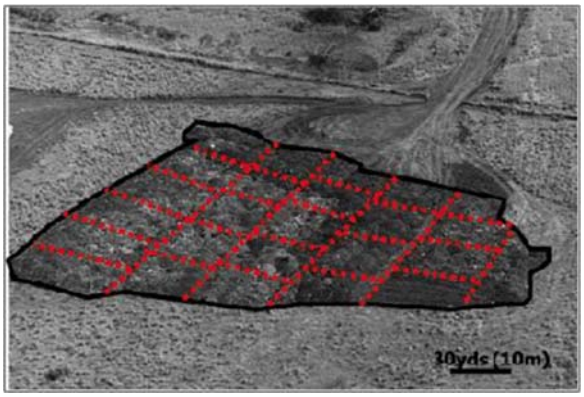


Figure 3-31. Stockpile Segregated into DU Volumes for Testing Based on Planned Reuse



Figure 3-32. DU Designation for an Investigation of Former Sugar Mill Drainage Canal

DU-1 is 75 feet long and averages 10 feet wide (750 ft^2). DU-2 and DU-3 are 250 feet long and again average 10 feet wide (2,500 ft^2). DU sediment volume is estimated at 15 yd^3 and 50 yd^3, respectively.

A DU volume of 100 cubic yards (yd^3) is recommended for a stockpile with an unknown history (Figure 3-31). This represents the approximate volume of soil needed to cover a hypothetical 5,000 ft^2 residential lot to a depth of six inches (see HDOH, 2017d; see also Subsection 3.4.2). Testing of stockpiles with an unknown history typically focuses on toxic and persistent chemicals such as arsenic, lead, organochlorine pesticides and PCBs. The presence of heavy oil is also typically tested (e.g., TPH-o). If concentrations of contaminants in each 100 yd^3 volume do not exceed Tier 1 action levels then it is assumed that the soil does not pose direct exposure concerns for unrestricted reuse (e.g., residential). See Appendix 3-A, *Guideline for Evaluation of Imported and Exported Fill Material*, for additional information pertaining to sampling of stockpiles.

3.5.9 SEDIMENT DECISION UNITS

The size of sediment DUs will vary widely depending on the nature of the release and the objectives of the investigation. Example shallow water sediment DUs are presented in Figures 3-32 through 3-36. The examples are taken from actual sites, although the details have in some cases been modified to illustrate specific points.

Figure 3-32 depicts sediment DUs designated for a drainage canal that once carried waste water from a sugar mill. Testing of surface soil at discharge points suggested that sediment in the canal might be contaminated with mercury (used as a fungicide). A relatively small DU is designated for the area of the canal immediately downstream of the discharge area (DU-1 in Figure 3-32). Two additional and somewhat larger DUs are designated for areas of the canal further downstream (DU-2 and DU-3). Two DU layers are designated, 0-6 inches and 6-12 inches. It is anticipated that contamination might be greater at depth, due to the long time interval since the cessation of operations at the facility.

The next example illustrates a single sediment DU designated at the outfall of a wastewater pipe. A single DU is designated given the anticipated similarity of impacts within the small area (Figure 3-33). The upper six inches of sediment is targeted for characterization. An 30+ increment MI sample is collected by maneuvering around the perimeter of the ponded area.

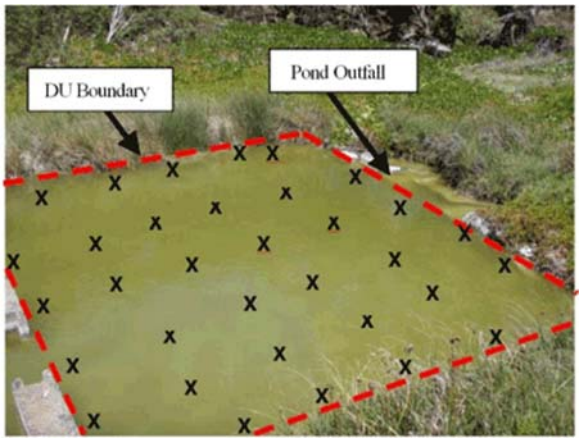


Figure 3-33. DU Designated for Characterization of Sediment at the Mouth of a Wastewater Pond Outfall

"Xs" indicate increment collection locations

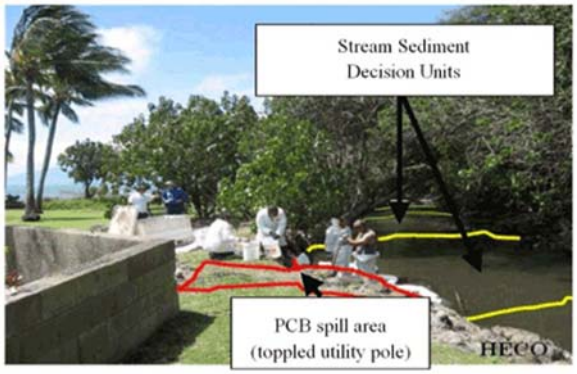


Figure 3-34. Sediment DUs Designated for a Spill of PCB-based Transformer Oil Beside a Small Stream

The DUs cover approximately 500ft^{2}areas to a depth of six inches (approximately10cyds per DU).

Figure 3-34 depicts hypothetical DUs for a PCB spill suspected to have entered a small stream. The area outlined in red depicts the upland area impacted by the spill. Spill Area DUs as described above are used to characterize this area, including Perimeter DUs to confirm that the edges of significant impact have been identified.

Relatively small DUs, depicted in yellow, are then designated in the stream itself for characterization of sediment. The location and size of the DUs might be based on stream flow characteristics (e.g., focus on individual depositional areas, including pools and bars) and the maximum volume of sediment to be included within a DU with respect to ecological and remedial considerations. In this example, DUs approximately 500 ft^2 in area were considered appropriate. In this example sediment cover in the stream was very thin, three to six inches in most areas, and the entire volume of sediment within each DU was targeted for characterization (approximately 5-10 cubic yards per DU). A Multi Increment sample was collected in each DU with triplicate samples collected in 10% of the DUs.

Figure 3-35 depicts a much larger sediment investigation carried out in the upper part of a spring-fed fifty-acre estuary suspected to have been impacted by historic arsenic-contaminated wastewater and runoff from past agricultural operations in the area. The pond is tidally influenced.

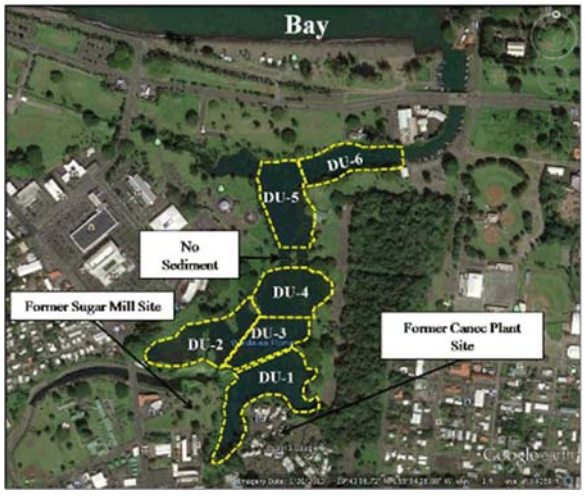


Figure 3-35. Decision Units Designated for Characterization of Arsenic-Contaminated Sediment in an Estuary

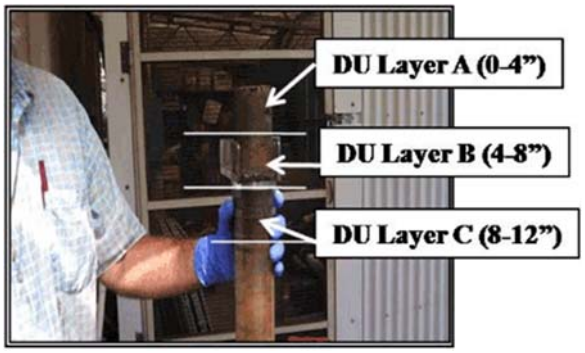


Figure 3-36. Sediment DU Layers Designated for the Estuary Example Depicted in Figure 3-35

In the example, DU-1 was placed to characterize sediment in the immediate areas of a former sugar mill and a former Canec production facility (used to make arsenic-infused, termite-resistant press-board panels from waste sugarcane fibers.). The remaining DUs reflect sediment areas more distant from the former Canec plant site. The area of the pond encompassed by DUs 2 through 5 are relatively low energy and characterized by fine silts. The lower area of the pond, DU-6, is higher energy due to focused tidal action and characterized by a mix of silts to medium-grained sand. A narrow, high-energy area between DU-4 and DU-5 was not sampled due to a lack of sediment.

Vertical DU Layers may be assigned based on factors that include observations from initial test cores (e.g., distinct layering, grain size, aerobic versus anaerobic zones, etc.), characterization of benthic zones for use in ecological risk assessments, estimated depositional depth since closure of an industrial facility formerly located in the area, and/or desired resolution for potential remedial actions. In this example, the sediment in each DU was ultimately divided for testing into three DU Layers for characterization (Figure 3-36): 1) 0-4 inches, 2) 4-8 inches and 3) 8-12 inches. Methods for the collection of MI sediment samples from the DUs are reviewed in Section 4.

3.5.10 TESTING OF DREDGE MATERIAL

Sediment targeted for dredging operations can be tested in place as described above or in stockpiles after dredging, as discussed in Subsection 3.5.7. Decision unit area and volume designation is based on targeted contaminants of concern and related environmental hazards as well as planned reuse or disposal of the dredge material. Offshore disposal of dredge material is overseen by the US Army Corps of Engineers in coordination with local environmental agencies.

Note that the use of dredge material from salty or brackish water bodies as fill material in upland areas is not recommended due to potential salinity problems. Soil salinity is evaluated in terms of Electrical Conductivity (EC) and Sodium Absorption Ratio (SAR; see HDOH, 2016). Salt intolerant plants begin to be affected by soil salinity at an EC greater than 2 mS/cm (1 milliSiemen/centimeter = 1 millimho/centimeter; see also Blaylock, 1994). Soil with an EC of greater than 32 mS/cm is toxic to even salt tolerant plants. Soil EC values of over 100 mS/cm were reported for samples of saline, dredge material collected by the HEER Office, indicating high toxicity to plants (HDOH, 2014).

Excess sodium associated with saline sediment can also cause soil to harden and form clods when dry, impeding the uptake of water during rainfall or irrigation and again reducing plant growth. A SAR value greater than 5.0 indicates sodic soils that could inhibit plant growth (see Dickson and Goyet,1994) Soil SAR values of over 200 were reported for the same dredge material noted above that was tested by the HEER Office (HDOH, 2014).

Other potential environmental concerns associated with the reuse of dredge material include runoff of saline water during rain events, as well as leaching of salt and impacts to underlying groundwater. (Note that while a high sodium content can inhibit leaching and runoff, this will also ensure that the soil remains saline and unusable for a long period of time.) Dredge material from heavily developed harbors and in the vicinity of urban runoff can also contain trace levels of other pollutants, including termiticides, petroleum, PCBs, and lead.

While the use of dredge material for beach replenishment and as fill in shoreline or near-shoreline areas may be appropriate on a case-by-case basis, the general use of dredge material from saline water bodies for fill material is not recommended without prior review and approval by HDOH. The HDOH Office of Solid and Hazardous Waste should be contacted for additional guidance and regulatory information on the reuse of dredge material.

3.6 SAMPLING AND ANALYSIS PLANS

The Sampling and Analysis Plan (SAP), developed during Step 6 of systematic planning, specifies the final design and configuration of the environmental measurement effort required to resolve issues and questions stated in the systematic planning steps (Steps 1- 5). The SAP is a comprehensive document that would enable an experienced field sampling team unfamiliar with the site to come in and examine the site and collect the required samples and field information. The SAP designates the types and quantities of samples or monitoring information to be collected; where, when and under what conditions they should be collected; the variables to be measured; and the Quality Assurance/Quality Control (QA/QC) procedures to ensure that sampling design and measurement errors meet the tolerable decision error specified.

The QA/QC procedures are described within the Quality Assurance Project Plan (QAPP), which is included within the SAP. The site-specific Health and Safety Plan is also included as part of the overall SAP (alternately, the Health and Safety Plan can be presented with the SAP in a site Work Plan). The SAP must be flexible and dynamic to deal with unexpected discoveries or circumstances that may be encountered during the site investigation. To ensure appropriate characterization of the site and to minimize the need to perform additional sampling, it is recommended that SAPs be reviewed and approved by the HEER Office. In addition, it is important to consult with the laboratory while developing the SAP to ensure objectives are in alignment with chosen laboratory practices, and to provide contingencies for matrix problems that may occur. Important among such issues to discuss with the laboratory are expectations for storing remaining portions of MI samples that have been analyzed, until site sampling decisions are completed. Based on initial data analysis or new information, additional analyses may be conducted from stored bulk MI samples rather than having to mobilize and collect additional samples in the field.

The suggested outline for the SAP is as follows:

I.	Introduction	VI.	Description of Sampling Activities
II.	Site Background	VII.	Analytical Methods
	a. Site description	VIII.	Quality Assurance Project Plan
	b. Site characteristics	IX.	Documentation and Reporting
III.	Investigation History	X.	Schedule
IV.	Site Investigation Objectives	XI.	Health and Safety Plan
V.	Scope of Work	XII.	References

More detailed information regarding the outline, format, and required content of the SAP is presented in Section 18.

3.6.1 SAMPLE COLLECTION STRATEGY

A sampling strategy should reflect the approach that will best meet investigation objectives within acceptable uncertainty limits, with consideration taken for efficient use of time, money, and human resources. Section 4 discuses sample collection strategies for soil and sediment.

Sample collection for soils generally falls under two main categories: Multi Increment samples and discrete samples (see Section 4):

- The HEER Office strongly encourages the use of Multi Increment/Decision Unit strategies to investigate contaminated soil. Multi Increment samples are collected using a probabilistic sampling theory and involve the collection of a large number of increments (30-100) from within the target DU. Each increment is made up of approximately 5 to 50 grams of soil. The increments are combined to form a single, Multi Increment sample for the DU. A detailed discussion of Multi Increment sampling approaches is provided in Section 4.
- Discrete samples (i.e., samples typically consisting of only one increment) are collected using either random or biased sample point locations based on professional judgment. In some cases, groups of discrete samples are combined for

analyses. A small number of discrete samples are typically not representative of average contaminant levels in a specific DU as are Multi Increment samples, and therefore not recommended in most cases. Discrete sample data can, however, prove useful at the early stages of a site investigation, especially when available from previous studies. This includes screening sites for the presence of large spill areas not obvious in the field, and providing data to help select DU boundaries for collection of more detailed Multi Increment samples (see Subsection 4.3).

See Section 6 for sample collection strategies for groundwater, and Section 13 for information and references regarding ecological risk evaluations.

Information regarding sampling design is also available in USEPA's *Guidance on Choosing a Sampling Design for Environmental Data Collection* (USEPA, 2002f), although the guidance focuses on the collection of discrete samples. Software is available to assist in designing a sampling strategy, although again, they are primarily applicable to discrete sampling approaches. One example is Visual Sample Plan [VSP] software available from Pacific Northwest National Laboratory (PNNL, 2005).

3.6.2 SAMPLING COLLECTION METHODS

After the sampling design is determined, sampling methods are selected to facilitate the sampling design. Sampling methods are specific to the sampling design and the needs of the site and are selected to meet requirements of the site investigation objectives and associated DQO.

Sampling design approaches are discussed in Section 4.Sampling soil DUs at depth typically involves additional time and resources compared to DUs for surface soil (refer to Subsection 3.4.4 and Section 4). Several sampling approaches might be useful for a given site. Sampling method procedural guidance for soil and sediment, groundwater and surface water, and soil vapor and indoor air is presented in Sections 5, 6, and 7, respectively. The application of Decision Unit approaches is recommended for characterization of sediment and surface water as well as soil.

3.6.3 HEALTH AND SAFETY PLANS

Hawai‘i hazardous substance release sites fall under the definition of "uncontrolled hazardous waste sites" pursuant to Occupational Safety and Health Administration (OSHA) Hazardous Waste Operations and Emergency Response (HAZWOPER) Title 29 Code of Federal Regulations (CFR) Section 1910.120(a)(1). A health and safety plan (HASP) is required under Title 29 of the Code of Federal Regulations, Section 1910.120 (Hazardous Waste Operations and Emergency Response), which includes a requirement for a hazard communication program meeting the requirements of 29 CFR 1910.1200. Like rules were adopted under Hawai‘i Administrative Rules (HAR) Title 12, Chapters 60 and 203.1, Division of Occupational Safety and Health Standards. The Health and Safety plan is typically a part of the SAP (or alternately, part of the site Work Plan). The HEER Office recommends that an employer develop a written Health and Safety Plan, which includes the following elements:

- An organizational structure
- A comprehensive work plan
- A site-specific health and safety plan
- A health and safety training program
- A medical surveillance program
- Standard operating procedures for health and safety
- Any necessary interface between general program and site-specific activities

The OSHA HAZWOPER Standard, Title 29 CFR 1910.120, requires that personnel working in and around hazardous waste have a site-specific HASP and competent safety officers to enforce health and safety rules. OSHA has determined that employees must be trained if they work in proximity to hazardous chemicals with a potential for release or substantial threats of release, without regard to the location of the hazard.

An OSHA-certified 40-hour class focusing on HAZWOPER training is required for those who are performing regular work on hazardous waste sites; an annual 8-hour refresher course is required to maintain the certification achieved through this training. An OSHA-certified 24-hour course is required for those who have occasional exposure to hazardous waste. In addition, an 8-hour course is required for supervisors and management personnel who oversee hazardous waste projects. The amount of training required is contingent upon an employee's responsibilities and involvement with hazardous materials; these must be clearly established by the employer and communicated to the employee(s). The HEER Office does not approve Health and

Safety Plans, but does require that one be in place for field activities at hazardous chemical release (or suspect release) sites. Contact the Hawai‘i Division of Occupational Safety and Health (HIOSH) for detailed information on HASPs and organizations offering HAZWOPER training.

3.7 QUALITY ASSURANCE PROJECT PLANS

Data acceptance criteria, developed during Step 5 of systematic planning, are presented in the Quality Assurance Project Plan (QAPP) which is the formal project document that specifies the operational procedures and QA/QC requirements for obtaining environmental data of sufficient quantity and quality to satisfy site investigation objectives. The QAPP is required for all data collection activities that generate data for use in decision-making. It contains information on project management, measurement and data acquisition, assessment and oversight, and data validation and usability. The QAPP integrates the DQO, the data collection design, and QA/QC procedures into a coherent plan to be used for collecting data that are of known quality and adequate for their intended use. The QAPP is typically presented as part of the SAP (Step 6 of systematic planning) and should include the following elements:

1. Quality assurance (QA) objectives for measurement
2. Sample chain of custody
3. Calibration procedures
4. Analytical methods
5. Data reduction, validation, and reporting
6. Internal quality control (field and laboratory checks)
7. Performance and system audits
8. Preventative maintenance
9. Data measurement assessment procedures (precision, accuracy, and completeness)
10. Corrective actions

Participation of the laboratory that will be utilized is important to ensure capabilities are agreed upon and not assumed. Other considerations such as potential changes to cleanup processes, lab filtration, etc. should be discussed ahead of time when potentially contaminated samples are collected.

More detailed information regarding the outline, format, and required content of the SAP, which includes the QAPP, is presented in Section 18.

Additional information regarding the development of a QAPP is available in the Uniform Federal Policy for Quality Assurance Project Plans (USEPA/DoD/DOE, 2005), Guidance for Conducting Remedial Investigation and Feasibility Studies under CERCLA (USEPA 1988), and Guidance for Quality Assurance Project Plans (USEPA, 2002g). In addition, Data Quality Assurance and Quality Control procedures are discussed in detail in Section 10.

3.8 DATA QUALITY ASSESSMENT

After the environmental data are collected, the data are validated in accordance with the QAPP. This data validation and assessment process establishes whether the type, quantity, and quality of sampling data are adequate to support the decision making process (Data Quality Assessment - DQA). Data Quality Assessment is performed during Step 8 of systematic planning. Given the quality of the data collected, the DQA process will verify if the estimated contaminant concentrations at the site meet the level of confidence specified in the SAP. Additional information regarding data validation and data quality assessment is available from USEPA in Guidance for Data Quality Assessment: Practical Methods for Data Analysis (USEPA, 2000d) and Data Quality Assessment: A Reviewer's Guide (USEPA, 2006).

3.8.1 DATA VALIDATION

Data validation is the process used to determine if the environmental data are accurate; specifically, it assures that methods specified in the SAP and QAPP were correctly specified on the chain of custody document(s) and carried out by the laboratory such that the data are useful for its intended purpose(s). The data validation process begins at the analytical laboratory. The laboratory analyst verifies instrumental data, calculations, transfers, and documentation, and corrects errors, if detected. The laboratory provides QA/QC information to assure data validity. Labs selected for conducting analyses should have well-documented QA/QC procedures. Participation in established lab certification programs such as the NELAC certified laboratory program can help to establish that a laboratory has well-documented QA/QC procedures that are periodically audited by the certifying body. Technical department managers, quality control specialists, or project managers should review the laboratory data reports and supporting documentation.

3.8.2 DATA QUALITY ASSESSMENT PROCESS

Data Quality Assessment (DQA) is a five step process with the goal of determining whether the type, quantity, and quality of sampling data are adequate to support the decision making process.

Step 1: Review the DQO and Sampling Design

Review the DQO and sampling design to ensure the issues at the site have been adequately addressed. If data are not sufficient to move forward with selection of a remedy or other next step, additional sampling may be required. For example, if sampling did not delineate the vertical or horizontal extent of contamination, or if groundwater was not encountered due to drilling refusal at a site where groundwater was believed to be impacted; then additional sampling would typically be required.

Step 2: Conduct a Preliminary Data Review

Conduct a preliminary data review. Start with a review of the data validation assessment. Look for data patterns, relationships, or potential anomalies.

Step 3: Select the Statistical Method

Select statistical methods to assess the data. During the DQO development process, limits on decision error tolerance are specified. Uncertainty limits are typically proposed by establishing performance goals of the analytical data for precision, accuracy, repetitiveness, completeness, and comparability parameters. In addition, uncertainty limits and performance data are developed in more detail in the QAPP (See Subsection 3.7). Examine uncertainty limits through statistical evaluation, which is an important tool used in the data assessment to determine:

- Whether the data meet the assumptions under which the DQO and the data collection design were developed
- Whether the total error in the data is small enough to indicate that the data are of sufficient quality to support decisions within the tolerable error rates expressed in the DQO

During field sampling, a triplicate sample is typically collected in one DU for each batch of up to 10 similar DUs to allow for statistical calculation of several important quantities including the standard deviation of the mean, the relative standard deviation (RSD) of the mean and/or the 95% UCL of the mean. These quantities are the statistical measures that are typically selected for evaluating the overall precision of the contaminant sampling. Use of field sampling replicates and laboratory

subsampling/analysis replicates to evaluate MI sample precision allows consideration of total sampling error (a combination of field sampling/field processing error and laboratory subsampling and analysis error), as well as evaluation of the magnitude of field sampling error compared to the laboratory subsampling and analysis error. The latter is evaluated by subtracting the laboratory subsampling/analysis error (the laboratory replicate data) from the total error (the field replicate data) to determine the magnitude of the field sampling error.

Step 4: Verify the Assumptions of the Statistical Method

Evaluate whether the underlying assumptions of the statistical methods hold, or whether departures are acceptable, given the actual data.

Step 5: Draw Conclusions from the Data

Draw conclusions about the data collected. Discuss the validity of the data that do not meet the performance criteria established in the DQO.

Note: The HEER Office requires that an Environmental Hazard Evaluation be prepared and submitted with a site investigation report. Representative COPC concentrations developed as part of this evaluation may involve further statistical evaluation, including, for example, the assessment of non-detect data. A detailed discussion of Environmental Hazard Evaluations is presented in Section 13.

3.9 SITE INVESTIGATION REPORTS

Accurate and thorough documentation of the sample plan design, sample collection and handling procedures, laboratory analyses, data assessment, and a summary of the data collected are crucial to the site investigation. The laboratory selected should adhere to a comprehensive Quality Assurance Plan and SOPs for sample analyses. The HEER Office strongly encourages active communication, including draft report reviews and subsequent meetings or conference calls, to prevent costly remobilizations to collect additional data. The following reports (and major elements) are typically prepared and submitted to the HEER Office for review.

- Sampling and Analysis Plan
    - Sampling design
    - Preliminary Conceptual Site Model
    - Preliminary site investigation objectives and DQO
    - QAPP
    - Safety and Health Plan
- Site Investigation Report
    - Site history
    - Site investigation objectives (including DQO)
    - Selection of Decision Units, including replicates
    - Figures displaying all DU locations on site
    - Identification of information needs
    - Sample collection and analysis methods
    - Summary of analytical results
    - Data assessment
    - Summary of extent and magnitude of contamination
    - Preliminary Environmental Hazard Evaluation
    - Conclusions and recommendations

Additional guidance on report formats and content is presented in detail in Section 18. The HEER Office requires that the lateral and, as needed, vertical extent of soil and groundwater (and in some cases soil gas) contamination be clearly depicted on to-scale maps and cross sections of the site. Shading or other graphics should be used to depict DUs suspected to be contaminated above levels of potential concern. This information is then used in the Environmental Hazard Evaluation to identify specific environmental hazards posed by the identified contamination as well as the specific areas of the site where these hazards are present (see Section 13). The results of the preliminary Environmental Hazard Evaluation may require that additional data be collected at the site (e.g., soil gas data to evaluate potential vapor intrusion concerns) or that additional tests be carried out on existing samples. After all environmental hazards are adequately identified, delineated and evaluated, the final Site Investigation and Environmental Hazard Evaluation reports are used to support and assist in the development of appropriate response actions.

Not all projects will require that formal sampling plans and related reports be submitted prior to initiating site investigation activities; this will vary from site to site and should be discussed with the overseeing project manager in the HEER Office.

3.10 ENVIRONMENTAL HAZARD EVALUATION

An Environmental Hazard Evaluation is the link between site investigation activities and response actions, if needed (refer to Figure 3-1). A detailed discussion of Environmental Hazard Evaluation, including EALs, is provided in the HDOH document *Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater* (HDOH, 2016). An overview of the document is provided in Section 13.

As noted previously, the collection of site data and the identification of potential environmental hazards are iterative processes. Environmental Hazard Evaluations as well as CSMs should stress fate and transport of COCs. As initial site data indicate potential environmental hazards, the need for additional data to fully define and evaluate the hazards and develop appropriate response actions must be evaluated. The identification of potential hazards early on during site investigation activities, even at a cursory level, can help guide the progression of fieldwork and reduce the need for continual remobilization and collection of additional data.

Screening field data for the presence of potential environmental hazards as soon it arrives from the laboratory is a critical step in the site investigation process and should not be delayed pending the completion of a formal site investigation report. In the absence of obvious conditions in the field (e.g., explosive levels of soil vapors), the most expeditious approach to identifying potential environmental hazards associated with contaminated soil or groundwater is a direct comparison of site data to the HDOH Tier 1 EALs (see Section 13).

The presence or absence of potential environmental hazards can be quickly identified by direct comparison of site data to HDOH Tier 1 EALs. If the reported concentration of a COPC exceeds the Tier 1 EAL in the subject media (e.g., soil, soil gas, or groundwater) then the specific environmental hazard(s) potentially posed by the chemical should be identified (see Subsection 3.3.2). Exceeding the Tier 1 EAL does not necessarily indicate that environmental hazards are present, only that further evaluation is warranted. Perhaps most importantly, use of the Tier 1 EALs allows site owners/operators, consultants, and regulators to quickly screen out contaminants that do not pose potential concerns and negate the presence of environmental hazards at sites with minimal contamination. This is most easily done using the HDOH EAL Surfer available for download from the HDOH Environmental Hazard Evaluation web page).

As potential environmental hazards are identified, the CSM for the site should be updated and the need for additional sample data evaluated. For example, the identification of elevated levels of lead in soil samples from one area of the site may indicate a need for additional soil samples from that area to better define the extent of contamination. The identification of potential leaching hazards associated with a COPC suggests that batch testing and/or groundwater data may be needed. The identification of potential vapor intrusion concerns suggests that soil gas data are needed.

Applying this type of dynamic and iterative approach to the site investigation process will expedite completion of the investigation and approval by the HEER Office. Screening preliminary data up front allows for a more complete site investigation to be prepared and submitted. This reduces the need for remobilizing months (or even years) after the initial sampling event and the need for multiple and time consuming reviews of site investigation reports by the HEER Office. Informal meetings with a HEER Office project manager or technical support staff person to discuss preliminary data and propose additional actions as the site investigation is being carried out are highly encouraged.

SECTION 3 REFERENCES

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Appendix 3-A
Guidance for Soil Stockpile Characterization and Evaluation of Imported and Exported Fill Material.

(see PDF file)

Appendix 3-A
Guidance for the Evaluation of Imported and Exported Fill Material, Including Contaminant Characterization of Stockpiles

Guidance for Soil Stockpile Characterization and Evaluation of Imported and Exported Fill Material

October 2017

State of Hawai'i Department of Health,
Hazard Evaluation and Emergency Response Office
Honolulu, Hawai'i

NOTE: This guidance document will be updated periodically, as needed. Please send any comments or suggestions for edits or improvements to Roger Brewer at roger.brewer@doh.hawaii.gov *in the Honolulu HEER Office, or to John Peard at* randall.peard@doh.hawaii.gov *in the Hilo HEER Office.*

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Guidance for Stockpile Characterization and Evaluation of Imported and Exported Fill Material

This document provides guidance on the import and export of fill material at chemical contaminant removal or remediation sites that are overseen by the Hawai'i Department of Health (HDOH) Hazard Evaluation & Emergency Response Office (HEER Office). However, this guidance is also useful for consideration at general construction projects not under HEER Office oversight when imported fill materials may be used, or where export of fill material is proposed. This guidance may be particularly appropriate for consideration at sites where "sensitive" populations such as children, the infirmed or the elderly reside, or will reside, and could have exposure to imported soils - for example at schools, daycare centers, community gardens, parks, and homes.

Included in this guidance is the HEER Office's definition of "acceptable fill material", an overview of the fill material determination process, sources of fill that should be considered suspect for contamination, and other fill material management considerations. Guidance for the characterization of fill material or soil stockpiles is provided as an update and expansion of Section 4.2.8 of the Hazard Evaluation and Emergency Response (HEER) Office *Technical Guidance Manual* (TGM) – *Collection of Multi Increment* Samples for Stockpiles*. This guidance does not apply to projects involving fill materials that will be placed in State of Hawai'i waters (as defined by the Clean Water Act in Title 40 U.S. Code of Federal Regulations Part 232 [40 CFR Part 232]), and does not preclude compliance with any other laws or regulations.

∗ *Multi Increment® is a registered trademark of EnviroStat, Inc.*

1.0 Potential Hazards Related to Fill Material

Fill material that is imported to or exported from sites where significant environmental contamination has been identified, or where cleanup projects are underway, could pose multiple environmental hazards if not appropriately characterized and managed. The import of fill material from a source that has not been evaluated could inadvertently re-contaminate a remediated property, and may be considered illegal dumping. The inadvertent export of contaminated soil or sediments for use as fill material at another property could move human health or ecological risks from one place to another. Contaminated fill material can also pose direct- exposure hazards to workers installing or repairing subsurface utilities.

The construction industry generally characterizes imported or exported fill material with respect to specific geotechnical requirements (e.g., suitability for structural support), but may not include an evaluation of potential environmental hazards. Although importing and exporting fill material is a common practice in the redevelopment process, users may be unaware if contaminated fill material is brought to or removed from their property. Understanding the source of the fill material and the potential for contamination is very important. Laboratory testing is recommended for suspect fill material prior to import or export. Outreach and education efforts are an important element to

ensuring property owners and developers understand the potential hazards related to imported or exported fill material.

2.0 Definition of Acceptable Fill Material

Imported or exported fill material could include a variety of materials, including soils, dredged sediments, and construction and demolition debris (e.g., bricks, concrete, etc.). Under typical scenarios for properties where the HEER Office provides oversight, clean or "acceptable fill material" is defined as:

A) Natural materials consisting of soil, clay, sand, volcanic cinder and ash, and rock; or a mixture or combination of such materials, which are:

- Excavated from a quarry, borrow pit or earthen bank; dredged sediment, or from sources such as agricultural settling ponds; *and either*

    1. Not suspected to contain hazardous substances above applicable HEER Office Tier I Environmental Action Levels (EALs) based on the historical use of the fill source area (i.e., as documented by an environmental due diligence review). Includes consideration of chemical contaminants of concern for the site, including past legal use of pesticides; data on natural background chemical concentrations in the area may also be considered, though typically the HEER Office Tier I EALs are above natural background levels.

        Or

    2. Not known to have concentrations of chemical contaminants of concern above applicable HDOH Tier I EALs or appropriate alternative action levels approved by the HEER Office. Chemical concentrations are determined through laboratory testing of representative field samples. Refer to the HEER Office *Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater* and EAL Surfer Excel File (HDOH 2016a) for further details on HDOH Tier I EALs. Refer to the HEER Office TGM Sections 3, 4, and 5 on strategies and methods for collecting field samples (HDOH 2016b).

B) Construction materials or demolition material exclusive of soil that:

- Are known or tested to be free of paints, coatings, grouts/mortar, or adhering residues containing regulated quantities of hazardous substances such as lead, organochlorine termiticides, or asbestos.
- And meet the definition of "inert fill" under the Solid Waste Pollution statutes (HRS 342H-1) overseen by the HDOH Solid and Hazardous Waste Branch (SHWB). In accordance with HRS 342H-1, inert fill generally means earth, soil, rocks, rock-like materials such as cured asphalt, brick, and clean concrete less than eight inches in

diameter with no steel reinforcing rod. The fill material shall not contain vegetation or organic material or other solid waste. Soil (earth) must meet Tier 1 EAL criteria noted in "A" above for natural materials.

- Except, asphalt is not considered acceptable fill (and should not be used as fill material) on chemical removal or remediation sites overseen by the HDOH HEER Office unless otherwise approved by that office.

Note that lead-based paint, defined as >5,000 mg/kg lead (USEPA 2008), must be removed from asphalt prior to recycling for use as fill material. Lead-based paint striping does not, however, require removal for milled asphalt that is to be reprocessed as asphalt for pavement.

Acceptable fill material should not:

- Be considered a regulated hazardous waste, as determined in a site-specific, hazardous waste designation as described below;
- Be subject to other regulatory requirements for chemicals such as, but not limited to, lead and asbestos abatement requirements;
- Contain mobile, free liquids based on visual inspection;
- Create public nuisances (e.g., odors) to users or at adjacent properties;
- Include a significant amount of construction material or demolition debris other than the
- (uncontaminated) materials noted in the definition of acceptable fill material above, and
- Include street sweepings, asphalt paving, incinerator ash, or similar residential, commercial, or industrial wastes. Using these materials as fill material is not recommended due to the potential variability of their composition, the potential for contamination, and the associated difficulty in accurate sampling and testing.

Figure 1 presents a flow chart of the hazardous waste determination process for soil that is exported or imported to properties overseen by the HEER Office. If the soil is designated for disposal to a landfill or reuse at another off-site location, then the generator must make a hazardous waste determination in accordance with the Hawai'i Administrative Rules (HAR) §11-261-2. Making a hazardous waste determination is a step-by-step process. This begins with determining whether the soil meets the definition of a waste and, if so, meets criteria for classification as hazardous waste.

A "waste" is defined under HRS § 342-H as follows:

> "'Waste' means sewage, industrial and agricultural matter, and all other liquid, gaseous, or solid substance, including radioactive substance, whether treated or not, which may pollute or tend to pollute the atmosphere, lands or waters of this State."

A "hazardous waste" is defined under HRS § 342-J as follows:

> "'Hazardous waste' means a solid waste, or combination of solid waste, which because of its

quantity, concentration, or physical, chemical, or infectious characteristics may: (1) Cause or significantly contribute to an increase in mortality or an increase in serious irreversible or incapacitating illness; or (2) Pose a substantial existing or potential hazard to human health or the environment when improperly treated, stored, transported, disposed of, or otherwise managed."

Determining whether a waste is hazardous under RCRA (Resource Conservation and Recovery Act) can be done through one of the following methods:

- Knowledge – see Construction and Demolition Waste Disposal General Guidance (HDOH 2011); and/or
- Testing – Testing the waste according to the methods set forth in subpart C of HAR 11-261.

Soil impacted by chemicals at concentrations equal to or below the HDOH Tier 1 Environmental Action Levels (EALs) for unrestricted land use (HDOH 2016a) is considered "Inert fill material" for the purposes of a hazardous waste determination. This can be used as "generator's knowledge" to exclude the need for additional testing (e.g., TCLP) provided that samples were collected in accordance with the HEER Technical Guidance Manual (HDOH 2016b) and guidance provided in this document.

Soil impacted by chemicals above HDOH Tier 1 Environmental Action Levels (EALs) for unrestricted land use (i.e., residential use; HDOH 2016a) is considered to be "polluted" and therefore meets the definition of a "waste" under HRS § 342-H. Toxicity Characteristic Leaching Procedure (TCLP) tests should be carried out on soil that exceeds Tier 1 EALs and is proposed for offsite disposal or reuse as part of the hazardous waste determination process in accordance with HAR §11-261-24. If concentrations meet or exceed TCLP levels and the soil is designated for offsite disposal or reuse, then the soil is a hazardous waste and must be managed in accordance with HAR §11-261.

Consideration of soil that exceeds Tier 1 action levels for unrestricted land use but meets the HDOH action levels for commercial or industrial land use (see Appendix 1, Table I-2 in HDOH 2016a) for offsite reuse at such sites must be approved by the HEER Office in consultation with the SHWB. This should include preparation of a site-specific, Environmental Hazard Evaluation (EHE) in accordance with Section 13 of the HEER TGM as well as a site-specific Environmental Hazard Management Plan (EHMP) prepared in accordance with Section 18 of the HEER TGM (2016b). The EHMP must present institutional controls for long-term tracking and management of the soil. Synthetic Precipitation Leaching Procedure (SPLP) is required as part of the EHE if Tier 1 action levels for potential leaching concerns are exceeded, in accordance with HDOH (2016c).

A hazardous waste determination must be carried out in accordance with HAR §11-261-24 for soil that exceeds Tier 1 action levels for unrestricted land and is proposed for offsite reuse. This must include TCLP test data if the concentration of the subject chemical in soil in milligrams per kilogram equals or exceeds twenty-times the promulgated TCLP level in milligrams per liter (Table 1). This represents the minimum mass of the subject chemical that must be present in the soil in order for the TCLP level to be potentially reached, assuming 100% extraction of the chemical from the soil during the TCLP leaching procedure. Yellow highlighting indicates chemicals with Tier 1 Soil EALs that exceed

twenty times the TCLP level (adjusted to mg/kg) but otherwise do not pose a significant risk to human health and the environment at the concentrations noted. TCLP data *are not required* for onsite or offsite reuse of soils that meet the Tier 1 EALs provided that characterization of the soil was carried out in accordance with the HEER Office *Technical Guidance Manual*.

Comparison of soil data to TCLP limits *is not* part of the EHE process. As indicated in Table 1, soil that meets TCLP limit could still pose significant risk to human health and the environment outside of a regulated, landfill environment. Individual counties might have additional requirements regarding the import or export of fill material. Contact the respective counties regarding fill material use or fill material export issues prior to movement of the material.

Figure 1. Hazardous waste determination process for exported or imported soil.

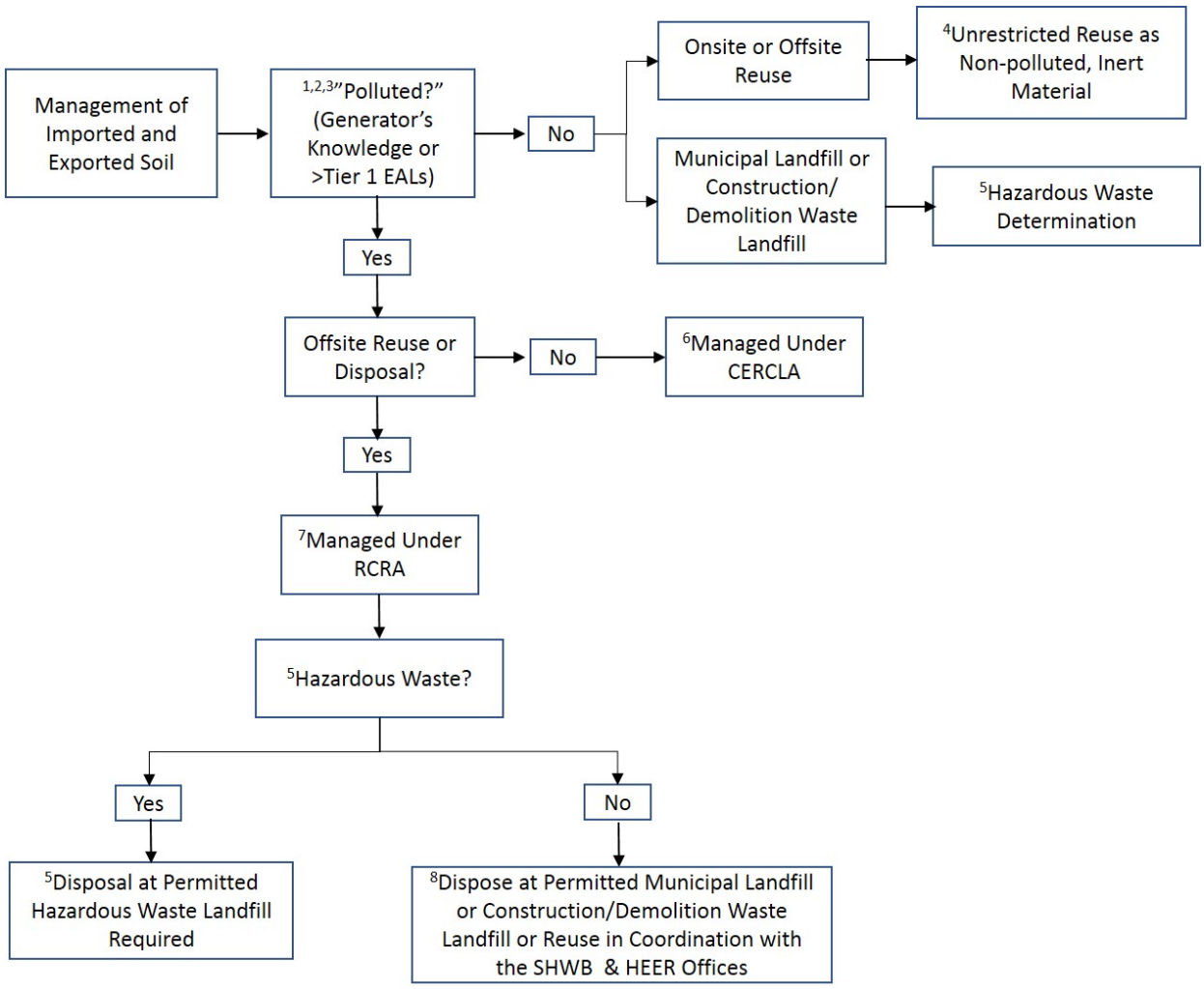


Figure 1 notes:

1. Imported or exported soil initially defined as a potential "waste" under HRS §342H-1 (Solid Waste Pollution). "Waste" defined as a "substance … which may pollute the atmosphere, lands or waters or Hawaii."

2. "Polluted" or "contaminated" soil defined as a soil with one or more potentially hazardous substances at a concentration that exceed HDOH Tier 1 EALs for unrestricted land use (HDOH 2016a; Tier 1 EALs for soil within 150m of a surface water body and situated over groundwater that is a source or potential source of drinking water).

3. Soil should be characterized in accordance with Decision Unit and Multi Increment Sample investigation methods described in the HEER *Technical Guidance Manual* (www.hawaiidoh.org) if testing is required due to insufficient generator knowledge of contamination potential.

4. "Inert Waste" includes "earth… which will not cause a leachate of environmental concern" (HAR §11-58.1, Solid Waste Management) *and* meets HDOH Tier 1 EALs for unrestricted land use.

5. Hazardous Waste Determination must include testing for Toxicity Characteristic Leaching Procedure if concentration of contaminant in soil (mg/kg) exceeds HDOH Tier 1 EALs for unrestricted land use AND is equal to or greater than 20 times the TCLP level (mg/L) for that chemical. TCLP data are not required as part of a hazardous waste determination if the concentration of the contaminant in soil is less than 20 times the TCLP level under any scenario. Soil cannot be disposed of at a municipal landfill or construction/demolition waste landfill if determined to be a hazardous waste under HAR §11-261 (Hazardous Waste Management). The soil must either be managed onsite under 128D through the HEER Office or disposed of at a permitted, hazardous waste landfill under the oversight of the SHWB.

6. Soil managed on-site under HRS §128-D (Environmental Response Law).

7. Soil managed for offsite reuse or disposal under HAR §11-261 (Environmental Response Law).

8. Offsite reuse of soil from a HEER project site that fails Tier 1 EALs for unrestricted land use but meets action levels for commercial/industrial land use *and* is not a hazardous waste must be carried out in coordination with the HEER Office and the Solid Waste Section of the SHWB. Land use restrictions and preparation of an Environmental Hazard Management for long-term management of the soil will be required under most circumstances.

Table 1. Comparison of Tier 1 Soil EALs with "20X TCLP" minimum concentration of chemical in soil necessary to require TCLP test data prior to disposal of soil in a municipal or construction/demolition waste landfill.

USEPA Hazardous Waste Number	Contaminant	CAS No. 2	[1]Regulatory Level (mg/L)	[2]20X Equivalent in Soil (mg/kg)	[3]HDOH Tier 1 Soil EAL (mg/kg)
D004	Arsenic	7440-38 -2	5.0	100	23
D005	Barium	7440-39 -3	100.0	2,000	1000
D018	Benzene	71 -43 -2	0.5	10	0.30
D006	Cadmium	7440-43 -9	1.0	20	14
D019	Carbon tetrachloride	56 -23 -5	0.5	10	0.10
D020	Chlordane	57 -74 -9	0.03	0.6	17
D021	Chlorobenzene	108-90 -7	100.0	2,000	1.5
D022	Chloroform	67 -66 -3	6.0	120	0.026
D007	Chromium	7440-47 -3	5.0	100	1000
D023	o -Cresol	95 -48 -7	200	4,000	-
D024	m -Cresol	108-39 -4	200	4,000	-
D025	p -Cresol	106-44 -5	200	4,000	-
D026	Cresol		200	4,000	-
D016	2,4-D	94 -75 -7	10.0	200	0.34
D027	1,4-Dichlorobenzene	106-46 -7	7.5	150	0.055
D028	1,2-Dichloroethane	107-06 -2	0.5	10	0.023
D029	1,1-Dichloroethylene	75 -35 -4	0.7	14	1.1
D030	2,4-Dinitrotoluene	121-14 -2	0.13	2.6	0.024
D012	Endrin	72 -20 -8	0.02	0.4	3.8
D031	Heptachlor (and its epoxide)	76 -44 -8	0.008	0.16	0.071
D032	Hexachlorobenzene	118-74 -1	0.13	2.6	0.22
D033	Hexachlorobutadiene	87 -68 -3	0.5	10	0.041
D034	Hexachloroethane	67 -72 -1	3.0	60	0.023
D008	Lead	7439-92 -1	5.0	100	200
D013	Lindane	58 -89 -9	0.4	8.0	0.029
D009	Mercury	7439-97 -6	0.2	4.0	4.7
D014	Methoxychlor	72 -43 -5	10.0	200	16
D035	Methyl ethyl ketone	78 -93 -3	200.0	4,000	6.2
D036	Nitrobenzene	98 -95 -3	2.0	40	0.0053
D037	Pentrachlorophenol	87 -86 -5	100.0	2,000	0.098
D038	Pyridine	110-86 -1	5.0	100	-
D010	Selenium	7782-49 -2	1.0	20	78
D011	Silver	7440-22 -4	5.0	100	78
D039	Tetrachloroethylene	127-18 -4	0.7	14	0.098
D015	Toxaphene	8001-35 -2	0.5	10	0.49
D040	Trichloroethylene	79 -01 -6	0.5	10	0.089
D041	2,4,5-Trichlorophenol	95 -95 -4	400.0	8,000	0.50
D042	2,4,6-Trichlorophenol	88 -06 -2	2.0	40	0.31
D017	2,4,5-TP (Silvex)	93 -72 -1	1.0	20	0.87
D043	Vinyl chloride	75 -01 -4	0.2	4.0	0.036

Table 1 notes.

1. Promulgated TCLP level for determination of soil as a hazardous waste. If the result of a TCLP test meets or exceeds the level noted for the subject chemical, then the soil is classified as a "hazardous waste" and cannot be disposed of in a municipal landfill or construction/demolition waste landfill.

2. Minimum concentration of the subject chemical that must be present in the soil (mg/kg) in order for the TCLP level (mg/L) to be potentially reached, assuming 100% extraction of the chemical from the soil during the TCLP leaching procedure. TCLP data are required for disposal of the soil at a municipal landfill or construction/demolition waste landfill if the concentration of the chemical in soil exceeds HDOH Tier 1 EALs for unrestricted land use AND is equal to or greater than twenty-times the TCLP level noted in the Table 1. TCLP data are not required for onsite or offsite reuse of soils that meet the Tier 1 EALs provided that characterization of the soil was carried out in accordance with the HEER Office *Technical Guidance Manual*.

3. HDOH Tier 1 Soil Environmental Action Level for unrestricted land use, including residential, schools, medical facilities, parks, etc., where children and other sensitive populations might be present on a regular basis.

3.0 Fill Determination Process

The purpose of the fill determination process is to determine if proposed fill material meets the HEER Office definition of acceptable fill material. Determination of the presence or absence of contamination above action levels in proposed fill material will help ensure that using the fill material will not adversely impact human health or the environment. Options to complete the fill determination process include:

Option 1 – An environmental due diligence review of the fill source property that concludes there is no evidence of past releases that could pose an environmental hazard(s) (as described in HDOH 2016a) or evidence of any other Recognized Environmental Condition (REC) (as defined in ASTM 2005) that suggests the proposed fill material could contain chemical contaminants above applicable HDOH Tier I EALs. This includes consideration of past legal use of pesticides. See Section 3.1.

Note: Obtaining fill material from a quarry that documents their fill material is acceptable based on an environmental due diligence review of their fill source property and the considerations noted in Option 1 would be a suitable determination for those using the fill. A copy of the quarry's environmental due diligence report should be available for reference and documentation, and it is important to verify with the quarry that the area from which the fill material was obtained is included in environmental due diligence report.

Option 2 – A fill material characterization report that summarizes representative analytical data for the proposed fill material from the fill source operator, fill importer, or fill exporter. See Section 3.2.

3.1 Environmental Due Diligence Review

This fill determination option involves conducting an environmental due diligence evaluation of the fill source area or property. One method to accomplish this is to conduct a Phase I Environmental Site Assessment (ESA) of the fill source area or property in accordance with ASTM Standard Practice E 1527-05 (ASTM 2005) and the U.S. EPA's *Final Rule on Standards for Conducting All Appropriate Inquiry* (AAI) (USEPA 2005). If the findings of the Phase I ESA indicate that there is no evidence of a significant release of a hazardous material at the fill source property (including petroleum products), then the material can be managed as acceptable fill material. If requested, the Phase I ESA report for the fill source property should be provided to the HEER Office for inclusion in the site file, otherwise citation to the Phase I ESA indicating no evidence of a chemical release should be included in reports. Preparation and submittal of a formal, Phase I ESA should be considered for sites where a significant amount of fill material is to be imported and spread over a large area that will remain exposed after development (e.g., large residential redevelopment). A formal Phase I ESA is generally not necessary for the import of small volumes of fill material from known source areas, especially if past evaluations of the fill source property are available to document that the fill material is not suspect for contamination. Final documentation judged appropriate should be incorporated into the Removal or Remedial Action report for the site for review by the HEER Office and inclusion as part of the public

record.

If the findings of an environmental due diligence evaluation suggest a potential that chemical contaminants are present above environmental action levels (e.g., in excess of HDOH Tier I EALs for unrestricted land use), then representative sampling and analytical testing of the fill material should be conducted.

3.2 Fill Material Characterization

This fill determination option involves representative sampling and analysis of the proposed fill material and preparation of a fill material characterization report. A qualified environmental consultant contracted by the fill material provider, importer, or exporter should carry out testing and analysis. Preparing a fill material characterization report facilitates the review process by the HEER Office. Information that should be provided in the fill material characterization report includes:

Intended use of the fill material and land use/zoning or planned future land use at the site where it will be utilized;

- Quantity of fill material to be imported, exported, or relocated on-site;
- Description of the fill material's original nature (i.e., undisturbed native condition) including the source property address, tax map key (TMK) number, and owner contact information;
- Fill material source property historic usage (i.e., industrial, residential, agricultural, etc.), and citation to Phase I ESA report, if applicable;
- Previous fill material use(s) when the material is other than undisturbed native material;
- Summary of sampling methodology and analytical results from the sampling of the fill material, including:

    1. Identification of decision units (DUs) (e.g., horizontal and vertical dimensions);
    2. Number of DUs per volume of fill material;
    3. Number of sampling increments in DUs;
    4. Number and location of replicate samples;
    5. Summary of laboratory analytical results and copy of laboratory data reports;
    6. Chain of custody documentation; and
    7. Any additional information that may be necessary to assess the fill material contamination status.

- Evaluation of sample data with respect to potential environmental hazards (e.g., comparison to HDOH Tier I EALs using the HDOH EAL Surfer Excel File (HDOH 2016a); and
- Identity/signature by party responsible for evaluation of each source of fill material.

Some of the information for the fill material characterization report may be available from a Phase I ESA or the laboratory analytical data reports from any previous investigation of the proposed fill material source.

As discussed in Section 5 of this document, the effort necessary to characterize a fill source is dependent on a number of site-specific factors. For example, the proposed use of comingled, existing stockpiles of unknown origin will require a more detailed investigation than proposed fill material from a single, known source (e.g., fill material from a former agricultural field). Proposed fill material that could be contaminated by highly mobile, volatile or leachable contaminants will require a more detailed sampling and characterization (due to vapor intrusion and groundwater protection concerns) than proposed fill material where targeted contaminants are limited to low-mobility chemicals (e.g., Polychlorinated biphenyls (PCB), dioxins, arsenic, lead, etc.).

Exceptions to the need for a fill material characterization report, as noted above, should be discussed with the HEER Office on a case-by-case basis. Citation to the environmental due diligence review, alternative documentation (i.e., brief overview of the fill source and potential for contamination), or a copy of the fill material characterization report should be included in the final Removal or Remedial Action report for the site (see Sections 14 and 16 of the HEER Office TGM).

4.0 Suspect Fill Material Sources

Certain property and land uses are at a higher risk for the possible presence of contaminated soil (Table 2). Fill material originating from these areas should be considered "suspect" and will generally require site-specific, representative sample data to make an acceptable fill determination.

Table 2 – Suspect Fill Sources

Commercial & Residential Sites	Industrial Sites	Agricultural & Other Sites
• Fuel stations • Automotive repair or maintenance shops • Junkyards or recycling facilities • Dry cleaners • Photographic processing facilities • Painting facilities • Sites where hazardous materials or hazardous wastes were used, stored, or generated • Sites where environmental cleanup activities have not achieved HEER Office Tier 1 EALs for unrestricted use • Rail lines • Former building sites where buildings were painted with lead-based paints, or were treated with persistent termiticides	• Landfills or disposal facilities • Metal processing plants • Bulk petroleum facilities or oil refineries • Waste treatment plants • Wood treatment facilities • Manufacturing facilities • Sites where hazardous materials or hazardous wastes were used, stored, or generated • Sites where environmental cleanup activities have not achieved HEER Office Tier 1 EALs for unrestricted use • Rail lines • Former building sites where buildings were painted with lead-based paints, or were treated with persistent termiticides	• Agricultural fields (current or former) • Pesticide storage or mixing areas • Pesticide container disposal areas • Seed dipping areas • Settling ponds • Bagasse piles • Former plantation housing areas • Rail lines • Area with existing fill • Dredged sediments from heavily developed areas (e.g., canals, harbors, etc.) • Military sites

Former agricultural fields are a common potential source of fill material in Hawai'i (e.g., former sugarcane and pineapple lands). For example, refer to map of estimated lands in sugarcane production in the HEER Office Fact Sheet *Arsenic in Hawaiian Soils: Questions and Answers on Health Concerns* (HDOH 2010a). The past use of pesticides on agricultural lands makes these areas suspect for potential contamination. Sections 3 and 4 of the HEER Office TGM discuss approaches for the investigation of former field areas. Section 9 of the HEER Office TGM provides an overview of past pesticide use in Hawai'i and includes guidance on the selection of contaminants of potential concern (COPC) for former sugarcane and pineapple lands.

As discussed below, proposed fill material suspected of contamination by volatile or highly leachable chemicals requires a more detailed and expensive evaluation before use as fill material. Using fill material that could include small but heavily contaminated pockets of volatile or highly leachable chemicals is strongly discouraged (e.g. greater than or equal to 20 cubic yards [yd^3] in volume). A summary of volatile and highly leachable chemicals listed in the current HEER Office Environmental Action Levels lookup tables is included as Appendix 1 to this document.

5.0 Fill Material Sampling Strategies and Methods

Scenarios where sampling proposed fill material is recommended include:

- Fill source where the findings of a Phase I ESA indicate that there is evidence or likelihood of a significant release of a hazardous material (i.e., could result in contamination above applicable action levels),
- Fill source where background information is unavailable, or
- Fill source where some chemical sampling data is available, but data is not representative for the material to be used, or does not include all contaminants of concern for the site.

Representative sampling must be conducted to ensure appropriate decision-making for use as fill material. Refer to the relevant sections of the HEER Office TGM for detailed guidance on designation of DUs (Section 3, as well as the collection and evaluation of Multi Increment (MI) soil samples (Section 4). A DU is a targeted area and volume of soil from which samples are to be collected and decisions made based on the resulting data. A MI sample is collected within each DU and analyzed to estimate the representative (i.e., mean) concentration of each targeted contaminant. The collection of discrete soil samples is usually discouraged. Alternative sampling approaches should be discussed with the HEER Office on a case-by-case basis.

5.1 Decision Unit Designation and Characterization

The level of effort necessary to characterize a fill source is dependent on a number of factors, including:

- Anticipated homogeneity or heterogeneity of large-scale contaminant distribution (e.g., potential presence of spill areas greater than 20 to 100 yd3);

- Anticipated mobility of targeted contaminants and associated, potential environmental hazards;
- Intended use of the fill material (e.g., residential versus commercial or industrial property);
- Size of receiving area and anticipated average depth of fill material; and
- Size and depth of the source area and the volume of fill material to be exported.

A site-specific sampling strategy could involve single or multiple DUs to generate representative data.

To avoid contamination of previously remediated sites or sites not known to be contaminated, the HEER Office strongly recommends that all sampling activities of proposed fill material be completed prior to delivery at the receiving site. It is important to include the time required to collect, analyze, and evaluate data for proposed fill material in the initial project budget and schedule.

5.1.1 Designation of Decision Unit Volume at the Fill Source Based on the Receiving Area

One approach for testing fill material before it is delivered to a receiving site is to designate "exposure area" DUs at the receiving site, estimate the volume of fill material to be placed in each DU, and then test a similar volume of soil at the source area. This approach is generally applicable only to fill sources where the suspect COPCs have been identified as "low mobility" contaminants, and not for fill sources where volatile or highly leachable COPCs are suspect (see Appendix 1).

For example, assume that a one-acre commercial/industrial site is subdivided into two, approximately 20,000 square feet (ft^2) "exposure area" DUs. The average thickness of fill material to be placed at the site is two feet. Each DU will therefore contain approximately 1,500 $yd^3$of soil. An equal DU volume of soil can then be designated at the fill material source area, whether it is an *in-situ* or stockpiled source. Whatever the volume selected under this approach, remember that representative sampling of that volume of fill is required, so the entire DU volume (at the fill source) must be accessible for possible increment collection, and multiple increments will need to be collected throughout the entire depth or height of the DU.

This approach is likely to be more efficient and cost-effective at sites where more than six-inches of fill material are to be placed, as assumed in the source-area DU designation approaches described below. Potential disadvantages are 1) using a larger DU associated with certain land use categories may not allow subsequent use or reuse for a land use category with a smaller DU recommendation without conducting additional sampling, and 2) reuse of the fill material at future sites, where the initial level of testing was not adequate to clear the soil if spread in a thinner layer over a broader area (e.g., six inches). Consultants should use their professional judgment based on the initial test results and knowledge of the source area to determine if these are potentially significant issues.

5.1.2 Source Area Characterization of In-situ Soil

Sections 3 and 4 of the HEER Office TGM provide guidance on the characterization of *in-situ* soil. In many cases, material that is intended to be excavated and used for fill material will be most efficiently sampled *in-situ*. Excavated and stockpiled fill material can be more difficult to access for representative

sampling unless a large amount of space is available to store and flatten large stockpiles. Excavated soil that is subsequently determined to be contaminated may require additional assessment, remediation, or containment.

As discussed in Section 3 of the HEER Office TGM, known or suspect spill areas should be individually investigated as separate DUs. This includes but is not limited to:

- Former pesticide storage and mixing areas;
- Soil around the perimeter of buildings potentially contaminated with lead-based paint;
- Soil around or under buildings suspected to be contaminated with persistent insecticides (e.g., organochlorine termiticides); and
- Obvious or suspected spill areas associated with underground storage tanks (USTs), aboveground storage tanks (ASTs), pipelines, PCB-containing transformers, and other commercial or industrial operations.

Dividing the fill source area into Exposure Area DUs is appropriate for sites where localized spill areas are not anticipated and the soil is not suspected to be contaminated with volatile or highly leachable chemicals.

Proposed fill source areas that are not suspected to include localized spill areas should be divided into Exposure Area DUs, as described in Section 3 of the TGM (i.e., primary environmental hazard is direct-exposure to soil). A summary of recommended, default DU areas, DU volumes, and sampling depth for the *in-situ* characterization of proposed fill material source areas is provided in Table 3. Fill sources that are flagged for possible contamination concerns but are not suspected to include localized spill areas should be sampled and characterized at a DU size of 5,000 ft^2 for unrestricted use. This is the default residential home exposure area, to a depth of 6 inches below ground surface.

A DU area of 20,000 ft^2 (approximately one-half acre) is acceptable to characterize a fill source area for use in large, high-density residential redevelopments or schools. Larger DU sizes may be acceptable for source areas that are to be used only for commercial or industrial fill material. Recommended DU numbers in Table 3 include a minimum of 18 DUs (rather than 15 DUs) to achieve a minimum 60% level of confidence that 95% of the entire site is "clean" at the scale of these large-sized DUs (see also Table 6). While potentially acceptable for some sites and land uses, characterizing a fill material source area at DU sizes larger than recommended for unrestricted use of the fill material can limit future use of the property where the fill material is placed. Characterization of fill material source areas should be discussed with the HEER Office on a case-by-case basis to help ensure appropriate objectives will be met.

Depending on the depth and volume of fill material to be excavated, *in-situ* sampling may need to be done in successive lifts or at incremental depths to allow access for representative sampling. Borings, trenches, or test pits can be used to access and characterize deeper soils as necessary, depending on the nature of the site and the proposed soil removal depth. For borings, the entire core from a targeted depth interval is the DU layer "increment" for that boring. Sending the full increment

to the lab for subsampling and analysis may be impractical for long cores. As an alternative, the targeted interval of a core can be subsampled by collecting a representative core-wedge sample or MI sample (e.g., using a small core sub-sampling device, refer to Section 5 of the HEER Office TGM). This approach will reduce the overall mass of the samples collected. It is recommended that the HEER Office be consulted when designing a subsurface sampling strategy for characterization of DU layers of varying thickness and depth.

When soil is going to be moved off-site for disposal or proposed reuse prompting the need for a hazardous waste determination under Hazardous Waste rules (HAR 11-262-11), *ex-situ* sampling of the soil (e.g., from excavated stockpiles) is generally preferred over *in-situ* sampling, to ensure the sampling is representative of the specific material designated to be moved off-site.

Table 3 – Default DU Area for *In Situ* Characterization of Proposed Fill Material Source Areas

[Assumes Only Low-Mobility Contaminants Present, and Absence of Known Spill Areas or Pockets of Volatile or Highly Leachable Contaminants]

Receiving Site Land Use Category	[1]Recommended DU Area/Volume/Depth	Comments
Unrestricted Use[2]	5,000 ft^2 /100 yd^3/6 in.	Default DU area for unrestricted land use.
Schools and High-Density Residential Developments[2]	20,000 ft^2/400 yd^3/6 in.	Based on an assumed exposure area of approximately 0.5 acre.
Commercial or Industrial use only (formerly developed fill source)[2,3]	20,000 ft^2/400 yd^3/6 in.	Based on an assumed exposure area of approximately 0.5 acre.
Commercial or Industrial use only[3] (agricultural field fill source)[2]	Minimum 18 DUs/soil volume will vary/6 in.	Proposed source area divided into a minimum of 18 DUs for characterization of fill material.

Notes:

DU Decision Unit

ft^2 square feet

1. Using DU sizes larger than recommended for unrestricted fill source areas may require retesting of property where fill material is placed if proposed for more sensitive land use in the future (e.g., residential).
2. Larger volumes may be acceptable on a case-by-case basis. DU volumes up to 400 yd^3 acceptable for unrestricted reuse on site-by-site basis if prior knowledge and a thorough Phase I indicates low potential for contamination above Tier 1 EALs. Collect triplicate MI samples in 10% of DUs (minimum one set).
3. Multiple vertical depths may need to be sampled, depending on volume of fill material being characterized. Refer to Section 5.1.1 for the option of basing the DU volume of the fill source on the planned use of fill at the receiving site.

5.1.3 Source Area Characterization of Stockpiled Fill Material

A general approach for the investigation of stockpiles is summarized in Table 4. Multiple factors need to be considered when developing a sampling strategy for stockpiled soil being considered for potential fill material, including but not limited to:

- Specific composition or type of fill materials in the stockpile;

- Number of source areas associated with the stockpile;
- Historical use of the fill source property or properties, if known;
- COPCs and associated environmental hazards;
- Existing fill material analytical data, if available;
- Planned use of the fill materials;
- Volume of fill to be imported or exported; and
- Scheduling of sampling activities.

Stockpiles of proposed fill material from different source properties with the potential for different types or degrees of contamination should be characterized separately. This will help avoid the need to re-segregate and characterize otherwise large volumes of acceptable fill material due to the inclusion of a relatively small volume of heavily contaminated soil. Similarly, stockpiles or significant portions of stockpiles (i.e., greater than 20 yd^3 in volume) that are suspected to contain pockets of heavy contamination ("spill areas") should be isolated and characterized separately. Proposed fill material from small but heavily contaminated stockpiles should not be deliberately mixed with "clean" or less contaminated stockpiles to dilute overall contaminant concentrations.

The approach described assumes that all fill material originating from a single fill source property will be used for the same purpose at the receiving site. If the fill material will be used for multiple purposes, it may be necessary to form individual stockpiles segregated by use. The HEER Office should be consulted prior to sampling for sites where fill will be used for multiple purposes.

Table 4 – General Approach for Sampling Stockpiled Fill Material

Steps/Activities
1. Segregate stockpiles of proposed fill material from different fill source properties.
2. Segregate volumes of proposed fill material from "spill areas."
3. Select appropriate DU volume(s) based on proposed land use and contaminants of concern.
4. Choose a sampling strategy and tools that will provide access to sampling points throughout each DU.
5. Collect triplicate Multi Increment samples in 10 percent of DUs (minimum one set).
6. Consult with HEER Office if proposed fill material from a single fill source property will be used for multiple purposes at the receiving site to determine if alternative sampling strategies need to be implemented.
7. Consider the specific timing of the sampling activities – sampling during stockpile formation is preferred to sampling after stockpile formation.

5.1.3.1 Stockpile Decision Unit Designation

Table 5 summarizes the DU volume recommended for characterization of fill material in stockpiles. Decision units for stockpiles should generally be designated in terms of volume, rather than area. The appropriate DU volume for a stockpile is based on a number of factors, including:

- Targeted contaminants and associated environmental hazards;
- Proposed use of fill material at receiving site (e.g., residential versus commercial or industrial property, etc.); and
- Total volume of fill material to be characterized.

Appendix 1 categorizes chemicals listed in the HEER Office Environmental Hazard Evaluation (EHE) and Environmental Action Limit (EAL) guidance (HDOH 2016a) in terms of volatility and leachability. As discussed below, these characteristics are used to flag chemicals that may pose significant vapor intrusion or leaching hazards that could require a more detailed characterization of the proposed fill material.

Table 5 – Summary of Default Stockpile DU Volumes Based on Targeted Contaminants of Concern

Targeted Contaminants of Concern[1]	Receiving Site Land Use Category	[1]Default Stockpile Decision Unit Volume	Example COPCs[2]	Associated Environmental Hazards
Volatile Compounds	Any	20 yd^3	TPHg, TPHd, BTEX, naphthalene, PCE, TCE, mercury	Potential vapor intrusion hazards
Highly Leachable, Non-Volatile Contaminants	Any	20 yd^3	Triazines (e.g., atrazine), chlorinated herbicides, perchlorate, explosives	Potential leaching and surface runoff or groundwater contamination hazards
Low Mobility Contaminants[,2,3,4,5]	Unrestricted Use	100 yd^3	PCBs, dioxins, arsenic, lead, PAHs, Technical Chlordane, DDT	Primarily pose direct exposure hazards
	Schools and High-Density Residential Developments	400 yd^3		
	Commercial or Industrial use only (formerly developed fill source)	400 yd^3		
	Commercial or Industrial use only (agricultural field fill source)	Minimum 18 DUs		
	Beaches (replenishment projects)	800 yd^3		

Notes:

COPCs	contaminants of potential concern
BTEX	benzene, toluene, ethylbenzene, and xylenes
PAHs	polycyclic aromatic hydrocarbons
PCBs	polychlorinated biphenyls
PCE	perchloroethylene
TCE	trichloroethylene
TPHg	total petroleum hydrocarbons as gasoline
TPHd	total petroleum hydrocarbons as diesel
yd^3	cubic yards
1	See text for description of contaminant categories, and Appendix 1 for a list of chemicals in these categories. DU volume recommended for volatile or highly leachable chemicals applies to remediated sites known to be contaminated above Tie 1 EALs and subsequently remediated (vs general site screening).
2	Collect triplicate MI samples in 10% of DUs (minimum one set).
3	Include SPLP batch tests for metals if Tier 1 EALs exceeded (HDOH 2016c).
4	Larger volumes may be acceptable on a case-by-case basis. DU volumes up to 400 yd^3 acceptable for unrestricted reuse on site-by-site basis if prior knowledge and a thorough Phase I indicates low potential for contamination above Tier 1 EALs. Using DU sizes larger than accepted for unrestricted fill source areas may require retesting of property where fill material is placed if property is proposed for more sensitive land use in the future (e.g., residential).
5	Using soil with potential pockets of low volatility and relatively immobile heavy oil as fill material not recommended due to gross contamination concerns (see also HDOH HEER Office, 2016a).

5.1.3.2 Stockpiled Fill Material Potentially Contaminated with Volatile Organic Compounds

A chemical is considered to be "volatile" if its Henry's Law constant is greater than 0.00001 atm m^3/mole and molecular weight is less than 200 (HDOH 2016a; refer to Table H in Appendix 1). Consideration of fill material from sites previously known to be contaminated with volatile compounds is not recommended, due to the high cost of testing and potential vapor intrusion hazards for nearby or future buildings if residual contamination is inadvertently missed. This includes gasoline and diesel fuels or chlorinated solvents (e.g., perchloroethylene [PCE], trichloroethylene [TCE], etc.). Mercury should be considered a volatile chemical, although volatility can decrease over time for releases to soil. Volatile contaminants also pose leaching and groundwater contamination hazards. Due to these concerns, characterization of stockpiles possibly contaminated with volatile organic compounds (VOCs) typically requires relatively small DU volumes.

If using the soil for fill material is still desired, then the HEER Office recommends a sample frequency of one DU per 20 yd^3. For reference, this DU volume equates to approximately 6 inches of fill material under a default 1,000 ft^2 building floor – the default building size in vapor intrusion models (HDOH 2016a). Individual increments should be collected using a VOC-specialized sampling device (e.g., Core N' One, Terra Core, Encore, etc.) and extruded into a container with a premeasured volume of preservative such as methanol. A minimum of a 1:1 ratio of sample preservative to sample media is recommended. "In-field preservation" of the increments is preferred to minimize loss of VOCs. Alternatively, the individual increments (stored in the VOC-specialized sampling device) can be frozen and submitted to the laboratory for combination into a Multi Increment sample. Refer to Section 4.2.7 of the HEER Office TGM (HDOH 2016b) for additional guidance on multi- increment sampling for VOCs. Note that this recommended DU volume does not apply for general screening of soil otherwise not anticipated to contaminated with VOCs or highly leachable chemicals (see below) as part of a due diligence investigation.

Petroleum-contaminated soil poses potential gross contamination concerns (e.g., buildup of explosive gases, general odor and aesthetic concerns, etc.), as well as leaching and vapor intrusion hazards. Using petroleum- contaminated soil as fill material is not recommended. The analytical costs of sampling the proposed fill material for lighter weight fuels (e.g., gasoline and diesel fuels) and chlorinated solvents may also be cost prohibitive. Although heavier petroleum oils are not considered significantly volatile or leachable, the potential for gross contamination concerns generally negates using soil that has potential pockets of heavy oil contamination from being used as fill material. Refer to HEER Office guidance for long-term management of petroleum-contaminated soil for additional information (HDOH 2007; see also Section 18 in HDOH 2016b). Incidental leaks and minor soil contamination associated with normal operations of equipment are generally not significant enough to trigger petroleum and other chemicals as COPCs (e.g., small leaks of oil from heavy equipment in a quarry).

5.1.3.3 Stockpiled Fill Material Potentially Contaminated with Highly Leachable, Nonvolatile Contaminants

For this guidance, a chemical is assumed to be highly leachable if the sorption coefficient (koc) is less than or equal to 1,000 cm^3/g (HDOH 2016a). This reflects a default Kd model value of 1.0 assuming a total organic carbon content in the soil of 0.1% (refer to Table H in Appendix 1). Consideration of fill material from sites that were known to be contaminated with highly leachable, non- volatile contaminants is not recommended (e.g., excess soil from former pesticide mixing areas or munitions disposal areas). As is the case for soils contaminated with volatile chemicals, the added analytical costs of sampling needed to clear the soil for use as fill material is likely to exceed the cost of the fill material itself.

Common COPCs that are considered highly leachable include (see also Appendix 1; HDOH 2016a):

- Triazine herbicides (e.g. ametryn, atrazine, and simizine);
- Organophosphate pesticides;
- Chlorinated herbicides (e.g. 2,4-D and 2,4,5-T, dalapon);
- 1,4 Dioxane;
- Perchlorate; and
- Explosive-related compounds (e.g., HDX, RDX, PETN, etc.).

Refer to Section 9 of the HEER Office TGM for more details on pesticide contaminants that could be a concern for certain sites. Leaching of these COPCs from fill material could pose a significant threat to groundwater resources. If using the proposed fill material is still desired, then the HEER Office recommends a sample frequency of one DU per 20 yd^3. This is assumed to represent the minimum size of a spill area that could pose potentially significant leaching hazards. If the reported concentration of a chemical exceeds HDOH leaching based action levels, then a site-specific soil leaching test can be carried out and an alternative action level developed (HDOH 2016c).

The mobility of metals in soil is generally assumed to be low, but should be evaluated on a site-by-site basis. If needed, potential metal mobility should be evaluated by a batch test in accordance with HEER Office guidance (refer to HDOH 2016c).

As discussed in Section 9.1 of the HEER Office TGM, former agricultural fields do not need to be tested for chlorinated herbicides and other pesticides with low persistence to clear these areas for redevelopment or to clear the soil in the fields for use as fill material. Sampling should instead focus on persistent, non-mobile, and potentially toxic chemicals such as arsenic, dioxins, and organochlorine pesticides. Testing of stockpiles for these types of chemicals is discussed in the following section.

5.1.3.4 Stockpiled Fill Material Potentially Contaminated with Low Mobility, Nonvolatile Contaminants

Characterization of stockpiled soil that is not suspected to be contaminated with volatile or otherwise highly mobile contaminants for use as fill material is not cost-prohibitive in most cases. Nonvolatile COPCs like metals, PCBs, organochlorine pesticides, dioxins, and PAHs primarily pose direct exposure hazards. Evaluating potential direct-exposure hazards in proposed fill material can be done

using DUs of larger volume in comparison to the DU volumes recommended for soil that might be contaminated with VOCs or highly mobile chemicals. The HEER Office recommends a sample frequency of one DU per 100 yd^3 of soil for unrestricted use of stockpile soil as fill material (see Table 5), with one Multi Increment sample per DU (plus replicates). This DU volume equates to the approximate volume of soil needed to cover a hypothetical, 5,000 ft^2 residential yard (default residential exposure area) 6 inches deep (default depth for evaluation of surface soil, direct exposure concerns).

If proposed fill material is to be used at a school, a high-density residential development (e.g., townhomes, apartment buildings, etc.) or a commercial or industrial site, then a default sample frequency of one DU per 400 yd^3 is recommended. This DU volume equates to the approximate volume of soil needed to cover a hypothetical, 20,000 ft^2 area 6 inches deep (default exposure area).

Larger DU volumes may be appropriate for large dredging projects if the source is expected to be relatively homogeneous. For example, dredge material is often used to replenish beaches. An exposure area size of 1 acre is generally appropriate for this type of setting. Assuming a depth of 6 inches, this equates to a stockpile DU volume of approximately 800 yd^3. Using dredged material as fill material for commercial or industrial areas, and in particular residential developments, should be discussed with the HEER Office on a case-by-case basis.

Section 3 of the HEER Office TGM includes additional information and options for selecting DUs for residential development projects.

5.1.3.5 Collection of Multi Increment Samples from Stockpiles

As described in Section 4 of the HEER Office TGM (HDOH 2016b), it is important to have equal and unbiased access to all parts of a soil stockpile during the collection of Multi Increment (MI) samples. An MI sample collected from a stockpile DU must be representative of the entire, three-dimensional mass of the stockpile. Sampling only the outer surface of a large stockpile is generally not acceptable.

The HEER Office recommends that a Multi Increment sample be collected from each stockpile DU, with each sample typically consisting of at least 30 to 75 increments, depending in part on the nature of the contaminant of concern (refer to Section 4.2.2 of the HEER TGM). Increments are typically collected and physically combined in the field into a single Multi Increment sample for laboratory analysis, though individual increments could be sent to and combined in the laboratory into a single MI sample. For non-volatile chemical samples, the less than 2-millimeter particle size fraction obtained by sieving the entire sample through a $\leq$ 2mm sieve, should be sub-sampled by the laboratory using a sectorial splitter or M1sampling methods and analyzed unless otherwise directed by the HEER Office. Multi Increment samples should be sub-sampled wet (or wet-sieved) for certain semi-volatile contaminants (see Semi-Volatile Chemicals in Appendix 1), but can be air dried and dry-sieved for some other "low mobility" semi-volatiles (and all non-volatile contaminants). Refer to Section 4 of the HEER Office TGM. Separation of the less than 0.25 mm particle size fraction is required for bioaccessible arsenic and lead analysis.

5.1.3.6 Sampling During Stockpile Formation

If sampling the proposed fill material *in-situ* is not practical, consider collecting MI samples as the fill material is being excavated and placed into stockpiles. Collecting samples from the soil while it is being transferred from the source area to a stockpile permits equal and unbiased access to the entire mass of soil and the preparation of representative samples. The collection of samples while heavy equipment is being used to form stockpile could pose safety issues. Close coordination with equipment operators is therefore very important.

Appropriate DU areas and volumes are established in the field in the same manner as done for an *in-situ* investigation. DUs are then excavated one at a time and sampled as the soil is being transferred to or placed in the stockpile. When implementing this approach, the individual increments can be collected directly from heavy equipment (e.g., front-end loader buckets) at appropriate intervals based on the designated DU volume as the stockpile is being formed.

For example, at a source property using 20-ton trucks to export fill material and with a target DU volume of 100 yd^3, ten increments of the proposed fill material could be randomly collected from five truckloads of material (total of 50 increments in the MI sample). Alternatively, at a source property using 20-ton trucks to export fill material and with a target DU volume of 1,000 yd^3, a single increment of the proposed fill material could be collected from each of 50 truckload-amount of material (total 50 increments in the MI sample).

The proposed fill material stockpile(s) should be kept separate from other stockpiles at the source property and clearly marked until receipt of the analytical data confirms the fill material is acceptable for its intended use.

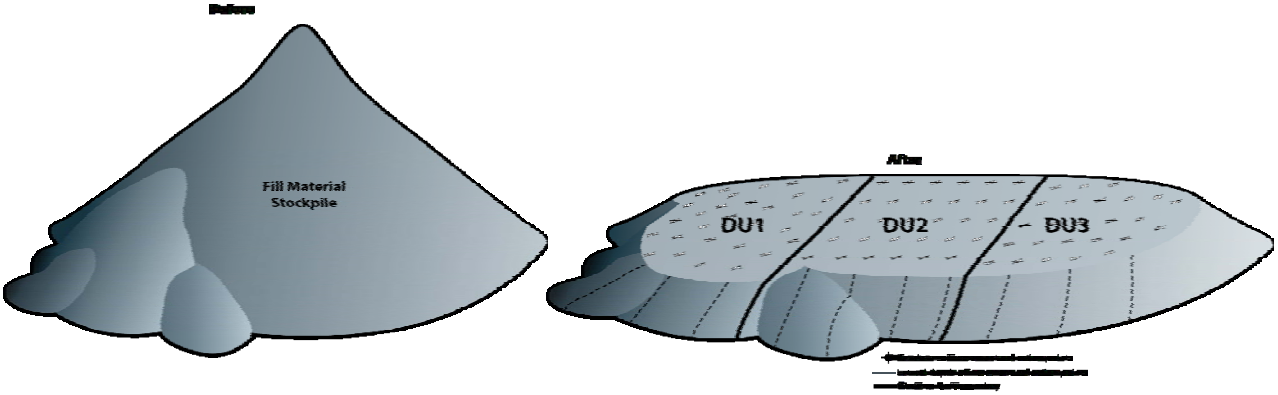
5.1.3.7 Sampling After Stockpile Formation

Sampling existing stockpiles presents a number of access and safety issues that may affect sample data quality. Where access or safety issues are significant concerns in collecting representative samples from existing stockpiles, the HEER Office should be consulted on options for alternate sampling strategies. A description of common approaches to sampling existing stockpiles is described below. If the soil is to be tested for volatile contaminants, increments should be collected from deeper than 6 to 12 inches below the surface of the stockpile using a VOC-specialized sampling device and preserved in methanol in the field (refer to Section 4.2.7 of the HEER Office TGM).

If room permits, existing stockpiles can be flattened or spread out sufficiently, so that the interior of the pile can be accessed with a hand coring tool or other device (see Figure 2; and refer to Section 5 of the HEER Office TGM). Another option is to move the stockpile to an adjacent or nearby location. As the fill material is being moved, individual increments can be collected directly from the heavy equipment (e.g., front-end loader buckets) at appropriate intervals (based on the designated DU volume). In essence, this is the same method as described for sampling during stockpile formation. If an existing soil stockpile is relatively large, the stockpile should be subdivided into multiple DU volumes as it is being moved. As the stockpile is being subdivided, individual increments can be collected directly

from the heavy equipment (e.g., front-end loader buckets) at appropriate intervals (based on the designated DU volume).

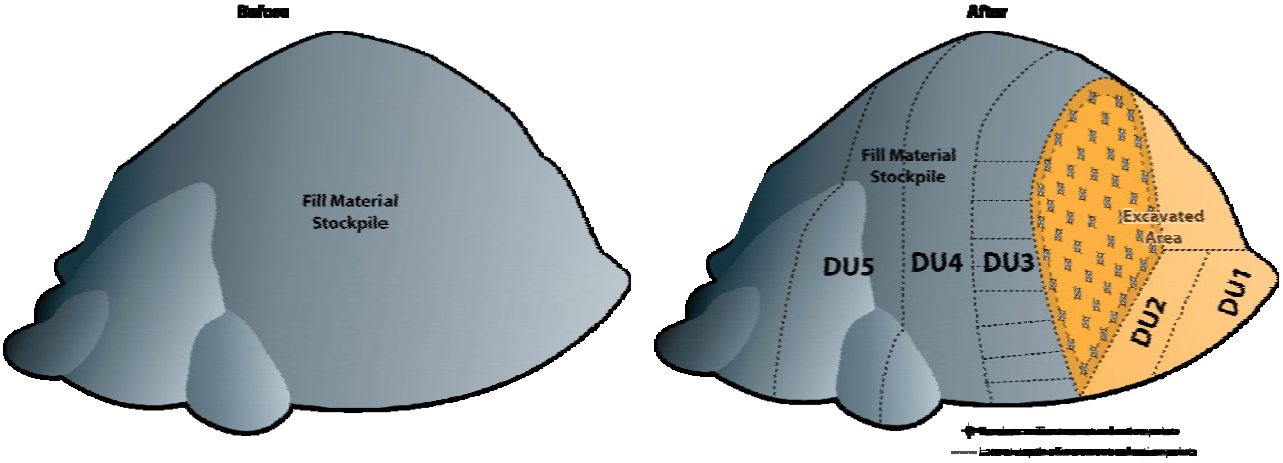
Figure 2 – Flattening or Spreading a Stockpile



The existing fill material stockpile (left) is too large to safely access. By flattening or spreading the stockpile (right), the fill material can be safely accessed and a representative MI sample can be collected from the surface using manual sampling techniques (e.g., hand coring tool).

If a stockpile cannot be moved or flattened, the interior of the stockpile can be accessed by successively removing a "face" of the stockpile and collecting increments from the newly exposed material (see Figure 3), or using manual sampling techniques to access the interior of the stockpile. This approach may require removing multiple faces of the stockpile to collect a representative MI sample.

Figure 3 – Removing "Faces" from a Stockpile



If an existing fill material stockpile (left) is too large to flatten or move, increments may be collected from the initially accessible portions of the stockpile. Then a "face" can be removed (right) to expose the previously inaccessible inner portions. Collect additional increments from each successive face of the stockpile and combine them to form an MI sample. Take appropriate safety precautions when using this approach.

5.1.4 Selecting DUs for Very Large Source Areas or Stockpile Volumes

Testing the entire area or volume of very large, *in-situ* or stockpiled sources of fill material at the default DU sizes (Tables 3 and 5) may not be practical due to feasibility issues and/or costs. An alternative is to test a select number of DUs within the entire population of potential DUs and base conclusions on acceptability of the results. Section 3 of the HEER Office TGM recommends use of a non-parametric, one-sided tolerance interval test to select an appropriate number of DUs from a large population based on a target confidence level, as summarized in Table 6 (also see USEPA 1989), similar to the approach used to test very large, agricultural fields (see TGM Section 3.4.8.2).

Table 6 – Selecting Number of DUs for Very Large Source Areas

Confidence in Concluding Source Area is Clean[1]	Number of DUs That Must be Tested
99%	90
95%	59
90%	46
80%	32
60%	18

Notes:

1. Assumes proportion of site that is clean is 95%, and all DUs tested are found below applicable action limits

Table 6 reflects the degree of confidence that the concentration of a contaminant in DUs that were not tested (across the entire large area or large stockpile volume) will be at or below the maximum-reported value for tested DUs at least 95% of the time. Clearance of the entire area or volume of soil requires that none of the tested DUs exceed target soil action levels. The HEER office TGM recommends the collection of a minimum 59 samples (DUs of the appropriate size with MI samples) from a large source area or stockpile in order to receive formal clearance from HDOH for unrestricted use. A smaller number of DUs and may be acceptable based on knowledge of the source area, sampling objectives, and professional judgment, although formal concurrence by the HEER Office should be agreed on ahead of time. Testing of a minimum of 18 DUs (plus triplicate samples collected in 10 percent of the DUs) to allow for a minimum 60% confidence level is recommended under any circumstance, and typically for only an industrial or commercial land use scenario. It is important to note that such a minimal degree of characterization may require institutional controls and an Exposure Hazard Management Plan for a property that specifies retesting of the receiving property before it can be converted to a more sensitive land use in the future.

DUs should be systematically, randomly selected within the subject source area or stockpile and tested for targeted COPC. All portions of the subject area or stockpile should have an equal opportunity for access and sampling.

If reported levels of COPCs in all DUs sampled are below applicable HDOH Tier I EALs, then the entire

source area or stockpile should be considered cleared to the applicable confidence interval based on number of DUs selected. If the reported concentration of COPCs in one or more DU exceeds the applicable HDOH Tier I EALs, then additional subdivision and testing of the fill material will be needed in order to isolate acceptable and unacceptable soil for use as fill material. The HEER Office should be consulted on evaluation or additional sampling strategies in these cases.

There may also be some cases for very large stockpiles of soil (e.g., thousands to tens of thousands of cubic yards) where the generator knows the origin and history of the soil well, and previous testing or knowledge about the site indicates that chemical contaminants do not exceed applicable environmental action levels. In these cases, only a minimal amount of testing is desired (by generator) to confirm the presence or absence of significant contamination and the generator is typically not seeking a "clean" concurrence letter from the HEER Office for unrestricted use. This is similar to informal screening of a very large former agricultural field with a smaller number of one-acre DUs than the 59 required to get a clean concurrence letter from the HEER Office (see Section 3.5 of the HEER Office TGM). For these cases, a maximum DU volume of 800 yd^3 (from a single fill source) is recommended. This is based on the volume of soil required to cover a one-acre area of land to a depth of six inches. An area of one acre is commonly used in risk assessments as an upper size limit for evaluation of direct exposure hazards posed by soil contaminants. Such soil data should be used as one of multiple lines of evidence regarding the potential for significant contamination to be present in the soil and for final decision-making.

6.0 Comparison to HDOH Soil Action Levels

Soil data should initially be compared to HEER Office Tier I Environmental Action Levels for soil under an unrestricted (e.g., residential) land use, assuming sites are situated within 150 meters of a surface water body and overlying groundwater that is a potential or current drinking water source (HDOH 2016a). Refer to that guidance document for additional information on case-specific evaluation of risk to human health and the environmental and development of potential alternative screening levels.

As described above, HEER Office guidance on leaching of contaminants from soil can be used to evaluate this potential concern if initial action levels are exceeded (HDOH 2016a). This may be a frequent issue for soil contaminated with trace amounts of semi-mobile pesticides such as dieldrin, endrin, and endosulfan. Laboratory batch tests typically determine that aged pesticides are essentially immobile in soil (e.g., Kd >20). This allows the leaching based action levels to be ignored, with a subsequent focus on (typically much higher) direct- exposure action levels for these chemicals (refer to Table I series in HEER Office EHE guidance, HDOH 2016a). Alternative soil action levels (e.g., alternative target risks, exposure assumptions, etc.) should be discussed with the HEER office on a case-by-case basis. Note that alternative action levels may restrict future, offsite reuse of the soil and require preparation of an Environmental Hazard Management Plan for long-term management of the soil. In some cases, a formal deed covenant that restricts offsite use of the soil may also be required.

7.0 Fill Material Categories

Fill material characterized under the environmental action level guidance presented above is placed

into four categories (Table 7):

Table 7 – Fill Material Categories and Use Considerations

Fill Material Category	Use Considerations
Class A	**Background – Unrestricted Use.** Within range of expected background conditions in non-agricultural and non-industrial areas. Class A fill material is likely to be limited to quarries and similar sites where there is minimal likelihood of anthropogenic contamination. No use restrictions.
Class B	**Minimally Impacted – Unrestricted Use.** Contaminants exceed expected background concentrations of contaminants but below[1] Tier I soil EALs for unrestricted land use (or acceptable alternatives). Most fill material from developed areas as well as former agricultural fields is anticipated to fall within into this category. No use restrictions.
Class C	**Moderately Impacted – Commercial/Industrial Land Use Only.** Contaminants exceed Tier I soil EALs for unrestricted land use but do not pose leaching, vapor intrusion or gross contamination hazards and concentrations do not exceed direct-exposure action levels for commercial/industrial land use. (Refer to Appendix 1, Table I-2 of EHE guidance (HDOH HEER Office 2016) and Tier II guidance for dioxins and arsenic (HDOH HEER Office, 2010b, HDOH HEER Office, 2010c). Fill material from former industrial areas or areas where fill material is impacted with incinerator ash may fall into this category. Use restricted to commercial/industrial areas only or as interim cover at a regulated landfill. These sites typically require institutional controls and an EHMP (see Sections 19.6 and 19.7 of the HEER Office TGM). TCLP tests must be carried out as part of a hazardous waste determination of offsite reuse or disposal.
Class D	**Heavily Impacted – Use As Fill not Recommended.** Exceeds Tier I soil EALs (or acceptable alternatives) and poses unacceptable risks to human health and the environment under any land use scenario. Use as fill material not recommended.

Notes:

1. Tier 1 EALs for unrestricted land use, for sites situated within 150m of a surface water body and overlying groundwater that is a potential or current source of drinking water.

8.0 Other Fill Material Management Considerations

Using Class A or Class B fill material (see Table 7) does not require a permit or long-term management practices. However, using fill materials is subject to other State of Hawai'i environmental laws and regulations (e.g., erosion and sediment control [county-specific grading ordinances], stormwater pollution prevention [HDOH Clean Water Branch – Hawai'i Administrative Rules Title 11 Chapter 55], etc.).

Using Class C fill material requires long-term management practices, an EHMP, and coordination with both the HEER Office and the SHWB. A hazardous waste determination that includes TCLP data must also be carried out (refer to Section 2 and Figure 1). Whenever "earthwork" occurs in Class C fill areas or the site use changes, the EHMP must be followed, as applicable, or the work/changes conducted under HEER Office oversight. In addition, the site EHMP may have to be updated as a result of any changes. The HEER Office should be consulted if Class C fill is proposed to be moved to another location for reuse. Since the receiving site land use category dictates the sampling needs for characterization, analytical data from larger DUs may not be appropriate to make determinations for a land use with smaller DU requirements (Table 3).

Landowners or developers are strongly encouraged to maintain the appropriate documentation supporting the fill determination process (e.g. the latest Phase I ESA, or fill material characterization report). The HEER Office will also maintain any submitted documentation in the site records in perpetuity. These documents will be made available for future environmental due diligence reviews or public file requests.

If earthen material under or directly adjacent to existing structures is planned for use as fill material, best management practices must be followed to remove materials such as lead-based paint, asbestos, canec, and other structure-related hazardous materials (e.g., mercury switches and light ballasts, PCB-containing equipment, etc.) prior to demolition. Take care to avoid cross-contamination to the underlying earthen materials.

It is important to recognize that soil adjacent to and under the foundations and slabs of pre-1990 buildings or building sites in Hawai'i may have been treated for termites with technical chlordane, aldrin, dieldrin, or other persistent and potentially toxic pesticides, as discussed in the HEER Office fact sheet on termiticides (HDOH 2011e). Soil under and adjacent to these buildings or at these former building sites should be considered suspect unless otherwise demonstrated to be "clean" by knowledge or by sampling and analytical testing (see sampling guidance for termiticides in HDOH 2011b). Testing of soils and plans for proper management should be initiated early in the planning stages of a redevelopment project.

All landfills in Hawai'i are prohibited from accepting regulated hazardous waste. Each landfill has its own acceptance procedures to ensure that they comply with this requirement. Generators should contact the specific landfill to ensure compliance with the landfill's acceptance criteria and operational procedures. Landfill owners/operators have the prerogative to implement requirements that are more

strict than state regulations.

The HEER Office suggests using the Commercial/Industrial receiving site land use category (Table 3) in determining recommended DU size (e.g., 400 yd^3) when testing soils for suitability as landfill daily/interim/ intermediate/ final cover. Some landfills accept soils with contaminant concentrations over Tier I EALs but less than Commercial/Industrial land use EALs for use as landfill daily cover. If soils are being tested for hazardous waste determination and/or suitability as landfill cover, the maximum recommended DU size should be considered, and verified as necessary with the HDOH Solid and Hazardous Waste Branch and/or with the landfill operator.

In some cases, the HEER Office allows capping and long-term management of contaminated soil on a property. The HEER Office recommends that utility trenches that could be periodically accessed for maintenance or other purposes be backfilled with acceptable fill material (Class A or Class B Fill, Table 7). This will minimize exposure to trench and utility workers to contaminated soil in the future, as well as help prevent the inadvertent reuse of excavated contaminated soil at another location. The use of Class C fill material is not recommended, as it will require additional health, safety, and environmental considerations (and possible HEER Office oversight) whenever trench work is performed in the future.

8.1 Excavation Activities on Sites with Environmental Hazard Management Plans

Excavation activities at sites with contaminated soil that is governed by a long-term environmental hazard management plan (EHMP) need to follow the site-specific procedures and precautions outlined in the EHMP (e.g., sub-surface utility or repair work in contaminated areas, refer to Section 19 of the TGM). If specific procedures or precautions for excavation are not detailed in the EHMP, the HEER Office should be consulted to review and approve the planned excavation. Any potentially contaminated soil proposed to be relocated to the surface, taken off-site, or moved to alternate locations other than those locations specified in the EHMP must be handled or tested, as appropriate. Actions related to the disturbance of contaminated soil will need to be documented, including making appropriate revisions or addendums to the EHMP, and submitting them to the HEER Office.

9.0 References

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Appendix 1: Chemical Mobility Categories

Chemical Categories and Relative Mobility

[1]Physiochemical Category	CHEMICAL	Physical State		Molecular Weight	[2]Vapor Pressure mm Hg (25C)	Sorption Coefficient K_{oc} (cm^3/g)	Henry's Law Constant H ($atm\text{-}m^3/mol$)
[2]Highly Volatile Chemicals	ACETONE	V	L	58	2.3E+02	1.98E+00	3.90E-05
	BENZENE	V	L	78	9.5E+01	1.66E+02	5.61E-03
	BIS(2-CHLOROISOPROPYL)ETHER	V	L	171	1.6E+00	6.10E+01	1.13E-04
	BROMODICHLOROMETHANE	V	L	164	5.0E+01	3.50E+01	2.12E-03
	BROMOFORM	V	S	253	5.4E+00	3.50E+01	5.37E-04
	BROMOMETHANE	V	G	95	1.6E+03	1.43E+01	6.34E-03
	CARBON TETRACHLORIDE	V	L	154	1.2E+02	4.86E+01	2.68E-02
	CHLOROBENZENE	V	L	113	1.2E+01	2.68E+02	3.17E-03
	CHLOROETHANE	V	G	65	1.0E+03	2.37E+01	1.10E-02
	CHLOROFORM	V	L	119	2.0E+02	3.50E+01	3.66E-03
	CHLOROMETHANE	V	G	50	4.3E+03	1.43E+01	8.78E-03
	CHLOROPHENOL, 2-	V	L	129	2.5E+00	4.43E+02	1.12E-05
	DIBROMOCHLOROMETHANE	V	S	208	5.5E+00	3.50E+01	7.80E-04
	DIBROMOETHANE, 1,2-	V	S	188	1.1E+01	4.38E+01	6.59E-04
	DICHLOROBENZENE, 1,2-	V	L	147	1.4E+00	4.43E+02	1.90E-03
	DICHLOROBENZENE, 1,3-	V	L	147	2.2E+00	6.17E+02	1.90E-03
	DICHLOROBENZENE, 1,4-	V	S	147	1.7E+00	4.34E+02	2.41E-03
	DICHLOROETHANE, 1,1-	V	L	99	2.3E+02	3.50E+01	5.61E-03
	DICHLOROETHANE, 1,2-	V	L	99	7.9E+01	4.38E+01	1.17E-03
	DICHLOROETHYLENE, 1,1-	V	L	97	6.0E+02	3.50E+01	2.68E-02
	DICHLOROETHYLENE, Cis 1,2-	V	L	97	2.0E+02	4.38E+01	4.15E-03
	DICHLOROETHYLENE, Trans 1,2-	V	L	97	3.3E+02	4.38E+01	9.27E-03
	DICHLOROPROPANE, 1,2-	V	L	113	5.3E+01	6.77E+01	2.93E-03
	DICHLOROPROPENE, 1,3-	V	L	111	3.4E+01	8.08E+01	3.66E-03
	DIOXANE, 1,4-	V	L	88	3.8E+01	1.00E+00	4.88E-06
	ETHANOL	V	L	46	5.9E+01	3.09E-01	6.29E-06
	ETHYLBENZENE	V	L	106	9.6E+00	5.18E+02	7.80E-03
	METHYL ETHYL KETONE	V	L	72	9.1E+01	3.83E+00	5.61E-05
	METHYL ISOBUTYL KETONE	V	L	100	2.0E+01	1.09E+01	1.37E-04
	METHYL TERT BUTYL ETHER	V	L	88	2.5E+02	5.26E+00	5.85E-04
	METHYLENE CHLORIDE	V	L	85	4.4E+02	2.37E+01	3.17E-03
	STYRENE	V	L	104	6.4E+00	5.18E+02	2.68E-03
	tert-BUTYL ALCOHOL	V	L	74	4.1E+01	3.70E+01	1.17E-05
	TETRACHLOROETHANE, 1,1,1,2-	V	L	168	4.6E+00	9.66E+01	2.41E-03
	TETRACHLOROETHANE, 1,1,2,2-	V	L	168	4.6E+00	1.07E+02	3.66E-04
	TETRACHLOROETHYLENE	V	L	166	1.9E+01	1.07E+02	1.76E-02
	TOLUENE	V	L	92	2.8E+01	2.68E+02	6.59E-03
	TPH (gasolines)	V	L	108	6.8E+02	5.00E+03	7.20E-04
	TRICHLOROETHANE, 1,1,1-	V	L	133	1.2E+02	4.86E+01	1.71E-02
	TRICHLOROETHANE, 1,1,2-	V	L	133	2.3E+01	6.77E+01	8.29E-04
	TRICHLOROETHYLENE	V	L	131	6.9E+01	6.77E+01	9.76E-03
	TRICHLOROPROPANE, 1,2,3-	V	L	147	3.7E+00	1.31E+02	3.41E-04
	TRICHLOROPROPENE, 1,2,3-	V	L	145	3.7E+00	5.10E+01	2.80E-02
	VINYL CHLORIDE	V	G	63	3.0E+03	2.37E+01	2.68E-02
	XYLENES	V	L	106	8.0E+00	4.34E+02	7.07E-03

Chemical Categories and Relative Mobility

[1]Physiochemical Category	CHEMICAL	Physical State		Molecular Weight	[2]Vapor Pressure mm Hg (25C)	Sorption Coefficient K_{oc} (cm^3/g)	Henry's Law Constant H ($atm\text{-}m^3/mol$)
[3]Highly Leachable Chemicals	AMETRYN	NV	S	227	2.7E-06	4.45E+02	2.39E-09
	AMINO,2- DINITROTOLUENE,4,6-	NV	S	197	-	1.01E+02	1.61E-10
	AMINO,4- DINITROTOLUENE,2,6-	NV	S	197	-	1.01E+02	1.61E-10
	ATRAZINE	NV	S	216	2.9E-07	2.30E+02	2.34E-09
	BIS(2-CHLOROETHYL)ETHER	SV	L	143	8.5E-01	1.50E+01	1.71E-05
	CHLOROANILINE, p-	NV	S	128	7.1E-02	7.25E+01	1.15E-06
	CYCLO-1,3,5-TRIMETHYLENE-2,4,6-TRINITRAMINE (RDX)	NV	S	222	4.1E-09	1.95E+02	6.34E-08
	DALAPON	NV	L	143	1.9E-01	2.74E+00	9.02E-08
	DIBROMO,1,2- CHLOROPROPANE,3-	SV	L	236	5.8E-01	1.31E+02	1.46E-04
	DIMETHYLPHENOL, 2,4-	SV	S	122	1.0E-01	7.18E+02	9.51E-07
	DICHLOROPHENOL, 2,4-	NV	S	163	9.0E-02	7.18E+02	2.20E-06
	DICHLOROPHENOXYACETIC ACID (2,4-D)	NV	S	221	8.3E-08	2.94E+01	3.41E-08
	DIETHYLPHTHALATE	NV	S	222	2.1E-03	1.26E+02	6.10E-07
	DIMETHYLPHTHALATE	NV	S	194	3.1E-03	1.40E+02	1.05E-07
	DINITROBENZENE, 1,3-	NV	S	168	2.0E-04	2.20E+02	4.88E-08
	DINITROPHENOL, 2,4-	NV	S	184	3.9E-04	3.64E+02	8.54E-08
	DINITROTOLUENE, 2,4- (2,4-DNT)	NV	S	182	1.5E-04	3.64E+02	5.37E-08
	DINITROTOLUENE, 2,6- (2,6-DNT)	NV	S	182	5.7E-04	3.71E+02	7.56E-07
	DIURON	NV	S	233	6.9E-08	1.36E+02	5.12E-10
	GLYPHOSATE	NV	S	169	9.8E-08	1.88E+01	4.15E-19
	HEXACHLOROBUTADIENE	NV	S	261	2.2E-01	9.94E+02	1.02E-02
	HEXACHLOROETHANE	NV	S	237	4.0E-01	2.25E+02	3.90E-03
	HEXAZINONE	NV	S	252	2.3E-07	6.14E+02	2.24E-12
	ISOPHORONE	NV	L	138	4.4E-01	5.83E+01	6.59E-06
	NITROBENZENE	SV	L	123	2.5E-01	1.91E+02	2.39E-05
	NITROGLYCERIN	NV	L	227	2.0E-04	1.31E+02	9.76E-08
	NITROTOLUENE, 4-	NV	S	137	1.6E-01	3.09E+02	5.61E-06
	NITROTOLUENE, 2-	SV	S	137	1.9E-01	3.16E+02	1.24E-05
	NITROTOLUENE, 3-	SV	S	137	2.1E-01	3.33E+02	2.39E-05
	PENTAERYTHRITOLTETRANITRATE (PETN)	NV	S	316	1.4E-07	1.51E+02	1.20E-11
	PERCHLORATE	NV	S	117	-	-	-
	PHENOL	NV	S	94	3.5E-01	2.68E+02	3.41E-07
	SIMAZINE	NV	S	202	2.2E-08	1.49E+02	9.51E-10
	TERBACIL	NV	S	217	4.7E-07	7.78E+01	1.20E-10
	TRICHLOROBENZENE, 1,2,4-	SV	S	181	4.6E-01	7.18E+02	1.41E-03
	TRICHLOROPHENOXYACETIC ACID, 2,4,5- (2,4,5-T)	NV	S	255	<7.5E-5	4.86E+01	4.63E-08
	TRICHLOROPHENOXYPROPIONIC ACID, 2,4,5- (2,4,5-TP)	NV	S	270	9.7E-07	8.04E+01	9.02E-09
[4]Semi-Volatile Chemicals	ACENAPHTHENE	SV	S	154	2.2E-03	6.12E+03	1.80E-04
	ACENAPHTHYLENE	SV	S	152	6.7E-03	2.50E+03	1.45E-03
	ANTHRACENE	SV	S	178	6.6E-06	2.04E+04	5.61E-05
	BIPHENYL, 1,1-	SV	S	154	8.9E-03	6.25E+03	3.17E-04
	CYANIDE (Free)	SV	S	27	1.0E+00	-	-
	FLUORENE	SV	S	166	3.2E-04	1.13E+04	9.51E-05
	MERCURY	SV	S	201	2.0E-03	-	-
	METHYLNAPHTHALENE, 1-	SV	S	142	6.7E-02	3.04E+03	5.12E-04
	METHYLNAPHTHALENE, 2-	SV	S	142	5.5E-02	2.98E+03	5.12E-04
	NAPHTHALENE	SV	S	128	8.5E-02	1.84E+03	4.39E-04
	PHENANTHRENE	SV	S	178	1.2E-04	1.40E+04	3.93E-05
	PYRENE	SV	S	202	4.5E-06	6.94E+04	1.20E-05
	TPH (middle distillates)	SV	L	170	2 to 26	5.00E+03	7.20E-04

Chemical Categories and Relative Mobility

[1]Physiochemical Category	CHEMICAL	Physical State		Molecular Weight	[2]Vapor Pressure mm Hg (25C)	Sorption Coefficient K_{oc} (cm^3/g)	Henry's Law Constant H ($atm\text{-}m^3/mol$)
[5]Low Mobility Organic Chemicals	ALDRIN	NV	S	365	1.2E-04	1.06E+05	4.39E-05
	BENZO(a)ANTHRACENE	NV	S	228	5.0E-09	2.31E+05	1.20E-05
	BENZO(a)PYRENE	NV	S	252	5.5E-09	7.87E+05	4.63E-07
	BENZO(b)FLUORANTHENE	NV	S	252	5.0E-07	8.03E+05	6.59E-07
	BENZO(g,h,i)PERYLENE	NV	S	276	-	1.60E+06	1.44E-07
	BENZO(k)FLUORANTHENE	NV	S	252	9.7E-10	7.87E+05	5.85E-07
	BIS(2-ETHYLHEXYL)PHTHALATE	NV	S	391	1.4E-07	1.65E+05	2.68E-07
	CHLORDANE (TECHNICAL)	NV	S	410	9.8E-06	8.67E+04	4.88E-05
	CHRYSENE	NV	S	228	6.2E-09	2.36E+05	5.12E-06
	DIBENZO(a,h)ANTHTRACENE	NV	S	278	9.6E-10	2.62E+06	1.22E-07
	DICHLOROBENZIDINE, 3,3-	NV	S	253	2.6E-07	7.49E+03	5.12E-11
	DICHLORODIPHENYLDICHLOROETHANE (DDD)	NV	S	320	1.4E-06	1.53E+05	6.59E-06
	DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	NV	S	318	6.0E-06	1.53E+05	4.15E-05
	DICHLORODIPHENYLTRICHLOROETHANE (DDT)	NV	S	354	1.6E-07	2.20E+05	8.29E-06
	DIELDRIN	NV	S	381	5.9E-06	1.06E+04	1.00E-05
	DIOXINS (TEQ)	NV	S	356	1.5E-09	2.57E+05	2.20E-06
	ENDOSULFAN	NV	S	407	1.7E-07	2.20E+04	6.59E-05
	ENDRIN	NV	S	381	9.2E-06	1.06E+04	6.34E-06
	FLUORANTHENE	NV	S	202	9.2E-06	7.09E+04	8.78E-06
	HEPTACHLOR	NV	S	373	4.0E-04	5.24E+04	2.93E-04
	HEPTACHLOR EPOXIDE	NV	S	389	2.0E-05	5.26E+03	2.10E-05
	HEXACHLOROBENZENE	NV	S	285	4.9E-05	3.38E+03	1.71E-03
	HEXACHLOROCYCLOHEXANE (gamma) LINDANE	NV	S	291	4.2E-05	3.38E+03	5.12E-06
	INDENO(1,2,3-cd)PYRENE	NV	S	276	1.2E-10	2.68E+06	3.41E-07
	METHOXYCHLOR	NV	S	346	4.2E-05	4.26E+04	2.02E-07
	PENTACHLOROPHENOL	NV	S	266	1.1E-04	3.38E+03	2.44E-08
	POLYCHLORINATED BIPHENYLS (PCBs)	NV	S	326	7.7E-05	7.56E+04	2.93E-04
	PROPICONAZOLE	NV	L	342	1.0E-06	5.56E+03	4.15E-09
	TETRACHLOROPHENOL, 2,3,4,6-	NV	S	232	4.2E-03	2.00E+03	8.78E-06
	TETRANITRO-1,3,5,7-TETRAAZOCYCLOOCTANE (HMX)	NV	S	296	2.4E-08	1.85E+03	8.54E-10
	TOXAPHENE	NV	S	414	6.7E-06	9.93E+04	6.10E-06
	TRICHLOROPHENOL, 2,4,5-	NV	S	198	-	1.19E+03	1.61E-06
	TRICHLOROPHENOL, 2,4,6-	NV	S	198	-	1.19E+03	2.68E-06
	TRIFLURALIN	NV	S	335	4.6E-05	9.68E+03	1.02E-04
	TRINITROBENZENE, 1,3,5-	NV	S	213	6.4E-06	1.09E+03	3.17E-09
	TRINITROPHENYLMETHYLNITRAMINE, 2,4,6- (TETRYL)	NV	S	287	1.2E-07	2.14E+03	2.68E-09
	TRINITROTOLUENE, 2,4,6- (TNT)	NV	S	227	8.0E-06	1.83E+03	4.63E-07
[6]Assumed Low-Mobility Metals	ANTIMONY	NV	S	122	-	-	-
	ARSENIC	NV	S	75	-	-	-
	BARIUM	NV	S	137	-	-	-
	BERYLLIUM	NV	S	9	-	-	-
	BORON	NV	S	14	-	-	-
	CADMIUM	NV	S	112	-	-	-
	CHROMIUM (Total)	NV	S	52	-	-	-
	CHROMIUM III	NV	S	52	-	-	-
	CHROMIUM VI	NV	S	52	-	-	-
	COBALT	NV	S	59	-	-	-
	COPPER	NV	S	64	-	-	-
	LEAD	NV	S	207	-	-	-
	METHYL MERCURY	SV	S	216	-	-	-
	MOLYBDENUM	NV	S	96	-	-	-
	NICKEL	NV	S	59	-	-	-
	SELENIUM	NV	S	81	-	-	-
	SILVER	NV	S	108	-	-	-
	THALLIUM	NV	S	204	-	-	-
	VANADIUM	NV	S	51	-	-	-
	ZINC	NV	S	67	-	-	-

Notes:

1. References: Appendix 1, Table H of HEER office EHE guidance (HDOH 2016a). Vapor Pressures from National Library of Medicine TOXNET or ChemID databases.

Physical state of chemical at ambient conditions (V - volatile, NV - nonvolatile, S - solid, L - liquid, G - gas). Koc: Organic Carbon Partition Coefficient; H: Henry's Law Constant

2. Chemical considered to be "volatile" vapor pressure >1 mm Hg. Volatile chemicals pose potential vapor intrusion hazards. Volatile chemicals can also pose potential leaching hazards and direct-exposure hazards (due to vapor emissions at ground surface).

3. Chemicals with a sorption coefficient (koc) less than 1,000 g/cm^3 pose potential leaching hazards. Some highly leachable compounds are also semi-volatile and could pose vapor intrusion hazards at high source strengths.

4. Chemical considered to be "semi-volatile" if vapor pressure <1 mm Hg but Henry's number (atm m3/mole) >0.00001 and molecular weight <200. Semi-volatile chemicals can pose vapor intrusion hazards at sufficiently high concentrations and source strength (e.g., free product present) and can also pose potential direct exposure hazards. Most compounds in middle distillate fuels are semi-volatile, especially in aged releases.

5. Chemical considered to be "Low Mobility" if non-volatile and not significantly leachable. Low-mobility chemicals primarily pose potential direct-exposure hazards.

6. Metals primarily pose direct-exposure hazards. Evaluate metal mobility using batch tests as necessary (HDOH 2016a).

Appendix 2: Construction and Demolition Waste Disposal General Guidance

Guidance for

Construction & Demolition (C&D) Waste Disposal

State of Hawaii, Department of Health

2013

Background Information

This C&D waste disposal guidance supersedes the previous letter dated May 24, 1996. Although the waste composition varies from project to project, C&D wastes generally consist of concrete, wood, metal, glass, plastic, asphalt, tile, drywall, roofing and insulation material. These wastes are often bulked as one waste stream when sent for disposal. With advance planning, most of these wastes can be reused on the job site and/or salvaged for recycling opportunities.

Another type of C&D waste stream sometimes generated from a construction project is excavated soil. If the C&D waste is designated for disposal to a landfill or to any other off-site location, the contractor must make a hazardous waste determination in accordance with the Hawaii Administrative Rules (HAR) §11-262-11. Making a hazardous waste determination is a step-by-step process, and should start with determining whether the waste is excluded, then if listed, and finally if characteristic. Determining whether a waste is hazardous under RCRA (Resource Conservation and Recovery Act) can be done through one of the following methods:

Testing

Test the waste according to the methods set forth in subpart C of HAR 11-261.

Knowledge

Collecting a representative sample of the bulk C&D waste or excavated soil waste is crucial to characterizing environmental samples. If a sample is not representative, there are legal and environmental consequences. Each generator would be responsible for its own sampling plan. We advise contractors to work with experienced environmental companies and labs for guidance and implementation.

Note - *Construction wastes with lead-based paint may be exempt from HAR §11-262-11. Provided wastes: were from a residential structure; and from renovation, remodeling or abatement work; and contain no other listed constituents – refer to HAR §§11-261-20 and 11-261-30.*

- In some cases, a generator can use his/her knowledge of a waste to make a determination as to whether the waste is a characteristic hazardous waste. In order to use knowledge to characterize the waste, the generator must consider the raw materials that constitute the waste or the **process(es)** that result in the waste being generated.

  In considering the materials that make up the waste, the generator needs to examine the specific chemical and physical characteristics of the waste material. Information such as Material Safety Data Sheets (MSDSs) can be a helpful resource. However, while MSDSs can provide useful information regarding ignitability (flash point), corrosivity (pH), and reactivity, they tend to be less useful when it comes to identifying the toxic characteristics of waste. MSDSs are not required to list all of the ingredients in a certain material, but only those that make up greater than 1% of the total constituents of that material. This means that a waste may contain a toxic constituent exceeding the regulatory limit (making it a hazardous waste), but this constituent may not necessarily be included on the MSDS. Generators should also be aware that MSDSs are representative of raw materials; the MSDS may not accurately represent a waste material that is generated by the use of a particular raw material.

Guidance for

Construction & Demolition (C&D) Waste Disposal

State of Hawaii, Department of Health

2013

Knowledge

In considering the **process** that generates the waste, the generator needs to ask himself/herself: How does the operation/process affect the waste? For example, does the process make the waste ... more concentrated? ... more dilute?... contain free liquids?... become contaminated? ...etc.

One critical factor in using knowledge to characterize waste is that the knowledge must be applied appropriately. In other words, the knowledge that is applied must be valid and verifiable. A generator should not just assume that a waste is non-hazardous without providing some type of supporting, verifiable information to justify that conclusion. Using knowledge of the waste to conduct a hazardous waste determination involves a well thought out process in which the waste materials or the process generating the waste are considered. It should be noted that, more often than not, it is easier to use knowledge of the waste to characterize it as hazardous than it is to characterize it as non-hazardous.

- In many cases knowledge alone is inadequate to properly characterize the waste, specifically in those cases where the waste is cross-contaminated or inherently non-homogeneous. If you are generating a waste and your knowledge of the waste is insufficient to completely and accurately characterize it, you will need to get the waste tested by a lab that is certified to perform the tests that need to be conducted on the waste. Generators that use knowledge of process in waste determinations must be able to demonstrate the basis for their claim.
- An initial characterization must be done on each waste stream and a re-characterization must be performed at least every twelve months, or whenever there is a process change. It is recommended that MSDSs and other "knowledge of process" information be specifically reviewed during re-characterizations to ensure that neither the raw materials nor the process associated with the waste have changed.
- According to 40 CFR 262.40, a generator must keep records of any test results, waste analysis, or other determinations made in accordance with 40 CFR 262.11 for at least three years from the date that the waste was last sent to on-site or off-site treatment, storage, or disposal. Generators that use knowledge of process in waste determinations must be able to demonstrate the basis for this claim.

Appendix 3: Cover Letter (October 6, 2017)

DAVID Y. IGE
GOVERNOR OF HAWAII

VIRGINIA PRESSLER, M.D.
DIRECTOR OF HEALTH

STATE OF HAWAII
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In reply, please refer to:
File: RB-261-2017

Date: October 6, 2017

To: Steve Chang, Chief
Solid and Hazardous Waste Branch (SHWB)

Fenix Grange, Program Manager
Hazard Evaluation and Emergency Response (HEER)

Through: Lene Ichinotsubo, Supervisor
SHWB - Solid Waste Section

Paul Kalaiwa'a, Acting Supervisor
SHWB - Hazardous Waste Section

Steve Mow, Supervisor
HEER Site Discovery & Response

Kathy Ho, Deputy Attorney
HEER

Wade Hargrove, Deputy Attorney
SHWB

From: Roger Brewer, PhD
Hazard Evaluation and Emergency Response

Subject: Updates to joint, HEER-SHWB 2011 document *Guidance for the Evaluation of Imported and Exported Fill Material, Including Contaminant Characterization of Stockpiles*

This technical memorandum serves as a cover letter to the October 2017 update of the joint, HEER-SHWB document *Guidance for the Evaluation of Imported and Exported Fill Material, Including Contaminant Characterization of Stockpiles* ("Clean Fill" guidance). The document was re-titled *Guidance for Soil Stockpile Characterization and Evaluation of Imported and Exported Fill Material* as part of the 2017 update. Signature by the above recipients denotes concurrence with these updates.

The 2011 version of the Clean Fill guidance document was updated to clarify issues related to the following topics:

1. Removal of lead-based paint striping for asphalt to be used as inert fill material; and
2. Discussion of salinity concerns related to the reuse of dredged sediment from coastal areas; and
3. Clarification on use of HDOH Tier 1 Soil Environmental Action Levels for unrestricted land (Tier 1 EALs) use as part of the hazardous waste determination process.

The need to remove lead-based paint from asphalt to be recycled for unrestricted reuse includes input from Solid Waste Section Supervisor and is relatively straight forward, as are added notes

regarding plant toxicity concerns for dredge material that has a high salinity. Refer to the updated guidance document for additional information.

Use of HDOH Tier 1 EALs (HDOH 2016a) as part of the hazardous waste determination process is based on the following points (see Figure 1):

1. HDOH soil Tier 1 EALs, in use and regularly updated since 1995, are protective of human health and the environment under any land use scenario, including use for residences, parks and schools, and are also protective of leaching and potential impacts to underlying groundwater;

2. A conclusion by the HEER Office that "No Further Action" is required for a contaminated property that has been remediated to meet Tier 1 EALs is reasonably intended to relieve the property owner and/or responsible parties of further oversight by the state and allow unrestricted onsite and offsite use of the subject soil;

3. Consideration of soil that *exceeds* HDOH Tier 1 EALs to be "polluted" under HRS § 342-H and meets the intent of that statute;

4. A requirement that Toxicity Characteristics Leaching Procedure (TCLP) test data be included as part of a hazardous waste determination under HRS § 342-J for disposal and/or offsite reuse of soil that exceeds HDOH Tier 1 EALs is reasonable and meets the intent of that statute (TCLP test not required if concentration of chemical is less than twenty-times the TCLP level; Table 1);

5. Soil that is not classifiable as a hazardous waste under HRS § 342-J by meeting the "20X" *di minimis* concentration limit or by meeting TCLP limits for disposal at a municipal landfill can still exceed HDOH Tier 1 EALs and pose a potential risk to human health and the environment and must be managed accordingly (refer to Table 1).

Determinations regarding the potential risk to human health and the environment posed by chemicals in soil should carried out in accordance with the HDOH guidance document *Screening for Environmental Concerns at Sites with contaminated Soil and Groundwater* and predicated on sample data collected in accordance with the HEER Office *Technical Guidance Manual* (http://eha-web.doh.hawaii.gov/eha-cma/Org/HEER/). Additional information is provided in the attached update to the HEER Office *Clean Fill* guidance.

Attachment:

Ocotber 2017 update to HEER "Clean Fill" guidance

Figure 1. Flow chart depiction of the hazardous waste determination process for soil that is exported or imported to properties overseen by the HEER Office.

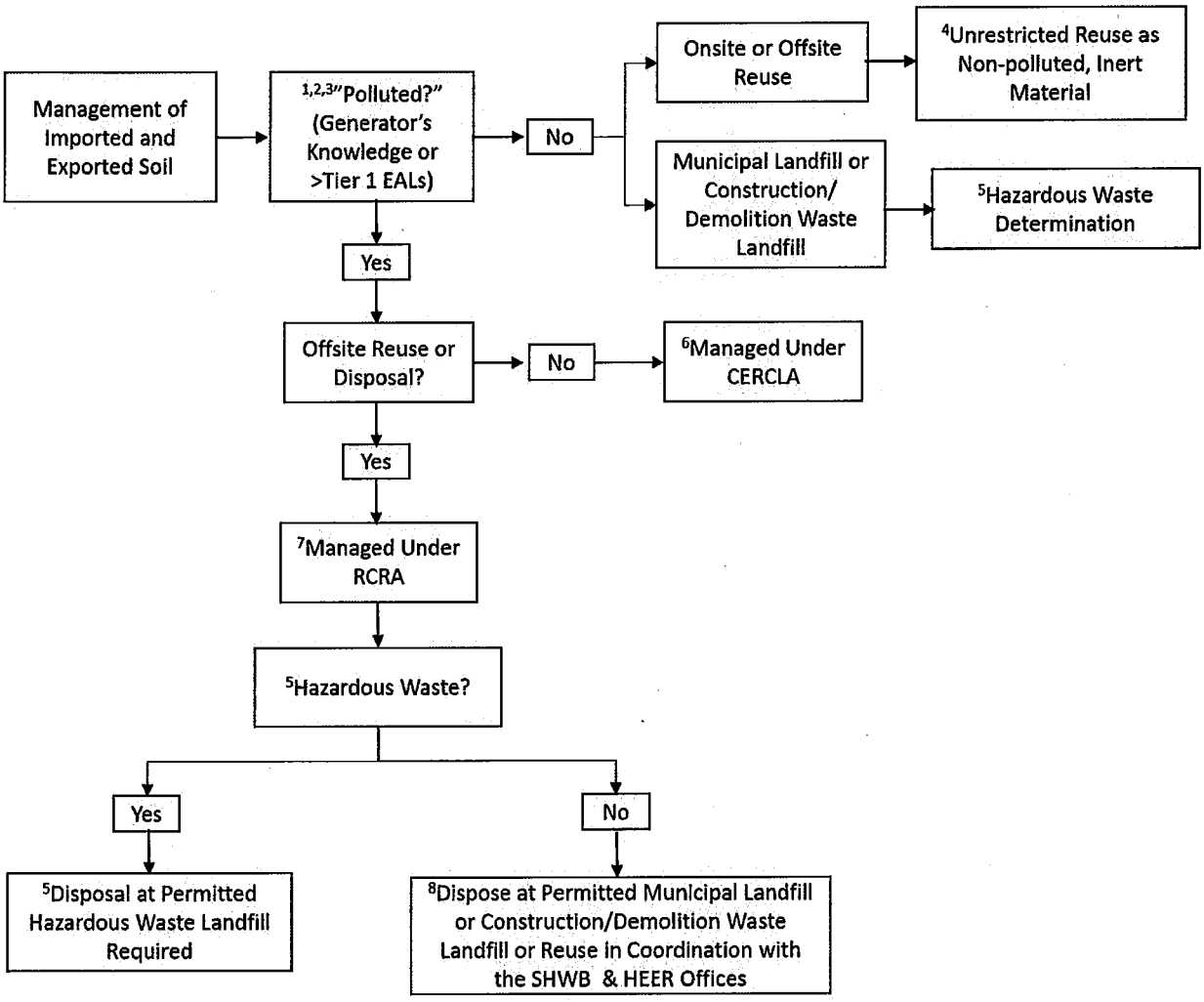


Figure 1 notes:

1. Imported or exported soil initially defined as a potential "waste" under HRS §342H-1 (Solid Waste Pollution). "Waste" defined as a "substance … which may pollute the atmosphere, lands or waters or Hawaii."

2. "Polluted" or "contaminated" soil defined as a soil with one or more potentially hazardous substances at a concentration that exceed HDOH Tier 1 EALs for unrestricted land use (HDOH 2016a; Tier 1 EALs for soil within 150m of a surface water body and situated over groundwater that is a source or potential source of drinking water).

3. Soil should be characterized in accordance with Decision Unit and Multi Increment Sample investigation methods described in the HEER *Technical Guidance Manual* (www.hawaiidoh.org) if testing is required due to insufficient generator knowledge of contamination potential.

4. "Inert Waste" includes "earth… which will not cause a leachate of environmental concern" (HAR §11-58.1, Solid Waste Management) *and* meets HDOH Tier 1 EALs for unrestricted land use.

5. Hazardous Waste Determination must include testing for Toxicity Characteristic Leaching Procedure if concentration of contaminant in soil (mg/kg) exceeds HDOH Tier 1 EALs for unrestricted land use AND is equal to or greater than 20 times the TCLP level (mg/L) for that chemical. TCLP data are not required as part of a hazardous waste determination if the concentration of the contaminant in soil is less than 20 times the TCLP level under any scenario. Soil cannot be disposed of at a municipal landfill or construction/demolition waste landfill if determined to be a hazardous waste under HAR §11-261 (Hazardous Waste Management). The soil must either be managed onsite under 128D through the HEER Office or disposed of at a permitted, hazardous waste landfill under the oversight of the SHWB.

6. Soil managed on-site under HRS §128-D (Environmental Response Law).

7. Soil managed for offsite reuse or disposal under HAR §11-261 (Environmental Response Law).

8. Offsite reuse of soil from a HEER project site that fails Tier 1 EALs for unrestricted land use but meets action levels for commercial/industrial land use *and* is not a hazardous waste must be carried out in coordination with the HEER Office and the Solid Waste Section of the SHWB. Land use restrictions and preparation of an Environmental Hazard Management for long-term management of the soil will be required under most circumstances.

Table 1. Comparison of HDOH Tier 1 EALs for chemicals with "20X" TCLP level.

USEPA Hazardous Waste Number	Contaminant	CAS No. 2	[1]Regulatory Level (mg/L)	[2]20X Equivalent in Soil (mg/kg)	[3]HDOH Tier 1 Soil EAL (mg/kg)
D004	Arsenic	7440-38 -2	5.0	100	23
D005	Barium	7440-39 -3	100.0	2,000	1000
D018	Benzene	71 -43 -2	0.5	10	0.30
D006	Cadmium	7440-43 -9	1.0	20	14
D019	Carbon tetrachloride	56 -23 -5	0.5	10	0.10
D020	Chlordane	57 -74 -9	0.03	0.6	17
D021	Chlorobenzene	108-90 -7	100.0	2,000	1.5
D022	Chloroform	67 -66 -3	6.0	120	0.026
D007	Chromium	7440-47 -3	5.0	100	1000
D023	o -Cresol	95 -48 -7	200	4,000	-
D024	m -Cresol	108-39 -4	200	4,000	-
D025	p -Cresol	106-44 -5	200	4,000	-
D026	Cresol		200	4,000	-
D016	2,4-D	94 -75 -7	10.0	200	0.34
D027	1,4-Dichlorobenzene	106-46 -7	7.5	150	0.055
D028	1,2-Dichloroethane	107-06 -2	0.5	10	0.023
D029	1,1-Dichloroethylene	75 -35 -4	0.7	14	1.1
D030	2,4-Dinitrotoluene	121-14 -2	0.13	2.6	0.024
D012	Endrin	72 -20 -8	0.02	0.4	3.8
D031	Heptachlor (and its epoxide)	76 -44 -8	0.008	0.16	0.071
D032	Hexachlorobenzene	118-74 -1	0.13	2.6	0.22
D033	Hexachlorobutadiene	87 -68 -3	0.5	10	0.041
D034	Hexachloroethane	67 -72 -1	3.0	60	0.023
D008	Lead	7439-92 -1	5.0	100	200
D013	Lindane	58 -89 -9	0.4	8.0	0.029
D009	Mercury	7439-97 -6	0.2	4.0	4.7
D014	Methoxychlor	72 -43 -5	10.0	200	16
D035	Methyl ethyl ketone	78 -93 -3	200.0	4,000	6.2
D036	Nitrobenzene	98 -95 -3	2.0	40	0.0053
D037	Pentrachlorophenol	87 -86 -5	100.0	2,000	0.098
D038	Pyridine	110-86 -1	5.0	100	-
D010	Selenium	7782-49 -2	1.0	20	78
D011	Silver	7440-22 -4	5.0	100	78
D039	Tetrachloroethylene	127-18 -4	0.7	14	0.098
D015	Toxaphene	8001-35 -2	0.5	10	0.49
D040	Trichloroethylene	79 -01 -6	0.5	10	0.089
D041	2,4,5-Trichlorophenol	95 -95 -4	400.0	8,000	0.50
D042	2,4,6-Trichlorophenol	88 -06 -2	2.0	40	0.31
D017	2,4,5-TP (Silvex)	93 -72 -1	1.0	20	0.87
D043	Vinyl chloride	75 -01 -4	0.2	4.0	0.036

Table 1 notes.

1. Promulgated TCLP level for determination of soil as a hazardous waste. If the result of a TCLP test meets or exceeds the level noted for the subject chemical, then the soil is classified as a "hazardous waste" and cannot be disposed of in a municipal landfill or construction/demolition waste landfill.

2. Minimum concentration of the subject chemical that must be present in the soil (mg/kg) in order for the TCLP level (mg/L) to be potentially reached, assuming 100% extraction of the chemical from the soil during the TCLP leaching procedure. TCLP data are required for disposal of the soil at a municipal landfill or construction/demolition waste landfill if the concentration of the chemical in soil exceeds HDOH Tier 1 EALs for unrestricted land use AND is equal to or greater than twenty-times the TCLP level noted in the Table 1. TCLP data are not required for onsite or offsite reuse of soils that meet the Tier 1 EALs provided that characterization of the soil was carried out in accordance with the HEER Office *Technical Guidance Manual*.

3. HDOH Tier 1 Soil Environmental Action Level for unrestricted land use, including residential, schools, medical facilities, parks, etc., where children and other sensitive populations might be present on a regular basis.

SECTION 4
DECISION UNIT CHARACTERIZATION

Interim Final – April 2021

State of Hawai‘i
Department of Health
Office of Hazard Evaluation and Emergency Response
2385 Waimano Home Road #100
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SECTION 4 ACRONYMS AND ABBREVIATIONS

%	Percent
°C	Degree Celsius
µm	Micrometers (micron)
≤	Less than or equal to
ASTM	American Society for Testing and Materials
atm-m³/mol	Moles per cubic meter for air to moles per cubic meter for water
cm	Centimeters
COPC	Chemicals (or Contaminants) of Potential Concern
DQO	Data Quality Objective
DU	Decision Unit
EAL	Environmental Action Level
ft	Feet
ft²	Square feet
GPS	Global Positioning Satellite
HDOH	Hawai'i Department of Health
HEER Office	Hazard Evaluation and Emergency Response Office
kg	kilogram
km	kilometer
mg/kg	Milligrams per kilogram
MIS	Multi Increment sample(s)
mm	Millimeter
MOU	Memorandum of Understanding
PAH	Polynuclear Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
QA	Quality Assurance
QA/QC	Quality Assurance and Quality Control
QC	Quality Control
RDX	Hexahydro-1,2,5-Trinitro-1,3,5-Triazine
RSD	Relative standard deviation
RSL	Regional Screening Level
SAP	Sampling and Analysis Plan
SD	Standard deviation
SOP	Standard Operating Procedure
SVOC	Semi-volatile organic compound
TGM	Technical Guidance Manual
TPH	Total Petroleum Hydrocarbons
TSCA	Toxic Substances Control Act
UCL	Upper Confidence Level
USEPA	United States Environmental Protection Agency
VOC	Volatile Organic Compound
XRF	X-Ray Fluorescence

4.0 CHARACTERIZATION OF DECISION UNITS

Section 3 discusses the importance of Decision Unit (DU) designation as part of the Systematic Planning process of an environmental investigation. A DU is an area and volume of soil for which a decision is to be made. In most cases this will involve an estimation of the mean concentration of contaminants of concern for each DU. This Section discusses the use of Multi Increment sampling methods to accomplish this objective.

Ideally, the entire, targeted volume of soil or other targeted media (e.g., sediment, water or air) included in a DU would be collected and sent to the laboratory for analysis. This is of course not practical under most circumstances and a representative sample (or samples) of the media must instead be collected and tested. It is important that the selected sampling approach generates precise and unbiased ("accurate") data that meet the objectives of the site investigation. Understanding the factors involved in collecting a representative sample is therefore critical and the essence of the field of sampling theory.

Multi Increment[1] sampling ("MI sampling or "MIS") methods are recommended for characterization of a DU. This sampling approach, long used in the mining and agricultural industries, is specifically designed for characterization of soil and addresses short comings of traditional discrete soil sampling methods. Of particular importance is the ability of MI sampling methods to overcome and represent small-scale, random variability of contaminant concentrations in soil that plagues traditional discrete sample site characterization approaches.

The section begins with a brief overview of "scale" in environmental investigations and the use and misuse of concepts such as "hot spots." The results of a detailed field investigation carried out by the HEER Office in 2014 are used to demonstrate how inherent random, small-scale variability of contaminant concentrations in soil limit the usefulness of discrete sample data. The predictability of this variability is discussed in terms of sampling theory. Assumptions regarding an anticipated small-scale "uniformity" of contaminant concentrations in soil served as the basis for much of the discrete sampling site investigation guidance written in the 1980s and 1990s. Limitations on the use of discrete sample data in site investigation is summarized. A detailed analysis of these topics is provided in the reports prepared for the 2014 HEER Office field study (HDOH, 2015, b).

The section focuses on background and use of Multi Increment sampling methodologies to characterize DUs. Topics addressed include Multi Increment sample collection, laboratory processing, use of replicates to evaluate data precision, collection of subsurface Multi Increment samples, and use of MIS for volatile chemicals and characterization of stockpiles.

The document *Incremental Sampling Methodology* (ISM), published by the Interstate Technology Regulatory Council (ITRC), is referenced in parts of this Section (ITRC, 2012). Several staff from HDOH as well as Hawai'i consultants assisted in preparation of the guidance. The ITRC document provides a basic overview of sampling theory and "incremental sampling" methods as well as examples of Decision Unit designation under different site scenarios. The document is especially strong in laboratory processing of "incremental" samples. Discussion of the collection of incremental samples in the field is basic, due in part to the lack of significant field experience (at the time) among members of the ITRC ISM team.

The discussion of the limitations of discrete soil sampling methods in the ITRC document is incomplete, however, with the potential impression that incremental sampling and thus "Multi Increment" sampling methods are simply one available alternative to traditional discrete sampling methodologies. This is not the case and was one motivation for the more detailed, HDOH field study of discrete sample variability and reliability in 2014 (HDOH, 2015). At the time the ITRC document was prepared, an analysis based on field studies of discrete sample variability and reliability was lacking (the statistical analysis included in the ITRC document was based on a computer-generated database). As discussed in detail in this Section, it should be emphasized that traditional discrete soil sample data, while potentially useful for large-scale screening purposes, fail to meet basic requirements of sampling theory for the collection of representative data and should not be used for final decision making purposes. Decision Unit and Multi Increment sampling methods are not simply "another tool in the toolbox". This sampling strategy addresses serious deficiencies of past discrete sampling methods, and represents an entirely new set of science-based tools. DU-MIS methods are recommended to obtain scientifically defensible and representative data for contaminants in soil and sediments on projects overseen by HDOH.

[1] *Multi Increment® is a registered trademark of EnviroStat, Inc.*

4.1 SAMPLING THEORY AND VARIABILITY OF CONTAMINANT CONCENTRATIONS IN SOIL

4.1.1 LARGE-SCALE AND SMALL-SCALE VARIABILITY

The term "large-scale" is used in this document to describe variability in mean contaminant concentrations between distinctly different areas of a site, such as the "spill area" DUs, "exposure area" DUs, and "perimeter area" DUs described in Section 3. The identification and characterization of such areas is often an objective of an environmental investigation. The term "small-scale" is used to describe variability in mean contaminant concentrations below the designated scale of interest. This includes variability at distances near discrete soil samples or individual increments as well as within an individual discrete sample or increment collected. Small-scale variability can be highly random in nature and unrelated to large-scale trends of interest. While it is important to capture and represent small-scale variability in a sample collected to represent a DU, understanding the precise nature of small-scale variability within a DU is ultimately unknowable and not pertinent to the objectives of the investigation.

The concentration of a contaminant in soil will vary based on the mass of soil tested. A single value would be reported if the entire DU mass of soil within a targeted exposure area could be collected, extracted and analyzed as a single sample. The value reported represents the true *mean* concentration for the volume of soil as a whole. The concentration of the contaminant will vary above and below the true mean if smaller subsets of the soil are tested.

For example, a single mean contaminant concentration will represent a targeted Spill Area or Exposure Area DU (Figure 4-1). If the DU was divided into four subareas for independent testing, the concentration of targeted contaminant can be expected to be higher in some soil volumes (red blocks) and lower in others (yellow blocks; see Figure 4-1). Variability can be expected to increase as the area is divided into smaller and smaller soil volumes for testing. This *distributional heterogeneity* ultimately extends down to the scale of individual, adjacent molecules, with the concentration of the contaminant being 100% in one molecule and 0% in the other. At this extremely small scale, the simple question of the "maximum" concentration of a contaminant in soil is therefore very straightforward; it's either 100% (if present) or 0% (if absent).

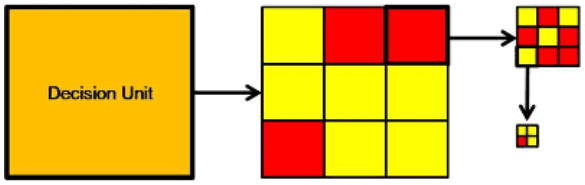


Figure 4-1. Variability of Mean Contaminant Concentration within Progressively Smaller Areas and Volumes of Soil within an Initially Designated DU

At some scale contaminant concentration variability will become random and unrelated to larger-scale trends. Variability at the scale of the mass of soil typically collected as a "discrete" sample (e.g., 100-200 grams) and tested by the laboratory (e.g., 1-30 grams) clearly falls into this category (Figure 4-2).

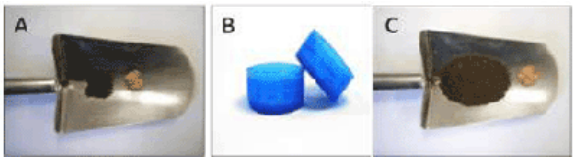


Figure 4-2. Mass of Soil Typically Tested by a Laboratory

A) Metals (1 gram), B) Volatile organic compounds (5 grams; approximate mass to fill a soda bottle cap), and C) Organic chemicals (10-30 grams)

Keep in mind that the true size of a discrete sample is the actual extraction and analysis mass removed from the original field sample at the laboratory. For example, the standard commercial lab subsample masses are: 0.5 grams for Hg; 1 gram for metals; 5 grams for VOCs; 10 grams for dioxins; and 30 grams for TPH, pesticides, and PAHs. For comparison, the cap of a soda bottle holds approximately 5 grams of soil which is the size of a laboratory subsample tested for VOCs (Figure 4-2).

This scale of variability was demonstrated in a field study carried out by the HEER Office in 2014 (HDOH, 2015, b). Hundreds of discrete soil samples were tested at each of three study sites. Figure 4-3 depicts a study area sampled within a former radio broadcasting facility known to be heavily contaminated with polychlorinated biphenyls (PCBs; Study Site C). A 6,000-ft² area was selected for characterization as a hypothetical Exposure Area DU. Multi Increment sample replicate data indicated a mean PCB concentration for the area of 104 mg/kg (95% UCL 346 mg/kg). The high Relative Standard Deviation for the replicate data (138%) indicates significant heterogeneity and a need to either increase the number of increments used and/or subdivide the original DU into smaller DUs for more precise characterization.

The site history, as well as discrete soil sample data collected as part of the study, suggests an overall higher concentration of PCBs in the eastern half of the study site where electrical equipment was formerly stored. This area is observable in the field by the presence of reddish fill material. This information could be used to divide the original study site into smaller DUs for more detailed characterization, if needed, for decision making purposes (see dashed lines in Figure 4-3).

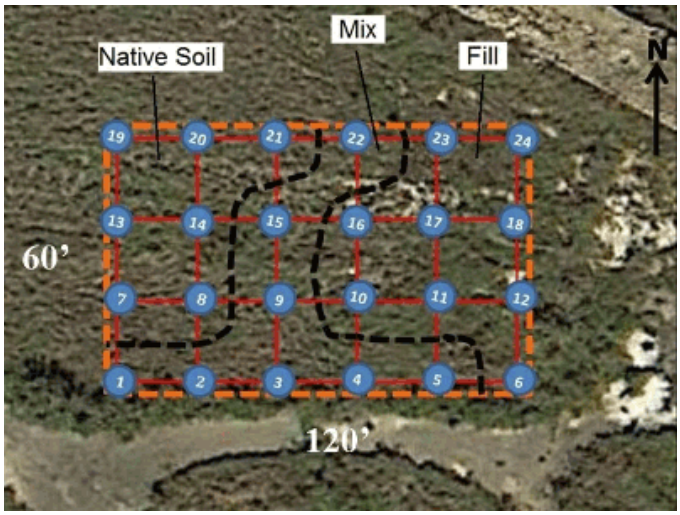


Figure 4-3. Study Site C in 2014 HDOH Field Investigation of Discrete Sample Variability

Soil types: A) Native soil, B) Mixed fill and native soil, C) Fill. Electrical equipment was formerly stored in the area underlain by fill material. Dashed lines indicate hypothetical division of original study site area into smaller DUs for more detailed characterization.

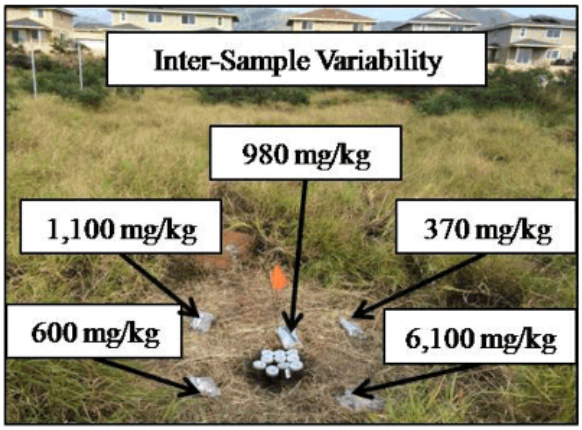


Figure 4-4. Example "Inter-Sample" Variability of PCB Concentrations in Soil

Data for processed, discrete samples collected within a 50-cm radius of a grid point (HDOH, 2015).

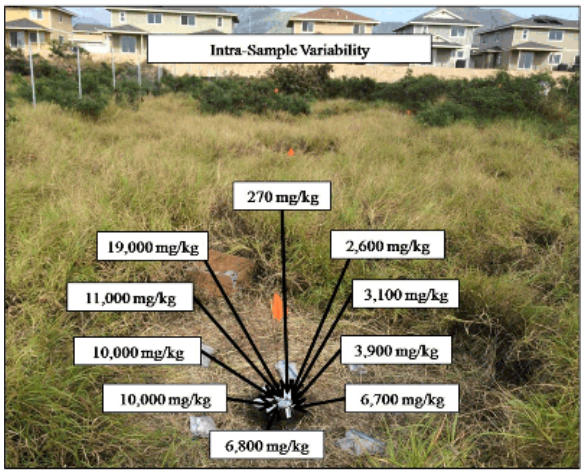


Figure 4-5. Example "Intra-Sample" Variability of PCB Concentrations in Soil

Data for 10 subsamples tested from a single discrete soil sample (HDOH, 2015).

An attempt to use discrete soil sample data to better characterize these areas could be highly misleading. As depicted in Figure 4-4 and Figure 4-5, concentrations of PCBs in discrete samples collected within a few feet of each other ("inter-sample" variability) as well as concentrations of PCBs repotted within individual samples ("intra-sample" variability) could vary by more than an order of magnitude HDOH, 2015). The variability was spatially random and unrelated to larger-scale trends.

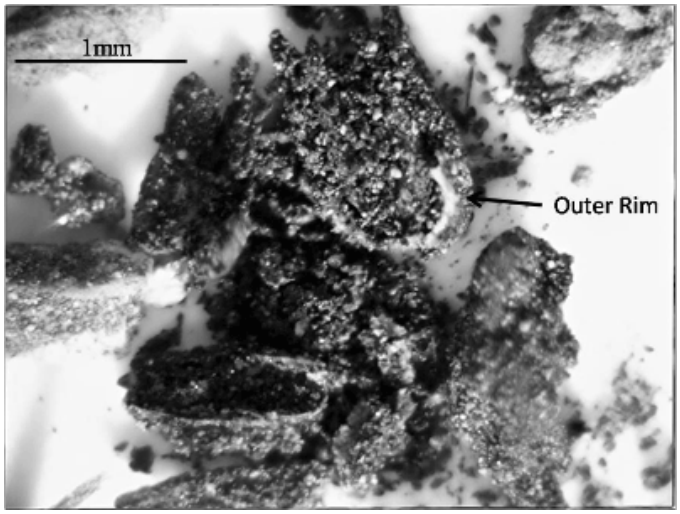


Figure 4-6. Photomicrograph of Possible PCB-Infused Nugget of Silty Soil

Interpreted to represent a remnant drop of waste transformer oil that sank into the soil (HDOH, 2015).

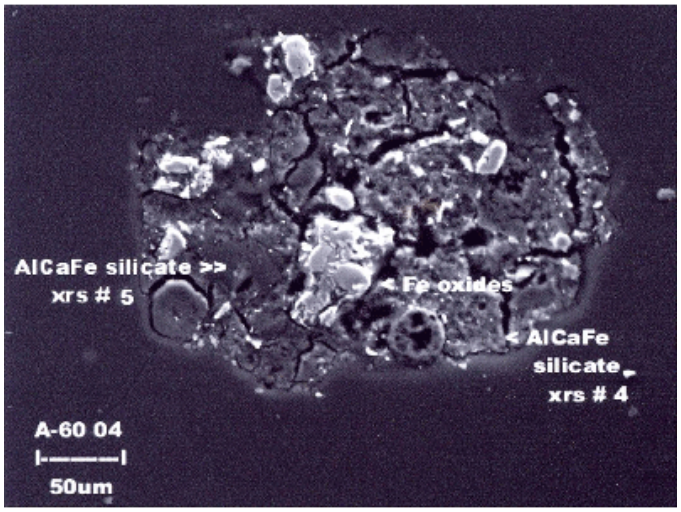


Figure 4-7. Arsenic-Infused Nuggets of Iron-Hydroxide in Volcanic Soil

Soil impacted by spraying of arsenic-based pesticides (photo courtesy of William Cutler).

This variability increases as the scale of measurement decreases. Microscopic evaluation identified what appear to be "fossilized" drops of PCB-infused transformer oil in soil from Study Site C (Figure 4-6; HDOH, 2015). Although not directly tested as part of the study, it is conceivable that the concentration of PCBs in the nuggets could approach the originally porosity of the soil following biodegradation of the mineral oil carrier, or several tens of percent.

Similar nugget effects for munitions, lead paint and other contaminants have been documented for soil (see ITRC, 2012). Figure 4-7 depicts a photomicrograph of arsenic-contaminated soil from Hawai'i. Electron microprobe analysis of the soil indicates that arsenic is concentrated in micrometer-scale "nuggets" of iron hydroxide randomly dispersed within the soil. The concentration of arsenic within the iron hydroxide nuggets is orders of magnitude greater than in the surrounding soil matrix (Cutler et al., 2006, 2011).

4.1.2 IMPLICATIONS OF RANDOM, SMALL-SCALE VARIABILITY

The implications of ubiquitous random contaminant concentration variability in soil at the scale of a traditional discrete sample are significant. Discrete sampling methods are based on the premise that an individual sample can be assumed to represent the immediately surrounding area and that variability between individual samples is predictable and reflective of larger-scale trends of interest:

> The PCB level is assumed to be uniform within [a contamination zone/spill area] and zero outside it (USEPA, 1985;
>
> To apply this [discrete sampling] method… [it must be assumed that] any sample located within the contaminated zone will identify the contamination (USEPA, 1987);
>
> When there is little distance between points it is expected that there will be little variability (in contaminant concentrations) between points (USEPA, 1989b).

The mass of soil to be collected as a discrete sample only need meet the mass required by the laboratory for analysis, including quality control (default 100 grams per sample recommended; USEPA, 1987). The concept of "data quality" was then shifted to the laboratory with the main source of error presumed to be associated with analytical error.

As discussed in the HDOH field study reports, these critical and ultimately erroneous assumptions were not evaluated in sufficient detail in the field or in the laboratory prior to publication of these and other guidance documents. Decision making error based on the use of discrete sample data is high and even unavoidable in several critical stages of site investigation, including (HDOH, 2015b):

- Comparison of individual data points to soil action (or screening) levels;
- Estimation of the lateral and vertical extent of contamination;
- Preparation of isoconcentration maps;

- Design of remedial actions for removal of contaminated soil;
- Estimation of contaminant mass of *in situ* treatment;
- Estimation of mean contaminant concentration for use in a risk assessment.

Comparison of individual, discrete sample points to risk-based action levels can be highly unreliable. As documented in the HDOH field study, it is inevitable that concentrations will at some point vary both above and below the target action level. This will result in a high risk of "false negatives" and a potential that contamination that could pose a significant risk to human health and the environment might go undetected (see HDOH, 2015b). Indeed, this is the likely cause of large contaminated concentration variations for some co-located discrete samples, and "failed" confirmation samples when discrete soil data are used to guide remedial actions.

Both the HDOH Environmental Action Levels (EALs; HDOH, 2016) as well as the USEPA Regional Screening Levels (RSLs; USEPA, 2014) are intended for comparison to the *mean* concentration of a contaminant within a defined, exposure or spill area. They are not intended for direct comparison to individual, discrete sample points. This was discussed in early risk assessment guidance but not fully appreciated in field investigation guidance being developed during the same time period:

> For Superfund assessments, the concentration term (C) in the equation [of risk-based screening level models] is an estimate of the *arithmetic average* concentration for a contaminant based on a set of site sampling results [i.e., for an exposure area]. (USEPA, 1992b)

The unreliability of a single discrete soil sample to approximate mean contaminant concentrations for comparison to screening levels and decision making was similarly recognized but not fully appreciated in early risk assessment guidance:

> Sampling data from Superfund sites have shown that data sets with fewer than 10 samples per exposure area provide poor estimates of the mean concentration. (USEPA, 1992)

This concern about unreliable data includes the use of small numbers of discrete soil samples to estimate the extent of chemical contamination above levels of potential concern.

Random, small-scale variability of contaminant concentrations in soil above and below an action level or geostatistical isoconcentration contour is expressed on maps by seemingly isolated "hot spots" and "cold spots" within a contaminated area (see HDOH, 2015b). These "spots" are real only in the sense that they reflect the variability (i.e., "noise") of contaminant concentrations in the soil at the scale of the discrete sample tested.

Large clusters of discrete data points consistently above a target level might serve as gross indicators of larger-scale contaminant patterns of interest. Such conclusions should be verified by the designation of DUs and collection of Multi Increment sample data, however, as discussed in the next section.

The implications of random small-scale variability of contaminant distribution and concentrations in soil for investigation of contaminated sites can be summarized as follows:

- Soil action (screening) levels apply to the mean concentration of a contaminant over a targeted area (e.g., spill area or exposure area), not to individual discrete points within that area (see HDOH, 2016).
- The objective of an environmental site investigation of soil is to determine if the mean concentration of a contaminant in a sufficiently large area (and volume) exceeds some critical threshold that could indicate a potential a risk to human health and the environment.
- The appropriate area and volume of soil for decision making is determined as part of the Decision Unit designation process (e.g., spill area or exposure area DUs; see Section 3).
- Determining the range of contaminant concentrations within a DU at some pre-specified small scale (e.g., mass of a typical laboratory subsample) is not practical, necessary, or relevant for the purposes of an Environmental Hazard Evaluation (see Section 13).
- The mean concentration of contaminants of concern for these areas (and volumes) of soil can be most reliably estimated through the use of Multi Increment sampling methods.

The cause of decision error associated with the use of discrete sample data is ultimately simple – the sample mass collected and tested is too small to overcome random small-scale variability of contaminant concentrations in soil. This fact is both predicted and addressed by sampling theory and the use of Multi Increment sample data to characterize well-thought-out DUs.

4.1.3 USE OF SAMPLING THEORY AND MULTI INCREMENT SAMPLING TO IMPROVE SAMPLE REPRESENTATIVENESS

Sampling theory dictates that the representativeness of a sample is controlled by four primary factors (after Pitard, 1993, 2005, 2009; Minnitt et al., 2007; ITRC, 2012; see also US Navy, 2015): 1) Random fluctuations in the distribution of the target analyte

in soil ("distributional heterogeneity"), 2) Sample collection methods, 3) Sample processing methods and 4) Analytical error. Decision units and Multi Increment sampling methods are used to minimize and evaluate these potential sources of error. Field sampling and processing error, as well as laboratory subsampling error, are likely to far outweigh error attributable to the analytical method used to test subsamples of soil extracted from bulk samples.

Uncertainty associated with the first factor is referred to as "Fundamental Error." Although Fundamental Error can never be completely eliminated, its effect can be minimized by careful sampling design and processing of samples for analysis. The mass of soil necessary to represent a targeted area can be predicted by sampling theory. Factors include the range and shape of particle sizes present in the sample and the desired precision of the data (e.g., parts-per-hundred versus parts-per-billion).

As discussed in the next section, the estimated sample mass required is then collected from a large number of points within the targeted DU area. Each point represents an "increment," with individual increments combined to form a bulk "Multi Increment" sample. Bulk MI Samples are typically air dried and sieved at the laboratory to remove particles larger than 2mm. The processed sample is then subsampled in the laboratory using a sectorial splitter or Multi Increment sampling in same manner as it was collected in the field to maintain representativeness, and this subsample is tested for target contaminants of concern. A modified approach using the collection of increments in methanol or freezing of individual increments is used for volatile organic compounds. Field and laboratory replicates are used to test the precision of the resulting data.

4.2 USE OF MULTI INCREMENT SAMPLES TO CHARACTERIZE DU'S

The HEER Office strongly encourages the use of Multi Increment sample collection strategies to enhance sample representativeness in the investigation of contaminated soil. As described in this Section, Multi Increment samples are prepared by the collection and combination of a large number of small "increments" of soil from multiple locations within the targeted Decision Unit (DU). Multi Increment samples improve the reliability of sample data by reducing the variability of the data compared to past discrete sampling strategies (Ramsey and Hewitt, 2005; Jenkins et al., 2005). Multi Increment sample data generally have much lower variability than discrete sample data and a higher reproducibility. Higher reliability supports greater confidence for decision making.

The theory supporting Multi Increment sampling is based on particulate sampling approaches developed by geologist Pierre Gy to improve the quality of data for mineral exploration and mining (Pitard, 1993, 2005, 2009; USEPA, 1999c; Minnitt et al., 2007). The approach can be used for both non-volatile and volatile contaminants, and testing of both surface and subsurface soils. The approach can also be used for sediment. These topics, as well as the use of Multi Increment sampling for stockpile investigations are discussed separately below, following a general discussion of Multi Increment sample collection.

To properly infer a representative average contaminant concentration by collecting and analyzing only a small portion of soil within the DU, it is very important that the sample collection and analysis be both unbiased and precise. Unbiased sampling requires random increments to be collected using the appropriate sampling tool and sampling method. Collection of precise samples requires an adequate volume of soil as well as a sufficient number of random increments from across the DU. Precision and absence of bias are needed to meet the Data Quality Objectives (DQO) established for soil investigations during systematic planning. Representative samples are generally collected with a soil coring device or other equipment to collect core-like samples across the DU from a minimum of 30 to 75 systematic random or stratified random locations. The resulting data are used to estimate average contaminant concentrations for the targeted area and volume of DU soil as a whole.

A Multi Increment sampling approach is recommended for the investigation and characterization of contaminated soil. Alternative approaches should be clearly discussed in a Sampling and Analysis Plan (SAP) presented to the HEER Office for review and meet data quality standards of Multi Increment sampling methods. This includes the need to test and verify the field precision of data (e.g., for any discrete sampling).

For surface soils where the use of hand tools is feasible, Multi Increment soil sample collection is relatively simple to accomplish (typically for non-volatile contaminants). Multi Increment soil sampling is more time and cost intensive for subsurface soils because in many situations, soil-drilling equipment or soil excavation equipment must be used. Limitations of the sampling data should be clearly discussed in the site investigation report if the recommended minimum number of increments (e.g., 30 to 75) cannot be collected in a subsurface DU due to site or cost constraints (e.g., reduced certainty in mean concentrations of targeted COPCs). Under these circumstances, it is important that a judgment call be made prior to sampling as to whether collecting limited sampling data would meet the DQO of the investigation, or some other option should be pursued as an alternative. The collection of replicate samples from one or more DUs will assist in evaluating the precision of the data (see Subsection 4.2.7).

Multi Increment sampling of subsurface soils contaminated with volatile chemicals involves similar challenges and warrants careful review of DQO, as well as options available for sampling. In addition, Multi Increment sampling for volatiles requires close coordination with the laboratory to implement appropriate modifications to the traditional "methanol method" for volatiles sampling in soils (see Subsection 4.2.9).

Professional judgment is critical in reviewing relevant information and choosing DUs where COPCs will be representatively sampled. Decision units represent the desired scale of mean contaminant concentration for decision making. As discussed in Section 3, considerations in choosing DUs include:

- Present and potential future exposure scenarios;
- The type of environmental hazard presented by the COPCs;
- Knowledge of any spill areas;
- Site physical characteristics that could influence the distribution of COPCs (e.g., soil types);
- Historical information on past site activities (e.g., Phase 1 ESA or equivalent reports);
- Observations from a complete site walk around;
- Documentation of any areas not accessible for sampling;

- Evaluation of any existing (site or adjacent land) screening or sampling data;
- Other relevant factors.

Based on a review of such information, judgment is used to define DUs that will best represent COPCs at the site. Once DUs are selected, representative sampling methods are employed to sample and infer average contaminant concentrations across each DU. A single Multi Increment sample is collected to represent a DU, with replicate samples collected in at least 10% of the DUs to evaluate the combined field and laboratory precision of the data. Assuming the data meet precision requirements established in the DQOs, the average contaminant concentrations are compared to applicable HDOH Environmental Action Levels (EALs) or approved, alternative screening levels to make decisions regarding the need for any subsequent response actions.

4.2.1 MULTI INCREMENT SAMPLING METHODOLOGY

Multi Increment samples are prepared by collecting a large number of small increments of soil from random locations within a specified DU (Figures 4-8a&b). The increments are combined into a single bulk sample referred to as a "Multi Increment sample."



Figure 4-8a. Example Decision Units (see also Subsection 3.4)

DU for spill area contaminated with lead. Flags represent increment locations for confirmation sample collected at bottom of excavation.

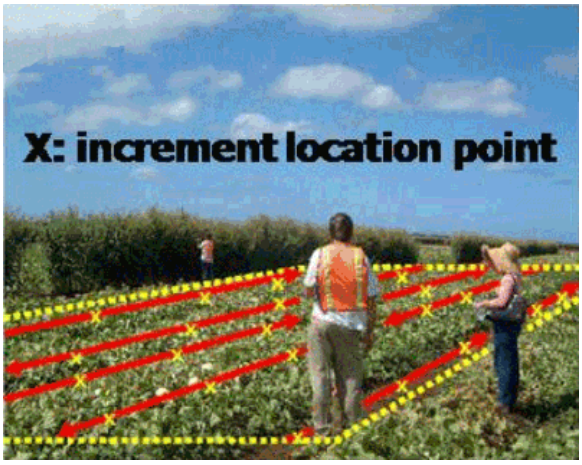


Figure 4-8b. Example Decision Units

DU for hypothetical, residential lot on former agricultural land. Rows and increment collection points start from a single random location, and are arranged in a manner that ensures a minimum of thirty increments are collected across entire DU.

Most DUs will be tabular in shape, with the length and width significantly greater than the vertical thickness, similar to a flat lying book. Cores used to collect increments should typically cover the entire thickness of the DU. Note that there may be one or more designated vertical DUs below ground surface, depending on the site DQOs, or to further delineate the results from initial surface interval DUs. It is important that increments collected within a targeted DU be of the same approximate mass, shape, and size (see Subsection 4.4). An exception to the latter is a scenario where the thickness of the targeted layer of soil varies within the DU (e.g., very thin soil over bedrock, or an obvious layer with specific soil characteristics that is targeted in the DQOs). In this case the increment should again cover the entire thickness of the DU, but increment lengths and masses will vary to target the specific (variable-depth) layer. This allows for individual increments to be more representative of the volume of soil represented by that DU. A variable total mass of sample may also apply to subsampling of cores extracted from subsurface DUs, where a regular subsampling spacing is used between core increments (e.g., every 2-4 inches), but different total subsample masses may be generated from different vertical layer depths being sampled.

It is important to identify and document significant specific areas of soil within a proposed DU or site that are not accessible for sampling (e.g., under building foundation pads [unless drilled], very dense un-cleared vegetation, areas down steep inclines, etc.). These areas represent "data gaps" when reporting sampling results. Any area that is not accessible for systematic random sampling in the targeted DU(s) is not represented by the mean contaminant concentration determined with MI sampling. Inaccessible areas should be clearly identified in the site investigation report and on site maps.

4.2.2 MINIMUM NUMBER OF INCREMENTS

The number of increments to be selected for the Multi Increment samples in a site investigation should be evaluated during systematic planning as part of the DQO and documented in the SAP. A minimum of 30 to 75+ increments per sample is recommended. This is based on MI sampling theory, 10 years of MIS field work experience in Hawai‘i, as well as additional published information (see Subsection 4.1; ITRC, 2012).

A minimum of 30 increments is recommended for release scenarios where small-scale variability (i.e., variability at the scale of an individual increment) can be assumed to be relatively low. This includes soil suspected to be contaminated by aerial fallout (e.g., downwind of an incinerator) or for liquid-based chemicals that were released in a uniform manner (e.g., sprayed, water-based pesticides). A minimum of 75 increments per sample is recommended for contaminants suspected to be present as small nuggets in soil. This includes chips of lead-based paint, lead shot, oil-based chemicals that could form clumps in soil after release (e.g., PCB-infused transformer oil), and munitions and explosives of concern (MEC). A minimum of 50 increments per sample is recommended for other release scenarios. This includes, for example, characterization of fill material that includes lead-contaminated incinerator ash and sites where the relative degree of contaminant heterogeneity is uncertain. These minimum increment numbers are provided for initial guidance only. The representativeness of Multi Increment samples and precision of the resulting data for a site should ultimately be evaluated through the collection of replicate samples, as discussed in Subsection 4.2.7.

The number of increments incorporated into the field Multi Increment samples, and the overall mass of the Multi Increment samples collected are not dependent on the size of the decision unit. If the decision unit is the size of a small backyard garden suspected to be impacted by sprayed pesticides, then a minimum of 30 increments of similar mass is collected. If the decision unit is a 10-acre former field likewise suspected to be impacted by sprayed pesticides, then a minimum of 30 increments of a similar mass is again collected.

It may be desirable to increase the number of increments whenever contaminant distribution is expected to be especially heterogeneous or demonstrated to be so by replicates samples. Collection of an increased number of increments in each DU would be expected to reduce field sampling error and minimize the variation from the mean among replicate samples used to evaluate representativeness of the data collected. This could be especially important if the contaminant concentrations are very near the EAL, where the degree of sampling error could be critical for a final site decision (see Subsection 4.2.7).

4.2.3 TARGET MULTI INCREMENT SAMPLE MASS

Individual soil increments typically weigh between 5 and 50 grams, with bulk Multi Increment samples typically weighing between 300 and 2,500 grams (mass sufficient to minimize Fundamental Error for sample collection) after sieving soil samples to the target particle size. A target bulk sample mass of 1,000 to 2,500 grams is recommended for samples to be tested for non-volatile chemicals. Note that sieving of soil samples to the <2mm particle size, typically performed in the laboratory sample preparation process for testing of non-volatile chemicals, will reduce the amount of soil mass available for analysis. This needs to be taken into consideration during the collection of samples in the field.

The target bulk sample mass should be reflected in the target mass of individual increments. For example, a target 1.5 kg bulk sample can be prepared by the collection and combination of 50, 30-gram increments. A minimum 10-gram increment mass is required to obtain a minimum bulk sample mass of 300 grams for a 30-increment bulk sample. The final mass of the Multi Increment samples depends on the number of increments collected and the size (i.e., coring tool diameter) and depth of the increments. Although based primarily on sampling theory and the need to collect a representative sample, the sampling scheme should also be reviewed with the laboratory to ensure that the final mass will be adequate for the total number and type of analyses planned and QA/QC requirements.

Care should be taken to ensure that individual increments are of adequate mass to produce the target mass of the bulk Multi Increment sample. Removal of large sticks, stones and other particles from bulk Multi Increment samples can be carried out in the field. Processing of samples in the field, such as sieving for the designated analysis particle size, is generally not recommended due to the potential to introduce additional error into the data under variable field conditions. In most cases processing is best carried out in a controlled laboratory setting (see Subsection 4.2.6).

Any processing of bulk MI samples that does occur in the field, including representative subsampling to reduce the bulk sample size or sieving bulk samples to the designated analysis particle size should be conducted under an established operating procedure developed as part of the Sampling and Analysis Plan. This field processing procedure should accommodate contingencies for variable weather conditions, include appropriate equipment and workstation set-up to carry out the processing and clean equipment as may be needed. Field processing of samples should be documented with photos, recorded in the sample log, and discussed in the site investigation report (see Subsection 5.5).

The collection of 1,000 grams or more of soil may not be practical for samples to be tested for volatile chemicals, due to the large amount of methanol required (see Subsection 4.2.9). The use of one-liter amber jars to collect soil samples will normally limit the mass of soil that can be collected to approximately 300 grams, or 60, 5-gram plugs of soil (assuming a 1:1 soil to

methanol ratio). Testing and discovery of VOCs over EALs in vadose-zone soil should normally be accompanied by the concurrent or follow-up collection of groundwater (Section 6) and/or soil vapor samples (see Section 7). Volatile chemicals primarily pose potential leaching and/or vapor intrusion hazards. These concerns can be more directly addressed through testing of groundwater and soil vapors.

4.2.4 INCREMENT DISTRIBUTION

4.2.4.1 SYSTEMATIC RANDOM GRIDS

A systematic random ("systematic") increment collection scheme is recommended for the collection of a Multi Increment sample from a DU (Figure 4-9). Under this approach increments are collected in a grid fashion at a fixed spacing, beginning from a random starting point in the DU. Systematic sampling approaches have been demonstrated in field studies to generate more reproducible data than purely random approaches, where each increment location is independently selected, as well as stratified random or related sampling schemes (Figure 4-10). The collection of closely spaced increments from more widely spaced rows as depicted in Figure 4-10 is likewise not considered to be reliable.

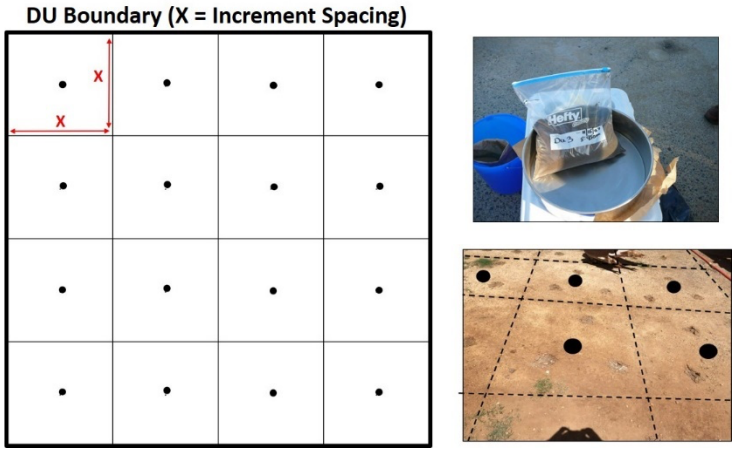


Figure 4-9. Example Increment Collection Locations Based on a Systematic Random Grid Scheme

Grid spacing determined based on DU area and number of desired increments. Initial increment location selected as center point of grid cell or other random location. Subsequent increments collected at uniform spacing within DU.

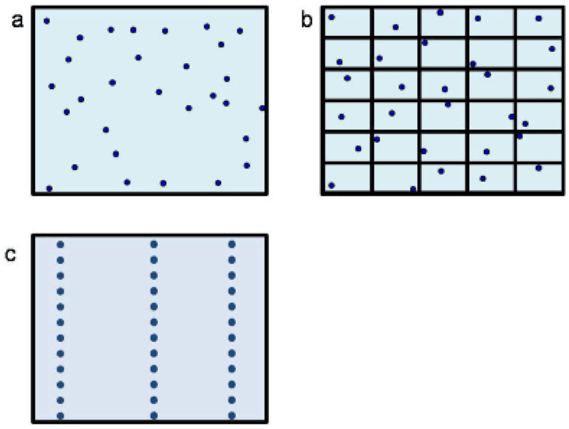


Figure 4-10. Examples of Simple Random (a) and Stratified Random (b) Increment Location Patterns and Collection of Closely Spaced Increments from More Widely Spaced Rows (c) Each approach leads to uneven coverage of the DU and has been demonstrated in field tests to be less reliable and reproducible than systematic random sample collection (see Figure 4-9).

Systematic sampling requires that increment locations be evenly spaced between all axes of the grid to the extent feasible in the field. The spacing of increments within a DU is a function of the area of the DU and the number of increments to be collected. The increment spacing is calculated as the square root of the DU area divided by the targeted number of increments:

$$Increment\ Spacing = \sqrt{\frac{DU\ Area}{\#\ Increments}} \qquad \text{Eq. 1.)}$$

The calculated spacing reflects hypothetical division of the DU into a number of cells equal to the targeted number of increments (see Figure 4-9). The area of each cell is calculated as the total area of the DU divided by the number of increments. Taking the square root of this area yields the length of each side of the cell, assuming a square shape.

Actual increment collection locations reflect a random offset of this grid, with increments collected from an identical (i.e., systematic) location within each cell. The spacing can be slightly adjusted (e.g., rounded to nearest whole foot) as needed in the field to aid in establishing the grid in the field for sample collection.

In the example depicted in Figure 4-9 the increment is collected from the lower left-hand corner of each cell. In the field the initial increment point can be placed anywhere within the targeted spacing distance of the DU corner; i.e., anywhere within the first cell. This point is subsequently used to establish a grid of increment collection points within the DU using the spacing estimated from the above equation.

For example, consider a 5,000-ft² DU from which a Multi Increment sample composed of 50 increments is to be collected in a systematic random fashion. A target increment spacing of 10 ft is calculated. This reflects a hypothetical division of the DU into 50, 10-ft by 10-ft cells, each with an area of 100 ft². An initial increment collection location is then designated in a corner cell. Use the center point as a default, although any location within the cell is appropriate. A grid with a spacing of 10 ft is then initiated at this point outward toward the boundaries of the DU until the next subsequent point would fall outside of the DU boundary. Table 4.1 provides approximate increment spacing in feet for a range of DU sizes and numbers of increments selected.

Table 4-1. Approximate Increment Spacing (in feet) for Decision Unit Area (see Equation 1)

Number of Increments	Decision Unit Area (acres)								
	0.10	**0.20**	**0.25**	**0.50**	**1.0**	**2.0**	**3.0**	**4.0**	**5.0**
30	12	17	19	27	38	54	66	76	85
40	10	15	16	23	33	46	57	66	73
50	9	13	15	21	29	41	51	59	66
75	8	11	12	17	24	34	41	48	54
100	7	9	10	15	21	29	36	41	46

This approach will work for DUs of any shape and size in most cases, including squares, rectangles and DUs with irregular or unequal sides. In the latter case the number of increments collected within rows may differ in different parts of the DU (Figure 4-11). The increment spacing calculation remains the same, however. When possible, inclusion of at least one, square corner for a DU from which to initiate increment collection will greatly facilitate establishment of a grid within the rest of the DU and help expedite sample collection. Note that the collection of increments from partial cells along the outer edges of the DU will result in a somewhat larger, final number of increments than initially used to establish the grid spacing (e.g., upper boundary and right boundary in Figure 4-11).

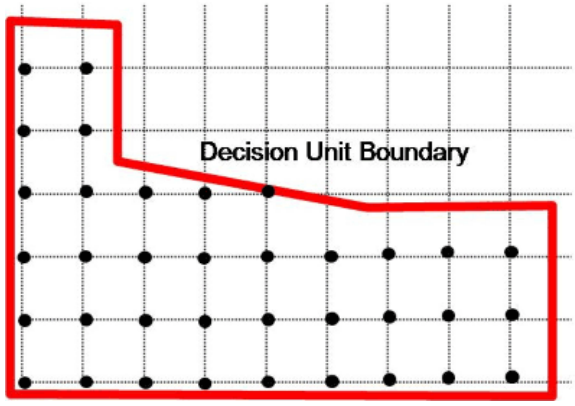


Figure 4-11. Systematic Increment Locations for Odd Shaped DUs (compare to Figure 4-9)

The number of increments collected within grid rows can vary in different areas of the DU.

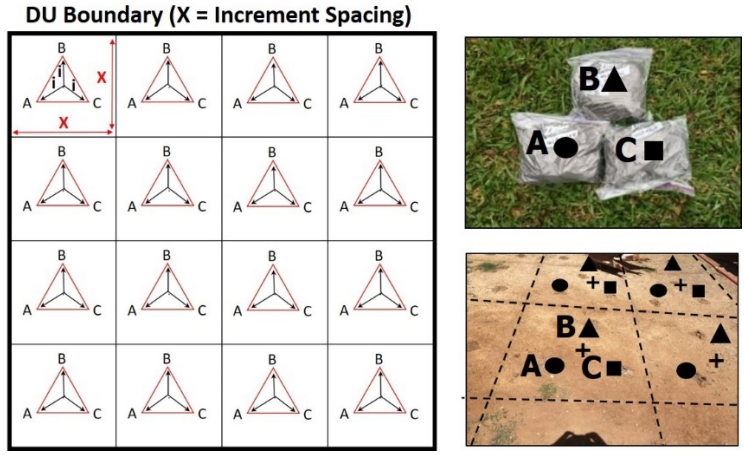


Figure 4-12. Example Collection of Increment Location Points for Triplicate Multi Increment Samples
Increments collected in a systematic random method. Circles, triangles and squares depict increment collection locations for three, respective Multi Increment samples (increments collected in equilateral triangular fashion around center point of grid cell).

Exceptions to the above approach include long, narrow DUs where the width is less than the increment spacing calculated above, for example a drainage ditch (see following subsection). In this case the length of the DU should simply be divided by the desired number of increments and this distance used to space increments.

A simple approach for the collection of field replicate samples and in this case triplicate Multi Increment samples is depicted in Figure 4-12. A single increment is collected from each point of an equilateral triangle centered on the midpoint of the cell, with each point dedicated to one of the three samples to be prepared for the DU as a whole (e.g., Sample A, Sample B and Sample C depicted in figure). Increments associated with the same point within cells are combined to prepare a bulk sample. For

example, all increments collected from Point A in cells are combined to prepare Sample A, etc. The points of the triangle should be located approximately 1/4th of the calculated increment spacing for the DU from the midpoint of the cell in order to ensure adequate separation of the final, bulk samples. The collection and evaluation of replicate data is discussed in more detail in Subsection 4.2.7.

The above increment spacing examples are for general guidance only. Other increment collection schemes are possible. An effort should be made, however, to ensure that increments are evenly spaced and distributed within a DU. Replicate samples should be collected to verify the reproducibility of the sampling approach. The final approach used to space and collect increments should be clearly described in the site investigation report.

4.2.5 SAMPLE COLLECTION

A detailed, logistical discussion of the collection of increments and Multi Increment samples in the field is provided in Section 5. An overview of the basic design of Multi Increment sample collection is provided below.

4.2.5.1 LOCATING INCREMENT COLLECTION POINTS

The corners of the DU(s) (or enough points to delineate the DU shape, if irregular) should be recorded via Global Positioning System (GPS) to document the DU location. Note that GPS location information can be several meters off. Use of tape measures or equivalent approaches in the field is recommended to document the exact dimensions of a DU. If there are buildings on the site near established DUs, physical (tape) measurements from these fixed locations can also be made to help generate maps and GPS DU locations using existing GPS map resources.

Approximate increment spacing should be estimated using Equation 1 given in Subsection 4.2.4.1. A tape measure (or careful pacing) can be used to identify increment locations within the DU. Documenting or flagging the location of every individual increment collected within a DU is not necessary, although spacing and number of increments collected per DU should be stated in the site investigation report. Flagging the locations of increment rows along the perimeter of a DU is usually adequate to guide collection of increments within the DU itself (Figure 4-13). A few rows of flags can also be placed within large or long DUs as needed to help guide increment collection.

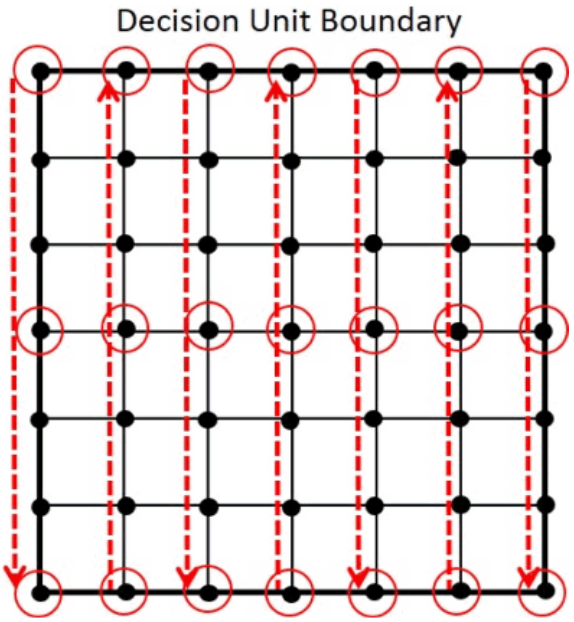


Figure 4-13. Example Flag Placement (red circles) for Collection of Increments in the Field

Increment collection direction noted by arrows.

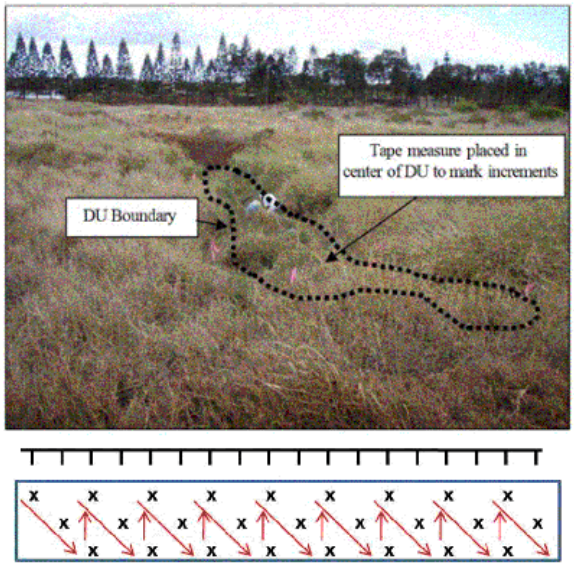


Figure 4-14. Collection of Increments in a Long, Narrow DU

Tape measure or measured rope placed in DU; arrows indicate direction of increment collection (note even placement of increments).

Use of a GPS in the absence of flags can expedite the location and collection of increments for very large DUs, where error in increment location within a few meters is acceptable and where pacing might not be accurate or practical due to vegetation, topography, or other access issues (e.g., DUs of tens or hundreds of acres).

Increments should be collected in an evenly spaced, zig-zag pattern in long narrow DUs, as depicted in Figure 4-14. A tape measure or rope with flags tied at the appropriate spacing can be placed in the DU to assist in increment collection, without the need to flag individual points.

4.2.5.2 INCREMENT AND BULK SAMPLE COLLECTION



Figure 4-15. Multi Increment Sample Collection

Collect an "increment" of soil at each point. In this example (very soft soils), a sampling tube is used to extract a cylindrical volume of soil to a depth of approximately 10 cm. Each increment typically weighs 20 to 50 grams. Subsequent increments for the target DU are placed in the same container.

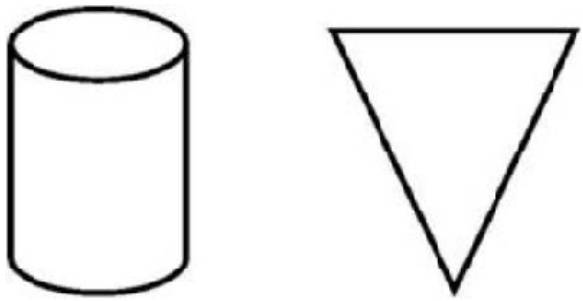


Figure 4-16. Core-shaped Versus Wedge-shaped Increments

Core-shaped increments provide equal coverage across the entire targeted depth of soil. Hand trowels are more likely to produce wedge-shaped increments with most of the soil coming from the upper few inches of the targeted depth.

A detailed logistical discussion of the collection of increments and Multi Increment samples in the field is provided in Section 5. Individual increments collected are placed into a single sample container to produce the bulk, Multi Increment sample (Figure 4-15).

Using the wrong tools or collecting a sample that contains more soil particles from the top of the targeted DU than the bottom will lead to biased sample results and potentially non-representative data, due to a heterogeneous vertical distribution of contaminants in the soil. As shown in Figure 4-16, a core-shaped increment is ideal.

Core-shaped increments can be collected using a soil coring sampler, soil sampling tubes (both preferred), or drills with specialized bits. This ensures equal coverage at all depths of the targeted DU layer. Hand trowels tend to produce wedge-shaped increments, with a bias towards the upper section of the targeted soil and are generally not recommended. If used, an effort should be made to extract core-shaped increments.

Proper planning should be carried out to ensure that the final bulk Multi Increment samples will be reasonably close in size to the original targeted mass (e.g., 1-2 kg; Figure 4-17). Processing of a bulk Multi Increment sample in the field to reduce the mass of soil beyond removal of sticks and large rocks is not recommended, due to potential logistic issues and weather-related conditions that could introduce error into the sample data. This can be accomplished by establishing a target mass for individual increments up front and using proper tools to collect the increments.

Testing of smaller groupings of increments collected within a single DU (e.g., 4 groupings of 10 increments each) is likewise invalid, since the resulting data cannot be assumed to be representative of the area from which the increments were collected. Doing so may be wasteful of both field time and analytical budgets. The collection of an adequate number of increments and sample mass from each area during the initial field work should not add significantly to the time or cost of the project and will significantly improve the usefulness and reliability of the resulting data.

If a greater resolution of contaminant distribution might be required for a targeted area then the initial designated DU should be subdivided into smaller DUs from the start, with a defensible Multi Increment sample collected from each area (see Subsection 3.4.1). The same holds true in cases where significant contamination is identified in a large DU where contamination was not initially anticipated. If a greater resolution is subsequently desired to optimize remedial actions, then the DU should be subdivided accordingly, and proper Multi Increment samples collected from each new DU.



Figure 4-17. Increments Combined to Generate 1-2 kg Bulk Multi Increment Sample

Note that the collection of co-located increments or "splits" of initially collected increments for later, individual testing is not recommended or valid in terms of sampling theory. The prevalence of random, small-scale variability of contaminant concentrations within small masses of soil negates the reliability of any given increment to be representative of the immediately surrounding soil (see Subsection 4.1.2). Simple "splits" of increments can vary by orders of magnitude, as can the concentration of contaminants between co-located increments or discrete soil samples.

4.2.6 LABORATORY PREPARATION OF SAMPLES

Talk to your laboratory ahead of time to ensure they are familiar with the Multi Increment sampling strategy and associated laboratory drying, sieving, and subsampling requirements, as well as minimum laboratory subsample mass requirements based on particle size, and other topics discussed below. Discrete soil samples, if collected, should also be processed in the manner described if the investigation DQOs requires that data representative of mean contaminant concentrations in DUs be obtained.

Data for samples that are not processed at the laboratory using procedures described in this subsection, or equivalent, cannot reliably be considered representative of the bulk MI samples provided from the field. Documentation of sample processing methods should be included in the laboratory report and summarized in the investigation report. Ensure that the laboratory has a Standard Operating Procedure for Multi Increment sample processing and analysis that conforms to HDOH recommendations prior to submittal of samples for testing.

Bulk MI samples collected in the field should be kept to a maximum mass of approximately 2 kilograms unless otherwise coordinated with the laboratory, due to handling and storage limitations. Laboratories might charge extra for processing and disposal of excess soil. Sample mass can be reduced in the field using incremental subsampling methods if a larger amount of soil is inadvertently collected (see Subsection 4.2.3). This is not recommended as a standard practice, however, due to the potential to introduce additional error and uncertainty into the data. Any field processing of bulk samples should be clearly described in the investigation report.

Laboratory processing of Multi Increment samples typically consists of the following steps:

- Empty entire bulk sample onto tray made of or lined with material compatible with contaminant of interest and drying temperature;
- Spread evenly into thin layer;
- Allow to air dry until a constant weight is established by re-weighing or air dry until soil agglomerates are crushable and a separate subsample can be used for moisture analysis and dry weight correction;
- Sieve entire bulk sample to <2mm to remove greater than "soil-sized" particles;

- Subsample entire sieved portion using a sectorial splitter or Multi Increment sampling methods to collect appropriate mass for each targeted analysis (minimum 10 grams for the <2mm particle size; including testing for metals).

Soil particles <2mm sized are generally considered "soil" for the purposes of an environmental investigation and contaminant analysis, including comparison of data to risk-based action levels (HDOH, 2016). Sieving to <2mm to remove gravel, sticks and other large debris also establishes the maximum particle size of the sample, which is necessary (in accordance with sampling theory) to determine the minimum subsample mass necessary for extraction and analysis in the laboratory.

Although sieving to the <2mm particle size is typical, there could be contaminant investigations or analyses where alternate particle sizes are of interest. For example, bioaccessible arsenic tests require that the <250 µm fraction be tested (see Section 9). In these cases, the rationale for sieving to other specific particle sizes (and associated changes to lab processing/analysis) should be clearly discussed in the DQO/SAP.

In certain cases, grinding of the sample may be required to reduce Fundamental Error and/or include contaminants in larger particles in the data. Grinding is not recommended as a default step in sample processing, however, unless specified by EPA analysis method (e.g., Method 8330b for explosives residues). The HEER Office should be consulted when grinding is proposed as part of the site investigation Sampling and Analysis Plan.

Sample processing is discussed in more detail in the sections below. Contaminant analyses of all soil samples, regardless of how they were collected, should be reported on a dry weight basis. Data for samples that are air dried to constant weight and sieved prior to analysis can be considered dry weight without additional analysis for moisture content. The moisture content should be tested for samples that are not dried prior to the collection of subsamples for analysis (e.g., TPH-d and semi-volatile chemicals). Any remaining soil is disposed of by the laboratory, normally after thirty days (consult laboratory for details). If archiving of samples is warranted or decisions on potential additional analyses of remaining MIS soils have not been made within 30 days, special arrangements should be made with the laboratory for longer-term storage.

4.2.6.1 SAMPLE PROCESSING

Bulk Multi Increment samples should be spread into a thin layer (~0.5 to 1.0 cm) on a large tray and placed in a ventilated area. Aluminum or plastic trays are commonly used for drying, but should be avoided if aluminum, phthalates or other plastic components are contaminants of potential concern. Paper liners should be avoided if organic carbon is to be tested for or if contaminants are present that could sorb to the paper (e.g., heavy oil).

Samples to be tested for non-volatile chemicals should be air dried under ambient conditions (e.g., 15 to 30°C). Soil moisture content should be reduced to achieve a constant air-dried weight for the samples, as determined by periodic re-weighing or air dry until soil agglomerates are crushable and a separate subsample can be used for moisture analysis and dry weight correction. Drying times can vary between a few hours for course soils with initially low moisture to several days for wet, fine-grained soils. Higher temperature (and faster) drying methods are acceptable provided that the laboratory has a Standard Operating Procedure and it has demonstrated this procedure will not result in significant chemical loss or transformation.

Wet, clayey samples should be periodically crushed with a pestle to avoid formation of hard bricks. Disaggregation should be done in a manner that avoids crushing of rock fragments and other naturally large particles. More intensive particle reduction methods (e.g., grinding) are described below.

Samples should be sieved to <2mm following drying and then subsampled as described below. Note that soil (or sediment) samples that consist entirely of <2mm material do not require drying and sieving to address fundamental error concerns, although some degree of drying and sieving may be desirable by the laboratory for testing purposes. Exceeding recommended holding times for non-volatile chemicals in order to permit drying, sieving, and more definitive subsampling and data is generally acceptable but should be minimized to the extent practicable (see Section 11; see also USEPA, 2003c).

4.2.6.2 SUBSAMPLE COLLECTION

Subsampling for collection of a mass of soil for extraction and analysis is accomplished with a sectorial splitter (Figure 4-18; also called a rotary riffle splitter, this subsampling method is generally considered best). Note that multiple splits using a sectorial splitter may be necessary to reduce the bulk sample mass down to the desired amount for extraction and analysis. As an alternative, a representative subsample can be collected by removing approximately 30 small increments in systematic random locations and of sufficient mass to generate the desired subsample for testing (Figure 4-19). The processed sample (e.g., dried and sieved) is spread into a thin (e.g., <1 cm) layer for collection of subsample increments when using the MI subsampling method.



Figure 4-18. Use of a Sectorial Splitter to Collect Laboratory Subsamples from Bulk MI Field Samples

Sectorial splitter (rotary riffle splitter) used to collect lab analysis subsamples from a bulk Multi Increment sample that has been dried and sieved to the <2mm particle size. If a sectorial splitter is not available, then collect Multi Increment subsamples of appropriate mass by hand (see Figure 4-19).



Figure 4-19. Manual Collection of Subsamples in the Laboratory

The laboratory subsamples the bulk Multi Increment sample that has been air-dried and sieved to the <2mm particle size. Approximately 30 increments are collected. The mass of each increment is based on the total mass of sample needed for the relevant analyses (typically a minimum of 10 grams).

Subsampling is used to collect a representative mass of soil from a single Multi Increment sample (and any lab replicates), and to provide representative subsamples for multiple analyses. The mass of soil needed for the analytical test or tests is used to determine the parameters for splitting the sample with the sectorial splitter, or in determining the mass of each subsample increment if collected by hand. In either case, it is critical that the entire mass of dried and sieved sample be utilized for the subsampling process.

The Gy sampling theory, which is the foundation of the Multi Increment sampling approach, is also the basis of two primary references on laboratory subsampling and analysis of particulate samples: United States Environmental Protection Agency (USEPA, 2003b) and American Society for Testing and Materials (ASTM, 2003). These, as well as the laboratory processing information provided in the ITRC Incremental Sampling Methodology guidance (ITRC, 2012), are recommended as lab guidance by the HEER Office. Of all the laboratory steps necessary to process and analyze environmental samples, subsampling is widely believed to present the greatest potential for error. The lab subsampling guidance applies to all types of soil samples collected in the field, whether Multi Increment, discrete, or judgmental samples.

One issue discussed in both the USEPA and ASTM guidance documents is the choice of a minimum subsample mass for extraction/analysis of soil samples in order to reduce "Fundamental Error" of the lab analyses to approximately 15% or less, which is also recommended by the HEER Office as a primary lab data quality objective (see also ITRC, 2012). The minimum appropriate mass is based on the maximum particle size in the soil samples. For samples with a maximum particle size of <2mm, the minimum extraction/analysis mass is 10 grams.

Laboratories may need to modify USEPA methods appropriately to achieve the minimum 10-gram subsample mass for extraction and analysis (for example modify extractions for metals analysis), or conduct multiple small subsample extractions and combine them for analysis. This is primarily a concern for metals, where methods may call for only 1 gram to be tested. With the possible exception of mercury, extraction and testing of 10-gram subsamples is feasible for most metals if specifically requested. Mercury sample extraction mass might be limited to 5 grams or several grams due to the laboratory method involved. If this is the case, then a minimum of 5 grams should be extracted, with multiple extracts combined and tested as a single extract solution as necessary. Milling of samples is another option, provided that the method used does not generate excess heat that could cause elemental mercury to volatize (see Subsection 4.2.6.3). If the laboratory is unable to test the recommended minimum sample mass for any analyses, then replicate subsamples (i.e., triplicates) should be tested for these samples in order to evaluate subsampling precision.

For analyses of fine particulates (e.g., <250µm), a one-gram subsample may in theory be adequate to reduce Fundamental Error below 15%. If a larger mass can be reliably run by the method (e.g., 2-10 grams), however, the HEER Office recommends

doing so to help reduce opportunity for error. Note that this applies to bioaccessible arsenic tests (see Section 9 for bioaccessible arsenic information).

4.2.6.3 PARTICLE SIZE REDUCTION

Milling ("grinding") of samples beyond crushing of soil clumps by hand or using a simple mortar and pestle is not normally recommended as a default sample processing procedure, unless specified by an EPA analysis method (e.g., Method 8330b for explosives residues). However, milling could be necessary in some other specific cases, and these should be discussed with the HEER Office as part of the planning process for site investigations. Data for sieved but un-milled samples are typically more appropriate for evaluation of chronic health risks under current site conditions. The evaluation of direct-exposure risk to contaminants in soil is generally based on the concentration of the contaminants in the <2mm or smaller particle fraction of the soil (USEPA, 2011d). Milling of the <2mm fraction can also overestimate the risk posed by metals in rock fragments and mineral grains that would otherwise be tightly bound and not available for uptake.

Milling of soil samples could be appropriate in the following circumstances:

- Presence of large (i.e., >2mm) fragments of contaminants in the sample that could contribute to the potential risk to human health and the environment;
- Need to reduce particle size to address Fundamental Error and achieve greater reproducibility of analytical results, or
- Need to test smaller subsample masses (e.g., ≤10 grams; see Subsection 4.2.6.2)

Examples of the first scenario include the suspected presence of large chips of lead-based paint in soil around the perimeter of a building. The chips could break down overtime into finer particles. In such cases testing of both un-milled and milled samples should be carried out to evaluate current and potential future risk. The same is true of lead shot in soil. Samples should be milled if particles that could pose potential leaching hazards are present in the sample and could be excluded from the data if un-milled samples are tested (e.g., large nuggets of munitions related compounds such as RDX). Note that batch leaching tests are normally run on subsamples from un-milled samples. As noted in Subsection 4.1, releases of PCB containing oils and similar liquids can form "nuggets" in the soil, causing error in both sample collection in the field and subsample collection in the laboratory.

Milling can be especially useful when data for replicate, Multi Increment samples are highly variable, in order to help discern if the problem is related to field versus laboratory error. Milling samples to achieve very uniform small particle sizes can help reduce Fundamental Error and improve the precision of laboratory subsampling when replicate data suggest a problem. Milling also allows for a smaller subsample and extraction/analysis mass for non-volatile contaminants.

See the ITRC Incremental Sampling Methodology document for a detailed review of milling options (ITRC, 2012). Milling of a minimum 300 grams of soil is recommended (minimum mass necessary to address Fundamental Error; see Subsection 4.2.3). Milling of larger masses (e.g., 1 kg) is preferable. Milling of a minimum 20-gram subsample is recommended in cases where milling of larger masses is not feasible. Collection of a representative subsample following the procedures described in Subsection 4.2.6.2 should be adhered to if the bulk sample is too large to be milled.



Figure 4-20. Puck and ring mill, used to crush small masses of soil to very fine grain size

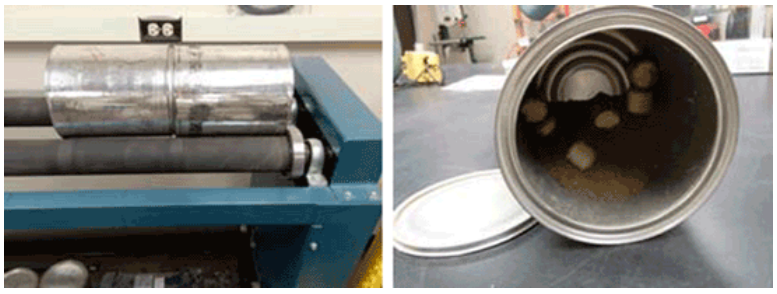


Figure 4-21. Ball mill with ceramic cylinders used for moderate crushing of large soil volumes

Puck and ring mills (“puck mills” Figure 4-20) and ball mills (Figure 4-21) are most commonly employed. Puck mills are able to reach a finer consistency, but can increase the temperature of samples and result in a loss of organic compounds. Puck mills can also normally only grind a small mass of soil at a time. Ball mills are able to mill larger masses of soil (e.g., up to 1+ kg),

provide more gentle, particle-size reduction and minimize heat generation in comparison to traditional puck mills. Ball mills cannot grid a sample to the same fineness as a puck mill but are normally adequate for environmental investigations.

Consider the chemical composition of the mill and target analytes of interest when selecting an appropriate mill. Pucks and rings in puck mills and cylinders in ball mills are typically composed of stainless steel, tungsten carbide and ceramic. Stainless steel pucks and rings or cylinders should, for example, not be used when chromium is an analyte of interest or when heat generation is a concern (e.g., elemental mercury). Ceramic equipment can contribute aluminum to the sample.

Note that non-elemental, mercury-based compounds used as fungicides at former sugarcane operations such as phenylmercuric acetate are not considered to be significantly volatile or susceptible to loss during processing, especially in aged releases to soil (USNLM, 2016; see Subsection 4.2.6.4). Nonetheless, use of a ceramic mill is recommended in order to minimize heating of the sample.

USEPA SW-846 Method 8330b for processing and analyzing energetic compounds calls for grinding the samples to meet data quality objectives (USEPA, 2006d). This method also includes guidance on field Multi Increment sampling for energetic compounds. Note that suitable grinders are expensive, add cost to processing and analysis of samples, and may not be available at many labs.

4.2.6.4 SEMI-VOLATILE AND UNSTABLE CHEMICALS

Samples to be tested for semi-volatile chemicals or non-volatile chemicals with a very short half-life (e.g., <30 days) should be immediately subsampled for testing after receipt by the laboratory and prior to air drying and sieving in order to minimize significant contaminant loss (e.g., >10% of original mass; see Appendix 4-A). Information on the collection of Multi Increment samples to be tested for volatiles is provided in Subsection 4.2.9.

For the purposes of this Section, a chemical is considered to be semi-volatile if its vapor pressure is between 0.1 and 1.0 mm Hg or if it is a liquid at 25ºC or if the Henry's Law Constant exceeds 0.00001atm-m³/mol (USEPA, 2015). Chemicals listed in the HDOH EAL guidance that fall into this category include TPH-d, some PAHs, and elemental mercury. A chemical is considered to be unstable if its half-life is less than 30 days. This will most commonly be a potential concern for pesticides with a low persistence. These criteria might be overly conservative for aged chemicals in soil or other factors that could reduce volatility in comparison to fresh product. Discuss the acceptability to subsample without drying and sieving with the laboratory. Note and justify any deviation from the default recommendations in the laboratory report.

Appendix 4-A provides information on specific SVOCs (including TPH-d, some PAHs, and mercury), pesticides and other chemicals that are highly biodegradable, chemically unstable, or otherwise have a low persistence (i.e., half-life less than 30 days). See Section 9 and Appendix 9-B for a list of chemicals with low persistence that are known to be have been used in sugarcane and pineapple agriculture in Hawai‘i.

Multi Increment samples for SVOCs and unstable chemicals should be cooled immediately after collection. The samples should be subsampled and extracted for analysis within holding times recommended for those chemicals, as noted in Section 11 or otherwise agreed upon with the HEER Office.

At the laboratory, bulk Multi Increment samples to be tested for SVOCs and unstable chemicals should be spread out and subsampled prior to drying and sieving. Surface soil samples that have been exposed to air on site prior to sample collection are acceptable for air drying (if needed) even when determining higher vapor pressure SVOCs. This and other alternative approaches should be discussed with the HEER Office and described in the investigation Sampling and Analysis Plan. Check with the laboratory to determine feasibility of wet sieving the sample to remove >2mm particles prior to subsampling (see ITRC, 2012). An effort should otherwise be made to collect <2mm particles in lab subsamples (i.e., avoid collection of gravel or larger materials if possible). A separate subsample should also be collected from the wet material in the same manner as done for targeted analytes and used to test for soil moisture, so analytical results can be converted to a dry-weight basis.

Note that mercury in soils impacted by release of phenylmercuric acetate and similar mercury-based fungicides is not anticipated to be significantly mobile or volatile and normal MI sample processing methods are acceptable (USNLM, 2016; see also Appendix 9-A and Appendix 9-B in Section 9). When released to soil, these compounds are expected to dissociate forming relatively stable cations and adsorb to organic matter and clay more strongly than the parent compounds. Volatilization from moist soil and water surfaces will not be significant. This is supported by high concentrations of mercury in surface soils at former sugarcane, seed dipping operations decades after the releases occurred (Subsection 9.1.4.3).

Follow standard sample drying and sieving methods described above if additional tests are required for non-volatile chemicals using a different lab analysis. If both SVOC and non-volatile PAHs are targeted as contaminants of potential concern then include testing for both in laboratory subsamples collected from the Multi Increment sample prior to drying and sieving. Note that testing of soil for semi-volatile PAHs potentially associated with diesel and other middle distillate fuels is no longer required

(tested for groundwater only; see Section 9). Note also that naphthalene can be reported under most VOC analyses if the laboratory is notified ahead of time.

4.2.6.5 BIOACCESSIBLE ARSENIC

Multi Increment samples collected for arsenic analyses that contain >24 mg/kg total arsenic should subsequently be tested for bioaccessible arsenic (see Subsection 9.1.3.2; see also HDOH, 2016). On some sites where numerous DUs exceed 24 mg/kg total arsenic, analyzing a subset of the samples for bioaccessible arsenic is acceptable (e.g., two or three samples with highest total arsenic). This should be discussed with a HEER Office project manager. The same Multi Increment samples collected for total arsenic (for example, the entire remaining <2mm fraction of these samples) should be further sieved to the <250 µm particle size, representatively subsampled and analyzed for bioaccessible arsenic using the SBRC assay method (gastric phase only; this requires 1-2 grams; SBRC, 1999). Total arsenic in the <250 µm fraction should also be reported by the laboratory to examine the magnitude of "enrichment" of total arsenic in the <250 µm fraction compared to the <2mm particle size fraction.

4.2.6.6 OTHER LABORATORY ISSUES

High concentrations of iron and titanium in volcanic soils and calcium in carbonate-rich, coastal soils (or sediments) can interfere with the detection of other metals, resulting in an overestimation of metal concentrations:

- High levels of iron and titanium can interfere with the detection of arsenic, beryllium and cadmium;
- High levels of calcium can interfere with the detection of barium.

Notify laboratory if soil or sediment samples could have high concentrations of these metals and ask them to modify sample preparation procedures to remove the interference as needed to meet target soil action levels (for example, modified extraction or analysis method).

Reduced iron and calcium in the <250µm particle fraction (fraction required for bioaccessible arsenic analysis) can remove the interference but be aware that natural background levels of total arsenic in this fraction can approach 50 mg/kg or higher in comparison to the <2mm particle size fraction (generally <24 mg/kg, default HEER Office EAL background level).

4.2.7 REPLICATE SAMPLES

Proper sample collection (mass, shape, etc.) is the first element of the quality control process (Subsection 4.2.5). A DU is further considered to be adequately characterized when repeat testing of the same DU with independent samples yields similar estimates of the average concentration of a contaminant. These are referred to as "replicate" samples. Replicate samples are used to test the precision of the overall sampling method for the subject DU or for a DU(s) reasonably considered to have a similar history and distribution of contaminants. If the samples are collected in accordance with Gy's Theory of Sampling as described in this guidance document and the reported concentration of a target contaminant is very similar between replicates, then data collected for the project can be assumed to be reasonably representative of actual field conditions and usable for final decision making.

Re-testing of DUs due to failed replicate samples or identification of contamination after a site has been cleared can be very expensive. Careful evaluation of sample collection methods in the field and sample processing and analysis procedures at the laboratory prior to initiation of a project is therefore important. Replicate subsamples should also be collected and tested by the laboratory in order to evaluate the precision of the subsampling method. This is carried out in a similar manner as done for field replicates.

4.2.7.1 FIELD REPLICATE SAMPLES

Replicate samples are collected in exactly the same manner as the initial Multi Increment sample. This includes the number, shape, depth and mass of individual increments as well as the sampling design (e.g., systematic random) and spacing between increments. The final bulk sample mass of replicate samples should also be similar.

Under ideal circumstances replicate samples would be collected in each DU in order to document the reproducibility of the MIS data on a DU-specific basis. The HEER Office recognizes that this is not feasible in terms of time and cost for many projects, however, or even necessary for decision making in cases where there is already a high confidence of the reproducibility of the data. The collection of representative Multi Increment samples using sufficiently large numbers of increments and well-thought-out DU sizes and placements, may decrease the overall number of replicate samples needed to evaluate the site investigation.

Replicate samples should be collected from at least a representative subset of DUs investigated at a given site. Each site will be unique in terms of number and similarities of DUs. The rationale for the use of a single set of replicate samples to represent multiple DUs should be clearly discussed in the SAP as well as the final investigation report. Replicate samples collected in one DU can be used to represent other DUs provided that the DUs are similar in terms of use history, soil type, size and mechanism of contaminant release, and anticipated degree of small-scale contaminant heterogeneity (see Subsection 3.5). Note that this is

similar to one per "batch" of 10-20 samples for replicate analysis selection used by laboratories to evaluate subsampling and analysis precision.

Field replicates should be collected from a minimum of 10% of DUs characterized as part of a site investigation. A minimum of one set of replicate samples should be collected, if less than 10 DUs are to be characterized. At a minimum, collect replicate samples in the DU (or DUs) with the highest anticipated contamination, since the need for remedial actions will initially be determined based on data from this area of the site. Replicate samples are also recommended for the DU that represents the highest likelihood for exposure to contaminants (e.g., currently used playground), if different from the suspect, most contaminated DU. It is also important to have replicates representing all the different COPCs that may be investigated in DUs at a particular site.

The collection of a separate set of replicate samples intended to represent anticipated low-contamination areas is also recommended. This will avoid the need to assess the precision of data collected in these areas in terms of a potentially high relative Standard Deviation for replicate samples collected in a high-concentration area.

Triplicate samples (i.e., original sample plus two replicates) should be collected to evaluate the precision of field sampling methods used. Each set of replicate increments must be collected from completely independent (systematic random) locations. An example of increment spacing for the collection of replicate samples is given in Figure 4-12. Collection of increments around a single grid point is not appropriate for replicate samples, since this might not adequately test small-scale variability within the DU.

Replicate sample increments are typically collected along the same approximate directional lines established through the DU for the initial Multi Increment sample, though at different systematic random locations (Figure 4-22). For example, increments for separate samples can be collected in a triangular patter around the center point of grid cells (see Figure 4-12). This helps to simplify sample collection in the field.

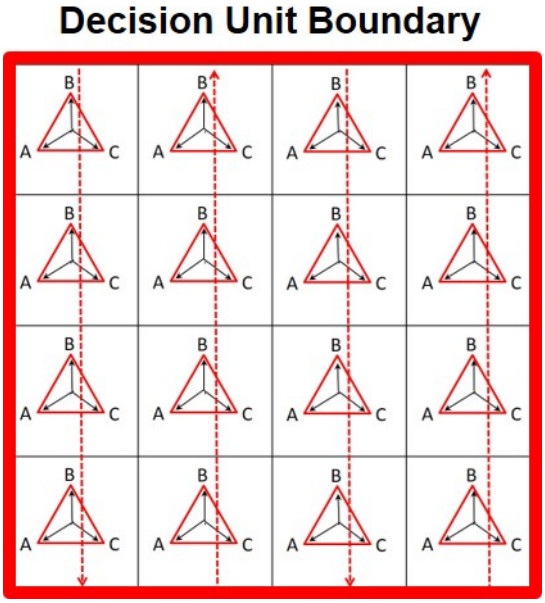


Figure 4-22. Example Pattern of Increment Collection for Triplicate Multi Increment Samples (see also Figure 4-12)

Replicate samples are sent to the laboratory as "blind" samples, meaning the sample(s) are labeled so that the laboratory does not know they represent replicate samples of the initial Multi Increment sample(s). The replicate samples are prepared and analyzed in the same manner as carried out for the initial sample.

The statistical evaluation of replicate sample data and overall MI sample data quality is discussed in Subsection 4.2.8. Experience with replicate data under different contaminant release scenarios will improve sampling methodologies and minimize the need for additional sample collection following an initial investigation.

4.2.7.2 LABORATORY REPLICATE SAMPLES

Laboratory replicate samples are collected in the same manner as that used to collect the initial laboratory subsample for analysis (see Subsection 4.2.6.2). Reprocessing or mechanical mixing of the sample is not required between replicate samples. Separate subsamples can be collected from the sectorial splitter, if used. If subsamples are collected by hand, then approximately 30 increments should again be collected in a systematic random fashion from different locations within the processed bulk sample.

Triplicate samples (i.e., original subsample plus two replicates) should be collected to evaluate the precision of the laboratory subsampling methods used. Laboratory replicates should be collected from a minimum of 10%-20% of Multi Increment samples submitted for analysis. A minimum of one set of replicate samples should be collected, if less than 10 Multi Increment samples are collected. At a minimum, conduct a laboratory subsampling replicates for the Multi Increment sample anticipated to have the highest contamination. Designating laboratory subsampling replicates to be conducted for one or more of the field replicate samples can prove useful when conducting the data evaluation (see Subsection below). As noted earlier, if samples are labeled in a way that the laboratory does not know which samples are field replicates, then designating one or more of the field replicate samples to be included as the laboratory subsampling replicate can also be done in a "blind" manner.

4.2.8 EVALUATION OF DATA REPRESENTATIVENESS

4.2.8.1 SAMPLE COLLECTION AND PROCESSING

Data verification is a completeness check that all specified activities involved in data collection and processing have been completed and documented and that the necessary records (objective evidence) are available to proceed to data validation. For example, if the sampling design called for Multi Increment (MI) samples to be prepared by combing 50 increments of soil from a targeted DU but only 30 increments were taken, this would be documented during the data verification evaluation.

The quality of the sample data generated must be reviewed to determine if the data are reliable to answer the risk and/or remediation-based questions prepared at the beginning of the project. This requires a review the sampling plan design and the methods used to collect the samples. The precision and reproducibility of the data generated must also be reviewed.

A checklist summary of each topic is provided in Table 4-2. The table is not intended to be comprehensive for all aspects of the investigation and should be modified as appropriate on a site-specific basis. See the noted sections of this guidance document and related appendices for detailed information on each topic. Deviations from the recommended methods should be discussed in the investigation report and resulting limitations of the data collected described and considered in the report recommendations. Methods to help minimize data error when the sample collection and analysis conditions noted in Table 4-3 cannot be met are discussed in the associated appendices.

Table 4-2. Sample data quality and usability checklist.

Acceptable?	Site Investigation Stage
	Conceptual Site Model and Decision Unit Designation (Section 3)
	• Site history and potential sources and type of contamination well understood?
	• Site investigation questions used to designate DU for testing clearly stated and based on risk and/or optimization of anticipated remediation?
	• Questions and decision statements developed for individual DU presented?
	• Area and total volume of soil associated with each DU noted and acceptable for intended purposes?
	• To-scale map depicting location and size of DU provided?
	Field Sample Collection (Subsection 4.2.5)
	• Summary of sample collection methods provided, including approximate final mass of each sample?
	• Multi Increment samples prepared by collecting and combining a minimum of increments appropriate to chemical present and nature of contamination?
	• Increments appropriately spaced and collected?
	• Complete, unobstructed access to all portions of the DU soil available for sample collection?
	• Core-shaped increments collected?
	• Samples to be tested for volatile chemicals preserved in methanol in the field or met requirements for alternative preservation and testing methods?
	• Minimum sample mass of 1-2 kilograms met (minimum 300 grams for samples to be tested for volatile contaminants)?
	• Triplicate Multi Increment Samples collected in at least 10% of DUs (minimum 1 set) to test total data precision?
	Laboratory Processing and Testing (Subsection 4.2.6)
	• Samples to be tested for non-volatile chemicals air-dried and sieved to target particle size for each specific DU?
	• Analytical subsample collected using a sectoral splitter or manually collected from at least 30 points?
	• Minimum 10-gram analytical subsample mass extracted for <2mm particles (increase to 30 grams when possible)?
	• Minimum 1-gram analytical subsample mass extracted for <250 µm particles (increase to 10 grams for unground samples when possible)?
	• Triplicate analytical subsamples collected from at least 10% of samples submitted (minimum 1 set)?
	• Holding times met?
	• Analytical quality control and quality assessment criteria met (e.g., spikes, blanks, etc.; refer also to USEPA, 2002)?
	Data Precision (Subsection 4.2.7 and Table 4-3)
	• Replicate field sample and laboratory subsample data meet data precision requirements?
	• Source of error for replicate data that exceed an RSD of 35% determined?
	• Laboratory subsampling error identified and subsamples recollected after grinding of primary sample or larger subsample mass collected?
	• Data adjusted or new samples collected for DUs with replicate data that exceed an RSD of 50%?

4.2.8.2 REVIEW OF REPLICATE DATA PRECISION

The total precision of MIS sample data is evaluated based on a comparison of data for replicate samples collected from the same Decision Unit. Replicate sample data can only be used to evaluate the total precision of the overall sample collection and testing method. The term "precision" is different from the term "accuracy." Precision describes the reproducibility of the overall sampling method. The accuracy of the data with respect to the true mean concentration of the contaminant in the subject Decision Unit area and volume of soil can only be known by extracting the chemical from the entire volume of soil and measuring the mass.

This is routinely done in mining operations (e.g., extraction of gold from crushed ore) but not as part of most environmental investigation, although error in sample data can sometimes be belatedly estimated following a failed, in situ remediation project. The accuracy or true error in environmental data can otherwise not be determined. The potential for significant error in environmental data can, however, be assessed by review of how the samples were collected, processed and tested as described above and a review of the precision of replicate sample data. Proper collection of samples in accordance with Gy's Theory of Sampling is especially important.

Statistical evaluation of replicate sample data precision is a two-step process. The first step is to calculate the relative standard deviation (RSD) of the contaminant concentration for the data set. The RSD represents the ratio of the standard deviation of the replicate set over the mean of the replicate set, expressed as a percentage:

$$RSD\% = \frac{Replicate\ Standard\ Deviation}{Replicate\ Mean} \times 100\% \qquad \text{Eq. 2)}$$

The RSD reflects the precision of the total sampling method, including combined field and laboratory error. The lower the RSD, the more precise the sampling method used and the more reproducible and reliable the data for individual DU where replicate samples were not collected.

The second step is to evaluate the RSD of the data set. The lower the RSD, the more precise the sampling method used and the more reliable the data for decision making. As summarized in Table 4-3, an RSD for replicate sample data <35% suggests that the sampling method has good reproducibility and, assuming the samples were properly collected and processed, the data can be used for reliable decision making. An RSD >35% but <50% indicates less reliable but still acceptable data for decision making, given the typical safety factor built into risk-based action levels. An RSD >50% but <100% indicates poor data precision and the need to either retest affected DUs using samples with a greater number of increments and increased bulk sample mass. As an alternative, if deemed acceptable by a risk assessor trained in DU-MIS investigation methods, see the maximum replicate concentration for decision making. For DUs where replicate samples were not collected, increase the data by the RSD to generate a hypothetical, "maximum" concentration of the contaminant. An RSD >100% indicates very poor data precision and the likely need to resample the affected DUs, with the possible exceptions discussed below.

Review replicate subsample data from the laboratory to determine if laboratory error appears to account for most of the total error in the sample data. If laboratory replicate are reasonably close, then error is most likely related to collection of the sample in the field. Note that high RSDs can become unavoidable as contaminant concentrations approach the laboratory method reporting and detection limits. Replicate sample RSDs also typically increase as the contaminant contamination increases.

The collection of a minimum of 50 increments per sample and a minimum, bulk sample mass of 1-2 kg is normally reliable to achieve a replicate sample RSD of <35%. The collection of a larger number of increments (e.g., 75 to 100) and a larger bulk sample mass (e.g., 2-3 kg) samples is, however, recommended for soil that might contain high-concentration nuggets of contamination (see Subsection 4.2). Examples include soil impacted with lead shot, chips of lead-based paint and PCBs in the form of tarry balls or fragments of caulking or sealants.

Use the mean RSD for individual contaminants for assessment of data precision in cases where replicate samples are collected from more than one DU within a specific project area. Evaluate data representativeness separately for areas of a project where contamination characteristics are known or assumed to be different (see Subsection 4.2.7.1).

Sample data that significantly exceed target action levels are generally acceptable for decision making even if the RSD of replicate sample data indicate very poor precision. Resampling is also not generally required in cases where all sample data are well below action levels and not indicative of significant risk. As a general rule and taking into account safety margins built into the HEER Office EALs, risk can be considered to be insignificant and the need to resample avoided if: 1) Samples were otherwise collected and processed in accordance with guidance presented in this document and 2) The maximum concentration of the contaminant reported for a replicate sample or for a DU where replicate samples were not collected is less than one-third of the applicable EAL.

Table 4-3. Recommendations for assessment of data quality based on the relative standard deviation of replicate samples.

Replicate Sample Data Precision	Use of MI Sample Data for Decision Making
Good (RSD≤35%)	• **Data for acceptable for final decision making;** • Compare data to target action levels or use to calculate risk (use the arithmetic mean of replicate sample data); • Collection of follow-up, confirmation samples for DUs where remedial action is necessary *not required* if data for laterally and vertically adjacent DUs meet target action levels.
Moderate (35%<RSD≤50%)	• **Data acceptable for final decision making, with the noted exception for remedial confirmation samples;** • Review and discuss sampling methods and laboratory processing and analysis methods and summarize potential sources of error and suggestions for future improvements in report (e.g., inadequate increment collection methods, insufficient number of increments, inadequate laboratory processing, etc.); • Compare data to target action levels or use to calculate risk (use the arithmetic mean of replicate sample data); • Collection of follow-up, more reliable confirmation samples for DUs where remedial action is necessary *required* even if data for laterally and vertically adjacent DUs meet target action levels (e.g., increase number of increments and total sample mass, improve in laboratory processing steps as needed, etc.).
Poor (50%<RSD≤100%)	• **Data not acceptable for final decision making in absence of adjustment to improve margin of safety;** • Review and discuss sampling methods and laboratory processing and analysis methods and summarize potential sources of error and suggestions for future improvements in report; • If the majority of the total error is due to subsampling or (less likely) analysis in the laboratory, require the laboratory to reprocess and retest the samples, including milling of samples if necessary, with additional replicate subsamples collected and tested to reassess precision; • If replicate sample data precision is still poor, consider retesting affected DUs using samples with a greater number of increments and total, bulk mass; OR, if determined acceptable by a risk assessor trained in Multi Increment sampling methods: • For DUs with replicate sample data, compare of the highest reported concentration of the contaminant to the action or cleanup level; • For DUs without replicate sample data, adjust the reported contaminant concentration upwards by the RSD calculated for the DU with replicate sample data (Adjusted Conc = Reported Conc + (Reported Conc. X RSD); • Additional evidence of data acceptance (or rejection) should be provided to support decision-making purposes, including site history and potential for contamination above the level of concern, adequacy of methods used in collecting, processing and analyzing samples, closeness of data to action levels and safety margins built into the action levels, and other information as available and pertinent. • Collection of additional confirmation sampling in DUs where remedial action is necessary required, using samples with a greater number of increments and total, bulk mass.
Very Poor (RSD>100%)	• **Data not acceptable for final decision making except in noted cases and with approval of overseeing regulatory agency;** • If the majority of the total error is due to subsampling or (less likely) analysis in the laboratory, require the laboratory to reprocess and retest the samples, including milling of samples if necessary, with additional replicate subsamples collected and tested to reassess precision; • Review and discuss field sampling methods and laboratory processing and analysis methods and summarize potential sources of error in reports for future reference; • Retesting is not required for DUs where the need for remediation is already clear from the data and other field evidence. • Consider the collection of new samples in DUs using the following approach: a) If known, designate suspected source areas as separate DUs for individual characterization, b) Collect a minimum of 75 increments per sample; c) Increase final sample mass to 2-3 kg; d) Collect replicate samples in all anticipated high-concentration and high-risk DUs; • As an alternative, consult with a risk assessor trained in Multi Increment sampling methods regarding the safety level incorporated into the target action level or cleanup level and the need to resample high exposure risk areas (e.g., all sample data less than one-third of action levels). • Additional evidence of data acceptance (or rejection) should be provided for decision-making purposes, including site history and potential for contamination above the level of concern, adequacy of methods used in collecting, processing and analyzing samples, closeness of data to action levels and safety margins built into the action levels, and other information as available and pertinent. • Collect replicate confirmation samples in all DUs requiring remediation.

4.2.8.3 ADDITIONAL STATISTICAL ANALYSIS OF REPLICATE SAMPLE DATA

Mining vs. Environmental Industry Data Quality Requirements. Gy's Theory of Sampling was developed in the mining industry over several decades for testing of crushed ore to be sold for processing and extraction (Pitard, 2019; see Subsection 4.1). This was due to routine failure of discrete sample data to accurately predict the mass of a commodity ("contaminant") such as gold or iron in the ore. Significant error in the mass of the commodity present predicted based on sample data versus the mass of the commodity ultimately extracted from the ore can result in severe financial penalties and the rejection of future shipments. A high degree of replicate sample data precision in addition to a careful review of sample collection and processing methods is therefore a critical part of data quality review, with replicate sample RSDs as low as 5% often required. Obtaining such a high degree of data precision and accuracy can come at a significant cost in the field and in the laboratory, with crushing and grinding of bulk samples as large as one metric ton necessary to reliably meet data quality requirements.

While desirable, such a high degree of data precision and accuracy is not required in the environmental industry. Environmental action levels normally include a significant margin of safety, often up to an order of magnitude or more. Less stringent data quality requirements in terms of the precision of MI replicate samples are therefore acceptable, provided that samples are properly collected, processed and tested as described in this section. A stronger, economic incentive to obtain higher quality samples exists for data to be used to optimize *in situ* remedial efforts. These actions more closely resemble mining operations, since a reasonably accurate estimate of contaminant mass is required to control cost and carry out a successful operation. A higher degree of replicate sample data precision might therefore be desirable. This can be accomplished through the use of smaller DUs and/or the collection of larger samples collected from an increased number of increment points.

Consideration of 95% UCLs for MI Sample Data. Additional manipulation of replicate sample data is not an integral part of Gy's Theory of Sampling. Routine calculation and use of a 95% UCL based on replicate sample data was strongly discouraged in conversations with Francis Pitard and a group of international, sampling statisticians during the World Conference on Sampling and Blending in Beijing, China, in 2018 (Pitard, 2018, personal communication; see also Pitard, 2019). Doing so can lead to false conclusions regarding potential error in the data. This is especially true when the methodology used to collect and process samples does not meet requirements for testing of particulate matter, as is common in traditional discrete sample investigations.

Some risk assessors may nonetheless desire the use of a 95% UCL calculated from replicate MI sample data as an added measure of confidence that the true mean of the DU does not exceed a targeted action level or risk. Examples include action levels for contaminants that include only a minimal safety margin and the need to more conservatively address risk in anticipated high-exposure areas. This and the specific statistical test(s) to be used to calculate a 95% UCL should be discussed with the HEER Office project manager at the beginning of systematic planning process and incorporated into decision statements for individual DUs. A recommendation by the risk assessor for the collection of replicate MI samples and use of a 95% UCL for comparison to action levels or direct estimation of risk is likely to be applicable to only a small subset of the DUs associated with a given project.

Note that calculation of a 95% UCL for a single set of MI replicate samples is unrelated to calculation of a 95% UCL for a single set of discrete samples. Traditional risk assessment methods called for use of a 95% UCL based on discrete sample data in order to address variability in data between individual points. As discussed above, decades of experience in the mining industry have clearly demonstrated this approach to be unreliable. This is because the 95% UCL only addresses potential error in the statistical test employed to estimate a mean for the data set provided. Error in the data set itself due to poor sampling collection methods remains unknown in the absence of replicate sets of discrete sample data for comparison (see Brewer et al., 2017b). Use of a 95% UCL based on a single set of discrete sample data for final decision making is therefore not allowed by the HEER Office. Such error is controlled (but never fully eliminated) under an MI sampling approach through collection and processing of samples in accordance with Gy's Theory of Sampling.

4.2.8.4 PROPOSALS FOR ALTERNATIVE SAMPLING METHODS

Proposals for alternative sampling methods other than those discussed in this guidance document must be reviewed and approved by the HEER Office. Data reliability must be demonstrated by providing field and laboratory research to support the sampling method to be employed, including the following information:

1. Provide research demonstrating that the sampling method employed generates reasonably accurate estimates of the contaminant mean (e.g., mass of contaminant in targeted volume of material predicted by sample data closely matches mass of contaminant ultimately extracted from the material);
2. Provide replicate subsample sample data to demonstrate that data generated by the laboratory are reproducible within data quality requirements (e.g., replicate RSD $\leq$35%); and
3. Provide replicate field sample data to demonstrate that data for an individual sample or data for an individual set of samples used to estimate a mean are reproducible within data quality requirements (e.g., replicate RSD $\leq$35%).

Simple reference to historic use of a proposed sampling method and past acceptance by this or other regulatory agencies will not be accepted. Contact the HEER Office project manager for additional information and guidance.

4.2.9 OTHER CONSIDERATIONS

4.2.9.1 MULTI INCREMENT SOIL SAMPLE COLLECTION FOR VOLATILE ANALYSES

A detailed discussion of the field collection of Multi Increment samples to be tested for volatile contaminants is provided in Section 5. For the purposes of soil sample collection, a chemical is considered to be volatile if the molecular weight is less than 200 and the vapor pressure is greater than 1 mm Hg (25ºC) or the Henry's Law Constant is greater than 0.00001 atm-m³/mol (see Appendix 4-A). Samples to be analyzed for VOCs (including TPH-g) are collected separately from samples to be analyzed for SVOCs and non-volatile chemicals (including TPH-d and TPH-o). The collection of soil gas samples is also recommended at sites where significant VOC contamination is known or suspected (see Section 7).

Decision Unit and Multi Increment sampling approaches should be used to characterize soil for volatile organic compounds (VOCs). This includes testing of samples from cores, excavation bottoms and walls, stockpiles and underneath paved areas. Volatiles are not typically sampled in surface soils, especially for any aged/historic releases. The use of discrete soil samples to characterize soil for VOCs is not considered to be reliable due to potentially high small-scale variability, the minimal mass of soil tested at the laboratory (e.g., 5 grams), and the resulting unreliability of the data.

Distinct spill areas are oftentimes associated with the release of volatile organic chemicals. Primary environmental hazards posed by VOC-contaminated soil include vapor intrusion, leaching and gross contamination hazards. This normally requires that spill areas be designated and characterized as separate DUs.

Multi Increment sample collection points are established for a DU in the same manner as discussed above. A minimum of 30 increments should be collected. Samples will most commonly be collected from subsurface DU layers and associated increment borings (see Subsection 3.4.4 and Section 5.6). Other DU examples include an area of obvious staining and the walls and floor of an excavation. In some cases each side wall and floor of an excavation area may be separate Decision Units, or the floor of an excavation could be divided into more than one Decision Unit to evaluate a more specific area where contamination may have migrated. In other cases, certain side walls or all the side walls maybe combined into a single Decision Unit. The rationale for selecting DUs within an excavation should be clearly addressed in the DQO/SAP for the site investigation.

As described in Section 5, testing of soil for VOCs should follow approaches described in USEPA Method 5035 *Closed System Purge-and-Trap and Extraction for Volatile Organics in Soil and Waste Samples* (see MADEP, 2002, TNRCC, 2002, CalEPA, 2004b), modified to incorporate DU-Multi Increment sampling approaches. This test method includes procedures for the collection, preservation, handling, and preparation of soil samples to minimize the loss of the VOCs prior to analysis.

Soil gas data are also highly recommended for characterization of sites contaminated with volatile chemicals, and may be more appropriate for some site investigations than soil sampling. Soil gas data are much more reliable than soil data for evaluating potential vapor intrusion hazards associated with volatile contaminants in soil (and groundwater). Soil gas data are also very useful for identifying and locating areas of heavy contamination. See the HDOH guidance document *Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater* (HDOH, 2016) and Section 7 of this TGM for additional information.

4.2.9.2 COLLECTION OF SUBSURFACE MULTI INCREMENT SAMPLES

Decision Unit designation for subsurface soil is discussed in Subsection 3.4.4. A detailed discussion of the collection of Multi Increment samples from subsurface soil is provided in Section 5.

The following circumstances are examples of when delineation of the vertical distribution of contaminants in soil might be warranted:

- Potentially leachable contaminants are found in surface soils above HDOH EALs;
- Groundwater data suggest that a release has occurred and contamination has migrated through the vadose zone;
- The property is to be redeveloped and significant disturbance of subsurface soil is anticipated with some soil potentially being reused at the surface;
- The property is to be sold or a property lease terminated, and a potential buyer or landowner requires documentation that subsurface soil has not been contaminated by past activities.
- Excavation and offsite disposal or reuse of soil is planned and there is reason to suspect that deeper soils could be contaminated.

The collection of samples from subsurface soils is more challenging than for exposed surface soils.

Data for each Multi Increment sample are used to generate a three-dimensional map of contaminant concentrations in soil. The core from a targeted DU layer in a single boring represents the "increment" for the DU layer, identical to increments collected from a surface soil decision unit. Use of a direct-push rig allows collection of continuous cores and collection of the full interval of targeted DU layers.

Most DU layers are tabular shaped, with the vertical thickness being significantly less that the lateral width and length. In such cases, increments should cover the full thickness of the DU layer, as done for surface soil. Increments of adequate mass to produce a 500-gram to 2-kg bulk sample should be collected from systematic random core locations across the DU.

Ideally, the entire core section of the DU layer would be used to prepare a bulk Multi Increment sample for tabular, subsurface DUs. This may not be practical due to soil volume constraints at the laboratory, however, and as described in Section 5 subsampling of core increments in the field will be required to generate a manageable bulk sample mass for processing and testing. Core increments will ideally be subsampled by slicing a thin wedge from the full length of the targeted DU layer. This

provides 100% vertical coverage of the increment and minimizes bias. Increment wedges from same-depth layers are then combined to generate the bulk Multi Increment sample.

This may not be feasible in sandy or gravelly soils. As an alternative, increments can be subsampled by the removal of regularly spaced plugs of equal mass from the core. As a default, the removal of 5- to 10-gram plugs at two- to four-inch intervals is recommended (similar to the method used for VOCs), or as otherwise necessary to generate a 1- to 2-kg bulk sample following combination of all subsampled increments for a DU layer. Note that 30+ subsamples, as recommended for DUs in general, are not required from each core increment for DU layers.

In some cases collection of the recommended minimum number of increments from subsurface DU layers may not feasible due to access or cost constraints. Reducing the number of increments collected for the Multi Increment may be necessary. If this is the case, it is important to recognize that the quality and reliability of the resulting data will be compromised. This should be taken into account when used to estimate the extent of contamination and the mean concentration of contaminants in the targeted DU layer. Replicate field samples will be critical to help evaluate precision of the data collected in these circumstances (see Subsection 4.2.7).

A smaller number of increments might be useful to identify the general presence or absence of a contaminant in a DU and even the general magnitude of contamination. As discussed in Subsection 3.4.4, the use of single boreholes to initially explore a site for the presence or absence of subsurface contamination is common practice. In such cases, however, the core borehole should be subdivided into targeted layers for testing (e.g., based on apparent or suspect contamination). Subsamples of the targeted layers could be collected in the field (as described above) or the entire core interval could be submitted to the laboratory for MIS processing and subsampling (the latter option is typically more feasible for non-volatile contaminants). Narrower DU intervals are used to provide a higher vertical resolution of contaminant distribution as needed. This provides a significantly more reliable screen of contamination than traditional discrete soil samples collected from a single point within a core.

The collection of replicate samples from subsurface DUs to help evaluate the field precision of the data is equally important as it is for surface soils. Two types of replicate samples should ideally be collected (Figure 4-22 and Figure 4-23; see also Figure 3-12 in Section 3): 1) Replicates to evaluate precision with respect to distributional heterogeneity within the DU Layers, and 2) Replicates to evaluate the precision of core increment subsampling.

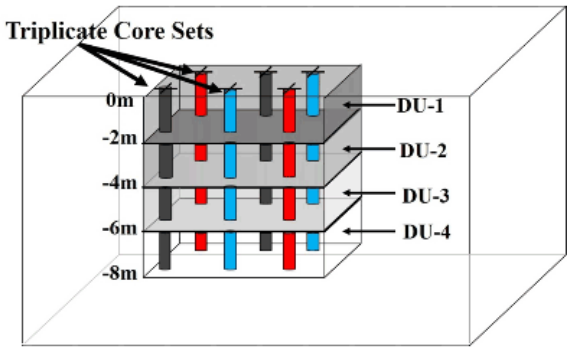


Figure 4-23. DU Layer Replicates Collected from Separate Sets of Cores to Test Precision of Data with Respect to Distributional Heterogeneity

Each color represents one set of cores used to prepare a Multi Increment sample for each layer, with increments of the same color combined to prepare a bulk sample for that layer (all cores not shown, ideally 30 cores per replicate sample; see also Figure 4-9 and Figure 3-12 in Section 3).



Figure 4-24. Collection of Increment Subsample Replicates (Triplicates) from Subsurface Core Increments

Used to test precision of subsampling from subsurface cores (plugs being placed in methanol for VOC analysis in example photo)

Replicates to test field precision in terms of contaminant distributional heterogeneity within a DU are collected and evaluated in an identical manner to replicates collected from exposed surface DUs (see Figure 4-10). Triplicate samples recommended for at least 10% of DU layers. If this is not practicable due to access or cost reasons then this should again be noted and discussed in the review of data quality and limitations. Replicate samples must be collected from entirely separate borings and cores. The collection of separate subsamples from single cores evaluates subsampling precision, not field precision in terms of distributional heterogeneity.

Sets of increment subsample replicates should be collected from core increments for a DU. For example, three separate wedges or three sets of plugs of soil might be removed from a of a core increment layer, (see Figure 4-24; e.g., most suspect contaminated layer). A minimum 10 to 50 grams of soil should be removed from each increment, similar to the mass recommended for increments collected from surface samples. A default, 2- to 4-inch (5- to 10-cm) spacing for removal of 5- to 10-gram plugs is recommended, with the adequacy of this approach verified by comparison of replicate data. This process is repeated for each core increment from each boring until triplicate samples are prepared for the targeted DU layer(s). Each replicate sample is then independently processed and tested.

Increment subsample replicates are typically unique to the collection of subsurface samples, where limitation of individual increments to 30-50 grams is not typically feasible and the mass of individual increments must be reduced to prepare a manageable bulk sample (see also HDOH, 2011i). The collection of subsampling replicates is recommended anytime that subsampling of core increments is required. Triplicate samples are recommended for at least 10% of DU layers.

Replicate data for DU layers and increment subsamples should be evaluated in the same manner as described in Subsection 4.2.7, with potential limitations on use of the data discussed. Variance in the resulting data for each set of replicates reflects the sum of both lab and field error. Lab replicates for one or more of the samples can be used to evaluate the proportion of error attributed to each source. Field error is likely to dominate error, given the much larger masses of soil involved. If it is possible for the entire cores to be retained in case additional subsampling to improve data reproducibility is necessary (e.g., for non-volatile contaminants), that should be considered. For example, if increment subsampling replicate data indicates a poor degree of precision (e.g., RSD >50%), then select cores could be re-sampled to improve data quality and decision making.

Alternative characterization approaches should also be considered to support subsurface Multi Increment soil samples, for example the collection of soil gas samples for volatile contaminants or testing of groundwater for contaminants that pose potential leaching hazards. Sampling constraints and potential impacts on data quality and decision making should be discussed in the resulting site investigation report and Environmental Hazard Evaluation (see Section 13).

4.2.9.3 COLLECTION OF MULTI INCREMENT SAMPLES FOR STOCKPILES

Multi Increment sampling is recommended for characterization of soil stockpiles. Designation of DU volumes for stockpiles based on planned reuse of the soil is discussed in Subsection 3.5.7. Segregating and flattening stockpiles for Multi Increment sample collection is discussed in Section 5. Stockpile sampling strategies and methods are addressed in greater detail in the *Guidance for the Evaluation of Imported and Exported Fill Material, Including Contaminant Characterization of Stockpiles* (See Appendix 3-A; HDOH, 2017d).

It is important that all portions of the stockpile are equally accessible for the collection of increments during sampling. Replicate samples should be collected from a minimum of 10% of the DUs in order to evaluate data precision (see Subsection 4.2.7). The HEER Office should be consulted on options for alternate sampling plans in cases where access and/or safety issues hamper the collection of proper samples from stockpiles.

4.3 USE OF DISCRETE SAMPLES

A "discrete sample" refers to the collection of a small mass of soil, typically 100-200g, from a single point within an area targeted for investigation. Discrete samples have traditionally been used to help identify the lateral and vertical extent of contamination. The use of discrete soil sample data is not recommended for final decision making purposes as part of an environmental investigation (HDOH, 2015,b; Brewer et al., 2016; see Subsection 4.1.2). Random, small-scale variability of contaminant distribution and concentration in soil limits the reliability of discrete sample data for estimating the extent of contamination that could pose an unacceptable risk to human health and the environment.

It is also important to note that the HDOH Environmental Action Levels for soil *are not* intended for direct comparison to individual, discrete sample data points (HDOH, 2016; see Subsection 4.1 and Section 13) as well as the USEPA Regional Screening Levels (USEPA, 2014). Action/screening levels for direct-exposure, for example, assume random contact with soil throughout the DU over many years. Comparison to the mean action level in designated Exposure Area DUs is therefore appropriate (see Section 3; see also USEPA, 1987, 2013b). The concentration of a contaminant at any given discrete sample point within a DU, whether it be above or below an action or screening level, is not relevant to the overall risk posed by contamination for the DU as a whole (see also HDOH, 2015b).

Existing discrete sample data and grids of discrete samples can, however, be useful for designation of DUs for a more intensive, Multi Increment sample investigation. For new projects, consider the collection of a large mass of soil from multiple locations around a sample collection point (Figure 4-25 A&B). Such "large-mass" discrete samples will help improve the representativeness of the resulting data for the associated grid point. For example, collect 1-2 kg of soil (recommended MI sample mass, minimum 300 grams; Subsection 4.2.3) from multiple (e.g., 5-10+) points within a few feet of the grid point in order to reduce Fundamental Error and capture random, small-scale variability of contaminant concentrations over short distances (see Subsection 4.1.2). Individual masses of soil should be collected in a similar manner as described for MI increments, including proper shape, depth and mass (Subsection 4.2.5.2). Bulk samples to be screened in the field should be tested multiple times until a representative mean can be determined, for example through use of a portable XRF (Subsection 8.4.1). Samples submitted to a laboratory for testing should be processed and tested following standard MI procedures to ensure that representative data are obtained, including testing of a minimum 10-gram mass (Subsection 4.2.6). Note that the latter requirement could negate the cost-benefit of implementing a discrete sample grid approach to screen a site in comparison to the collection of MI samples from reasonably small DUs. If samples are not processed for testing then this limitation should be noted in the report and additional care taken in interpretation of the data.

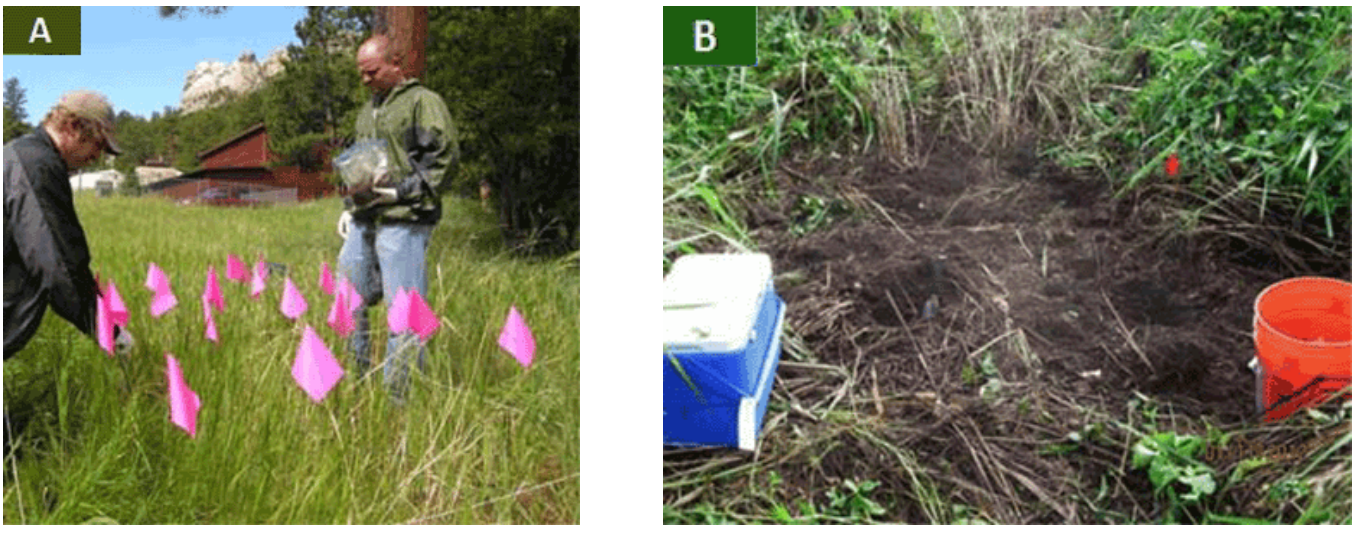


Figure 4-25 A&B. Collection of large-mass discrete soil samples from multiple locations around a single sampling point in order to improve data representativeness (A: USGS, 2016; B: see ERM, 2008).

This approach reduces the susceptibility of traditional discrete soil samples to random error and improves the ability to identify larger-scale contaminant patterns of interest. Note that these types of samples are sometimes informally referred to as "composites" in USEPA and other field investigation guidance (e.g., USEPA, 1989, USGS, 2014, USGS, 2016). Use of the term “composite” is discouraged for projects overseen by HDOH, however, due to potential confusion with more formal use of the term to indicate the intentional mixing of soil from what would otherwise be considered separate DUs (see Subsection 4.4.11).

Discrete soil sample data can in theory be used to estimate mean contaminant concentrations for a targeted DU area provided that samples are collected in a manner consistent with sampling theory (e.g., proper, size, shape, mass, etc.) and the data can be demonstrated to be reproducible. As discussed below, however, this is unlikely to be cost effective in comparison to the use of Multi Increment sample data to estimate mean contaminant concentrations.

4.3.1 INTERPRETATION AND PRESENTATION OF ISOCONTOUR MAPS

Isocontour maps (e.g., concentration, thickness, etc.) based on discrete sample data should not be used for decision making purposes without adjustment to reflect additional site knowledge and professional judgment. This is due to the unreliability of small-scale patterns and the reduced accuracy of isocontours based on traditional discrete soil (and sediment) sample data as discussed above (HDOH, 2015b, Brewer et al., 2016). Specific errors often encountered in unadjusted, isocontour maps include:

- Artificial "hot spots" and "cold spots" caused by random, small-scale variability of contaminant concentrations at the scale of a discrete sample;
- Erroneous "zero" isocontours around the perimeter of contaminated areas due a lack of outward data points;
- Inherent lack of precision of isocontour placement.

Unrecognized, these errors can lead to a false sense of precision in computer-generated isocontour maps and lead to erroneous decisions regarding the need to continue or halt site investigations or remedial actions (HDOH, 2015b; see also Subsection 4.1). This includes calls for remediation of isolated "hot spots" based on single or small numbers of discrete samples and premature termination of site investigations or remedial actions due to false "cold spots" in the discrete sample data.

Isocontour maps should be adjusted to reflect site knowledge and professional judgment not reflected in computer-generated maps. Such adjustments are not possible in existing computer programs to the knowledge of HDOH and must be done by hand. Boundaries between apparent large-scale patterns should necessarily be dashed. Small-scale heterogeneity within larger-scale patterns generated by small numbers of discrete sample points *should not be presented on final maps* included in the report.

For example, Figure 4-26 depicts a nine-acre site formerly used for storing and mixing pesticides. The northern area of the site was known to be heavily contaminated with arsenic based on previous collection of both discrete and Multi Increment samples. The exact area of elevated arsenic was uncertain based on previous testing although the area of the former mixing shed was most suspect. No obvious signs of contamination were recognizable in the field.

A significant number of large-mass, discrete surface soil samples (0-6 inches) were collected from a 50-foot grid across the site (ERM, 2008). Each discrete sample was collected from multiple points around each grid point in order to help address random, small-scale heterogeneity and increase data representativeness (see Figure 4-25b). Samples were analyzed using a portable XRF. A subset of samples was analyzed in a laboratory for comparison. As can be seen in the figure, the XRF helped to identify at least one large spill area of arsenic-contaminated soil in the northern part of the site. Smaller clusters of discrete samples with higher reported levels of arsenic might or might not be reflective of actual conditions in the field. False patterns of higher and lower levels of contamination can be produced by samples that are too small to capture and smooth out random heterogeneity of contaminant distribution in soil (see Subsection 4.1; HDOH, 2015b).

Three distinct areas of arsenic contamination are apparent in the figure (see Figure 4-26). The concentration of arsenic in the majority of discrete samples collected from Area A is below a screening level 20 mg/kg, with occasional "outliers" that exceed this value. Arsenic is randomly above 20 mg/kg in any given, discrete soil sample collected from Area B. Arsenic is above 20 mg/kg in the majority of discrete samples collected from Area C, with random "outliers" below this value.

The appearance of seemingly isolated, "hot spots" and "cold spots" within larger-scale, distinct areas most likely reflect small-scale contaminant distribution that may or may not represent true areas of higher or lower contamination that can be mapped (see Subsection 4.1; HDOH, 2015b). If grid points were moved over a few feet and new samples collected and analyzed, then a similar large-scale pattern would appear, but small-scale "hot spots" and "cold spots" within these areas would be located in different places. This type of field error is an artifact of the individual sample being too small to overcome and capture random, small-scale heterogeneity of the contaminant in the soil. Attempts to design remedial actions based on single samples or even small sets of discrete sample data is highly unreliable and is not recommended or acceptable for final decision making purposes.

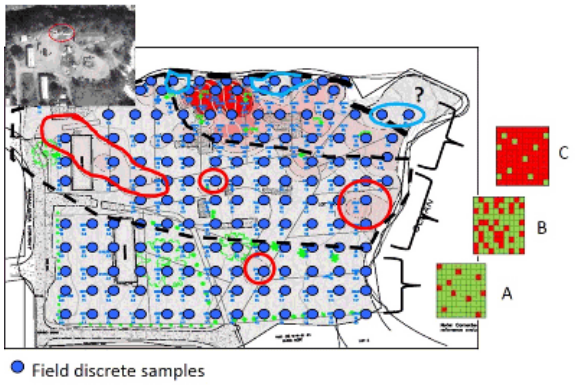


Figure 4-26. Unadjusted Isoconcentration Map from Discrete Sample Arsenic Data at a Nine-Acre Former Pesticide Storage Site
Red-shaded areas denote total arsenic concentrations >20 mg/kg. Most contaminated area corresponds to former pesticide mixing area denoted by red circle on 1979 aerial (modified from ERM, 2008). Three large-scale areas of arsenic distribution hypothesized (HDOH, 2015b): A) Arsenic below 20 mg/kg in majority of discrete sample-size masses of soil; B) Arsenic above and below 20 mg/kg in any given, discrete soil sample and C) Arsenic above 20 mg/kg in majority of discrete sample masses of soil. Small-scale patterns are interpreted to be artifacts of random, small-scale heterogeneity and may or may not be reproducible (see HDOH, 2015b).

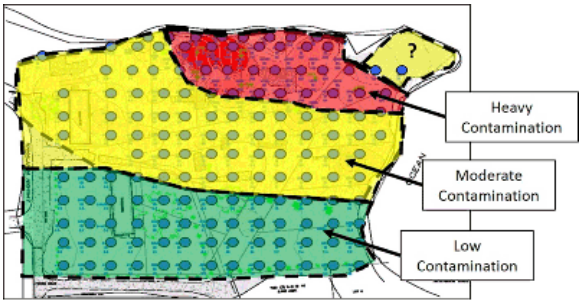


Figure 4-27. Adjusted Arsenic Isoconcentration Map for a Former Pesticide Storage Site
The adjusted map more accurately reflects the resolution of arsenic distribution in soil across the site that can be reliably extracted from the discrete sample data.

As discussed below, such maps can subsequently be used to help designate Decision Units and carry out a more reliable and higher resolution Multi Increment sample characterization of the site. Preliminary maps such as these could also be used to carry out initial remediation actions, for example removal of soil from the heavily contaminated area, followed up with a DU-Multi Increment investigation to assess the need for additional actions. This assessment requires significant experience and professional judgment on the part of decision makers.

Large-scale patterns reliably identified by grids of discrete soil samples can, however, be used in conjunction with other available information to designate DUs for the collection of Multi Increment samples. Figure 4-27 presents an adjusted map of arsenic distribution in soil that more accurately reflects the resolution of arsenic distribution across the site that can be extracted from the discrete sample data.

4.3.2 DESIGNATION OF DECISION UNITS

In spite of the limitations noted above, tight grids of discrete sample data utilizing field screening tools can provide useful screening level data to help identify large-scale areas of contamination, and help guide a more thorough DU-MIS investigation (see Subsection 4.2). Examples of field screening tools include portable X-Ray Fluorescence (XRF) instruments and immuno-assay tests. Field screening tools need to be reliable for the application employed, and those handling the tools for site investigations should have experience with their use. Additional information on use of field screening methods is provided in Section 8.

Continuing with the example presented above, Figure 4-28 depicts hypothetical DUs designated for the former industrial facility based on a combination of historical information, the results of the discrete soil sample study, proposed redevelopment for one-acre residential lots, and optimization of potential remedial actions (for example only; not included in original report).

One-acre DUs are designated in the lower area of the site, where historical information and discrete sample data suggest minimal contamination (Area A in Figure 4-28). The DUs reflect hypothetical exposure areas for the planned



Figure 4-28. Example DUs Designated for a Former Pesticide Storage Site
Based on a combination of historical information, the results of the discrete soil sample study, proposed redevelopment for one-acre, residential lots and optimization of potential remedial actions.

residential redevelopment of the site and the lowest recommended "resolution" for site characterization (see Subsection 3.4). It is anticipated that remediation will not be required within this area. The DUs designated for Area B in Figure 4-28 are intentionally scaled smaller. This reflects the increased chance that some degree of remediation may be required for this area and a desire to increase the resolution of the data. This is done by reducing the sizes of DUs in order to optimize remediation and minimize potential removal of otherwise clean areas of soil that are inadvertently included with otherwise contaminated areas. This approach is also emphasized in Area C, where both historical information and discrete sample data verify the presence of significant contamination and the need for remedial actions. The use of small DU areas and volumes ensures an adequate resolution of data for preparation of the most cost-effective remedial action plan possible. See Subsection 3.4 for additional information on DU designation for investigation and remedial purposes.

4.3.3 ESTIMATION OF MEAN CONTAMINANT CONCENTRATIONS IN RISK ASSESSMENTS

Discrete soil sample data have traditionally been used to estimate the mean contaminant concentration for targeted exposure areas in environmental site assessments and remedial actions (e.g., USEPA, 1987, 2013b). The reliability of this approach was called into question by the HEER Office in 2006, due to the inability to verify the field representativeness of a single date set. Multi Increment sampling methods provide significant advantages for estimation of contaminant means in comparison to discrete sample data, including:

- Consideration of sampling theory to determine the mass of soil required to collect a representative sample and method of sample collection and analysis;
- Improved coverage of the targeted area (number of increments collected far greater than typical number of discrete samples);
- Systematic and standardized approach for sample collection in order minimize bias in the field (e.g., size, shape and mass of individual increments);
- Reduced number of samples required for analysis; general greater statistical precision of replicate samples (e.g., lower RSDs);
- Samples processed and subsampled at laboratory in order to ensure representative data;
- Replicate sample data provide additional information on field representativeness of samples and precision of data.

Nonetheless, mean contaminant concentrations for DUs can be estimated using discrete sample data provided that a systematic approach is used collect and process the samples in accordance with sampling theory, including sample shape and mass (see Subsection 4.1 and 4.2, and that the data can be demonstrated to be representative of actual field conditions through evaluation of replicate samples. Such quality control measures in the field are critical to the overall quality and representativeness of the resulting data, and go beyond simple consideration of the number of samples collected and the variance between individual data points. The HEER office should be contacted to discuss the collection and use of discrete sample in a risk assessment for a specific site.

An evaluation of the representativeness of a discrete sample data set should be carried in the same manner as done for Multi Increment samples (see Subsection 4.2). The accuracy of an estimated mean contaminant concentration for a DU is evaluated in terms of *precision*, or reproducibility, and *bias*, or systematic over- or under-estimation (ITRC, 2012). This is illustrated in Figure 4-29.

In order for an estimated mean to be accurate, the data set must be both unbiased and precise. Statistical analysis of a single set of discrete sample data only evaluates the precision of the estimated 95% UCL in terms of the variance of the data set provided and the statistical method used to evaluate the data. The number of discrete samples included in a data set can be increased in order to decrease the variance and provide an acceptable degree of precision.

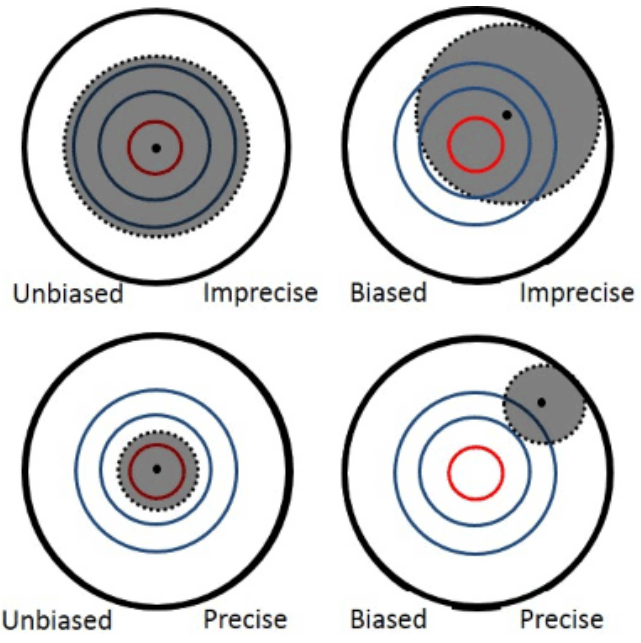


Figure 4-29. Four Possible Relationships between Bias and Precision (after ITRC, 2012)
The center point of the target is the true mean. The mean estimated from a single set of discrete samples, or a single Multi Increment sample, represents one point on the target. The gray area around the point represents uncertainty in the estimate

Analytical precision only reflects one aspect of potential error, however. The complete precision of the data set in terms of field representativeness cannot be evaluated from a single set of discrete samples. This can only be evaluated through the collection and comparison of replicate sets of samples, as done for Multi Increment samples (See Subsection 4.2.7; see also ITRC, 2012). Complete replicate sets of discrete samples are rarely, if ever, collected to test the quality of the estimated mean, however.

Past USEPA guidance has recommended that a minimum of 20 to 30 discrete samples are required to adequately represent contaminant heterogeneity within a targeted area:

> Data sets with 20 to 30 samples provide fairly consistent estimates of the mean (i.e., there is a small difference between the sample mean and the 95% UCL). (USEPA, 1992b)

Replicate Multi Increment data reviewed by the HEER Office, including a field study carried out in 2014 (HDOH, 2015b, b) as well as statistical simulations included in the ITRC ISM document (ITRC, 2012) suggest that error in terms of field representativeness could still be substantial when a relatively small number of discrete samples (e.g., <30) are used to characterize a targeted DU (see also Subsection 4.2.2).

If discrete sampling is proposed for use at a site overseen by the HEER Office, specific approaches to address both precision and bias in the data should be discussed in the SAP (see Subsection 4.1). This should include a review of sample collection approaches in terms of sampling theory (e.g., number, size, shape, mass, etc.). Note that the mass of a discrete sample has been primarily dictated by the needs of the laboratory for analysis (default 100 grams per sample recommended; USEPA, 1987), rather than sampling theory. This issue should likewise be addressed in the SAP.

"Outlier" discrete sample data points (e.g., comparatively very high concentrations) *should not* be omitted from a data set in order to force the data set to fit a geostatistical model (USEPA, 1989, 2006b, g; see also HDOH, 2015b); (Note that this conflicts with recommendations in the USEPA Pro UCL guidance; USEPA, 2013b). The true mean is the concentration of the target contaminant that would be reported if the entire DU volume of soil could be tested as a single "sample." "Outliers" simply reflect a high distributional heterogeneity of contaminant concentrations in the soil at the scale a discrete sample and are an artifact of the sampling approach employed. The omission of supposed outlier data points from calculations distorts the representativeness of the data set and generates a technically unsupportable mean. For comparison, MIS increments that fall on small but obviously contaminated areas of a DU would not be excluded from the bulk Multi Increment sample. All discrete sample data must be included in an estimate of the mean, with the precision of the data set as a whole statistically evaluated. If additional sample points are required to improve precision then the samples should be collected using Multi Increment sampling approaches.

4.4 COMMON DU-MIS INVESTIGATION MISTAKES AND PROBLEMS

4.4.1 INAPPROPRIATELY SIZED DUS

The designation of Decision Units for site characterization is discussed in Subsection 3.4. It is important to ensure that DUs are appropriately sized to meet site investigation objectives. Decision Units should ultimately be sized to address potential environmental hazards posed by contaminants in soil at the site. This always includes direct exposure and depending on the contaminant can also include leaching, gross contamination and other concerns (see Section 13).

Direct exposure concerns under current site conditions are most directly evaluated through the designation of Exposure Area DUs (see Subsection 3.4.2). As discussed below, however, separate characterization of known or suspected spill areas within an exposure area is still recommended. Leaching, gross contamination and other concerns are most directly evaluated based on Spill Area DUs. The latter requires a more detailed understanding of the locations of potential heavy contamination (i.e., "spill areas") based on the site history, field observations, and interviews with people knowledgeable of the site and related information. Spill Area DUs are commonly a few hundred to a few thousand square feet in size and typically smaller than Exposure Area DUs that might be designated at the same site. The maximum size of a Spill Area DU for characterization purposes is generally set to the maximum DU size likely to be acceptable for exposure areas (e.g., default HDOH residential exposure area of 5,000 ft²; see Subsection 3.4.2).

Failure to adequately identify and characterize suspect spill areas at the beginning of an investigation can have several consequences. Foremost is the need to identify suspect spill areas as a basic objective of an environmental investigation under the State Contingency Plan (see Section 2). If historical information or field observations suggest that contamination might be concentrated in a specific area of a site then this area must be characterized separately from anticipated clean areas (i.e., areas suspected to have only low levels of contaminants, below HDOH Tier 1 EALs). The inclusion of small areas of heavy contamination (e.g., a few hundred to a few thousand square feet) with large areas of otherwise clean soil for characterization can also cause the entire DU to fail and unnecessarily drive up cleanup costs.

Assume for example that an older building on a 5,000-ft² lot is to be demolished and a new home constructed. The entire lot might be considered to represent a single, "Exposure Area" DU for evaluation of direct exposure risk (Subsection 3.4.2). Soil around the perimeter of the existing house is, however, suspected to have been treated with Technical Chlordane (chlordane), widely used in the past as a termiticide. Exceptionally high concentrations of chlordane in this area could erroneously imply that the entire property is contaminated above soil action levels.

This highlights the need to characterize the house perimeter as a separate, Spill Area DU, with the remaining area of the yard tested as an Exposure Area DU (see Figure 3-20 in Section 3). The perimeter of the house will likely be flagged for potential direct exposure concerns. If the new house is to be constructed on the existing foundation then exposure to treated soil in this area can subsequently be minimized by placing gravel, landscaping or pavement around the perimeter.

Contamination associated with spill areas can also extend below the depth of soil included in the original Exposure Area DU. This deeper soil could potentially be excavated during future redevelopment and spread out across the surface, resulting in a higher exposure area concentration of chlordane than estimated from the original investigation.

Significant disagreement between replicate samples can indicate the presence of a localized spill area(s) within an initially large DU. If this occurs and the resulting data are inadequate for decision making (see Subsection 4.2.7), then the original DU should be subdivided into smaller DUs for re-characterization. This situation can be avoided for contaminants known to be subject to potential exceptionally high small-scale variability (e.g., lead shot, PCBs, etc.) by designating reasonably small DUs up front and increasing the number and/or mass of increments collected within a DU (e.g., no more than a few hundred to a few thousand square feet; see Subsection 3.4.3; see Subsection 4.2.2).

The use of *inappropriately small DUs* can also interfere with an efficient site investigation. Decision unit sizes are guided by the need to address risk and optimize remedial efforts. While a strong resolution of contaminated versus clean areas is desirable, the use of excessively small DUs (e.g., less than a few hundred square feet) to characterize an area is generally not beneficial and unnecessarily adds to the cost of the investigation.

4.4.2 DATA GAPS BETWEEN SURFACE DU'S OR SUBSURFACE DU LAYERS

Traditional discrete sampling methods require extrapolation of contaminant concentrations between individual sample points, where data are not available. As discussed in the HDOH field study of discrete sample variability, extrapolation between discrete data points can be highly unreliable (HDOH, 2015, b). Under a DU-MIS investigation approach, the data generated represent the mean contaminant concentration for a designated area rather than a single point. The use of adjoining DUs and subsurface DU layers minimizes gaps in data obtained for a site. This helps avoid the need for additional characterization should contamination be found as well as help optimize remedial actions. Data gaps for precise delineation of the lateral or vertical extent of a spill area might be acceptable under some circumstances but should be reviewed and discussed on a site-by-site basis.

Perimeter DUs surrounding suspect spill areas of heavy contamination should ideally be placed immediately adjacent to the Spill Area DU, with no gaps of untested soil present (see Subsection 3.4.5). Multiple rings of DUs might be advantageous in case inner DUs unexpectedly fail action levels. If gaps are unavoidable, for example due to buildings or other access limitations between spill areas and anticipated clean areas, then contamination in the untested area of soil should be assumed to be similar to that identified for the primary spill area unless additional information suggests otherwise.

The same need to minimize data gaps holds true for subsurface soil. Traditional discrete sampling of subsurface cores involved testing of soil at widely-spaced intervals at depth below the ground surface (e.g., every 5 feet). Contamination was typically assumed to extend halfway between points where concentrations above and below action levels were reported. Under a DU-MIS investigation approach the entire depth of soil targeted for sample collection is divided into separate but adjoining, DU layers for representative sampling and characterization (see Subsection 3.4.4). Extrapolation across data gaps is not necessary or desirable.

4.4.3 INADEQUATE NUMBER OF INCREMENTS AND MASS

Sampling theory requires that a sample of adequate mass be collected from an adequate number of points within a targeted DU to capture and represent distributional heterogeneity within the DU and to estimate a reliable mean (see Subsection 4.1). Recall that the number of increments collected and the representative sample methodology used is independent of the size of the DU (see Subsection 4.2.2). The number of increments may vary somewhat based on the form of the contaminant (e.g., more for lead nuggets or PCB droplets) or other suspicions about the degree of contaminant heterogeneity, but increasing increments in such cases would apply to both small and larger DUs as well. The number of increments collected and the representative sample methodology used is independent of the size of the DU (see Subsection 4.2.2). The number of increments may vary somewhat based on the form of the contaminant (e.g., more for lead nuggets or PCB droplets) or other suspicions about the degree of contaminant heterogeneity, but increasing increments in such cases would apply to both small and larger DUs as well.

A minimum of 30 to 75+ increments per DU is recommended, with a default of 50 for sites where the nature of contamination is uncertain (see Subsection 4.2.2). If the target contaminant does not show an unusual degree of heterogeneity in the DU soil, then approximately 30 to 50 increments are typically adequate to determine a representative mean concentration (determined by the collection and analysis of field replicate samples). For contaminants or situations where there is a relatively high degree of contaminant heterogeneity in the DU, larger numbers of increment (and/or larger masses for increments) are typically needed to obtain representative mean values. The adequacy of the number and mass of increments included is tested through the collection of replicate samples (see Subsection 4.2.7)

An adequate mass and number of increments to obtain a representative sample is required for both surface soil as well as subsurface soil, discussed below. If a less-than-recommended number of increments can be collected from a targeted DU, especially in the case of subsurface soil, then field replicate data is crucial to help evaluate the usefulness of the data for decision-making. In general, using fewer increments than recommended increases the likelihood that the data may not prove to be adequately representative. Any limitations of the data identified should be discussed in the investigation report, as well as the potential need for more reliable characterization in the future.

Some sampling guidance documents and training classes have suggested that increments initially collected from a DU be combined into smaller "sampling unit" subsets for separate testing in order to provide a better understanding of contaminant distribution variability within the DU (e.g., ITRC, 2012). For example a DU might be divided into four subareas with 8 increments collected from each "SU" and combined and tested separately. This approach suffers from several shortcomings. Most importantly, DUs should be appropriately sized to the desired scale of decision making at the start of the investigation. If better resolution might be needed for an initially large DU then the DU should simply be subdivided into smaller DUs with a multi increment sample of adequate mass and number of increments collected from each DU.

Testing of poor quality samples from DUs when a proper number of increments could have been collected is wasteful of investigation resources and should be avoided. The resulting data cannot be assumed to be representative of the area where the combined increments were collected (see HDOH, 2015, b). From a field perspective, the added time and cost to collect an adequate number of increments (e.g., 30 to 75+) from each smaller area is also negligible, especially given the importance of the resulting data in decision making.

Collecting an adequate mass of soil (e.g., 1-2 kg) is usually feasible for a project, as is the collection of an adequate number of increments from exposed, surface soil. The collection of a large number of increments from subsurface soil DU layers might not be practical, however, due to cost or access issues (see Subsection 4.2.9.2). If this is the case then limitations on the reliability of data should be clearly discussed in the investigation report. Replicate data from at least 10% of the DUs are especially important in such cases (see Subsection 4.2.7). Data for other DUs should be adjusted as necessary in accordance with Subsection 4.2.7. If this adjustment indicates that contamination above levels of potential concern could in fact be present, then the soil should be included in remediation work plans and/or managed under a site EHMP until such time that it is more accessible.

4.4.4 IMPROPER INCREMENT SPACING

As a shortcut in the field it can be tempting to collect large numbers of tightly spaced increments from a few widely spaced lines within a DU (see Figure 4-10). While this approach might address sampling theory requirements in terms of the mass and number of increments used to prepare a bulk MIS sample, it may not be representative of mean contaminant concentrations within the DU. The described approach does not meet the sampling theory requirement of randomly located increments and is therefore unacceptable. There are three options - purely random, systematic random and stratified random, with systematic random increment collection demonstrated to produce the most reliable results.

Unevenly spaced increments can cause localized areas of heavy contamination within the DU to be both over- or under-represented by the resulting bulk sample data. This can also cause replicate samples to fail and require re-characterization of the DU, wasting resources and unnecessarily extending the time and cost required to complete the project.

Sample data are most reproducible when increment locations are distributed at evenly spaced locations, referred to as "systematic random" (see Figure 4-9). Increments should be equally spaced in both the x and y axis directions. While simple in concept this can be complicated to implement in the field without prior practice and experience.

4.4.5 IMPROPER INCREMENT SHAPE

Gardening trowels are easy to use and decontaminate in the field for the collection of soil samples. Such tools are prone to collect wedge-shaped increments, however. This can bias the subsequent MI sample to the upper portion of the targeted DU layer, where the greater mass of soil was collected, and call into question the representativeness of the data in terms of the site investigation objectives. Note that this bias would not necessarily be reflected in replicates samples collected from the same DU, since the same error is carried forward in each individual sample.

Trowels should be avoided when tools that allow the collection of more core-shaped increments can be utilized (e.g., sampling tubes). A core-shaped increment is ideal, since it equally represents the targeted DU layer in both the vertical and lateral direction (see Subsection 4.2.5.2). The use of trowels and/or other tools might be unavoidable for hard-packed or gravely soils, however (see Subsection 5.3). If this is the case then an effort should be made to collect cylindrical-shaped increments that are equally representative of the full thickness of the DU. This approach might also be required for dry, loose soils that would otherwise fall out of sampling tubes or not be evenly extracted with drills or other coring equipment. Non-coring sampling alternatives may result in the collection of larger individual increment masses and larger bulk MI samples. This needs to be considered when planning the investigation and coordinating with the laboratory.

4.4.6 CO-LOCATED DISCRETE SAMPLES AND INCREMENT SPLITS

Field studies carried out by HDOH indicate that contaminant concentrations within a single sample or increment and co-located samples or increments can vary by orders of magnitude in an unpredictable and random manner (see HDOH, 2015, b). The concentration of the contaminant in a simple subdivision of the discrete sample or increment (sometimes referred to as a split) or otherwise co-located sample/increment could well have no bearing on the concentration of the contaminant in the increment collected from the same location. Attempting to combine small groups of co-located increments into bulk MI samples for testing similarly poses the same risk of non-representativeness as described above.

Note also that replicate samples should not be collected from the same (or co-located with) initial increment locations (see Subsection 4.2.7). While technically a separate sample, the precision of the DU-MI sample data is accurately assessed by the collection of replicate samples from widely separated and completely independent locations.

4.4.7 INADEQUATE LABORATORY PROCESSING

Inadequate processing of a MI sample negates the field representativeness of the sample and the validity of the resulting data. The resulting data reported by the laboratory can be considered to be no more useful than a single discrete sample collected from within the DU area.

It is important to ensure that the laboratory that receives the MI samples has a written standard procedure in place to properly process and collect a subsample for testing (see Subsection 4.2.6). For non-volatile contaminants this includes drying, sieving and subsampling in accordance with sampling theory methodologies. Request a copy of the laboratories Standard Operating Procedure (SOP) for incremental sample processing and testing. Ideally the lab should be visited and the procedures used to manage Multi Increment samples demonstrated.

4.4.8 INADEQUATE SUBSAMPLE MASS FOR ANALYSIS

The mass of soil collected in the field and extracted for analysis by a laboratory is dictated by sampling theory (see Subsection 4.1). A minimum subsample mass for analysis of 10 grams is recommended for soil samples sieved to the <2mm particle size (Subsection 4.2.6). When possible, a larger subsample mass (e.g., 30+ grams) is preferable to help further reduce the potential lab subsampling error and improve the precision of laboratory subsample replicates (see Subsection 4.2.7.2). Grinding (milling) of samples to a smaller particle size can allow for collection of a smaller lab subsample where appropriate for the contaminant or specified in a standard lab method (see Subsection 4.2.6.3). Such cases should be discussed with the laboratory and the HEER Office during sample investigation planning.

Standard laboratory methods for testing of metals in soil only require 1 gram or less to meet analytical needs. Unless the bulk sample has been ground, however, this is inadequate to ensure that the resulting data will be representative of the sample collected. The need to extract a larger mass of soil for metals analysis should be clarified with the laboratory prior to the initialization of field work.

Extraction of a larger subsample mass and/or grinding of the sample might be required if laboratory replicate samples indicate poor subsampling precision (see Subsection 4.2.7.2). This should be discussed with the laboratory prior to submittal of the samples and procedures for retesting of samples included in the investigation work plan and instructions to the laboratory.

4.4.9 LACK OF FIELD REPLICATE SAMPLE DATA

The need to collect replicate data might seem redundant with experience gained for a specific contaminant or a geographical area (Subsection 4.2.7). For example, 30-increment MI samples have been routinely demonstrated to generate reproducible data for most former sugarcane-growing soil sites contaminated by arsenic-based pesticides in Hawai‘i (e.g., see HDOH, 2015). The representativeness of a DU sample can only be evaluated and documented if replicate samples are collected, however. Routine collection of field replicates is required to demonstrate that correct sampling procedures were utilized (e.g. number of increments, systematic random sample spacing, correct increment shape and adequate sample mass, field handling/processing procedures, etc.).

The precision of MI samples can decrease as the mean concentration of a contaminant increases. Unanticipated areas of localized contamination within DUs can also lead to decreased precision of normally acceptable MI samples. Field studies carried out by HDOH indicate that the concentration of a contaminant can vary by an order of magnitude or more in replicate samples collected from the same DU, even when an MI sample consists of greater than 50 increments (HDOH, 2015, b). Under some circumstances even the higher recommended default of 75 increments per sample could be inadequate to demonstrate a representative mean contaminant concentration in a DU, such as when contaminants are distributed in a very heterogenic "nugget" form (e.g. lead pellets, or lead paint chips).

Testing of large numbers of discrete samples from a DU, for example with a portable XRF (see Section 8), can provide a semi-quantitative indication of the degree of small-scale variability within the DU and provide an indication of the relative number of increments necessary to collect a representative MI sample (e.g., greater number of increments needed for increasing heterogeneity; see Subsection 4.3). Statistical methods used to estimate the number of discrete samples needed to estimate the mean concentration of a contaminant within a DU (USEPA, 2013b) are not, however, directly translatable to the number of increments required under an MI investigation and cannot be used as a substitute for the collection of replicate samples. This is due to multiple factors, including consistency in the manner in which the individual discrete samples were collected (e.g., shape, mass, etc.) and perhaps more importantly the mass of soil represented by each sample data point in comparison to the mass of soil typically represented by a single increment.

4.4.10 REVERSION TO DISCRETE SAMPLING

Perhaps the most egregious error in site investigations is a reversion to discrete sampling due to real or perceived difficulties for the collection of proper MI samples in the field. This is especially common for characterization of subsurface soil. Sampling theory and the use of Multi Increment samples to characterize soil is not just one alternative to past discrete sampling methods, it is a much needed update.

The concept of “DUs” was an inherent part of past, discrete soil sample investigations (see Subsection 3.4). Discrete soil sample collection points were typically designated based on a desire to characterize contamination in one area versus another. As

discussed below, the area intended to be represented by a single, discrete sample point (or cluster of sample points) is designated as a separate DU for characterization. A large-mass, Multi-increment sample is then collected from multiple (e.g. 30-75+) locations within this area rather than reliance on a small, discrete soil sample collected from a single location. The number of DUs designated for a particular investigation not coincidentally corresponds with the number of discrete soil samples or clusters of samples that might have been collected under past approaches.

The unreliability and inefficiency of discrete sample data remains the same regardless of the nature and location of the targeted soil. Consideration of sampling theory is still required to ensure that the resulting data are technically defensible and useful for decision making purposes. The fact that a targeted layer of soil is covered by additional soil that must first be penetrated for the collection of an MI sample cannot be used as a reason to revert to discrete sample collection approaches.

Targeted DU areas and layers, rather than single horizons, must always be designated as part of a site investigation regardless of the manner used to characterize the soil (Subsection 3.4.4). Methods to collect MI samples from subsurface DU layers are described in Subsection 4.2.9 and Subsection 5.4. As is the case for surface soil samples, subsurface samples must be of adequate mass and distribution within the DU to address fundamental error. Samples must also be processed at the laboratory in accordance with multi increment subsampling methods. If an ideal number of increments cannot be included in a DU layer sample due to access or cost limitations then limitations regarding the reliability of the resulting data must be assessed and discussed based on a review of the replicate sample data. Identification of data limitations is also important where single borings are used for decision making purposes (see Subsection 3.4.4).

Another error sometimes encountered in site investigations is a reversion to the collection of a single discrete sample when the targeted DU is very small, for example <100 ft² or even <10 ft² or less. Sampling theory is independent of DU area and volume (Subsection 4.1). A minimum 1-2 kg sample must still be collected from the DU in order to address fundamental error. If collection of the recommended default number of increments from the DU is somehow not practical then this should be noted and replicates collected and reviewed to determine precision of the sampling data. Any limitations identified through analysis of the replicate data should be discussed when reporting the results. The sample must be processed and subsampled for testing at the laboratory in accordance with multi increment sample methods.

If the DU is so small that the entire volume of soil is to be collected and submitted to the laboratory, then processing and subsampling in accordance with Multi Increment sampling methods are still required (e.g., testing of sediment in a small sump). In this sense the soil submitted is not a true "sample" in terms of sampling theory, since the entire DU volume of interest is collected for analysis. The use of Multi Increment sampling methods to collect a representative sample from the DU in the field was not necessary. Any error in the resulting data would be fully attributable to laboratory subsampling and analysis errors, since the entire mass is not being analyzed and a laboratory subsample must be collected.

Similar concerns and requirements as noted above also apply to the characterization of sediment that happens to be covered by a layer of water. Simplistic contouring between discrete sample points cannot be assumed to be reliable beyond the gross recognition of large contaminant patterns (see HDOH, 2015b). Decision Unit layers, rather than single horizons should be designated and targeted for characterization (see Subsection 3.4). Increments collected within a DU must be of adequate shape, number and mass to address fundamental error and generate a representative sample. It is possible that fewer numbers of increments might be adequate to collect a representative sample of sediment from designated DU areas, due to the nature in which the contaminant was released and the sediment deposited. This issue has not been evaluated in detail in the field to our knowledge, however. Limitations on the reliability of resulting data when an adequate number of increments cannot be collected must be discussed in the investigation report.

4.4.11 DU-MIS INVESTIGATIONS UNDER TSCA

The investigation, cleanup, verification and disposal of soil contaminated with polychlorinated biphenyls (PCBs) is regulated under 40 CFR § 761.61 (PCB remediation waste) of the Toxic Substances Control Act (TSCA; USEPA, 1998h). The Hawai'i State Contingency Plan also authorizes HDOH to require the investigation and remediation of PCB-contaminated properties (see Section 2). This joint authority has caused problems as USEPA lags behind HDOH in the transition to multi increment sampling methods from outdated discrete sampling methods prescribed in 40 CFR 761.61(a) *self-implementing on-site cleanup and disposal of PCB remediation waste* and associated guidance documents (e.g., USEPA, 1985, 1986).

Use of alternative procedures is provided for in 40 CFR 761.61(c)(1) *risk-based disposal approval,* subject to the approval of the USEPA Regional Administrator:

> Any person wishing to sample, cleanup, or *dispose* of PCB remediation waste in a manner other than prescribed in paragraphs (a) or (b) of this section [...] must apply in writing to the EPA Regional Administrator in the Region.

A Memorandum of Understanding (MOU) that outlines a technical and regulatory pathway for the incorporation of DU-MIS investigation methods under TSCA is currently being pursued between HDOH and USEPA Region IX. This MOU would then be

referenced for continued investigation and remediation of PCB-contaminated sites under HDOH oversight following methods described in this guidance manual, with notification and allowance for review and comment made to USEPA Region IX.

Until such an arrangement has been made, responsible parties are encouraged to contact the TSCA office of USEPA Region IX when concentrations of PCBs in soil greater than 50 mg/kg are reported for MI samples. Under TSCA, soil with a concentration of >50 mg/kg PCBs must be disposed of at a hazardous waste landfill in the mainland USA. Workplans for DU-MIS investigations at such PCB sites must be approved on a case-by-case basis by both HDOH and USEPA Region IX.

Of particular concern under TSCA is the need to minimize "**dilution**" of heavily contaminated soil with soil from surrounding, clean areas in sample data. Doing so might cause a conflict with Section 761.1(b)(5) of TSCA regulations, which states "No person may avoid any provision specifying a PCB concentration by diluting the PCBs, unless otherwise provided." This concern can be avoided by designation of well-thought-out and researched Spill Area DUs at known or suspected PCB release sites in accordance with this guidance document and in coordination with HDOH. If PCB concentrations >50 mg/kg are identified in any DU then USEPA Region IX may also request to review and approve DUs designated for characterization of the site.

Dilution, as described under TSCA, can occur when samples intended to represent distinctly different areas (i.e., DUs) of a site are intentionally combined for a single analysis. The use of "*composite*" samples is also limited under TSCA regulations and guidance (e.g., USEPA, 1985, 1986). As interpreted by HDOH, a Multi Increment sample is not a composite sample in the sense used in TSCA. A sample becomes a "composite" when soil from what should otherwise be separate DUs is combined. Under TSCA, each individual discrete sample is assumed to potentially represent an individual, PCB "contaminated zone" or "sampling area," referred to in this guidance as "Spill Area DU" (see Subsection 3.4.3)(USEPA, 1985):

> The PCB level is assumed to be uniform within (a contamination zone/spill area) and zero outside it.

The spacing of individual discrete samples was based in part on the anticipated size of a spill area in order to ensure that at least one sample was collected from each potential area (USEPA, 1987):

> The decision maker must determine […] the acceptable probability of not finding an existing contaminated zone in the suspected area. For instance, it might be determined that a 20% chance of missing *a 100-ft by 100-ft (10,000-ft²) contaminated zone* is acceptable but only a *5*% chance of missing a 200-ft by 200-ft (40,000-ft²) zone is acceptable.

Under this scenario, TSCA regulations and associated guidance allow soil from multiple DU areas to be combined or "composited" into a single sample for analysis in order to reduce the total cost of laboratory analysis (Figure 4-30; USEPA, 1985, 1987, 1998h). This in effect allowed intentional "dilution" of suspect spill areas with surrounding areas of cleaner soil that should otherwise be separately characterized. The resulting data therefore had to be divided by the number of samples included

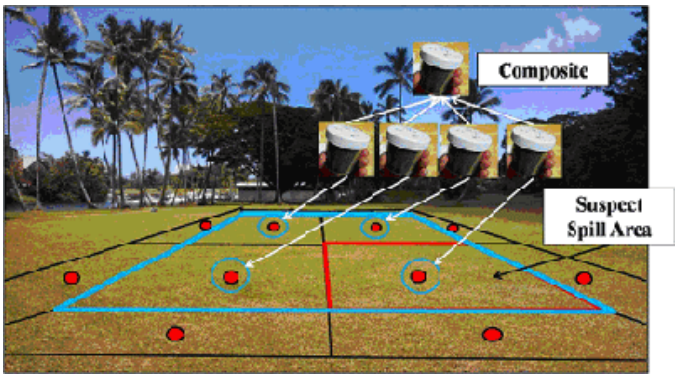


Figure 4-30. Limited "Compositing" and "Dilution" Allowed Under TSCA to Reduce Laboratory Costs.

Soil *combined across separate "sample areas" or "contaminated zones,"* referred to in HDOH guidance as *"Decision Units (DUs)"* represents a composite sample. This can lead to a potential *dilution* of a higher PCB concentration in otherwise separate "hot spots," referred to as "Spill Area DUs" by HDOH. Under TSCA the laboratory result must be divided by the number of discrete samples, or more specifically otherwise separate areas represented by the composite sample for comparison to the screening level. This ensures that no single area, i.e., DU, exceeds the target screening level.

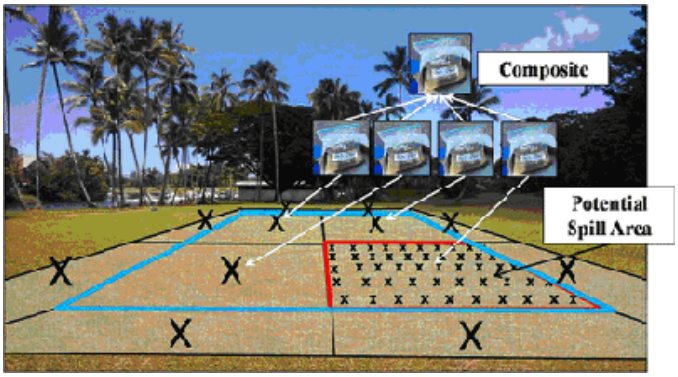


Figure 4-31. Theoretical Compositing of Multi Increment samples.

Multi Increment samples from separate DUs combined into a single sample for processing and testing at the laboratory. The laboratory data are divided by the number of samples (DUs) included in the composite sample for comparison to screening levels. Note that a single MI sample collected within a single DU *is not a composite*. **Compositing of MI samples *is not allowed* under HDOH site investigation guidance.** See Section 3 of HDOH Technical Guidance Manual for information on designation of Decision Units at contaminated properties.

in the composite, however, in order to ensure that no single "sampling area" exceeded the target cleanup level. A maximum of 10 discrete samples was permitted to be included in a single composite, based on a target cleanup level of 10 mg/kg and a laboratory detection level of 1 mg/kg. Note that risk assessment guidance was still under preparation at the time that TSCA guidance and regulations were being prepared and the concept of "exposure areas" and risk were still not widely understood.

Under a more up-to-date, DU-MIS investigation, "compositing" in the sense initially intended under TSCA guidance would involve the intentional combination of Multi Increment samples collected from separate DUs into a single sample for testing. (Figure 4-31) The resulting data would again need to be divided by the number of DUs and MI samples included in the composite, however, in order to ensure that no single DU area might exceed the target cleanup level.

Although this would save on analytical cost, *compositing of MI samples is not allowed* under HDOH guidance. An independent MI sample, representing what in the past might have been a single discrete sample, must instead be collected from each DU and individually tested for comparison against target action or cleanup levels. Intentional inclusion of suspect spill areas with anticipated clean areas for characterization as a single DU could be interpreted to violate the "anti-dilution" clause in TSCA regulations. For these reasons it is important to closely coordinate DU designation at PCB-release sites with HDOH and, as necessary, with USEPA Region IX.

As noted earlier, the intentional mixing of known or anticipated contaminated areas (i.e., "Spill Areas") with clean areas as part of a site investigation is poor practice. Doing so risks unnecessarily increasing the area and volume of soil requiring removal or long-term management. Relatively small DUs, usually a few hundred to a few thousand square feet, should be designated for characterization within suspect spill areas (see Subsection 3.4.3). Perimeter DUs of a similar area and volume should be designated in anticipated clean areas around suspect spill areas. The maximum size of DUs in outer, anticipated clean areas should be limited to the size of current or anticipated exposure areas (default residential exposure area 5,000 ft²; see Subsection 3.4.2). These approaches will help ensure that the investigation and cleanup PCB-contaminated soil is carried out in an efficient and effective manner.

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APPENDIX 4-A
RECOMMENDATIONS FOR MIS FIELD PRESERVATION OR LABORATORY SUBSAMPLING BASED ON OVERALL CHEMICAL STABILITY

TABLE 4-A1
Volatile Chemicals Requiring Field Preservation of Soil Sample Increments

CHEMICAL PARAMETER	[1]Physical State		Molecular Weight	[2]Vapor Pressure mm Hg (25C)	Henry's Law Constant (H) (atm-m³/mol)
VOLATILE CHEMICALS Preserve Samples in Methanol in the Field (or approved alternative, see text) (VP>1 *and* Molecular Weight <200)					
ACETONE	V	L	58	2.3E+02	3.9E-05
BENZENE	V	L	78	9.5E+01	5.61E-03
BIS(2-CHLOROETHYL)ETHER	V	L	143	1.6E+00	1.7E-05
BROMODICHLOROMETHANE	V	L	164	5.0E+01	2.1E-03
BROMOFORM	V	S	253	5.4E+00	5.4E-04
BROMOMETHANE	V	G	95	1.6E+03	6.3E-03
CARBON TETRACHLORIDE	V	L	154	1.2E+02	2.7E-02
CHLOROBENZENE	V	L	113	1.2E+01	3.2E-03
CHLOROETHANE	V	G	65	1.0E+03	1.1E-02
CHLOROFORM	V	L	119	2.0E+02	3.7E-03
CHLOROMETHANE	V	G	50	4.3E+03	8.8E-03
CHLOROPHENOL, 2-	V	L	129	2.5E+00	1.1E-05
DIBROMOCHLOROMETHANE	V	S	208	5.5E+00	7.8E-04
DIBROMOETHANE, 1,2-	V	S	188	1.1E+01	6.6E-04
DICHLOROBENZENE, 1,2-	V	L	147	1.4E+00	1.9E-03
DICHLOROBENZENE, 1,3-	V	L	147	2.2E+00	1.9E-03
DICHLOROBENZENE, 1,4-	V	S	147	1.7E+00	2.4E-03
DICHLOROETHANE, 1,1-	V	L	99	2.3E+02	5.6E-03
DICHLOROETHANE, 1,2-	V	L	99	7.9E+01	1.2E-03
DICHLOROETHYLENE, 1,1-	V	L	97	6.0E+02	2.7E-02
DICHLOROETHYLENE, Cis 1,2-	V	L	97	2.0E+02	4.1E-03
DICHLOROETHYLENE, Trans 1,2-	V	L	97	3.3E+02	9.3E-03
DICHLOROPROPANE, 1,2-	V	L	113	5.3E+01	2.9E-03
DICHLOROPROPENE, 1,3-	V	L	111	3.4E+01	3.7E-03

DIOXANE, 1,4-	V	L	88	3.8E+01	4.9E-06
ETHANOL	V	L	46	5.9E+01	6.3E-06
ETHYLBENZENE	V	L	106	9.6E+00	7.8E-03
METHYL ETHYL KETONE	V	L	72	9.1E+01	5.6E-05
METHYL ISOBUTYL KETONE	V	L	100	2.0E+01	1.4E-04
METHYL TERT BUTYL ETHER	V	L	88	2.5E+02	5.9E-04
METHYLENE CHLORIDE	V	L	85	4.4E+02	3.2E-03
STYRENE	V	L	104	6.4E+00	2.7E-03
tert-BUTYL ALCOHOL	V	L	74	4.1E+01	1.2E-05
TETRACHLOROETHANE, 1,1,1,2-	V	L	168	4.6E+00	2.4E-03
TETRACHLOROETHANE, 1,1,2,2-	V	L	168	4.6E+00	3.7E-04
TETRACHLOROETHYLENE	V	L	166	1.9E+01	1.8E-02
TOLUENE	V	L	92	2.8E+01	6.6E-03
TPH (gasolines)	V	L	108	6.8E+02	7.2E-04
TRICHLOROETHANE, 1,1,1-	V	L	133	1.2E+02	1.7E-02
TRICHLOROETHANE, 1,1,2-	V	L	133	2.3E+01	8.3E-04
TRICHLOROETHYLENE	V	L	131	6.9E+01	9.8E-03
TRICHLOROPROPANE, 1,2,3-	V	L	147	3.7E+00	3.4E-04
TRICHLOROPROPENE, 1,2,3-	V	L	145	3.7E+00	2.8E-02
VINYL CHLORIDE	V	G	63	3.0E+03	2.7E-02
XYLENES	V	L	106	8.0E+00	7.1E-03

Reference: Appendix 1, Table H in HEER Office Environmental Hazard Evaluation guidance (HDOH, 2016).

1. Physical state of chemical at ambient conditions (V - volatile, SV - Semi-Volatile (*SV - Treated as "volatile" in USEPA risk assessment models if H $\geq$ 0.00001), S - solid, L - liquid, G - gas).
2. Vapor Pressures from National Library of Medicine TOXNET or ChemID databases.
3. Check with lab to determine feasibility of wet sieving sample to remove >2mm particles prior to subsampling.
4. Soil or sediment samples that consist entirely of <2mm material *do not* require drying and sieving to address fundamental error concerns, although some degree of drying and sieving may be desirable by the laboratory for testing purposes.

APPENDIX 4-A
RECOMMENDATIONS FOR MIS FIELD PRESERVATION OR LABORATORY SUBSAMPLING BASED ON OVERALL CHEMICAL STABILITY

TABLE 4-A2a
Semi-volatile or Otherwise Unstable Chemicals Requiring Laboratory Subsampling of Soil Samples Prior to Processing

CHEMICAL PARAMETER	[1]Physical State		Molecular Weight	[2]Vapor Pressure mm Hg (25C)	Henry's Law Constant (H) (atm-m³/mol)
SEMI-VOLATILE AND OTHER SEMI-STABLE CHEMICALS [3,4]Subsample Multi Increment Bulk Sample at Laboratory Upon Receipt Without Drying (VP 0.1 to 1.0 OR Liquid at 25C OR Henry's Constant >1.0E-05)					
BIPHENYL, 1,1-	*SV	S	154	8.9E-03	3.2E-04
BIS(2-CHLOROISOPROPYL)ETHER	*SV	L	171	8.5E-01	1.1E-04
DALAPON	*SV	L	143	1.9E-01	9.0E-08
DIBROMO,1,2- CHLOROPROPANE,3-	*SV	L	236	5.8E-01	1.5E-04
DIMETHYLPHENOL, 2,4-	SV	S	122	1.0E-01	9.5E-07
HEXACHLOROBUTADIENE	SV	S	261	2.2E-01	1.0E-02
HEXACHLOROETHANE	SV	S	237	4.0E-01	3.9E-03
ISOPHORONE	SV	L	138	4.4E-01	6.6E-06
[5]MERCURY	*SV	S	201	2.0E-03	-
METHYL MERCURY	SV	S	216	-	-
NITROBENZENE	*SV	L	123	2.5E-01	2.4E-05
NITROGLYCERIN	SV	L	227	2.0E-04	9.8E-08
NITROTOLUENE, 4-	SV	S	137	1.6E-01	5.6E-06
NITROTOLUENE, 2-	*SV	S	137	1.9E-01	1.2E-05
NITROTOLUENE, 3-	*SV	S	137	2.1E-01	2.4E-05
[6]PAHs (varies, see Table 4-2b)	*SV	S			
PHENOL	SV	S	94	3.5E-01	3.4E-07
PROPICONAZOLE	SV	L	342	1.0E-06	4.1E-09
[7]TPH (middle distillates)	*SV	L	170	2 to 26	7.2E-04
TRICHLOROBENZENE, 1,2,4-	*SV	S	181	4.6E-01	1.4E-03

Reference: Appendix 1, Table H in HEER Office Environmental Hazard Evaluation guidance (HDOH, 2016).

1. Physical state of chemical at ambient conditions (V - volatile, SV - Semi-Volatile (*SV - Treated as "volatile" in USEPA risk assessment models if H ≥ 0.00001), S - solid, L - liquid, G - gas).

2. Vapor Pressures from National Library of Medicine TOXNET or ChemID databases.

3. Check with lab to determine feasibility of wet sieving sample to remove >2mm particles prior to subsampling.

4. Soil or sediment samples that consist entirely of <2mm material *do not* require drying and sieving to address fundamental error concerns, although some degree of drying and sieving may be desirable by the laboratory for testing purposes.

5. The stability of a targeted metal depends in part on the species present and can be highly variable. Identification of specific species of a metal may require the collection of aliquots prior to drying and sieving and should be evaluated on a site-by-site basis with respect to the site investigation objectives

6. PAHS - See Table 4-A2b. Eighteen targeted PAHs listed in Section 9 of the HEER Office TGM.

7. TPH diesel may not be adequately extractable from soil or sediment when placed in methanol; aliquots should be collected and extracted at the laboratory (e.g., using methylene chloride).

APPENDIX 4-A
RECOMMENDATIONS FOR MIS FIELD PRESERVATION OR LABORATORY SUBSAMPLING BASED ON OVERALL CHEMICAL STABILITY

TABLE 4-A2b
Physiochemical Constants for Targeted PAHs

[3]Targeted PAHs	[1]PhysicalState		Molecular Weight	[2]VaporPressure mm Hg (25C)	Henry's Law Constant (H) (atm-m³/mol)
Semi-Volatile PAHs (VP 0.1 to 1.0 OR Liquid at 25C OR Henry's Constant ≥1.0E-05) [3,4]Subsample Multi Increment Bulk Sample at Laboratory Upon Receipt Without Drying					
ACENAPHTHENE	*SV	S	154	2.2E-03	1.8E-04
ACENAPHTHYLENE	*SV	S	152	6.7E-03	1.5E-03
ANTHRACENE	*SV	S	178	6.6E-06	5.6E-05
FLUORENE	*SV	S	166	3.2E-04	9.5E-05
METHYLNAPHTHALENE, 1-	*SV	S	142	6.7E-02	5.1E-04
METHYLNAPHTHALENE, 2-	*SV	S	142	5.5E-02	5.1E-04
NAPHTHALENE	*SV	S	128	8.5E-02	4.4E-04
PHENANTHRENE	*SV	S	178	1.2E-04	3.9E-05
PYRENE	*SV	S	202	4.5E-06	1.2E-05
Non-Volatile PAHs (VP <0.1 AND Solid at 25C AND Henry's Constant <1.0E-05) [4]Dry and Sieve Multi Increment Samples for Preparation of Aliquots					
BENZO(a)ANTHRACENE	NV	S	228	5.0E-09	1.2E-05
BENZO(a)PYRENE	NV	S	252	5.5E-09	4.6E-07
BENZO(b)FLUORANTHENE	NV	S	252	5.0E-07	6.6E-07
BENZO(g,h,i)PERYLENE	NV	S	276	-	1.4E-07
BENZO(k)FLUORANTHENE	NV	S	252	9.7E-10	5.9E-07
CHRYSENE	NV	S	228	6.2E-09	5.1E-06
DIBENZO(a,h)ANTHTRACENE	NV	S	278	9.6E-10	1.2E-07
FLUORANTHENE	NV	S	202	9.2E-06	8.8E-06
INDENO(1,2,3-cd)PYRENE	NV	S	276	1.2E-10	3.4E-07

Reference: Appendix 1, Table H in HEER Office Environmental Hazard Evaluation guidance (HDOH, 2016).

1. Physical state of chemical at ambient conditions (V - volatile, SV - Semi-Volatile (*SV - Treated as "volatile" in USEPA risk assessment models if H ≥0.00001), S - solid, L - liquid, G - gas).

2. Vapor Pressures from National Library of Medicine TOXNET or ChemID databases.

3. PAHS - Eighteen targeted PAHs listed in Section 9 of the HEER Office TGM. Recommendation to subsample the Multi Increment sample without drying applies primarily to acenaphthene, acenaphthylene, anthracene, fluorene, methylnaphthalenes, naphthalene and phenanthrene and pyrene.

4. Soil or sediment samples that consist entirely of <2mm material *do not* require drying and sieving to address fundamental error concerns, although some degree of drying and sieving may be desirable by the laboratory for testing purposes.

APPENDIX 4-A
RECOMMENDATIONS FOR MIS FIELD PRESERVATION OR LABORATORY SUBSAMPLING BASED ON OVERALL CHEMICAL STABILITY

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Volatile Chemicals Requiring Field Preservation of Soil Sample Increments

CHEMICAL PARAMETER	[1]Physical State		Molecular Weight	[2]Vapor Pressure mm Hg (25C)	Henry's Law Constant (H) (atm-m^3/mol)
VOLATILE CHEMICALS Preserve Samples in Methanol in the Field (or approved alternative, see text) (VP>1 AND Molecular Weight <200)					
ACETONE	V	L	58	2.3E+02	3.9E-05
BENZENE	V	L	78	9.5E+01	5.61E-03
BIS(2-CHLOROETHYL)ETHER	V	L	143	1.6E+00	1.7E-05
BROMODICHLOROMETHANE	V	L	164	5.0E+01	2.1E-03
BROMOFORM	V	S	253	5.4E+00	5.4E-04
BROMOMETHANE	V	G	95	1.6E+03	6.3E-03
CARBON TETRACHLORIDE	V	L	154	1.2E+02	2.7E-02
CHLOROBENZENE	V	L	113	1.2E+01	3.2E-03
CHLOROETHANE	V	G	65	1.0E+03	1.1E-02
CHLOROFORM	V	L	119	2.0E+02	3.7E-03
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DIBROMOETHANE, 1,2-	V	S	188	1.1E+01	6.6E-04
DICHLOROBENZENE, 1,2-	V	L	147	1.4E+00	1.9E-03
DICHLOROBENZENE, 1,3-	V	L	147	2.2E+00	1.9E-03
DICHLOROBENZENE, 1,4-	V	S	147	1.7E+00	2.4E-03
DICHLOROETHANE, 1,1-	V	L	99	2.3E+02	5.6E-03
DICHLOROETHANE, 1,2-	V	L	99	7.9E+01	1.2E-03
DICHLOROETHYLENE, 1,1-	V	L	97	6.0E+02	2.7E-02
DICHLOROETHYLENE, Cis 1,2-	V	L	97	2.0E+02	4.1E-03
DICHLOROETHYLENE, Trans 1,2-	V	L	97	3.3E+02	9.3E-03
DICHLOROPROPANE, 1,2-	V	L	113	5.3E+01	2.9E-03

DICHLOROPROPENE, 1,3-	V	L	111	3.4E+01	3.7E-03
DIOXANE, 1,4-	V	L	88	3.8E+01	4.9E-06
ETHANOL	V	L	46	5.9E+01	6.3E-06
ETHYLBENZENE	V	L	106	9.6E+00	7.8E-03
METHYL ETHYL KETONE	V	L	72	9.1E+01	5.6E-05
METHYL ISOBUTYL KETONE	V	L	100	2.0E+01	1.4E-04
METHYL TERT BUTYL ETHER	V	L	88	2.5E+02	5.9E-04
METHYLENE CHLORIDE	V	L	85	4.4E+02	3.2E-03
STYRENE	V	L	104	6.4E+00	2.7E-03
tert-BUTYL ALCOHOL	V	L	74	4.1E+01	1.2E-05
TETRACHLOROETHANE, 1,1,1,2-	V	L	168	4.6E+00	2.4E-03
TETRACHLOROETHANE, 1,1,2,2-	V	L	168	4.6E+00	3.7E-04
TETRACHLOROETHYLENE	V	L	166	1.9E+01	1.8E-02
TOLUENE	V	L	92	2.8E+01	6.6E-03
TPH (gasolines)	V	L	108	6.8E+02	7.2E-04
TRICHLOROETHANE, 1,1,1-	V	L	133	1.2E+02	1.7E-02
TRICHLOROETHANE, 1,1,2-	V	L	133	2.3E+01	8.3E-04
TRICHLOROETHYLENE	V	L	131	6.9E+01	9.8E-03
TRICHLOROPROPANE, 1,2,3-	V	L	147	3.7E+00	3.4E-04
TRICHLOROPROPENE, 1,2,3-	V	L	145	3.7E+00	2.8E-02
VINYL CHLORIDE	V	G	63	3.0E+03	2.7E-02
XYLENES	V	L	106	8.0E+00	7.1E-03

Reference: Appendix 1, Table H in HEER Office Environmental Hazard Evaluation guidance (HDOH 2016).

1. Physical state of chemical at ambient conditions (V - volatile, SV - Semi-Volatile (*SV - Treated as "volatile" in USEPA risk assessment models if H $\geq$ 0.00001), S - solid, L - liquid, G - gas).
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3. Check with lab to determine feasibility of wet sieving sample to remove >2mm particles prior to subsampling.
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RECOMMENDATIONS FOR MIS FIELD PRESERVATION OR LABORATORY SUBSAMPLING BASED ON OVERALL CHEMICAL STABILITY

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DIMETHYLPHENOL, 2,4-	SV	S	122	1.0E-01	9.5E-07
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HEXACHLOROETHANE	SV	S	237	4.0E-01	3.9E-03
ISOPHORONE	SV	L	138	4.4E-01	6.6E-06
[5]MERCURY	*SV	S	201	2.0E-03	-
METHYL MERCURY	SV	S	216	-	-
NITROBENZENE	*SV	L	123	2.5E-01	2.4E-05
NITROGLYCERIN	SV	L	227	2.0E-04	9.8E-08
NITROTOLUENE, 4-	SV	S	137	1.6E-01	5.6E-06
NITROTOLUENE, 2-	*SV	S	137	1.9E-01	1.2E-05
NITROTOLUENE, 3-	*SV	S	137	2.1E-01	2.4E-05
[6]PAHs (varies, see Table 4-2b)	*SV	S			
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PROPICONAZOLE	SV	L	342	1.0E-06	4.1E-09
[7]TPH (middle distillates)	*SV	L	170	2 to 26	7.2E-04
TRICHLOROBENZENE, 1,2,4-	*SV	S	181	4.6E-01	1.4E-03

Reference: Appendix 1, Table H in HEER Office Environmental Hazard Evaluation guidance (HDOH, 2016).

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7. TPH diesel may not be adequately extractable from soil or sediment when placed in methanol; aliquots should be collected and extracted at the laboratory (e.g., using methylene chloride).

APPENDIX 4-A
RECOMMENDATIONS FOR MIS FIELD PRESERVATION OR LABORATORY SUBSAMPLING BASED ON OVERALL CHEMICAL STABILITY

TABLE 4-A2b
Physiochemical Constants for Targeted PAHs

[3]Targeted PAHs	[1]PhysicalState		Molecular Weight	[2]VaporPressure mm Hg (25C)	Henry's Law Constant (H) (atm-m^3/mol)
Semi-Volatile PAHs (VP 0.1 to 1.0 OR Liquid at 25C OR Henry's Constant ≥1.0E-05) [3,4]Subsample Multi Increment Bulk Sample at Laboratory Upon Receipt Without Drying					
ACENAPHTHENE	*SV	S	154	2.2E-03	1.8E-04
ACENAPHTHYLENE	*SV	S	152	6.7E-03	1.5E-03
ANTHRACENE	*SV	S	178	6.6E-06	5.6E-05
FLUORENE	*SV	S	166	3.2E-04	9.5E-05
METHYLNAPHTHALENE, 1-	*SV	S	142	6.7E-02	5.1E-04
METHYLNAPHTHALENE, 2-	*SV	S	142	5.5E-02	5.1E-04
NAPHTHALENE	*SV	S	128	8.5E-02	4.4E-04
PHENANTHRENE	*SV	S	178	1.2E-04	3.9E-05
PYRENE	*SV	S	202	4.5E-06	1.2E-05
Non-Volatile PAHs (VP <0.1 AND Solid at 25C AND Henry's Constant <1.0E-05) [4]Dry and Sieve Multi Increment Samples for Preparation of Aliquots					
BENZO(a)ANTHRACENE	NV	S	228	5.0E-09	1.2E-05
BENZO(a)PYRENE	NV	S	252	5.5E-09	4.6E-07
BENZO(b)FLUORANTHENE	NV	S	252	5.0E-07	6.6E-07
BENZO(g,h,i)PERYLENE	NV	S	276	-	1.4E-07
BENZO(k)FLUORANTHENE	NV	S	252	9.7E-10	5.9E-07
CHRYSENE	NV	S	228	6.2E-09	5.1E-06
DIBENZO(a,h)ANTHTRACENE	NV	S	278	9.6E-10	1.2E-07
FLUORANTHENE	NV	S	202	9.2E-06	8.8E-06
INDENO(1,2,3-cd)PYRENE	NV	S	276	1.2E-10	3.4E-07

Reference: Appendix 1, Table H in HEER Office Environmental Hazard Evaluation guidance (HDOH, 2016).

1. Physical state of chemical at ambient conditions (V - volatile, SV - Semi-Volatile (*SV - Treated as "volatile" in USEPA risk assessment models if H $\geq$0.00001), S - solid, L - liquid, G - gas).

2. Vapor Pressures from National Library of Medicine TOXNET or ChemID databases.

3. PAHS - Eighteen targeted PAHs listed in Section 9 of the HEER Office TGM. Recommendation to subsample the Multi Increment sample without drying applies primarily to acenaphthene, acenaphthylene, anthracene, fluorene, methylnaphthalenes, naphthalene and phenanthrene and pyrene.

4. Soil or sediment samples that consist entirely of <2mm material *do not* require drying and sieving to address fundamental error concerns, although some degree of drying and sieving may be desirable by the laboratory for testing purposes.

SECTION 5
FIELD COLLECTION OF SOIL AND SEDIMENT SAMPLES

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Department of Health
Office of Hazard Evaluation and Emergency Response
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SECTION 5 ACRONYMS AND ABBREVIATIONS

ASTM	American Society for Testing and Materials
BGS	Below ground surface
COPC	Chemicals (or Contaminants) of Potential Concern
DQO	Data Quality Objective
DU	Decision Unit
EHMP	Environmental Hazard Management Plan
EM	Electromagnetics
ft	Feet
FTC	Fast Track Cleanup
GC/MS	Gas Chromatography-Mass Spectrometry
GPR	Ground Penetrating Radar
GPS	Global Positioning Satellite
HDOH	Hawai'i Department of Health
HEER Office	Hazard Evaluation and Emergency Response Office
HIOSH	Hawai'i Occupational Safety and Health
HOCC	Hawai'i One Call Center
HRS	Hawai'i Revised Statutes
HSA	Hollow-Stem Auger
IDW	Investigation-Derived Waste
kg	kilogram
lb	Pound(s)
MCS	Modified California Sampler
MDL	Method Detection Limit
MI	Multi Increment
MIS	Multi Increment sample(s)
mL	Milliliter
mm	Millimeter
NAPL	Non Aqueous Phase Liquid
NJDEP	New Jersey Department of Environmental Protection
PID	Photo Ionization Detector
PPE	Personal Protective Equipment
PUC	Public Utilities Commission
QA	Quality Assurance
QA/QC	Quality Assurance and Quality Control
QAPP	Quality Assurance Project Plan
QC	Quality Control
RCRA	Resource Conservation and Recovery Act
SAP	Sampling and Analysis Plan
SCP	Hawai'i State Contingency Plan

SHWB	HDOH Solid and Hazardous Waste Branch
SPT	Standard Penetrometer Test
TCLP	Toxicity characteristic leaching procedure
TGM	Technical Guidance Manual
TSCA	Toxic Substances Control Act
US Army	United States Department of the Army
US Navy	United States Department of the Navy
USCS	Unified Soil Classification System
USDA-NRCS	United States Department of Agriculture, Natural Resources Conservation Service
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UST	Underground Storage Tank
VOC	Volatile Organic Compound
XRF	X-Ray Fluorescence

5.0 FIELD COLLECTION OF SOIL AND SEDIMENT SAMPLES

This Section describes procedures, methods, and equipment for the collection of Multi Increment soil and sediment samples (refer to Section 4). Alternative sampling approaches, including discrete sampling, must be demonstrated to the HDOH Hazard Evaluation and Emergency Response Office (HEER Office) to meet sampling theory requirements and yield reproducible data in both the field and the laboratory if they are to be used for final decision making purposes (e.g., USEPA, 1995b; USACE, 1996; NJDEP, 2005; Nielsen, 2006; see Subsection 4.3).

A site-specific Sampling and Analysis Plan (SAP) and associated Quality Assurance Project Plan (QAPP) should be developed prior to mobilization for sample collection (see Section 3). The SAP describes the types and quantities of samples to be collected and the rationale for their collection. The plan also describes Quality Assurance/Quality Control (QA/QC) procedures to ensure that sampling design and measurement errors are controlled sufficiently to meet the tolerable decision error rates specified in the DQOs.

Individuals planning or conducting site investigations are encouraged to communicate with the HEER Office regarding the guidelines during all stages of investigation to discuss issues such as:

- Appropriate decisions, data needs, DQOs;
- Aligning sampling strategy with investigation data needs;
- Deviation from sample collection procedures presented in the HEER TGM (e.g. alternative test methods);
- Deviation from approved sample collection methods due to unexpected conditions encountered in the field; and
- Use of technologies or methods not covered in this guidance.

The sampling guidelines presented in this Section are intended to ensure that sample integrity is maintained by capturing and preserving site representativeness to the greatest extent possible.

The HEER Office has developed the process of Fast Track Cleanup (FTC) as an investigation option. For eligible sites, the FTC approach requires less intermediate regulatory review and approval of formal sampling plans by involving increased communication and consultation with the HEER Office. It places a greater burden of technical justification on the FTC participant to demonstrate to the HEER Office prior to conducting an investigation that the chosen sampling strategy will adequately address needs based on site-specific DQO and that proper QA/QC will be performed. If the HEER Office does not believe the quality of work will meet the needs of that investigation, a greater degree of planning and coordination (which may involve submittal of a formal work plan) will be required or disqualify the participant from an FTC agreement. This places responsibility on the FTC participant to hire a knowledgeable consultant who understands the current laws and guidelines. Specific details of the FTC process are presented in Section 15.

5.1 INITIAL SITE INSPECTION

A site visit is imperative to evaluate conditions that might influence the design and implementation of the Sampling and Analysis Plan. Historic site information and data are compiled and reviewed during the first and second steps of Systematic Planning of the site investigation (see Section 3). This information is used to identify potential areas of concern and designate initial DU areas for sample collection.

Finalization of the location, area, and depth of final DUs is carried out during the site visit. Logistical needs to carry out sampling are then assessed, including necessary access agreements, the need to remove equipment, debris and/or vegetation prior to sample collection, presence of pavement that may require drilling, presence of subsurface utilities, soil conditions, and optimal tools for sample collection and related details. These topics are discussed in detail in the following sections.

5.1.1 DECISION UNIT DESIGNATION

Designation of Decision Units (DUs) for characterization is an important part of the initial site investigation process (see Section 3). Decision Unit locations are based on the site history and known or suspect areas of contamination.

Once established, the boundaries of final DUs should be marked using flagging, paint or similar means. A to-scale map of the DU locations and boundaries is an important component of the site investigation report. This allows the investigated area to be relocated in the future if needed. Simple sketch maps are not acceptable. The dimensions of the DU should be carefully measured and recorded, with key corners and boundaries georeferenced or surveyed. The approximate area of the DU should be determined and recorded. This information will also be required to help establish the spacing of increments within the DU for sample collection (see Subsection 4.2.4). Use of a data sheet or data log is strongly encouraged to ensure that essential information regarding the selected DUs is documented for the site investigation report (see Figure 5-47).

5.1.2 SURFACE CONDITIONS

Assess the type and compactness of soil within potential DU areas during the initial site visit. Bring tools to test the type and compaction of the soils and potential presence of shallow rocks or buried debris, for example a sampling tube and a small pick. Different tools are required for the collection of samples from different soil types. For example, sampling tubes are appropriate for soft fine-grained soils, while sampling tubes with slide hammers or battery-powered hammer drills with spade bits might be required for compacted or hard soils. In most cases multiple types of tools should be taken to the field to ensure that samples can be collected should unforeseen circumstances arise.

Areas of gravel, asphalt or other materials covering DUs targeted for sampling should be noted. The need to remove or dig or drill through this material should be included in site planning. Vehicles, debris, or other material within DUs that will need to be moved for access should be discussed with the property owner. Clearing of grass and weeds to improve access and expedite sample collection might be required in some areas. It is important to remember that data representing the mean contaminant concentration for DUs are only valid if systematic random increment locations in the DUs are accessible for sampling. Any substantial areas of a site that are not accessible to locate planned systematic random increments (e.g. former building foundation pads or paved/graveled roadways that cannot be drilled through, clusters of dense vegetation that cannot be cleared or accessed for sampling, etc.) should be identified/mapped as data gaps and documented in the site investigation report.

Look for the potential presence of shallow subsurface utilities or other features that might interfere with surface (or subsurface) soil sample collection. For example check for potential irrigation lines in landscaped areas or obviously well-watered lawns or shallow electrical conduits attached to sidewalk lighting. Look for sprinkler heads and water piping or electrical conduits extending from buildings or outside air conditioning units, water heaters, etc.

Note the presence of overhead utilities, trees or structures that might interfere with access of field equipment. For example low, overhead utilities or structures might require the use of a smaller track-mounted push rig for the collection of subsurface samples. General precautions for overhead clearance are given in Occupational Safety and Health Administration (OSHA) guidance on Cranes and Derricks in 29 CFR 1926.550(a)(15), but these should be regarded as bare minimums. Provide photographs and/or videos to the drill operator if they will not able to visit the site prior to the initiation of field work.

5.1.3 SUBSURFACE CONDITIONS

If the collection of subsurface soils is to take place then the presence of buried utilities or other features should be noted during the initial site evaluation. Look for direct surface connections and other indirect potential indicators of subsurface utilities and features. These indicators might manifest themselves in various ways:

- Prior subsurface location surveys – Worksites often have multiple stages of construction or other site work that involve their own subsurface surveys. It is not uncommon to find markings from prior surveys indicating subsurface utilities or features. Examples of these markings include surface paint marks, stakes, pins and small, wire flags.

- Direct attachments to subsurface utilities – These are the surface segments directly attached to subsurface utilities or features. This includes manholes, valve pits, valves, standpipes, hose bibs and hydrants.

- Irregularities in surface or surface cover – These are caused by or associated with but not directly attached to subsurface utilities or features. Example of these are: linear cuts in concrete/asphalt cover, linear depressions, raised surfaces, sharply defined lack of vegetation, patches or other irregularities in surface cover that suggest a definable feature.

Have a plan to modify boring and increment locations due to unanticipated underground utilities or other defined obstacles. These impediments to sample collection should be included in the site investigation report discussed in Subsection 3.9.

A review of existing information should also be carried out to assess soil types likely to be encountered in the subsurface, as well as the anticipated depth to groundwater. Direct push rigs are preferable for the collection of continuous cores and subsurface Multi Increment samples. Other methods might be required for very dense or rocky soils or for drilling through bedrock.

5.2 SITE PREPARATION

Physical clearance of DUs to permit and expedite the collection of surface samples and/or allow access to subsurface boring locations will be necessary for many if not most projects. Subsurface utility clearance will normally be required for subsurface soil investigations.

5.2.1 SURFACE CLEARING OF DEBRIS AND VEGETATION

It is important to visit a site prior to finalization of a site investigation work plan. This is necessary to refine and finalize the designation of DUs and also helps ensure that the need to remove debris or clear vegetation prior to sample collection is identified and addressed prior to field activities. Multi Increment sampling methods require access to dozens or even hundreds of systematic random locations within a site for the collection of samples (refer to Subsection 4.2.4). Attempting to clear vegetation, or move debris, large equipment, vehicles, and other obstacles after the field team has already been mobilized to the site can significantly increase sample collection time and pose hazards for field workers (Figure 5-1).



Figure 5-1. Large Equipment Interfering with Access to a DU Targeted for MI Sample Collection

The need to maneuver around debris and skip or alter increment collection locations can also compromise the representativeness of samples. Debris can also serve as a home for wasps, centipedes, fire ants and other stinging insects. Request the property owner to remove such material from the area well ahead of time. Check the site to make sure that this has been completed prior to mobilizing a field crew.

Thick grass and other vegetation can considerably slow down sample collection. Certain types of tall grasses can have thin sharp blades that require long-sleeve shirts for protection. Clearing of vegetation prior to sample collection can usually be done at a minimal cost in comparison to the overall investigation (Figure 5-2). Heavy equipment (e.g., bulldozer) can be used to clear DUs in heavily overgrown areas (Figure 5-3). Care must be taken not to significantly disturb or remove soil immediately beneath the surface vegetation root zone if the DQOs for the investigation target the area just below the surface root zone as part of the DU vertical layer. Where the site investigation DQOs includes sampling soil through the root zone, vegetation should be cut off just above the ground surface to allow access, rather than scraping the surface with a bulldozer.



Figure 5-2. Clearing of Thick Grass from a Targeted DU Prior to the Collection of MI Sample Increments



Figure 5-3. Bulldozer used to Cut Access Paths and Clear 59 Lot-size (5,000 ft2) DUs within a 500-Acre Field

(Photo from Bureau Veritas)

Clearing prior to field work can also help identify otherwise unnoticed dump areas or suspect areas of elevated contamination within a designated DU that should be investigated as separate DUs. If clearing a site is not possible before site inspection or site investigation, then carry tools to do so in the field as necessary. This might include gas-powered weed trimmers, swing blades, saws, clippers or similar tools. A breaker bar (o'o), essentially a long metal bar with a flattened and sharpened tip, can sometimes be used to punch holes through old asphalt for the collection of increments if a power tool is not available. Check with nearby hardware stores for daily tool and equipment rentals in order to minimize the amount of equipment that must be transported between islands. Note that vegetation can grow rapidly in many areas (especially the windward areas), with up to several feet of grass appearing in an area that was cleared only weeks before.

Characterization of DUs within very large heavily overgrown areas that cannot be cleared can be especially challenging. Strategically located paths corresponding to increment collection grid lines can be cut through large heavily overgrown DUs to provide access and stake out increment location points ahead of time (Figure 5-4). This can be time consuming but can also significantly improve the efficiency of field work and help ensure that representative samples are collected.



Figure 5-4. Path Matching Increment Grid Locations

Cut Through Thick Vegetation Covering a 50-acre DU; Increment Locations Pre-staked to Expedite Sample Collection

5.2.2 SUBSURFACE UTILITY CLEARANCE

5.2.2.1 *INFORMATION GATHERING*

An effort must be made prior to subsurface field work to gather information on underground utilities or features at the investigation site. This primarily involves activities below a depth of three feet, but could also pertain to shallow utilities in the vicinity of buildings. Intrusive activities can involve drilling to collect soil cores, collection of soil gas samples and installation of monitoring wells as well as excavating and trenching. The goal of the information gathering and potential underground geophysical survey is to accomplish either or both of the following tasks:

- Locate subsurface utilities or features that may be targets of the investigation, (e.g., potentially leaking underground storage tanks) in order to aid in identifying the proper location, arrangement, and depths of subsurface samples to best investigate the identified object.
- Identify other subsurface utilities or features that should be avoided by the intrusive activity in order to minimize the potential for damage to underground utilities and other functional structures (e.g. utility lines) and to minimize potential for associated physical injury.

Pertinent information sources should be contacted prior to any field effort in order to obtain as-built plans, historical photos, utility maps and other available information concerning subsurface utilities and/or subsurface features at a site. Such information sources can include but should not be limited to the following:

- Utilities (e.g., Board of Water Supply, Hawaiian Electric);
- Communication companies (e.g., cable/telephone companies);
- Landowners or property management companies;
- Facility or site managers;
- Department of Defense or other federal agencies owning or controlling facilities;
- Utility Notification Center – One Call Center.

For the most part, the listed information sources will provide information only on a single type of utility (e.g., buried power lines owned by Hawaiian Electric) but will not provide the same information for other utilities or subsurface features at an individual facility. Additionally, the utilities might not provide information on lateral connections to their main service corridors. Conversely, landowners or facility managers might have information on multiple utilities or features but only for a single facility within the property or only for the immediate area around individual buildings at the facility.

One Call Center Background

Hawai'i One Call Center, established in 2006, is similar to other centers operating throughout the nation requiring mandatory participation by both excavators (e.g., contractors) and operators (e.g., public utilities). The One Call Center system provides advanced warning to excavators of the location of underground lines before they begin digging. This mandatory "Call Before You Dig" program provides excavators with a single phone number to call for locating and marking underground lines, including lines for electric, gas, telecommunications, cable, water and sewer facilities. (www.DigSafelyHawaii.com)

Hawai'i One Call Center Telephone Number
(Toll Free) 1-866-423-7287
(online; http://www.callbeforeyoudig.org/hawaii/index.asp)

5.2.2.2 *ONE CALL CENTER NOTIFICATION*

Use of the Hawai‘i One Call Center service is required by Hawai‘i state law, under Hawai‘i Revised Statute (HRS) Chapter 269E, enacted in 2006 (HRS, 269E). The law includes two requirements related to subsurface utilities in the State of Hawai‘i:

- That the State of Hawai‘i establish a one call center …"that provides advance warning to excavators in this State of the location of subsurface installations in the area of an excavation for the purpose of protecting those installations from damage."
- That excavators within the state of Hawai‘i notify the one call center of the location of subsurface intrusive activity at a work site at least five working days before the activity.

The One Call Center in Hawai‘i (HOCC) is administered by the Hawai‘i Public Utilities Commission (PUC). Information on the HOCC, as well as answers to common questions, is contained in a handbook available from the PUC and One Call Center entitled "Dig Safely Hawai‘i" (PUC, 2008; www.DigSafelyHawaii.com).

The phone number for the Hawai‘i One Call Center is 1-866-423-7287. Information can also be submitted online (http://www.callbeforeyoudig.org/hawaii/index.asp) The service requires the following information by phone and in writing with respect to the site to be excavated or sampled:

- Site address;
- Maps and related information that identify the site location;
- The specific location(s) that subsurface work is to be conducted at the site, including marking proposed intrusive locations on the ground surface in the field with white paint;
- Contact information for the individual/agency responsible for or performing the subsurface work;
- The type of intrusive work being performed;
- The client or landowner for whom the work is being performed.

After receiving the information, the One Call Center will notify the publicly-owned utilities to mark the locations of their subsurface utilities or other features in and around the specific site work locations. The Utility Notification Center website states that: "…under normal circumstances it takes between 2 days to 5 days from the time you call (not counting weekends or holidays) to have the underground lines marked." No fees are charged for this service.

Note that the HOCC does not cover federal facilities or other utilities or facilities not listed as "Participating Facility Operators" in the HOCC handbook (PUC, 2008).The HOCC is also *not* required to identify inactive subsurface utilities, even though these could interfere with subsurface activities.

5.2.2.3 *FIELD EVALUATION OF POTENTIAL SUBSURFACE FEATURES*

It is advisable to conduct an independent field effort to identify subsurface utilities or features in addition to contacting the HOCC. This should include a site inspection by a person knowledgeable of indications of subsurface utilities. Inspections with persons familiar with the facility since its inception can be invaluable. The site-specific SAP and Health and Safety Plan should define the clearance procedures that are necessary to identify the presence of subsurface utilities or other features that could impact or be impacted by sampling activity.

Facility construction diagrams can be a useful initial indicator of active or inactive subsurface utilities (e.g., a suspected former fuel pipeline). Field indications of potential subsurface utilities should be compared to information obtained earlier from HOCC and other sources. Manholes indicate access points to subsurface utilities. Long, linear patches in pavement often represent trenches dug for installation or subsequent repair of subsurface water, fiber optic or electric lines, or other types of pipeline (e.g., stormwater). Rectangular patches a few hundred square feet or smaller in area might indicate the location of an existing or former underground storage tank (UST). A U-shaped vent pipe extending from the ground surface and attached to the side of a building might indicate the presence of a current or former UST.

These features may or may not be present on construction drawings, particularly if the diagrams are out-of-date and site surface features used for orientation on the diagram such as buildings or fence lines have been subsequently removed or altered. If the linear patch in the above example corresponds to a fuel pipeline on the diagram and leads directly to a fuel valve pit then

confidence in the construction diagram might be considered high. If the patch leads to a fire hydrant then the location of the fuel line, if indeed present, comes into question and further toning of the area may be required.

Locations of potential subsurface features should be marked on the ground surface by whatever means is appropriate for the surface cover at the sampling location. Multiple subsurface utilities or features can also connect or overlap at different depths, further complicating the investigation. The situation can sometimes create a complex subsurface environment as illustrated in Figure 5-5. Initial hand digging may be required at such locations if samples are to be collected. Hand digging, or other methods such as air or water jetting, may be required at some facilities. The latter can pose problems with the integrity of the samples collected and must be discussed in the investigation work plan.



Figure 5-5. Field Indicators of Underground Features

The photograph depicts field indicators for subsurface utilities or underground features as follows:

- Potential subsurface feature running left to right indicated by the cut in asphalt in the upper left center portion of the photo. This surface indication does not continue in the right center portion.
- Manhole and potentially associated cut suggest a storm drain parallel to the previous feature. In this case the field indicator was found to relate to a subsurface feature. Subsequent comparison to as-built plans showed the cut was unrelated to the storm drain and instead indicated yet another subsurface feature.
- Surface cut in the yellow curb, an associated break in asphalt cover associated with the curb cut, and an apparently connected asphalt patch in the upper right corner of the photo suggest yet another potential subsurface feature.

5.2.2.4 *SUBSURFACE SURVEY METHODS*

A wide variety of commonly available surface-based survey methods can be used to identify and evaluate potential subsurface features at a site. Common survey methods used in Hawai'i include the following:

- Resistivity/Electromagnetics;
- Magnetometer; and
- Ground-Penetrating Radar

Resistivity/Electromagnetics

Electromagnetics and resistivity (EM) are the general name for a variety of methods to measure for changes in subsurface electrical conductivity. The methods provide a means of measuring the electrical conductivity of subsurface soil, rock, and ground water. Electrical conductivity (the inverse of electrical resistivity) is a function of the type of soil, porosity, permeability, and the conductivity of fluids in the pore spaces. The EM method can be used to map natural subsurface conditions and conductive contaminant plumes. Additionally, trench boundaries, buried conductive wastes such as steel drums, metallic utility lines, and steel underground storage tanks, might be located using EM techniques (see Figure 5-6). Equipment and operators

for EM methods are readily available in Hawai‘i. Under ideal circumstances the methods are able to penetrate several hundred feet of soil or bedrock for mapping of large-scale, subsurface changes (e.g., soil or rock interfaces). The methods are more commonly regarded as good to excellent for detecting single objects (e.g., pipelines or 55-gallon drums) at depths of 6 to 8 feet below ground surface (bgs) (Nielsen, 2006). The disadvantage to the methods is that they are potentially affected by metal fences, piping, buildings and vehicles at the surface.



Figure 5-6. Subsurface Survey to Identify Underground Features

Example of survey to identify features prior to intrusive sampling. The photograph depicts use of an EM detector to identify subsurface utilities. Painted arrows on the asphalt surface mark the location of a utility line.

Magnetometer

Magnetometers measure the intensity of the earth's magnetic field. The magnetometer will respond only to ferrous materials, including differences between subsurface soil and rock types (Nielsen, 2006). The presence of boulders, drums, underground tanks or pipes in the subsurface can cause measurable changes in the field. Magnetometers are readily available and typically have a depth penetration of 25 to 50 feet, depending on the type of instrument and the size, type, and number of objects in the subsurface. The presence of multiple drums in a burial pit will, for example, create a larger signal than a single drum.

Ground-Penetrating Radar

Ground-Penetrating Radar (GPR) uses electromagnetic waves from the high frequency radar spectrum (100 to 1,000 megahertz [MHz] range, radiated downward into the ground from a transmitter and reflected back to an associated receiving antenna, to identify subsurface changes in layering, cementation, moisture, and density, including the presence of voids and fractures (Nielsen, 2006). The receiver and antenna are usually towed in tandem over the area to be surveyed. Reflections of the radar wave occur whenever there is a change in dielectric properties of the subsurface materials.

GPR has both advantages and disadvantages over other subsurface survey methods. Under ideal conditions GPR can produce a much higher resolution of subsurface features (down to inches) in comparison to other geophysical methods. A continuous plot of subsurface data over time and location can produce a relatively rapid and picture-like image of subsurface features. "Echoes" from dense material can, however, obscure imaging of deeper features. High soil moisture, particularly in saltwater or brackish environments, can also mask subsurface features.

A GPR investigation performs best in coarse or massive material that is dry (e.g., unconsolidated coralline sediments, sandy soils and unweathered basalt formations). Subsurface penetration of 15 to 30 feet bgs can often be obtained, an effective depth for most environmental investigations. The high electrical conductivity of expansive clays or saprolite derived from volcanic rock can limit the usefulness of GPR in some areas of Hawai‘i. Clays can cause the GPR signal to rapidly attenuate and limit

penetration to only a few feet. Consult an expert with experience in Hawai‘i prior to initiating full-scale use of this method. Experienced operators and GPR equipment can be expensive and difficult to obtain in Hawai‘i.

5.3 SURFACE SOIL SAMPLE COLLECTION

The collection of samples reflects the culmination of significant research and planning prior to initial field activities. It is important that the samples ultimately collected be as technically defensible and representative of site conditions as possible. As discussed in Subsection 4.2.5.2, the tool(s) selected for sample collection must ensure that soil increments are core-shaped or otherwise not biased with respect to depth and of relatively equal mass, and that mass of individual increments be adequate to collectively meet the target bulk mass for resulting Multi Increment samples.

The collection of Multi Increment samples from exposed surface soil should be relatively straight forward with proper planning and tools. The top two to six inches of soil bgs is generally considered for surface soil DUs, depending on the site-specific DQOs (USEPA, 2011d; CalEPA, 2013). On Hawai'i sites, the top 0-6 inches or 0-4 inches of soil are commonly selected for surface soil DUs. The same tool used for surface soils can often be used to collect deeper, near-surface soil samples (e.g. 6-12 inches bgs) if that is part of the site investigation objectives, or required to further delineate contamination that is documented at the surface. The collection of Multi Increment samples from DUs layers greater than one to three feet bgs typically requires the use of drills or other equipment (see Subsection 5.5). Although not typically carried out for surface soils, methods for the collection of Multi Increment samples to be tested for VOCs are described in Subsection 5.6.

Various types of sampling equipment are available for the collection of surface soil samples. Soil type, compaction, abundance of rocks, and increment depth typically drive selection of the most appropriate tool for a given site. For example, a simple sampling tube is generally most appropriate for relatively non-compacted, fine grained soils. Sampling tubes with core catchers or using a trowel might be most appropriate for very loose, sandy soil, although care must be taken with the latter to collect increments that are not biased with depth. An electric drill with a bit specially designed to remove cuttings can allow the rapid collection of increments and Multi Increment samples in fine-grained, semi-compact volcanic soils common in the Hawaiian islands. A sample tube with a slide hammer, a mattock, electric hammer, or in some cases even a backhoe may be required to collect samples in very compact or very gravelly soil.

The discussion below is presented in terms of tool options for various soil types and field conditions. These are presented as general guidelines only and based in part on the field experience of HEER Office staff; some tools might be applicable for multiple soil types and site conditions. As previously discussed, an inspection of the site to assess soil conditions by someone experienced in sample collection is imperative. Multiple types of tools should be carried to the field to address unanticipated field conditions and ensure that representative samples can be collected.

Wire flags, marked tape measures or rope, and rolling measures can be used to fully or partially mark the location of individual increments to aid in Multi Increment sample collection, based on the targeted increment spacing, and DU documentation (see Subsection 4.2.4). Ensure that all sampling devices are of sufficient quality to avoid contamination of the samples being collected with paint, chrome plating, grease or other material. Sampling equipment should be either: (1) easy to decontaminate, or (2) cost-effective enough to be disposable.

5.3.1 SOFT, FINE-TO COURSE-GRAINED SOILS

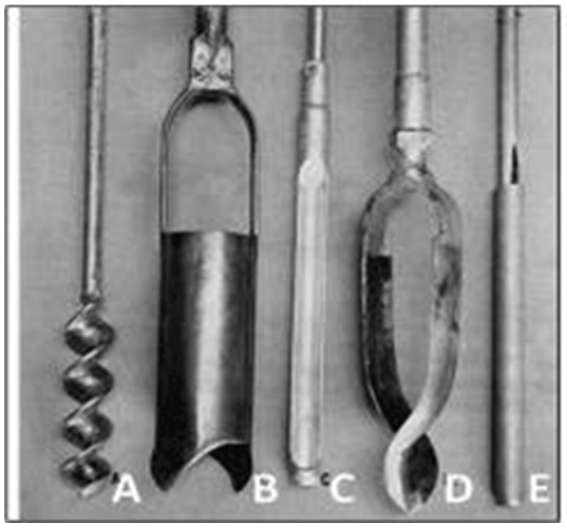


Figure 5-7. Various Soil Coring Sampling Tools
Source: (USDA-NRCS, 2007)

The most common hand tools used for the collection of surface soil samples are sampling tubes or coring devices ("C" and "E" in Figure 5-7) and screw-type drills ("A" in Figure 5-7). Stainless steel soil coring devices rather than augers are recommended for the collection of Multi Increment samples. Augers tools ("B" and "D" in Figure 5-7) can mix soils throughout the vertical depth penetrated, or penetrate a variable width column through the depth of interest, and therefore may be less reliable. If augers are used, methods used to avoid or address these types of problems should be clearly discussed in the site investigation report. Even using the screw –type drills ("A" in Figure 5-7) requires careful attention to extract the full length or core of soil from the targeted depth, as soil can be mixed through the vertical increment drilled. Coring devices made of other materials (e.g., plastic) might also be appropriate for certain contaminants or soil sampling situations.

Small-diameter (e.g., 0.75 to 1.5 inch) sampling tubes are generally preferable in soft or loose, clayey to sandy soils that are not rocky. The tubes are simple, efficient and effective and can help minimize compaction and disturbance of a site when increments from multiple near-surface layers are being collected. They are a good primary sampling tool for quick sampling events, for very large DUs where considerable walking is required, and for cases when only one person is collecting samples. They also serve as a useful backup or alternative to a drill (see below) because there is no need to wait for batteries to charge. Importantly, small-diameter tubes also allow for the collection of 30- to 50-gram increments from the upper 4 to 6 inches of soil, ideal for the collection of a Multi Increment sample.

Larger diameter tools (e.g. 2 inch and up) collect a proportionately larger amount of soil from a single location and may require extra subsampling of the final bulk MIS sample in the field or by the laboratory. Talk with the laboratory to know the maximum total mass of bulk MI sample they are willing to accept and process using their standard MIS processing protocols (typically in the range of 2.0 to 2.5 kg), and select a sample core diameter that will keep you at or under that total mass for the number of increments that will be collected. Note that larger mass bulk MI samples are generally more representative, so the choice of the sample core diameter is a balance between what is effective to utilize in the field, amount of contaminant heterogeneity expected, and cost for the laboratory to process.

Sampling tubes are utilized with extension rods and T-handle attachments (Figure 5-8).The tube is twisted into the ground to the desired depth, cutting into and retaining the soil in the hollow, open-face core barrel. The tube is then withdrawn to extract the increment from the ground. The increment is then removed and placed into a collection bucket for the DU sample. A flat-edged screwdriver or similar tool is useful for removing an increment of clayey or hard-packed soil.



Figure 5-8. Collection of Increments with a Sampling Tube

(Photos from Bureau Veritas)
Left photo: Use of an open-sided sampling tube to collect surface increments in soft soils.
Right photo: Use a flat-headed screwdriver to remove soil increment from tube.

A foot-assisted coring tool developed by the Army Corps of Engineers can also be useful for the collection of increments in soft but cohesive fine-grained soils (Figure 5-9; USACE, 2007). The core barrel is pushed into the soil and retracted. The increment is extruded into the container with a spring-operated plunger. These tools can allow the very rapid collection of Multi Increment samples in uncompacted soils without gravel.



Figure 5-9. Foot-operated Core Sampling Device Developed by the US Army Corps of Engineers

Sampling tubes and core barrels such as those shown above do not work well in very loose soils that lack sufficient cohesion and will not allow particles to be retained or removed by the tool. Use of core catchers, if available for the coring device in use, may be an effective alternative. Alternatively, scoops with flat bottoms or similar hand tools are generally utilized in these conditions (Figure 5-10). If scoops or trowels are utilized, it is important to remember that the goal is to remove similar-sized core-shaped increments in the DU (increments of uniform diameter through the vertical depth targeted), as well as limit increment mass to that needed to prepare a bulk, 1-2 kg Multi Increment sample. The flat lip of the scoops shown in the figure 5-10 can help to ensure that wedge-shaped increments are not collected (refer to Subsection 4.2.5.2).



Figure 5-10. Flat Bottom Scoops to Collect Soil Increments from Very Loose Soil.

5.3.2 MODERATELY COMPACT, FINE-TO COURSE-GRAINED SOILS



Figure 5-11. Use of Cordless Drill for Sample Collection

Cordless drill used with one-inch diameter, hollow auger bit to collect surface soil samples. Wear nitrile or latex gloves and change gloves between DUs (not shown in demonstration photos).

Upper left photo: Use of a 28V cordless rotary hammer drill to collect increments (e.g. Milwaukee or Grainger models) Use a paper plate with a pre-cut, one-inch hole

placed on top of increment location. The center of the plate must be held down to keep soil from piling up under the plate; keep any tears around the hole pressed together to minimize soil loss.
Upper right photo: Keep drill vertical and advance bit to target depth (marked on bit) as soil piles up on plate. Hold the drill firmly so gravel or hard soil that might cause drill to lurch doesn't strike the second person.
Bottom left photo: Empty soil into sample container (e.g. decontaminated plastic bucket).
Bottom right photo: Similar drill-bucket sample kit; bucket fits on metal foot plate with drill guide; soil increment extracted directly into the bucket (AMS Compacted Soil Sampler).

A cordless drill used in conjunction with a paper plate can be time and cost-effective for semi-compact to hard-packed soils without significant gravel, but can require two people unless a specially designed, foot plate is used (Figure 5-11). Use a heavy-duty cordless drill (such as a 28V) with a one-inch drill bit and a battery or portable generator. Weaker drills are prone to overheat or quickly drain batteries, especially in clayey or hard-packed soils. These drills can generally be used for up to 100 increments per battery and field chargers are available for vehicles. Drills powered by portable generators can often be rented from local tool rental or hardware stores.

Use a one-inch, hollow auger bit (e.g., Speedbore bit) to improve soil removal from the ground and control the collected soil mass (see Figure 5-11). These bits generally produce 30 to 50 grams of soil per six-inch depth.

Hollow center auger bits typically work better in the field than wide-flight bits (Figure 5-12). Hollow auger bits are designed to more efficiently remove cuttings from a boring without bringing up excess soil. The area where soil is removed from a boring is less easy to control with a wide-flight bit, and the bits can either bring up too much or too little soil with respect to the target increment mass.

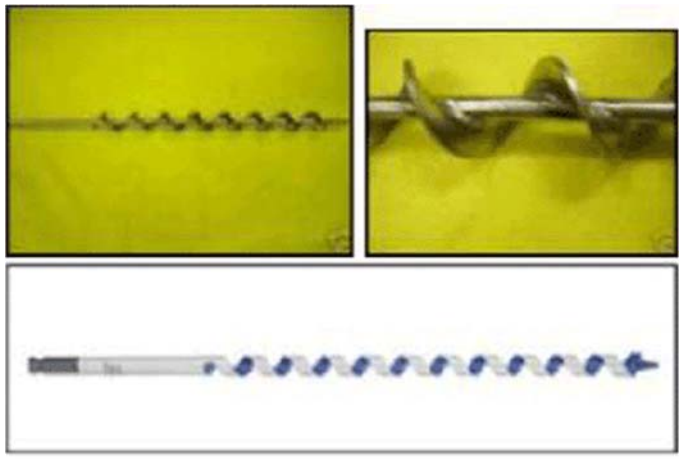


Figure 5-12. Comparison of Auger Bit Designs

Upper photos: One-inch diameter wide-flight auger; can work in loose soil but depth and volume of soil recovered can be difficult to control.
Lower photo: Recommended one-inch diameter hollow-center auger bits provide good recovery for fine-grained semi-compact soil (e.g. Speedbor Ship Auger Bit)

Heavy-duty paper plates work well in the field under dry conditions (see Figure 5-11). Pre-cut holes save field time; several plates might be required per DU if the plate tears excessively during increment collection. Wooden or metal plates might also be

useful. Care should be taken not to get fragments of the plate into the sample due to potential interference in laboratory analysis from glues or metals targeted as part of the site investigation.

The drill bit does not need to be decontaminated between increments within a single DU but must be decontaminated between replicate samples and between DUs. Recent sampling kits available from soil testing supply stores include a metal foot plate with a drill guide that attaches to the base of a sampling bucket, with increments directly deposited into the bucket (see Figure 5-11).

Heavier duty drills with portable generators are also an option (Figure 5-13). This setup avoids the need for recharging batteries and is able to drill through more compact soils. These drills should only be used by an experienced person, however. The sudden torque of the drill if a rock or compact object is encountered can cause severe injury to the wrists.



Figure 5-13. High-Powered Drill and Portable Generator

Left photo: Using a high-powered, Hilti drill with a portable generator (photo from Weston Solutions)
Right photo: Using a Hilti drill and paper plate to collect soil increments (photo from Weston Solutions)

A manual, hydraulic, or electric slide hammer can also be used to advance the coring device into shallow soil (Figure 5-14). Slide hammers are effective for collecting harder packed soils but require considerable effort and energy to use in the field. A weighted slide hammer is physically lifted and lowered along a guide rod to drive the attached tool string into the ground to collect shallow soil samples.



Figure 5-14. Use of a Slide Hammer to Collect Soil Increments

Top photo: A slide hammer assembly with rod and split spoon coring tool

Lower photos: Core barrel hammered into soil; removed core placed in increment collection bucket.

5.3.3 VERY COMPACT AND/OR GRAVELLY SOILS

For very hard or gravelly soils, a hammer-action electric drill with a masonry bit or spade bit can be very useful to loosen the soil (Figure 5-15). A hand trowel is then used to collect an increment from the location. The trowel should be used in a manner to allow collection of a core- or slab-shaped increment that collects an equal amount of soil from the entire targeted depth.



Figure 5-15. Use of an Electric Hammer and Spade Bit

Left photos: Electric hammer (14 lb) connected to 4,000 watt, gasoline-powered portable generator used to loosen dense, hard-packed soil.
Right Photo: Trowel used to collect increment from loosened soil.

Generators, drills and bits are usually available for rent from a local hardware store. Gradually push the soil to one side as the bit moves toward the targeted depth, opening up a small gap in the ground (Figure 5-16). Use a trowel to remove a core- or slab-shaped increment from side of opening, being careful to collect an equal amount of soil from all depths. Remove large rocks from the bulk Multi Increment sample as it is being collected. Ensure that an adequate amount of <2mm material is being collected per increment to prepare a bulk sample. Collect a similar mass of finer-grained soil from each increment location to the extent practical.

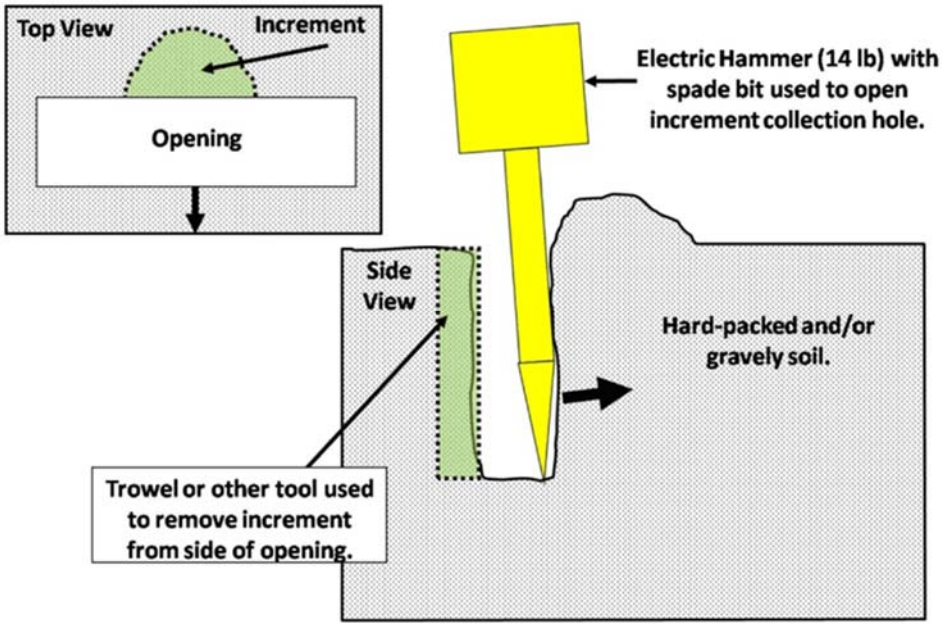


Figure 5-16. Collection of Increments Soil Loosened by a Spade Bit or Heavy Duty Hand Tool

Other options include the use of a mattock or heavy-duty rock hammer to loosen core-shaped volume of soil from the hard-packed ground (Figure 5-17). A trowel is then used to collect the increment. This avoids the need to carry and rely on an electric drill and generator but adds significantly to the time and effort required to collect samples.



Figure 5-17. Heavy Duty Hand Tools

Left Photo: Narrow spade (root digger), o'o (pry bar) and mattock for collection of increments from hard-packed soil
Right Photo: Breaker bar used to cut through old asphalt surface and collect soil increments

Heavier duty hand tools can also be useful to break through hard surfaces or cut through concrete or asphalt it order to access underlying soil. This can be very labor intensive, however, and can significantly slow down sample collection activities. Chisel or spade bits used with an electric hammer show above or a tunnel bit used with an electric drill (Figure 5-18) can be used to more rapidly remove plugs of asphalt or concrete.



Figure 5-18. Tunnel Bit Use to Cut Through Asphalt or Concrete and Access Soil

(Dewalt 2-3/4 inch x 22" bit shown)

Tunnel bits are not recommended for the collection of increments from hard-packed or gravelly soil, in spite of the ability to extract a core-shaped cutting. The mass of material collected inside a standard, 2 ¾ inch bit exceeds that needed for the collection of a 1-2 kg Multi Increment sample, requiring subsampling of the bulk Multi Increment sample in the field or laboratory to reduce mass for additional processing. Removing soil and large gravel from the bit can also be tedious and time consuming.

5.4 SUBSURFACE SOIL SAMPLE COLLECTION

Designation of Decision Units for the collection of subsurface Multi Increment samples is discussed in Subsection 3.4."Subsurface" soil is generally considered soil that is below one foot bgs or soil that is otherwise difficult to access with standard tools used for surface samples. A subsurface DU can be thought of as a surface DU that is covered with an additional layer of soil. The fact that the targeted DU layer is covered by additional soil does not negate the need to collect high quality samples (refer to Subsection 4.2). The same applies to characterization of sediment that is covered by a layer of water.

Shallow subsurface soil (e.g., <12-18 inches bgs) might be accessible using a sampling tube, slide hammer, or electric drills as described in Subsection 5.3 for surface soils. Hand tools such as shovels could also be used to access deeper soil. The collection of increments and samples below this depth or from hard-packed soils will generally require the use of a push rig able to collect continuous cores. A backhoe or similar equipment can also be used for trenching or pot holing in order to gain access to deeper soil.

Overviews of push rigs and other drilling equipment are provided in ASTM Standard D 6169 (ASTM, 2005b) and ASTM Standard D 6286 (ASTM, 2006c). Direct push technologies can be used to collect samples to depths of up to 30 feet bgs or more, depending on the compaction of the soil and the presence of rocks. Auger drilling can reach depths of 100 feet bgs or more. Rotary drilling can reach depths of 1,000 feet bgs or more.

Each of these technologies is discussed in more detail below. Although included in the discussions below, auger and rotary drilling is more amenable to geotechnical investigations or the installation of monitoring wells than the collection of soil samples. This is due to the difficulty in collecting continuous cores as well as the expense, effort, and space required to operate the equipment. Drill cuttings and cores from such equipment might, however, be useful for initial screening of subsurface conditions and the need for a more intensive investigation (e.g., presence of absence of staining, potential COPCs, boundary between contaminated fill and native soil boundary, etc.; (see Subsection 3.4.4).

Tables 5-1 and 5-2 discuss the various drilling methods and performances.

5.4.1 DIRECT PUSH TECHNOLOGIES

Direct push technologies are a category of equipment that push or drive small-diameter hollow steel rods into the subsurface without rotating the drill rods. Direct push drilling can yield high-quality continuous cores of soil from targeted depth intervals quickly and cost effectively in the right type of soil conditions and is ideal for MI sampling strategies. Push rigs can also be used to collect soil gas or groundwater samples. Soil gas sampling is discussed in Section 7. The use of push rigs to install small-diameter monitoring wells for groundwater collection is discussed in Section 6.2. Smaller track-mounted rigs could be used for sampling areas with limited space. These rigs also normally remotely controlled and can be programmed to collect increments from a pre-established grid.



Figure 5-19. Direct Push Drill Rigs

Upper Left Photo: Truck-mounted push rig; solid drive cap and rod just prior to breaking into the subsurface. The hydraulic hammer, just above the drilling rod, moves up and down by a hydraulic piston, which can use the rig's weight to drive the drilling rods into the ground. Stabilizing legs are used for balance as needed.
Upper Right Photo: Smaller, track-mounted rig used to access tighter areas and/or extract cores from pre-programmed grid coordinates.
Lower Left and Right: Small push rig used to collect surface soil samples.

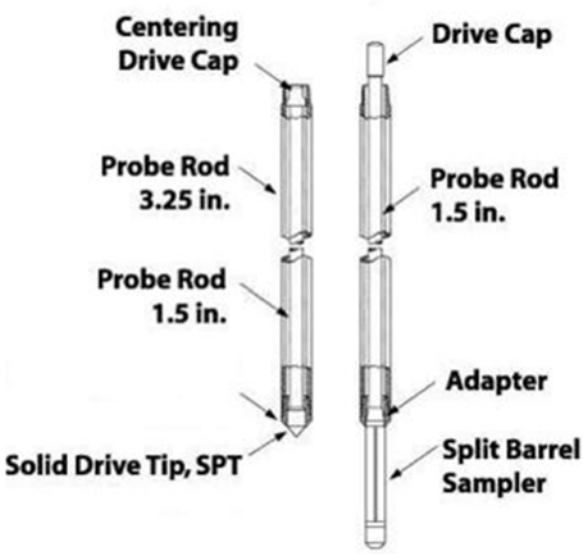


Figure 5-20. Drilling Rods for a Direct Push Drill Rig

Rod on left used to achieve specific sampling depth; solid drive cap penetrates into subsurface. Rod on right is the split barrel sampler. Multiple samplers may be used to delineate the entire soil column.

A hydraulic hammer is used to progressively drive the steel rods into the soil, with the weight of the drill rig used to provide a constant force on the drill string (Figures 5-19 and 5-20). Casing is advanced with a solid point held in place by an internal rod. A 1.5 to 2.25-inch diameter inner rod and core barrel are typically combined with a 3.25- to 4.5-inch diameter outer casing. As each section of the rod is advanced into the subsurface, another section of casing and rod can be attached to achieve greater depths. Two- to five-foot drive rods and samplers are typically used, depending on the depth and thickness of the targeted DU layers. Multiple drives might be required to extract the full length of core needed.

The steel rods and driving tip are pulled from the subsurface when the top of the desired soil interval (i.e., top of DU layer) is reached, with the outer casing left in place. The solid point is removed from the end of the inner rod and a split-spoon or open-barrel sampler is attached.

A split-spoon sampler is a stainless steel, machined, hollow cylinder that can be opened lengthwise into two halves (Figure 5-21). Split spoons can be used with hand-operated slide hammers, push rigs or larger drilling rigs. The cylinder is fitted with threaded ends. A cutting shoe is connected to the downhole end and a driving cap is connected to the uphole end. Split-spoon samplers can be lined with a clear Teflon or polyethylene lining to help keep cores intact after the sampler is opened. Six-inch stainless steel or brass tubes are also sometimes used, although they are less amenable for the collection of Multi Increment samples.



Figure 5-21. Split Spoon Sampler

Left Photo: Assembly shown with cutting shoe to left and end cap to the right and threaded to extension rod.
Right Photo: Split spoon sampler opened; note stainless steel liner above split spoon

After the coring device is attached, the drill string is placed back into the casing and driven to the desired depth. A hydraulic hammer can be used in conjunction with the push rig for compact soils. The drive rod can be marked to help monitor depth (e.g., every six inches). A drop hammer can be used to measure blow counts as part of a Standard Penetration Test if required as part of the investigation (ASTM, 2011b). For example, a 140 lb hammer is dropped 30 inches and blows counted to advance each of three consecutive, 6-inch increments for a total of 18 inches. The resulting data are used to help evaluate structural properties of the soil, including consistency, in-situ strength, and susceptibility to liquefaction.



Figure 5-22. Continuous Cores Collected using a Push Rig

Left Photo: Push rig cores with top of acetate liner removed to access soil
Right Photo: Oil-stained interval in left core targeted for screening and testing. Entire section submitted to laboratory for processing and subsampling as a single sample.

The drill string is retracted and brought back the surface after the base of the targeted interval has been reached. A continuous and relatively undisturbed core is ideally collected within the device. The sample barrel is opened and the core exposed (Figure 5-22). The top of the plastic liner, if used, is cut away to allow access to the soil.

5.4.2 BOREHOLE CORE INCREMENT SUBSAMPLE

Each core section represents a single increment for a targeted DU layer in the same manner that a smaller core of soil collected from a surface DU with a sampling tube represents a single increment for that DU. Initial single borings might be collected to help target subsurface DU layers for more detailed testing and identify contaminants of potential concern (see Figure 5-22). If so, then the entire, suspect interval of the core should be submitted to the laboratory for processing as a single sample. The collecting of discrete soil samples from specific depths within a core rather than targeting specific depth intervals for MI sampling is not recommended (see Subsection 4.2.8.2 and Section 4.3).

Targeted DU layers are identified and marked in the core (Figure 5-23). The mass of an individual core increment collected with a push rig is typically too large for use in preparation of a bulk Multi Increment sample, and field subsampling of the core increments is required. Each increment for an individual DU layer is subsampled, with the extracted soil placed in a container

specific to that layer. This can be accomplished by cutting a narrow wedge of soil from the entire length of the increment interval or by removing regularly spaced plugs of consistent mass from the increment (e.g., 5-10 grams; see Figure 5-24).



Figure 5-23. Identifying Targeted DU Layers in Cores

Left Photo: DU core increment placed on table for inspection and subsampling.
Right Photo: Targeted DU layer increments identified within core for subsampling and preparation of bulk Multi Increment samples.



Figure 5-24. Subsampling of Core Increments for Preparation of a Bulk Multi Increment Sample

Left photo: Removal of a continuous wedge of fine-grained soil from a core increment
Right Photo: Removal of regularly spaced, five-gram plugs of soil from a core increment using a TerraCore sampler

Under ideal circumstances the wedge method is preferred, since the resulting subsample provides 100% vertical coverage of the core increment. Removal of a continuous wedge from a core may not be possible if rocks are present or loss of volatiles may be an issue, however, and subsampling of core increments using the plug approach is most common.

Increment subsamples are combined in the field to prepare a single, bulk Multi Increment sample for the DU layer in the same manner as carried out for surface soil bulk Multi Increment sample. Note the individual soil plugs are *subsamples* of a single core increment and do not represent individual increments themselves. Individual subsample plugs cannot be counted towards the total number of increments collected from a subsurface DU layer since they were not collected from independent, random locations. The minimum recommended number of increments for testing of a DU (e.g., 30 to 75; see Subsection 4.2.2) *does not* apply to subsampling of core increments using subsample plugs.

The mass of soil included in a single core wedge or as the sum of plugs removed from a single core increment is dependent on target mass of soil designated for the final bulk DU layer. For example, if a 1.5 kg bulk sample is desired and 30 core increments are to be collected to represent a DU layer, then the mass for each core increment subsample should total approximately 30-50 grams. Careful consideration of the soil subsample mass collected from each core increment prior to subsampling is critical in order to ensure that mass of the resulting bulk sample will be adequate to meet target requirements (e.g., 1-2 kg) but not so large that additional subsampling in the field or laboratory will be required.

If a core wedge cannot be collected, then the target subsample mass should be collected from what is anticipated to be a representative number of points within the core increment layer. For example, if the collection of an approximately 1 kg bulk Multi Increment sample from a one-foot thick DU layer is targeted, and thirty increment cores are to be collected in the DU, then six, five-gram plugs at a spacing of two inches could be extracted from each of the 30 one-foot thick core increments for a total bulk MI sample mass of approximately 900 grams for the DU layer. The mass of soil removed from each individual core increment should be kept constant, assuming a constant DU layer thickness. Maintain consistent wedge width or plug spacing for subsampling of core increments collected from DU layers with varying thicknesses between borings (see HDOH, 2011i).

The collection of replicate Multi Increment samples to evaluate the precision of both increment subsampling and the overall sampling approach is recommended (see Subsection 4.2.8.2). Replicate sets of increment subsamples (e.g., triplicates) should be collected from one or more of the targeted DU layers and combined into independent bulk Multi Increment samples for testing. If the resulting data are reasonably consistent (e.g., RSD <35%) then the precision of the subsampling methods used can be considered to be good (see Subsection 4.2.7). Independent sets of borings are used to collect replicate samples in select DUs in order to test the precision of the overall approach, in the same manner as done for surface samples.

5.4.3 PIT OR TRENCH SAMPLE COLLECTION

The use of pits or trenches to collect Multi Increment samples might be required in situations where considerable debris, rubble, or rock create obstructions in the subsurface. Pits and trenches can also provide useful information on the nature of subsurface soils within a DU.

Pits have also been used to collect increments from multiple DU layers at sites where heavy equipment is already readily available, or a push rig would have to be brought over from another island (Figure 5-25 and 5-26). Increments are collected from pit sidewalls in the same manner as done for a continuous core (i.e. in a core-like shape). It is again important to ensure that an appropriate mass of soil is included in each increment in order to meet the targeted bulk sample mass.



Figure 5-25. Use of Shallow Pits to Collect Increments from Multiple Layers within a DU

Left Photo: Backhoe used to dig increment collection pits with large DUs at a former golf course
Right Photo: Vertical soil horizons and DU layers targeted for collection of increments and assessment of arsenic concentrations with depth (e.g., 0-6", 6-12" and 12-24"). An increment is collected across the entire targeted DU layer depth, and all increments from that same depth in multiple pits/trenches (e.g. 30-75+) are combined to prepare a bulk Multi Increment sample for that layer



Figure 5-26. Example Use of Trenches for Site Investigation

Increments collected from trench sidewalls at successive depths through DU layers in order to prepare bulk Multi Increment samples, being careful not to include collapsed sidewall material from upper DU layers.

Trenches can be strategically placed within a DU to investigate the presence of buried debris and evaluate the soil stratigraphy as well as collect Multi Increment samples. When collecting increments at multiple or at successive depths in excavations, care needs to be taken not to collect material collapsed from the sidewalls of upper soil layers.



Figure 5-27. Use of Shallow Trenches to Collect Multi Increment Samples from Exposed DU Layers

DU boundaries noted in blue. Surface Multi Increment sample (e.g., 0-6") collected prior to excavation of trenches. Increments for subsurface DU layers collected across the full vertical thickness of the exposed targeted horizon in order to prepare a bulk Multi Increment sample (layers depicted).

In Figure 5-27, a trench approximately three feet wide is excavated to a depth of three feet in order to access the sides of targeted DU layers for sample collection. An initial Multi Increment sample was collected from the surface DU layer (0 to 6

inches) using standard, soil sample collection methods. The trench was then excavated to the target depth. A Multi Increment sample was subsequently collected from exposed face of each of two targeted DU layers, situated from 6-18 inches and 18-36 inches below the ground surface. Increments were collected across the entire, vertical extent of the DU layer. With the possible exception of very narrow DUs, multiple trenches like that depicted in Figure 5-27 are typically needed to collect all increments in a systematic random fashion across DUs.

Field replicates can be collected within the same trench in order to assess the precision of the data with respect to the exposed portion of the DU layer. Independent sets of trenches within select DUs could be used to collect replicate samples in the same manner as done for surface samples and further assess the precision of the data.

Safety precautions are imperative to protect workers collecting samples during trenching. Note that the Hawai'i Occupational Safety and Health Division (HIOSH) requires that any excavation that is over 4 feet in depth be shored or properly sloped when personnel will be working within the excavation (USDL, 2002). Use of the backhoe bucket to collect increments from sidewalls might be required for deep or otherwise unstable excavations.

5.4.4 HOLLOW STEM AUGER DRILLING



Figure 5-28. Hollow-Stem Auger Drill Rig

Left Photo: Large rig for deep boreholes; requires a high overhead clearance for the mast. The auger flights (right in photo, on ground) are rotated and pressure is applied from the drill rig to advance the drill string downwards.
Right Photo: Smaller, track-mounted auger rig used for shallower borings or drilling in limited clearance areas.

Hollow-stem augers were already in use for drilling and coring in unconsolidated soils for geotechnical work at the advent of environmental investigations in the 1980s. The use of auger rigs to collect soil samples has largely been replaced by more compact and efficient push rigs described above, although they are still frequently used for the installation of larger-diameter monitoring wells.



Figure 5-29. Auger Drill Bit and Drill String

Left Photo: Bit attached to bottom of auger to move soil to the side as the rotating auger advances.
Right Photo: The auger flights bring soil cuttings from the

drill bit upwards to the surface. The asphalt was cut prior to drilling. Flights are added as needed as the auger advances. Plastic sheeting on the ground keeps potentially contaminated soil and water brought up by the auger from mixing with surface soils or impacting the pavement.

Auger drilling usually requires a larger drill rig than is used with direct push drilling. The entire rig can stand 20 to 40 feet and require high overhead clearance (Figure 5-28). The use of auger rigs is described in ASTM Standard D 5784 (ASTM, 2006; see also USACE, 1996; Nielsen, 2006). The rigs are capable of reaching depths of 100 feet in unconsolidated to semi-consolidated soil and even coral, but cannot normally penetrate volcanic basalt or tuff formations.

Augers used for environmental investigations typically have an outside diameter of 6 to 10 inches (Figure 5-29). As the name implies, the auger itself is hollow with a helix wound around the outside. In this manner the auger serves both as a cutting tool to advance downwards and as casing for the collection of soil samples or the installation of wells. The tip of the bottom most auger string is designed to push soil cuttings to the outside of the flights where the helix can bring the cuttings to the surface.

As pressure is applied from the weight of the rig, the flights are rotated and the soil cuttings are brought to the surface by the flights. As the flight is drilled into the subsurface new flights can be added to achieve greater depths. Each flight must be removed individually to remove the auger drill string from the boring.

Similar to a push rig, the auger flights can be left in place while a split spoon or an open barrel sampler is used to collect a soil sample or a monitoring well is installed. The sampler is attached to the end of a heavy rod and driven to the targeted depth using a percussion hammer or hydraulic hammer. The coring device is then retracted and the sample removed.

Hollow stem auger can also be used to install monitoring wells (refer to Subsection 6.2). The monitoring well casing is installed within the auger once the desired depth interval is reached. Clean sand is placed around the monitoring well casing as the auger flights are slowly retracted.

5.4.5 ROTARY DRILLING

A detailed discussion of air or mud rotary drilling is beyond the scope of this technical guidance. Rotary drilling is generally used for geotechnical studies or the installation of wells through bedrock rather than for collection of soil samples (Nielsen, 2006; US Navy, 2007). These rigs are less amenable for the collection of subsurface soil samples to be tested for contaminants. Aside from the expense and space required to operate the rigs, complete recovery of cores during drilling is difficult when drilling in unconsolidated and semi-consolidated lithologies, such as clays, silts, and sands. The rigs are most useful for the collection of continuous rock cores for geologic or geotechnical studies. Standard rock coring methods are summarized in ASTM guide D 2113 (ASTM, 2008). Standard rotary drilling methods are summarized in ASTM guide D 5782 (ASTM, 2006b).

Rigs are typically designed for the use of multiple drilling methods, including both auger and air or mud rotary (Figure 5-30). In the simplest type of rotary drilling a drill rod with an attached bit is continuously rotated against the bottom of a borehole in order to pulverize and break up encountered material. The pulverized fragments are carried up to the surface by air or specially formulated mud pumped into the borehole and pushed back to the surface under pressure. The mud also serves to lubricate and cool the bit during drilling. Rotary drills can also be designed to collect continuous cores of material.



Figure 5-30. Large Truck-Mounted Drilling Rig

Left Photo: Truck-mounted rig capable of both auger and rotary drilling.
Right Photo: Mud-rotary drilling operation.

Drilling fluids, including air, are selected based on the anticipated nature of subsurface conditions, including soil or rock type, depth, temperature, and pressure. The HEER Office does not typically allow the use of any fluid other than air for drilling carried out as part of an environmental investigation. Drilling mud can compromise the representativeness of samples collected as well as introduce contaminants into the targeted formations. Use of a foam suppressant composed of a surfactant and polymer mud might be required, however, in rare cases where there is a need to core into a zone where potentially flammable product is present.

Figure 5-31 shows a compressed air drilling setup. Caution should be taken with air rotary rigs to prevent particles (or exhaust) from entering the borehole during drilling, particularly if samples are to be collected for contaminant analysis. On occasion, potable or distilled water may need to be added, but only in the situation that cuttings cannot be brought to the surface by air alone. Drilling under these circumstances should be discussed with the HEER Office before implementation.





Figure 5-31. Pressurized Air Discharge from an Air Rotary Assembly

Left Photo: Compressed air is pumped down through the drill bit and drives cuttings up through the outside of the core barrel. Cuttings and compressed air are directed to a cyclone mechanism (on right) that dissipates air pressure and velocity and allows for cutting collection in a drum below cyclone.
Right Photo: Rotary cutting bit.

Rotary core barrels typically range from 1 to 10 inches in diameter. A single tube core barrel is rarely used due to poor sample recovery and sample disturbance. A double tube core barrel is most frequently used in rock core sampling for geotechnical engineering applications. A triple tube core barrel is used in zones of highly variable hardness and consistency. In this design a separate, non-rotating liner is added to the double tube core barrel in order to improve sample recovery and minimize sample handling and disturbance (refer to US Navy, 2007).

A variety of coring bits, core retainers, and liners are used in various combinations to maximize the recovery and penetration rate of the selected core barrel. Example cores and coring bits are illustrated in Figure 5-32. Bits are fitted with diamond or carbide teeth to facilitate cutting. The outer barrel rotates to allow the bit to penetrate the formation. As the outer barrel is advanced, the sample rises and is retained in an inner liner, which in most drill string assemblies does not rotate with the outer barrel. The bit cuts an annular groove in the formation to allow passage of the drilling mud or air. Cuttings are forced up the outside of the core barrel. A split-spoon barrel is typically used to collect five-foot cores.





Figure 5-32. Example Recovered Cores and Rotary Drill Coring Bits

Left Photo: Rock Cores Collected Using Air Rotary Drilling.
Right Photo: Rotary Drill Coring Bits.

Table 5-1. Overall Performance Estimation for Various Types of Drilling/Excavation Methods

	Direct Push	Hollow-Stem Auger	Rotary Drilling	Trenching
Relative Site Impact	Low- Moderate	Moderate	High	Low-Moderate
Relative Cost	Low- Moderate	Moderate	High	Low-Moderate
IDW Generated	None to Minimal	Moderate to High Volume	High Volume	Moderate to High Volume
Depth Potential	Shallow (to approximately 30 feet)	Moderate (to approximately 100 feet)	Deep (to 1,000 feet)	Shallow (to approximately 20 feet)
Soil Condition Limitations*	Un consolidated	Semi-Consolidated Unconsolidated	Consolidated	Semi-Consolidated Unconsolidated
Monitoring Well Installation Size	Small (1 inch well casing)	Medium (2 to 6 inch well casing)	Large (2 to 24 inch well casing)	None
Types of Sampling	Soil Gas, Soil, and Groundwater	Soil and Groundwater	Soil and Groundwater	Soil and Groundwater

Vehicle Requirements	Truck mounted	Specific Heavy Rig required	Specific Heavy Rig required	Excavator or pick/shovel
Other Issues	Vehicle access	Vehicle access, overhead clearance	Vehicle access, overhead clearance	Open area required, access for excavator

Notes:*
Also See Table 5-2: Relative Performance of Commonly Utilized Drilling/Excavation Methods Versus Commonly Encountered Substrate

Table 5-2. Relative Performance of Commonly Utilized Drilling/Excavation Methods Versus Commonly Encountered Substrate

Subsurface Formation/ Material	Direct Push	Auger-Hollow Stem	Trenching	Air Rotary
Sand	E	G	G	NR
Loose sand and gravel	E	G	G	NR
Loose boulders in alluvium	NR	P	G	NR
Clay, silt	G	E	E	NR
Coralline Limestone with and without fractures	NR	NR	NR	E
Tuff	NR	P to G	NR	E
Basalts-thick layers	NR	NR	NR	G
Basalts-highly fractured	NR	NR	NR	P

Notes:
E = Excellent
G = Good
P = Poor
NR = Not Recommended
Adapted from (US Navy, 2007)

5.5 COLLECTION OF SAMPLES FROM STOCKPILES

The designation of DUs for stockpiles is discussed in Subsection 3.4.6. Sampling strategies and methods specific to stockpiles are discussed in the HEER Office document *Guidance for the Evaluation of Imported and Exported Fill Material* (See Appendix 3-A; HDOH, 2017d). A summary is provided below.

It is important to allow equal access to all soil with a stockpile DU for the collection of increments. Increments collected from only the exposed surface of a stockpile, for example, might not be representative of deeper soil. When space is available, the stockpile should be flattened to a thickness of three feet or less to allow equal access to all soil in the pile. Increments are then collected from the top, middle, and bottom of the pile in a systematic random fashion (Figure 5-33).

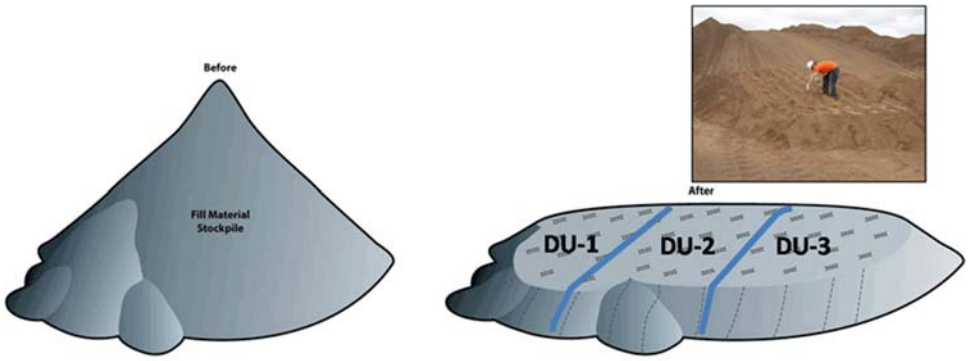


Figure 5-33. Collection of Increments and Multi Increment Samples from a Flattened Stockpile

Increments are collected alternately from top, middle, and bottom of flattened DU in order to collect a representative bulk Multi Increment sample.

Another option is to collect increments as the stockpile is being formed (Figure 5-34). For example, increments could be collected from front-end loader buckets at appropriate intervals of soil volumes as the soil is being excavated or moved. Increments could also be collected as piles are formed at the end of a conveyor belt, or when stockpiles are being moved from one location to another. This allows equal access to each portion of the pile as it is constructed, avoids the need to reconstruct a stockpile, and saves space required to flatten a stockpile for sampling. The collection of soil samples during these activities can interfere with the operation of heavy equipment, however, and requires close coordination with the other parties.



Figure 5-34. Examples of Opportunities to Collect Increments and Bulk Multi Increment Samples during Stockpile Formation or Movement

A third option is to progressively characterize small volumes of soil in an unflattened stockpile as needed (Figure 5-35). Increments could be collected from the surface and shallow depths within the exposed face of the stockpile. Soil represented by the resulting, bulk Multi Increment sample can be cleared for reuse or disposed as appropriate. Replicates could be collected as described, but from alternate systematic random locations from the surface and shallow depths within the exposed face of the stockpile to assess the precision of the sample collection method.

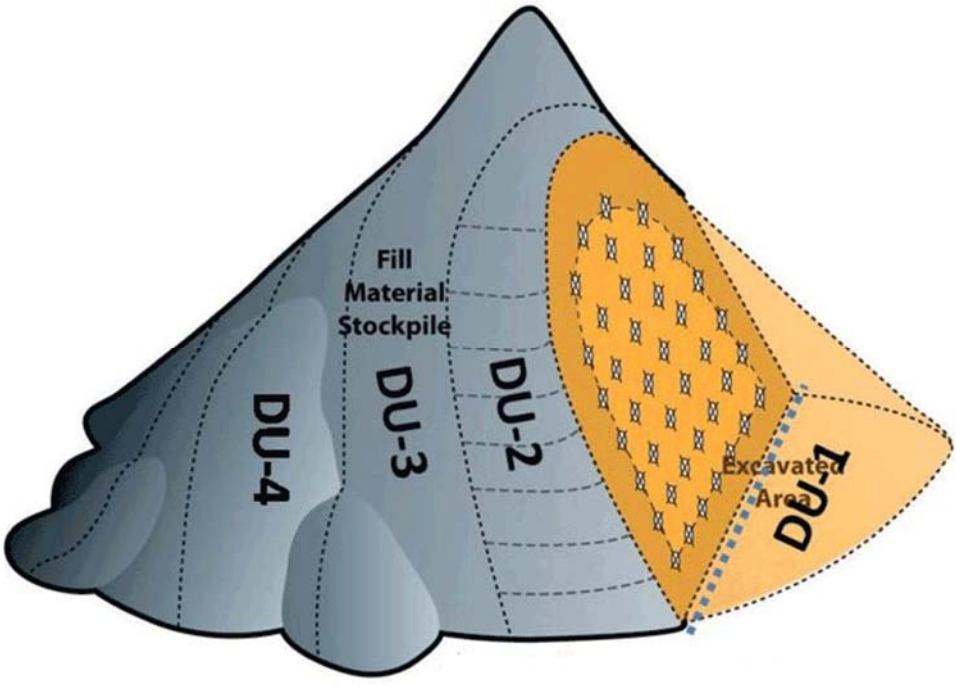


Figure 5-35. Progressive Testing of DUs from an Unflattened Stockpile

Increments collected from the surface and shallow depths within the exposed face to prepare the bulk Multi Increment sample.

5.6 COLLECTION OF MULTI INCREMENT SAMPLES FOR VOC ANALYSIS

Testing of Multi Increment samples for volatile organic compounds (VOCs) is discussed in Subsection 4.2.8. Samples to be tested for VOCs are typically collected from cores that represent increments extracted from subsurface DU layers rather than exposed surface soils (see Subsection 3.4.4). Testing of samples from freshly exposed faces of excavations for VOCs might be required as part of a response to a recent spill or for remedial actions, however (see Subsection 3.4.5).

The collection of soil samples to be tested for VOCs is similar to that described for non-volatile contaminants, except that increments (or more likely subsamples of DU layer increments collected from cores) are placed in an extraction solution in the field. The collection of samples to be tested under this method should be discussed with the laboratory well in advance of field work. A sampling and analysis work plan should also be provided to HDOH for review prior to the commencement of field activities. The analytical laboratory should be consulted prior to sample collection to discuss sample containers, sample handling, preservative type and volume, shipping of samples in methanol, anticipated laboratory method detection limits, etc.

Method 5035 allows for samples to be extracted in the field by placement in a selection of solutions, based on desired detection limits, sample preservation method, and holding time limitations (USEPA, 2002h; refer also to MADEP, 2002, TRNCC, 2002 and CalEPA, 2004b). The guidance recommends that soil samples, or in the case of Multi Increment sampling methods soil increments, to be tested for VOCs should be placed in containers with pre-measured amounts of either methanol (most common) or reagent-grade (e.g., distilled) water. However, the use of reagent-grade water for preservation is not recommended by the HEER Office due to concerns regarding extraction efficiency and very short hold times (See Subsection 11.2). The volume of the solution (typically provided by the laboratory in pre-weighed amber bottles) is based on the anticipated mass of soil sample to be collected. Although individual increments are not typically weighed in the field, coring devices with calibrated sample collection volumes are generally utilized so reasonable estimates of total mass can be made. The total mass of soil placed in the solution should closely match what was planned for a particular DU/site investigation to help ensure the amount of methanol provided by the laboratory is adequate to keep the soil covered by methanol at all times.

Methanol is the most commonly used solution for field preservation of soil samples. This allows for a holding time of 14 days prior to analysis by the laboratory. The samples should ideally reach the laboratory within 48 hours in order to verify that methanol is not being lost from the sample container. Potential problems with the use of methanol include an increase in method detection levels due to the need to dilute the solution for analysis, as well as logistical issues related to obtaining, storing and shipping the flammable solution around the islands.

The use of water as an extraction solution is not recommended (See Subsection 11.2. This approach was included in the original, USEPA 5035 lab method in order to allow for lower detection limits of VOCs in soil in comparison to samples extracted into methanol (USEPA, 2002h). Improvements in laboratory methods since that time should provide methanol based reporting limits of 50 µg/kg for volatile chemicals, which is more than adequate for screening purposes. The water-based extraction is also significantly less effective in comparison to methanol according to laboratories contacted by the HEER Office. While the precision of the data in terms of the analytical method might be higher than for methanol, there is a strong possibility that the concentration of the VOC reported will under-represent the actual concentration in the sample collected. In addition, VOCs will be less tightly held in water than in methanol and can be lost when the sample bottle is opened repeatedly to add increments. A further disadvantage is that samples must either be tested within 48 hours or frozen to -7ºC by that time and then tested within seven days from the sample collection date. This limited holding time can pose additional problems for samples that must be shipped to the mainland for analysis.

The use of an acidic, sodium bisulfate solution as an alternative to water provides both an extended holding time (up to 14 days) and allows for similarly low detection levels. Reaction with organic matter, effervescence and loss of VOCs in calcareous soils, and other potential problems interfere with the use of this approach in the field, however. Both of these issues can be significant problems in Hawai'i and the use of sodium bisulfate is generally limited (See Subsection 11.2; and Alternative Approaches, Subsection 5.6.3).

5.6.1 INCREMENT COLLECTION

A volume of methanol adequate to accommodate the estimated mass of increments to be collected for a Multi Increment sample is placed in the sample bottle prior to collection of the sample (Figure 5-36). A minimum 1:1 ratio of solution to soil is recommended (i.e., 1 milliliter of methanol to 1 gram of soil). The laboratory will typically provide sample jars with pre-measured

amounts of the solution based on direction from the sampler regarding the approximate mass of soil to be added. Additional methanol may be required to ensure the sample mass is completely submerged. This should be discussed with the laboratory that will receive and analyze the samples.

To select the appropriately sized sample container, consideration should be given to the total volume of soil to be collected and preservative required. A minimum 300 g mass of soil should be collected to prepare a bulk Multi Increment sample (refer to Subsection 4.2.3). For example, 60 increments of 5 g each for a total of 300 g of soil (minimal mass recommended for Multi Increment samples) would require approximately 300 ml of preservative. Utilize a container that is large enough to accommodate additional preservative (if needed) and to prevent loss of preservative through splashing as soil increments are dropped into the container. This can normally be accomplished using one-liter, amber glass bottles pre-filled at the laboratory with 300 ml of methanol.

It is very important to remember that soil samples (increments) collected for VOC analysis need to be placed in methanol as soon as possible (i.e. within a minute or two) to prevent potential loss of volatiles due to volatilization and/or biodegradation. Good planning of the field sampling effort is essential to help ensure VOC samples are collected appropriately.



Figure 5-36. Subsampling DU Layer Increments from Borehole Cores with Methanol Preservation

Upper Left Photo: DU layers identified in core (depicted by arrows).
Upper Right Photo: Core increment subsampled by collection of 5 gram plugs at regular spacing to collect targeted increment subsample mass (inexpensive TerraCore™ sampler shown). Subsample plugs placed in jar with pre-measured volume of methanol intended to provide a 1:1 ratio of methanol to soil.
Lower Left photo: Total weight of subsample plugs collected from increment monitored to ensure consistency between boreholes, and that the target bulk Multi Increment sample mass is met.
Lower Right Photo: Use of sealable, 5-10g coring devices for collection and storage of individual increment subsamples when field use of methanol is not practical (Core N' One™ device shown). Increment subsamples (or actual increments) immediately frozen and shipped to laboratory for subsequent combination, extraction into methanol and testing.

5.6.2 SUBSURFACE DU LAYERS

Small coring devices, as described in Subsection 5.4.2, can be used to collect Multi Increment samples from subsurface boring cores to be tested for VOCs (HDOH, 2011i). Recall that each section of core extracted from a targeted DU layer represents an increment, as is the case for surface Multi Increment samples (see Subsection 4.2.7). Individual core increments extracted from borings will normally need to be subsampled prior to placement in a container due to their large mass (see Subsection 5.4.2).

Evenly spaced plugs of soil should be removed from the core increment and placed in the preservative solution (i.e. methanol) container specifically designated for that DU layer (Figure 5-36). The use of plugs rather than wedges helps to control the total mass of soil collected, and may result in less disruption of the soil core that could contribute to loss of volatiles. Subsamples from core increments from other borings installed into the same DU layer are progressively added to the container as the field investigation advances in order to prepare a final bulk Multi Increment sample for that layer.

The mass of soil removed (subsampled) from each individual core increment should be kept constant, assuming a constant DU layer thickness, and adequate to ensure that a minimum 300 g bulk Multi Increment sample is collected from the DU layer. As a default, the collection of 5-10 g plugs every 5-10 cm (2-4 inches) along a core increment is recommended (refer to HDOH, 2011i). This should be adjusted based on target mass of soil to be collected from a targeted DU layer. Maintain consistent plug spacing for subsampling of core increments collected from DU layers with varying thicknesses between borings (see HDOH, 2011i).

As noted in Subsection 5.6.1, when sampling VOCs in soils it is important to ensure that soil is placed in the preservation fluid (methanol) within a few minutes after collection to reduce losses due to volatilization and biodegradation. This can be especially challenging when collecting samples or subsamples from multiple subsurface borings and multiple DU layers per boring. Very close coordination is necessary between the drill crew and the sampling crew to coordinate appropriate timing and handling of each soil boring to minimize the time between soil extraction and subsampling into methanol. The timing of each soil boring collected by the drill crew should be carefully synchronized with the rate at which the sampling team can access and subsample the soil boring quickly. A well organized work station for processing the subsamples needs to be set up, all sample containers should be pre-labeled to save processing time, and adequate storage containers/coolers provided to accommodate samples collected. If a nearby indoor workstation is not available for use, then a field work station with tarps or covers for rain, sun, and/or wind protection will likely be needed. An adequate number of personnel are needed on the sampling team to ensure subsamples from all DU layers in the soil boring can be obtained and placed in methanol within minutes of each boring being obtained and opened for access.

Increments should be collected using tools that minimize the loss of volatile chemicals during sample collection (i.e. cause the least disaggregation of soil during collection) and allow the collection of at least a five-gram mass of soil. Syringe-type, core-shaped devices that can be pushed directly into the soil are preferable. Examples include the TerrCore™, Core N' One™ and Encore™ tools (see Figure 5-36). Plastic, inexpensive devices that cannot be sealed (e.g., disposable syringes with forward ends cut off, TerraCore™ device) are most suitable for sample collection when methanol can be used in the field. These types of devices can also be used for the collection of samples to be tested for nonvolatile chemicals.

Somewhat more costly but sealable, Core N' One™ or Encore™-type devices are commonly used to collect increments or increment subsamples for projects where the use of methanol in the field is not practical (see Subsection 5.6.3 below).

As depicted in Figure 5-36, the device is pushed into the soil, retracted, and the increment collected is immediately extruded into a container with a premeasured volume of preservative (e.g. methanol). Then end of device can be trimmed to make a scoop for subsampling of gravelly soils. This is repeated with each increment or increment subsample. Dedicated sampling devices should be used between different DU layers within a single borehole, but can be reused for subsampling of core increments in multiple DU boreholes for the same DU layer.

A single large jar with a pre-measured volume of methanol adequate for the entire targeted DU layer could in theory be used to prepare a bulk Multi Increment sample in the field (i.e., plugs from subsample increments combined from 30+ borings). However, this risks an expensive total loss of the sample should the jar be accidentally broken in the field or at the laboratory.

An alternative approach is to place subsample plugs for individual core increments into a smaller jar specific to each borehole (e.g., see HDOH, 2011i). Methanol from individual jars (aliquots) representing the same targeted DU layer can then be combined at the laboratory for testing. This approach can also allow for different vertical and lateral combinations of core increments to be evaluated in order to obtain a better resolution of the location of the core mass of contamination at depth, and help optimize remediation (see HDOH, 2011i).

Subsample replicates should be collected from 10% of the borings and compared to evaluate the precision of method used (refer to Subsection 4.2.8.2). This will involve the collection and combination of three separate sets of subsample plugs from the

same boring for each of the targeted DU layers. The relative standard deviation of the replicate data sets should be compared and subsampling methods modified, as needed, to achieve acceptable precision. Increasing precision could require a decrease in plug spacing and/or an increase in the mass of subsamples collected from individual increments.

5.6.3 ALTERNATIVE APPROACHES

Because methanol is a hazardous material with flammability and toxicity concerns, shipping by air is highly restricted unless it is in accordance with specific rules. The U.S Department of Transportation and the Airline industry (International Air Transportation Association or IATA) regulations on air shipping of hazardous materials provide "Excepted" quantities of methanol that can be shipped by air without special packing materials or special training/certification of the shipper. The excepted quantity for air shipping of methanol is no more than 30 milliliters per inner container, and a maximum of 0.5 liter per cooler or package. There is no limitation on the number of separate coolers or packages that can be shipped as long as each one meets the "Excepted" quantity requirements (confer with airline used and applicable IATA regulations). Those that are shipping Excepted quantities still need to ensure that the package(s) are properly labeled, and they have knowledge regarding the samples and sampling methods used. Check with the shipper beforehand to ensure that containers are properly labeled and shipping requirements met. Restrictions could vary between islands and airlines. For shipping methanol above the Excepted quantities, a hazmat-trained shipper or packer should be utilized, or someone with equivalent training/certification and knowledge of applicable IATA regulations.

Wherever volumes of methanol greater than 30 milliliters per container presents problems for air shipping (especially for sites not on Oʻahu) alternatives can be considered in consultation with the laboratory. For example, collect Multi Increment increments into the full recommended volume of methanol in the field. Agitate the sample and allow the solution to equilibrate over a twenty-four hour contact period. Decant at least 20ml of the solution into a standard 40ml VOA vile (check with laboratory on required volume). This alternative should only be conducted under a specific SOP provided by the laboratory and is included in the site investigation report. Ship the samples to the laboratory under the "Excepted" quantity category for methanol (in accordance with airline used, and applicable IATA regulations). Method 5035A also notes that sonification of samples at 40°C for 30 minutes can be carried out for samples with less than 24 hours contact, so if this option is available it could be used shorten methanol contact time required before subsampling and shipping samples by air (include this practice in SOP with laboratory, if used). Note that the remaining spent methanol mixture is classifiable as a listed hazardous waste and must be managed accordingly (F003, spent, non-halogenated solvents; Hawaiʻi Administrative Rules §11-262-11). The spent mixture might also be classifiable as a hazardous waste due to ignitability. However, quantities of waste methanol generated will likely be minimal, in which case regulations for conditionally exempt small quantity generators found in Hawaiʻi Administrative Rules §11-26—1-5 will apply (100 kg limit).

A potential limitation of the extraction of samples in methanol is an increase in method detection limits (MDLs). This could cause the MDLs to be above relevant HDOH EALs for certain targeted chemicals. Multi Increment soil samples for volatile analyses can be tested using Selected Ion Monitoring (SIM) laboratory methods to reduce method reporting limits to target action levels for samples preserved in methanol. The SIM methods target a small number of select compounds instead of a full standard VOC list, and typically allow an order-of-magnitude reduction in reporting limits in comparison to standard Method 8260 analysis.

Another alternative used in Hawaiʻi due to methanol air shipping restrictions is to immediately freeze individual MI increments for shipping and have the increments combined in methanol at the laboratory prior to analysis (refer to USEPA, 2002h; also see Subsection 11.2). Individual increments for MI samples are collected in separate sampling devices that have vapor tight seals and are designed for zero headspace (e.g. Core N' One™, EnCore™, or equivalent type sampler). The samples are either stored on ice between 2°C and 6°C and must be analyzed within 48 hours, or immediately frozen in the field to between -7°C and -15°C (or stored immediately on ice between 2°C and 6°C and frozen within 48 hours to between -7°C and -15°C) and must be analyzed within 14 days of sample collection (see Subsection 11.2). Note that to freeze samples in small cores with vapor-tight seals to temperatures between -7°C and -15°C (for temporary storage and shipping) use water ice with added salt (Hewitt, 1999), and document that suitable freezing temperatures are achieved. Dry ice may be another option, though sample temperatures could go below -20°C and compromise the integrity of the seals on the small air-tight cores. Consequently, if dry ice is utilized packing methods should be developed to keep the dry ice from direct contact with the samples and document that temperatures of the samples remain between -7°C and -15°C. Check with the shipper for procedures to ship dry ice, including the amount of dry ice that can be placed in a single cooler, package labeling, and requirements for the use of a vented cooler.

Although not ideal, the approach of freezing individual increments of MI samples for VOC analyses may be unavoidable for samples collected on islands other than Oʻahu due to the logistical difficulties of obtaining, storing, and shipping methanol from other islands and the time required to ship samples to a laboratory on the mainland for testing. If problems persist, then the DQOs of the investigation should be reviewed and discussed with the HEER Office. High-quality (e.g., MIS) data with elevated detection limits are preferable to low-quality data (e.g., discrete soil samples) with lower detection limits. In most cases use of the laboratory detection limit as a screening level when the EALs cannot be met will be acceptable (refer to EHE guidance; HDOH, 2016). If discrete soil samples are collected and tested then the data should be considered usable for qualitative,

screening level purposes only (e.g., presence or absence). Decision making should be supported by the collection of soil gas sample data at the site (recommended for all sites impacted with potentially significant amounts of VOCs; refer to Section 7).

5.7 SEDIMENT SAMPLING

5.7.1 SEDIMENT SAMPLING EQUIPMENT

A brief overview of sediment sampling approaches and equipment is provided below, primarily for shallow sediment sampling scenarios. This section will be expanded in the future to include more detailed information. Well-thought-out Decision Units and investigation objectives are required for sediment investigations in the manner as done for soil investigations. Multi Increment samples should be used to characterize sediment DUs (see Section 4). Random, small-scale variability limits the reliability of data for small discrete sediment samples. This can be especially critical for vertical characterization of contaminants in sediment.

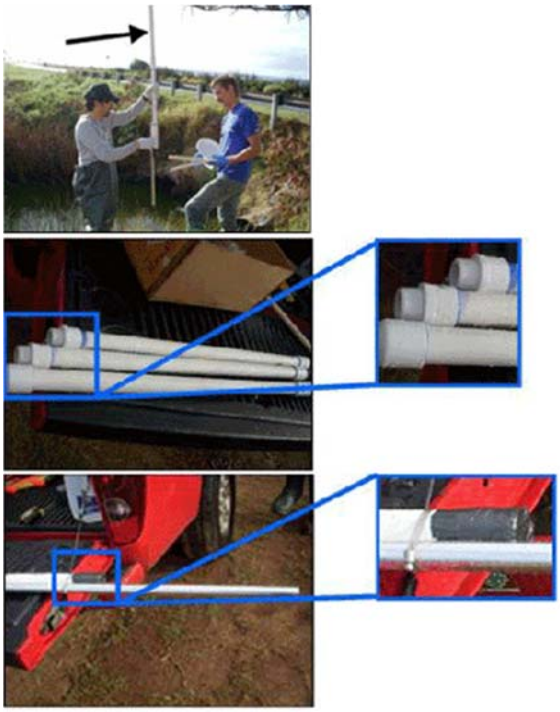


Figure 5-37. Sediment Sampling Tube Center

left photo: Ten-foot long PVC pipe used as a pole handle, cut into five 2-foot lengths for easy air transport and assembly in the field (1-inch diameter, Schedule 40 PVC).
Center right photo: Screw ends attached to cut PVC, with solid cap on end of one piece, to keep the water out.
Bottom left photo: Two-foot long, one-inch aluminum sampling tube (thin-walled towel holder) attached to the bottom of the PVC pole.
Bottom right photo: Sampling tube attached to bottom PVC piece with two metal hose clamps. The bottom piece of PVC is sealed to keep mud and water out. (Examples in Figure 5-37 made by Weston Solutions, not patented)



Figure 5-38. Collection of Sediment Increments from a Drainage Canal

Upper left photo: Increment collection point accessed.
Upper right photo: Sampling tube pushed into sediment to target depth.
Bottom left photo: Increment core pushed out of tube using disposable 3/4-inch wooden dowel. Tilt the tube slightly backward before pushing out sample in order to drain excess water, being careful not to lose the sediment.
Bottom right photo: Increment collected on disposable plate and placed into sampling container (e.g. one-gallon freezer bag carried in clean bucket). Note cylindrical shape of increment.

Additional procedural information on sediment sampling is available from many sources including Superfund Program, Representative Sampling Guidance, Volume 5: Water and Sediment (USEPA, 1995c), USGS National Field Manual for the Collection of Water-Quality Data (USGS, 2005), and Field Sampling Procedures Manual (NJDEP, 2005). These documents focus on older discrete sample collection methods but still include useful considerations for Multi Increment sampling approaches.

With proper planning and equipment, the collection of Multi Increment samples from sediment in relatively shallow water (e.g., <15 ft deep) does not involve significantly more effort than required for the collection of surface soil samples. Various types of sampling equipment are available for collecting sediment samples. Consider the type and characteristics of the water body associated with the sediment to be sampled when selecting sampling equipment. Factors such as the width, depth (especially if tidally influenced), flow, and bed characteristics of the water body are important.

Increments collected from sediment should be core-shaped (see Subsection 4.2.5.2). Consider a tube-shaped sampler for collection of increments to ensure cylindrical-shaped increments (see Figures 5-37 and 5-38).



Figure 5-39. Alternative Scoop-Shaped Samplers for Thin Sediment Layers

Left photo: Collection of increments from a canal with a thin sediment cover using a scoop sampler (scoop made by Tetra Tech EMI).
Right photo: Flat-bottom scoops with upright, flat sides to help avoid a bias toward the upper layers of sediment

If the sediment cover is exceptionally thin (e.g., < 4 inches) then use of use of a cup-type device or a flat-bottom, scoop sampler might be most practical (Figure 5-39).These devices might also be required for the collection of increments from coarser-grained sediment or other situations where use of a core catcher for the tube sampler is not practical. A flat-bottom scoop with upright square sides (Figure 5-39) will also help to avoid bias to the upper portion of the sediment.



Figure 5-40. Collection of Multi Increment Sediment Increments from a Drainage Canal

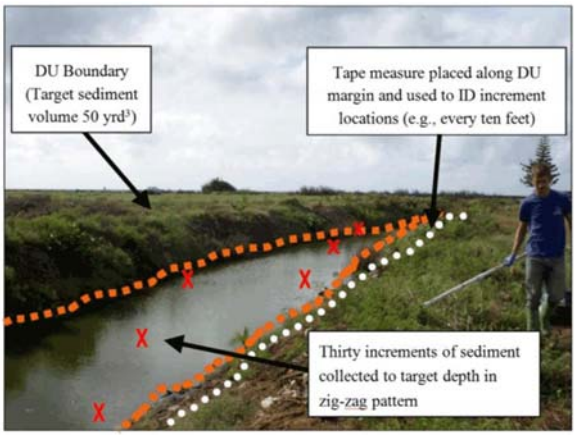


Figure 5-41. DU Designation and Collection of Multi Increment Samples from a Sugar Mill Drainage Canal

Marked, floatable rope used to assist in increment spacing and collection	Tape measure placed along DU boundary to assist in increment location and collection

Marking sediment increment collection locations in a stream or canal can be challenging. Consider placing a long, floatable rope (or tape measure) with a marked spacing within the DU (Figure 5-40). A long tape measure with increment positions marked by pins or flags can also be placed along the edge of the waterway to guide sample collection (Figure 5-41). Refer to Subsection 4.2.5.1 for guidance on increment spacing in long, narrow DUs.

Take care to minimize disturbance and loss of an increment as the sampling device is being lifted. If sediment fines are preferentially lost during increment collection then the resulting Multi Increment sample will not be representative. Decant excess water from collected sediment Multi Increment sample by waiting several minutes and then carefully pouring excess water out of the container. Use a cellulose paper filter to catch and re-place fine sediment back into the container as necessary. Note that the collection of undisturbed, anaerobic sediment samples for geochemical analysis, if required, might require alternative methods. This should be discussed with the HEER Office prior to sample collection.

Alternative tools and methods are required for the collection of sediment samples from larger and/or deeper water bodies. Figure 5-42 depicts a core sampler used to collect Multi Increment sediment samples from the large estuary pond depicted in Figure 3-32 of Section 3. Twenty-four Multi Increment samples consisting of 30 increments each were collected from 6 DUs designated in the pond over a 4-day period, including triplicates from one of the DUs.

A clear two-foot tube is attached to the end of the extendable push rod. A small boat and GPS can be used to maneuver to pre-established, increment collection locations within the pond. The coring device was manually forced into the sediment to the targeted depth and retrieved. A valve at the top of the sampling tube helps to hold in the sediment as the core is extracted from the increment location. As the core is being from the water, the base of the sampling tube is capped to prevent sediment loss. The sampling tube is then removed from the valve/push rod, capped on the other end and stored.



Figure 5-42. Use of Core Sampling Device to Collect Sediment Increments

Left Photo: Core sampler attached to valve and push rod
Middle Photo: Manual collection of sediment core increment from skiff
Right Photo: Individual core increments collected from a sediment DU

Once all cores (e.g. 30) for a DU have been collected, the individual cores containing multiple DU layers are extracted from the sampling tubes and the respective DU layers are combined to form bulk MI samples(Figure 5-43). The base cap is removed from the bottom of the tube and the tube placed on a plunger. The upper cap is removed and the tube is progressively forced downwards. Targeted DU layers are removed and placed in containers specific to that DU layer to form a bulk Multi Increment sample.

Bulk Multi Increment samples can either be sent to the lab for processing or, if needed, processed in the field to reduce mass. In the latter case, the sample is placed on clean, plastic sheeting and spread out to a thickness of about ½ inch (Figure 5-44). A flat edge spatula is then used to collect subsamples from the sample in a systematic, random fashion. A minimum of 30 subsamples is recommended. The initial bulk sample and/or split samples can be submitted to the laboratory for further processing and testing in accordance with incremental sampling methods.



Figure 5-43. Removal of Sediment Core Increments from Sampling Tubes

Upper Photo: Target DU layers in a core increment.
Middle Photo: Removal of increment by forcing sampling tube downward on a plunger; target DU layers removed from core and placed in dedicated container for combination with increments from other cores collected from the DU.
Lower Photo: initial bulk Multi Increment samples prepared by combination of core increments for each DU layer (layers representing 3 different sediment depth intervals in the DU).



Figure 5-44. Field Subsampling of a Sediment Multi Increment Bulk Sample

Upper Photo: Sample spread out into a 0.5 inch layer; large rocks and debris removed.
Middle Photo: Flat-edge spatulas used to collect subsamples in a systematic, grid fashion.
Lower Photo: Bulk Multi Increment sample prepared by representative subsampling, for shipment to the laboratory.

Alternative types of sediment samples are available for deeper or otherwise less accessible sediment. A Vibracore sampling tool was used to evaluate the feasibility of collecting Multi Increment samples from deep-water (50 ft) in a field study carried out by HDOH in 2013 (Figure 5-45). A small pontoon boat equipped with a GPS was again used to locate pre-established increment location points. A 30-increment Multi Increment sample from the upper foot of sediment in a DU was collected over a period of five hours using the approach described below.

A metal sampling tube with an inner liner is fitted to the base of an electric motor. The device is lowered to the sediment interface using a small wench. The motor is then used to vibrate the sampling tube into the sediment. The depth of penetration is monitored at the surface using a tape measure attached to the top of the device. A sediment catch is connected to the base of the tube to retain the sediment core when collected. To help speed the collection effort, an 8 foot long collection tube was used to collect up to 6 to 8 one-foot deep increments (target layer depth was 0-1 ft below sediment surface in the DU) without bringing the vibracore aboard the boat between collecting those increments. After the first increment was collected (and held in the tube by the sediment catch) the vibracore was lifted off the sediment floor several feet and slowly moved to the next increment location for another 1-foot sediment collection in the same sampling tube.

The sampling device is then retrieved to the surface. The liner and sediment core are removed from the sampling tube. An attempt to collect subsample increments to reduce the mass of the larger volume of sediment collected in the 8 ft core by cutting wedges or regularly spaced plugs had limited success (Figure 5-46; see also Subsection 5.4.2).The repeated vibration action of the vibracore during the period that multiple DU increments were collected in the same sampling tube (as well as the nature of the sediment in that location) tended to cause the sediment in the tube to disaggegate and run or mix together. If sediment collected under these circumstances is to be representatively subsampled, the sediment from the entire core would need to be collected, spread to a thin layer on a large flat surface, and systematic random increments collected, as illustrated in the example in Figure 5-44.

An additional concern noted in the use of the Vibracore was the loss of some very fine sediment when the sample tube was placed horizontally on the pontoon boat for core liner extraction. If the sediment in the core liner can be removed from the core tube in a vertical orientation (or other technique to limit loss of fine sediment particles), that would result in a more representative sample for contaminant evaluation.



Figure 5-45. Use of a Vibracore Device to Collect Sediment Samples in Deep Water

Left Photo: Vibracore sediment coring device; electric vibrator attached to top of sampling tube.
Right Photo: Vibracore lowered to top of sediment at increment collection location.

Other devices used to collect surface sediment samples include center pivot grabs, clamshell pivot grabs and drags, sleds, and scoops. Sediment core-type samplers are capable of collecting sediment samples at depths comparable to benthic grab samplers and when feasible are more suitable for MI samples. Sediment core samplers have the ability to retain the integrity of sediment horizons with minimal disturbance and allow the collection of unbiased core-shaped increments.



Figure 5-46. Removal of Core Increment from Vibracore Sampling Tube and Subsampling

Bulk Multi Increment sample prepared by combination of increment subsamples from all cores collected within the targeted DU.

Several types of sediment core samplers and benthic grab samplers are described in the following documents, among other sources.

- New Jersey Department of Environmental Protection (NJDEP) Field Sampling Procedures Manual. August 2005.
- United States Geological Survey (USGS), National Field Manual for the Collection of Water-Quality Data, Book 9, Handbooks for Water-Resources Investigations, Chapter A8, Bottom-Material Samples. Version 1.1. June 2005.

For sediments that consist primarily of <2mm particles, consider subsampling Multi Increment samples in the laboratory for extraction and analysis *without drying*, in order to reduce sample preparation and analysis time. Drying and sieving are carried out primarily to remove large particles. A sediment moisture content analysis is also necessary if the laboratory subsamples are collected without first drying the bulk MI sample(s), in order to report the laboratory data on a dry weight basis.

If both sediment and surface water samples are collected in the same location, collect the surface water sample first. If several sediment samples are collected from a streambed, collect the most downstream sample first with subsequent samples collected while proceeding upstream. Follow appropriate sample handling and analysis procedures, which are described in Section 11.

5.8 FIELD DOCUMENTATION

5.8.1 SURFACE SOIL SAMPLING LOGS

Accurate field logs are essential for evaluation and interpretation of analytical results and for preparation of the site investigation report. Details of all field activities, both during initial site inspections and during sample collection, should be recorded. The latter includes documentation of the possession and handling of samples from the time of collection through analysis and final disposition. Copies of the sampling logs, pertinent notes, and photograph logs should be included in the site investigation report.

Similar information should be recorded for borings, trenches, or pits installed to collect MI samples from subsurface DUs as well as the use of any discrete soil samples for initial screening purposes. Deviations from the sample plan caused by conditions encountered in the field (e.g. inadequate tools for sample collection, unanticipated surface debris or subsurface obstacles in sample collection, weather delays, etc.) are also important to document. Site visits to assess field conditions prior to mobilization for the collection of samples are essential and should also be documented in field logs.

An example of a surface soil sampling log is presented as Figure 5-47. Include similar information for any discrete soil samples collected. The intended use of the discrete samples and limitations regarding their representativeness should be clearly discussed in the investigation report (refer to Subsection 4.3). Copies of the field logbook, sampling logs, and (if available) photograph logs should be included in the site investigation report.

A log should be prepared for each DU included in the investigation. The logs should at a minimum include the following information:

- Site name and identifier;
- Name(s) of field personnel or sampler;
- Date, time;
- Unique sample ID or code;
- Sketch map depicting DU shape, dimensions, adjoining DUs, landmarks, north arrow, etc;
- Decision Unit coordinates (e.g., latitude and longitude of DU corners);
- Photographs of DU areas;
- Depth of DU sampling interval;
- Increment spacing;
- Number of increments collected for bulk Multi Increment sample(s);
- Type of sampling equipment used;
- Sample containers;
- Approximate bulk sample mass;
- Describe any field processing of sample(s);
- Soil description;
- Planned sample analyses;
- General comments (e.g., odor, staining, etc.).



Sample Information Sheet

Site Name: Sample ID:
Sampler's Name:
GPS Coordinates (center point):
Date: Start Time: End Time:
Weather Conditions: Clear Overcast Rain Wind Other (describe):
Media: Soil Sediment Other (describe):
Type of Sample: MIS Discrete
Approx DU Area (e.g., ft²): DU Depth Interval (e.g., 0-6"):
Number of MI Increments:
Increment Spacing (feet, meters, etc.):
Sampling Equipment: Soil Probe Drill Trowel Other (describe):
Soil Description:
Field Processing:
Approximate Bulk Sample Volume/Mass:
Sample Container:
Number of Replicates Collected:
Field Observations (structures, vegetation, barren areas, debris, staining, odors, etc.):

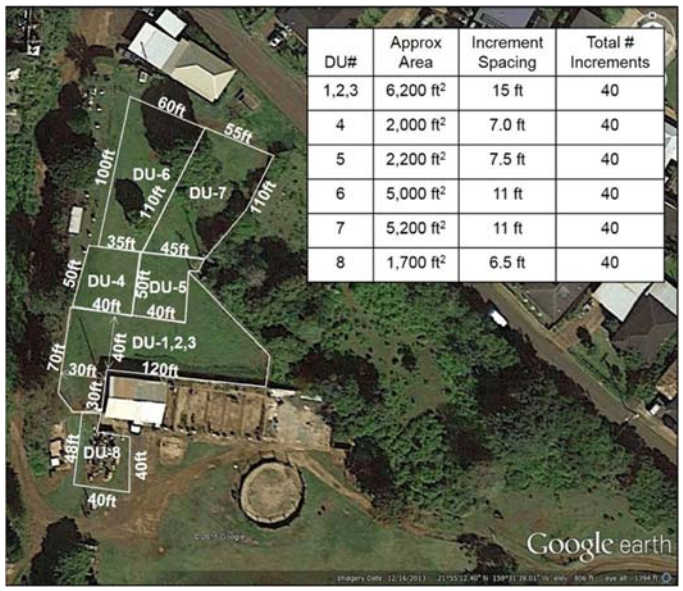
Photographs: Yes No Video: Yes No
Decision Unit Description (include basis for DU designation):

Sketch of Decision Unit (include approximate shape, dimensions, adjoining DUs, landmarks, north arrow, GSP coordinates, etc.):

Figure 5-47. Example Surface Soil Sample Log

Adequate information should be included in the sketch map and sample information log to generate a to-scale map of DU locations in the final report (e.g., shape, dimensions, adjoining DUs, landmarks, north arrow, etc.). Depictions of DUs on high-altitude (e.g., satellite) maps or with low-altitude (e.g., drones) photos is acceptable and even preferred provided that distortion is not too great to prevent accurate estimation of dimensions (Figure 5-48). Draft DU maps can be made prior to sample collection

and adjusted in the field as needed. Final DU maps depicted on aerial imagery can significantly aid in future re-identification of investigated areas.



DU#	Approx Area	Increment Spacing	Total # Increments
1,2,3	6,200 ft²	15 ft	40
4	2,000 ft²	7.0 ft	40
5	2,200 ft²	7.5 ft	40
6	5,000 ft²	11 ft	40
7	5,200 ft²	11 ft	40
8	1,700 ft²	6.5 ft	40

Figure 5-48. Demarcation of Decision Units and DU Information Using a Google Earth Image

Coordinates determined via hand-held Geographic Positioning System (GPS) equipment is acceptable to record the boundaries of Decision Units (e.g. four corners of a rectangular-shaped Decision Unit). The accuracy of the equipment to be used should be documented in the SAP. Any potential variability caused by surrounding forests, structures, or other obstructions to the GPS unit acquiring satellite signals should be taken into account and documented in the investigation report.

A more detailed survey of the site and DU boundaries by a surveyor licensed in the State of Hawai'i is required for maps to be included in an Environmental Hazard Management Plans (EHMP). This is necessary to more precisely document locations where contamination will be left in place for long-term management. The EHMP should include the latitude and longitude of key DU boundary points, along with ground surface elevation data determined within the Hawai'i State Plane Coordinate System to an accuracy of 0.1 foot. Locations of existing buildings or other major landmarks should also be surveyed for reference to the targeted area under long-term management.

The basic rational for designation of the DU (e.g., suspect spill area, perimeter DU, etc.; see Subsection 3.4) should be noted in the site documentation. The tools and method used to collect Multi Increment (or other) samples should be described in the sample logs. Note the increment spacing used for each DU (see Subsection 4.2.4). Record any field processing of the sample(s) collected, including the need to reduce the sample mass due to the original bulk sample(s) being too large for lab processing (refer to Subsection 4.2.3).

Record information for field observations and field screening methods used to assist in the identification of potential contaminants of concern or test samples in the field (see Section 8). This might include visual and olfactory observations, or the use of tools such as a photo-ionization detector (PID), portable X-ray fluorescence device (XRF), immunoassay test kits or a field Gas Chromatography-Mass Spectrometry [GC/MS] unit. A dehumidification tip should be used with the PID. Field measurements should be recorded and included in the log for the targeted DU.

Recording the spacing of increments is important in order to document that the sample was collected in a systematic random manner. As discussed in Subsection 4.2.4, the specific locations of individual increments *do not* need to be recorded or included on a map of the DU. This is in part because individual increments cannot be assumed to be representative of the immediately surrounding soil, due to uncertainties from random small-scale variability (refer to Subsection 4.1.2 and Section 4.2.4). The exact location of any given individual increment collection point therefore does not need to be documented.

A basic soil description and classification should be included with the sample log (see Subsection 5.8.3). Additional and more detailed information regarding soil taxonomy, geotechnical properties and other characteristics that might be required to meet

the project objectives should be included as appropriate. A brief overview of consistency, cementation, structure, rock classification, and other information is provided in Subsection 5.8.4.

5.8.2 SUBSURFACE SOIL SAMPLING/BORING LOGS

Logs for samples collected from subsurface DUs should include the same type of information noted above for surface soil samples regarding site conditions, sample collection methods, boring spacing, etc. Record the rational for the selection of targeted DU layers in the same manner as done for surface soil (refer to Subsection 3.5.6). This might include the anticipated known or anticipated depth of contamination, visual or olfactory evidence of contamination during test borings or abrupt changes in soil characteristics. Field processing of samples is typically required for subsurface Multi Increment samples due to the mass of individual core increments and should be described in the logs (refer to Subsection 5.4.2).

Additional information is required for exploratory borings or borings to be used for the installation of wells. A log for each boring should be prepared which includes the following items, as applicable:

Name of drilling contractor; Borehole coordinates – latitude and longitude; Sketch showing the borehole location (including reference distances); Diameter and total depth of borehole; Type of drilling equipment used (e.g., direct push, auger, air or mud rotary); Drilling fluid and angle (if applicable); Blow counts/Resistance; Depth to water table	Important stratigraphic boundaries encountered (e.g. depth bedrock); Hydrogeologic information (e.g. transmissivity, etc.); General comments (e.g., odor, staining, etc.); Field measurements (e.g., PID, XRF, etc.); Designated DU layers for sample collection; Sample collection equipment used; Core recovery and portion submitted for analysis; Sample identification number; Planned sample analyses

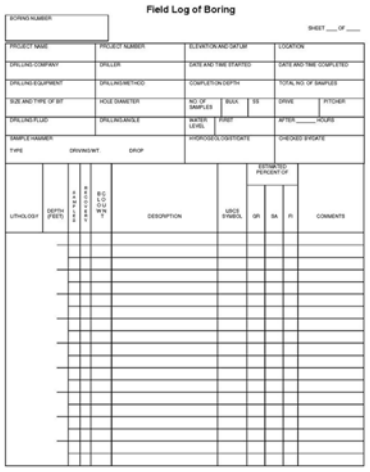


Figure 5-49. Example Log for Exploratory Borings or Borings Used for the Installation of Wells

An example boring log is depicted in Figure 5-49. The soil descriptions should also include information on density or consistency (primarily when borings are conducted using hollow stem auger) and appearance descriptors of cementation, structural appearance of layers and other features, and other appearance descriptors as applicable to the project.

5.8.3 SOIL DESCRIPTION

Soil descriptions for soil sampling events should be made by a trained geologist, geotechnical engineer or soil scientist. The Unified Soil Classification System (USCS) is recommended for basic soil descriptions (ASTM, 2006d; see also ASTM, 2006e; USDA, 1987, USDA-NRCS, 2007; Nielsen, 2006; US Navy, 2007).

The level of detail appropriate for soil descriptions for a given site is tied to and should be addressed in the site investigation objectives (DQOs). At a minimum the color and estimated nature of the soil in terms of average particle sizes (e.g., gravel versus sand versus clay) should be recorded using a standardized approach. More detailed soil descriptions, including laboratory-based measurement of particle size distribution, might be required for more detailed investigations of contaminant fate and transport or to design remedial actions. Maps with taxonomic names for soil on each island are published by the US Department of Agriculture (USDA, 2015). The accuracy of the maps in highly developed, urban area where soil from other areas may have been imported should be verified.

A summary of key elements of the classification system is provided below. If an alternative classification scheme is used then a summary of terms used and particle size categories should be included in the report.

5.8.3.1 *RECOMMENDED PARAMETERS FOR SOIL DESCRIPTIONS*

Classification of soil in accordance with the USCS involves a group symbol, name, and complete word description (ASTM, 2006d). Key descriptive parameters include:

- Relative proportion of gravel, sand and fines and USCS classification name and symbol;
- Color (Munsell method preferred);
- Consistency;
- Moisture content;
- Staining/discoloration/odor;
- Glass, wire, porcelain fragments or other debris indicative of disposal or fill;
- Other descriptive terms

Descriptive terms denoting the geologic nature of the soil can also be added, including such terms as "saprolite" for soil directly derived from weathered rock or "sediment" for soil associated with unconsolidated terrestrial or marine sediments. Additional soil descriptors can be included as needed based on the DQOs of the investigation (e.g., plasticity, angularity, etc.; refer to ASTM, 2006d). Properties regarding the *in situ* structural nature of the soil might be required in projects that include a geotechnical component (e.g., density, structure, etc.). A review of properties commonly recorded as part of subsurface borings is provided in Subsection 5.4.

Include notes regarding odors and other observations during drilling, even if these are not apparent in the samples collected. Field aids that combine the USCS classification system with examples of particle sizes, percent estimation of individual components, color, particle angularity and other descriptive criteria are available commercially.

Classification Group Name

An abbreviated summary of the USCS classification scheme is provided in Figure 5-50 (after ASTM, 2006d). Soils are initially classified as "coarse-grained" or "fine-grained," depending on the dominance of gravel and/or sand-size particles versus silt and/or clay-size particles. The term describing the dominant particle size is further modified based on the abundance of other particle sizes, with a code applied to each grouping. The classification scheme somewhat confusingly uses a minimum of 12% clay + silt to describe a sand or gravel as "with fines" but a minimum of 15% sand + gravel to describe a fine-grained soil as "with sand" or "with gravel."

Figure 5-50. USCS Soil Classification Scheme (after ASTM 2006d)

Major Divisions			Code	Description
Coarse-Grained Soils More than 50% retained on a 0.075 mm (No. 200) sieve	**Gravels** 50% or more of course fraction retained through a 4.75 mm (No. 4) sieve	Clean Gravels (<5% fines)	GW	Well-graded gravels, sandy gravels or gravels with sand; little to no fines
			GP	Poorly-graded gravels, sandy gravels or gravels with sand; little to no fines
		Gravels with Fines (≥5% fines)	GM	Sandy gravels with silt, gravels with sand and silt
			GC	Sandy gravels with clay, gravels with sand and clay
	Sands 50% or more of course fraction passes through a 4.75 mm (No. 4) sieve	Clean Sands (<5% fines)	SW	Well-graded sands, gravelly sands, or sands with gravel; little to no fines
			SP	Poorly-graded sands, gravelly sands, or sands with gravel; little to no fines
			SM	Silty sands, sands with silt

		Sands with Fines (≥5% fines)	SC	Clayey sands, sands with clay
Fine-Grained Soils More than 50% passes through a 0.075 mm (No. 200) sieve	**Silts and Clays**		ML	Silt, sandy silt, clayey silt, silt with fine sand and clay
			CL	Clay, silty clay, clay with silt and fine sand
			OL	Organic silt and clay (loam)
Highly Organic Soils			PT	Peat and other highly organic soils

Notes:

1. Gravel: ≥5.0mm to <75mm), sand: 0.075-5.0mm, silt: 0.005-0.075mm); clay: <0.005mm.
2. Grading refers to the range of particle sizes in the soil. “Well-graded” gravels and sands contain a wide range of coarse particle sizes, poorly graded soils do not.
3. Describe coarse-grained soils as “with fines” if ≥12% silt and clay; combine terms if between 5% and 12% fines (e.g., GW-GM). Describe soil as “with sand” or “with gravel” if the soil contains ≥15% sand or gravel.
4. Silts and clays can be further defined in terms of liquid limit and plasticity as well as other criteria (see ASTM 2006d).

If the second-most dominant grain size makes up >30% of the soil type then include that grain size with the name. For example a soil composed of 30% fines and 75% sand is described as a "silty-clayey sand (SM)." If dominance of the fines by silt versus clay is known then a more specific code can be assigned, for example "SM" for a silty sand or "SC" for a clayey sand. Note that it can be difficult in the field to distinguish between fine sand, silt and clay without significant experience.

A sand with 12% to <30% silt and clay is described as "sand with fines (SM-SC)." Sands with 5% to 12 % fines require dual symbols that include a description of grading, for example "well-graded sand with silt (SW-SM)". A sand with <5% fines is simply described in terms of grading, for example "poorly graded sand (SP)".

Fine-grained soils with >30% sand or gravel are described as "sandy" or "gravely." Fine-grained soils containing 15% to <30% sand or gravel are described by adding "with sand" or "with gravel" to the group name (e.g., silt and clay with sand, ML-CL). Although not called for in the ASTM document referenced above, it is reasonable for the purposes of an environmental investigation to add "with sand" or "with gravel" to fine-grained soils that contain 5% to 15% coarse-grained particles. Dual classification of a soil type is appropriate if a sample has properties that do not distinctly place it into one group (e.g., SC/CL). Refer to the documents referenced above for additional soil descriptive terms.

Visual Estimation of Grain-Size Distribution

In practice the accurate classification of soils with a large fraction of fines can be challenging in the field without first drying and sieving the sample. Detailed analysis of particle size distribution is most accurately carried out in the laboratory if required as part of the investigation DQOs (e.g., Method D422; ASTM, 1998). As an alternative, field estimation of particle size distribution can be carried out in the following manner:

- Select a representative sample (Multi Increment sample preferred).
- Remove all gravel-size (>75mm or approximately three inches) or larger particles from the sample. Estimate and record the percent by volume of these particles. Only the fraction of the sample smaller than 75mm is classified.
- Estimate and record the percentage of gravel.
- Considering the rest of the sample, estimate and record the percentage of sand particles, typically the smallest particle visible to the unaided eye.
- Assign the remaining percentage to "fines"; do not attempt to separate silts from clays.

Estimate percentages to the nearest 5 percent. If one of the components is present in a quantity considered less than 5 percent, indicate its presence by the term "trace." Percentage composition figures can assist in estimation of different size or particle type makeup of a sample. More precise lab methods might be required to accurately distinguish fine sand from silt and accurately determine clay composition if this information is required for completion of the field investigation.

Munsell Color

Color is described by hue and chroma using the Munsell Soil Color Chart (Munsell, 2000). For uniformity, the HEER Office recommends that investigators utilize this chart for soil color classification. This assists in comparisons of soils from different areas of a site or between sites. The Munsell Color Chart is a small booklet of numbered color chips with names like "5YR 3/4", a specific type of reddish brown. The first part of the code (e.g., 5YR) describes the sample in terms of the basic color group ("hue"). The second part of the code (e.g., 3/4) describes the color in terms of lightness and darkness ("value") and color intensity ("chroma").

Descriptors should also note layering, mottling, gradation, or banding of colors. It is important to note and describe staining that might be related to contamination, particularly if the observation is correlated with other observations of odor, moisture, or appearance (e.g., presence of apparent petroleum liquids or green staining possibly related to contamination with copper-chromium-arsenic).

Consistency

Consistency describes the strength at which soil particles are held together. Descriptors include:

- Loose – Soil easily falls apart;
- Friable – Soil initially holds together but easily crushed with gentle pressure;
- Firm – Soil crushes under moderate pressure and resistance is noticeable;
- Very Firm – Strong pressure required to crush soil; difficult to accomplish with thumb and forefinger.

Soils that are loose and easily crumbled even when wet are usually indicative of a low clay content. Dry soil that is very firm is usually indicative of a moderate amount of clay.

Moisture Content

The moisture content of the soil should be described qualitatively using the following terms and the corresponding definitions:

- Dry - Absence of moisture, dry to the touch.
- Moist - No visible water but moisture is sufficient to bind soil matrix.
- Wet - Visible water, usually when soil is sampled from a water table. In other instances, the wetness may also indicate the presence of non-aqueous phase liquid (NAPL), if accompanied by strong odor or unusual liquid color or viscosity.

Submit samples to a laboratory for followup moisture analysis.

Staining, Odor and the Presence of Contamination

Unusual odors should be noted in logs and soil descriptions if detected when sampling, as they may be related to hydrocarbons, solvents, or other chemical contamination in the subsurface. Hydrocarbon odor may range from gasoline to lubrication oil. Contaminant-related odors also might have a distinctive smell of decaying vegetation or a stronger astringent or sweet odor that could be indicative of solvent compounds.

Use of a field organic vapor analyzer for screening purposes is recommended when volatile or semi-volatile organic contaminants are expected at a site (refer to Section 8). Direct inhalation should be avoided if odors suspected to be related to contaminants are detected. A health and safety plan should be prepared for sites where volatile or semi-volatile contaminants are anticipated. A respirator may be required under some circumstances, in additional to other personal protective equipment (e.g., gloves, tyvex suits, safety boots, etc.).

Note and describe staining or unusual moisture found in combination with unusual odors, as the combination of characteristics is often indicative of solvents, petroleum or other Non-Aqueous Phase Liquid (NAPL) contamination in soil (i.e., separate phase liquid not dissolved into water). The staining or moisture indicative of NAPL is often gray to brown in hue but can range in appearance from clear to completely black. Gasoline sometimes imparts a greenish to bluish hue to soil. Along with unusual odor and color, the moisture indicating NAPL contamination most often has an unusual textural aspect. For example, hydraulic fluids may feature a tacky or sticky feel accompanied by a sweet odor, while lubrication oil is most commonly much more viscous than water and accompanied by a dark color and a heavy, musky odor.

Appearance of coarser fragments

Angularity of coarser particles is often an indicator of mode of deposition. The following criteria describe the angularity of coarse sand and gravel particles:

- Rounded particles have smoothly-curved sides and no edges;
- Subrounded particles have nearly plane sides, but have well-rounded corners and edges;
- Subangular particles are similar to angular, but have somewhat rounded or smooth edges;
- Angular particles have sharp edges and relatively plane sides with unpolished surfaces. Freshly broken or crushed rock would be described as angular.

Note that both angular and rounded particles can be associated with depositions of volcanic ash.

5.8.3.2 *EXAMPLE SOIL DESCRIPTIONS*

Description of coarse-grained soil samples

A coarse-grained soil is one that is primarily composed of sands and/or gravel particles. A soil is classified as a sand if greater than 50 percent of the coarse fraction is "sand-sized." It is classified as a gravel if greater than 50 percent of the coarse fraction is composed of "gravel-sized" particles.

The written description of a coarse-grained soil should contain the following information:

- USCS classification name based on soil properties (particle size and percentage, plasticity, and other parameters as defined by USCS);
- Munsell color and color number;
- Moisture content;
- Relative density (if determinable);
- Coarse particle angularity and makeup by predominant particle type (e.g., coralline or basaltic).

An example coarse-grained sample description is presented below:

> *POORLY-SORTED SAND WITH SILT, medium- to coarse-grained, SW/SM (minor silt with approximately 80 percent coarse-grained sand-sized shell fragments, and 20 percent medium-grained basalt sand, and 5 percent to 15 percent ML), light olive gray, 5Y 6/2, moist, no odor, subrounded grains.*

Description of fine-grained soil samples

Fine-grained soil is subdivided into clays and silts according to its plasticity. Clays are plastic while silts have little or no plasticity. The written description of a fine-grained soil should contain similar information as noted above, in addition to information on plasticity An example fine-grained sample description is presented below:

> *SANDY CLAY WITH TRACE GRAVEL, CL (70 percent fines, 30 percent fine sand, with minor amounts of basalt gravel [< 5 percent]), light olive gray, 5Y 6/2, moist, faint odor, firm, moderately plastic.*

5.8.4 ADDITIONAL SAMPLE INFORMATION

Additional sample information that might be required for a project includes moisture content, density/consistency, cementation, structure, and rock classification. A brief overview of these topics is provided below (see also Nielson, 2006, US Navy, 2007).

Density/Consistency (borings)

Density and consistency describe a physical property that reflects the relative resistance of a soil to penetration. The term "density" is commonly applied to coarse to medium-grained sediments (i.e., gravels, sands), whereas the term "consistency" is normally applied to fine-grained sediments (i.e., silts, clays). There are separate standards of measure for both density and consistency that are used to describe the properties of a soil.

The density or consistency of a subsurface soil is determined by observing the number of blows required to drive a standard 1 3/8-inch (35 mm) inner diameter (ID) split barrel sampler (commonly termed a standard penetrometer test [SPT] or terzaghi sampler) 18 inches using a drive hammer weighing 140 lbs (63.5 kilograms [kg]) dropped over a distance of 30 inches (0.76 meters). Record the number of blows required to penetrate each 6 inches of soil in the field boring log during sampling. The first 6 inches of penetration is considered to be a seating drive; therefore, the blow count associated with this seating drive is recorded, but not used in determining the soil density/consistency. The sum of the number of blows required for the second and third 6 inches of penetration is termed the "standard penetration resistance," or the "N-value." The observed number of blow counts must be corrected by an appropriate factor if a different type of sampling device is used (e.g., most commonly in Hawai'i, a Modified California Sampler [MCS] with liners). For a 2-inch ID MCS equipped with brass or stainless steel liners and penetrating a cohesionless soil (sand/gravel), the N-value from the MCS must be divided by 1.43 to provide data that can be compared to the 1 3/8-inch ID SPT sampler data (University of Southern California, 2001).

For a cohesive fine-grained soil (silt/clay), the N-value for the MCS should be divided by a factor of 1.13 for comparison with 1 3/8-inch ID SPT sampler data (US Navy, 2007).

Drive the sampler and record blow counts for each 6-inch increment of penetration until one of the following occurs:

- A total of 50 blows have been applied during any one of the three 6-inch increments; a 50-blow count occurrence shall be termed "refusal" and noted as such on the boring log.
- A total of 150 blows have been applied.
- The sampler is advanced the complete 18 inches without the limited blow counts occurring, as described above.

If the sampler is driven less than 18 inches, record the number of blows per partial increment on the boring log. If refusal occurs during the first 6 inches of penetration, the number of blows will represent the N-value for this sampling interval. Tables 5-3 and 5-4 present representative descriptions of soil density/consistency verses N-values.

Table 5-3. Measuring Soil Density with Standard Penetration Test and Modified California Sampler – Sands, Gravels

Description	Standard Penetration Test Sampler Field Criteria (N-Value)	Modified California Sampler Field Criteria (N-Value)
	1 3/8 in. ID Sampler	2 in. ID Sampler using 1.43 factor
Very Loose	0–4	0–6
Loose	4–10	6–14
Medium Dense	10–30	14–43
Dense	30–50	43–71
Very Dense	> 50	> 71

Table 5-4. Measuring Soil Density with a Standard and California Sampler – Fine Grained Cohesive Soil

Description	Standard Penetration Test Sampler Field Criteria (N-Value)	Modified California Sampler Field Criteria (N-Value)
	1 3/8 in. ID Sampler	2 in. ID Sampler using 1.13 factor
Very Soft	0–2	0–2
Soft	2-4	2-4
Medium Stiff	4-8	4-9
Stiff	8-16	9-18
Very Stiff	16-32	18-36
Hard	>32	>36

Cementation

Cementation is used to describe the friability of a soil. Cements are chemical precipitates that provide important information as to conditions that prevailed at the time of deposition, or conversely, diagenetic effects that occurred following deposition. Seven types of chemical cements are recognized by Folk (1980). They are as follows:

1. Quartz – siliceous;
2. Chert – chert-cemented or chalcedonic;
3. Opal – opaline;
4. Carbonate – calcitic, dolomitic, sideritic (if in doubt, calcareous should be used);
5. Iron oxides – hematitic, limonitic (if in doubt, ferruginous should be used);
6. Clay minerals – kaolinite, chlorite;
7. Miscellaneous minerals – pyritic, collophane-cemented, glauconite-cemented, gypsiferous, anhydrite-cemented, baritic, feldspar-cemented, etc.

Of these, only 4 through 6 are commonly encountered in Hawaiian substrate.

If the clay minerals are detrital or have formed by recrystallization of a previous clay matrix, they are not considered to be a cement. Only if they are chemical precipitates, filling previous pore space (usually in the form of accordion-like stacks or fringing radial crusts) should they be included as "kaolin-cemented," "chlorite-cemented," etc.

The degree of cementation of a soil is determined qualitatively by utilizing finger pressure on the soil in one of the sample liners to disrupt the gross soil fabric. The three cementation descriptors are as follows:

- Weak – friable (crumbles or breaks with handling or slight finger pressure);
- Moderate – friable (crumbles or breaks with considerable finger pressure);
- Strong – not friable (will not crumble or break with finger pressure).

Structure

This variable is most appropriate to the vertical extent observed in borings and sometimes to lateral extent observed in trenches. The variable is used to qualitatively describe physical characteristics of soil that are important to incorporate into hydrogeological and/or geotechnical descriptions of soil at a site. Appropriate soil structure descriptors are as follows:

- Granular – spherically shaped aggregates with faces that do not accommodate adjoining faces;
- Stratified – alternating layers of varying material or color with layers at least 6 mm (1/4 inch) thick; note thickness;
- Laminated – alternating layers of varying material or color with layers less than 6 mm (1/4 inch) thick; note thickness;
- Blocky – cohesive soil that can be broken down into small angular or subangular lumps that resist further breakdown;
- Lensed – inclusion of a small pocket of different soil, such as small lenses of sand, should be described as homogeneous if it is not stratified, laminated, fissured, or blocky;
- Prismatic or Columnar – particles arranged about a vertical line, ped is bounded by planar, vertical faces that accommodate adjoining faces (prismatic has a flat top, columnar has a rounded top);
- Platy – particles are arranged about a horizontal plane.

Other sample appearance descriptors include:

- Mottled – soil that appears to consist of material of two or more colors in blotchy distribution;
- Fissured – breaks along definite planes of fracture with little resistance to fracturing (determined by applying moderate pressure to sample using thumb and index finger);

- Slickensided – fracture planes appear polished or glossy, sometimes striated (parallel grooves or scratches).

Rock Classification

The purpose of rock classification is to thoroughly describe the physical and if possible, mineralogical characteristics of a rock sample collected through rotary sampling, or significant rock fragments encountered in a soil matrix drilled into by hollow stem auger, or in a trench, and to classify it according to a common system. Because rock classification systems vary, and to date there is no universally accepted rock system equivalent to the soil USCS, the HEER Office recommends a general rock classification system similar to the US Navy standard operational procedure developed for description of rock types; however, it is modified because the Navy system includes rock types not found in the state of Hawai‘i (US Navy, 2007).

Rock descriptions preferably should be made by a trained geologist or geotechnical engineer. The items essential for classification include: Rock Name (e.g., coral limestone), Color (according to the Munsell code), Texture/Grain size (e.g. fine-grained, porphyritic), Structure (e.g., fractured, massive, porous), degree of weathering, and overall Classification according to the following general rock types:

- Conglomerate (CG) – Coarse-grained, consolidated sedimentary rock, including conglomerate and breccia.
- Sandstone (SS) – Consolidated sedimentary rock composed primarily of sand-sized particles.
- Mudstone (MS) – Consolidated sedimentary rock composed primarily of silt-sized or finer particles.
- Carbonates (LS) – Chemical or biological precipitates including coralline limestone, algal limestone, cemented shell limestone.
- Basalt (IE) - Although it is conceivable that very deep borings may encounter intrusive igneous rock, the predominant igneous rock that will be encountered in Hawai‘i is basalt. The description of basalt should include an identification of the encountered rock as predominantly a‘a or pahoehoe. Descriptions of basalt should also have an indication of degree of weathering (if possible) and any identifiable dominant zones, depths, identifiable fracture orientations, clinker zones in a‘a, or interconnected / elongated vesicles in either lava type. All of these may indicate preferential pathways for groundwater travel.
- Tuff (T) – Descriptions of tuff should include boring structure characteristics as described previously, degree of friability, and degree of weathering.

Where possible, rock types should also be identified according to depth range below ground surface. Descriptions of rock type should pay primary attention to characteristics that potentially affect groundwater behavior (e.g. basalt fracturing, carbonate porosity). An example rock description is as follows:

> Tuff (T), dusky red, 2.5 YR 3/2, welded, horizontal layers (~0.5 inch) of sand-sized ash/rock fragments grading upwards to laminated fine grained ash, 5 to 6 feet bgs, no fracturing with upper laminations highly weathered and altering to clay.

Other Subsurface Boring Soil/Rock Information

Optional but desirable associated information to accompany the boring logs would be photographs of boring locations, and for deeper borings, photographs of recovered samples. Each photograph should have a unique qualifying identification number or code. This code and some of the pertinent boring/soil sample information indicated on the list above should be written down and included within the photograph. A common method to include the information is to write it on paper or a reusable dry-erase type of board and to place the paper or board within the view of the photograph along with a common object (e.g., pen) for scale.

5.9 EQUIPMENT PREPARATION / DECONTAMINATION



Figure 5-51. Triple Wash Decontamination of Sampling Equipment

Decontaminate sampling devices used to collect samples prior to use and between DUs. This includes drill rods and coring used for the collection of subsurface increments and samples. Decontamination of sampling equipment during the collection of increments *within a DU* for preparation of a bulk Multi Increment sample is not necessary. This includes the collection of samples or subsamples for the same DU layer, when multiple DU layers and core increments are being sampled (e.g. subsurface borings). Decontamination of equipment *between DU replicates* samples is recommended, since replicates are intended to be completely independent.

Protect decontaminated equipment from incidental contact with potential contaminant sources by placing in sealed plastic bags or otherwise keeping the equipment well covered.

The following, triple-wash approach is recommended as a default procedure for decontamination of sampling equipment where trace levels of contaminants are being investigated (Figure 5-51).

1. Removed caked soil and debris from sampling equipment by hand;
2. Wash with light detergent;
3. Rinse with tap-water;
4. Rinse a second time with tap-water.

The use of solvents to clean equipment should be avoided in order to minimize the generation of potential hazardous waste (see Section 5 & USEPA 2015). Document the decontamination procedure in the SAP and the final investigation report. These procedures may not be adequate for decontamination of equipment used to collect water samples (refer to Section 6). Carry multiple sets of sampling tools in order to expedite sample collection and allow decontamination of equipment in batches, ideally just once a day at the start or end of a sampling day.

Heavy equipment parts necessary for the advancement of any sampling device must be steam cleaned or high pressure/hot water washed between DU locations. Examples of these types of equipment include auger flights, drill rods, and backhoe buckets.

The collection of soil samples beneath concrete pads, floors, or asphalt paved areas may sometimes be necessary. If the equipment used to remove the concrete or asphalt has the potential to come into direct contact with the underlying soil, it must also be decontaminated. Decontaminate this equipment prior to and between sample locations in a manner similar to decontamination procedures discussed above for heavy equipment.

The collection and testing of equipment rinsate samples is not required or necessary for typical soil investigations. The practice is designed for "ultraclean" sampling approaches most typically associated with the collection of water samples, where parts-per-trillion level accuracy of laboratory data is desired. The collection of large Multi Increment soil (and sediment) samples also minimizes the potential for cross contamination of samples if small amounts of soil are inadvertently left on sampling tools, provided that the basic decontamination procedures described above are followed.

5.10 INVESTIGATION DERIVED WASTE

Investigation-derived waste (IDW) generated during the collection of environmental samples must be properly managed and disposed of following completion of the investigation. Typical types of IDW include (after USEPA 2014; see also USEPA 1991, SERAS 1994):

- Personal protective equipment (PPE, e.g. disposable coveralls, gloves, booties, respirator canisters, splash suits, etc.)
- Disposable sampling equipment and related items (e.g., plastic trowels, core samplers, broken or unused sample containers, sample container boxes, tape, etc.);
- Soil cuttings from drilling or hand augering;
- Drilling mud or water used for mud or water rotary drilling;
- Decontamination wash water, rags, towels, etc.;
- Spent solvents used in sample preparation (e.g., methanol preservation) or cleaning;
- Other non-hazardous waste (plastic ground cloths, packing and shipping materials, etc.).

An effort should be made to minimize the amount of IDW generated during a site investigation to the extent practicable.

It is the responsibility of the property owner and the party conducting the sampling to properly dispose of all waste generated in accordance with local, state and federal regulations. If IDW is designated for disposal to a landfill or any other off-site location then the generator must make a Hazardous Waste Determination under RCRA (Resource Conservation and Recovery Act) and in accordance with Hawai'i Administrative Rules (HAR) §11-262-11. Material that meets the regulatory classification as "hazardous waste" must be disposed of at a permitted, hazardous waste treatment, storage or disposal facility. There are currently no hazardous waste landfills in Hawai'i. Therefore, IDW classifiable as hazardous waste must be disposed of at a regulated facility on the mainland.

A hazardous waste determination is a step-by-step process. First determine if the waste is specifically exempted by HAR §11-261-4. Petroleum-contaminated soil and materials are also excluded from hazardous waste regulations and can be disposed of at a municipal landfill, provided that it does not contain other contaminants which could cause it to be classifiable as hazardous waste. Wastes that are not specifically excluded are further assessed as part of the hazardous waste determination as follows (HAR 11-261-2):

- Listed Wastes: Specifically listed as a hazardous waste in HAR §11-261-2 (F-listed waste)
- Testing - Testing the waste for toxicity, ignitability, corrosivity, or reactivity according to the methods set forth in subchapter C of HAR §11-261; and/or
- Knowledge (e.g., known flammable solvent; see also Construction and Demolition Waste Disposal General Guidance (HDOH, 2015 and updates).

Waste that meet criteria for classification of "hazardous" under these methods must be disposed of at a permitted facility. Categorization as a "listed" hazardous waste primarily applies to pure product (e.g., some pesticides) or process wastes (e.g. spent methanol and other solvent) and is not generally applicable to IDW. Hazardous waste regulations most commonly apply to excess soil that fails a leaching test criteria for disposal in a municipal landfill, referred to as the Toxicity Characteristics Leaching Procedure (TCLP). These materials must be managed as hazardous waste and disposed of accordingly at a permitted facility.

Soil, including borehole cuttings, that is not classifiable as hazardous waste can be placed on site or disposed of as follows:

Soil meets Tier 1 EALs for unrestricted land use (e.g., residential):

- No restrictions on reuse provided that DU volume is <100 yd^3 (see HDOH, 2017d).

Soil fails Tier 1 EALs but meets commercial/industrial EALs and appropriate for current site use:

- Place within the area where the soil was collected (surface soil).
- Put back into the boring (subsurface cores);
- Place in an on-site disposal unit (any disposal unit exceeding one cubic yard should be discussed with the HDOH SHWB to evaluate if a permit is required);
- Transport to a HDOH-permitted off-site treatment/disposal facility.

Long-term management under an EHMP is required for soil that fails Tier 1 EALs for unrestricted reuse (or alternative, approved action levels) but is to be left on site (Section 13; see also HDOH, 2007). Soil that fails Tier 1 EALs but meets commercial/industrial EALs should not be placed in otherwise clean areas of the site or taken offsite for reuse at another location.

For decontamination fluids:

- Pour onto ground in area where samples were collected to allow infiltration or evaporation;
- Transport to a HDOH-permitted off-site treatment/disposal facility.

Used disposable tools, PPE, waste rags, towels, packing material, ground cloths, etc., (maximum 100kg per site investigation in order to qualify for small quantity generator exemption; refer to USEPA 1991, 2014).

- Double bag and dispose of in an on-site trash container, at a waste collection center, or a municipal landfill.

Always check with the landfill operators to determine their acceptance and testing requirements (if applicable) for non-hazardous IDW materials being disposed. The generation of hazardous IDW should be minimized. Most routine investigations should not produce any hazardous IDW. The use of solvents for cleaning of equipment should be minimized (USEPA 2014). Solvent-free cleaning procedures for routine cleaning and decontamination as described in Section should be referred to (see also USEPA 2015). If the use of solvents is required, for example at sites impacted with tarry material, the volume should be minimized and mixing of waste solvent with detergent/wash water mixes avoided.

Management and disposal of waste groundwater generated during developing and purging activities is discussed in Section 6 and summarized below. Development and purge water can be disposed of on the ground immediately downgradient of the well provided that it is generated from the uppermost groundwater unit, is not impacted above action levels applicable to the site, does not contain free product or exhibit a sheen, and is not allowed to runoff into a surface water body or storm drain (refer to USEPA 2014). If these criteria cannot be met then the water must be disposed of at an offsite, regulated facility (e.g., municipal landfill or other treatment facility). Development and purge water should not be disposed in monitoring wells. Non-hazardous IDW such as drill cuttings, drilling mud, purge or development water, decontamination wash water, etc., should not be disposed of in dumpsters. [Note that guidance presented above replaces and supersedes guidance presented in the 2009 version of Section 6; scheduled for updates in 2017]

If knowledge of the contaminant or analytical testing determines the IDW falls under hazardous waste regulations then the material must either be (1) managed off-site at a permitted facility approved for the waste or (2) stored securely on-site in accordance with HAR §11-262-34, unless HAR §11-261-5 is applicable. Regulated hazardous waste left on-site must be handled in a fashion that does not pose an immediate threat to human health or the environment. The Solid and Hazardous Waste Branch (SHWB) should be contacted for concurrence with the manner of treatment or handling of IDW characterized as hazardous waste. The proximity of residents and workers in the surrounding area and site security must be considered before deciding to leave hazardous waste on site.

5.11 FIELD WORK COMPLETION

The field investigation team should restore the investigation site once soil sampling and associated field investigation is completed to as close to pre-investigation condition as possible. This includes, but is not limited to the following:

- Demobilization of all equipment (e.g. drill rigs);
- Removal of field-related structures (e.g. temporary field trailers);
- Proper management or disposal of IDW;
- Repair of structural changes made to the site as a result of investigation (e.g., patching or resurfacing of concrete/asphalt surfaces cut for borings).

In particular, after any subsurface soil sampling is completed and if no other field investigation activity is to be conducted within a boring location (e.g., monitoring well installation, product removal) the borehole must be securely closed and sealed. If not properly closed and sealed, boreholes may otherwise act as a conduit for contamination. All procedures and materials for sealing boreholes should be outlined in the SAP for review prior to initiation of the field investigation. The procedures for closing and sealing boreholes recommended by the HEER Office follow those for abandoning and closing monitoring wells, as described in Subsection 6.2.5.

In some instances where follow-on activity at the site is planned but not yet initiated (e.g., subsequent soil removal) or if a potential exposure pathway or other hazard exists (e.g., unstable structure), retaining some structures such as temporary fencing or signage onsite is appropriate and should be implemented and documented in the site investigation report.

The HEER Office strongly recommends that site restoration as close as possible to pre-investigation conditions be documented in photographs, and the photographs be included as part of the site investigation report.

SECTION 5 REFERENCES

Citation references for this TGM Section denoted with an "a", "b", "c", etc… after the year of publication may not appear in sequence as these refer to the order placed in the Master References List for the entire TGM.

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SECTION 6
GROUNDWATER AND SURFACE WATER SAMPLING GUIDANCE

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SECTION 6 ACRONYMS AND ABBREVIATIONS

ASTM	American Society for Testing and Materials
BTEX	Benzene, toluene, ethylbenzene, and total xylenes
CalEPA	California Environmental Protection Agency
DNAPL	Dense Non-Aqueous Phase Liquid
DPT	Direct Push Technologies
DQO	Data Quality Objective
HDLNR	Hawai'i Department of Land and Natural Resources
HDOH	Hawai'i Department of Health
HEER Office	Hazard Evaluation and Emergency Response Office
HNO_3	Nitric acid
IDW	Investigation-Derived Waste
LNAPL	Light Non Aqueous Phase Liquid
mg/L	Miligrams per liter
MGP	Manufactured gas plants
MIBK	Methyl isobutyl ketone
MTBE	Methyl tertiary butyl ether
NJDEP	New Jersey Department of Environmental Protection
NTU	Nephelometric turbidity units
PAH	Polynuclear Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
POC	Purgeable organic compounds
POX	Purgeable organic halogens
PRP	Potentially Responsible Party
PTFE	Polytetrafluoroethylene
PVC	Polyvinyl chloride
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QC	Quality Control
SAP	Sampling and Analysis Plan
SVOC	Semi-volatile organic compound
TOC	Total Organic Carbon
TOX	Total Organic Halogens
TPH	Total Petroleum Hydrocarbons
US Army	United States Department of the Army
US Navy	United States Department of the Navy
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VOC	Volatile Organic Compound

6.0 GROUNDWATER AND SURFACE WATER SAMPLING GUIDANCE

The sampling guidelines presented in this section are intended to ensure that water samples collected as part of an environmental investigation are representative of the in-situ condition of the groundwater or surface water, and that data derived from these samples can be used for decision making purposes. This section also presents guidance for monitoring well construction, purging, and sampling, as well as an overview of sampling equipment available for the collection of groundwater or surface water samples.

This section refers to information in other TGM sections that are relevant to groundwater and surface water sampling. For instance, site investigations may sometimes feature groundwater as the sole media of concern, but groundwater sample collection is most frequently performed as part of a larger investigation that also involves subsurface soil sampling and/or soil vapor sampling. In either case, the initial site preparation and boring/drilling methods described in Section 5 are required for proper installation of monitoring wells.

Prior to sample collection efforts, a site-specific Sampling and Analysis Plan (SAP) and associated Quality Assurance Project Plan (QAPP) should be developed as described in Section 3.0. The SAP designates the types and quantities of samples or monitoring information to be collected; where, when and under what conditions they should be collected; and what variables are to be measured. The Quality Assurance/Quality Control (QA/QC) procedures ensure that sampling design and measurement errors are controlled sufficiently to meet the tolerable decision error rates specified in the Data Quality Objectives (DQO).

6.1 GROUNDWATER MONITORING WELL PLACEMENT

The SAP must identify the site-specific monitoring well design and include a map showing the proposed well locations together with the area(s) of environmental concern and site boundaries. The preferred map scale is 1 inch is less than or equal to 50 feet. The well design and placement must be based on:

1. The Preliminary Conceptual Site Model and other site characteristics data (discussed in Section 3) that describe the site topography, the geologic setting, and the presumed groundwater hydrology
2. The area of environmental concern
3. The contaminants of potential concern
4. Potential receptors such as potable water supply wells, irrigation wells, and surface streams connected to groundwater
5. Influences on hydrology such as injection wells or tidal fluctuation

6.1.1 INITIAL GROUNDWATER INVESTIGATION PHASE

The initial investigation phase described in this section assumes a straightforward scenario consisting of the following conditions: (1) a single point source or area of suspected contamination, and (2) prior groundwater investigation has not been conducted.

The preliminary conceptual model (see Section 3) developed during this phase should include information obtained from published reports such as the Aquifer Identification and Classification Reports: Groundwater Protection Strategy for Hawai'i (Mink, J.F. and L.S. Lau, 1990a; 1990b; 1992; 1992b; 1993; 1993b), published by the Water Resources Research Center at the University of Hawai'i.

The initial phase of the investigation determines whether contaminants have impacted the uppermost water bearing zone including perched groundwater. During this phase, a minimum of three wells are required for each known or suspected contaminant source area. Three wells, if placed at the proper angles relative to one another, will provide sufficient data to establish the local groundwater flow direction through static groundwater level measurements.

Place at least one of these wells in proximity to the source area (i.e., the area known or suspected to have the greatest levels of contaminants). Place at least one of these wells slightly down gradient of the source area (USEPA, 1995c). Place the third well approximately cross gradient so the three wells form a triangle.

During the initial investigation phase, the well screens must extend across the water table and groundwater sampling must include the uppermost water bearing zone, including perched groundwater. Monitoring wells with screens extending across the water table are typically installed with 7 feet of screen interval below the water table (i.e., the saturated interval) and 3 feet of screen interval above the water table. This allows for the assessment of groundwater level fluctuations as well as the accumulation of free product on the water table surface.

6.1.2 SUBSEQUENT INVESTIGATION PHASES

If contamination is confirmed during the initial investigation phase, additional wells may be required to delineate the horizontal and/or vertical extent of the groundwater contamination plume. In general, contamination resulting from petroleum products (which are less dense than water, and float) requires less vertical delineation than contamination resulting from chlorinated solvents (which are denser than water, and sink).

To delineate the horizontal extent of groundwater impacts, monitoring wells are installed cross gradient, up gradient, and down gradient of the source area (identified in the initial investigation phase) to assess contaminant dispersion. The installation of one or more wells upgradient in unaffected areas for the collection of background data is recommended (USEPA, 1995c). Background data are especially important if one or more contaminants of concern occur naturally in the soil and groundwater at the site.

To delineate the vertical extent of groundwater impacts, monitoring wells are installed with successively deeper screen intervals. Screen intervals at multiple subsurface horizons can be accomplished through the use of multi-level wells or through the use of multiple wells in clusters or nests (see Subsection 6.3.9). Multiple well placements in a single borehole are not recommended (USACE, 1998).

When delineating the vertical extent of the plume, it is extremely important to maintain the integrity of any confining units between upper and lower aquifers to prevent the vertical spread of groundwater contamination. When possible, drill to and collect geotechnical samples from the confining unit (for permeability testing) without compromising the integrity of the confining unit. Pumping tests may be required to establish that the confining unit is impermeable and that the underlying water bearing unit is not hydraulically connected to the impacted upper water bearing unit.

6.2 MONITORING WELL INSTALLATION AND ABANDONMENT

Monitoring wells at investigation sites can serve several purposes including the determination of the potential presence, extent, and movement of contaminant plumes in groundwater, as well as the assessment of aquifer characteristics (for use in groundwater models). Monitoring wells must therefore facilitate hydrologic testing and facilitate the collection of representative groundwater samples. There is no "typical" monitoring well for achieving this objective.

Monitoring well construction and materials are a function of the anticipated nature of the contaminants, groundwater quality, desired sampling depth(s), the aquifer's lithology and its overburden, the borehole diameter, and the drilling procedure. Chemical incompatibility could preclude the use of some materials. Soil grain size may dictate the filter material grain size. A deeper or larger diameter well will need a stronger casing than a shallow or smaller diameter well.

To ensure that samples are representative of groundwater conditions, monitoring well design should reflect anticipated contaminant properties. For example, if the contaminant is a light non-aqueous phase liquid (LNAPL), it will float on top of the water table; in this case, the well screen must be installed across the water table. If the contaminant is a dense non-aqueous phase liquid (DNAPL), it will sink to the bottom of the topmost aquifer where it may pool on a confining layer; in this case, the well screen must provide access to the bottom of the aquifer. If the contaminant is soluble in water, it may impact the entire saturated zone; in this case, multiple screen intervals may be required to assess the vertical extent of the dissolved contaminant plume.

In many cases a mixture of different chemicals will be present, including soluble as well as insoluble chemicals. As a practical matter, therefore, monitoring wells may be of various designs on the same site.

Well design also must be protective of the aquifer that it accesses. The well must not provide a pathway for surface contaminants into the aquifer or for contaminant transport between hydraulically separated water bearing units.

6.2.1 PERMANENT MONITORING WELLS

All permanent groundwater monitoring wells have certain design components in common (USEPA, 1991a). A schematic of a standard groundwater monitoring well is presented in Figure 6-1. The monitoring well design components are:

- Casing consisting of solid riser, screen intervals, and a top and bottom cap
- Filter pack(s)
- Annular seal(s)
- Well head protection

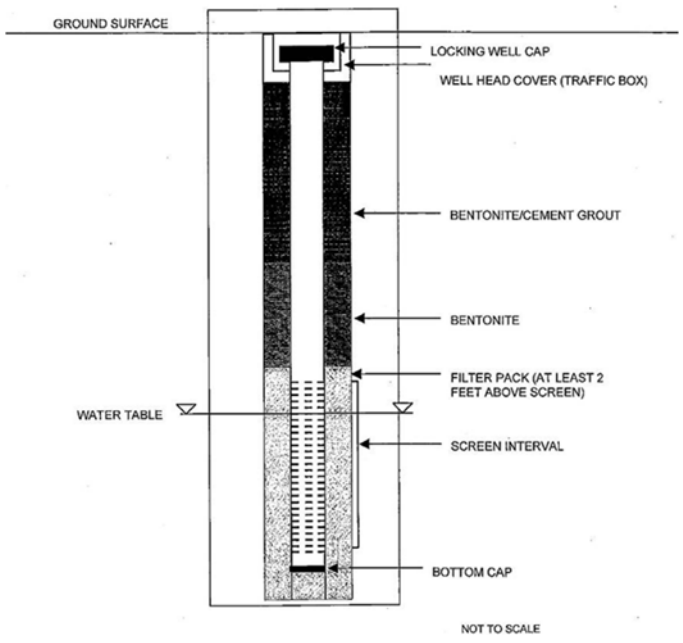


Figure 6-1. Diagram of a Typical Groundwater Monitoring Well

This illustration shows the screen interval across the water table, which is used for the assessment of LNAPLs. [Source: US Navy, 2007.]

6.2.1.1 WELL CASING

In general, the casing consists of a solid well riser and a well screen, which keeps the borehole open and provides access to groundwater for the collection of a water sample. The casing should always include a bottom cap to exclude material from entering the bottom of the well and a top cap to exclude surface material or water from entering the well from the surface.

Well casing materials include steel, polyvinyl chloride (PVC), fiberglass, ABS plastic and polytetrafluoroethylene (PTFE) commonly referred to as Teflon®.

Well diameters range from 1 inch to greater than 12 inches and depend upon the proposed well use. Typical well diameters for environmental investigations are 2 to 4 inches, depending on the objective of the well installation (e.g., site investigation or groundwater remediation) and the proposed monitoring and test equipment. When practical, the casing diameter should not exceed 4 inches to avoid generating large volumes of potentially contaminated soil and groundwater requiring management and disposal during well installation, development and purging activities. Larger diameter wells may be considered for use in free product recovery activities.

Consider the following in the selection of the casing material (USEPA, 1991a; CalEPA, 1995b).

1. The casing material must not alter the groundwater chemistry by leaching, sorbing or desorbing
2. It must be strong enough to withstand the forces acting upon it, such as the hydrostatic pressure
3. It must be resistant to chemical or physical deterioration for the life of the well



Figure 6-2. Portion of PVC Well Screen and Flush Threaded Bottom Cap

The filter pack, typically consisting of clean silica sand is installed around the well screen and allows groundwater to flow into the monitoring well for the collection of groundwater samples.



Figure 6-3. Hollow Stem Auger with PVC Well Casing.

Hollow stem auger with 2 inch diameter PVC well casing. To form the filter pack surrounding the well screen, clean silica sand is poured down the center of the auger as the auger is slowly withdrawn from the subsurface.

For additional guidance on casing material selection, see the following:

- Standard Practice for Design and Installation of Ground Water Monitoring Wells, (ASTM, 2004a).
- Handbook of Suggested Practices for the Design and Installation of Groundwater-Monitoring Wells (USEPA, 1991a).
- Test Methods for Evaluating Solid Waste, Volume II, Chapter 11. SW-846 (USEPA, 1991c).
- Monitoring Well Design and Construction for Hydrogeologic Characterization, Guidance Manual for Ground Water Investigations (CalEPA, 1995b).
- The Chemical Composition of Leachate from a Two-Week Dwell-Time Study of PVC Well Casing and Three-Week Dwell-Time Study of Fiberglass Reinforced Epoxy Well Casing (Cowgill, 1988).
- Sorption of Aromatic Hydrocarbons by Materials Used in Construction of Ground-Water Sampling Wells (Gillham et. al., 1990).
- Adsorption of Selected Organic Contaminants onto Possible Well Casing Materials (Jones et. al., 1988).
- Evaluation of Four Well Casing Materials for Monitoring Selected Trace Level Organics in Ground Water (Parker et. al., 1989).

In general, the well riser and well screen should be of the same material. Various mechanisms are used to join the casing sections. The recommended method uses flush threaded joints, which ease the installation process and the later use of downhole equipment by eliminating ridges on the outside and inside of the casing. An example of a well screen with a flush-threaded bottom cap is illustrated in Figure 6-2.

Joining methods that use solvent welding are not acceptable (USEPA, 1991a), since the practice may introduce solvents into the well. The United States Environmental Protection Agency (USEPA) also excludes the use of welding for stainless steel casings (USEPA, 1991a).

Select the screen for a large percentage of open area, non-clogging slots, resistance to corrosion, and sufficient structural strength (USEPA, 1995c). Select the screen slot size such that it will retain 90 to 100 percent of the filter pack material (USEPA,

1991a). For typical investigations of shallow groundwater in Hawai'i, a 2-inch diameter PVC casing with a screen slot size of 0.020 inches combined with a filter pack constructed of clean silica sand is typically employed.

The maximum recommended screen length is typically 10 feet. The screen length should be kept as short as possible to accomplish the required task. For initial investigations or sites where LNAPLs are present, typical shallow monitoring wells are constructed with 7 feet of screen interval below the water table (i.e., the saturated interval) and 3 feet of screen interval above the water table. This allows for the assessment of groundwater level fluctuations as well as the accumulation of free product on the water table surface.

The casing at the bottom of the well screen must be closed against soil infiltration from the bottom by an attached cap. The bottom of the casing, i.e. the cap, must not be more than 0.5 foot below the bottom of the lowest screen. A solid riser below the screen may lead to stagnant environments, which may alter the groundwater chemistry (USACE, 1998).

The total borehole depth should not be more than 1 meter below the planned bottom of the monitoring well in order to avoid preferential vertical groundwater flow originating from below the well screen. If a borehole extends greater than 1 meter below the planned bottom of the monitoring well, backfill the lower portion of the borehole with a chemically inert, low permeability material such as grout. In highly permeable aquifers, where vertical flow is not a concern, the borehole may be backfilled with chemically inert sand up to the design depth.

The well casing must be free of foreign matter (labels, soil, grease, etc.). Utilize a new and factory cleaned well casing when possible, or wash the casing prior to installation. Washing is not necessary if the casing is used directly out of its intact manufacturer's packaging.

Whenever possible, install the well screen and casing within the center of the drill casing (in most cases, the hollow stem auger). Following placement of the well screen and casing, install the filter pack and annular seal while slowly removing the drill casing from the subsurface. Exercise caution to prevent borehole collapse during installation of the filter pack and annular seal. Figure 6-3 illustrates a 2 inch diameter PVC well casing in place in the center of a hollow stem auger drill rod and the placement of a filter sand pack.

6.2.1.2 FILTER PACK

The purpose of the filter pack is to prevent particle infiltration from the surrounding formation into the well. The filter pack is installed in the annular space surrounding the well casing. In most geologic settings it is necessary to install an artificial filter pack. The use of natural formation material as the filter pack only is not acceptable.

The filter pack must be a chemically inert granular material with a grain-size larger than the screen slots but smaller than the particles in the surrounding formation. Due to its chemical inertness and its abundant natural occurrence, the use of well-rounded, well-sorted silica sand is encouraged. For permanent wells, there should be at least 2 inches clearance around the screen (but no more than 8 inches) to allow for addition of the filter pack and to help prevent bridging during filter pack installation. For example, for 2 inch and 4 inch diameter monitoring well screens/casings, the borehole or auger used should have an inside diameter of at least 6 and 8 inches, respectively (USEPA, 1991a). Placing the filter pack slowly down the borehole will minimize bridging and surging of the well.

The use of well centralizers may be considered for wells deeper than 20 feet. When used, they should be of PVC, PTFE, or stainless steel and attached to the casing at regular intervals by means of stainless steel fasteners or strapping. Centralizers should not be attached to any portion of the well screen.

The filter pack should extend from below the bottom of the well screen to 2 to 5 feet above the well screen, if feasible. In areas of shallow groundwater, a site-specific plan is recommended before installation of the wells begins. The filter pack above the screen interval buffers any settling during well development and maintains the separation of the annular seal from the screen. In deep wells the filter material may not compress when initially installed and subsequent settling may be significant. Therefore, the deeper the well the higher the filter pack must be installed above the top of the screen. In wells more than 200 feet deep, the filter pack must be installed to 5 feet above the screen. Care must be taken to ensure that filter material does not extend across a confining layer into an overlying aquifer.

To prevent intrusion of annular sealant material into the top of the filter pack, consider installing a layer of fine sand between the primary filter pack and the annular seal (CalEPA, 1995b). The secondary filter pack should be at least 6 inches thick, but should not exceed 2 feet.

Calculate and record the volume of filter pack material expected based on the construction design. Also record the actual volume used during well construction. Explain any discrepancy between the calculated and actual volume.

Well development can be performed in two stages: predevelopment and development (see Subsection 6.2.1.7). Predevelopment takes place upon installation of the well casing and filter pack, but prior to placement of the annular seal. Predevelopment may be necessary in aquifers of low permeability. Clean water may be circulated down the well through the screen into the filter pack and out of the top of the borehole to aid in removal of the fines (USACE, 1998). All water introduced into the borehole must be removed. It is therefore important to record the water volume injected and the water volume removed from the well. Do not use this technique if the borehole bridges water bearing units that are not hydraulically connected, since it may induce cross contamination.

6.2.1.3 ANNULAR SEAL

The annular seal extends from the top of the filter pack to the top of the well and generally consists of bentonite (pellets, chips, or powder) or cement, or bentonite/cement mixtures (USEPA, 1991a). Bentonite is a naturally occurring clay mineral that expands upon hydration. Neat cement is a mixture of Portland cement (Type I for general use) and water, at a ratio of 5 to 6 gallons of water per 94-pound bag of cement. The grout must have a minimum design strength of 2,500 pounds per square inch.

The annular seal must prevent vertical migration of liquids into the borehole annular space. The annular seal should:

1. Provide a lasting seal between the borehole and casing that is less permeable than the surrounding formation. The sealant permeability is typically at least one to two orders of magnitude lower than the formation permeability.
2. Be chemically inert to resist chemical deterioration.
3. Resist physical deterioration.

As shown in Figure 6-1, the annular seal consists of a bentonite seal immediately above the filter pack. Above the bentonite seal, a bentonite/cement grout is used as the annular seal to the approximate ground surface.

The annular seal material and placement is dependent upon whether the screen interval is below the water table (fully saturated screen interval) or extends across the water table.

For a fully saturated screen interval, a 3 to 5 foot thick bentonite seal, if feasible, is installed above the filter pack. In areas of shallow groundwater, a site-specific plan is recommended before installation of the wells begins. Pelletized bentonite is preferred for this application. The thickness of the bentonite is measured prior to hydration. The pelletized bentonite must be allowed to completely hydrate in conformance with the manufacturer's instructions prior to filling the remainder of the annular space with a bentonite/cement grout, as described below.

For a fully saturated screen interval, a bentonite seal can be installed through the use of a slurry mixed from powdered bentonite and clean water. It must contain a minimum of 20 percent solids by weight and have a density of 9.4 pounds per gallon or greater. The slurry should have a batter-like, high viscosity consistency. The project plan should provide and discuss the design and installation details for slurry seals since the bentonite/cement grout installed above the slurry seal is usually denser and may intrude into the slurry.

For screen intervals extending across the water table, a 3 to 5 foot thick bentonite seal is also installed above the filter pack. Bentonite pellets and tablets are preferred since bentonite chips have higher moisture content and are slower to swell (USACE, 1998). The bentonite should be installed in 6 to 12 inch lifts and should be allowed to hydrate for approximately 30 minutes prior to installation of the next lift. The bentonite must be allowed to completely hydrate in conformance with the manufacturer's instructions prior to filling the remainder of the annular space with a bentonite/cement grout, as described in Subsection 6.2.5.3. The use of slurry seals when the filter pack is above the saturated zone is not recommended due to the potential for infiltration and clogging of the filter pack.

Following installation of the bentonite seal, the remainder of the annular space is filled with a bentonite/cement grout. The grout must be placed from the bottom up using a tremie pipe equipped with a side discharge.

When installing the bentonite seal and the bentonite/cement grout, calculate and record the volume of bentonite and bentonite/cement grout expected based on the drilling log. Also record the actual volume used during well construction and explain any discrepancy between the calculated and actual volume.



Figure 6-4. Installation of Well Head Protection
Well head consists of flush-mounted well vault sealed with cement above the annular seal.



Figure 6-5. Traffic Rated Flush Mounted Well Head Box



Figure 6-6. Above Ground Well Head Box with Steel Bollard Guards

6.2.1.4 WELL HEAD PROTECTION

Protect the top of the permanent monitoring well casing with a well head box. The purpose of the well head box is to prevent contaminant infiltration into the subsurface and vandalism or damage of the monitoring well. The well head box must allow access to the well with all anticipated measuring devices.

When setting well head boxes, they must be anchored in the surface seal placed above the bentonite/cement grout. A flush mounted box must be set slightly above the surrounding elevation to prevent pooling of surface water on the well. Provide protection from infiltration into the annular space by installing a surface seal made of a water-tight material such as neat cement or concrete. Install the surface seal on top of the annular grout seal so that it extends down to at least one foot below ground surface. The surface seal must form an apron at ground surface that is at least 2 feet wide and 4 inches thick. The concrete apron must slope away from the well (a minimum of 1 percent) to prevent surface water leakage into the well head.

A flush mounted well head box during installation is illustrated in Figure 6-4. A traffic rated flush-mounted well head box installed in a parking lot is illustrated in Figure 6-5. The top of the well casing should be closed with a water tight cap, such as a compression cap.

Protect the well head from unauthorized access by using well head boxes and well caps equipped with locking or tamper proof mechanisms. As needed, install concrete or steel bollards to prevent accidental damage to the well head projecting from the ground surface. Install bollards outside the surface seal apron. An installation featuring guards is illustrated in Figure 6-6. Bumper guards must not be installed in the protective apron to avoid cracking of the surface seal, should a vehicle accidentally hit the guard. In instances where wells are installed in areas where heavy machinery is operated, wellhead protection may require enhanced construction such as well boxes specifically designed to withstand heavy vehicle traffic and reinforcing the concrete.

6.2.1.5 WELL INSTALLATION LOG

Throughout the drilling and well installation process, record detailed observations. It is essential that all relevant data be recorded during the field activities, so that detailed well logs may be generated for inclusion in the final report. Prepare a well installation log for each monitoring well. An example well installation log is illustrated in Figure 6-7.

At a minimum, the log will include:

1. Project name and location
2. Well designation and location relative to contaminant source
3. Date and time of well installation start and completion
4. Environmental consulting company and on-site consultant
5. Drilling company
6. Drilling method
7. Volume of drill fluid and/or pre-development fluid lost into well during installation
8. A graphical depiction of the well
9. Casing material type, diameter, joint type, and screen slot size
10. Filter pack material, calculated and actual volume
11. Annular seal material, calculated and actual volume
12. Annular grout seal material, calculated and actual volume
13. Placement method for filter pack, seal and grout (tremie, pumped, gravity)
14. Borehole diameter
15. Depth to bottom of borehole
16. Depth to bottom of casing
17. Depth to bottom and top of screen interval
18. Depth to bottom and top of solid riser
19. Depth to bottom and top of filter pack
20. Depth to bottom and top of annular bentonite seal
21. Depth to bottom and top of annular grout
22. Depth to bottom of surface seal
23. Depth to the water table
24. Surface seal and well apron design
25. Protective box/casing and cap designs
26. Ground surface elevation
27. Top of casing elevation

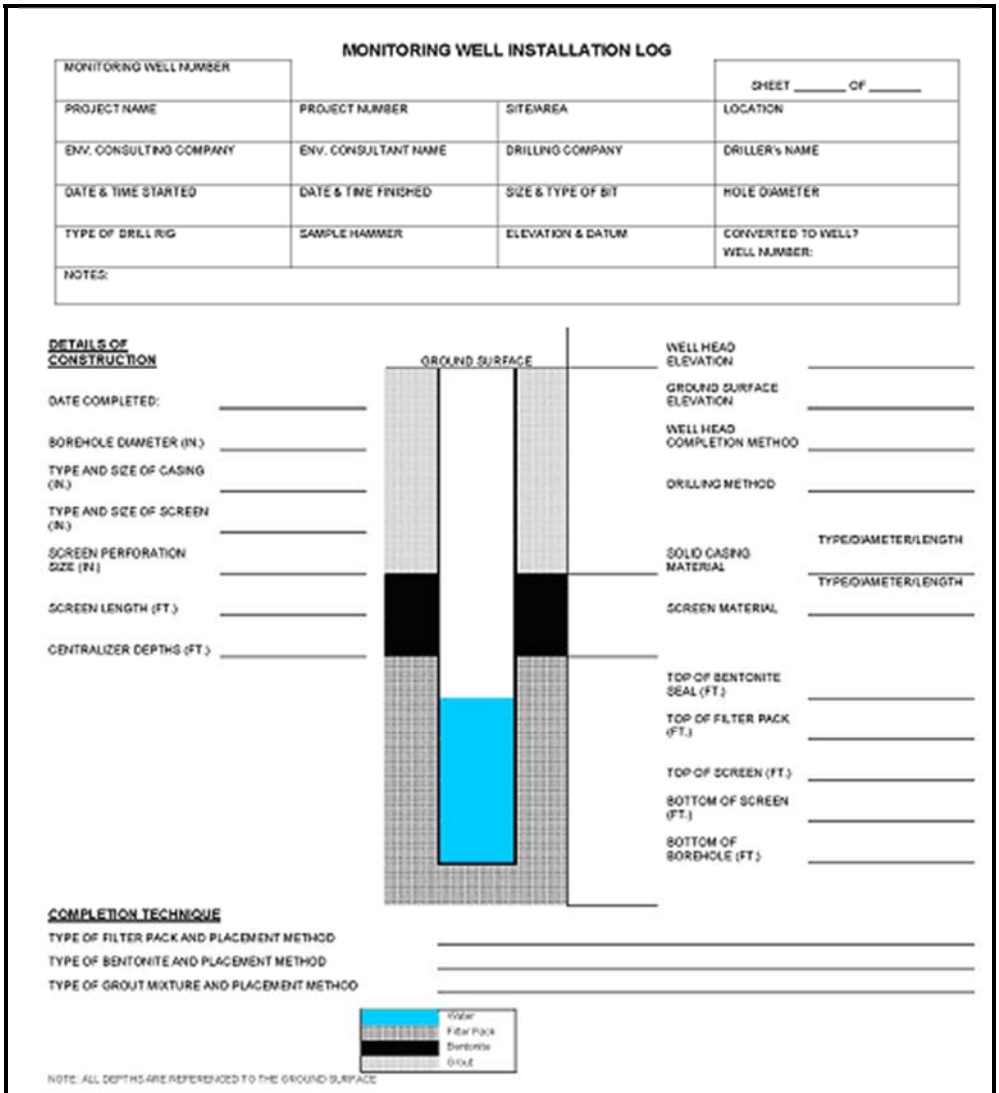


Figure 6-7. Example Monitoring Well Installation Log

6.2.1.6 WELL SURVEY

All wells being used to assess the hydraulic gradient and the groundwater flow direction must be surveyed by a licensed professional surveyor. Record the well locations in the Hawai‘i State Plane Coordinate System. Determine the top of casing elevations within ±0.01 foot. Reference the elevations to an established National Geodetic Vertical Datum. Resurvey the top of well casing if the protective cover and or well casing sustain damage.

The surveyor must mark the surveyed reference point on the top of the casing. Reference all downhole measurements to the surveyed reference point. Using a reference point on other parts of the well head is not acceptable, since other parts of the well head are exposed and therefore are more readily disturbed.

6.2.1.7 WELL DEVELOPMENT

The purpose of well development is to restore the aquifer's hydraulic conductivity following drilling and monitoring well installation. Well development removes drill cuttings, mud, and mobile particulates and gases from the well, the filter pack and the adjacent formation. Development must extract a sufficient water volume from the well casing, filter pack, and adjacent formation such that the resulting inflow is representative of the groundwater flow in the surrounding aquifer.

Final well development proceeds after well installation is completed and the grout has had time to cure. Initiate well development no sooner than 48 hours and no later than 7 days after well completion.

Acceptable well development methods are mechanical surging, pumping, backwashing, bailing, and high velocity hydraulic jetting. The use of air for well development is not acceptable (CalEPA, 1995b; USACE, 1998).

During well development by pumping, water is extracted from the well at high rates, dislodging and removing loose material in the process.

During well development by surging, a surge block is moved up and down in the well similar to a piston in a cylinder. The surge block is usually attached to a drill rod or stem and operated by a drill rig. The movement of the surge block pushes and pulls water through the well screen, dislodging fine particulates from the screen, filter pack and adjacent formation. Surging is alternated with groundwater pumping to remove groundwater and sediment accumulated in the well during surging. Use of a vented, rather than un-vented, surge block is recommended to minimize the volume of water in the well that is forced into the formation on the down stroke of the surge block.

During well development by backwashing, water is pumped through the well into the filter pack and formation. The backwashing dislodges particulates stuck in the well screen and filter pack. Backwashing is alternated with groundwater pumping to remove groundwater and the sediment suspended in the groundwater due to well development. A combination of surging, backwashing, and pumping may be used to develop a well in the presence of fine particulate materials.

During well development by bailing, a bailer is used in a similar manner as a surge block to agitate the well water and dislodge particulates in the filter pack and well screen. After surging, water is removed from the well by withdrawing the full bailer to the surface. When surging with a bailer, a surging period of 10 to 20 minutes is recommended prior to removing water from the well.

During well development by high velocity hydraulic jetting, water is jetted through the well screen from several horizontal jets. The water jet dislodges particulates from the well screen, filter pack and adjacent formation. Hydraulic jetting is alternated with groundwater pumping to remove groundwater and sediment accumulated in the well by jetting.

When using water during drilling, pre-development or hydraulic jetting, at least three times the volume of water added should be removed during well development.

The following criteria are typically achieved during well development (USEPA, 2002b):

1. Removal of at least three times the calculated volume of standing water in the well. The calculated volume of standing water should include the saturated filter pack (assuming 30 percent porosity of the filter pack).
2. The well water pH stabilizes to within plus or minus (±) 0.1 pH units for three successive readings. Readings are separated by the removal of one well volume of water.
3. Well water temperature stabilizes to within ±1 degree Celsius.
4. Well water conductivity stabilizes to within ±3 percent.
5. Well water oxidation-reduction potential stabilizes to within ±10 millivolts.
6. Well water dissolved oxygen concentration stabilizes to within ±0.3 milligrams per liter.
7. The well water is clear to the unaided eye, in areas where the local groundwater is known to be clear and the turbidity readings are below 10 nephelometric turbidity units (NTUs).
8. Turbidity stabilizes to within ±10 percent at concentrations larger than 10 NTU. In areas of known turbid groundwater, the final well water may be turbid to the eye.
9. The sediment thickness in the well is less than 1 percent of the well screen length or less than 0.1 foot for wells with screens less than 10 feet long.

Use the methods listed in Table 6-1 to determine the water quality parameters. For the specific methods refer to the USEPA document entitled "Methods for Chemical Analysis of Water and Wastes" (USEPA, 1983) and the ASTM standards identified in Table 6-1

Table 6-1
Test Methods for Water Quality Parameters

Water Quality Parameter	EPA Method	ASTM Standard
pH	0150.1	D1293, D5464
Temperature	0170.1	
Conductivity	0120.1	D1125
Turbidity	0180.1	D1889
Oxidation Reduction Potential		D1498
Dissolved Oxygen		D888, D5462

If the well recharge rate is so slow that (1) the required water volume cannot be removed within 48 hours of development, (2) excessive sediment remains in the well after development, or (3) high turbidity persists, then the Hawai'i Department of Health (HDOH) Hazard Evaluation and Emergency Response Office (HEER Office) should be contacted for consultation.

During all purging and sampling activities, prevent potentially contaminated water from spilling onto the ground surface surrounding the well. All water and sediment extracted during well development must be placed in containers conforming to requirements of the United States Department of Transportation. The containers must be properly labeled and stored on site pending disposal. The label should include at a minimum: project name, project location, date, container contents, emergency contact name and phone number.

6.2.1.8 WELL DEVELOPMENT LOG

Present a well development log for each monitoring well. ASTM Standard D5521 (ASTM, 2005a) presents additional guidance on groundwater well development. An example well development log is illustrated on Figure 6-8.

At a minimum, the log should include the following information:

1. Project name and location
2. Well designation and location
3. Well construction including total depth of well and screen length
4. Date and time of well completion
5. Date and time of well development
6. Well development technique
7. Average pumping or water extraction rate
8. Estimated recharge rate
9. Static water level from top of casing before development
10. Sediment level from top of casing prior to development
11. Static water level from top of casing- 24 hours after development
12. Sediment level from top of casing- 24 hours after development
13. Volume of liquids lost into well during drilling, predevelopment and development
14. Volume of water standing in the well casing and saturated filter pack, assuming a 30 percent filter pack porosity
15. A running log of:
    a. Time
    b. Water volume removed, both incremental and total
    c. Field measurement of pH, temperature, conductivity, oxidation- reduction potential, and turbidity
    d. Field measurements of dissolved oxygen
    e. Visual and olfactory observations such as color, clarity, passive odor observations, particulates, etc.
16. Total volume of water removed
17. Total time needed for development
18. Investigation derived waste (IDW) inventory including type and number of IDW containers, location of IDW storage

6.2.1.9 TIMELINE FOR DRILLING, WELL INSTALLATION, DEVELOPMENT, AND SAMPLING

Commence monitoring well installation within 12 hours of borehole completion for holes that are uncased or only partially cased with temporary drill casing. For holes that are fully cased with temporary drill casings, commence installation within 48 hours of borehole completion. Once well installation is begun, proceed without interruption until the monitoring well casing is installed and grouted and the drill casing removed (USACE, 1998).

Commence well development no sooner than 24 hours and no later than 7 days after well completion.

The HEER Office recommends that groundwater gauging, purging and sampling be conducted no sooner than 14 days after well development. The 14-day hiatus is a "rule-of-thumb" (USACE, 1998). Guidance from other agencies for the time interval between monitoring well completion and groundwater sample collection ranges from 24 hours (US Navy, 2007) to 48 hours (SC DHEC, 2005) to several weeks (Puls and Barcelona, 1989). Generally, high permeability formations require less time (e.g. 24 to 48 hours) to equilibrate than low permeability formations (e.g. days to weeks).

If a different time frame from 14 days (e.g. 24 to 48 hours) is proposed based upon known site conditions, overall project considerations, or other pertinent information, the interval, rationale, and evidence supporting the proposal must be noted in detail in the SAP or by consultation with the HEER Office.

WELL DEVELOPMENT RECORD

	PROJECT		WELL NUMBER
	JOB NUMBER	LOCATION	RECORDED BY
	AIR TEMPERATURE	WEATHER	SUBCONTRACTOR

METHOD

HAND PUMP _____

SUBMERSIBLE PUMP _____

BAILER _____

OTHER _____

DATE OF DEVELOPMENT

DEVELOPMENT CRITERIA

REMARKS

HOLE DIAMETER D_H =

CASING DIAMETER

INSIDE $D_C ID$ =

OUTSIDE $D_C OD$ =

DEPTH TO:

WATER h =

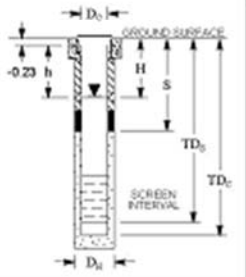
BASE OF SEAL S =

BASE OF SCREEN TD_S =

BASE OF SUMP TD_C =

ESTIMATED FILTER PACK POROSITY P =

Diameters in (inches) : Depths in (feet)



PURGE VOLUME CALCULATION

CASING VOLUME

$V_C = \pi\left(\frac{D_C ID}{24}\right)^2 (TD_C - H) = 3.14\left(\frac{\quad}{\quad}\right)^2 (\quad - \quad)$

= ft^3

FILTER PACK PORE VOLUME

$V_f = \pi\left[\left(\frac{D_H}{24}\right)^2 - \left(\frac{D_C OD}{24}\right)^2\right] (TD_S - (S \text{ or } H)) (P)$

= ft^3

TOTAL WELL VOLUME

$V_T = V_C + V_f =$ $ft^3 \times 7.48\ gal/ft^3 =$ gal

(* If S > H, use S; If S < H, use H)

DEVELOPMENT LOG					CUMULATIVE TOTAL REMOVED		WATER CHARACTERISTICS				COMMENTS
DATE	TIME BEGIN	TIME FINISH	METHOD	WATER REMOVED (GAL)	GAL	WELL VOLUMES	pH	CONDUCTIVITY (mmhos/cm)	TURBIDITY (NTU)	TEMPERATURE (°F)	

Figure 6-8. Example Well Development Log

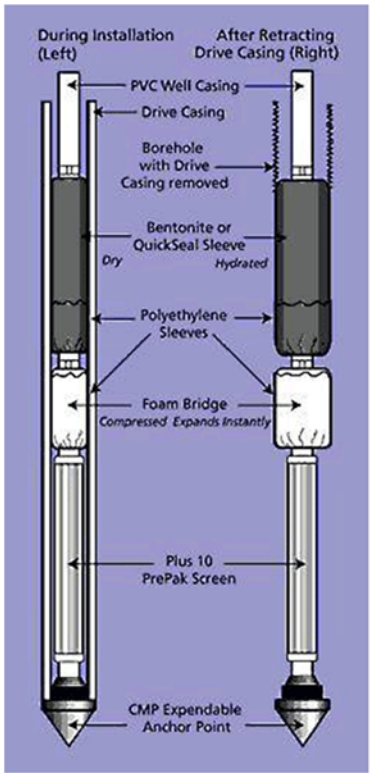


Figure 6-9. Diagram of Pre-Pack Monitoring Well Assembly

Assembly during installation (left) and following retraction of drive casing (right).
[Source: GeoInsight Online, 2008.]

6.2.2 TEMPORARY MONITORING WELLS

Temporary groundwater monitoring wells or sampling points are generally installed in boreholes driven by direct push technology (DPT). After completion of the borehole, a well casing consisting of a solid riser, well screen, and bottom cap is inserted into the borehole. A filter pack may or may not be installed. Hydraulic connectivity to the surrounding formation is then established by purging the monitoring well according to the procedures outlined in Subsection 6.4.

The use of temporary groundwater monitoring wells is not as rigorous as the construction and development of permanent groundwater monitoring wells, and the samples collected may not be representative of the aquifer. However, the information collected from temporary monitoring wells may be useful in screening for potential contaminants of concern or for use in guiding the final placement of permanent monitoring wells during future investigation phases. In general, the use of temporary monitoring wells may present a lower cost alternative to the initial characterization or delineation of potential groundwater impacts.

While the use of temporary monitoring wells may be advantageous in some instances, they are not suitable for long-term monitoring of groundwater or for final decision making purposes. The intended use of data collected from temporary monitoring wells should be described in the SAP and discussed with the HEER Office.

6.2.3 OTHER WELLS

Other wells used for groundwater sampling include micro wells, existing production wells and potable wells. The following sections provide guidance for the use and sampling of these wells.

6.2.3.1 MICRO WELLS

Microwells are also referred to as small diameter monitoring wells. Microwells are generally installed in boreholes driven by DPT and are typically less than 2-inches in diameter. Microwells installed by the direct push method must be constructed using a pre-packed well screen. An example of a pre-packed well assembly designed to be installed via direct push equipment is illustrated in Figure 6-9. A sand grout barrier, installed directly above the pre-packed well screen, prevents grout from entering the screens.

For a microwell, the sand grout barrier shall:

1. Be placed directly above the pre-packed well screen in the annulus between the well casing (riser pipe) and the borehole wall as the probe rods are retracted.
2. Extend not more than 2 feet above the top of the pre-packed well screen.

An annular seal extending from the filter pack to the top of the well should be installed in general conformance with Subsection 6.2.1.3. The annular seal must prevent vertical migration of liquids into the borehole annular space. Installation requirements presented in Subsections 6.2.1.4 through 6.2.1.9 apply to the construction of microwells.

6.2.3.2 PRODUCTION/ POTABLE WELL SAMPLING

Collection of water samples for analysis from wells other than groundwater monitoring wells should be approved by the HEER Office. The request should be accompanied by the following information:

1. Well installation date
2. Well construction logs including casing material, well depth, depth of bottom and top of well screen, filter pack material and depth, seal material and depth
3. Elevation of screen interval
4. Depth to groundwater table and bottom of unconfined aquifer
5. Depth to top and bottom of confined aquifer(s)
6. Contaminants of concern
7. Characteristics of contaminants of concern (LNAPL, DNAPL, solubility etc.)
8. The depth at which contaminants are expected to occur. The depth estimate should be supported by existing site-specific data
9. A description of how the sampling data will be used

Collect raw water samples from a supply well as close to the well head as possible (before any treatment). Purge the well long enough to obtain a representative sample of groundwater with a minimal residence time in the collection/distribution system. The purge volume may be substantial for large diameter wells with long screen intervals.

6.2.4 SPECIAL CONSIDERATIONS FOR MONITORING WELLS

Consider special designs for:

1. Monitoring wells that are intended to permanently hold downhole equipment.
2. Monitoring wells where free-phase LNAPL or DNAPL plumes are anticipated.
3. Monitoring wells that are installed in fractured bedrock.
4. Monitoring wells that are installed in semi-confined caprock.

6.2.4.1 MONITORING WELLS WITH PERMANENT DOWNHOLE EQUIPMENT

Dedicated sampling equipment that will reside within a groundwater monitoring well must not alter the chemistry of the groundwater and must be resistant to chemical or physical deterioration. Inspect the equipment periodically for damage, deterioration, and proper operation. The equipment must not interfere with aquifer tests, well maintenance, and water level measurements (CalEPA, 1995b).

6.2.4.2 MONITORING WELLS AT SITES WITH LNAPL PLUMES

If free phase LNAPL plumes are present or suspected to be present, design and install wells to provide access to the part of the aquifer where the free-phase plumes reside. For LNAPL plumes, provide sampling access across the water table and capillary fringe of the uppermost water bearing unit. If the aquifer in question is tidally influenced, free phase liquid may be trapped in pore spaces below the capillary fringe when the water table is at its highest and above the capillary fringe when the water table is at its lowest.

In addition, provide access to the part of the aquifer where dissolved phase contaminants are expected. To delineate the dissolved contaminant plume vertically, screen wells below the depth of the LNAPL plume. In a tidally influenced aquifer, the

uppermost sampling interval for dissolved contaminants must be below the free phase plume smear zone. In addition, install wells cross, up and down gradient to delineate the horizontal extent of the free phase and dissolved contaminant plumes.

6.2.4.3 MONITORING WELLS AT SITES WITH DNAPL PLUMES

Most DNAPLs that are commonly found in soil and groundwater contamination fall into four groups (USEPA, 2004c):

1. Chlorinated solvents used in metal finishing, semiconductor manufacturing, dry cleaning, chemical manufacturing, and equipment maintenance
2. Creosote mixtures used in treating wood products
3. Polychlorinated biphenyls (PCBs) used primarily in electrical transformers and condensers
4. Byproducts (e.g., coal tars and oils) from manufactured gas plants (MGP)

The tendency of DNAPLs to move independently of groundwater flow makes it difficult to delineate and remediate free phase DNAPL plumes. Most DNAPLs are slightly soluble or contain components that are soluble. Some of these soluble ingredients are deemed to be a great health risk and environmental risk, and clean up goals are set at low dissolved concentrations. If a free phase DNAPL plume resides in the saturated zone, it becomes a constant source for dissolved contaminants. Therefore, it is important to locate and remediate the free phase plume.

Most DNAPLs are relatively immiscible in water and tend to remain in a separate non-aqueous phase due to their low solubility. If their density is sufficiently high compared to water density and they are present in a great enough free phase volume, they will sink through the saturated zone and pool on the uppermost confining unit. DNAPLs with a high enough density, therefore, migrate vertically rather than following groundwater movement. In addition, they may migrate according to the slope of the uppermost confining unit, which may differ from the regional groundwater flow direction. The migration of DNAPLs with a density (specific gravity) closer to 1 will be influenced by groundwater movement to a greater degree.

The USEPA has published a guidance document that helps in the selection of delineation techniques at DNAPL contaminated sites. The document is entitled: "Site Characterization Technologies for DNAPL Investigations." Techniques entail geophysical as well as non-geophysical methods for characterization. The following DNAPL properties help in selecting the appropriate delineation techniques (USEPA, 2004c):

- As a chemical class, DNAPLs are electrically resistive (non-conductive)
- Chlorinated solvents are generally volatile and may be found in soil gas plumes
- The dissolved phase of chlorinated solvents is relatively mobile and sufficiently soluble to be readily detectable
- Most PCBs are not volatile and are not sufficiently soluble to be readily detectable in groundwater. The lighter end PCBs do have some solubility [3 milligram per liter (mg/L) range] and will volatilize to some extent
- Coal tar byproducts are a mixture of phenols and cresols; the aromatics benzene, toluene, ethylbenzene, and xylenes (BTEX); naphthalenes and light oils; and tars and heavy oils rich in polynuclear aromatic hydrocarbons (PAH). The aromatics and smaller polynuclear aromatics are volatile and sufficiently soluble to be detected as a groundwater plume
- Coal tar creosote mixtures are very diverse and may or may not be associated with groundwater plumes. They may contain several chemicals that fluoresce

The HEER Office requires that both the free phase and dissolved plumes are delineated at DNAPL sites. Borings and groundwater monitoring wells should be designed to accommodate the selected investigation techniques.

6.2.4.4 MONITORING WELLS IN FRACTURED BEDROCK

In fractured rocks, the fractures form a net of connected discontinuities. These discontinuities form the main passages for fluid flow, and the rock matrix between the fractures are considered impermeable. Whether a continuum approach or discontinuum approach is applied to the site depends on the connectivity and density of the fracture net compared to the scale of the project site. Choose a continuum approach if the fracture net across the site is dense enough that the fractured formation is hydraulically equivalent to a porous medium (Domenico et. al., 1990).

In most cases, on the scale of a typical response site, the condition of hydraulic equivalence to a porous medium is not satisfied. The flow must be described in relation to individual fractures and fracture sets. This has many consequences. For example, in a hydraulically isotropic, porous formation, the groundwater flow direction is perpendicular to the equipotential lines of the water table or potentiometric map. This assumption cannot be made in a fractured formation, since the flow direction will follow the fracture orientation. The following parameters need to be known to describe flow in fractured rock: orientation, fracture density, degree of connectivity, aperture opening, and smoothness of fractures (Domenico et. al., 1990).

The environmental consultant must carefully plan well placement and design, in fractured bedrock, and discuss the basis and assumptions in the SAP.

Guidance on hydrology in fractured rock is available at the United States Geological Survey (USGS) website (USGS, 2008). The USGS has been researching the hydrology of fractured rocks under its National Research Program and has compiled a reference list of its research spanning from 1998 to the present. This reference list is available on the USGS web site.

6.2.4.5 MONITORING WELLS IN CONFINED AQUIFERS

Confined aquifers are saturated zones that occur below a confining geological layer or unit. The confining layer or unit, referred to as an aquitard, prevents water contained in the aquifer from rising to its elevation of hydraulic equilibrium. The elevation of hydraulic equilibrium for a confined aquifer is the potentiometric surface. The potentiometric surface for a fully saturated confined aquifer lies above the bottom of the confining unit.

The aquitard prevents hydraulic communication between a confined aquifer and an overlying or underlying aquifer. The degree of hydraulic separation of the aquifers adjoining the same aquitard depends on the difference in permeability between the aquitard and aquifers. Hydraulic separation also prevents cross contamination between the aquifers.

Any boring and well installation that penetrates a confining unit becomes a potential pathway between the water bearing units and can result in cross contamination.

In many cases, the overlying aquitard protects the underlying confined aquifer from contamination. To determine if the confining layer will prevent cross contamination, collect soil samples from the aquitard for permeability testing. In addition, the HEER Office may require pumping tests to prove hydraulic separation. Soil sampling of the aquitard and pumping tests must be performed outside the contaminant plume(s) to avoid cross contamination of the confined aquifer.

Further investigations of the confined aquifer will be based on the outcome of the permeability test and pumping test. Design borings and wells that penetrate into the confined aquifer such that they do not open vertical water and contaminant pathways. Keep in mind that a well installed into a confined aquifer may be artesian and plan accordingly.

6.2.5 MONITORING WELL ABANDONMENT

The purpose of well abandonment is to prevent surface water from infiltrating into the subsurface and to prevent vertical groundwater movement within the aquifer (HDLNR, 2004). By eliminating water movement vertically within the former borehole, the borehole will cease to be a potential conduit for contaminant dispersion (USEPA, 1991a).

A groundwater monitoring well that is no longer needed, sustains damage serious enough to potentially affect the well's structural integrity, or is determined to be improperly installed must be decommissioned. The HEER Office will typically only issue "No Further Action" letters after submittal of sufficient documentation to verify that monitoring wells and soil borings are properly abandoned in accordance with this guidance. Any exceptions are judged on a site by site basis and approved by the HEER Office.

The well abandonment guidance presented in this document does not address any other county, state, or federal agency requirements; nor does it serve to absolve the owner of any responsibilities associated with past use of the well or any event that may occur after the well is decommissioned to the satisfaction of the HEER Office.

6.2.5.1 WELL ABANDONMENT PLANNING

All soil borings and groundwater monitoring wells will eventually require decommissioning and closure in accordance with the guidance provided in this document. Soil borings cannot remain open under any circumstances. Soil borings must be pressure grouted as detailed below. For wells with a diameter exceeding 12 inches, revised procedures should be submitted to the HEER Office for approval.

If soil borings and monitoring wells are constructed without HEER Office oversight, provisions must still be made for the decommissioning and closing of the borings and wells in accordance with the guidance provided in this document.

Notify the HEER Office at least one week prior to any well abandonment operations. A representative from the HEER Office may elect to be on site to witness the well or boring decommissioning. If so, the potentially responsible party (PRP) will be notified.

If borings/wells have been decommissioned without proper notification of the HEER Office, the PRP may be required to re-excavate the borings/wells and close them under proper HEER Office supervision.

A geologist or soil engineer should plan, supervise, and document well abandonment.

6.2.5.2 WELL ABANDONMENT PROCEDURES

The HEER Office recognizes three abandonment procedure options. Note that of the three options presented in this guidance, express advance approval must be sought from the HEER Office for the third option (Remove Well Materials and Backfill with Clean Soil). Descriptions of the options follow:

Option 1: Remove Well Material and Grout

1. Retain a geotechnical or environmental consultant to plan, supervise and document the abandonment procedures.
2. Notify the HEER Office at least one week in advance of the fieldwork.
3. Pull or overdrill and remove the entire casing from the borehole together with the annular fill.
4. Remove any sediment or sludge to the original well/borehole depth.
5. Pressure grout the borehole to within 5 feet of ground surface or to above the groundwater table, whichever is shallower (CalEPA, 1995b). Pressure grouting is described in more detail in Subsections 6.2.5.3 and 6.2.5.4.
6. Calculate the required volume of grout based on the depth and diameter of the borehole and record. Also record the volume actually used. Explain any discrepancy between the calculated and actual volume.
7. Remove the surface seal and protective surface box.
8. Backfill the top of the borehole with clean soil and match the surrounding surface completion (asphalt, concrete, soil, other).
9. Documentation must, at a minimum, include the information required for the completion of the "Abandonment of Monitoring Well Summary Report" (included in Section 18).

Option 2: Perforate and Grout Well Casing

1. Retain a geotechnical or environmental consultant to plan, supervise and document the abandonment procedures.
2. Notify the HEER Office at least one week in advance of the fieldwork.
3. Remove any sludge or sediment from the well.
4. Rip or perforate the entire well casing.
5. Pressure grout the well to within 5 feet of ground surface or to above the groundwater table whichever is shallower (CalEPA, 1995b). Pressure grouting is described in more detail in Subsections 6.2.5.3 and 6.2.5.4.
6. Calculate and record the required volume of grout based on the depth and diameter of the borehole. Record the volume actually used. Explain any discrepancy between the calculated and actual volume.
7. Remove the well head including the surface seal and the uppermost 3 to 5 feet of casing.
8. Backfill the top of the borehole with clean soil and match the surrounding surface completion (asphalt, concrete, soil, other).
9. Documentation must at a minimum include the information required for the completion of the "Abandonment of Monitoring Well Summary Report" (included in Section 18).

Option 3: Remove Well Materials and Backfill with Clean Soil

This option may be used only in areas where groundwater is not a current or potential source of drinking water or where contamination has not been left on-site. Express advance approval must be obtained from the HEER Office for this option.

1. Retain a geotechnical or environmental consultant to plan, supervise and document the abandonment procedures
2. Notify the HEER Office at least one week in advance of the fieldwork
3. Pull or overdrill and remove the entire casing from the borehole together with the annular fill
4. Remove any sediment or sludge to the original well/borehole depth
5. Backfill the borehole to within 5 feet of ground surface or to above the groundwater table whichever is shallower
6. The backfill must be composed of silty clay or clayey silt, free of deleterious materials. Any rock aggregates within the soil must not exceed 1 to 2 inches in diameter and constitute less than 50 weight percent of the backfill. Use on-site soil where possible. Documentation (generally by laboratory analysis) that the soil is not impacted by contaminants should be presented to the HEER Office in advance for approval when using this option
7. Keep the moisture content of the soil at an optimum for compaction. Add clean water as needed
8. Place the soil into the borehole in thin lifts and compact using mechanical means. Use this backfilling method to a depth of 5 feet below surface grade
9. In the upper 5 feet, compact the soil with appropriate compaction equipment to match or exceed the surrounding soil density. Field soil density tests are not a requirement for the summary report. However, provisions must be made to allow for additional compaction if satisfactory compaction cannot be achieved by the prescribed method as determined by the HEER Office
10. The HEER Office considers the backfilling complete when the final lift for the well and any ancillary excavations is compacted, and its finished grade matches the surrounding grade. Surface completion must match the surroundings (asphalt, concrete, soil, other)
11. Calculate and record the required volume of backfill based on the depth and diameter of the well. Record the volume actually used. Explain any discrepancy between the calculated and actual volume

12. Documentation must at a minimum include the information required for the completion of the "Abandonment of Monitoring Well Summary Report" (included in Section 18)

If unanticipated conditions arise during well closure that prevent the execution of the prescribed procedures, halt the field work until the HEER Office concurs with the procedural changes needed to complete well abandonment.

Properly manage all waste generated during well abandonment, label any containers used and store on site until disposal. Record the waste management method used as well as numbers and contents of any containers in the field log. Track the waste until final disposal. Complete proper disposal manifests. Any manifests should be documented in the project report files provided to the HEER Office.

6.2.5.3 GROUTING

Any grouting must proceed from the bottom of the well up to the top using a tremie pipe. Feed the grout into the borehole/well under pressure to ensure adequate penetration of the annular space and surrounding formation. Submerge the tremie pipe opening in the grout by two feet or more to prevent bridging. Free-fall placement of grout into the borehole is not acceptable (USEPA, 1991a; CalEPA, 1995b; USACE, 1998).

When the grout has reached to 5 feet below surface, leave it to settle and cure. After 24 hours, check the grout for settling and add additional grout as needed. Repeat checking and adding of grout as needed (USACE, 1998). The HEER Office will consider the grouting complete when the neat cement has hardened and no settlement has occurred.

If it is anticipated that the well location will have to be located in the future, a piece of metal such as rebar may be embedded into the grout near the surface to allow locating of the well location via toning.

Calculate and record the volume of grout required to complete the abandonment. Also record the actual volume used, and explain any discrepancy between the two.

6.2.5.4 GROUT COMPOSITION

Grouting materials acceptable for use to permanently abandon wells and borings are neat cement, concrete, sand-cement slurry, or cement-bentonite mixture (HDLNR, 2004). Cement used for these mixtures shall conform to the requirements of ASTM C150 for Portland cement, Type I (hereafter referred to as "Portland cement"). The different grout types and their mixtures are described as follows:

1. Neat Cement. Neat cement shall be mixed at a ratio of one 94-pound sack of Portland cement to not more than six gallons of potable water.
2. Concrete. Concrete shall contain 5.3 sacks of Portland cement per cubic yard of concrete and a maximum of 7 gallons of water per 94-pound sack of cement. The aggregate shall consist of 47 percent sand and 53 percent coarse aggregate conforming to ASTM C33.
3. Sand-Cement Slurry. Sand-cement for grouting shall be mixed at a ratio of not more than one part sand to one part Portland cement, by weight, and not more than six gallons of water per sack of Portland cement. Clean well-sorted sand shall be used.
4. Cement-Bentonite. A slurry of Portland cement, bentonite and water. The amount of bentonite added shall not exceed 8% bentonite per dry weight of cement (7.5 pounds of bentonite per 94 pound sack of cement). The volume of water used in preparing these slurries is limited to three quarters (0.75) of a gallon per 94 pound sack of cement for each 1% of bentonite added. The actual percentage of bentonite for a specific location should be based on the degree of volume expansion needed.

Different types of grout mixtures can be used for well abandonment. The materials selected depend on field conditions and long-term needs for each location (HDLNR, 2004). The HEER Office recommends use of cement-bentonite grout for the saturated zone for most monitoring well abandonments. It is not recommended to use neat cement in the saturated zone, particularly if the groundwater is acidic. Water with an acidic pH may corrode the cement (USEPA, 1991a). The rationale for the choice of grout mixture should be documented in the project-specific workplan and include consideration of factors such as depth and width of the soil boring or well borehole, and water composition in the saturated zone. After grouting, all wells must be sounded to determine if the grout has settled.

Grout should have a minimum design strength of 2,500 pounds per square inch. Strength capabilities may be demonstrated by documenting proper mix proportions and procedures based on the specific type of grout used. If cement/grout is ordered as a ready mix from a vendor, a verification of mixture (e.g., purchase order or receipt with order specification) should be submitted as part of the documentation of soil boring or well abandonment in the investigation report. The receipt must document that the grout was mixed as specified in this document and that it had the specified design strength. In instances where the depth of the well to be abandoned is greater than 100 feet, or where there is a specific need to withstand high load stress (e.g., high traffic

areas or locations where heavy equipment is used), a materials testing laboratory should be used to test the final cement for 7-day and 28-day compressive strength.

One mix of cement-bentonite may be used for both the water-bearing and vadose zone when abandoning wells in locations where load-bearing is not a concern and where groundwater is encountered at a depth of less than 20 feet below ground surface.

6.2.5.5 WELL ABANDONMENT REPORTING

Report well abandonment to the HEER Office within 30 days of fieldwork using the "Abandonment of Monitoring Well Summary Report" presented in Section 18. Alternatively, if this form is included in a site closure, monitoring or investigation report, submit the report within 60 days of well abandonment. Submit the following information together with the form (i.e., Abandonment of Monitoring Well Summary Report):

1. A copy of the original boring log
2. The well construction log
3. An abandonment log
4. A site map showing the location of the abandoned monitoring well
5. Disposal documentation for wastes generated during the abandonment process

6.3 GROUNDWATER GAUGING

The purpose of groundwater gauging is to construct a groundwater table map or a potentiometric surface map for the site under investigation. The data are used to calculate the hydraulic gradient(s) and the horizontal groundwater flow direction(s) across the site. Therefore, all measurements must be taken within a 24-hour period or less. Certain conditions require that measurements are taken within a shorter time period. These conditions include (USEPA, 1999a):

- The magnitude of the observed changes between wells appears too large.
- Atmospheric pressure changes occur.
- Aquifer is tidally influenced.
- Aquifer is affected by river impoundments and/or unlined ditches.
- Aquifer is stressed by intermittent pumping of production wells.
- Aquifer is recharged due to precipitation events or irrigation.

If time restrictions require the use of more than one measuring device, calibrate the devices against each other at the start or end of the work day. Calibrate the devices by comparing measurements in a single well. If free phase product is present at the site, the calibration well must contain free phase product to ensure proper calibration. In this case, calibrate the devices at the end of the day. To calibrate instruments at the start of the day, select a clean or the least contaminated well.

Gauge wells starting with the cleanest well and proceeding in order of increasing contaminant levels. Decontaminate the measuring device at the start and end of the day and between wells. Ensure that the decontamination procedures are adequate for the contaminants present.

The HEER Office requires a minimum of two rounds of groundwater gauging to verify the groundwater gradient(s) and flow direction(s). The two gauging events must be separated by a minimum of 30 days. Ensure that wells are continually connected to the aquifer, if gauging events are repeated over prolonged periods of time. Purge/redevelop wells as needed to reestablish hydraulic connectivity and equilibration with the aquifer.

On sites that are tidally influenced, perform a tidal study to determine the net groundwater flow direction. If site investigation, monitoring and remedial efforts continue over a year, include seasonal groundwater gauging into the investigation to determine the influence of seasonal variations in the aquifer.

Correct the measured groundwater elevations for tidal influences, barometric influences, and overlying free product thickness.

6.3.1 MONITORING WELL EQUILIBRATION

During well development, a large amount of groundwater is pulled through the surrounding formation as well as the filter pack and the well casing. This may disturb the chemical equilibrium of the surrounding formation with the groundwater. In addition, the filter pack may not reach chemical equilibrium with the aquifer.

Time must be allowed for chemical equilibration of the filter pack and the surrounding formation with the aquifer before the well may be sampled. At the same time, hydraulic equilibrium with the aquifer should be attained. This is especially important in low permeability aquifers, where water extraction during well development may draw down the aquifer adjacent to the well.

The HEER Office recommends that groundwater gauging and sampling be conducted no sooner than 14 days after well development. However, equilibration time may be based on site-specific factors. If a different time frame from 14 days is proposed based upon known site conditions (e.g. evidence of high hydraulic conductivity, either for the site itself or immediately surrounding area), overall project considerations, or other pertinent information, the interval, rationale, and evidence supporting the proposal should be noted in detail in the SAP or documented through consultation with the HEER Office. Additional discussion on equilibration is provided in Subsection 6.2.1.9.

6.3.2 DEPTH-TO-WATER MEASUREMENT

Reference all water level measurements to the survey mark at the top of the casing. The reference point must be surveyed and marked as detailed in Subsection 6.2.1.6, Well Survey. Use either a weighted steel tape with chalk or an electronic water level

indicator to measure the depth to water (USEPA, 2002b and 1999a). Select the measuring device carefully for wells deeper than 200 feet to ensure that the tape does not stretch (USEPA, 2002b). The measurement must be taken with an accuracy of ±0.01 feet.

Wells with submerged screens should have the well cap removed at least 15 minutes prior to gauging to eliminate the effects of rising or falling water levels prior to the gauging event. Rising or falling water levels prior to removing the well cap will create either pressure or a vacuum on the well that will impact the water level in the well unless sufficient time is allowed for the well to equilibrate. In addition, wells with submerged screens should be gauged continuously for several minutes to document that the water level has equilibrated.

If groundwater sampling is to be completed on the same day, measure the depth to water prior to sampling.

Calculate the water table/potentiometric surface elevation by subtracting the depth to water from the reference point elevation. Correct elevations for tidal, barometric and free phase density influences.

6.3.3 TOTAL WELL DEPTH

Measure the total well depth by lowering the probe to the bottom of the well and referencing the depth to the surveyor's mark. Note whether silt is encountered at the bottom of the well. Repeat the total well depth measurement at least once to confirm the measurement (USEPA, 1999a).

If groundwater sampling is to be completed on the same day, measure the total well depth after sampling has been completed to prevent suspension of silt into the water column (USEPA, 1999a).



Figure 6-10. Oil-water Interface Meter
[Source: Solinst, 2008]

6.3.4 FREE PRODUCT MEASUREMENT

Measure wells with free phase product last. Use an oil-water interface probe manufactured for use in free-phase product (See example in Figure 6-10). Measure the depth to the top and bottom of the free phase in reference to the surveyor's mark at the top of the casing. In LNAPL plumes, this would be on top of the water column; in DNAPL plumes at the bottom of the well.

Correct the water table elevation for the thickness of the free product floating on top of the water column. The corrections have to be based on the actual density of the LNAPL present at the site.

6.3.5 WELL GAUGING LOG

At a minimum record the following information on groundwater monitoring logs:

- Date

- Project name and location
- Field personnel
- Measuring devices used
- Calibration of measuring devices against each other
- For each well record:
    - Time of measurement
    - Depth to free product
    - Depth to groundwater
    - Depth to bottom of well
    - Observations (casing condition, well head condition, odor, color, sheen, silting, etc.)
- Activities that may influence water level (groundwater pumping, irrigation, etc.)
- Decontamination procedures

6.3.6 TIDAL EFFECTS

Aquifers at sites in proximity of the ocean with water table or potentiometric surface elevations close to sea level often show tidal influences. Tidal sea level changes result in changes of hydraulic pressure at the shoreline, where groundwater flows into the ocean. As the tide rises, hydraulic pressure increases and causes backpressure into the aquifer.

The larger the permeability or hydraulic conductivity of the aquifer formation, the farther the backpressure is felt inshore. The tidal efficiency and tidal lag of each well is dependent on its distance from the ocean and the hydraulic conductivity of the formation between the well and the shoreline.

6.3.6.1 TIDAL STUDY

Completion of a tidal study may be necessary at sites that are tidally influenced. Continually gauge and record groundwater elevations at the site for a minimum period of 72 hours. Gauge at least three monitoring wells on small sites and more wells on larger sites. In addition, measure the water elevation in the ocean in a place protected from wave action. Enclose the pressure gauge in a stilling well to filter out most of the surface ripples. If gauging in the ocean is not possible or no protected area can be found nearby, use tidal charts corrected for the site. Record gauging data at a frequency of six minutes or less. Synchronize data logging between all pressure gauges.

Calculate the groundwater gradient and flow direction for each sampling time. Calculate the net groundwater gradient and net flow direction.

Compare the times of tidal fluctuations between the ocean and each monitoring well to determine the tidal lag of each well. Compare the groundwater elevation changes within each well to the sea level changes to calculate the tidal efficiency (percent of groundwater elevation change compared to sea level change).

On a map, present the groundwater flow directions as they change throughout one tidal cycle. Present the groundwater gradient for each flow direction. In addition, present the net groundwater flow direction and gradient on the same map. If variations are seen between tidal cycles, present each tidal cycle on a map.

6.3.6.2 GAUGING AT TIDALLY INFLUENCED SITES

Groundwater gauging at tidally influenced sites requires careful planning. Choose the date and time of gauging according to tide charts. Choose the date when tidal fluctuations are minimal, such as on quarter moons. Choose the time of gauging when fluctuations in the wells are minimal. For example, bracket the time of high tide or low tide. Correct the times for tidal lag. Follow the same criteria for each gauging event.

Involve sufficient field personnel to accomplish gauging within a period of no more than 2 to 3 hours. Choose a reference well. Use the reference well to calibrate the field instruments against each other. Gauge the well at a minimum every half an hour between gauging other wells.

Assume that the change in groundwater elevation within the reference well is linear throughout the half hour between measurements. Use the linear regression of the groundwater elevation change in the reference well to correct the groundwater elevations for all wells for tidal influence. On sites with large variations in tidal efficiency choose more than one reference well.

6.3.7 SEASONAL EFFECTS

Groundwater flow may exhibit significant seasonal variations between the dry season and the wet season in Hawai‘i. Characterizing seasonal and temporal variations in groundwater flow is important at sites where the groundwater flow direction may change due to seasonal variations. It is also important for site investigations involving aquifer tests.

Initially, weekly or monthly water level measurements may be needed to characterize seasonal fluctuations, followed by quarterly or semi-annual monitoring after the water level variations have been described (CalEPA, 1995a).

6.3.8 TEMPORAL VARIATIONS

In addition to tidal and seasonal variations, the following processes can introduce temporal variations in the groundwater table/potentiometric surface and possibly in the groundwater flow direction (USEPA, 1992d; CalEPA, 1995a):

- Barometric effects
- Variations in precipitation and runoff/recharge rates
- On-site or off-site well pumping, recharge, and discharge
- Changes in land use by altering recharge or discharge patterns (e.g. paving, damming of rivers)
- Changes in lagoons, ponds, or stream stage
- Deep well injection

Identify and evaluate factors that result in short- or long-term variations in groundwater elevations and flow patterns. Measure the water levels frequently enough to detect and characterize temporal variations in groundwater flow.

6.3.9 DETERMINATION OF VERTICAL HYDRAULIC GRADIENT AND FLOW DIRECTION

Determine the vertical hydraulic gradient and flow direction on sites where vertical groundwater flow is significant. A deep vertical extent of a dissolved contaminant plume is an indication that vertical groundwater flow is significant.

To determine the vertical component of groundwater flow, install multiple piezometers or wells in clusters or nests, or multi-level wells or sampling devices. A piezometer or well nest is a closely spaced group of piezometers or wells screened at different depths, whereas a multi-level well is a single device providing access to more than one depth in a single well.

Both piezometer/well nests and multi-level wells allow for the measurement of vertical variations in hydraulic head. To obtain reliable measurements, consider the following criteria in the evaluation of data from piezometer/well nests and multi-level wells (USEPA, 1992d):

- Data obtained from multiple piezometers or wells placed in a single borehole may be erroneous. Sealant from one piezometer or well may migrate into the screened interval of another.
- Drilling and installing a piezometer close to others in a cluster may cause disturbance in the formation around neighboring piezometers.
- Water levels measured in piezometers that are closely-spaced, but separated horizontally, may produce imprecise information regarding the vertical component of groundwater flow

Installation of multiple piezometers closely spaced or within the same borehole is difficult, and evaluation of the data has large uncertainties. The limitations can be overcome by installing a single multi-level monitoring well or sampling device in a single borehole. Refer to the USEPA document entitled "Handbook of Suggested Practices for the Design and Installation of Groundwater-Monitoring Wells" (USEPA, 1991a) for a discussion of the advantages and disadvantages of these types of devices.

Install a minimum of two piezometer nests or multilevel monitoring wells on site. The two or more measurement points must be aligned parallel to the horizontal groundwater flow direction. During groundwater gauging in the piezometers, follow the procedures for groundwater gauging detailed in Subsection 6.3.

Calculate the vertical groundwater flow directions and hydraulic gradient using the water level measurements. Generate a vertical cross section across the measuring points depicting the flow net, piezometer screen depths and length of screen interval, geological units, and water bearing units.

Refer for guidance (USEPA, 1989a; Cedergren, 1977; and Freeze et. al., 1979) on construction and evaluation of flow nets in cross sections (vertical flow nets). The design of the piezometer arrangement must be discussed in the SAP.

6.4 PURGING

The purpose of well purging before groundwater sampling is to ensure that the samples will be representative of the groundwater and contaminant levels in the vicinity of the well. If a well is left untended for prolonged periods, the water contained within the well and possibly within the filter pack may not be representative of the surrounding aquifer formation water. For example, water extending above or below the well screen may be stagnant and may have undergone physiochemical changes, such as volatile loss into headspace, or change in oxidation-reduction potential through gas exchange with headspace, etc. Excessive purging may result in biased groundwater samples, since it may dilute or increase the contaminant concentrations at the sampling point (USEPA, 2002b).

Choose a purging device that will not alter the geochemical and physical parameters of the groundwater and dissolved contaminants or increase turbidity. Keep the contaminant characteristics in mind when selecting a purge device, for example, do not choose a purge device that will cause volatilization if the contaminant of concern is a volatile compound. Also ensure that the purging device material is chemically inert and that it does not adsorb contaminants (USEPA, 2002b). Preferred device materials are PVC, stainless steel and Teflon®.

If practicable, use low-flow submersible or positive displacement pumps with variable-speed control. Other purging devices include suction lift pumps or peristaltic pumps, and bailers, though due to the greater potential to alter geochemical and physical parameters of groundwater and other limitations, their use is generally limited to monitoring wells with specific characteristics and/or contaminants. Pumps and other purging/sampling devices are described in Subsection 6.5. Use purging devices dedicated to the well whenever possible to avoid cross contamination. If downhole equipment must be used in more than one well, decontaminate the equipment between wells. Choose decontamination procedures appropriate for the contaminants present.

There are two potential intake positions for well purging: above the well screen or within the well screen. If purging above the well screen (if the screen interval is below the water table), start purging at the water table and gradually lower the pump so that it sits just above the top of the well screen at the end of purging. This will ensure that the stagnant water above the screen has been purged. It also ensures that during sampling, the groundwater has the shortest riser length to pass (USEPA, 2002b).

If the intake is placed within the well screen interval, place the intake into the zone of highest contamination. This method is especially effective if a low-flow purging and sampling technique is used (USEPA, 2002b).

All groundwater extracted from wells during purging must be properly containerized, staged, sampled, and disposed. Do not allow water to flow onto the ground. Place all downhole equipment onto a clean plastic sheet to ensure that the ground around the well is not cross contaminated by groundwater, and to ensure that downhole equipment does not transfer surface materials into the well.

6.4.1 LOW-FLOW APPROACH

Researchers have evaluated the relative merits of traditional purging methods; improved methods of purging have evolved out of efforts to improve sample accuracy and precision and to collect more representative samples (Nielsen, 2006). One improved purge method includes low-flow purging (also commonly referred to as micro-purging, low-stress purging, low-impact purging, or minimal drawdown purging). Low-flow purging involves the same approach and equipment as low-flow sampling, as described in Subsection 6.5.1. The HEER Office recommends the improved methods of the low-flow purging and sampling approach be utilized whenever feasible to collect representative groundwater samples.

The purpose of the low-flow purging is to sample a specific depth within a well screen interval. Low-flow purging, whether using portable or dedicated systems, should be done using pump intake located in the middle or slightly above the middle of the screen interval. Placement of the pump at the top of the water column for sampling is only recommended in unconfined aquifers, screened across the water table, where this is the desired sampling point. Carefully place the pump into the well at the selected depth within the well screen to avoid turbulence within the well. Do not use this method with screens exceeding 10 feet in length (USEPA, 2002b).

The approach is based on the assumption that under minimal drawdown the pump will not draw down stagnant water from the well portion above the pump. Therefore, the drawdown in the well must be kept at a minimum and not exceed 0.33 feet or 0.1 meter (Puls and Barcelona, 1996). This involves regular water level measurements, i.e. gauging, throughout purging and

subsequent sampling. Gauging intervals can be as short at 30 seconds or as long as 5 minutes, depending on the hydraulic conductivity of the aquifer. Typically, flow rates on the order of 0.1 to 0.5 liters per minute are used; however, this is dependent on site-specific hydrogeology. The use of a variable-speed, low-flow sampling pump greatly assists in changing the flow rates and thus minimizing drawdown. Bailers, suction-lift pumps, and high-flow rate pumps cannot be used for low-flow purging and sampling. The low-flow method is applicable for all types of aqueous phase contaminants and naturally occurring chemicals in aquifers with low to high permeability. Low-flow purging and sampling is generally not appropriate for very low-yield monitoring wells, as noted in Subsection 6.4.3.

Generally, the time or purge volume required for parameter stabilization is independent of well depth or well volumes. Dependent variables are well diameter, sampling device, hydrogeochemistry, pump flow rate, and whether the devices are used in a portable or dedicated manner.

Throughout purging, regularly measure and record water quality parameters. Preferably, water quality parameters should be measured with a device that prevents contact with air, such as a flow through cell. The following criteria are typically achieved during well purging:

- Well water pH stabilizes to within ±0.1 pH units for three successive readings.
- Well water temperature stabilizes to within ±1 degree Celsius.
- Well water conductivity stabilizes to within ±3 percent.
- Well water oxidation reduction potential stabilizes to within ±10 millivolts.
- Well water dissolved oxygen concentration stabilizes to within ±0.3 milligrams per liter.
- Well water is clear to the unaided eye in areas where the local groundwater is known to be clear and the turbidity readings are below 10 NTUs.
- Turbidity stabilizes to within ±10 percent at concentrations larger than 10 NTU. In areas of known turbid groundwater, the final well water may be turbid to the eye.

The HEER Office recommends the use of flow-through cells when monitoring groundwater stabilization parameters during purging. Flow-through cells contain an inlet at the bottom of a cup that purge water is pumped into. The water is allowed to overflow into a bucket during purging. The field instruments used to monitor stabilization parameters are kept in the flow-through cell to provide a continuous readout.

6.4.2 WELL VOLUME APPROACH

As noted in Subsection 6.4.1, the newer and more representative low flow purging (and sampling) approach is preferred by the HEER Office. A summary of limitations of the fixed well-volume purging approach is provided in "The Essential Handbook of Ground-Water Sampling" (Nielsen et. al., 2007). The well volume purging approach is described below as a potential option for specific circumstances. Rationale for use of this purging approach should be clearly documented in the SAP or in consultation with the HEER Office.

The purpose of the well volume approach is to remove all stagnant water or non-representative water within the well, the filter pack, and the adjoining formation.

For wells where the water level is above the well screen (i.e., a fully saturated screen interval), start pumping near the water table and lower the pump slowly throughout the purging process. The final position of the pump should be just above the screen interval.

For wells where the water level is within the well screen, set the pump to a level such that the drawdown does not allow air to enter the pump. Set the pump high enough that sediment from the bottom of the well is not introduced into the pump (USEPA, 2002b). Keep the pump rate low enough to avoid turbulent flow within the well; for a 2-inch well that is typically less than one gallon per minute or 3.8 liters per minute (USEPA, 2002b).

Alternatively, use a bailer to remove groundwater from the well. Start bailing near the water table and keep lowering the bailer as purging continues. Do not lower the bailer to a depth where bailing will disturb sediment at the bottom of the well. Avoid introducing turbulence near the bottom of the well that could lead to suspension of sediment into the water column.

Monitor water quality parameters after removal of each well volume (the well volume includes the saturated filter pack volume). Continue purging until a minimum of three well volumes are removed and the water quality parameters have stabilized. The stabilization criteria typically monitored during purging are the same as those listed in Subsection 6.4.1.

6.4.3 PURGING LOW PERMEABILITY FORMATIONS

The procedures described in this section are for use in very low permeability formations, where wells are slow to recover.

In wells that are screened below the water table, purge water in storage in the well casing from above the screen, and avoid dewatering and introducing air into the well screen interval. Do not lower the pump into the well screen interval, but pump from the top of the water column, following the water level down to the top of the screen. This procedure requires pumping at low rates to prevent excessive draw down, so bailers or inertial-lift pumps should not be utilized (USEPA, 2002b).

In wells that are screened across the water table, it has been common practice to purge the well dry and let it recover for a minimum of 2 hours and until sufficient water volume is present to take a water quality sample or the well has recovered to 90%. Although it is recognized that purging to dryness may lead to significant problems such as loss of volatiles, increased turbidity, and changes in dissolved gases, alternatives for these low yield wells may be limited, especially in cases with less than 4 feet of water in the well and a depth to water of more than 20 feet (USEPA, 2002b).

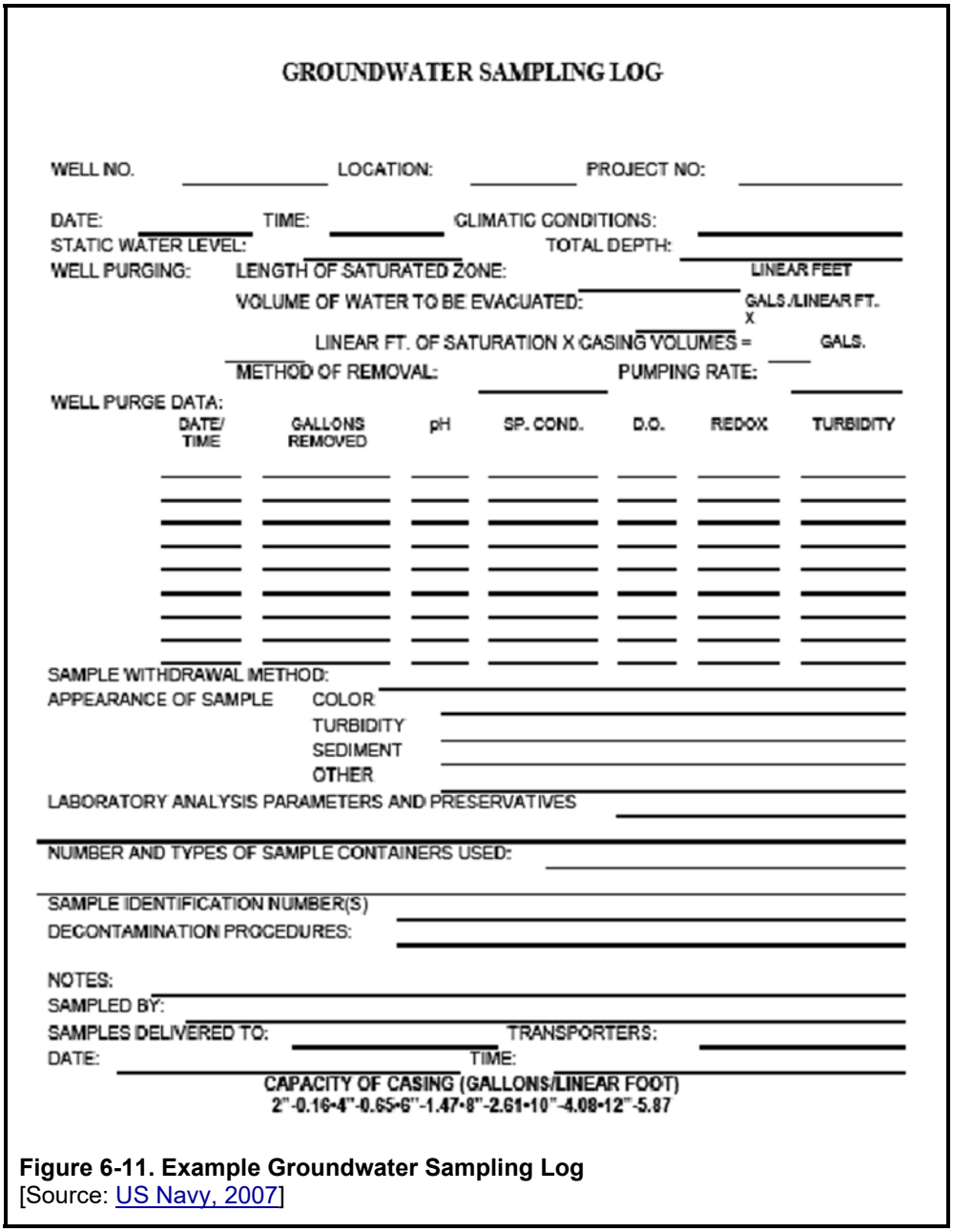
Another option is the use of "minimum-drawdown" purging for low yield wells as described in "Low-Flow (Minimal Drawdown) Ground-Water Sampling Procedures" (Puls and Barcelona, 1996). When sampling very low permeability wells, the rationale for purging and sampling strategy selected should be described in the SAP and discussed with the HEER Office prior to the first sampling event.

6.4.4 WELL PURGING LOG

A well purging log should be documented for each monitoring well. The log should include, at a minimum, the following information:

1. Project name and location
2. Well designation and location
3. Well construction including total depth of well and screen length
4. Well purging technique
5. Purging device
6. Average pumping or water extraction rate
7. Static water level from top of casing before purging
8. Total well depth and presence/absence of sediment
    a. For low-flow approach: measure total well depth after purging and sampling are complete
    b. For well volume approach: measure total well depth before purging
9. Water Volumes
10. For well volume approach: calculate well volume
11. For low-flow approach: calculate tube volume
12. A running log of:
    a. Time
    b. Water volume removed both incremental and totalized
    c. For low-flow approach: water level and drawdown
    d. Field measurement of pH, temperature, conductivity, oxidation reduction potential and turbidity
    e. Field measurements of dissolved oxygen
    f. Visual and olfactory observations such as color, clarity, odor, particulates, etc.
13. Total volume of water removed
14. Total time needed for purging
15. 15. IDW inventory including type and number of IDW containers, location of IDW storage

Refer to Table 6-1 in Subsection 6.2.1.7 for methods to determine water quality parameters during purging. Figure 6-11 presents an example Groundwater Sampling Log containing locations for recording purging parameters prior to the collection of groundwater samples.



GROUNDWATER SAMPLING LOG

WELL NO. _____ LOCATION: _____ PROJECT NO: _____

DATE: _____ TIME: _____ GLIMATIC CONDITIONS: _____

STATIC WATER LEVEL: _____ TOTAL DEPTH: _____

WELL PURGING: LENGTH OF SATURATED ZONE: _____ LINEAR FEET

VOLUME OF WATER TO BE EVACUATED: _____ GALS./LINEAR FT. X

LINEAR FT. OF SATURATION X CASING VOLUMES = _____ GALS.

METHOD OF REMOVAL: _____ PUMPING RATE: _____

WELL PURGE DATA:

DATE/ TIME	GALLONS REMOVED	pH	SP. COND.	D.O.	REDOX	TURBIDITY

SAMPLE WITHDRAWAL METHOD: _____

APPEARANCE OF SAMPLE COLOR _____

TURBIDITY _____

SEDIMENT _____

OTHER _____

LABORATORY ANALYSIS PARAMETERS AND PRESERVATIVES _____

NUMBER AND TYPES OF SAMPLE CONTAINERS USED: _____

SAMPLE IDENTIFICATION NUMBER(S) _____

DECONTAMINATION PROCEDURES: _____

NOTES: _____

SAMPLED BY: _____

SAMPLES DELIVERED TO: _____ TRANSPORTERS: _____

DATE: _____ TIME: _____

CAPACITY OF CASING (GALLONS/LINEAR FOOT)

2"-0.16•4"-0.65•6"-1.47•8"-2.61•10"-4.08•12"-5.87

Figure 6-11. Example Groundwater Sampling Log
[Source: US Navy, 2007]

6.5 GROUNDWATER SAMPLE COLLECTION METHODS

The purpose of groundwater sampling is to collect samples representative for the aquifer at the well location. Consider the characteristics of the contaminant(s) such as volatility, solubility, density (denser or lighter than groundwater) and their resultant fate in the subsurface (adhesion to soil particles, biodegradation etc.) during selection of the sampling approach.

The following sections describe different methods of groundwater sampling, the different types of equipment for each method, and details on the appropriate applications for each method. Table 6-2 presents the potential for representative analytical results for commonly utilized groundwater sampling methods for common contaminants of potential concern.

Table 6-2
Potential for Representative Analytical Results for Commonly Utilized Groundwater Sampling Methods for Common Contaminants of Potential Concern

	VOC	SVOC	Metals *	Pesticide/ Herbicide	Dioxins/ Furans	PAH	PCB	Explo-sives	Prod-uct
Positive Displacement Pump	E	E	E	E	E	E	E	E	NR
Submersible Pump	G	G	E	E	E	E	E	E	NR
Bailer	NR	P	P	G	G	G	G	G	G
Peristaltic Pump	P	P	G	G	G	G	G	G	G

Notes:
E = Excellent
G = Good
P = Poor
NR = Not Recommended
* - for dissolved metals analysis, samples must be filtered

6.5.1 LOW-FLOW SAMPLING

The purpose of low-flow sampling is to collect representative groundwater samples for a specific depth within a well screen interval. The method is based on the assumption that given sufficiently low removal rates, a sampling pump will not draw stagnant water from the water column above and below the position of the pump. Therefore the rate of removal must be kept to a minimum in order to minimize drawdown, which must not exceed 0.33 feet or 0.1 meter (Puls and Barcelona, 1996). Typically, flow rates on the order of 0.1 to 0.5 liters per minute are used; however, this is dependent on site-specific hydrogeology. The method is most applicable in aquifers with medium to high permeability. The HEER Office recommends the low-flow sampling approach be utilized where appropriate and feasible to collect representative groundwater samples.

Low-flow sampling is preceded by low-flow purging (see Subsection 6.4.1 Low-Flow Approach). In general, place the pump intake at the depth of highest contaminant levels. These are often the depths of highest hydraulic conductivity. Any other depth must be discussed and justified in the SAP and project reports. Do not move the pump intake location between the end of purging and the beginning of sampling. Any adjustment of the pump depth or pump speed will require renewed purging. Do not pause the pump between purging and sampling. Keep the pump rate throughout sampling low enough that the groundwater flow exiting from the discharge tube is laminar and does not induce turbulence in sampling containers. The types of pumps used for low-flow sampling and purging are positive displacement pumps (Nielsen, 2006). These types of pumps include:

- Bladder Pump
- Gear Pump
- Piston pump

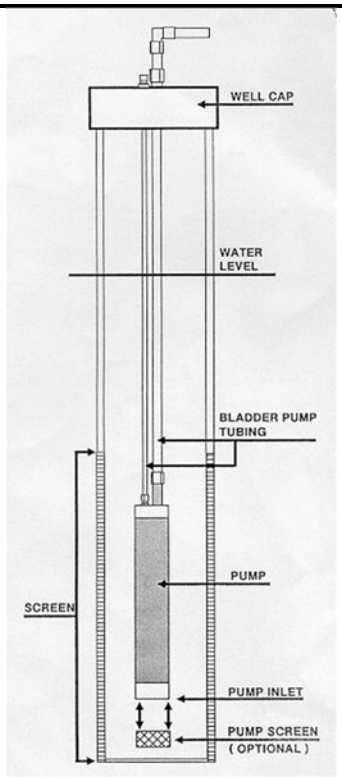


Figure 6-12. Low-flow bladder pump within a monitoring well

In this illustration the water level is above the screen interval

6.5.2 POSITIVE DISPLACEMENT PUMPS

Positive displacement pumps are suitable for collecting samples for all analyses, and particularly when samples are to be collected for analysis of volatile compounds (Nielsen, 2006). These pumps use a pushing motion, induced by the gears, pistons or bladders, and are the least likely of the well sampling methods described in this TGM to impart agitation, turbulence, or heat that could affect sample analysis results, particularly for volatile contaminants.

Until recently, positive displacement pumps were limited to use in wells larger than 2 inches in diameter. However manufacturers of bladder pumps and piston pumps have developed pumps with diameters as small as 0.625 inches that can be used in microwells installed via direct push methods. Gear pumps currently still require a well diameter of at least two inches (Nielsen, 2006). While both bladder and piston pumps can be used in a wide range of applications, piston pumps are relatively more complex and tend to be used more as pumps dedicated to individual wells (Nielsen, 2006). Owing to the relative simplicity of design and ease of field repair, bladder pumps are more widely used as portable units and are the most commercially available of the positive displacement pumps.

A bladder pump consists of a flexible membrane enclosed by a rigid housing. In the most common application, a pump is inserted below the water table in a well, and water enters the housing under hydrostatic pressure through an intake check valve. When the housing chamber is full, the intake check valve prevents the water from escaping back out to the well. The bladder is inflated from a compressed gas source or pump at the surface, and the pressure generated by the inflating bladder pushes the water upwards through another discharge check valve, then through a discharge tube upwards to the surface. An example of a bladder pump set up in a well is illustrated in Figure 6-12.

Setup of bladder pumps in the field typically require a compressed gas source to inflate the bladder and a controller unit to regulate the rate of inflation and, therefore, pumping. Compressed gas may be supplied from a tank or compressor. For deeper applications requiring greater pressures, a compressor driven by a dedicated motor is generally used. For these instances, care must be given to locate the motor upwind and away from the well being sampled. For shallower applications, some manufacturers have developed combined compressor/controller units that can be powered off of a portable battery or the battery of a field vehicle.

An example field setup of a portable bladder pump assembly is illustrated from different points of view in Figures 6-13 and 6-14.



Figure 6-13. Detail of Field Setup for Purging and Sampling Well

See Figure 6-14 for expanded view.

6.5.3 SUBMERSIBLE PUMPS

Submersible pumps move water up a well by applying positive pressure; however, instead of a pushing motion, submersible or centrifugal pumps typically use electric-motor driven impellers to drive the water to the surface. The impellor pressure is equal to the hydraulic head in the tubing extending from the pump to the top of the well.

Submersible pumps are portable, require less setup and equipment than positive displacement pumps, and do not require compressed gases or air pumps. They generally have higher discharge capacities than positive displacement pumps and may therefore be more effective as a well volume purging method and for collecting of samples for nonvolatile contaminants. They may also be used to collect samples for volatile contaminants but may not recover samples as representative as positive displacement pumps for volatile contaminant concentrations; the impellor motion may be prone to cavitation, inducing bubble formation that may affect pressure sensitive components such as dissolved gases or VOCs. The motors themselves may generate considerable heat that may also affect more volatile components (Nielsen, 2006). Many submersible pumps, particularly older models, may not be capable of producing sufficiently low discharge rates needed for low-flow sampling. In situations where volatile contaminants are being investigated and the investigation team selects submersible pumps as the method of sampling, the evidence and rationale for selection of this equipment over positive displacement pumps should be documented in detail in the project work plan, and concurrence with the approach should be obtained from the HEER Office prior to field investigation.



Figure 6-14. Field Setup for Purging and Sampling Well

Purging and sampling of groundwater monitoring well using a portable low-flow bladder pump driven by a portable air compressor and control box.

Select a pump to match the required lift at the required pumping rate. Do not underrate the pump as it will start running hot, which can alter the sample chemistry. The pump must have a variable-speed control. Select the power source and pump characteristics to allow the pump to run continuously throughout purging and sampling. Select the sample tube and associated equipment to be compatible with the site contaminants. Install a device that will prevent backflow to the pump to avoid groundwater contamination.

Install the pump at a sufficient height above the bottom of the well to avoid pumping sediment from the bottom of the well. Sediment can damage smooth internal surfaces, causing leaching of target analytes (NJDEP, 2005). In wells screened below the water table, set the pumping rate such that the water level is not drawn down into the screened section. Do not pump the well dry except as noted under limited circumstances discussed in Subsection 6.4.3 Purging Low-Permeability Formations.

Keep the pump rate low enough that the groundwater flow from the tube is laminar and does not induce turbulence in sampling containers. Choose sample containers appropriate to the contaminants of concern.

6.5.4 BAILER SAMPLING

A bailer is a well purging and/or sampling device that may be appropriate for use under limited circumstances. The simplest bailer consists of a rigid tube equipped with a check valve at the bottom and a means to attach a line to the top. The check valve allows water in to the interior chamber of the bailer as it is lowered into the saturated zone. When the bailer is raised the check valve is forced shut and a water sample can be retrieved from the well. Larger diameter bailers may be used for well volume purging, although care must be exercised in purging as described in Subsection 6.4.

If utilized, the HEER Office recommends dedicated disposable bailers that have a certification of laboratory-verified cleanliness available from the manufacturer. However, bailers may be dedicated to a single well to avoid cross contamination. In instances where well volume purging is also being done by bailer, the sampling and purging must be done with separate bailers intended and designed for the respective tasks.

The purpose of bailer sampling is to collect samples representative of the groundwater at the sampling point. Therefore, bailer sampling must be preceded by well purging. Purging has to follow either the well volume approach or the purging approach for low-permeability formations as described in this document.

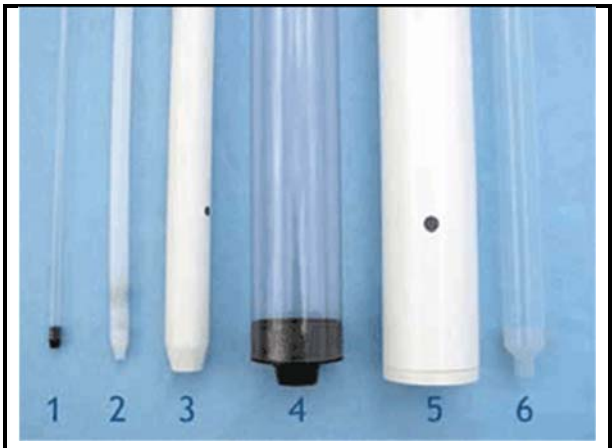


Figure 6-15. Bailers for Purging and Groundwater Sampling

The following representative bailers are shown
1. Micro Bailer
3. PVC Bailer
5. PVC Bailer
2. Mini Bailer
4. PVC Bailer
6. Teflon Bailer
[Source: Eon, 2008]

Bailers are available in a variety of sizes and construction materials, e.g., PVC, Teflon®, and stainless steel. Several different types of bailer materials, diameters, and discharge applications are illustrated in Figure 6-15.

For final decision-making purposes, sampling for volatile organics using bailers is not recommended due to potential bias introduced during sampling (Pohlmann et al., 1990; Yeskis et al., 1988; Tai, et al., 1991). Use of bailers for sampling of semi-volatile organic compounds (SVOCs) and metals is also generally considered a poor option (See Table 6-2). The use of low-flow pumps is recommended for these contaminants, and in some cases may be required by the HEER Office, particularly in situations where residential or sensitive populations are involved. A potential specific exception to this rule is when the recovery rate of a well can be documented to be less than 0.05 gallons per minute (200 milliliters per minute) and the water column in the well is less than 5 feet. Under these conditions, the "minimum-drawdown" purging and sampling approach as noted in Subsection 6.4.3 or the use of a bailer may be considered for volatile sampling. In low well recovery rate situations where volatile contaminants are to be sampled with a bailer, use one designed for volatile sampling; specifically, a bailer with a double check valve and a bottom emptying device with a control flow check valve.

For periodic, long-term monitoring events the use of a bailer may in some cases prove cost-effective; however, in these instances, an initial comparison between data collected from low-flow pumps and from bailers should be carried out.

When bailer use is proposed, the rationale must be documented in the project work plan, and concurrence with the approach obtained from the HEER Office prior to field investigation.

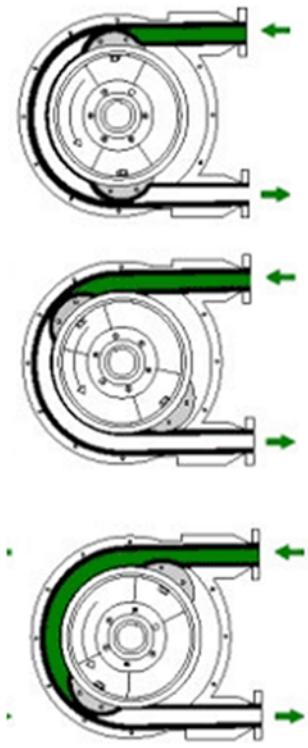


Figure 6-16. Peristaltic Pump Head
[Source: Environmental Pumping, 2008]

6.5.5 PERISTALTIC PUMP SAMPLING

A peristaltic pump operates by a circular motion creating a vacuum in an intake line drawing from the monitoring well. The vacuum draws groundwater up to the pump, where the water is dispensed from the end of the tubing. Tubing used for peristaltic pump sampling should be disposed of after one use. A diagram of the working end of a peristaltic pump is illustrated in Figure 6-16.

Peristaltic pumps have advantages in that they have few moving parts, do not need compressed gas or pumps, are generally very portable, and are easily set up and used; further, the tubing and pump heads can easily be replaced (USGS, 2002). Peristaltic pumps can produce a maximum lift of up to 20 to 25 feet and provide a pump rate of 1 to 2 liters per minute.

Peristaltic pumps do, however, have limitations in use and ability to collect representative samples for some contaminants. The vacuum induced in the downhole tubing can also result in loss of dissolved gases or volatile components. In addition, the tubing could diffuse atmospheric gases sufficiently to affect some target gases. Peristaltic pumps therefore are less likely to result in representative samples for the following analyses (NJDEP, 2005):

- Volatile organic compounds
- Semi-volatile organic compounds
- Dissolved oxygen
- Oxidation reduction potential
- Carbon dioxide
- pH
- Iron and its associated forms.

A peristaltic pump may be proposed for use primarily if the following conditions exist:

- Depth to water is less than 15 to 20 feet
- There is limited recovery of water in a monitoring well
- Contaminants of concern do not include any on the previous list (USEPA, 2002b)

Under these circumstances the rationale for peristaltic pump use must be documented in detail in the project workplan, evidence presented for the need to use the method in place of other methods, and concurrence with the approach obtained from the HEER Office prior to field investigation.

6.5.6 OTHERS

Other groundwater samplers include passive diffusion samplers for VOCs or SVOCs, HydraSleeve®, the syringe sampler, and the Gore Module™. Application of these devices is generally limited to field screening (see Section 8). Use of these devices in field investigations should be discussed with the HEER Office before use.

6.5.7 ORDER OF GROUNDWATER SAMPLING

Collect samples in groundwater monitoring wells no sooner than 14 days after well development. This delay applies to newly installed wells as well as to wells that necessitated re-development due to clogging or other conditions. If a different time frame from 14 days is proposed based upon known site conditions (e.g. evidence of high hydraulic conductivity, either for the site itself or immediately surrounding area), overall project considerations, or other pertinent information, the interval, rationale, and evidence supporting the proposal should be noted in detail in the SAP or by consultation with the HEER Office. See Subsection 6.2.1.9 for guidance concerning the timelines for drilling, well installation, development, and sampling.

Sample wells in order of increasing contaminant concentrations as determined from previous sampling events. If the order is not known from previous sampling events, use vapor readings collected at the top of the well casing to aid in determining the correct order. This sampling approach minimizes the potential for cross contamination. In addition, follow proper decontamination procedures appropriate for the site contaminants, and protect the ground surface around each well with plastic sheeting.

If the order of sampling must be changed, it should be described in the SAP and discussed with the HEER Office. The order in which analytical samples should be collected is as follows (NJDEP, 2005):

1. Volatile organic compounds (VOCs)
2. Purgeable organic compounds (POC)
3. Purgeable organic halogens (POX)
4. Total organic halogens (TOX)
5. Total organic carbon (TOC)
6. Base neutrals/acid extractables
7. Total Petroleum Hydrocarbon (TPH)/Oil & Grease

8. PCBs/pesticides
9. Total metals
10. Dissolved metals
11. Phenols
12. Cyanide
13. Sulfate and chloride
14. Turbidity
15. Nitrate and ammonia
16. Preserved inorganics
17. Radionuclides
18. Non-preserved inorganics
19. Bacteria

6.6 FILTRATION OF GROUNDWATER SAMPLES



Figure 6-17. In-line 0.45 Micron Filter

This filter type is typically used in the field collecting a filtered groundwater sample. An arrow on the body of the filter indicates the water flow direction when using the filter.
[Source: Aqua Merik, 2008]

Some contaminants and water quality parameters are impacted by excessive turbidity in the water sample. Therefore, it is important to avoid introducing turbidity into the water samples since the HEER Office groundwater EALs are intended for comparison to dissolved phase contaminants (and not contaminants adsorbed onto fine-grained soil particles).

If sediment has accumulated at the bottom of a well, use proper purging and sampling techniques to prevent turbulence and suspension of sediment. In these cases, the low-flow purging and sampling technique is preferred, since it will not agitate the water column within the well. Bailer sampling should be avoided in cases where sediment has accumulated in the well, because it is likely to introduce turbulence due to repetitive insertion and retrieval.

It may be impossible to collect non-turbid samples from wells installed in some areas. In cases where extremely fine-grained substrate is known or anticipated (commonly for sites near or adjoining the shoreline or in caprock substrate) filtering of groundwater samples prior to analysis for metals is generally accepted, and filtering for organic contaminants is also acceptable, especially for highly sorptive contaminants (PAHs, TPH, etc.) In these known or anticipated situations, the potential need for filtering samples intended for organic analysis should be documented in the work plan and concurrence obtained from the HEER Office prior to field investigation. The following sections describe the considerations for filtering of samples intended for metals analysis followed by a description of overall sample filtering procedures.

6.6.1 DISSOLVED METALS VERSUS TOTAL METALS

Some metals can take on more than one oxidation state or valence state. Often an increase in oxidation state leads to a decrease in solubility. The valence state of the dissolved metal is dependent on the oxidation-reduction potential of the groundwater. In-situ groundwater is often under-saturated relative to the oxygen concentration in air. Therefore, oxygen can dissolve from air into groundwater, resulting in an increased oxidation-reduction potential, which may change the oxidation state of dissolved metals and result in metal precipitation. It is therefore important to avoid aeration of groundwater collected for metals analysis.

Aeration may occur during collection or transport. To avoid precipitation of dissolved metals after filtration, the sample must be properly preserved, preferably using Nitric Acid (HNO_3). The proper preservation of filtered metals samples results in a pH lower than 2, which keeps the dissolved metals in solution.

A groundwater sample that is not filtered prior to preservation may yield false, elevated levels of dissolved-phase metals. Lowering the pH of an unfiltered sample may dissolve metals that are bound to particles suspended in the water sample. Therefore, a sample to be analyzed for dissolved metals must be filtered prior to preservation in the field and analysis at the laboratory.

Due to the potential phase changes of metals that may occur during groundwater sampling and filtration, the HEER Office may require that analytical data for filtered samples be accompanied by data for unfiltered samples, especially at sites where groundwater is used as a water supply or may discharge into a nearby surface water body.

6.6.2 FILTERING PROCEDURES

Filtration methods in the order of preference are: in-line filtration, pressure filtration and vacuum filtration. Vacuum filtration should only be used if the other two methods cannot be used. The use of a vacuum filtration method should be justified in the SAP and must be performed in strict adherence to manufacturer's recommendations (NJDEP, 2005).

Select a filter apparatus made of polyethylene, polypropylene or borosilicate glass. Use ungridded, 0.45-micron pore-diameter filters. The filters are to be one-time use, disposable, laboratory cleaned filters that have a laboratory certification available from the manufacturer. An example of an in-line filter used in the field for the collection of a filtered water sample prior to preservation is illustrated in Figure 6-17.

Filter the sample immediately upon collection in a manner that minimizes aeration. Do not let the filter cake become too thick. Discard the first 150 to 200 milliliters of sample to allow the filter to chemically equilibrate with the groundwater. Preserve the sample immediately upon filtration using proper preservation methods, in the most common case for metals, with nitric acid to a pH less than 2. Filtration must always precede preservation. Place samples on ice for shipment to the laboratory.

6.7 AQUIFER DATA COLLECTION METHODS

This section provides general guidance for the determination of key characteristics used for evaluation of contaminant transport through groundwater. Hydraulic conductivity is a measure of the formation's ability to transmit water. It is therefore dependent on the permeability of the formation and the fluid properties. This section also describes methods to evaluate related characteristics of transmissivity, the average water transmission potential for a specific aquifer, and storativity or specific yield, the amount of water that a confined or unconfined aquifer will drain up for a certain change in hydraulic head. Hydraulic head is most commonly represented by groundwater elevation.

Permeability of soil/rock samples can be determined in the laboratory and then converted to hydraulic conductivity using the density and viscosity of the fluid being transmitted, in this case water or free phase product.

However, soil/rock samples collected from soil borings may not be large enough to be representative of the aquifer and may be disturbed during the drilling and collection process. Therefore, it is quite possible that hydraulic conductivities calculated from laboratory permeability data differ by several orders of magnitude from data collected using field methods.

Commonly used field test methods for the determination of hydraulic conductivity are slug tests and pumping tests. Both tests require access to one or more groundwater monitoring well(s) on site. Ensure that the wells are properly developed and in equilibrium with the surrounding aquifer before commencing aquifer tests.

On sites that are tidally influenced or show temporal groundwater fluctuations, monitor groundwater fluctuations in background wells throughout the duration of the aquifer test. The background wells must be placed outside the zone of the stressed aquifer, but close enough to be representative of the temporal fluctuations expected in the test wells. Use the background monitoring data to correct for changes in the water table and potentiometric surface that are not related to the aquifer test. Methods are available for correcting for most seasonal and temporal effects. These should be considered when designing aquifer tests and interpreting the results (USEPA, 1992d).

On sites with stratified aquifers, perform multiple aquifer tests at different depths. Select the depths based on the stratification observed in the formation during drilling. Determination of the vertical hydraulic conductivity may also be required at sites with stratified aquifers or those sites where vertical groundwater movement is significant.

The guidance presented below is adequate for porous formations. Determination of hydraulic conductivity in fractured rock requires a different approach, since the groundwater flow may be turbulent.

The slug test assumes that the aquifer is confined. For pumping tests, solutions are available for confined aquifers (Theis non-equilibrium method), for leaky aquifers (Hantush, 1956) and for unconfined aquifers (Neuman, 1975).

6.7.1 SLUG TESTS

A slug test is typically performed in a single well. Perform the slug test by either adding or removing an object of known volume (referred to as a "slug") from a well and continuously monitoring the groundwater level while the well recovers to its original level (Freeze et. al., 1979). Addition or removal of the slug must be instantaneous and monitoring has to start immediately. Perform the slug test at least twice to confirm the results. There are commercially available software packages that can be used for evaluation of hydraulic conductivity.

If the well screen extends above the water table, use a slug withdrawal procedure (Domenico et. al., 1990). Do not add water to a monitoring well at a contaminated site. A slug can be a solid cylinder or closed stainless or PVC pipe filled with an inert material such as silica sand filter pack material. Ensure that the slug is heavy enough to instantaneously sink to the bottom of the well. If a slug is to be removed from the well, insert it into the water column, wait until the water level has recovered to its original level and then remove it as quickly as practicable.

In formations of high hydraulic conductivity, water level gauging must be continuous throughout the duration of the test. In this case, install a pressure transducer in the bottom of the well to log data continuously. Ensure that the water level has recovered to its original level after inserting the instrument prior to commencing the test. Design the test such that the slug does not interfere with the downhole equipment.

Accurately record the following: slug volume; water level within ±0.01 inch before, during and after the slug test; and the time of each water level measurement.

There are several graphic/calculation methods to evaluate hydraulic conductivity using slug test data. One example is the Bouwer method (Bouwer, H., 1989). Another is Hvorslev's method (Hvorslev, M.J., 1951).

Alternatively, determine the transmissivity and storativity of the aquifer by plotting the field data and comparing them with type curves. Cooper et. al. generated type curves for slug tests (Cooper et. al., 1967). Papadopulos et. al. later extended the range of curves (Papadopulos et. al., 1973). If different sections of the field data curve matches more than one type curve, Hvorslev's method should be used instead.

Specify in the project plan and report the methods used to interpret slug test data.

The slug test determines the transmissivity, storativity and hydraulic conductivity of the formation in the immediate surrounding of the well that was tested. The results are, therefore, limited. Conduct the slug test at different locations at each site to define the variability of the hydraulic conductivity and other parameters across the site (USEPA, 1992d).

Compare the results of the aquifer test with the data on the existing geologic units and confirm consistency between the hydrologic and geologic data.

6.7.1.1 SLUG TESTS IN STRATIFIED AQUIFERS

In stratified aquifers, determine the hydraulic conductivity for the various strata by performing slug tests either in wells that are screened within different stratigraphic units or by performing a multilevel slug test in one well. Only the stratigraphic units important for contaminant transport need to be tested.

The multilevel slug test data will only be reliable if the investigator succeeds in isolating portions of the aquifer, which is accomplished using two packers separated by a length of perforated pipe. The test is then performed by inducing water into the isolated section. The procedure provides reliable data when performed properly (USEPA, 1992d). Do not introduce water into a monitoring well that extends into a contaminant plume.

6.7.2 PUMPING TESTS

An accurate method of determining the hydraulic properties of water-bearing substrate is the pumping test. Pumping tests tend to involve a comparatively larger volume than slug tests and may be used as an alternative where large areas are of concern. Pumping tests also tend to involve greater effort and greater expense. Pumping tests involve the use of one or more pumping wells and may or may not include a varying number of observation wells. The change in hydraulic head is monitored, usually in terms of drawdown, or change in groundwater elevation in the aquifer in response to pumping and removal of water from the formation. The magnitude and rates of drawdown in the well, and rates of recovery after pumping has stopped can be used to evaluate the properties of transmissivity, storativity, and hydraulic conductivity of the aquifer surrounding the well.

6.7.2.1 SINGLE WELL PUMPING TEST

Single well pumping tests involve the measurement of water levels over time in a single monitoring well at different rates of pumping.

Measure the original water level in the well. Then pump down the well for a period of time. Record the time when pumping stops. At the time when pumping stops, start monitoring the recovery of the water level in the well as a function of time (Domenico et. al., 1990).

Storativity cannot be determined using a single well pumping test. The limitation of this single well test is that it determines only the transmissivity of the formation adjacent to the well. Perform the test in wells across the site to determine the variability in the aquifer transmissivity.

6.7.2.2 MULTI WELL PUMPING TESTS

Multi-well pumping tests involve one pumping well and one or more observation wells. The tests are based on the relationship between the observation well and the pumping well, which stipulates that the water level change in the observation well, at a specified distance from the pumping well, is a function of the pumping rate, the properties of the aquifer and time. The advantage of using a multi well pumping test is that the aquifer parameters determined in this fashion represent average values for the formation between the wells.

The pump test methods described are, strictly speaking, only applicable to cases where the wells fully penetrate the aquifer. However, Hantush and Walton have conducted research for partially penetrating wells (Hantush, 1961 and 1964) (Walton,

1970). Hantush supplies some general guidelines for pump tests in partially penetrating wells. As long as the observation well is at a minimum distance from the pumping well, the partial penetration will not affect the test results. The distance must be:

r > 1.5m (K/K')
r = distance between pumping and observation well
m = aquifer thickness
K = horizontal hydraulic conductivity
K' = vertical hydraulic conductivity

If the horizontal and vertical conductivity are of the same magnitude, the condition is r > 1.5m.

Confined Aquifers:

For confined aquifers, plot the pump test drawdown data versus time site curve on logarithmic paper of the same scale as the Theis non-equilibrium type curve. Match the graphed investigation curve to the type curve by superimposing it. Choose a matching point anywhere on the overlapping sheets. Characteristics read off the Theis curve for the match point are used to estimate transmissivity and storativity of the aquifer based on the response observed in the pumping test (Domenico et. al., 1990).

Leaky Aquifers:

Leaky aquifers are confined by a low permeability unit that will still allow some leakage into the aquifer. Leakage may also arise through other sources such as connected bodies of surface water etc. In general, the first part of the drawdown will resemble that of a confined aquifer until the hydraulic gradient is large enough to induce leakage. So that the first part of the drawdown versus time curve can be analyzed with the Theis non-equilibrium type curve as discussed above.

At the time that leakage starts, the drawdown versus time curve will deviate from the Theis non-equilibrium type curve.

For leaky aquifers, plot the pump drawdown data versus time on logarithmic paper of the same scale as the type curve for leaky aquifers in the same fashion as for confined aquifers, but the data is compared to different type curves based on values for a given leakage (Hantush et. al., 1955; Hantush, 1956). The vertical hydraulic conductivity for these solutions is a measure of the leakage into the aquifer. The thickness of the boundary low permeability formation must be taken from well boring logs (Domenico et. al., 1990).

Unconfined Aquifers:

When water is withdrawn from confined aquifers, the aquifer does not undergo dewatering, unless the groundwater elevation/head is lowered below the confining layer. The water is released from storage through elastic compression of the matrix and expansion of the water. In unconfined aquifers lowering of water levels actually causes some dewatering of the aquifer and the value of storativity increases by several orders of magnitude. In an unconfined aquifer the storativity is referred to as specific yield (Domenico et. al., 1990).

In an unconfined aquifer the transmissivity can decrease during pumping due to the decrease in saturated aquifer thickness. This is inherent in the definition of transmissivity:

T = Km,

Where:

T = transmissivity
K = hydraulic conductivity
m = aquifer thickness

Therefore, T is not a constant as assumed by the Theis equation. Another assumption of the Theis equation is that water is instantaneously released from storage with decline in head. If this does not hold true, then the response will deviate from the response of a confined aquifer and the Theis type curve does not apply. For unconfined aquifers, the time-drawdown curve has three sections. The early section follows the Theis non equilibrium type curve, followed by an intermediate section where the slope of the curve decreases similar to that in a leaky aquifer, and the curve at later time will reveal a slope increase that will again follow a Theis non equilibrium type curve. The early part of the curve represents the storativity of the formation while the late part represents the specific yield.

Use the equation K = T/m to derive the horizontal hydraulic conductivity K.

6.8 GROUNDWATER MODELING

The purpose of groundwater modeling is to generate a visual representation of an aquifer including the overall groundwater movement, and in the case of contaminated sites, the fate and transport of contaminants. Groundwater modeling is also used to predict contaminant plume movement into the future or to predict the aquifer and plume response to remedial activities.

Groundwater modeling may be done manually by using a calculator or spreadsheet and then creating a graphical depiction of the data using flow nets. Manual groundwater modeling methods may be useful for creating preliminary site conceptual models intended to depict aquifer characteristics and the initial contaminant plume extent.

However, if the purpose of groundwater modeling is to predict how a contaminant plume changes over time or how it will respond to water pumping or remedial activities, modeling becomes computationally intensive, and a computer model must be used. Thus computer modeling has become an important tool in the design of sampling strategies during site monitoring and in the design of groundwater remediation systems. Computer groundwater models are based on the geologic and hydrologic field data collected during drilling, geotechnical sample analysis and aquifer testing. Further, the computer models must be continually adjusted and calibrated based on additional information obtained throughout the project cycle.

6.8.1 GRADIENT AND FLOW DIRECTION DETERMINATION

The simplest way to determine the groundwater gradient and flow direction is by graphically constructing a flow net for the site. A flow net is composed of two sets of lines: the equipotential lines and the flow lines. The equipotential lines connect points of equal head and the flow lines depict the interpreted groundwater flow path or flow direction.

To construct a flow net for a site, measure the hydraulic head in wells across the site following the groundwater gauging procedures detailed previously in this section. Enter the measurements onto a site map. Interpolate the hydraulic head between wells assuming that the change in head is linear between neighboring wells. Connect points of equal hydraulic head to depict the equipotential lines. Choose equipotential line intervals such that the drop in head between adjacent lines is constant. The equipotential lines represent the height of the water table or potentiometric surface above mean sea level or other datum plane.

Add flow lines to depict the movement of groundwater at the site. Groundwater follows the path of steepest groundwater gradient. At a site where the aquifer formation is isotropic and porous, the steepest groundwater gradient is the shortest path between equipotential lines. The shortest path is perpendicular to the equipotential lines. Draw flow lines such that the flow is equally divided between adjacent lines.

Calculate the groundwater gradient as follows: Measure the distance between two equipotential lines along a flow line, i.e. the shortest path. Determine the head loss between the equipotential lines. Divide the head loss by the distance.

The groundwater flow direction is along the flow lines. Depict flow lines as arrows pointing in the direction of groundwater flow, i.e., in the direction of declining hydraulic head.

6.8.2 VELOCITY, TRANSMISSIVITY, CALCULATIONS,

Calculate the transmissivity, storativity and hydraulic conductivity using methods and references listed in Subsection 6.7, Aquifer Data Collection Methods.

Calculate the groundwater velocity (v) using the following equation:

$$v = q/ne = (K\ dh/dl) / ne$$

Where:

v = actual groundwater velocity
q = Darcy velocity
ne = effective porosity (connected pore space through which groundwater can flow)
K = Hydraulic conductivity
dh/dl = groundwater gradient (change in groundwater elevation in two wells over distance between the wells)

Compare the calculated groundwater velocity to the velocity range expected based on aquifer lithology.

Note that the equation is for laminar flow through porous media. Flow through fractured rock may require a different approach. If the fractured rock is hydraulically equivalent to a porous medium, the above equation may be used. If this condition is not fulfilled, describe the flow in relation to individual fractures.

In most cases on the scale of a typical response site, the condition of hydraulic equivalence to a porous medium is not satisfied and the flow must be described in relation to individual fractures and fracture sets. This has many consequences. For example, in a hydraulically isotropic, porous formation, the groundwater flow direction is perpendicular to the equipotential lines of the water table/potentiometric map. This assumption cannot be made in a fractured formation, since the flow direction will follow the fracture orientation. The following parameters need to be known to describe flow in fractured rock: orientation, fracture density, degree of connectivity, aperture opening, and smoothness of fractures (Domenico et. al., 1990).

One approach to describing fracture flow was developed by Snow (Snow, 1968). He developed an equation to calculate equivalent hydraulic conductivity for a set of planar fractures. One square meter of fractured rock with an equivalent hydraulic conductivity of K will conduct as much water as one square meter of porous medium with a hydraulic conductivity of K, under identical hydraulic gradients (Domenico et. al., 1990).

6.8.3 COMPUTER MODELS

Computer models may be used at a site for many different goals including: (1) estimating how the actual groundwater system functions; (2) selecting sampling approaches, objectives and locations; (3) predicting contaminant fate and transport at the site; (4) designing hydraulic containments; and (5) testing and designing remediation approaches and systems (USEPA, 1992a, 1995c).

Computer models may consist of analytical approaches or numerical approaches. Analytical approaches are relatively more simplistic, offer an inexpensive method to conduct preliminary groundwater analysis, and may be useful during the early phases of a project. Numerical approaches are generally more complex and require specialized knowledge and software. However, numerical approaches easily deal with variability in the groundwater flow and contaminant transport parameters, which provides flexibility in representing complex subsurface geologies. Numerical approaches are also useful for predictive evaluation of proposed remedial solutions and for the evaluation of environmental hazards.

A groundwater modeling report should, at a minimum, include (USEPA, 1992a):

- Previous studies
- Site conceptual model(s)
- Mathematical model describing the site conceptual model
- Selection of numerical model and codes
- Model calibration
- Model runs
- Model results
- Conclusions
- Tables, graphs, figures, maps etc.
- List of symbols, abbreviations, references, codes, etc.

6.9 SURFACE WATER SAMPLE COLLECTION METHODS

Environmental investigation sites featuring adjoining surface water bodies may require the collection of surface water samples to assess environmental impacts. Select the sampling approach and sampling equipment based on the type of surface water (flowing versus still), the sampling platform and the contaminant characteristics.

6.9.1 SAMPLING FLOWING AND STILL SURFACE WATERS

In general, an isokinetic water sampler is used to collect a sample from water flowing faster than 1.5 to 2 feet per second. Non-isokinetic water samplers are used for all other surface water sampling applications.

In flowing water, always position the sampler upstream of any disturbance caused by sampling activities. In standing water deploy the sampler away from any disturbance caused by sampling. Avoid contact of sampling equipment with the bottom sediment. Deploy the samplers in a fashion that minimizes disturbance and suspension of sediments.

6.9.1.1 ISOKINETIC SAMPLERS

An isokinetic sampler is constructed of a cap with a nozzle and a bottle or bag for sample collection. Fins are attached to the downstream end of the sampler, i.e. away from the nozzle, to keep the sampler aligned with the flow direction in the stream. Select the nozzle, cap and bottle material to be compatible with the contaminants of concern. Consult the manufacturer's specifications for limitations on the use of each sampler. Refer to United States Geological Survey (USGS) document entitled "Handbooks for Water-Resources Investigations - National Field Manual for the Collection of Water-Quality Data" for more information on isokinetic samplers (USGS, 2002).

Use an isokinetic sampler to collect a depth integrated, representative water sample continuously and isokinetically (that is, stream water approaching and entering the sampler intake does not change in velocity) from a vertical section of a stream while transiting the vertical at a uniform rate. An example of this type of sampler is illustrated in Figure 6-18.

Isokinetic samplers are rated for their maximum allowable transit rate based on the stream velocity. Refer to the manufacturer's rating to calculate the maximum allowable transit velocity. Use a lower than maximum transit velocity to ensure that a representative velocity-weighted sample is collected. Do not overfill the sampler bottle (USGS, 2002).



Figure 6-18. Isokinetic Sampler Constructed of Teflon [Source: USGS, 2008b]

6.9.1.2 NON-ISOKINETIC SAMPLERS

Laboratory Cleaned Bottles

The most widely used method for collection of surface water samples is simple immersion of the laboratory cleaned sample bottle below the surface of a surface water body. This method eliminates the need for other equipment and reduces the risk of introducing other variables into a sampling event.

Immerse the open bottle by hand into surface water and allow water to slowly run into the bottle minimizing turbulence. Collect samples for volatile organics analysis first to prevent loss of volatiles due to disturbance of the water. Do not disturb the sediment, especially when analytes (such as metals) could be impacted by turbidity.

Pond Sampler

The pond sampler may also be commonly referred to as a "Dipper". The pond sampler consists of an arm or handle with a clamp to attach a sampling beaker. The construction materials vary and are selected to be compatible with the site contaminants. Pond samplers can be assembled from equipment found in swimming pool supply stores and laboratory supply stores (NJDEP, 2005).

Slowly submerge and retrieve the sampling beaker with minimal surface disturbance. Transfer the sample slowly into a laboratory supplied sample bottle, allowing the water to flow gently down the inside of the bottle. Avoid turbulence in the sample stream. Always collect samples for volatile and semi-volatile analyses first.

Weighted Bottle Sampler

The weighted bottle sampler consists of a bottle and an attached weight, which maintains the upright bottle orientation during sample collection, and a stopper (when needed). The construction materials for weighted bottle samplers vary and are selected to be compatible with the analytes and/or site contaminants (if known).

Lower the weighted bottle sampler to the predetermined depth. Pull out the bottle stopper with a sharp jerk of the sampler line and allow the bottle to fill completely. When the bottle is filled, there should be no more bubbles rising to the surface. Retrieve sampler and transfer the sample slowly into a laboratory supplied sample bottle, allowing the water to flow gently down the inside of the bottle. Avoid turbulence in the sample stream. Always collect samples for volatile and semi-volatile analyses first.

Wheaton Dip Sampler

The Wheaton Dip Sampler consists of a glass bottle mounted at the end of a metal pole of fixed length. The bottle lid is rigidly attached to a second metal pole, which is loosely attached to the main pole. The second pole is used to unscrew the bottle cap at the required sampling depth.

Use the Wheaton Dip Sampler to collect samples in shallow surface water. With the bottle cap closed, lower the sampler to the required depth and unscrew the bottle cap. Once the bottle is filled, (i.e. when no more bubbles reach the water surface) screw the bottle cap back on and retrieve the bottle.

Transfer the sample slowly into a laboratory supplied sample bottle, allowing the water to flow gently down the inside of the bottle. Avoid turbulence in the sample stream. Always collect samples for volatile and semi-volatile analyses first.

VanDorn Sampler & Niskin Bottle Sampler

The Van Dorn sampler and Niskin bottle sampler are cylindrical samplers closed with water-tight stoppers on both ends. The stoppers are connected through an elastic band that runs through the inside of the sample collection cylinder. The stoppers can be pulled out and locked to the outside of the cylinder, leaving both pipe openings unobstructed, which allows for water to enter the cylinder. After the sampler has been placed at the pre-determined sampling depth, the lock on the stoppers can be triggered to release, causing the stoppers to close. The elastic band pulls the stoppers into their seat and maintains the closed position to create a water-tight seal. A valve at the bottom of the cylinder together with a vent at the top are used to drain the samplers while the stoppers remain in the closed position.



Figure 6-19. Niskin Bottle Sampler
Sampler shown with the end stoppers open (left) prior to immersion in the surface water body and closed (right) following sample collection. [Source: General Oceanics, 2008]

These samplers are commonly deployed from a boat. The Van Dorn sampler must be suspended on a dedicated line, while the Niskin bottles may be attached in series on a line and the closing mechanism triggered with auxiliary messengers.

Open the samplers and suspend them on a line to the sampling depth. Trigger the closing mechanism and retrieve the sampler. Transfer the sample slowly from the sampler drain valve into a laboratory supplied sample bottle, allowing the water to flow gently down the inside of the bottle. Avoid turbulence in the sample stream. Always collect samples for volatile and semi-volatile analyses first. An example Niskin bottler sampler is illustrated in Figure 6-19.

VOC Sampler

The VOC sampler has been manufactured for the USGS and is used to collect open water samples for volatile organic compound analysis. The device has been tested in the laboratory and field for analyte loss, reproducibility and cross contamination. The sampler is constructed of stainless steel and copper and consists of a cylinder that holds four 40-milliliter volatile organic analysis vials. Filling tubes extend from the sampler lid into the bottom of the vials (Figure 6-20).

When the sampler is lowered into water, the vials start to fill. The vials overflow into the inside of the cylinder, which has sufficient volume to let the vials overflow by seven times their volume. This allows sufficient time (i.e. 3 to 4 minutes) to lower the sampler to the required sampling depth. A cover over the inlet ports prevents contamination by surface oil and debris (NJDEP, 2005). It is important to evacuate air and other gases from the sampler prior to sample collection. Close and remove the vials from the sampler immediately upon retrieval.

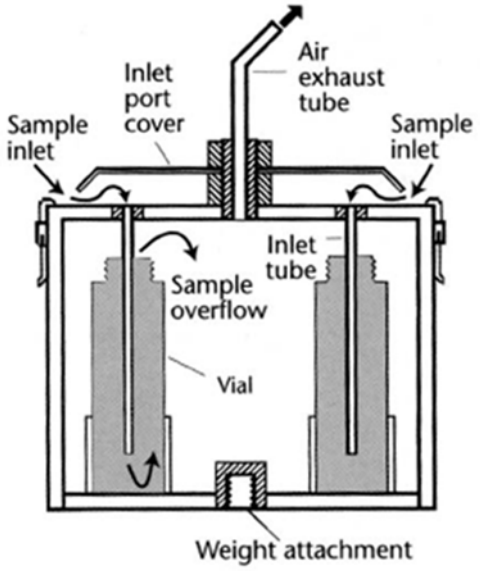


Figure 6-20. VOC sampler
Sampler contains 40-mL glass septum vials.
[Source: Rickly, 2008]

Double Check Valve Bailers

A double check valve bailer is a cylinder that is equipped with a check valve on both ends. Both check valves are designed to open as the bailer is lowered into water and to close when it is retrieved.

Dedicate the bailer to one sample location, when feasible. Suspend the bailer on rope to the selected sampling depth and then retrieve. Do not use the bailer for sampling air sensitive parameters (NJDEP, 2005). Transfer the sample slowly from the sampler drain valve into a laboratory supplied sample bottle, allowing the water to flow gently down the inside of the bottle. Avoid turbulence in the sample stream. Always collect samples for volatile and semi-volatile analyses first. Use a bottom emptying device with flow control when the bailer is used to collect water for volatile analysis.

6.9.2 COMPOSITE SAMPLING

Use composite sampling to represent a cross section of a water body. Composite samples vertically over the depth of a water body in one location or horizontally along a specific water depth.

Use an isokinetic sampler to collect a depth integrated, representative water sample continuously and isokinetically (that is, stream water approaching and entering the sampler intake does not change in velocity) from a vertical section of a stream while transiting the vertical at a uniform rate. Alternatively, collect discrete samples from varying depths along a vertical section and composite in a churn sampler, as described below.

For horizontal cross sections, collect discrete samples along one water depth traversing a body of water.

Determine the total water volume needed to fill all the sample bottles and add at least 10% for filter losses etc. Select the number of sub-samples based on the length of the vertical or horizontal cross section. Keep sample spacing at more than one foot. In a narrow or shallow stream or pond, sample the verticals or horizontals as often as required to collect a sufficient water volume. Ensure that all verticals or horizontals are sampled the same number of times.

Do not composite samples for volatile analysis. Do not composite samples for organic analysis, organic carbon, pesticides, herbicides and bacteria using a churn splitter. Do not collect these samples in any plastic device because of the potential for contamination. Use glass samplers for these analytes. Collect bacteriological samples in auto-claved plastic containers (NJDEP, 2005).

Churn Splitter

Composite the sub-samples using a churn splitter (Figure 6-21). Compositing the verticals and horizontals in the churn splitter creates single cross-sectional representations of the stream. Place the composited sample into the necessary sample containers for various analyses.

A churn splitter is an 8 or 14-liter plastic container equipped with a churning paddle and a drain valve. Use a churn splitter to composite surface water samples. Always collect a minimum of 3 liters of water volume for a composite sample when using the churn splitter. Note that a churn splitter does not reliably produce representative composited water samples when it contains less than 2 liters.

Prior to use, decontaminate the churn splitter as appropriate for the site contaminants. Prior to sampling, rinse the churn three times with 1 liter of sample water each. Let the sample water drain from the drain valve each time. This will allow the container to chemically equilibrate with the sample water.

Collect the required number of sub-samples and add to the churn. Keep the churn closed at all times except when adding sub-samples. Composite the water samples by moving the paddle up and down at least 10 times achieving a churning rate of 9 inches per second before withdrawing water (NJDEP, 2005). Faster or slower churning rates can cause maximum errors of 45% to 65%. The same rate of churning should be sustained throughout sample withdrawal.



Figure 6-21. Churn Splitters

Plastic Churn Splitter (top) and Fluoropolymer Churn Splitter (bottom).
[Source: USGS, 2002; Figure 2-8]

Increase the round trip frequency as the water volume in the splitter decreases so that the churning disc velocity is constant. The disc should touch bottom, and every stroke length should be as long as possible without breaking the water surface. Increase of the stroke length and/or disc velocity beyond the recommended rate will lead to a sudden change in sound and churning effort. This is accompanied by the introduction of excessive air into the mixture. This is undesirable because excessive air may tend to change the dissolved gases, bicarbonate, pH and other characteristics (NJDEP, 2005). However, inadequate stirring may result in non-representative sample splits.

Withdraw filtered samples last, directly from the mixing tank using a peristaltic pump or other device. Once all sample bottles have been filled, rinse the churn thoroughly with deionized water, allowing the rinse water to flow through the drain valve. Keep the churn lid closed at all times to avoid contamination with airborne particles.

Double bag the churn sampler during transport and storage to avoid contamination by airborne particles.

6.9.3 GRAB SAMPLING

Collect grab samples when:

- Natural stream conditions make compositing unnecessary. That is when the flow rate is high and mixing in the stream is uniform.
- Contaminant characteristics preclude compositing.
- Discrete samples are required.

Collect discrete samples using the appropriate sampler. Deploy the sampler away or upstream of any disturbance caused by sampling activities. Avoid touching the sediment with the sampler.

6.9.4 POINT SAMPLING

A point sample is collected at a specific sampling location from a specific depth. To obtain such samples use a double check valve bailer, a Van Dorn sampler, a Niskin bottle sampler, a VOC or other sampler. Lower the sampler to the target depth and trigger the closing mechanism. In shallow water collect the sample by submerging the closed sample containers by hand to the desired depth. Open the lid, let the container fill and replace the top, while the container remains at the sampling depth. Once the lid is in place remove the container from the water.

6.9.5 LAKE/STANDING WATER SAMPLING

Collect water from lakes and other standing water as point samples. Either composite the point samples or keep them as discrete samples as required in the SAP. Collect surface water samples at a depth of one meter. If the water is shallower than one meter, collect the sample from just below the water surface or at mid-depth. Sampling events should also be conducted during subsequent seasons, as there may be seasonal fluctuation.

If the temperature profile of the lake indicates stratification, collect discrete samples/point samples in the observed layers. These samples may be composited or analyzed discretely. Take care not to disturb the stratification with sampling activities such as a boat or wading or sampler deployment. Calm waters will possibly help keep a lake's stratification more observable and make sampling each observable layer easier. The stability of a lake's stratification depends on the lake's depth, shape, size, orientation of the wind, and inflow/outflow, so these considerations may need to be accounted for in the SAP.

6.9.6 ESTUARINE MARINE SAMPLING

Sample estuaries using the same methods employed for stream and lake sampling. Determine stratification in an estuary using conductivity and salinity measurements in addition to temperature. Both varying salinity and varying temperature can cause density variations that in turn cause stratification.

During the design of the SAP take the tidal stages and currents into account. Collect samples from a boat as far from the stern as practicable, and only after the turbulence of the wake has subsided. Approach any sampling site from downstream, and sample upstream of the boat.

6.9.7 TRACE ELEMENT SAMPLING

Sampling for trace elements requires a more rigorous sampling procedure. Follow the procedure recommended by the USEPA in its publication entitled: "Sampling Ambient Water for Trace Metals at EPA Water Quality Criteria Levels" (USEPA, 1996d).

6.9.8 FILTRATION

For surface water filtration follow the same procedures outlined for groundwater filtration of groundwater samples (Subsection 6.6, Filtration).

6.10 INVESTIGATION DERIVED WASTE

Properly contain all Investigation Derived Waste (IDW) generated during monitoring well installation, well development, well purging, and water sample collection activities. Contain all IDW in approved containers conforming to the requirements of the United States Department of Transportation. The containers must be labeled to include (at a minimum): project name, project location, date, container contents, and emergency contact name and phone number. Store IDW containers in a secure location on the project site, pending receipt of analytical results and eventual disposal. During field activities, record the number of IDW containers and their contents in the field log. Track the IDW containers until acceptance at the final disposal facility. Maintain proper disposal manifests in the project records. Subsection 5.8 provides additional information and procedures for IDW.

SECTION 6 REFERENCES

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SECTION 7
SOIL VAPOR AND INDOOR AIR SAMPLING GUIDANCE

Interim Final - December 2017

State of Hawai'i
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SECTION 7 ACRONYMS AND ABBREVIATIONS

%	Percent
°C	Degree Celsius
µg	Micrograms
µg/L	Microgram per Liter
µg/m^3	Micrograms per cubic meter
API	American Petroleum Institute
ASTM	American Society for Testing and Materials
BTEX	Benzene, toluene, ethylbenzene, and total xylenes
CalEPA	California Environmental Protection Agency
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COPC	Chemicals (or Contaminants) of Potential Concern
CSM	Conceptual Site Model
DTSC	Department of Toxic Substances Control
EAL	Environmental Action Level
EHE	Environmental Hazard Evaluation
GC	Gas Chromatograph
GC/MS	Gas Chromatography-Mass Spectrometry
HDOH	Hawai'i Department of Health
HEER Office	Hazard Evaluation and Emergency Response Office
HVAC	Heating, Ventilating and Air Conditioning
IEQ	Indoor Environmental Quality
in Hg	Inches of Mercury
ITRC	Interstate Technology and Regulatory Council
K	Kelvins (the Kelvin scale is a thermodynamic temperature scale)
LEL	Lower Explosive Limit
LVP	Large Volume Purge
MADEP	Massachusetts Department of Environmental Protection
MDNR	Missouri Department of Natural Resources
mg/L	Miligrams per liter
mg/m^3	Milligrams per cubic meter
mm Hg	Millimeters of mercury
MRBCA	Missouri Risk-Based Corrective Action
MS	Mass Spectrometer
MTBE	Methyl tertiary butyl ether
MW	Molecular Weight
NYDOH	New York Department of Health
One atmosphere	760 millimeters of mercury
OSWER	Office of Solid Waste and Emergency Response
PAH	Polynuclear Aromatic Hydrocarbon
PCE	Tetrachloroethylene

PID	Photo Ionization Detector
ppb	Parts per billion
ppbv	Parts per billion by volume
ppm	Parts per million
ppmv	Parts per Million by Volume
PRGs	Preliminary Remedial Goals
RCRA	Resource Conservation and Recovery Act
RFI	RCRA (Resource Conservation and Recovery Act) Facility Investigation
RME	Reasonable maximum exposure
RSL	Regional Screening Level
RWQCB	Regional Water Quality Control Board
SIM	Selected ion mode
SVOC	Semi-volatile organic compound
SW-846	USEPA publication entitled Test Methods for Evaluating Solid Waste, Physical/Chemical Methods
TPH	Total Petroleum Hydrocarbons
TVH	Total Volatile Hydrocarbons
TWG	Technical Working Group
USEPA	United States Environmental Protection Agency
VOC	Volatile Organic Compound

7.0 SOIL VAPOR AND INDOOR AIR SAMPLING GUIDANCE

This section of the *Technical Guidance Manual*l addresses the collection of subsurface soil vapor samples and indoor air samples. The guidance was developed following review of numerous guidance manuals, sampling protocols, technical reports and advisories published by the United States Environmental Protection Agency (USEPA) and other states, as well as other publications. A list of references consulted during development of this guidance is included at the end of the section.

The discussion of sample collection is preceded by an overview of the occurrence and nature of vapor plumes in the subsurface and the potential risks posed to outdoor air and overlying buildings. The development of HDOH soil, groundwater and soil gas ("vapors") action levels for evaluation of vapor intrusion hazards is described in the document *Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater* ("EHE guidance;" HDOH, 2016, see also HDOH, 2016b.). The discussion provided below and in Section 13 is intended to serve as a supplement to this guidance.

7.1 OCCURRENCE OF SUBSURFACE VAPOR PLUMES

Sites where releases of volatile organic compounds (VOCs) can be of concern include commercial, military and industrial fuel facilities with petroleum storage tanks and pipelines; degreasing, cleaning or dry cleaning operations where chlorinated solvents are utilized; and agricultural operations where fumigants such as dibromochloropropane were stored, mixed or applied. The size of contaminated sites can range from a few hundred square feet associated with a small, one-time release from an underground storage tank to several acres associated with large long-time releases from fuel pipelines and aboveground storage tanks.

The emission of volatile chemicals from contaminated soil and groundwater can create a plume of vapors in the vadose zone. These plumes can adversely impact indoor air if drawn into an overlying building, a key topic of this section. Vapors emitted at the ground surface can also affect outdoor air. This issue is addressed separately under direct-exposure models for contaminated soil, however, and is considered to pose less of a threat to human health than vapor intrusion into buildings (see HDOH, 2016). Vapors in vadose-zone soil could also migrate downwards and impact groundwater that has otherwise not been directly affected by the release. This has been recognized, for example, at MTBE release sites on the mainland.

The majority of subsurface vapor plumes in Hawai´i are associated with subsurface released petroleum fuels including gasoline, diesel and jet fuel. As discussed in Section 7.13, vapors emitted from petroleum fuels are evaluated in terms of Total Petroleum Hydrocarbons (TPH) and a short list of individually targeted, individual compounds including benzene, toluene, ethylbenzene, xylenes (BTEX), methyl tertiary butyl ether (MTBE, not widely used in Hawai'i) and naphthalene (see also Section 9). Methane, a biological breakdown product of petroleum or a component of landfill gas, can also be of importance at some sites. As discussed in Section 7.6, petroleum-related vapor plumes that could pose hazards for overlying buildings are almost always associated with the presence of relatively shallow, free product in vadose-zone soil or groundwater (see USEPA 2013). Under most site scenarios, the breakdown of petroleum compounds by naturally occurring bacteria in the soil will ensure that vapor plumes rarely migrate more than 15 to 30 feet vertically through unconsolidated soil and more than one-hundred feet laterally under pavement or buildings from the source area (see Section 7.6.1).

A smaller number of subsurface vapor plumes in Hawai'i are associated with releases of chlorinated solvents from dry cleaners (e.g., tetrachloroethene or “PCE”) or parts washing operations (e.g., trichloroethene or “TCE”). Vapors emitted from these releases are evaluated in terms of the primary product released as well as related breakdown chemicals, such as dichloroethenes or dichloroethanes and vinyl chloride. Although the volume of product released is typically much smaller in comparison to releases of petroleum fuel, the higher toxicity and in particular the greater persistence of chlorinated solvents can lead to potential vapor intrusion concerns even in the absence of free product in soil or groundwater. Dilute plumes of solvent-contaminated groundwater have, for example, been documented to travel thousands of feet downgradient of initial release areas and impact overlying homes and buildings (e.g., see API 2005, USEPA 2004e, USEPA 2012)

Both chlorinated solvents and non-chlorinated petroleum products could be present at some sites. Common examples include dry cleaning facilities that have a fuel tank associated with a boiler and/or that used Stoddard solvent during an earlier period of operation. The presence of high levels of vinyl chloride in groundwater or soil vapor at sites often indicates the presence of co-located petroleum contamination. The vinyl chloride is associated with reductive dechlorination of chlorinated solvents in the presence of petroleum. The presence of significant breakdown products in soil vapor or groundwater signifies the need to look for petroleum contamination in the same area.

Due to the inherent heterogeneity of VOCs in subsurface vapor plumes and the uncertainty of upward vapor migration from deeper areas, HDOH emphasizes the collection of soil vapor samples from immediately beneath a building slab for evaluation of potential vapor intrusion hazards (see Section 7.6.2.3). The concurrent collection and evaluation of deeper soil vapor samples is also typically recommended for heavily-contaminated properties. Data from deeper samples may indicate a need to seal cracks and gaps in floors as an added measure of protection even in cases where subslab data do not suggest a significant problem (see Subsection 7.14.1).

7.2 SOIL VAPOR TRANSPORT MECHANISMS AND CONCEPTUAL SITE MODELS

7.2.1 FACTORS AFFECTING SUBSURFACE VAPOR FLOW AND IMPACTS TO INDOOR AIR

As introduced in the previous section, understanding how vapors are generated, migrate in the subsurface and can intrude an overlying building is important for development of site investigation objectives and associated sampling plans. In theory, the rate and flux of VOC diffusion through the vadose zone is relatively simple to model (e.g., see USEPA 2004e). In practice, estimation of the upward, mass flux of vapor-phase VOCs in the subsurface and prediction of VOC concentrations in subslab soil vapor is very difficult.

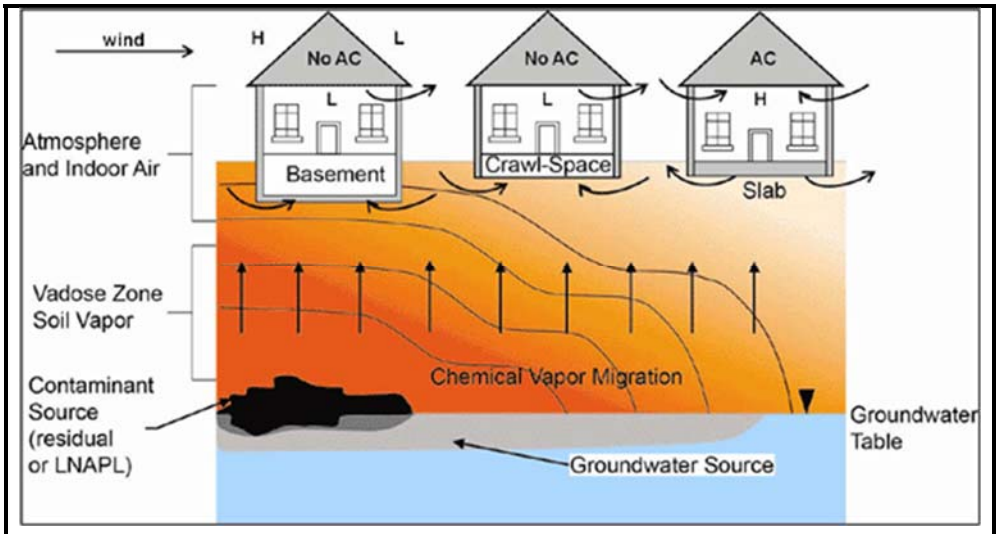


Figure 7-1: Example Vapor Plume Contours and Vapor Intrusion Pathways.

Vapor-phase chemicals diffuse away from a source area. Wind effects (or heating) can cause depressurization of buildings and advective intrusion of vapors. Air conditioning (AC) can over pressurize a building as fresh air is brought inside and induce an *outward* flow of air into the subslab space. Source: Modified from API 2005. Upward migration of vapors dominated by diffusion; advective flow limited to near vicinity (a few feet or less) of floors of under-pressured buildings.

Concentrations of VOCs in shallow or subslab soil vapor are oftentimes significantly lower than would be predicted by models based on the soil type observed in the field (see HDOH, 2016, USEPA, 2012). This is due in part to dissolution of vapors into soil moisture but can also include adsorption to or diffusion into clays in the soil and permanent removal from the vapor plume, a mechanism not directly taken into account in the vapor intrusion models. The heterogeneous nature of contaminant distribution in soil, both sorbed to soil particles and in vapor phase, complicates the collection of representative data. These factors highlight the need to collect soil vapor data in the immediate vicinity of potentially affected buildings as a routine part of vapor intrusion studies when general site knowledge suggest a potentially significant vapor intrusion risk. Limitations on the utility of traditional, small-volume sample data due random, small-scale heterogeneity can also be overcome by the collection of "Large Volume Purge" vapor samples beneath building slabs (Section 7.8.5).

Vapors migrate in subsurface soils primarily by diffusion from high- to low-concentration areas (Figure 7-1). Vapors diffuse much more rapidly through air-filled pore space than water-filled pore space. *Advective* flow of vapors caused by pressure differentials (e.g., flow from high- to low-pressure areas) can occur in the near proximity (few inches to few feet) of building floors in cases where the building is under-pressured in comparison to subsurface soils. This can be due to wind effects, changes in barometric pressure due to storms, heating of buildings (unlikely in Hawai'i), or the use of exhaust fans in kitchens or shop areas (see Figure 7-1; see also USEPA 2004e, ITRC 2007, USEPA 2012d). Wind-induced depressurization of buildings will be the most likely cause of vapor intrusion in Hawai'i. Wind can create a low-pressure zone on the downwind side of a building. Air pulled out

of the building as a result can lead to the advective flow of subsurface vapors through cracks and gaps in the floor. This is taken into account in building and HVAC system design.

Buildings with HVAC systems ("Heating, Ventilation and Air Conditioning") are specifically designed to minimize the infiltration of outdoor air via pathways other than the fresh air intake, in order to ensure efficiency and control costs. More likely for buildings in Hawai'i, air conditioning will cause buildings to be over-pressured as fresh air is pulled into the HVAC system ((Roberson et al 1998; see Figure 7-1). This could induce the *outward* flow of indoor air into subslab soils (see also USEPA 2012d). Samples of subslab soil vapor would in turn reflect the concentration of VOCs in indoor air samples, rather than a subsurface source. This presumably explains the apparent absence of significant vapors immediately beneath slabs of air-conditioned buildings that overlie shallow, petroleum free product or heavily contaminated soil. In this case, the sudden, upward "attenuation" of deeper soil vapors in the immediate vicinity of a building slab is not attributable to biodegradation.

Note that an upward diffusion of vapors into the subslab area could also occur when the air conditioning is turned off in the night time and on weekends. This issue has not been studied in detail. In theory, this could lead to the intrusion of subsurface vapors into the building during these time periods. In practice, this is likely to be offset by the time required for deeper vapors contaminants to diffuse into the zone of advective transport. Impacts to indoor air by intruding vapors are also likely to be offset by increased impacts from indoor sources (see Subsection 7.7). Impacts to indoor air from both subsurface and indoor sources during periods when the building air conditioning system is not operating are generally transient in nature, with contaminants quickly removed upon restart of the HVAC system. Additional information on this topic will be found in Brewer et al. 2014, in prep.

Evaluation of risk posed to occupants should be based on air quality during normal building operating conditions (see also Section 7.10.1). More detailed sampling could be required on a site-specific basis, however, at sites considered to be of high risk for potential vapor intrusion.

Concentrations of volatile chemicals in indoor air associated with indoor sources are also likely to increase when the building HVAC system has been turned off and reach levels significantly higher than reported for typical, indoor air (see Subsection 7.7.2). These types of temporal changes associated with operation of the building HVAC system are important to recognize as part of a vapor intrusion investigation and to consider when determining the timing and frequency of sample collection (see Section 7.10.1). As discussed in Section 7.11, if indoor air samples are desired or required to further assess potential vapor intrusion hazards then they should be collected under normal building ventilation and operation conditions that reflect periods when the building is occupied. This more accurately reflects the potential risk to occupants of the building.

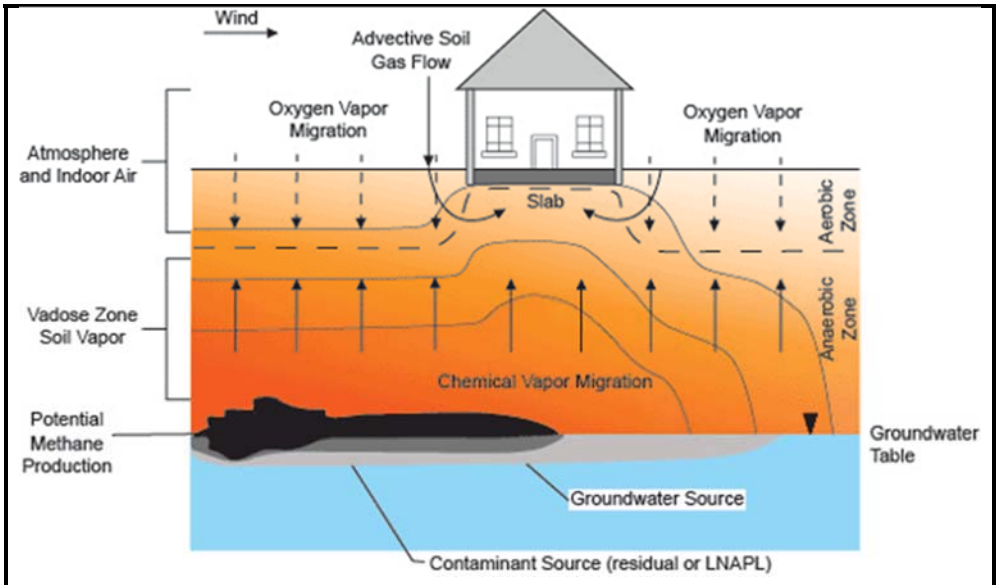


Figure 7-2: Conceptual Model of Soil Vapor

Transport Including Biodegradation Process. Source: Adapted from API 2005. Note hypothetical anaerobic zone immediately beneath the building due to biodegradation of vapor-phase petroleum compounds and inadequate replenishment of oxygen

In Hawai'i, seasonal weather variations typically include the "wet" season during the winter, and the "dry" season during the summer. The water table rises and falls accordingly. The magnitude of this rise and fall is minimal in coastal areas near sea

level. In inland areas the seasonal water table fluctuation can reach ten feet or more, however. The rise and fall of the water table can create a smear zone of contaminated soil of equal magnitude, especially in the case of petroleum releases that have reached groundwater. As the water table falls and exposes this smear zone, an increase in vapor emissions can occur. As the water table rises some product may rise with it and continue to pose vapor emission hazards. A substantial portion is likely to remain trapped in the smear zone below the water table, however. This can result in a substantial reduction in vapor emissions during the wet season. The collection of deep and/or subslab soil vapor samples during both the wet and dry season is, recommended for sites where exposure of a significant smear zone could vary dramatically over the year (see Section 7.10.1).

The rise and fall of the water table with fluctuating tides could also influence the migration of vapors in the vadose zone. Indoor air could be pulled out of the building and into the subslab zone as the water table falls. The same air, or a mixture of this air and VOCs from subsurface contamination, could be pushed back into the building as the water table rises if the building was not over-pressured. This phenomenon has not been studied in detail in Hawai'i. Small, tide-related fluctuations of the water table observed in coastal areas of Hawai'i, typically less than one-foot, are unlikely to cause significant fluctuations in vapor concentrations due to exposure and flooding of smear zones. Tidal pumping of air into and out of a building could also help maintain a well-oxygenated zone under a building slab and help protect against significant vapor intrusion associated with subsurface, petroleum contamination.

As discussed in Section 7.10.1, consideration of tidal pumping is not necessary for general screening purposes. The collection of subslab soil vapor samples during periods of both falling and rising water table may be recommended or required, however, at sites that overlie significant, shallow contamination.

7.2.2 PREPARATION OF CONCEPTUAL SITE MODELS FOR SOIL VAPOR INVESTIGATIONS

Consideration of subsurface vapors and the potential for soil vapor intrusion should be included in an overall conceptual site model (CSM) and used to design sampling strategies. The CSM should include information on the expected subsurface geology, depth to the potential source contaminants or groundwater, and actual or potential human or environmental receptors, as well as other specific information described in Section 3. The CSM should be used to develop a general understanding of the site, evaluate potential risks to public health and the environment, and assist in identifying and setting priorities for planned activities at the site.

The CSM should reflect the representative, *average* subsurface conditions and building susceptibility to vapor intrusion over time and during normal building operation. This is important, because the soil gas (and indoor air) action levels are based on average exposure over a six-year time period (noncancer hazard; e.g., TPH) to thirty-year time period (cancer risk; e.g., benzene and PCE). A focus on soil vapor samples collected during periods of high water table or vapor flux assumptions during periods when a building is over-pressurized can lead to the underestimation of potential vapor intrusion hazards. A focus on subsurface data collected during periods of low water table or periods when the building is under-pressured and most susceptible to vapor intrusion could overestimate the actual risk and lead to unnecessary remedial actions. An understanding of subsurface and building conditions throughout the year as part of the CSM is therefore very important.

A simple conceptual model of soil vapor transport includes the outward diffusion of vapor-phase chemicals from impacted soil or groundwater and the potential advective flow of the vapors into an overlying building (Figure 7 1). The chemicals could migrate to and intrude residential or commercial/industrial building interiors. Common vapor intrusion pathways into buildings include basements, crawl spaces, cracks, and utility penetrations in concrete slabs. The intruding vapors subsequently mix with indoor air and the concentration of initial chemicals in the vapors is attenuated.

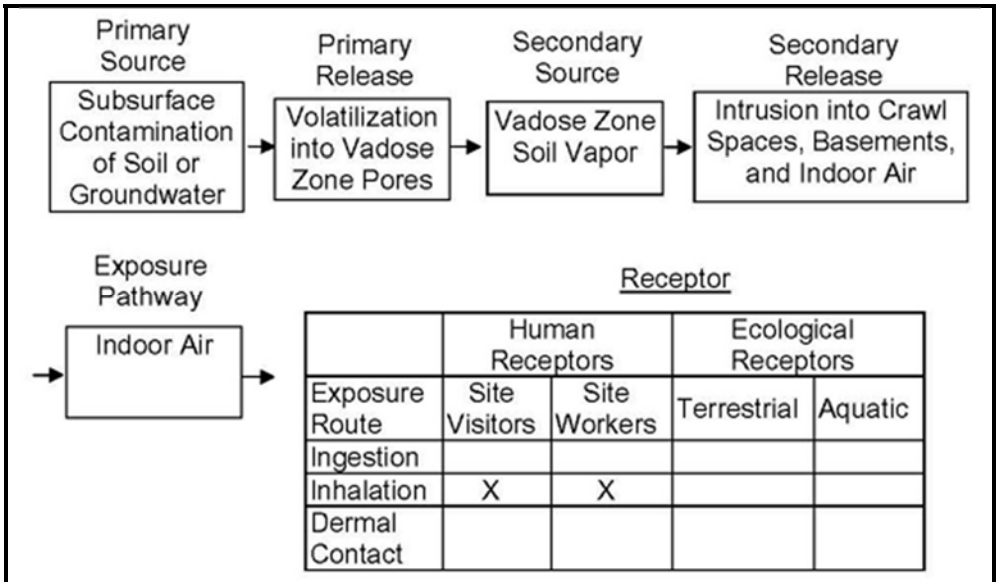


Figure 7-3: Complete Exposure Pathway CSM for Soil Vapor to Indoor Air

A more detailed conceptual model of soil vapor transport might consider spatial temporal variations in subsurface conditions and building operations (e.g., daily or seasonally). Concentrations of VOCs beneath the slab of a home or building are likely to be heterogeneous (USEPA 2012d; Brewer et al. 2014, in prep). This factor and uncertainty regarding specific, vapor entry routes complicates the investigation of potential vapor intrusion hazards. As discussed in Section 7.6.2.2, the biased collection of subslab soil vapor samples from center of slabs, presumed to be the worst-case area for vapor accumulation as well as potential vapor entry points in other areas of the building (e.g., cracks in floor and utility gaps) is recommended.

The CSM could also include biodegradation processes commonly observed with petroleum hydrocarbon or volatile organic compounds (VOC) impacted soil and groundwater (Figure 7-2). The biodegradation processes include aerobic and anaerobic degradation of contaminants and potential production of additional chemicals of concern (referred to as daughter products). These conditions could change over time, as the release ages. The vapor transport of daughter products, oxygen, CO2, and in the case of petroleum hydrocarbons, methane, should be considered when assessing aerobic or anaerobic biodegradation processes.

The exposure pathway for soil vapor should be included on the CSM, which serves as the basis of an exposure assessment (see HDOH, 2016). An exposure pathway is defined as “the course a chemical or physical agent takes from the source to the exposed individual”. A completed exposure pathway to a potential receptor has the following four elements: (1) a source of contamination, (2) a contaminant release mechanism, (3) an environmental transport mechanism, and (4) an exposure route at the receptor contact point with the chemicals of concern. An example of a complete exposure pathway CSM diagram for soil vapor to indoor air is provided in Figure 7-3.

For the chemicals of concern to reach a potential receptor, each of the four elements of an exposure pathway must exist and must be complete. If any of these four elements are missing, the path is considered incomplete and does not present a means of exposure under the conditions assumed in the CSM. Common pathways for vapor intrusion from the subsurface are cracks or utility penetrations through the slab or basement walls/floor, sumps with earthen floors, and drain pipes (see Section 7.7.2). Bathrooms, kitchens and utility rooms are often the primary entry points for intruding vapors.

As discussed in Sections 7.6.2 and 7.10.1, it is important that a well-thought-out CSM be prepared prior to an investigation and used to help determine the number and location of vapor collection points as well as the frequency and timing of sample collection. See Section 3 for more information on designing a CSM. See Subsection 13 and the HEER Office EHE guidance for details on environmental hazard evaluation. Section 7.14 discusses the use of a multiple-lines-of-evidence approach to evaluate potential vapor intrusion hazards on a site-specific basis for cases where a high risk of vapor intrusion is identified.

7.3 DEVELOPMENT OF VAPOR INTRUSION SCREENING TOOLS

Assumptions regarding the local nature of vapor intrusion and building ventilation can be used to develop environmental action levels for rapid screening of suspect sites. Development of the HDOH soil, groundwater and soil gas ("vapor") action levels for vapor intrusion is discussed in the HDOH EHE guidance document (HDOH 2016; see also HDOH, 2016b.). A detailed discussion of indoor air:subslab soil gas attenuation factors selected for use in Hawai'i is provide in Section 13 and serves as a supplement to the EHE guidance.

Application of the guidance and screening tools at petroleum-contaminated sites was evaluated in the HDOH study entitled *Field Investigation of the Chemistry and Toxicity of TPH in Petroleum Vapors: Implications for Potential Vapor Intrusion Hazards* (HDOH, 2012). The results of this study were incorporated into the petroleum section of the HDOH EHE guidance (HDOH 2016). A Question and Answer fact sheet on this document provides additional clarification on the application of the guidance and screening tools at petroleum-contaminated sites (HDOH, 2012c).

As discussed in Section 13 and the EHE guidance, the selected attenuation factors and associated HDOH action levels for vapor intrusion may not be adequately conservative for use in colder regions on the US mainland and elsewhere. Adjustment of the action levels to assumptions regarding vapor flux and building ventilation is required and should be discussed with the overseeing regulatory agency.

7.4 SOIL VAPOR INVESTIGATIONS

The following subsections discuss the collection and analysis of soil vapor and indoor air samples. Although the guidance presented is anticipated to apply under most site scenarios, issues such as sample location and depth, sample collection timing and frequency, collection of indoor air samples, etc., will necessarily be site-specific and should be discussed with the overseeing HDOH project manager.

Soil vapor samples, including samples collected immediately beneath building slabs, are collected following the discovery or suspected presence of volatile chemicals in subsurface soil or groundwater. Data are used for general site-characterization purposes and/or to assess vapor intrusion risk. Typical site investigation objectives include: 1) Characterization of in situ vapor plume conditions, 2) Assessment of potential vapor intrusion risks, 3) Assessment of worker-related environmental hazards in locations where soil vapor may accumulate (e.g., utility conduits or vaults beneath foundations, roadways and caps, 4) Development of remedial actions and 5) Monitoring or confirmation of remedial actions. Indoor air samples are collected as needed to further assess vapor intrusion risk and link or negate identified impacts to a subsurface source. Soil vapor data can also be used to assess potential impacts to groundwater posed by downward migrating vapors or volatile chemicals dissolved in downward migrating leachate (refer to HDOH 2017b).

The types of soil vapor samples collected and subsequent use of the data can vary based on the objective(s) of the site investigation. As discussed below, samples collected from multiple, “discrete” points beneath a building or in open areas and representing very small volumes of vapor (e.g., one to six liters) can be useful for identification of large-scale, vapor plume patterns. Reliance on individual sample points to identify plume boundaries or assess vapor intrusion risk is complicated, however, by the inherent variability of VOC concentrations in vapors at this small scale. The collection of “Large Volume Purge (LVP)” samples, representing thousands of liters of vapor, is recommended when feasible in order to improve data reliability (Section 7.8.5).

Testing of soil vapor is carried out through the collection of “active” or “passive” vapor samples from multiple points within the targeted investigation area and comparison of the resulting data to HDOH Environmental Action Levels (EALs) for vapor intrusion risk (HDOH 2017a). “Active” samples are collected by drawing vapor into canisters under a vacuum (Section 7.8.1) or by drawing vapor through a sorbent tube (Section 7.8.2). “Passive” samples are collected by burying and then retrieving and testing sorbent media at multiple points within the investigation area (Section 7.8.3). Small-volume, active samples(e.g., 1-6 liters) that minimize disturbance of a vapor plume and/or passive samples are used to characterize undisturbed, in situ subslab vapor conditions. Large-volume, active sample data are used to more reliably assess actual vapor intrusion risk. Although useful for general screening purposes, note that data for small-volume samples, both active and passive, are in theory not directly comparable to HDOH (2017a) action levels for vapor intrusion risk. The action levels more strictly apply to the mean concentration of a VOC in very large volumes of vapor assumed to intrude a building over many years, amounting to millions of liters of vapor per year (refer to Section 13.2; see also Brewer et al. 2014).

The use of LVP vapor sampling methods is recommended for more direct evaluation of vapor intrusion risk. This approach allows for a very large, risk-based volume of vapor to be represented by a single, active soil vapor sample (Section 7.8.5). The resulting data will thus be more directly representative of the large volume of vapor predicted to intrude into a building on a given day, for example the 3,000-liter, default, assumed daily vapor entry rate for buildings in Hawai´i discussed in Section 7.5.5. This method is currently most widely applied to the collection of subslab vapor data. The collection of deep LVP samples from areas with a thick vadose zone is feasible for soils with a relatively high vapor permeability, provided that monitoring for leakage to outdoor air is carried out. The collection of shallow (e.g., <25 ft) LVP samples from open (uncapped) areas will be hindered by potential downward leakage of outdoor air into the sampling train. In these cases, continued reliance on small-volume soil vapor sample data is still necessary. Collection and comparison of replicate sets of small-volume sample data can assist in understanding the representativeness of a single data set. Data from deeper strata are, however, less likely to be representative of a vapor plume that might form under the base of an overlying building after the effects of degradation and diffusion into a subslab advective zone are taken into account. This is especially true for nonchlorinated, hydrocarbon compounds associated with releases of gasoline and diesel fuels, where localized variability in degradation could result in a highly heterogenous vapor plume.

The information provided in this section is intended to apply to sites in the State of Hawai‘i where soil vapor and, if required, indoor air samples are collected, whether the evaluation is being conducted voluntarily by private individuals or corporations or under one of the state's environmental remediation programs. This guidance is intended to provide a technically defensible and consistent approach for the collection and evaluation of soil vapor or indoor air samples. However, this guidance is not

regulation and is only meant to provide a clear technical framework for collecting and evaluating soil vapor or indoor air samples. The information contained in this guidance is not intended to exclude technically equivalent alternate approaches or methodologies that may exist.

This guidance does not address safety or hazard mitigation efforts to prevent fires or explosions resulting from the accumulation of hazardous vapors (i.e., methane); however, methane concentrations should be monitored to determine whether these hazards exist. A brief discussion of methane hazards and additional reference documents is provided in Sections 9 and Section 13 of this guidance. Emergency or immediate response actions by qualified responders should be completed prior to the initiation of a soil vapor or indoor air sampling event. If the results from the soil vapor or indoor air sampling event indicate that there is an immediate concern for human exposures to vapor phase chemicals, then emergency response or interim actions are typically implemented as required under state and federal regulations.

The HEER Office recommends that Soil Vapor or Indoor Air sampling work plans be submitted for review and approval prior to the collection of soil vapor or indoor air samples in Hawai‘i. The work plan should describe the purpose and rationale for the soil vapor or indoor air sampling, targeted chemicals of concern, sample locations and depths, sample collection protocols, and analytical methods. A discussion of targeted chemicals of concern for petroleum releases is provided in Subsection 7.13.1.2 (see also Section 9). Work plans should be developed following the **systematic planning approach** and guidelines outlined in Section 3. Information on the recommended format and general content of investigation work plans is included in Section 18.

7.5 COLLECTION OF REPRESENTATIVE SOIL VAPOR SAMPLES

The basic concepts of site investigation design and data collection and interpretation discussed in Section 3 and Section 4 of this guidance apply to soil vapor and indoor air as well as of soil and sediment. A systematic approach (Section 3.3) should be used to identify potential environmental issues of concern develop a preliminary, conceptual site model (CSM), designate "Decision Units (DUs)" for sample collection with specific, investigation objectives and decision statements, collect and interpret sample data, refine the CSM and recommend additional investigation and/or remedial action as appropriate. This step-by-step approach to data collection should be documented in the work plan prepared for the site investigation.

The interpretation of soil vapor and indoor air data is discussed in Subsection 7.14. It is important that data be collected in a manner that is reflective of the investigation questions being asked. Data for traditional, small-volume samples collected from single points can be compared to HDOH subslab vapor action levels for initial identification of large-scale, subsurface vapor plumes that could pose potential vapor intrusion concerns (HDOH 2017b; see also Section 7.14.1). Random, small-scale variability of VOC concentrations within a vapor plume (e.g., at the scale of a one-liter vapor sample) can, however, lead to erroneous estimates of vapor plume boundaries ("false negatives") and estimation of vapor intrusion risk (Section 13.2; see also Brewer et al. 2014). Small-scale, "hot spot" and "cold spot" VOC patterns based on single samples within a large vapor plume can likewise be artifacts of random variability and very misleading of actual site conditions.

Although useful for initial screening purposes, HDOH soil vapor action levels for vapor intrusion apply to the mean or "true" concentration of a targeted VOC for the total volume of vapor anticipated to intrude a building over several years. Comparison of deep soil vapor data or data for small-volume samples collected immediately beneath a slab can useful for initial screening purposes but is not strictly appropriate for evaluation of vapor intrusion risk (refer to Section 13.2). This is similar to limitations on comparison of small-volume, "discrete" soil sample data to HDOH EALs rather than data for large-mass samples collected from well-thought-out, targeted DUs (Section 4.3; see also Brewer et al. 2017a, b).

Assumptions regarding the representativeness of small-volume vapor sample data should be used with other lines of evidence to assess long-term, vapor intrusion risk. This includes the nature of known releases, soil data (preferably MIS; Section 4), groundwater data and Large Volume Purge (LVP) vapor data collected directly beneath the slab, as discussed below and in Section 7.4.

A more systematic and well-thought-out sample collection approach similar to that used to assess the risk posed by contaminated soil is required to reliably assess vapor intrusion risk (see Section 3.4). The results of the Site Scoping (Section 3.1) and Systematic Planning process (Section 3.2) should be used to designate slab areas within the subject building for subslab vapor sample collection. This could include testing of subslab vapors:

- Beneath known or hypothetical, vapor entry points;
- Within known or suspect subslab utility trenches that could serve as preferential pathways for vapor flow;
- Above suspect soil or groundwater source areas;
- Beneath areas of the building with high-risk usage (e.g., daycare center) or, in the absence of other information;
- Beneath the center of the building slab or other potential vapor accumulation areas beneath the slab.

An indoor air study (Section 7.7) can in some cases be used to identify the general location of vapor entry points. In most cases, however, vapor entry points (if present) are rarely known during the initial stages of an investigation. As an alternative, subslab vapor samples for assessment of vapor intrusion risk are typically drawn from hypothetical entry points in worst-case areas of the slab.

A risk-based DU volume of soil vapor should be designated for sample collection, similar to the approach used for characterization of soil. The objective of sample collection is to estimate the true ("mean") concentration of targeted VOCs within this targeted volume of vapor. A default, DU vapor volume of 3,000 liters is recommended for use in Hawai´i. This represents the volume of subslab vapor assumed to intrude a building through a single gap in a floor over a one-day period, based on a daily vapor entry rate of 2 L/minute. The same vapor entry rate is used to calculate subslab soil vapor action levels presented in the HDOH EAL guidance (HDOH 2017a) and is predicted to be appropriate for tropical climates (Brewer et al. 2014). Larger subslab vapor DU volumes are appropriate for non-tropical climates due to potentially higher, vapor entry rates during periods when a building is being heated. The following vapor entry rates are estimated for different climate zones by Brewer et al. (2014):

Climate Region	Average Cooling Days per Year	Average Neutral or Heating Days per Year	Estimated Annual-Average Vapor Entry Rate (L/min)	Estimated Annual-Average Vapor Entry Rate (L/day)
Cold	62	303	4.5	6,466
Warm	122	243	4.0	5,756
Mediterranean	199	166	3.4	4,845
Tropical	**365**	**0**	**2.0**	**2,880**

The daily vapor entry rate estimated for tropical climate zones, rounded to 3,000 liters/day, was referenced for use as a default subslab vapor volume for LVP sample collection. Note that an LVP DU volume of 7,000 liters was used in the 2016 HDOH field study of LVP sample collection (HDOH 2017c), discussed in Section 7.8.5. This is excessively large for use in Hawai´i but might be appropriate for the collection of LVP samples in cold climate zones.

As a default, subslab vapor in soil or fill material within 15-25cm of the building slab should be targeted for sample collection. For example, screened, vapor extraction points might be installed to a depth of 15cm beneath the slab and a series of 3,000-liter, LVP vapor samples collected.

Characterization of targeted vapor DUs could in theory be accomplished by collection of an “adequate” number of small-volume vapor sample points. The number of samples required to obtain a representative concentration of the targeted VOCs in the vapor and use of the resulting data to assess vapor intrusion risk is uncertain, however. Use of individual data points is not strictly appropriate, since the small volume of vapors represented cannot be assumed to represent vapors intruding the building or even the general concentration of VOCs in vapors in the immediately surrounding area (see Section 13.2). Statistical analysis can be used to estimate a mean concentration for a set of small-volume, vapor sample data points, but the total volume of vapor directly represented by the samples will again be very small in comparison to the DU volume of vapors of interest. The field representativeness of a single set of small-volume, vapor points cannot be directly assessed in the absence of multiple, replicate sets of individual data points for comparison. This same problem hampers the reliability of single sets of discrete soil samples as discussed in Section 4.3.

Sample data that represent large, risk-based volumes of vapor (e.g., thousands of liters), similar to the concept of “Multi Increment” soil sample data (Section 4) are required for more reliable characterization of subsurface vapor plumes and vapor intrusion risk. Such “LVP” methods are currently mostly widely used for testing of vapors beneath building slabs where breakthrough to indoor air can be minimized (Section 7.8.5). The collection of LVP samples helps ensure that isolated, subslab vapor “hot-spots” that might be missed by small-volume vapor samples are incorporated into the data used to assess potential vapor intrusion risk and provides a volume-weighted average vapor concentration more applicable to comparison with subslab vapor action levels (HDOH 2017a; Section 7.14.1). Direct correlation of LVP data to identified impacts to indoor air might still not be practical, given the typical lack of knowledge of the exact point of vapor entry into a building, if in fact this is occurring.

7.6 SOIL VAPOR SAMPLING STRATEGIES

7.6.1 DETERMINING WHEN TO COLLECT SOIL VAPOR SAMPLES

Table 7-1 Decision Logic for Subsurface Vapor Hazards

Site Scenario	[1]Regularly Occupied Buildings within 100 ft of Source Area	Soil Vapor Data
Contaminants in Vadose Zone [2]Soil and/or [3]Groundwater Pose Potential Vapor Intrusion Hazards	Yes	Collect source area vapor data and data to evaluate potential vapor intrusion hazards.
	No	Collect source area vapor data to evaluate potential future vapor intrusion hazards or, at a minimum, recommend soil vapor investigation prior to future subsurface work or construction of buildings.
Post-Remediation Confirmation of Previously Identified Vapor Intrusion Hazard	Yes or No	Collect soil vapor data to confirm and document absence of remaining, significant vapor intrusion hazards.
[4]No Potentially Significant Vapor Intrusion Hazards Identified	Yes or No	Collection of soil vapor samples not necessary; conclude in EHE that contamination does not pose significant vapor intrusion hazards.

Notes:

1. For petroleum sources only - Source area within vertical thirty feet of building slab or crawl space.
2. VOC concentrations above Tier 1 soil action levels for vapor intrusion, significant volume (e.g., >10m^3) of VOC-contaminated soil is present, or potential for elevated vapors under a building slab otherwise suspected (e.g., PCE vapors under a dry cleaner).
3. Free product on groundwater table or dissolved VOC concentrations above Tier 1 groundwater action levels for vapor intrusion.
4. VOC concentrations below Tier 1 EALs for both soil or groundwater *and* significant volume (e.g., >10m^3) of VOC-contaminated soil or other potential source of elevated vapors under a building slab not suspected.

An example, decision flow chart for the collection of soil vapor samples is presented in Table 7-1. Soil vapor samples are collected to help locate and characterize areas of contaminated soil and groundwater that pose vapor intrusion risks for existing or future buildings. Direct comparison of groundwater data to HDOH action levels intended to address potential vapor intrusion concerns in the absence of initial, soil vapor (or indoor air) data is generally acceptable (HDOH 2017a). The groundwater action levels are intended to be conservative, assuming that representative samples are collected. If action levels are exceeded then the additional collection of soil vapor samples is recommended. If a significant threat to indoor air is deemed likely, then the concurrent collection of indoor air samples is likewise recommended (Section 7.7).

Note, however, that groundwater action levels presented in the HDOH EHE guidance are not applicable for sites where the depth to groundwater is less than ten feet due to limitations in the models and data used to develop the levels. The direct collection of soil vapor samples is recommended in these scenarios.

Reliance on soil samples to adequately identify and characterize the presence of VOC-contaminated soil is, in contrast, significantly prone to errors. This is in part due to the small size of the soil aliquot typically tested by the laboratory for VOCs (five grams) and the heterogeneous nature of contaminants in soil (refer to Sections 3, 4 and 5 of the TGM). The chance that a small number of discrete, five-gram soil samples will be representative of the targeted area and volume of subsurface soils and capture a representative number of "hot spots" is minimal. The chemicals may also be present predominantly in vapor phase in very dry soil (e.g., beneath a dry cleaner building slab). This could be overlooked by the collection of only soil samples.

The collection of soil vapor samples is therefore recommended at all sites where a significant amount of VOC-contaminated soil could be present in the vadose-zone and/or the contaminant could be present primarily in the vapor phase. A soil volume of at least 10m3 is generally needed in order to pose significant, long-term vapor intrusion hazards, based on mass-balance models for assumed exposure duration and typical contaminant concentration in heavily-impacted soil; HDOH, 2007c, HDOH, 2016). This can be evaluated on a site-specific basis as needed, although short-term, acute or nuisance impacts must also be considered. Direct collection of soil vapor samples regardless of soil and/or groundwater data is also recommended for sites with a very high potential for the release of volatile chemicals. This includes gas stations and dry cleaners (see Section 7.6.2.2).

As is the case for groundwater, volatile chemicals in subsurface soils tend to more evenly disperse over relatively large areas due to diffusion flow. A soil vapor sample is also representative of a significantly larger volume of soil (liters) than a discrete soil sample (five grams, around three milliliters). This emphasizes the usefulness of soil vapor samples to identify the presence or absence of significant VOC contamination in the subsurface. The use of multi-increment subsampling approaches can significantly increase the usefulness of VOC soil data from cores (see 5), but widely-spaced cores could still miss relatively small but still significant areas of VOC-contaminated soil that might pose leaching or vapor intrusion hazards. Even so, and as discussed elsewhere in this section and in Subsection 13.2, random, small-scale variability in VOC concentrations between closely located points can still be considerable and limits the reliability of data that represent very small volumes of vapor.

Although not explored in detail in this guidance document, soil vapor data can also be used to evaluate leaching hazards at sites contaminated with volatile chemicals. Traditional soil leaching models estimate the concentration of a contaminant in vadose-zone leachate based on input soil data (HDOH 2017a). This can be highly unreliable, due to complexities in soil composition, moisture content and other factors. In the case of VOCs, a more precise estimate of the dissolved-phase concentration of a contaminant in vadose-zone leachate can be made by simply dividing the concentration of the VOC in vapor samples by the Henry's Constant (unitless) for that chemical. This approach is used to develop soil vapor screening levels for leaching and groundwater protection concerns in the Tropical Pacific edition of the HDOH Environmental Hazard Evaluation guidance (HDOH 2017b).

Additional guidance on the use of soil vapor samples to help evaluate potential leaching hazards at sites will be included in future editions of the TGM. In addition to the identification of subsurface VOC-contaminated soil, subsurface vapor samples are most commonly used to evaluate potential vapor intrusion hazards for existing or future buildings. The HEER Office recommends the following three-step approach for the initial evaluation of vapor intrusion hazards at sites where soil or groundwater is contaminated with volatile chemicals (HDOH, 2016):

1. Compare groundwater and soil analytical data to appropriate HDOH environmental action levels (EALs) prescribed in *Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater* (HDOH, 2016) or site-specific action levels approved by HDOH. See Table C-1a for Groundwater Action Levels and Table C-1b for Soil Action Levels, located in Appendix 1 of the EHE document; or use the EAL surfer.
2. Collect soil vapor samples immediately beneath building slab (preferred; LVP sampling methods recommended) or adjacent to buildings if groundwater EALs for vapor intrusion are approached or exceeded or if a potentially significant source of VOCs in vadose-zone soil is suspected, (see Section 7.6.2.2; see also HDOH, 2016, Table C-2 in Appendix 1). Collect soil vapor samples from within deeper, source areas if widespread, heavy contamination is known to be present (see Section 7.6.2.3). Collect soil vapor samples beneath the footprint of anticipated, future buildings if a building is not currently located in that area. Recommended sampling depths for uncovered (unpaved) locations proposed for future construction or uncovered locations adjacent to existing structures are discussed in the following section.
3. Consider remedial actions at sites where Shallow Soil Gas Action Levels are approached or exceeded. This is necessarily site-specific, but could include sealing of floors and active treatment of source areas or the installation of vapor barriers under future buildings. Consider the collection of indoor air samples if the concentration of a VOC in vapors immediately beneath a building slab exceeds the soil gas action level *and* is greater than 1,000 times (sensitive land use, including residential) to 2,000 times (commercial/industrial) typical background indoor air (see Subsection 7.7.1). For crawl spaces, consider the collection of indoor air samples if the concentration of a targeted VOC is greater than ten times the anticipated indoor or outdoor background level. Compare results to Indoor Air Action Levels (HDOH, 2016, Table C-3 in Appendix 1) and known or anticipated background levels in indoor air.

Table 7-1 provides the decision logic for determining when soil vapor sampling is recommended (Step 2) based on the occurrence of VOCs in soil and/or groundwater and the distance between the building and the source area.

The initial collection of soil vapor samples will generally focus on source area and immediately under overlying or nearby buildings. A lateral separation distance of 100 feet from a subsurface source area is considered adequate to prevent potentially significant vapor intrusion problems (ITRC 2007). The adequate vertical separation distance is highly site and contaminant specific. Vertical separation distances appropriate for attenuation of vapors associated with chlorinated solvents have not been adequately studied.

Layering of soil horizons due to weathering, past deposition of sediment, etc., can lead to the presence of clay-rich moist units with very low vapor permeability that significantly impede the upward diffusion of vapors (diffusion rates through water are typically four orders-of-magnitude slower than through soil; see Appendix 1 in HEER EHE guidance, HDOH, 2016). Thin lenses of perched groundwater can further reduce upward vapor flux. Aerobic biodegradation of non-chlorinated, vapor-phase, petroleum compounds can also result in a significant and often abrupt attenuation of vapors within a few feet of a source area (e.g., heavily contaminated soil or free product on groundwater).

A discussion of targeted chemicals of concern for petroleum releases is provided in Section 7.13.1.2 (see also Section 9). Recent studies have suggested that ten meters (thirty feet) of clean soil (i.e., TPH <100 mg/kg) is adequate to reduce vapor concentrations to below levels of concern for potential vapor intrusion hazards, regardless of the mass or concentration of petroleum in underlying soil or the presence of free product on groundwater (e.g., Abreu et. al 2009, McHugh 2010; USEPA 2013). For dissolved-phase contaminants a “vertical separation” distance of fifteen feet or less was observed to be adequate. These studies are ongoing, but appear to be consistent with observations in Hawai´i. With the exceptions noted below, these separation distances can be used to determine the need to collect actual soil vapor samples at a site. For example, if no contaminated soil is present in the upper thirty feet of the vadose zone then potentially significant vapor intrusion hazards can be ruled out without the collection of soil gas samples. If the water table is at a depth of greater than fifteen feet year round and no free product is present on groundwater *and* contaminated soil is not present in the vadose zone, then potential vapor intrusion hazards can again be ruled out without the collection of soil vapor samples.

Shorter vertical separation distances might be appropriate, but should be evaluated and supported on a site-specific basis before a concurrence to negate the need to collect additional soil vapor samples can be granted. This should include borings to characterize subsurface soil types and the collection of a small number of soil vapor samples (e.g., one to three) from an area considered to be representative of overall site conditions. In practice, significant long-term vapor intrusion hazards are unlikely to be posed by dissolved-phase petroleum contaminants in groundwater under any site scenario due to low source strength and rapid biodegradation of vapors in the vadose zone. The collection of soil vapor samples over dissolved-phase plumes can, however, help negate (or identify) the presence of previously unidentified petroleum contamination in the vadose zone. (For dissolved-phase solvent plumes, soil vapor samples are always strongly recommended if action levels for vapor intrusion are approached or exceeded, regardless of the depth of the plume.)

Shorter lateral separation distances (i.e., <100 ft) might also be appropriate at a site but again this should be evaluated on a site-by-site basis. Significant, lateral migration of petroleum vapors away from source areas is of particular concern at sites covered with pavement or buildings, where replenishment of oxygen in subsurface soils is hindered. Large volumes of shallow, contaminated soil or widespread free product on shallow groundwater (i.e., <30ft deep) could lead to the accumulation of vapors under caps and a progressive outward expansion of anaerobic conditions and migration of petroleum vapors over time.

Exceptions to the above guidelines are likely to be rare, but could include sites that directly overlie bedrock (e.g., fractured basalt) that could allow for significantly greater vertical and lateral migration of petroleum vapors prior to attenuation below target action levels. Other potential exceptions include substantial subsurface releases of petroleum in areas with a very deep water table (e.g., >50ft). This could lead to the presence of a thick, deep column of heavily contaminated soil. Anaerobic conditions could develop for a significant distance above and away from the plume, as the natural replenishment of oxygen is overwhelmed. Anaerobic conditions and less inhibited vapor migration could also develop under paved areas that overlie deep (i.e., >30ft) widespread, heavily contaminated soil or free product on groundwater. Such scenarios could be possible with large releases from fuel pipelines, fuel hydrant systems at airports, or large, aboveground tank facilities.

Additional guidance on the investigation and evaluation of petroleum releases is provided in the HEER guidance *Long-Term Management of Petroleum-Contaminated Soil and Groundwater* HDOH, 2007c).

7.6.2 SOIL VAPOR SAMPLING DESIGN

7.6.2.1 OVERVIEW

The design of a soil vapor sampling plan should reflect the objectives of the investigation. Investigations are typically carried out to identify large-scale vapor plume patterns vs vapor intrusion assessment. Factors considered in the design of a soil vapor investigation include the objectives of the investigation, soil type, depth to groundwater, the number and size of existing buildings, and current site use or future development plans. Additional considerations for the sampling strategy include access to building interiors or through concrete slabs, the conceptual migration model, and regulatory requirements.

Small-volume (e.g., one-liter) soil vapor samples are typically used for in situ characterization of subsurface vapor plumes (see Section 7.2). Large-scale patterns implied by the data can be used to help identify the presence of VOC sources, locate points for collection of LVP samples and design remedial options. Small-scale patterns depicted by single sample points are less reliable, due to potential random variability of VOC concentrations within a vapor plume at the scale of a few liters or less. The use of Large Volume Purge (LVP) methods for collection of vapor samples immediately beneath building slabs and more direct assessment of vapor intrusion risk are discussed separately in Section 7.5 and Section 7.8.5. The collection of one or more LVP samples to initially assess vapor intrusion risk is appropriate for general due diligence purposes, especially in absence of known or suspect, vadose-zone source area. The collection of multiple, small-volume vapor samples for in situ characterization of large-scale, vapor plume patterns is recommended if localized source areas are known or suspected beneath a building slab. The data can then be used to designate LVP sample collection points for more direct evaluation of vapor intrusion risk.

As discussed below, soil vapor sampling locations are selected based on areas the CSM identifies as having the potential for complete exposure pathways from the subsurface to the building interior. The sample locations can be selected to investigate a single point or based on lateral and vertical delineation considerations. Following the selection of sample locations, soil vapor samples can be collected using temporary driven probes or by installing permanent soil vapor sampling probes (see Subsection 7.9). When assessing the source of subsurface vapors, samples are typically collected within the suspected or known source area, and upgradient, downgradient, and cross-gradient of the source area because soil vapor can migrate in a different direction than groundwater flow. When assessing upward, vertical migration, vapor samples from multiple depths may be useful or even required to evaluate upward attenuation of vapors or highlight the need to identify preferential pathways through otherwise low-permeability soils that might connect deeper sources to overlying buildings.

As also discussed in more detail below, the frequency of soil vapor sampling is dependent upon the purpose of the soil vapor investigation. Characterization and delineation can require one or two surveys, while remediation assessment or long term monitoring can require repeated surveys on a pre-determined schedule (e.g., weekly for remediation assessment and semi-annually or annually for long term monitoring). Remediation assessment and long term monitoring of contaminants of concern are typically refined during the characterization and delineation phases of the project. Remediation assessment or long term monitoring generally should be conducted using permanent probes to ensure data comparability.

As noted, this guidance does not address safety or hazard mitigation efforts required in the event of explosive vapor accumulation (i.e., methane); however, methane concentrations should be monitored to determine whether these hazards exist. Methane is a non-toxic, lighter than air gas, which is an explosive hazard when present at concentrations in excess of five percent (%) by volume in air (approximately 50,000 parts per million by volume, which is referred to as the Lower Explosive Limit [LEL] for methane). At contaminated sites, additional soil vapor sampling events and possible interim corrective measures should be considered if methane exceeds 1/10 of the LEL (see Section 9.4).

7.6.2.2 SOIL VAPOR SAMPLING POINT LOCATIONS

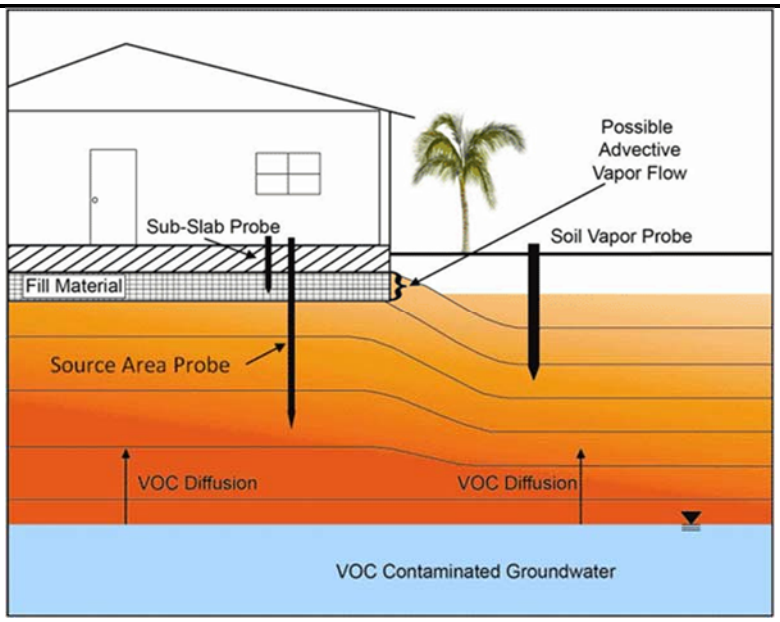


Figure 7-4: Schematic of Soil Vapor Concentration Profile.

VOCs volatilize out of a groundwater plume and diffuse vertically toward the surface. Vapor phase concentrations are highest at the groundwater-vadose zone interface and decrease with decreasing depth. Vapors can accumulate under buildings or paved areas as the ability to diffuse outward and be emitted to the

atmosphere becomes limited or as anaerobic conditions develop due to insufficient replenishment of oxygen

Small-volume point samples are used during the initial phase of investigation to identify large-scale vapor plume patterns and initially estimate potential vapor intrusion risks to overlying, existing, or future buildings. A relatively small number of soil vapor samples (e.g., three to ten) are typically used to initially identify the presence or absence of potential subsurface VOC source areas. Samples are typically collected from within suspect soil source areas or immediately above suspect groundwater sources. The additional collection of soil vapor samples from the fill material immediately under the building slab is recommended for initial site characterization at sites where the distance to the source area is greater than 5 feet (see Section 7.6.2.3). This will provide information on the upward attenuation of VOCs away from a source area. (Note that reliable correlation between vapor points will be limited by uncertainty regarding the magnitude of random, small-scale variability within the vapor plume). Confirmation of the plume boundaries based on multiple points is necessary to avoid false negatives and under estimation of the overall plume size. The location and shape of a vapor plume might not mimic the shape of the primary source area (i.e., contaminated soil or groundwater). This is because the outward, lateral migration of vapors away from the source area is strongly influenced by small-scale heterogeneities in the soil and associated preferential pathways that may not be obvious in the field. In the experience of the HEER Office, high concentration areas of vapor plumes can be located some distance from the primary source area, complicating identification of the latter based on soil vapor data alone.

Locations for soil vapor sampling should be selected based on the objectives of the investigation. If the objective is to identify and map large-scale vapor plume patterns, then strategically located sampling points over and around the suspected source area are appropriate, with samples collected at similar depths or targeted to suspected preferential pathways. Samples collected directly within a suspect vadose-zone source area or immediately above a groundwater source can be useful for evaluating the strength of the source. Lateral spacing between sample locations should take into consideration subsurface utilities, building foundations, or planned future use of the site. Care should be taken to avoid utilities when collecting vapor samples within or nearby utility corridors.

If the objective of the investigation is to assess potential vapor intrusion impacts at an existing building, then targeted sampling locations at the building, at the vapor source, and possibly in-between may be appropriate. Grids of passive soil vapor samples should also be considered (see Section 7.8.3 and see Section 7.12). The collection of small-volume soil vapor samples from immediately beneath building foundations (i.e., below the concrete slab or within crawl spaces) can also assist in subsequent designation of LVP subslab vapor points for more direct assessment of potential vapor intrusion risk (Section 7.8.5). For example, LVP samples could be collected directly within high-concentration areas of a plume in order to assess worst-case, vapor intrusion conditions. In contrast, LVP samples might be collected from localized, low-concentration areas within a plume suspected to indicate active vapor intrusion, as less-impacted air is advectively drawn into this area of the plume.

Note that dry soil under slabs can serve to enhance vapor concentrations in comparison to soils with a higher moisture content, even though the total concentration/mass of VOCs in both scenarios is similar (USEPA 2012d). Small- and/or large-volume samples from utility corridors may be warranted, since coarse fill in the trenches can serve as a conduit for vapors to the slab as well as to utility penetrations and other potential preferential pathways through the floor and into the building (see also USEPA 2012d). Sample collection adjacent to buildings can be considered if the source of contamination is not below the building or the collection of vapor samples directly beneath the building is limited due access issues or the presence of subsurface utilities. If this is the case then samples should be conservatively collected from a depth of five to ten feet below ground surface (or no more than two to three feet above groundwater for shallow water tables) in order to take into consideration the potential buildup of vapors under existing or future building slabs.

Small-volume soil vapor sample data for in situ characterization of a subslab vapor plume can be collected above suspect sources areas beneath the building slab, in the vicinity of utility corridors that could serve as preferential pathways for vapor migration, beneath high-risk areas of the building based on use or penetrations in the slab or, in the absence of other information, from the center of the building slab (USEPA 2012d; CalEPA 2011; see Section 7.7.2). Vapor points also should be placed in the vicinity of the building where vapor intrusion is considered to be most likely, as well as between the center of the building and adjacent sources that do not directly underlie the building (see Subsection 7.7.2).The number of probes that can be installed for in situ characterization of a vapor plume will in part be limited by cost and logistical considerations, including accessibility of locations for sample collection and the presence of subslab utilities.

As discussed above, the type of chemicals present in the soil vapor should also be considered in selecting soil vapor sampling locations. Biodegradation can play an important role in the subsurface migration of petroleum-related contaminants and can significantly reduce the concentration of VOCs in vapors over short distances. At sites where the chemicals of concern are chlorinated compounds (e.g., dry cleaner sites), however, biodegradation is unlikely to be an important process, and elevated concentrations of VOCs can persist for significant distances. Elevated concentrations of VOCs in soil vapors can also persist for long periods of time in the vadose zone following active, in situ remediation of contaminated groundwater (“residual vapor plume,” see Table 7-1). The San Diego County Site Assessment and Mitigation (SAM) Manual, among other references, provides a useful source of soil vapor sampling strategies for a variety of site scenarios (SDC 2011).

7.6.2.3 SOIL VAPOR SAMPLE DEPTHS AND DEPTH INTERVALS

The depth of soil vapor points depends on the objectives of the investigation (Figure 7-4). Characterization of known or suspected source areas should consider such factors as the nature and magnitude of the release, the subsurface geology and the depth to groundwater. The investigation of potential vapor intrusion hazards will require the placement of sample points within shallow, vapor flow pathways, including utility trenches and fill material immediately beneath slabs (e.g., first 6 to 12 inches of soil beneath building slab).

Ideally, the lateral and vertical extent of vapor plumes should be delineated to HDOH Tier 1 soil vapor action levels applicable to residential land use (HDOH, 2016). Small-volume sample data are currently most appropriate to accomplish this task, due to limitations on the collection of LVP samples from deeper soil or from open, uncapped areas and the potential for breakthrough to outdoor air. Less conservative soil vapor action levels may be appropriate for assessment of vapor intrusion risk at commercial/industrial sites. Failure to compare site data to residential action levels may impose the need for a land use restriction on the site, however.

The collection of small-volume vapor samples and/or LVP samples from the fill material immediately beneath a building slab (e.g., first 6 to 12 inches of soil) is an important part of a vapor intrusion investigation. Relatively permeable, sandy silts are typically used as fill material under building slabs to provide structural stability. This fill material is often more permeable to vapors than the native, clayey soils in Hawai‘i and can serve as a preferential pathway for subsurface vapors via connecting utility trenches or other conduits.

Soil vapor samples should therefore *always* be collected in the fill material immediately beneath the slab for evaluation of current vapor intrusion hazards, even if deeper samples are also collected. A focus on deeper soil vapor sample data can be misleading, since the samples do not take into account upward attenuation from the source area (especially important for petroleum). Deeper data could also miss contamination that is restricted to the fill material immediately beneath the building slab associated with indoor spills of solvents and other VOCs and downward migration through the floor or through broken drain pipes. Underlying soils might be relatively un-impacted, even though the concentrations of VOCs in vapors within the fill material are extremely high. This is a common scenario for dry cleaners, where high levels of PCE and related VOCs may be detected in subslab soil gas but not in deeper soil samples (or even soil samples collected from under the slab)

The presence of a building slab or other paving also significantly slows, or prevents, soil vapor from diffusing upwards and escaping to the atmosphere. This can result in elevated soil vapor VOC concentrations beneath the slab/paving in comparison to adjacent, uncovered areas. **Note, however, that diffusive VOC transport can never lead to higher concentrations under the slab than at the source.**

The collection of soil vapor samples from both the fill material immediately under the building slab and the suspected or known source area is recommended at sites where the distance to the source area is 5 feet or greater, but no closer than 2-3 ft to the water table to avoid pulling water into the sample collection device (see Figure 7-4; see also Sections 7.9.3 and 7.10.1). Small-volume sample data can be used to assess large-scale, vapor plume patterns. The collection of LVP sample data is recommended for more direct assessment of vapor intrusion risk (Section 7.8.5). This will help assess the need to seal cracks and utility gaps in the building floor as an added measure of precaution, in the event that nearby portions of the vapor plume exceed subslab soil vapor action levels, even though the measured concentrations of volatile chemicals in actual soil vapor do not, and potential preferential pathways into the building were overlooked (se Section 7.14.1). As discussed below, in cases where the extent and magnitude of contamination is relatively small, the site could still receive case closure without further monitoring or action (see also HDOH 2007c). In other cases additional monitoring to verify that adverse, vapor intrusion impacts are unlikely to occur will be needed (see Section 7.10.1). This will typically require the periodic collection of LVP vapor samples beneath targeted areas of the slab, similar to the collection of periodic samples from groundwater monitoring wells. Reliance on small-volume samples might, however, be required for monitoring of vapors beneath building slabs that cannot be sufficiently sealed for LVP sample collection. The collection of LVP data likewise might not be feasible for sites with low-permeability soil immediately beneath the building slab, although this would likewise reduce the risk of advective flow of vapors into the building.

Collection depths for small-volume sample data to be used to assess vapor intrusion risk in open areas where LVP sample data are not practical depends in part on the VOCs present. At sites with recalcitrant compounds (e.g. chlorinated solvents) soil vapor samples should be collected from no less than five feet below ground surface. Soil vapor samples collected from depths of less than five feet can underestimate the concentrations of recalcitrant compounds that could accumulate if a building were present. Soil vapor samples should be collected from a minimum depth of ten feet for petroleum-contaminated sites or no more than two to three feet above groundwater for sites with a shallow water table. This is necessary in order to take into consideration the potential buildup of vapors under existing or future building slabs due to low-oxygen conditions and a reduced potential for biodegradation.

Additional sample depths will depend on site-specific conditions and the investigation focus. In some cases it may also be desirable to assess the vertical distribution of vapor-phase contaminants between the source media and the ground surface or the foundation of a building. This will require the collection of samples from a minimum of two depths, typically one within or

immediately above the source and one at the target receptor point. Three or more sample depths may be beneficial at sites with deep sources or water tables.

The site geology should also be considered when identifying sampling depths. In general, installation of vapor sampling probes in relatively high permeability horizons is preferred; however, the overall CSM should be taken into account as well. Permanent soil vapor probes should be installed above the maximum-anticipated, seasonally- or tidally-influenced elevation of the water table.

7.6.2.4 SOIL VAPOR SAMPLE SCREEN INTERVALS

Screens used for subslab samples should match the thickness of permeable, fill material immediately beneath the slab, typically four to six inches. Both small-volume and LVP vapor samples are typically collected though a temporary or permanent six-inch (15cm) screen or "implant." The length and placement of the screen depends on the investigation objectives. Longer screening might be warranted for more reliable characterization of large-scale, vapor plume patterns. As discussed above and in Section 7.8.5, data for small volumes of vapor can be useful for identification of large-scale plume patterns but are not necessarily pertinent to assessment of vapor intrusion. This is similar to issues related to the use of discrete sample data for very general screening purposes versus the use of "large-mass," Multi Increment soil sample data to more directly evaluate risk.

Six- to twelve-inch vapor point screens are generally desirable for characterization of subslab vapors, since HDOH soil vapor action levels are intended to apply to vapors within the assumed narrow, advective zone in the immediate vicinity of a vapor entry point. Much longer screens might be desirable for in situ, larger-scale characterization of deeper portions of a vapor plume. For example, a five-foot (1.5m) length of a two inch-diameter (15 cm) well screen contains approximately 30 liters of air. Allowing the air inside of the well screen to equilibrate with vapors in the surrounding soil would allow a sample collected from the well screen to represent a much larger volume of vapor than the vapor actually captured within a canister. The resulting data would provide a more reliable and reproducible characterization of the plume at that specific location in terms of vapor intrusion risk. Replicate samples could be collected over time to assess data precision and temporal variability within the vapor plume.

Note that the same is true with respect to the representativeness of a groundwater sample collected from a five-foot, monitoring well screen or from a much smaller interval using grab samples or passive diffusion bags (see Section 6). Additional guidance on this topic, including the concept of "Decision Units" for the collection or groundwater sample data will be incorporated into Section 6 of this guidance document in the future.

7.7 INDOOR AIR SAMPLING STRATEGIES

7.7.1 DETERMINING WHEN TO COLLECT INDOOR AIR SAMPLES

Although counterintuitive, testing of indoor air to identify and evaluate potential vapor intrusion concerns is fraught with potential error and generally discouraged except in cases where subslab soil vapor data indicate a clear threat to indoor air (see HDOH, 2016). This is due to the common presence of the same suite of targeted VOCs in soil vapor in indoor air from sources within or outside of the building (e.g., USEPA 2011e).

As noted in Table 7-2, background levels of VOCs in indoor air from indoor sources exceed conservative action levels for many common chemicals. Correlation of indoor air data with subsurface, soil vapor data can therefore be difficult if not impossible if the concentration of VOCs identified in indoor air falls within the range of anticipated background. Although precautionary measures could be taken to mitigate potential vapor intrusion (e.g., sealing of floors, improved ventilation, etc.), as a general rule a home or building should not be flagged for potential vapor intrusion hazards unless this is supported by multiple lines of evidence, including indoor air data well above anticipated, background levels. This is discussed further in Section 7.14.2.

The presence and concentration of contaminants in indoor air is influenced by several factors, including the following: (1) the input rate of the contaminant from the source, (2) degree of ventilation and air exchange in the building, and (3) the input rate of other sources within or near the building (i.e., from outdoor air and not the subsurface). Assessments of vapor intrusion should consider the following factors:

Table 7-2 Comparison of HEER Indoor Air Action Levels to Typical Indoor Air Concentrations of Common VOCs.

Volatile Chemical	[1]HEER Indoor Air Action Level (ug/m^3)	[2]Range of Background Indoor Air Concentrations
Benzene	0.31	<RL-4.7
Ethylbenzene	0.97	1–3.7
Toluene	1,000	4.8–24
Xylenes	21	2.6-17.6
[3]Naphthalene	0.057	0.18-1.7
[4,5]Total Petroleum Hydrocarbons	131	116-594
Tetrachloroethene	0.41	<RL–2.2
Trichloroethene	1.2	<RL–1.1

1. HDOH, 2016; residential indoor air action level noted.
2. USEPA 2011b; Range of 50th percentile noted (<RL = less than laboratory reporting limit).
3. Jia and Batterman 2010; urban houses.
4. HDOH, 2016; indoor action level equal to sum of vapor-phase, TPH aliphatic and aromatic compounds (see Section 7.11).
5. MADEP 2008; range TPH 50th to 90th percentile.
6. Indoor air sources (other than soil vapor);
7. Outdoor air sources (other than soil vapor);
8. Location and characteristics of known or suspected soil vapor source;
9. Building ventilation and air exchange rate;
10. Building materials and condition.

A number of commonly used household products contain some of the same compounds of concern as targeted in vapor intrusion investigations (e.g., TPH and BTEX from cleaners and fuels, PCE from dry-cleaned clothes, TCE and TCA from degreasing solvents, etc.,). Common sources of VOCs in indoor air include (USEPA 2011e, ITRC 2007, HDOH, 2016):

Building Materials:

- Carpets and adhesives;
- Composite wood products
- Plastics;
- Paints;
- Sealing caulks;
- Parts cleaning solvents;
- Upholstery fabrics;
- Varnishes;
- Vinyl and linoleum floors;
- Polyester resins and epoxies;

Home and Personal Care Products:

- Air fresheners;
- Air cleaners;
- Cleaning and disinfection products;
- Cosmetics;
- Fuel oil and gasoline;
- Mothballs;
- Running automobiles, generators or lawn equipment;

Behaviors:

- Smoking;
- Dry cleaning;
- Hobbies that involve glues;
- Newspapers;
- Non-electric space heaters;
- Photocopiers;
- Stored paints and chemicals.

In some areas, especially urban centers, TPH, benzene and related contaminants associated with auto exhaust in outdoor air can also exceed conservative, indoor air action levels.

For these reasons, testing of indoor air to evaluate potential vapor intrusion impacts is generally discouraged unless concentrations of targeted chemicals in subslab soil vapor are more than one-thousand times typical indoor air concentrations for residences and two-thousand times typical indoor air concentrations for commercial/industrial buildings (assumed indoor air:subslab soil gas attenuation factors; see Subsections 7.3, 7.14 and Table 7-2; see also HDOH, 2016). Indoor air sampling

may also be warranted if field screening of potential vapor pathways inside of a building suggest that vapors could be impacting indoor air at levels significantly above background and the pathways are unlikely to be sealed in the absence of indoor data to support such actions (e.g., PID readings around utility gaps in floors, drains, wall sockets, etc.; see Section 7.7.2; see also MADEP 2002b, CalEPA 2011, New York State DOH 2006).

The evaluation of potential vapor intrusion hazards and decisions regarding the need for remedial actions will instead, in most cases, focus on subslab or crawl space data. Shallow soil vapor data or data for samples collected under paved areas can be taken into consideration for sites without existing buildings.

Subslab (including sub-basement) soil vapor samples should be collected for buildings with a slab-on-grade construction. For buildings with a crawl space design, shallow soil vapor samples should be collected adjacent to the building in addition to samples from the crawl space. In both cases, it is preferable that soil vapor and/or crawl space samples be collected *prior to* collection of indoor air samples and used to determine the need to collect the latter (see HDOH 2016). If a significant source of potential vapors is present below the building (e.g., petroleum free product on shallow groundwater) then the collection of source area soil vapor samples is also recommended (see Subsections 7.6.2). Together, subslab and source area data should be reviewed to determine the need for the collection of indoor air samples.

If indoor air sampling is still desired or required, then sample collection and interpretation of data should be carried out under the direction and oversight of HDOH. Soil vapor (or crawl space) samples should be collected at the same time in order to assist in the interpretation of the indoor air data (see Subsection 7.14). Indoor air data should never be used as the only line of evidence for vapor intrusion.

Indoor air data should be compared to both risk-based screening levels and anticipated background concentrations. More than one round of sampling is recommended if a significant source of vapors is identified beneath a building (see Subsection 7.11.3). If representative concentrations of targeted VOCs fall within the range of anticipated background concentrations then active measures to address vapor intrusion are not necessary (see Section 7.14.2) , although sealing of cracks and gaps in floors should be carried out as a precautionary measure (see Section 7.14.1).

7.7.2 INDOOR AIR SAMPLING DESIGN

Specific guidance regarding the location, duration, and frequency of indoor air sampling is provided in Section 7.11. The following factors will influence an indoor air quality sampling strategy:

Sources: All of the potential sources of indoor air contamination should be considered in developing a sampling plan. Sources can include, but are not limited to, subsurface contamination (i.e., vapor intrusion), indoor sources (i.e., use/storage of VOC containing chemicals), and outdoor background sources (i.e., VOCs in the ambient background air around a building).

Pathways: Likely or potential pathways for VOCs to enter the building air should be considered in developing a sampling strategy. Common pathways for vapor intrusion from the subsurface are cracks or utility penetrations through the slab or basement walls/floor, sumps with earthen floors, and drain pipes. Elevator shafts could also serve as pathways for vapor intrusion, although these structures tend to mimic chimneys by conducting air out of rather than into buildings, including vapors that might intrude into the bottom area of the shaft. Bathrooms, kitchens and utility rooms are often the primary entry points for intruding vapors. VOCs can also enter a building through the heating, ventilation, and air conditioning (HVAC) system intake if the ambient air contains VOCs (if a VOC source is located upwind of the HVAC intake, higher concentrations of VOCs can be introduced to the indoor air than would be expected based on the general ambient air conditions around the building). Most buildings have indoor sources of VOCs-- these should be carefully evaluated and, if possible, removed prior to sampling.

Heating, Ventilating, and Air Conditioning: Operating conditions of the HVAC system can have a significant effect on VOC concentrations over a short time frame (see Section 7.1). The concentration of VOCs will generally be lowest when the HVAC air conditioning system is operating, due to the inflow of fresh air, dilution of vapors from indoor sources and the reduction of subsurface vapor intrusion when the building is over pressurized. Indoor air quality will be lowest when the HVAC system is not operating, due to the lack of fresh air entering the building to offset VOC emissions from furniture, plastics, glue and other indoor sources as well as the potential for the building to become under-pressured due (at least in Hawai'i) to outside wind effects that could induce an upward flow of subsurface vapors.

Occupants: The presence and activities of building occupants can have a significant effect on VOC concentrations in indoor air. For example, freshly dry-cleaned clothing can introduce PCE to the indoor air, and smoking can release a variety of VOCs including benzene. Opening of doors and windows can increase the building air exchange rate and thereby lower VOC concentrations (assuming that higher concentrations are not present in outdoor air).

To prevent, investigate, and resolve indoor air quality problems, it is important to understand the role each of these factors can play.

The indoor air sampling strategy should identify the location, duration, and frequency of indoor air sampling. As with soil vapor sampling strategy, location, duration, and frequency will be influenced by site-specific conditions and the study objective. For example, if the goal of the study is to obtain a representative estimate of the average concentration of contaminants in indoor air that could present potential risk to the occupants of a building, then several indoor air samples should be collected in various portions of the occupied space and weighted accordingly. If the goal of the study is to measure the highest concentration to which an occupant might be exposed, then sampling could be conducted in the area closest to the suspected source or pathway for contamination (MADEP 2002b).

7.8 SAMPLING APPROACHES AND EQUIPMENT

The collection of soil vapor or indoor air samples can be more involved and complex than soil or groundwater sample collection. This is due in part to the need for special sampling equipment and containers to address the reactivity of vapor-phase chemicals and the need to prevent leaks during sample collection.

Based on the type of sampling equipment and containers, soil vapor or indoor air sampling approaches can be grouped into the following categories: (1) whole air sampling; (2) sorbent tube sampling; (3) passive sampling using sorbent materials; and (4) flux chamber sampling. The first two methods are often referred to as active sampling (see Hartman 2002). Whole air sampling involves collecting a volume of gas in a sample container, such as a Summa canister or a Tedlar bag, and analyzing the gas from that container directly. The concentration of targeted compounds is directly reported.

Sorbent tube sampling involves drawing a specified volume of soil vapor or indoor air through a sorbent material using a pump or other vacuum source and analyzing the sorbent material. The concentration of a targeted compound in the media tested is calculated by dividing the mass of the compounds collected on the sorbent material by the volume of vapor or air drawn through the sampler. If reanalysis of a sample might be required, then a collection method that relies on extraction of the sample (e.g., sorbent tubes) rather than purging (e.g., Summa canister) should be considered. The ability to reanalyze a sample collected in a Summa canister is limited due to the fixed volume collected versus the volume required for a specific analytical method. This should be discussed in more detail with the laboratory as needed.

Passive sampling methods rely on the placement of a sorbent material at a sample location for a period of time. The mass of a targeted compound collected on the sampler is then measured. Flux chambers are traditionally used to measure vapor emission rates from point sources such as waste ponds. Their use in soil vapor investigations is more limited but in some instances can be beneficial. A comparison of the key advantages and disadvantages to each of these approaches is provided in Table 7-3.

Similar to soil and groundwater sample collection, a combination of sampling approaches can be used if analyzing for a broad range of chemical compounds. For example, relatively inexpensive passive sampling can be used to initially screen a site for shallow vapor plumes and assist in the identification of areas for active soil vapor sampling. For the investigation of vapors associated with releases of diesel and other middle distillate fuels, a combined used of both Summa canisters and sorbent tubes is recommended (see Subsection 7.13.1.2). Data from Summa canister samples can be used to determine concentrations of individual VOC and short-range TPH compounds (e.g., <C12 aliphatics). Sorbent tube samples can be collected to evaluate longer range TPH compounds and semi-volatile organic compounds (SVOCs).

Each of these methods is discussed in more detail in the following sections. Consultation with the analytical laboratory to discuss specific standard operating procedures and sampling methods is strongly recommended during the planning phase for each project requiring the collection of soil vapor or indoor air samples.

Equipment that could come in contact with a vapor sample should be cleaned or decontaminated between samples to avoid cross contamination by trace levels of contaminants. Summa canisters and sorbent tubes should be certified clean by the laboratory. Used tubing should be disposed of. Reuse of Swageloks and ferrules between samples is discouraged. This is primarily a concern for the collection of outdoor or indoor air samples, where data are compared to very low action levels.

Table 7-3 Comparison of Soil Vapor & Indoor Air Sampling Approaches

Sampling Approach	Container/ Equipment	Advantages	Disadvantages
Active	Summa Canister	Familiar, widely accepted, rugged, no pump required (vacuum), excellent inert surface, low detection levels (ppbv), up to 30-day hold time from time of sample collection, easily air-shipped	Cost, bulky in field, slower fill time, fixed volume, collection of VOCs over restricted volatility range

	Tedlar Bag	Inexpensive, availability, easily transported, rapidly filled	Less rugged, fixed volume, requires additional collection equipment, inner surface may sorb VOCs, medium detection levels (ppmv), short holding time, not recommended for air shipping
	Sorbent Tube	Large-volume samples possible, collection of VOCs over a larger volatility range, low detection levels (ppbv), up to 40-day hold time (extraction within seven days of sample collection), easily transported and air shipped	Cost, requires additional collection equipment, saturation of tubes possible, sorbent media varies with respect to VOC and anticipated VOC concentration, tubes require storage at 4°C
Passive	Sorbent	Cost, ease of use, multiple samplers can be combined for analysis, long sampling times	Cannot directly measure vapor concentration
	Water	Estimation of vapor concentrations possible, multiple samplers can be combined for analysis, long sampling times	Currently costly to install, cannot directly measure vapor concentration
Flux Chamber	Flux Chamber	Measures VOC flux at surface	Does not measure *in-situ* concentrations, identification of vapor emission points difficult

Table 7-4 Common Soil Vapor Concentration Unit Conversion Factors

Units	Convert to:	Multiply By:
µg/L	µg/m^3	1,000
mg/m^3	µg/m^3	1,000
ppmv	ppbv	1,000
ppbv	µg/m^3	MW/24
µg/m^3	ppbv	24/MW
ppbv	ppmv	0.001

Definitions:
MW - molecular weight
mg/m3 - milligrams per cubic meter
µg/m3 - micrograms per cubic meter
µg/L - micrograms per liter
ppbv - parts per billion by volume
ppmv - parts per million by volume



Figure 7-5 Summa Canisters (spherical and cylindrical containers) with Flow Controllers (smaller gauges and blue box).



Figure 7-6 Summa Canister and Flow Controller Setups (note smaller flow controller on left).

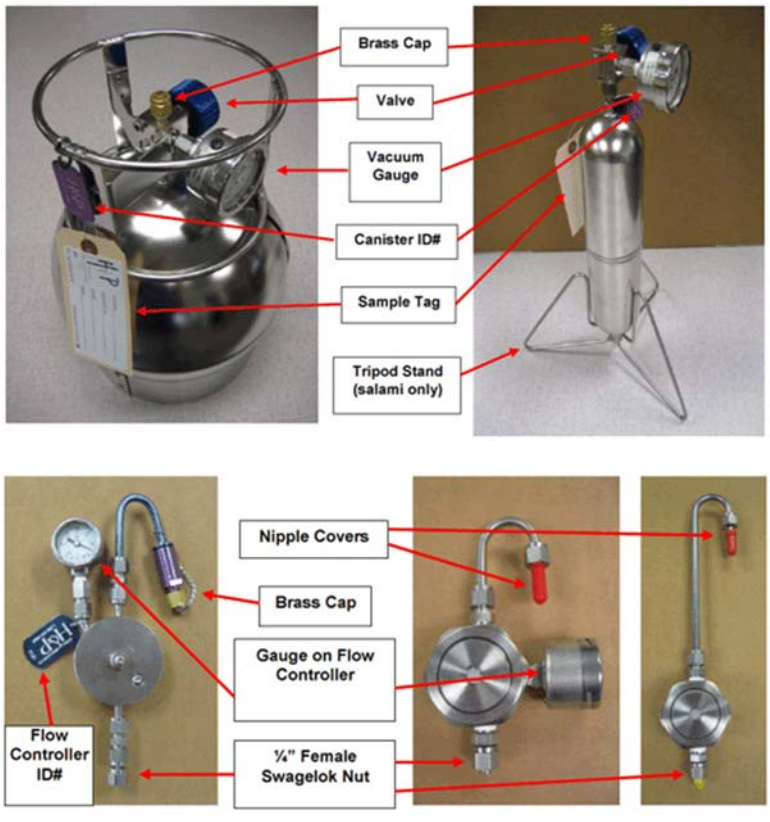


Figure 7-7: Summa Canister and Flow Controller Parts.



Figure 7-8: One-liter Tedlar Bag with Disposable Syringe and Three-way Valve for Filling.





Figure 7-9: Sorbent Tubes. Upper photo: Sorbent tubes connected in series with a union fitting. Lower photo: Single sorbent tube connected to a 60ml syringe for collection of vapor sample (see also Figure 7-27).



Figure 7-10 Two Examples of Passive Soil Vapor Sample Collectors.

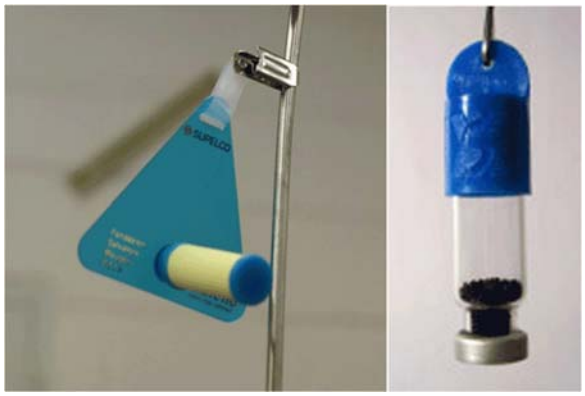


Figure 7-11: Two Examples of Indoor Air Passive Sample Collectors.



Figure 7-12: Passive Diffusion Sampler (PDS). Schematic of sampler on left and photo of a sampler being installed on the right.

Table 7-5 Comparison of TCE and PCE Results for Passive Diffusion Sampler and Active Soil Vapor Sample

	TCE Results			PCE Results		
Location	Mean PDS	Mean Active	PDS/Active Percentage	Mean PDS	Mean Active	PDS/Active Percentage
1	4,536	6,500	70%	ND	ND	ND
2	27,584	16,000	172%	384	300	128%
3	56,001	20,000	280%	752	285	264%
4	41,073	25,000	164%	744	385	193%
5	466	190	245%	ND	ND	ND
6	3,283	550	597%	ND	ND	ND
7	5,234	2,000	262%	ND	ND	ND
8	1,970	1,900	104%	ND	ND	ND
9	503	440	114%	ND	ND	ND
10	482	1,500	321%	ND	ND	ND

Average			**233%**			**195%**

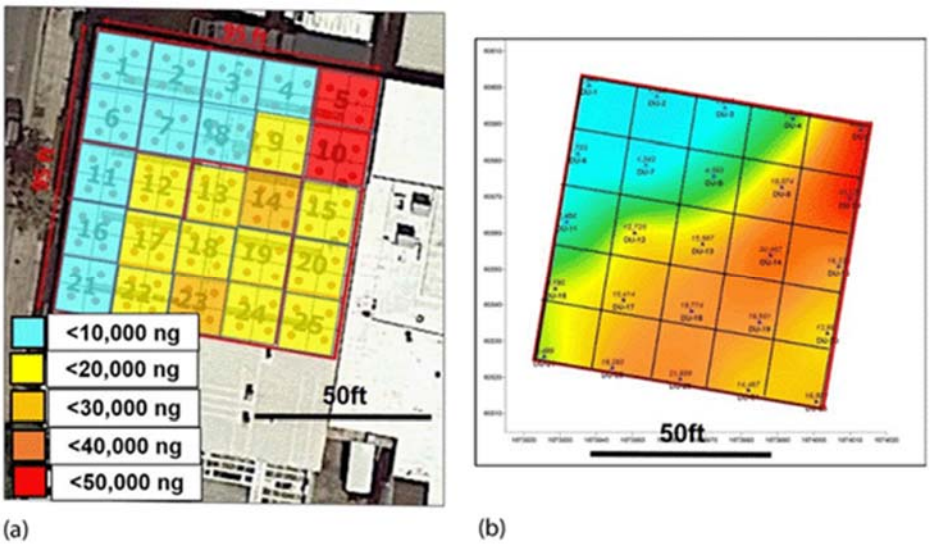


Figure 7-13 Summary of high-density, passive sampler data for PCE vapors beneath the slab of a former dry cleaner: a) True data resolution based on PCE mass reported for each grid cell; (b) Extrapolated isopleth map based on assignment of data to center point of grid cell and use of contouring program.



Figure 7-14. Designation of soil vapor DU beneath a building slab for collection of LVP samples; recommended default DU volume of 3,000 liters represents the default, daily vapor entry rate used to develop HDOH (2017a) soil vapor action levels for vapor intrusion risk.

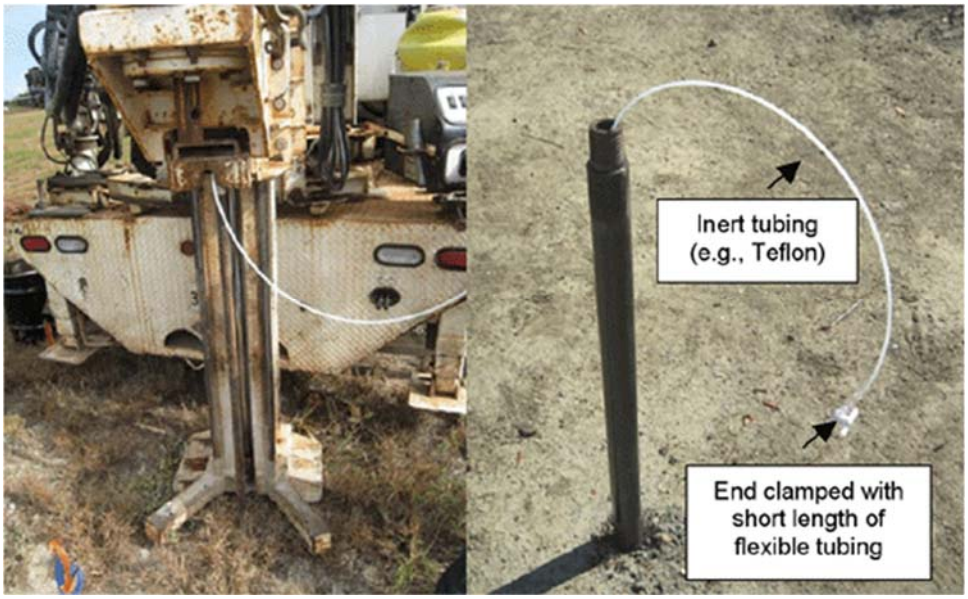


Figure 7-15. Example options for designation of purge points for collection of LVP subslab vapor samples: A) High-risk occupancy room within building; B) Subslab utility trench and preferential pathway; C) High-concentration area based on result of small-volume vapor sample data; D) Center of slab.



Figure 7-16. Floor drain and suspect deep cracks sealed with bentonite slurry to minimize downward leakage of indoor air into purge point during LVP sample collection.

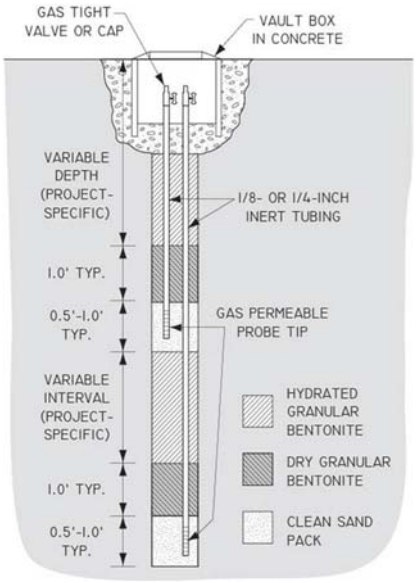


Figure 7-17. Simplified schematic of Large Volume Purge sampling train.

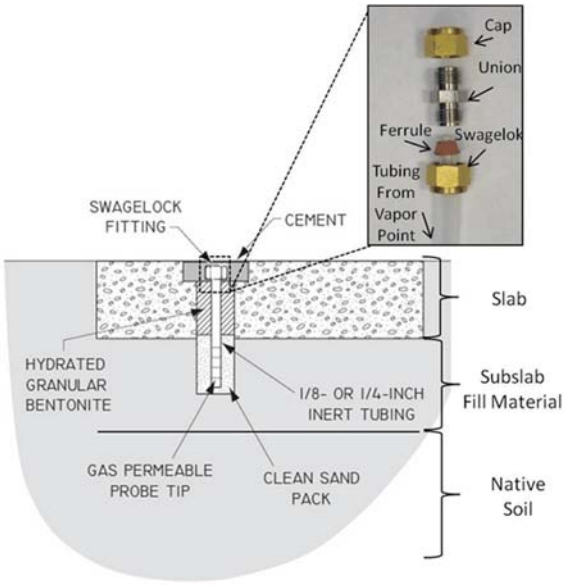


Figure 7-19. Installation of LVP vapor extraction point used in HDOH (2017c) field study: a) Circular saw used to cut eight-inch hole in concrete for installation of vapor point and protective casing (latter not normally included); b) Completed hole; c) Two-inch PVC vapor point; d) Completed vapor point (interior sealed with cement grout). A smaller diameter hole will normally be adequate for a two-inch soil vapor point.



Figure 7-20. Example, completed field LVP sample collection set up (HDOH 2017c; Shop-Vac pump not shown).

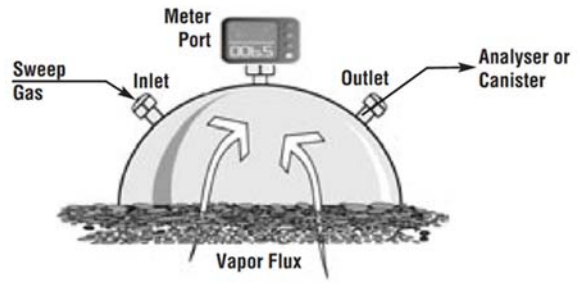




Figure 7-21: Schematic Diagram and Photograph of Flux Chamber

7.8.1 WHOLE AIR SAMPLING

Whole air samples are typically collected in Summa canisters when definitive data with low detection levels are required; however other containers such as Tedlar bags, gas-tight vials, and syringes are also suitable for some applications. Low detection levels can also be obtained using sorbent tubes and TO-17 analytical methods, although the volume of air or vapor drawn through the tubes is limited by the sorptive capacity of the media used. Individual laboratories often publish guidance on the use of various whole-air methods (e.g., Air Toxics 2012). Whole air sampling (or other active soil vapor sampling) is recommended to quantify concentrations of vapor-phase chemicals for an exposure or risk assessment. Contaminant concentrations can be quantified in units of volume of gas per unit volume of air (e.g., parts per million by volume [ppmv] or part per billion by volume [ppbv]) or in units of mass per unit volume (e.g., milligrams per liter [mg/L] or micrograms per cubic meter [µg/m^3]). Concentrations should be reported in units of µg/m^3 for comparison to HDOH EALs.

It is important to note that unlike aqueous samples, volume units are not equivalent to mass units for gaseous samples. The molecular weight of the analyte and the temperature and pressure of the sample must be used to convert from volume units to mass units. The conversion can be achieved using the Ideal Gas Law equation. The following equation simplifies the Ideal Gas Law equation assuming atmospheric pressure (one atmosphere = 760 millimeters of mercury [mm Hg]) and standard room temperature of 298 Kelvin (K) (25 degrees Celsius [° C]):

$$\mu g/m^3 = \frac{ppbv \times MW}{24.45}$$

Where:

ppbv = Parts per billion by volume
µg/m^3 = Micrograms per cubic meter
MW = Molecular Weight (chemical-specific)

Table 7-4 presents other common unit conversion factors and HDOH has developed a Vapor Unit Conversion spreadsheet that converts between concentrations and is available for download from the EHE web page (HDOH 2016).

See Table H in Appendix 1 of the HDOH EHE guidance for the molecular weight of common chemicals (HDOH, 2016). In general, target compounds conducive to whole air sampling are chemically stable and have a vapor pressure greater than 0.1

torr at 25 ˚ C and 760 millimeters of mercury (one atmosphere). Effective recovery of chemicals from active soil vapor samples depends on sample humidity, chemical activity of the sample matrix, and the sample container's degree of inertness.

7.8.1.1 SUMMA CANISTERS

A Summa canister is a stainless steel container that is placed under a vacuum and then used to collect a soil vapor or air sample. The canister is cleaned internally using electropolishing and chemical deactivation to produce an interior surface that is nearly chemically inert. This minimizes reactions with the vapor sample and maximizes recovery of volatile compounds from the container. Recovery is generally limited to chemicals with up to ten carbon molecules for aromatic compounds, however, including naphthalene, and up to twelve carbon molecules for aliphatic compounds.

Summa canister volumes range from 400 milliliters (ml) to 6 liters, with one-liter and six-liter canisters being most commonly deployed in the field (Figures 7-5 & 7-6). Larger canisters provide more sample volume for the laboratory and allow for lower detection levels. For indoor or outdoor air sampling, six-liter canisters are typically most appropriate as they support the low detection levels necessary for risk assessment or screening against indoor air standards. They are also better suited to collecting time-integrated samples (e.g., eight to twenty four-hours). Smaller canisters are typically used for soil vapor samples, for which screening levels are typically several orders of magnitude higher than for indoor air. Collection of vapor samples greater than one-liter can be problematic as well as time consuming at sites with relatively tight soils. HDOH recommends a minimum sample size of one-liter for soil vapor samples in order to assist in the collection of data that are representative of the site being investigated. HDOH further recommends the use of Summa canister data and/or sorbent tube data (provided a minimum one-liter sample is drawn) for final decision making purposes.

General procedures when planning a soil vapor investigation using Summa canisters include:

1. Obtain the field equipment checklist and inventory equipment and materials needed for the soil investigation before proceeding to rent, obtain and stage all equipment
2. Order clean-certified Summas and related equipment from the laboratory based on the number of samples to be collected plus a minimum of one extra canister and flow controller. Ideally this should be done by two weeks before the scheduled field work in order to give the laboratory adequate time to prepare the canisters and ship them to Hawai‘i.
3. Check the vacuum of all the canisters as soon as they arrive. Use the pressure gauge the lab sends with the canister. If more than one gauge is sent, use the same gauge to check the canisters before and after sampling in order to ensure consistency. Record the date, time and readings on both the canister tags and field forms. Vacuum readings should be approximately 30 inches of mercury. Consider rejection any canisters that differ from others by three inches of mercury or more.

Summa canisters should be certified clean by the analytical laboratory that supplies them. The laboratory cleans the Summa canisters after each use. The cleaning process is certified by filling a canister with a clean gas (e.g., nitrogen) and then analyzing the gas using method TO-14 or TO-15. Canisters are typically either batch certified or individually certified. For batch certification, a portion of canisters from a cleaning batch is tested (e.g., 10%). For individual or 100% certification, each individual canister is tested.

The Summa canister is prepared by the lab for sampling by evacuating the contents to a vacuum of approximately 30 inches of mercury (in Hg). This ensures that the volume of air drawn into the canister will be approximately equal to the canister volume. The vacuum in each canister should be documented prior to sampling. This can be done by attaching a separate vacuum gauge to the canister and opening the intake valve. The flow controller can also be attached then capped at the intake port and the Summa canister intake valve again opened. Doing both allows testing of the flow controller vacuum gauge for accuracy, a not-uncommon field problem.

Flow controllers (or flow restrictors) are essential equipment for the collection of vapor samples with Summa canisters. The controllers limit the rate at which a sample can be drawn into a canister and assure that the sample flow rate is appropriate for the targeted sample collection time (see Section 7.10.3). Flow controllers also help ensure that an excessive vacuum is not applied to soil. Doing so could potentially strip VOCs from free product or sorbed to soil and bias the vapor sample collected. Older flow controllers tend to be bulky, less reliable and increase the chance for leaks (e.g., see Figure 7-6). Newer flow controllers are more compact and easier to use in the field (See Figure 7-7). In some cases, they may come preset and pre-attached to the Summa canister. A vacuum gauge at the vapor collection point is used to monitor the vacuum pulled during the collection of LVP vapor samples (Section 7.8.5).

The analytical laboratory providing the Summa canisters and flow controllers should be consulted during the planning stages to ensure the appropriate size canisters and appropriately calibrated flow controllers are provided (Figure 7-7). Laboratories typically provide matched canisters and flow controllers. It is advisable to order extra canisters and flow controllers in case insufficient vacuum is present in a canister or the flow controller does not work properly.

A 10% certification of Summa canisters (i.e., 10% of canisters) is recommended for standard TO-14 or TO-15 analysis for soil vapor or other applications where very low detection levels are not required. This is appropriate for routine ambient air applications and the collection of high-concentration soil vapor and landfill gas samples where parts-per-million or parts-per-billion reporting levels are required. A 100% certification is recommended when "Low Level" or selected ion monitoring (SIM) analyses will be conducted and parts-per-trillion reporting levels are required (e.g. for indoor air). If desired, certification can usually be provided at an additional cost for specific pairs of flow controllers and canisters that are labeled as such by the laboratory.

The Summa canister valve should be closed and sample collection ceased once a residual vacuum of 3-5 inches of mercury is reached and the final vacuum recorded. This will help notify the lab of potential container leakage and compromised samples during storage and shipment. A holding time of 30 days is recommended once the sample has been collected (USEPA 1999b). Most laboratories recommend that canisters be returned within 14 days of receipt in order to help ensure the integrity of the canister and ensure that hold times are not exceeded prior to analysis.

7.8.1.2 TEDLAR BAGS

HDOH recommends the use of Summa canisters or sorbent tubes for sample collection if the data are to be used for final, decision making purposes. Tedlar bags are flexible, plastic bags that can be used for the collection of air or vapor samples with a syringe or a lung box. Tedlar bags can offer an inexpensive, screening tool for initial site investigations or monitoring, however. A Tedlar bag is made from two layers of Tedlar film sealed at the edges and containing a valve allowing for soil vapor or indoor air sample collection using a syringe or lung box . Tedlar is a trade name for a polyvinyl fluoride film that exhibits a low permeability to gases, chemical inertness, weathering resistance, and low off-gassing. The manufacturer of Tedlar, DuPont, announced in 2009 that they would phase out support for Tedlar film in the sample bag market. As a result, true Tedlar bags are becoming more difficult to obtain and are being replaced by bags made of alternative materials.

Similar to canisters, Tedlar bags range in volume up to five liters, and can be used to collect high-concentration grab samples or ambient air samples. The Tedlar bags can be used for projects involving analysis of low concentrations of compounds, in the ppbv range; however, they are less robust and more prone to leaking and diffusion than Summa canisters. Shipment by air is generally not recommended, since a decrease in atmospheric pressure as the plane ascends can cause a Tedlar bag sample to expand and leak. If the use of Tedlar bags and shipment by air is not avoidable, then the bags should only be filled to 50% or less of their total capacity.

As described in Section 7.10.4, soil vapor or indoor air samples are collected in Tedlar bags using a lung box or a glass syringe equipped with a 3-way valve (Figure 7-8). Note that a plastic syringe is depicted in the figure. The use of glass syringes for sample collection is recommended due to the potential sorption of VOCs to plastic. Tedlar bags are normally disposed of following use to collect one sample since VOCs can absorb to the bag interior. This excludes bags used to screen for fixed gases like O2, CO2 and CH4, which are not significantly sorptive.

7.8.1.3 WHOLE AIR SAMPLE HANDLING

In order to preserve the integrity of whole air samples, the following guidelines should be observed.

- Do not chill samples during storage as is common with soil and water samples.
- Sample containers should not be left in the direct sunlight.
- The maximum holding time in Summa canisters is typically 30 days from the time the canisters are initially cleaned, depending on the lab (labs often request return of canisters within 14 days of receipt).
- The maximum holding time for Tedlar bags is 24 to 72 hours after the sample has been collected, depending upon the compound (CalEPA 2012, SDC 2011).

Petroleum compounds and biogenic gases (e.g., methane, carbon dioxide) are less stable and should be analyzed within 24 hours for samples collected in Tedlar bags, while chlorinated compounds are more stable and bags can typically be held for up to 72 hours. However, as noted above, Tedlar bags are being phased out and replaced by bags made of alternative materials. Appropriate holding times vary depending on the material. Therefore, the supplier of sample bags not made of Tedlar, typically the laboratory, should be consulted regarding the appropriate holding time for the site contaminants of concern.

7.8.2 SORBENT TUBE SAMPLING

Sorbent tube sampling involves drawing a known volume of soil vapor or air through a sorbent material using a pump or other vacuum source and analyzing the sorbent material. Concentration is calculated by dividing the mass of a targeted compound by the volume of vapor or air drawn through the sampler. Photographs of sorbent tubes and sorbent tube sampling trains are

provided in Figure 7-9. Individual laboratories publish guidance on the use of various sorbent methods (e.g., Air Toxics 2012b). Method TO-17 is the most common setup and analysis used for sorbent tubes (see Subsection 7.13).

Sorbent tubes are an optional method for short-chain VOCs (e.g., BTEX, PCE, TCE, etc., including naphthalene) and the most appropriate method for longer-chain, SVOCs that cannot be recovered from a Summa canister. The latter includes acenaphthene, methylnaphthalenes and other PAHs with molecular weights up to 200 but including pyrene, with a molecular weight of 202 (see HDOH, 2011b). As discussed below, sorbent tubes in combination with Summa canisters are recommended for testing of vapors associated with diesel and other middle distillate fuels if a significant (e.g., >10%) amount of longer-chain hydrocarbons could be present (e.g., >C10 aromatics or C12 aliphatics; see Section 7.13.1.2).

A variety of sorbent cartridges and pumping systems are provided by commercial vendors or laboratories. It is important to discuss the anticipated types and concentrations of target VOCs and SVOCs with the laboratory in order to optimize the type and amount of sorbent used to prepare the tubes. Sorbent tubes are typically shipped and stored chilled to 4°C but should be brought to ambient temperature prior to use in the field.

A low-flow pump or syringe is used to draw soil vapor or air through the sorbent over a pre-established time period. A maximum flow rate of 200 ml/minute is recommended in order to minimize the risk of leaks around the probe annulus as well as minimize the vacuum imposed on the soil and stripping of VOCs from the soil or free product (see Section 7.10.3). Pumps are typically used for the collection of larger volume, indoor or outdoor air samples. If a pump is used then the volume of soil vapor drawn through the tube is calculated by multiplying the average flow rate by the draw time. This will require recording and averaging the flow rate several times if it varies over collection of the sample.

Calibrated syringes that can be easily read in the field provide a more accurate estimation of the volume drawn through a sorbent tube for small-volume samples. A syringe draw time of no less than 15 seconds, for example, is recommended for a 50ml soil vapor sample. This is the maximum draw volume typically allowed by laboratories for collection of high-concentration soil vapor samples associated with petroleum in order to avoid saturation of the sorbent material in the tube and multiple dilutions at the laboratory. Note that the syringes should not be re-used between sample points to avoid potential contamination of sorbent tube media due to a high concentration breakthrough in a previously drawn sample.

The presence of very high concentrations of volatile compounds at some sites can significantly limit the volume of soil vapor that can be drawn through a sorbent tube without saturation of the sorbent material. Unlike canister samples, sorbent tubes have maximum reportable concentrations for VOCs, based on the sorptive capacity of the material used. Once this capacity is reached, breakthough will occur and true concentration of the chemical present cannot be determined. This can be addressed in part by using larger sorbent tubes, adjusting the sorptive material used and/or connecting two or more sorptive tubes in series and adding the masses of targeted VOCs captured in each tube.

Note that PIDs primarily target aromatic compounds and are not good indicators of total TPH levels in soil vapors without inclusion of a correction factor, since vapors are likely to be dominated by aliphatic compounds. This is especially important to consider for testing of aromatic-poor vapors from diesel fuel or other middle distillate fuels (refer to HEER Office petroleum vapor study; HDOH, 2012). PID readings for similar vapor concentrations from gasoline versus diesel can be significantly lower for diesel. An FID can be used to minimize this problem but they are not widely used in Hawai‘i. An FID responds to both methane and petroleum-related compounds, but does not respond strongly to chlorinated solvents, and perhaps most important for rural or inter-island work in Hawai‘i requires a ready supply of hydrogen. High humidity or low-oxygen environments can also extinguish the FID flame. This can be an issue for screening of subsurface vapor associated with degrading petroleum releases.

When possible, screening level Photoionization Detector (PID) data should be provided to the laboratory prior to sample collection in order to assist the lab in optimization of sorbent tube preparation. For heavily contaminated, petroleum-release sites in particular, the amount of soil vapor drawn through a sorbent tube might still be limited to volumes as small as 50ml. Smaller volumes are not recommended under any circumstances as they are unlikely to be representative of site conditions. This should be discussed with the laboratory prior to preparation of the sorbent tubes for sample collection. If necessary, a series of connected sorbent tubes can be used to collect larger-volume samples (see first photo in Figure 7-9).

If sorbent tubes are to be used in a high-concentration, soil vapor environment (e.g., to evaluate TPH in vapors associated with diesel-contaminated soil or groundwater) and the volume of vapors to be drawn is less than one liter then the concurrent collection of a one-liter or larger Summa canister sample is also recommended (see Section 7.13). The Summa canister sample should be collected first to help ensure that the vapor point is adequately purged and to improve the representativeness of the sorbent tube sample. The well point should then be closed using a valve or pinched shut (similar to the sampling train leak test), using a small length of flexible tubing to prevent the backflow of ambient air into the tubing and soil. Allow adequate time for the vacuum on the soil to dissipate with the vapor sampling point remaining closed. This could take several minutes for tight soils. The sorbent tube sampling train should then be connected, the vapor point re-opened, and the sample collected.

After the sample is drawn, the sorbent tube should be chilled to 4°C and sent to the laboratory for analysis. The concentration of a targeted chemical in the original vapor is calculated as the mass of the chemical sorbed divided by the volume of vapor drawn through the sorbent.

The storage and holding time for sorbent tubes vary depending on the sorbent material used and targeted VOCs but are typically up to 30 days after the tubes are prepared. Removal and testing of the sorbent material may be required by the laboratory within 14 days of sample collection for some methods.

Concurrent PID data should be provided to the laboratory in order to determine if dilution of sample is necessary prior to analysis and help reduce analytical time and costs. Note that petroleum vapors are dominated by aliphatic compounds. PIDs primarily target aromatic compounds and are not good indicators of total TPH levels in soil vapors without inclusion of a correction factor. This is especially important to remember for aromatic-poor vapors from diesel fuel or other middle distillate fuels (refer to HEER Office petroleum vapor study; HDOH, 2012). PID readings for similar vapor concentrations from gasoline versus diesel can be significantly lower for the latter. A Flame Ionization Detector (FID) can be used to minimize this problem but they are not widely used in Hawai‘i. High humidity or low-oxygen environments can extinguish the FID flame. An FID also responds to methane as well as petroleum-related compounds, does not respond strongly to chlorinated solvents, and perhaps most important for rural or inter-island work in Hawai‘i requires a ready supply of hydrogen.

When used in combination at a petroleum site, the Summa canister sample should be tested for TPH as the sum of C5-C12 compounds (Section 7.13) as well as targeted, individual compounds (e.g., BTEX and naphthalene) using TO-15 or an equivalent method. The sorbent tube sample should be tested for TPH as the sum of C5-C18 compounds using TO-17 or an equivalent method. Although not directly comparable due to different lab methods, the difference in the two, reported concentrations of TPH in the vapor samples will give some idea of the proportion of compounds greater than C12. As an alternative, the lab can be asked to quantify TPH in the sorbent tube sample as the both the sum of C5 to C18 compounds and C12 and higher compounds. The data can then be used to evaluate the most appropriate sample collection method for characterization of the site. For example, if less than 10% of the total TPH is estimated to be composed of C12 and higher compounds then Summa canisters can be used to collect additional samples (see also Section 7.13.2)

7.8.3 PASSIVE SAMPLING

Passive sampling involves using adsorbent materials to collect vapor phase chemicals without the use of a pump or Summa canister. The vapor is not induced to flow over the adsorbent; instead the chemicals in the vapor passively contact the adsorbent and adsorb to it. Both VOCs and SVOCs are captured by the adsorbent material and can be characterized, although extremely volatile chemicals (e.g., vinyl chloride) may not concentrate sufficiently on the adsorbent and the less-volatile SVOCs may not have sufficient vapor pressure to be detectable.

Passive sampling approaches requires less equipment and is more straightforward in the field than active sampling. Data for samplers can be used to identify vapor-phase chemicals for additional site characterizations and vapor intrusion studies (e.g., USEPA 2009). These methods give a time-integrated measurement and capture temporal variations in VOC concentrations that could be missed with short-duration, active samples. Passive sampling methods have also been used to estimate VOC concentrations in soil vapor.

Calculation of the vapor concentration from passive sampling results is, however, sometimes attempted by estimating the volume of vapor that passes by the buried adsorbent during the burial time period and a vapor diffusion model. Another method is to determine an uptake rate for the passive collector. At present, comparative studies between actively measured soil vapor concentrations and those estimated from passive sampling are at best within an order of magnitude (e.g., USEPA 2009). Due to this uncertainty, passive soil vapor data are considered to give qualitative or semi-quantitative vapor concentration results and generally are considered a screening tool for soil vapor investigations. An emerging exception could be the use of water-based passive samples, discussed in a following section.

Implementation of passive sampling approaches requires less equipment and is more straightforward in the field than active sampling. Therefore, passive sampling can be beneficial for the initial stages of site characterization or vapor intrusion studies.

Advantages of passive sampling include:

- Quick and relatively inexpensive method to investigate large areas and to map plumes;
- Able to detect any contaminant that has an appreciable vapor pressure and can be adsorbed in sufficient quantity to determine relative presence or absence, including lighter-end SVOCs like naphthalene, even if present in very low concentrations;
- Results can be used to more cost-effectively design and optimize follow-on active sampling;

- Individual samples can be combined for extraction and testing to increase coverage for targeted area (check with lab prior to collection);
- Useful in situations where active methods may not be applicable, (e.g., areas of extremely low permeability and high moisture content, high-traffic/limited access areas, etc.);
- Can be used to find preferential pathways into a structure or around a structure, such as utility corridors;

Disadvantages of passive sampling include:

- Not useful for generating vertical vapor profiles unless sampling intervals can be effectively isolated;
- Actual vapor concentrations can only be estimated, limiting use of the method to screening, plume mapping, and other semi-quantitative applications.

An additional drawback is that passive sampling requires two visits to the field, one to deploy the adsorbents and a second trip to retrieve them, and does not allow for the acquisition of real-time data. Intentional or accidental disturbance and even vandalism of passive samplers can also be a problem

Passive sampling can be applied to either soil vapor or indoor air. Although the principle is the same in application to these media, the sampling equipment is different, as described in the two sections below.

7.8.3.1 PASSIVE SOIL VAPOR SAMPLE COLLECTORS

Qualitative passive soil vapor sample collection involves placing an adsorbent into the subsurface for a pre-specified exposure period to allow the adsorption of soil vapor chemicals onto the adsorbent material. Compound uptake rates are not required to be known for this approach. The sample exposure duration can be from days to weeks, with a typical exposure period of one week to identify source areas and two weeks when tracking contamination in groundwater or when heavier molecular weight compounds are of concern (e.g., naphthalene and 2-methylnaphthalene). Longer exposure durations are recommended for comparison of data to lower action levels. Request that the technology vendor provide specific guidance on sample exposure periods based on sampling objectives and site conditions.

Passive soil vapor sample collection involves placing an adsorbent into the subsurface for a known exposure period (e.g., one to two weeks) to allow the adsorption of soil vapor chemicals onto the adsorbent material. Sample collection procedures are described in Section 7.12. The absorbent is typically placed in the upper end of an inverted container having an open bottom, or in a fine wire mesh or polymeric material, to facilitate contact with the soil vapor but not the soil. Photographs of two vendor-supplied sample collectors are provided in Figure 7-10.

Although the results are qualitative, passive soil vapor sampling can provide useful information when investigating subsurface vapor plumes or preferential pathways for vapor intrusion studies.

One evolving approach is to subdivide a site into targeted Decision Units (DU) for screening characterization. Active soil vapor sampling will be targeted for the DU with the highest, relative concentration of VOCs identified in passive samples. Rather than deploy a single passive sampler in each DU, multiple samplers are deployed to provide better coverage and then combined at the laboratory for a single extraction and analysis. For example, five to ten passive samplers can be installed within each targeted area of a site. After collection, the laboratory can be instructed to combine and carry out a single extraction for groups of samplers from targeted DUs. This increases the accuracy and quality of field data without increasing lab cost.

USEPA conducted a verification study of the major vendor-supplied passive diffusion sample collectors in the late 1990's (USEPA 1998, USEPA 1998d). As part of this study, the results of passive diffusion samplers were compared to active soil vapor measurements. These studies showed that:

- The passive soil vapor sampling systems detected the same compounds in each sample as the active method, as well as several VOCs that the active method did not detect. This performance characteristic suggests that the passive soil vapor sampling systems may detect VOCs that are at lower concentrations in the subsurface than the active soil vapor sampling method can detect and/or that the passive samples were able to better capture temporal changes in vapor concentrations due to the longer exposure period.
- The results also indicated a general, relative correlation between passive soil vapor sampling results and active method data (e.g., high or low). However, at high contaminant levels, the ratio between the passive and active results decreased, suggesting that sorbent saturation might have occurred. This decreases the resolution capability of the passive samplers in heavily contaminated areas.

- Because the passive soil vapor sampling systems and the active method use different techniques to collect soil vapor samples, it is not expected that the two methods will provide the same response or that the data will be directly comparable.

7.8.3.2 PASSIVE SAMPLING OF INDOOR AIR

Passive indoor air sample collection involves hanging an adsorbent-containing sample collector at a location in a building where indoor air chemical concentration data are desired. A typical sample collector consists of a glass vial with the adsorbent material inside – the vial is capped with a gas-permeable membrane, which allows vapors to enter the vial but excludes any particulate matter in the air.

As discussed earlier, another alternative is to deploy multiple samplers within targeted rooms, floors, etc., to provide better coverage and then have the laboratory combine groups of samplers for a single extraction and analysis. This can help reduce concerns about air flow and the inclusion of stagnant areas of the building in the indoor air evaluation.

Passive sampling of indoor air is a technique that has two primary applications. First, as a low-cost screening tool, the technique can be used to provide wide coverage of a building or set of buildings with a minimal amount of field equipment. Second, because the adsorbent equilibrates with the indoor air over a longer period of time than is typically practical with whole air sampling, the result of passive sampling reflects a longer-term average concentration that can be useful as another line of evidence in risk assessment.

Photographs of two vendor-supplied sample collectors are provided in Figure 7-11.

7.8.3.3 EMERGING TECHNOLOGIES

The field of soil vapor and indoor air passive sampling is rapidly developing. There are a number of technologies that can be applicable to specific site characterization needs. One emerging technology, the use of passive diffusion samplers, is described below.

High-Density Passive Sampler Deployment

The use of high-densities of passive samplers to characterize the in situ nature of vapor plumes beneath building slabs was evaluated in an (HDOH, 2017) investigation of a PCE vapor plume beneath the slab of a former dry cleaner. The approach involves the installation of multiple, rather than single, passive samplers beneath targeted areas of the slab and subsequent collection and combination of the samplers for testing under a single analysis. Testing of multiple individual samplers installed within a single 300 ft2 grid cell indicated significant variability between closely located points. This has significant implications regarding the reliability of small-volume vapor sample data to accurately delineate plume boundaries and variability within larger-scale plumes (Section 7.5; see also Section 13.2 and Brewer et al. 2014).

Four samplers were installed in each grid cell for the (HDOH, 2017) study and combined for analysis. Replicate sets of samplers (triplicates) were installed in three grid cells in order to assess the precisions of the data. The replicate data indicted very good precision. The number of samplers required to obtain consistent, reproducible results for a targeted area has not been studied in detail and at this point is necessarily site specific.

Isopleth maps of the vapor plume identified beneath the dry cleaner in the HDOH field study are presented in Figure 7-13. The first map reflects the true resolution of the passive sampler data at the scale of an individual grid cell. The second map was generated by assigning the concentration of tetrachloroethylene (PCE) reported for each cell to the center point of the cell and then using a contouring program to generate corresponding isopleths. While clearly superior to typical, small-volume vapor sample investigations, the practicality of installing large numbers of passive samples beneath a building slab will necessarily be site specific.

The combination of multiple passive samplers for testing should be discussed with the laboratory prior to the commencement of field work. This approach helps to capture and represent small-scale, random heterogeneity of VOC concentrations within a targeted area and provide more representative data for site characterization purposes. Although less well-defined in terms of sampling theory, this is similar in concept to the collection of a “Multi Increment” soil sample from multiple, rather than a single point within a targeted area for improved data resolution and reliability (Section 4.2). Refer to the HDOH 2017c study for additional information.

Passive Diffusion Sampler

A passive diffusion sampler (PDS) has been developed by the USEPA Office of Research and Development for soil vapor characterization (Paul 2009). This sampler uses water as the media into which contaminants partition rather than the solid adsorbent approach described above. This sampling technology is in the developmental phase, but it has advantages for

characterization of contaminants that might not be well adsorbed on solid media, including more polar compounds. More reliable estimates of VOC concentrations in soil vapor may be possible.

The PDS is constructed using a 40 ml VOA vial filled with de-ionized water and with the Teflon septa replaced with a vapor-permeable membrane. The PDS is inserted into a custom-made messenger (hollowed-out plastic cylinder) and deployed in two-inch diameter, monitoring wells with a screened interval placed at the desired soil vapor depth interval. Figure 7-12 shows a schematic of the PDS and a photo of the sampler being deployed in the field. An O-ring on the messenger seals the targeted depth interval from ambient air. Further installation details and a Standard Operating Procedure (SOP) are available from the developer of this technology (Paul 2009).

Once the sampler is installed, the permeable membrane in the PDS is exposed to the screened interval and contaminants diffuse through the membrane into the water-filled PDS until the water reaches equilibrium with the surrounding soil vapor. The PDS is recovered from the well after an appropriate equilibration period, typically one month for most VOCs. The addition of preservatives to the PDS sample after collection should be considered in the similar manner as done for groundwater samples (see Section 6). The water is then analyzed for targeted VOCs, with results expressed in units of mass per volume of water (e.g., ug/L). The concentration of the VOC in water is then multiplied by the Henry's Law constant for that chemical to estimate the average, equilibrium concentration of the VOC in the surrounding soil vapor.

Several comparative field studies of this technology in application to petroleum and chlorinated solvents have been carried out (e.g., USEPA 2009). Table 7-5 lists the results of one study wherein PDS sampler results were converted to vapor concentrations using Henry's Law and then compared to a collocated active (e.g., Summa) soil vapor measurement. In this study, the PDS estimated concentrations of vapor-phase VOCs were consistently higher than those reported for the active samples for both PCE and TCE (USEPA 2009). Among other possibilities, this suggests either: 1) A consistent error in conversion of dissolved-phase VOCs to equivalent vapor-phase VOCs and/or 2) The existence of subsurface spatial and/or temporal vapor “hot spots” that were captured by the PDS sampler due to their longer exposure time but missed by the short-duration active samples.

Another potential advantage of PDS samples is the ability to collect and then combine multiple samples within individual, targeted Decision Unit areas for comparison to adjacent areas or for estimation of time-averaged VOC concentrations for use in vapor intrusion studies. Whether or not PDS samples can indeed be used to obtain a more representative picture of long-term subsurface soil vapor conditions at a site is still under investigation.

7.8.4 LARGE VOLUME PURGE SAMPLING

“Large Volume Purge (LVP)” soil vapor collection methods, referred to as “High Purge Volume” samples by McAlary et al. (2010), have been used sporadically to assess vapor intrusion risk since the early 2000s but only casually mentioned in USEPA or state agency guidance (e.g., CalEPA 2015). Under this approach an active or passive vapor sample is continuously collected from a stream of vapor being purged from a point installed into the bottom-floor slab of a building. Problems hindering routine use of the approach included: 1) Lack of awareness of the limitations of traditional, soil vapor data (see Section 13.2), 2) Lack of a systematic approach to soil vapor investigations and designation of risk-based, “Decision Units (DUs)” of vapor for sample collection and characterization, 3) Limited information on the engineering design of LVP sampling collection system; and 4) Misplaced concerns regarding the need to identify the exact, subslab source of vapors purged during sample collection.

These issues were evaluated in an HDOH field study of the collection of LVP vapor samples carried out in 2016 (HDOH 2017c). The use of high-density, passive sampler installation to characterize the in situ nature of vapor plumes beneath building slabs and assist in designation of LVP sample collection locations was also included in the HODH study (see Section 7.8.3.3). A brief overview of the design of the sampling system is provided below. Refer to Section 7.5, Section 13.2 and the HDOH (2017c) study for additional background information. The sample collection design presented is intended as an example only and is similar in nature to a standard, soil vapor extraction pilot test. It is anticipated that more efficient LVP sample collection methods will be developed in the future.

7.8.4.1 INVESTIGATION OBJECTIVES AND LVP DU DESIGNATION

Large Volume Purge vapor data are used to more directly assess potential vapor intrusion risk at existing buildings, rather than characterization of in situ VOC concentrations in vapors beneath a slab (refer to Section 7.5). This should be clearly stated in the project workplan. The latter might be necessary if LVP data indicate a potentially significant risk, or might be carried out beforehand in order to assist in in designation of an LVP sample collection point.

A default, subslab vapor DU volume of 3,000 liters is recommended (Figure 7-14). This reflects a default vapor entry rate of 2 L/minute estimated by Brewer et al. (2014) for buildings in tropical climate zones (see Section 7.5). Deviations from the default volume should be discussed in the workplan. A consecutive series of five LVP purges is recommended. This is intended to reflect potential vapor intrusion through the designated LVP sample collection point over a five-day period and better capture large-scale variability of VOC concentrations within a vapor plume underlying a building slab. Collecting separate samples over

a series of LVP purges also reduces the risk of biasing the full data set if leakage into the system is identified during later stages of sample collection.

7.8.4.2 LVP SAMPLE POINT DESIGNATION AND SLAB PREPARATION

State the rationale for designation of the targeted LVP sample collection point or points in the investigation workplan. Potential LVP sample collection points include:

- At or near suspect or known vapor entry points;
- Within or adjacent to known or suspect subslab utility trenches that could serve as preferential pathways for vapor flow;
- Directly above suspect, subsurface soil or groundwater source areas; and
- Sensitive-use areas of the building, or in the center of the slab (Figure 7-15).

Existing small-volume vapor sample data might also be used to designate an LVP collection point, if available, although the collection in advance of small-volume vapor samples is not necessary unless a source area above groundwater is specifically suspected or if significantly heterogeneity of VOC concentrations within an underlying groundwater plume is suspected.

Obtain as-built designs for the targeted slab or consult a structural engineer prior to designation of points for LVP sample collection. Geophysical toning and a review of as-built building plans should be carried out to identify subsurface utilities and the presence of rebar in the slab. Slabs under commercial buildings are typically between four and 20 inches thick and may or may not be reinforced with steel reinforcing bars (rebar) or other material. Slabs constructed for commercial or industrial buildings are not typically uniform. A slab will typically be thicker (supported by an underlying foundation) in areas anticipated to bear significant weight from machinery or walls. These structures could in theory compartmentalize and isolate individual pockets of vapor beneath a slab and should be taken into consideration for designation of sample collection points if as-built diagrams of the building slab and foundation are available.

Seal visible and accessible utility penetrations, floor drains, cracks suspected to penetrate the slab and other potential routes for downward leakage of indoor air to the extent practical during the collection of LVP samples (Figure 7-16). Methods to seal cracks and gaps in floors include bentonite slurry and heavy-duty tape. Avoid the use of compounds with volatile compounds that could affect sampling results. Methods to assess leakage through the slab during the collection of LVP samples are described in Section 7.8.4.6.

The distance from the sample collection point that the floor should be sealed can be estimated as the worst-case, vapor draw area with respect to the targeted, total DU purge volume. Assume, for example, that a one-meter wide by one-meter deep utility trench is present beneath or nearby the selected sample point and could serve as a preferential pathway for vapor flow. Based on a total LVP purge volume of 15,000 liters (i.e., five, 3,000 liter purges) and an effective, air-filled porosity of 28% (default value used in HDOH EAL calculations), the vapors will be drawn from an approximate 50 m3 volume of soil beneath the slab. This suggests that the slab within 25 m of the LVP purge point should be sealed, assuming an equal length of influence in both directions along the utility trench. The source area of the vapors cannot be determined from the purge data and will be influenced by preferential pathways in the soil. Exact knowledge of the source area is not important for assessment of potential vapor intrusion risk but could be useful for identification of subslab source areas and/or utility corridors and other features that could serve as preferential pathways. The source of purged vapors can be approximated by installing additional probe points through the slab and monitoring of the vacuum drawn at in different locations around the LVP point. This might be desirable if significant levels of VOCs are reported in LVP samples and a better understanding of vapor source areas is needed, as discussed below.

These distances are for example only. In practice, all potential, accessible gaps within the slab should be sealed prior to sample collection as a conservative measure and in order to minimize the potential for leakage of indoor air into the sample and call into question the reliability of the data. Leak checks should then be included as part of LVP sample collection (Section 7.8.4.4).

The exact vapor draw area does not need to be determined as part of an LVP investigation since, aside from an increased flow rate, sample collection is intended to directly mimic upward vapor flow through the designated point. This includes potential leakage of outdoor air under the edges of the slab during sample LVP purges. As discussed in Section 13.2, subslab vapors that intrude and impact indoor air in most cases originate as outdoor air that has been drawn in under the edges of the slab and is contaminated by volatile chemicals slowly diffusing out of a soil or groundwater source as the air flows toward the vapor entry point.

Knowledge of the approximate location of the vapor source area might, however, be beneficial as part of a follow-up characterization to identify subslab source areas and design remedial action plans if LVP data indicate potentially adverse impacts to indoor air. Be aware, however, that subslab vapor plumes are often not co-located with the soil or groundwater source area. An additional soil and/or groundwater investigation will typically be required to identify vapor source areas. Strategies for the investigation of soil and groundwater contamination by volatile chemicals are discussed in Section 4 and Section 6, respectively.

7.8.4.3 LVP SAMPLE TRAIN DESIGN AND TEST

A detailed description of the system used in the HDOH (2017c) LVP field test is provided in the report for that study. The system was modeled largely after an approach published by McAlary et al. (2010) and is similar to designs used for a soil vapor extraction pilot test. It is anticipated that the design utilized in the field study can be scaled down for routine use.

A schematic of the LVP design is provided in Figure 7-17. The design used in the HDOH (2017c) field study is depicted in Figure 7-18. The basic configuration consists of a two-inch polyvinyl chloride (PVC) pipe connected to a vapor sampling point installed in the center of the slab. A Shop-Vac® was used in the field study to produce a vacuum on the sample point and purge the targeted volumes of vapors. Rotron or similar types of fans or blowers can also be utilized. Multiple sample ports should be installed into the PVC piping to allow the vacuum on the well point and vapor flow rate to be monitored and ensure a continuous draw of a vapors from the purge stream into or through the selected collection apparatus.

In practice the volume of vapors purged and the mass of VOCs in the purge stream will be relatively small. The system should be exhausted to outdoor air in order to avoid adverse impacts to indoor air and downwind of nearby receptors.

The components of the setup depicted in Figure 7-18 include (upstream to downstream):

- Two-inch Schedule 40 PVC;
- 1/4-inch wedge valve near the intake "T", with tubing connected to a Dwyer Magnehelic Gauge (0-100 in-H2O) pressure/vacuum gauge;
- Summa sample valve (1/4-inch wedge valve with Teflon tubing);
- PID meter and O2/CO2 meter port (1/4-inch wedge valve equipped with Teflon tubing to the PID meter) – opposite side of Summa Port (peristaltic pump used to overcome vacuum imposed on purge stream and draw influent to the PID and O2/CO2 meter port);
- Pitot Tube port (3/8-inch ID threaded pipe, ½-inch length);
- Flow meter port (3/8-inch ID threaded pipe, one-inch length).

A summa canister is used to collect a sample from the LVP purge stream in Figure 7-17 and Figure 7-18 (Section 7.8.1). The system could also be designed to allow a continuous stream of vapors to pass through a sorbent collection tube (Section 7.8.2). No experience with the use of sorbent tubes in LVP sample collection systems was available at the time this guidance was prepared. Discussions with consultants familiar with the approach suggest that the use of sorbent tubes to collect LVP samples would be limited due to the vacuum imposed on the purge train.

The PID sample port should be placed immediately opposite the summa sample port and used to monitor oxygen, carbon dioxide and total VOC concentrations periodically using a Tedlar bag and vacuum chamber (“lung box”) during each purge event (see Figure 7-18). This ensures that PID readings will be representative of the collected samples.

Installation of an Averaging Pitot Tube (“Pitot tube”) upstream of the flow meter port is recommended in order to confirm flow rates based on a thermal, anemometer flow meter. A minimum ten-pipe-diameter upstream separation distance and five-pipe-diameter downstream separation distance between any fittings or ports and the Pitot tube and flow meter should be maintained, in order to minimize turbulence that could affect the accuracy of the instruments (see HDOH 2017c).

A limited amount of low-volatile, non-chlorinated, PVC cement can be used at joints in the piping, if necessary to ensure secure fittings. If used, then the vapor purge system should be allowed to aerate for several days prior to use in the field and tested with a PID to confirm that no VOCs are present in the piping and fittings.

Carry out a shut-in test on the sampling train to ensure that no leakage is occurring around joints and fittings. This will be similar to the shut-in test described in Section 7.10.5.1 for soil vapor sampling trains in general. Test the vacuum of the pump (e.g., Shop-Vac) to be used for sample collection by attaching it directly to a vacuum gauge and measuring the vacuum drawn for at least 15 seconds. Connect the pump to the LVP sampling train, close the valve to the extraction point, and re-measure the vacuum drawn for at least 15 seconds. Compare this value to the vacuum previously measured. A difference of greater that 10% indicates a significant leak somewhere in the sampling train. Correct any problems identified and redo the shut-in test. The results of the shut-in test and bench test should be documented and described in the report for the LVP investigation.

Once the system is deemed to be tight, carry out a bench test to optimize the design of the system and evaluate the purge rate under different vacuums imposed on the vapor entry point. Ensure that the flow meter(s) are functioning properly. In the HDOH (2017c) field study, purges were directed into a spherical, latex-rubber weather balloon in order to verify the accuracy of flow meters attached to the purge stream. Verifying the precision of flow rate measurements is critical, since the DU volume of vapors purged per sample is a critical part of sample collection and data evaluation.

A vacuum of between 30 and 40 in-H2O is typical of field conditions when a 6.5 HP Shop-Vac is used to purge a well point (see also McAlary et al. 2010). Note that this is well below the maximum recommended vacuum to be applied to a vapor sample point of 100 in-H2O or seven inches of mercury (in-Hg), intended to avoid stripping of vapors from free product entrained in soil (refer to Section 7.10.3.2; see also CalEPA 2015). A flow rate of 300 to 3,000 liters per minute (10 to 100 standard cubic feet per minute) is typical, depending on the permeability of the material below the floor slab. This corresponds to an estimated purge duration of approximately 1 to 10 minutes to collect an LVP sample from a default, 3,000 liter DU volume of subslab vapor. Smaller diameter piping will require a longer purge time for any given sub-slab permeability because of frictional losses. As discussed in Subsection 7.8.4.5, correspondence of the purge time with the flow rate of the Summa canister is critical when a canister is used for the collection of an LVP sample.

7.8.4.4 EXTRACTION POINT INSTALLATION

An example extraction point design is depicted in Figure 7-19. (Note that the building had been removed prior to LVP sample collection.) The LVP extraction point should be installed in a manner that allows access to the targeted depth interval beneath the slab and prevents downward leakage of indoor air during purges of subslab vapor. In the HDOH (2017) LVP field study, the extraction point was constructed as a two-inch PVC well, set within an eight-inch diameter steel casing installed to from the surface to the base of the slab. The latter was installed due to the vulnerability of the sampling point in the field to surface traffic (building previously removed). A narrower diameter installation and even narrower diameter piping will likely be adequate for most investigations.

The LVP extraction well in the HDOH (2017c) study was constructed with 10-slot, two-inch diameter screened PVC with a solid end-cap. Smaller- or larger-diameter well points might also be practical. The well screen should be extended from the base of the concrete pad to the depth of targeted, subslab vapor DU (e.g., 12 inches). Include a solid endcap on the well point in order to help focus the draw area of influence to the targeted layer of soil. Install a sand pack to a height of several inches above the top of the well screen. Add a minimum, two-inch layer of hydrated bentonite above the sand pack. Seal the gap between the extraction point and the slab with Portland cement to further prevent downward leakage. A water dam can be used to confirm the absence of leakage in this seal (see Subsection 7.10.5.2). Build a dam around the seal and add water. The water should not disappear during the LVP purge. The top of the extraction point can be installed either below or above the top of the slab, depending on the needs of the investigation. Fit the top of the tube with a solid PVC screw cap in order to seal and secure the top of the well.

Alternative extraction point installation designs are possible, provided that the objectives of LVP sample collection are met. Alternative designs should ensure that collection of vapors from the targeted subslab DU interval is optimized, that leakage around the extraction point is minimized, that the resulting flow rate is compatible with the sample collection method and that the resulting samples will be sufficiently representative.

7.8.4.5 LVP SAMPLE COLLECTION

Figure 7-20 depicts a completed, LVP sample collection system set up taken from the (HDOH, 2017) field study. A field pilot test should be carried out to estimate the flow rate of the LVP under sample collection conditions. The test should be kept as short as possible in order to limit disturbance of subslab vapors. A duration of less than 60 seconds is anticipated to be adequate.

Record the flow rate and estimate the time required to complete the targeted, DU purge volume. Ensure that the minimum draw time is greater than the time required to complete the LVP purge if a Summa canister is to be used to collect the LVP sample (minimum draw rate typically 200 ml/minute). Six liter canisters are recommended in order to ensure that the canisters do not fill prior to completion of the time required to achieve the targeted purge.

The collection of LVP samples can begin immediately after the purge test. Carry out a final shut-in test to ensure the tightness of the sampling train. Connect the sample collection apparatus (e.g., Summa canister) to the sampling train. Carry out a shut-in test on the sampling train itself to ensure tightness. Attach additional sample collection equipment (e.g., Summa canisters or sorbent tubes) to the sampling train as needed to collect replicate samples in accordance with the investigation work plan.

Turn on the pump attached to the LVP system while simultaneously opening the Summa canister valve or the connection to a sorbent tube collection system. This will allow a continuous portion of the purge stream to enter or pass through the sample collection device. Collection of a concurrent, indoor air sample(s) in the immediate vicinity of the LVP well point is also recommended (Section 7.7). The sample should be tested for targeted, subslab VOCs as well as oxygen, carbon dioxide, substances used for leak detection (e.g., isopropyl alcohol) and other gases that might prove useful for evaluation of potential downward leakage of indoor air through the slab and into the LVP sampling point during purges (Section 7.8.4.6).

Include tests for leaks at the well point and at connections in the LVP sampling train upstream of the sample collection ports (Section 7.10.5). This could include placement of rags soaked in isopropyl alcohol (standard rubbing alcohol) around the wellhead extraction point connection, fittings upstream of the vacuum gauge, and fittings immediately downstream of the vacuum gauge and prior to the sample collection ports (see Figure 7-20). Accidental contamination of sampling containers and

subsequent contamination of laboratory equipment and bias of test results can be difficult to avoid, however. A simple shut-in test is considered adequate by many field experts.

Record flow data and the vacuum at the extraction point for each purge at an interval adequate to document sampling conditions. A series of readings at the beginning of a purge until conditions stabilize (e.g., every 30 to 60 seconds) followed by a reading at the mid-point and end of the purge is recommended. Use a PID and landfill gas meter with a Tedlar Bag and Lung Box to periodically (or continuously) monitor oxygen, carbon dioxide and if feasible total VOCs during the purge. Record the time required to achieve the target DU purge volume. Cease sample collection if leakage of indoor air into the LVP train is suspected.

Record the starting and final vacuum of the summa canister. Use this to estimate volume of the vapor sample collected in the canister. Discuss minimum sample volume necessary to meet testing requirements with the laboratory prior to sample collection (typically 1-2 liters).

Turn off the LVP sampling train pump when the target purge volume has been reached. Immediately close the Summa canister valve (or port to sorbent tube) as well as the valve to the vapor extraction point. Disconnect the sample collection apparatus (e.g., Summa canister or sorbent tube). Connect the apparatus for collection of the next LVP series sample. Repeat the same steps noted above until the full series of LVP samples targeted for the subject purge point have been collected.

Submit the LVP samples to the laboratory for analysis. Ensure that the samples are tested for oxygen, carbon dioxide and any other gases used to assess potential leakage in addition to VOCs targeted as part of the vapor intrusion investigation.

7.8.4.6 DATA QUALITY CONTROL

Field quality control should include (Section 7.10.5): 1) Shut-in test of LVP sampling train prior to and after connection to vapor extraction; 2) Leak testing of sampling train using isopropyl alcohol or comparable method throughout each purge event; 3) Collection of a background indoor air sample(s); 4) Collection of O2, CO2 and other potential tracer gas data for preliminary subslab vapors prior to sample collection and as part of all LVP and background indoor air sample analyses; and 5) Collection of triplicate LVP sample(s) for the first purge of a sampling event if a non-continuous draw method is used to collect an LVP sample.

Test for and record oxygen and carbon dioxide levels in subslab vapors at the well point prior to the collection of LVP samples. These data will be important for assessment of potential leakage of indoor air into the system during LVP sample collection. All LVP samples should likewise be tested for O2, CO2 and other potential gases that could prove useful in leakage tests (e.g., indoor air contaminants not anticipated to be present in subslab vapors).

Evaluation of the overall integrity of the sampling train during LVP sample collection should be used in conjunction with preliminary subslab sample data, field data recorded during LVP sample collection and LVP sample and indoor air sample data to assess the magnitude of indoor air leakage into the sampling train during purge events. Oxygen levels in subslab vapors are often depleted in comparison with indoor (and outdoor) air. This is accompanied by a typical increase in carbon dioxide levels in subslab vapors.

These observations and data can be used to assess the relative magnitude of leakage into the sampling train during purge events. A leakage rate of <10% is considered insignificant in terms of data quality and use of the data to assess potential vapor intrusion risk (i.e., >90% of sample volume represented by subslab vapors). An absence of significant isopropyl alcohol in the samples implies minimal leakage at these points. Consistent depletion of carbon dioxide in LVP samples in comparison to indoor air is a particularly useful indicator of minimal leakage. Comparison of other tracer gasses found in indoor air but absent or at significantly depleted levels in pre-sample collection, subslab vapors might also prove very useful (e.g., TPH, BTEX, non-targeted solvents, etc.)

The collection of concurrent, replicate samples during an LVP purge to test data representativeness and reproducibility is not necessary for continuously collected samples, since vapor from 100% of the purge stream is included in the resulting data (i.e., replicate samples not normally needed). At least one set of replicate samples (triplicates) per LVP collection event is, however, recommended for sample collection methods that involve only periodic testing of vapors from the purge stream. For example, a small “increment” of vapor might be allowed to enter the sample collection system (or field testing equipment) every minute or some fraction of a minute. In this case the resulting data represents the mean of the vapor increments collected and the representativeness of the complete purge stream cannot be directly assured. The collection of concurrent triplicate samples will allow the precision of a single LVP sample data point to be tested in a manner similar to that applied to the collection of replicate Multi Increment soil and sediment samples (Section 4.2.7). This assumes, of course, that the samples were collected in a scientifically valid manner to begin with.

7.8.4.7 LVP INVESTIGATION REPORT

Information to be provided in the LVP investigation report includes:

- Site background and summary of existing data;
- Rationale for targeted DU volume of subslab vapors to be characterized and selection of LVP sample collection point;
- Summary of sample collection methods;
- Summary of data quality control measures, including leak detection;
- Summary of data for targeted VOCs;
- Investigation conclusions, including evaluation of potential vapor intrusion risks and any limitations on data reliability;
- Field photographs;
- Laboratory reports;
- Field data sheets.

Summary information for an LVP investigation can be included as part of a larger investigation provided that all necessary information is provided.

7.8.5 FLUX CHAMBER SAMPLING

Flux chambers are enclosures that are placed directly above on the surface (e.g., ground, floor) for a period of time and the resulting contaminant concentration in the enclosure is measured (Kienbusch 1986, Eklund 1992, Hartman 2003, ITRC 2007; Figure 7-21). Flux chambers were originally designed to estimate vapor emissions from open waste pits in terms of mass per unit area per unit time (e.g., mg/m^2-hour). This method offers advantages in some cases because it yields the actual flux of the contaminant out of the ground, which eliminates some of the assumptions required when using other types of subsurface data in vapor intrusion models. Unlike soil vapor or indoor air samples, flux chamber data can be used to definitively identify and document the emission of vapors from subsurface sources to the atmosphere or to the interior of buildings. The method has long been used by regulatory agencies at hazardous waste sites and it is widely used for measuring trace emissions from natural soils.

HDOH considers its quantitative value for soil vapor and vapor intrusion assessments to be limited, and HDOH should be contacted prior to the use of flux chambers in site investigations or vapor intrusion studies. Flux chambers are primarily useful as a qualitative tool to locate surface fluxes of VOC contamination and entry points into structures. This is due in part to the small area tested and difficulty in capturing the heterogeneity of subsurface vapors, as well as short term temporal variations in downward versus upward vapor flux (e.g., due to changes in barometric pressure). Use in open areas also does not mimic vapor flux into buildings. The presence of small-scale, preferential pathways in soils (e.g., desiccation cracks, root structures, soil heterogeneity, etc.) to optimize placement of the chambers is also difficult to identify in the field.

The testing is typically conducted in one of two modes: static or dynamic. In dynamic systems, a sweep gas is introduced into the chamber to maintain a large concentration gradient across the emitting surface. The effluent air from the chamber is collected using canisters and analyzed for chemicals of concern. The method is best suited for situations where large fluxes are anticipated. In static systems, a chamber is placed on the ground or floor and the contaminant concentration build-up is measured over time. This method is best suited for situations where lower fluxes are anticipated.

Flux chambers are not well-suited for structures with covered floor surfaces such as single family residences, because the primary entry points of soil vapor into the structure (cracks, holes, sumps, etc.) are often concealed by floor coverings, walls, stairs, etc. For structures, the method has more application to larger industrial and commercial buildings with slab-on-grade construction where the slab is mostly uncovered. A building survey using a real-time analyzer or on-site GC can be used to attempt to identify the primary locations of vapor intrusion.

Regardless of the method used, enough chamber measurements should be collected to get a representative value under the footprint of the building (analogous to placing enough borings on a typical site), and ensure that they are located near edges where the slab meets the footing, over any zones with cracks or conduits, and over the center of the contamination if known. In all cases, it is recommended that chambers should be deployed for long enough periods to enable temporal variations to be assessed, similar to indoor air measurements (8 to 24 hours depending upon the conditions; 24 hours if large temperature differences exist between day & night) (SDC 2011).

7.9 ACTIVE SOIL VAPOR PROBE INSTALLATION



Figure 7-22: Typical Temporary Soil Vapor Probe Typical temporary soil vapor probe, designed to be driven by a direct-push drill rig. The probe tip components (from left to right in the lower left photo) include a disposable drop-off point, probe tip (threaded to attach the tip to a steel drill rod), inert tubing connecting the probe tip to a sampling pump on the surface, and a steel drill rod. A fine mesh screen is located inside the probe tip.

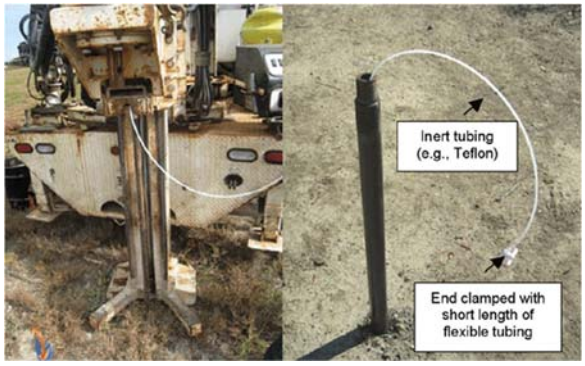


Figure 7-23: Installing a Temporary Soil Vapor Probe Using a Direct-Push Drill Rig After the probe is driven to the desired sampling depth, the steel rod is retracted approximately 1 to 6 inches, allowing the drop-off point to remain at the bottom of the boring, and creating a cavity in the soil that provides access to the soil vapor at the desired depth for sampling. The photograph on the right shows a temporary soil vapor sampling probe in place

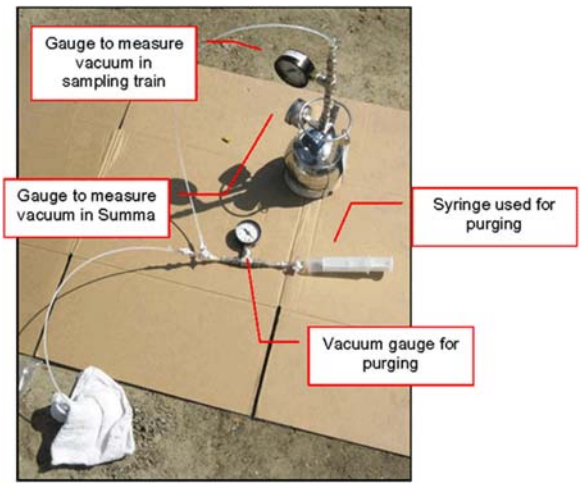


Figure 7-24 Vapor Point Completions Left: Surface completion of flush-mounted well with valve installed. Right: Flush mounted nested well with Swagelok fittings; well in background being purged using an electric pump set at a draw rate of 200 ml/minute.

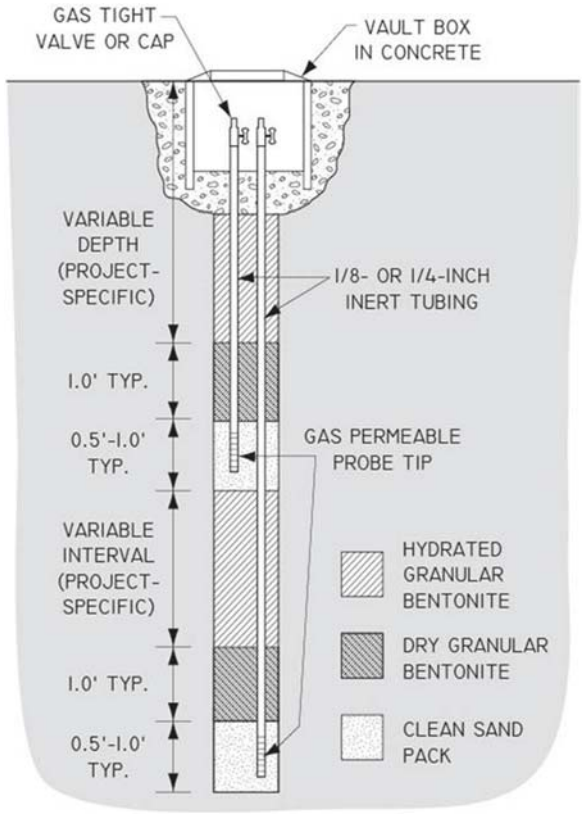


Figure 7-25 Typical Nested Permanent Soil Vapor Sampling Probes



Figure 7-26 Installation of a Permanent Soil Vapor Probe Upper left photo: Hand-augering the borehole. Upper right photo: Preparation of soil vapor sampling point. Bottom left photo: Hydrating the bentonite seal. Tape used to measure depth of borehole, sand pack, and bentonite. Bottom right photo: Purging the completed vapor probe. Surface completion is a 9-inch length of 3-inch diameter Schedule 40 PVC pipe placed into upper 6 inches of the borehole around the probe tubing. A slip cap is placed over the PVC when not purging/sampling.

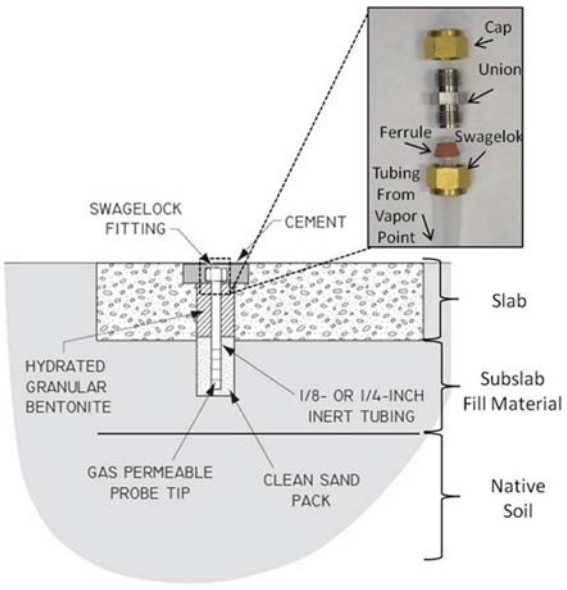


Figure 7-27 Schematic of Typical Sub-Slab Soil Vapor Sampling Probe (see also Figure 7-28 & 7-29).



Figure 7-28 Sub-Slab Soil Vapor Sampling Probes Upper left photo: Drilling hole with hand-held rotary hammer drill. Upper right photo: Temporary probe tip. Middle sequence: Inserting probe assembly into hole, pouring granular bentonite, hydrating bentonite seal. Bottom Left: Temporary probe completion. Bottom Middle and Right: Vapor probe with Swagelok termination fitted to hole (note larger diameter hole near surface), final completion with Swagelok fitting on tubing cemented in place (see Figure 7-25).

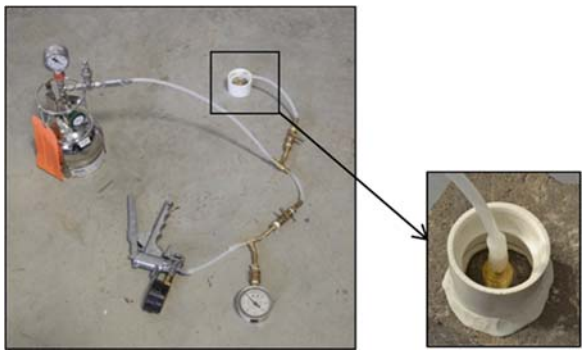


Figure 7-29 Sub-Slab Soil Vapor Sampling Probes Left: Example dual Swagelock setup for connection of vapor point to collection device (see Figure 7-25 and Figure 7-28) Right: Tubing from vapor point and collection device connected with a union joint.



Figure 7-30: Installation of a Vapor Pin™ with a silicon sleeve directly into slab for collection of subslab vapor samples (screw-on protective cap shown in photo to right). Sample collection tubing is connected directly to the top of the probe point (after rubber slip-on cap is removed) and the sample drawn through the base.

The purpose of soil vapor probes is to provide access to subsurface soil vapor so that an active sample can be collected. Soil vapor probes must be properly installed to collect representative soil vapor samples and to minimize the effects of changes in barometric pressure, temperature, or breakthrough of ambient air from the surface. Probes can be either temporary or permanent. The latter typically include a sandpack in the target depth interval of interest and a surface completion that includes a valve and/or a access port for periodic sampling.

7.9.1 TEMPORARY PROBES

Temporary probes typically consist of hollow steel rods driven into the subsurface using manual or direct push drilling methods. The temporary probes are driven to the bottom of the desired sampling interval using expendable or retrievable drive points. Then, the probe rods are withdrawn approximately 1 to 6 inches, leaving the expendable drive point in place and exposing the sampling interval. Narrow tubing with a threaded adaptor at the bottom end is inserted through the steel rods and threaded into the probe tip to form a gas tight seal. The use of tubing with a 1/4-inch to 3/8-inch outside diameter is most common (see Section 7.9.4). An example temporary probe sampling apparatus and typical installation are shown in Figure 7-22 and Figure 7-23.

Sample collection is performed through tubing that is run through the hollow drill rod and connected directly to the sampling probe tip. After collecting shallow samples using rods with retrievable tips, the rods can be advanced to collect deeper samples. The potential for cross contamination should be considered when using the same push rod for the collection of samples at multiple depths.

7.9.2 PERMANENT PROBES

Permanent probes are constructed similar to groundwater monitoring wells installed using auger or direct push drilling techniques. However, permanent probes also can be installed manually within building interiors. Soils should be logged, field screened, and sampled for select contaminants during probe installation using auger or direct push drilling techniques. Documenting soil lithology can be important for development of conceptual site models, including an understanding subsurface vapor transport pathways and mechanisms, and for selecting vapor probe depths.

Permanent probes typically consist of small, inert tubing (e.g. 1/4-inch outside diameter; see Section 7.9.4) extending from the subsurface sampling interval to the ground surface and sealed in place with bentonite to prevent vertical air migration during sample collection. The subsurface end of the tubing is connected to a stainless steel screen or porous stone (airstone) probe tip to prevent particulates from entering the sample probe. Note that polyethylene probe tips are not recommended as VOCs might adsorb to the filter material. The probe tip is typically set halfway between the top and bottom of the sampling interval within a sand pack. Permanent screen implants are typically six inches in length. Placement of a few inches of sand below and above the implant is generally recommended for a total sample-interval sand pack length of approximately one-foot, although deviations can be considered with justification. A sampling interval of greater than one-foot increases the uncertainty in interpretation of measurements since the concentration is averaged over a larger vertical interval ((API 2005). This is especially important for subslab soil vapor samples, where the average concentration of VOCs within one-foot of the slab around

preferential pathways into the building should be targeted (see Section 7.6.2.2). Figures 7-24 and Figure 7-25 present several examples of flush-mounted soil vapor points and a schematic diagram of vapor probe point designs.

Approximately 1 foot of dry granular bentonite should be placed on top of the sand pack to prevent infiltration of hydrated bentonite into the sand pack. The borehole is typically sealed to the surface, or to the bottom of the next highest sampling interval, with hydrated bentonite. When installing permanent probes at several depths in the same borehole, the deepest sample interval is always installed first. Figure 7-26 depicts the installation of a permanent vapor probe using a hand auger. Permanent probes should be finished to preclude infiltration of water or the exchange of ambient air in the sample tubing. Surface completions of permanent probes typically include a fitting that allows for soil vapor sample collection and a gas tight valve at the surface when the probe is not in use. Flush mounting or above ground vaults for surface completions are site specific and should be evaluated accordingly. Permanent probes should be purged of three system volumes immediately following installation (see Section 7.10.3) and allowed to equilibrate prior to sampling (see Section 7.10.2).

7.9.3 ADDITIONAL RECOMMENDATIONS FOR SUBSLAB PROBES

Refer to Section 7.8.4 for guidance on the installation of Large Volume Purge (LVP) subslab vapor samples. Temporary, small-volume vapor sample subslab probes are installed in a similar manner as permanent probes. The probe consists of 1/4- to 3/8-inch (outside diameter) inert tubing (see Subsection 7.8.2) with a stainless steel or porous stone probe tip or “implant.” Probe implants should be placed within the first 6 to 12 inches of soil (see Subsection 7.6.2.2). If the probe is to be left in place, the surface termination should be a stainless steel or brass Swagelok compression fitting with a threaded plug to seal the probe. For temporary installations, the probe can be completed with 6 to 12 inches of tubing above the surface with a 2-way valve to seal it. Deeper vapor points can also be set beneath buildings slabs to investigate source-area vapor concentrations (see Section 7.6.2.3). Reviewing as-built plans and screening proposed vapor points using GPR or similar methods to check for rebar and other potential obstacles to drilling is recommended.

As discussed in Section 7.6.2.2, a targeted placement of subslab probes should include: 1) locations of known or suspected, localized subslab sources of contamination; 2) in the absence of the former, the center of the building slab, where concentrations of VOCs from deeper are anticipated to be the highest; 3) between the center of the building and outer, adjacent sources contamination; and 4) in the vicinity of cracks and gaps in the building slab where vapor intrusion is considered to be most likely (see also USEPA 2012d, CalEPA 2011). Examples of the latter include areas where utilities penetrate the building slab, or areas where cracks in the floor could serve as preferential vapor pathways.

Traditional subslab probes are installed by drilling a hole of appropriate diameter through the slab at the targeted location and installing a sample collection point directly into the underlying fill material. Using a rotary hammer drill, a 1¼-inch diameter hole is drilled approximately 1½ inches into the slab to make room for the Swagelok fitting. A 3/4-inch diameter hole is then drilled through the remaining slab thickness and 6 to 12 inches into the underlying sub-slab base material (typically engineered fill).

The inside of the hole should be cleaned out and wiped with a damp towel to remove the drilling dust and ensure an airtight seal. The probe assembly is then inserted into the hole so that the probe tip is just below the slab. The tubing should be cut to the appropriate length so that probe tip is just below the slab and the Swagelok termination is slightly recessed or flush with the slab surface. Clean sand is then poured into the hole until the probe tip is covered to form a filter pack. Granular bentonite is poured to the top of the 3/4-inch hole and hydrated. Care should be taken not to allow water to leak into the filter pack sand.

The Swagelok fitting is then sealed in place with a small amount of quick-drying cement (see Figure 7-27). Either plastic or stainless steel ferrules can be used for Swagelok fittings (plastic shown in photo; steel ferrules include an additional ring washer). To avoid cementing the probe closed, the cement should be poured no higher than flush with the top of the compression fitting. Cement should not be allowed to flow around the threaded plug. Figure 7-28 & Figure 7-29 depict completions for subslab vapor points.

Alternative approaches that can reduce the time, effort and cost of collecting subslab soil vapor samples are being developed. One example includes the “Vapor PinTM,” which is installed directly into the floor slab and does not require the installation of a separate, gas permeable probe tip and tubing into the underlying fill material (Figure 7-30; flush-mount shown). A core is removed from the slab in a similar manner as described above. The side of the boring should be brushed to remove loose material prior to installing a pin in order to obtain a strong seal. A shop vac or similar method should not be used to clean the hole due to the potential to disturb subsurface conditions. If done, then a minimum of 24 hours is recommended to reestablish equilibrium conditions.

The hollow, brass or stainless steel pin is then hammered into the boring (see Figure 7-30). A silicone sleeve around the pin provides a seal against the sides of the hole to prevent leakage of ambient air, eliminating the need for grout. The sampling train tubing is connected to the top of the pin and the sample is drawn directly through the base of the pin. Guidance for installation of the pins and leak tests should be followed if used at sites in Hawai‘i (Cox-Colvin 2013, b). Similar devices are likely to be developed in the future and can be proposed for use on a site-specific basis. These types of pins have a good record for installation in concrete slabs but difficulty in obtaining an adequate seal has been reported for asphalt. If a slab crumbles during drilling, then silicon putty or similar, non-volatile material may be useful to help seal the annular space around a point.

A small amount of water can be added to holes drilled in slabs ("wet drilling") if high levels of methane or other potentially explosive gases could be present beneath a slab or other capped area. This can help prevent sparks when the drill bit breaks through the bottom plane of the slab. If used, then an equilibrium time of at least two hours following installation of the vapor point (including vapor pins) is recommended.

7.9.4 SOIL VAPOR PROBE TUBING

Inert, rigid-walled tubing, such as Teflon, nylon (e.g. Nylaflow), or stainless steel should be used as the primary tubing for soil vapor sampling probes (Ouellette 2004, SDC 2011, USEPA 2009). Tests using these materials show minimal (<10%) loss of VOCs during sample collection. Tubing within an outside diameter (OD) of 1/4-inch and 3/16-inch (0.1875) inside diameter (ID) and/or 3/8-inch OD and 1/4-inch (0.25) ID is most commonly used (see Figures 7-25 and 7-26).

Polyethylene and other flexible tubing (e.g., Tygon) as well as and copper tubing adsorb VOCs and should be avoided. Losses up to 80% of VOCS due to absorption has been documented with some types of flexible tubing. A few inches of flexible tubing that can be pinched closed may be needed in addition to the rigid-wall tubing (see Figure 7-23), however, or to connect rigid-wall tubing to sampling equipment (e.g., to syringes; see Figure 7-26). The use of larger diameter tubing to connect smaller rigid tubing introduces a potential for leakage during sampling (see Section 7.10.5),so swageloks should be used instead for connections where possible (e.g., see Figure 7-27). Sampling trains should be tested using a shut-in test prior to collection of samples regardless of the types of connections used.

Storage and handling of tubing is critical. Tubing should be stored in a sealed container to prevent contamination from ambient air or other sources. Avoid leaving tubing near open sources of vapors (e.g., fuel cans, cleaners, etc.) or near auto exhaust..

7.9.5 SOIL VAPOR PROBE ABANDONMENT

When soil vapor probes are no longer needed they should be properly abandoned. Abandonment procedures for temporary probes are the same as for any direct-push borehole (e.g., backfill with hydrated bentonite).

Well vaults should be over-drilled and removed. Several inches of the bentonite seal should be removed and the probe tubing cut as far down as practical. A thin layer (~one-inch) of bentonite should be placed back over the tubing and hydrated to seal it. The well-vault holes should then be filled with concrete and finished flush with the surrounding surface. The concrete used should be of suitable grade for the location. A layer of several inches of sand between the bentonite and the concrete will help prevent heaving of the concrete plug due to wetting/drying cycles of the bentonite. Probes installed in unpaved areas should be abandoned similarly except that clean surrounding soils should be used to fill the holes to grade.

Sub-slab probes should be drilled out, the inside of the hole cleaned with a damp cloth, and the hole filled flush with the slab with lime-based cement, or an epoxy cement or putty otherwise formulated for concrete repair. It is important to carefully clean the hole prior to pouring the cement to ensure a good seal so that the former probe hole does not become a conduit for VOCs to enter the building.

7.10 ACTIVE SOIL VAPOR SAMPLING PROCEDURES

Table 7-6 Sand Pack Porosity Volume (ml)

Filter Pack Length (inches)	Borehole Diameter (inches)					
	1.25	1.5	2.0	2.5	3.0	3.5
6	36	52	93	145	208	284
12	72	104	185	290	417	568
18	109	156	278	434	625	851
24	145	208	371	579	834	1,135

Note: Assumes sand pack porosity of 30%.

Table 7-7 Tubing Volume (ml)

Tubing Length (feet)	Tubing Inner Diameter (inches)			
	1/16 (0.085)	1/8 (0.125)	3/16 (0.1875)	1/4 (0.25)
1	1	2	5	10
2	2	5	11	19
3	3	7	16	29
4	4	10	22	39
5	6	12	27	48
10	11	24	54	97
15	17	36	81	145
20	22	48	109	193
25	28	60	136	241



Figure 7-31: Soil Vapor Probe Purging Devices Upper photo: Disposable syringe with 3-way Luer valve (see also Figure 7-26). Middle photo: Pump with flow meter. Lower photo: Large Summa used for purging. Smaller Summa to left used to collect sample after purging; purge Summa closed during sample collection

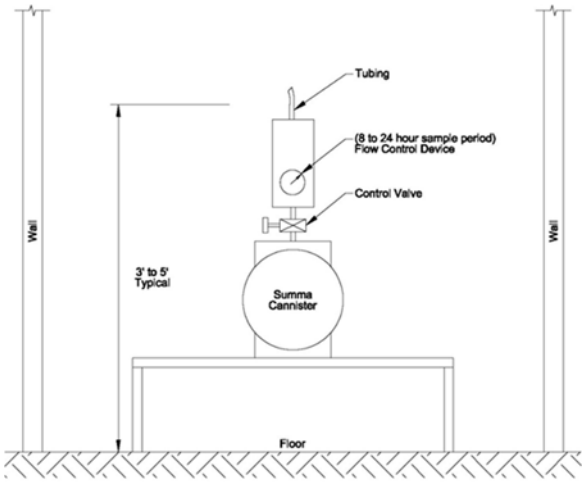
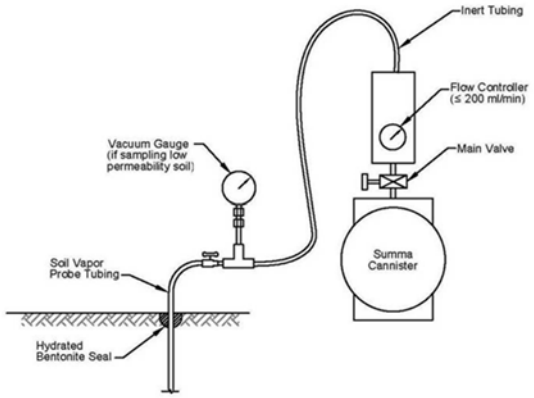
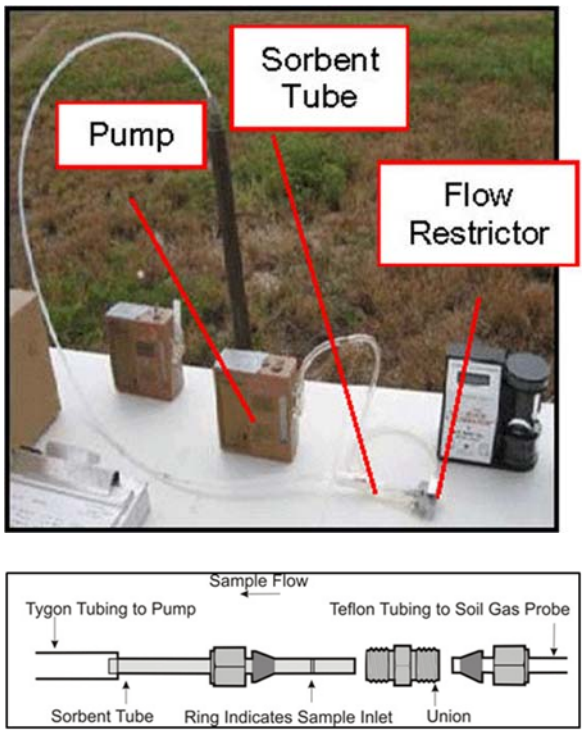


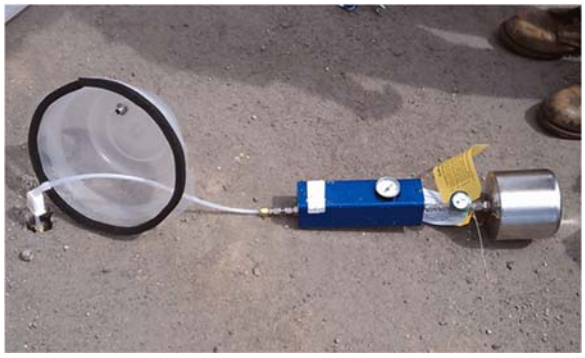
Figure 7-32: Example Vacuum Gauges for Purging and Sample Collection using a Summa Canister Sampling Train (see also Figure 7-34 and Figure 7-35).



Figure 7-33: Lung Boxes with Tedlar bag. Vacuum is drawn on sealed lung box, causing the Tedlar bag to pull vapor from the collection point and fill







. **Figure 7-34: Summa canister sampling trains.** Upper schematic: Diagram of Summa canister soil vapor sampling apparatus. Lower photo: Teflon tubing connected to flow controller with swage lock and to well point with short length of flexible tubing (allowed well point to be closed for followup sorbent tube sample). Note Tupperware shroud used for leak test.

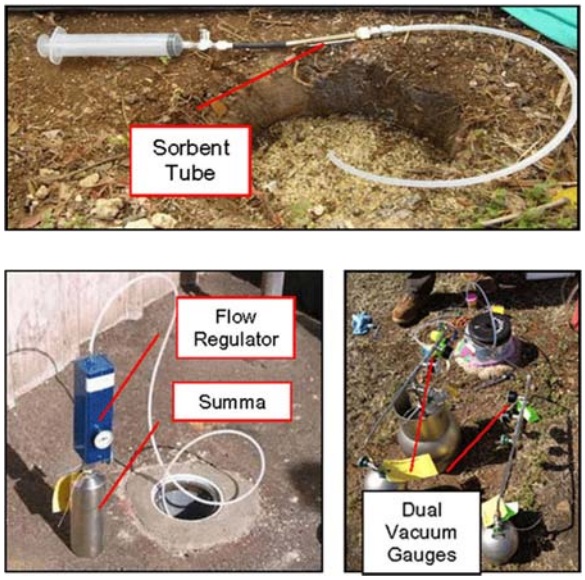


Figure 7-35: Example Soil Vapor Sample Collection Setups Upper photo: Battery powered sampling pump draws soil vapor through the Teflon tubing from the temporary soil vapor probe tip to the sample sorbent tube. A restrictor device reduces the pump flow to the required rate (usually set at laboratory). Note the black and silver air pump calibrator near the restrictor; before sampling, the flow rate is calibrated and recorded for each type of sorbent tube media. Middle schematic and photo: TO-17 sorbent tube soil vapor sampling apparatus. Vapor point tubing connected to sorbent tube inlet with a union and swage lock; pump or syringe connected to outlet of sorbent tube and used to draw sample (latter shown in photo). Lower left photo: Summa canister used to collect soil vapor from a permanent soil vapor point. The blue-bodied flow controller is laboratory-calibrated to restrict sample inflow to a predetermined flow rate. A gauge on the controller's side indicates vacuum remaining in the canister. Lower right photo: Manifold setup to allow collection of duplicate samples (see also Figure 7-36). Small Summas used to collect samples; large Summa used to purge vapor point. Dual vacuum gauges in each setup used to monitor Summa vacuum and vacuum at well point (flow regulator installed between gauges). Shut-in leak test critical to ensure that sampling train is tight.

Table 7-8 Comparison of Tracer Leak Check Methods

Method	Advantages	Disadvantages
Tracer Method 1	• Smaller shroud requires less tracer gas; • Easier and faster to collect samples.	• Integrity of sampling train not confirmed by laboratory analysis.

Tracer Method 2	• Single process to check entire apparatus; • Integrity of sampling train confirmed by laboratory analysis for tracer gas.	• Unnecessarily replicates shut-in test; • Larger shroud requires more tracer gas; • Costlier and more time consuming to implement in the field; • Source of leak at sampling train vs vapor point or annular seal cannot be determined (although successful shut-in test would imply the latter).

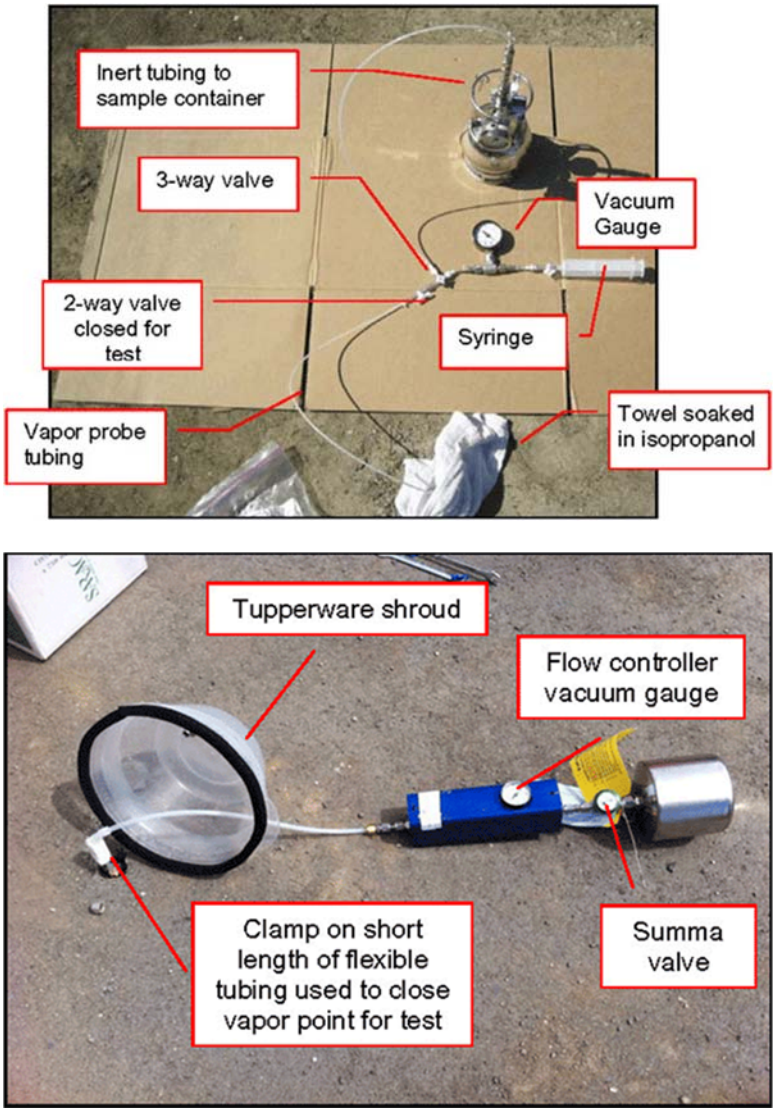


Figure 7-36: Soil Vapor Sampling Trains Arranged for Shut-in Test (see also Figure 7-35)

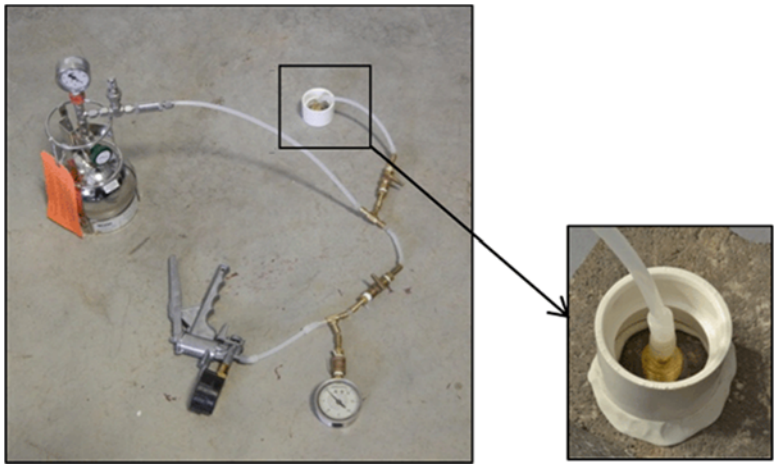
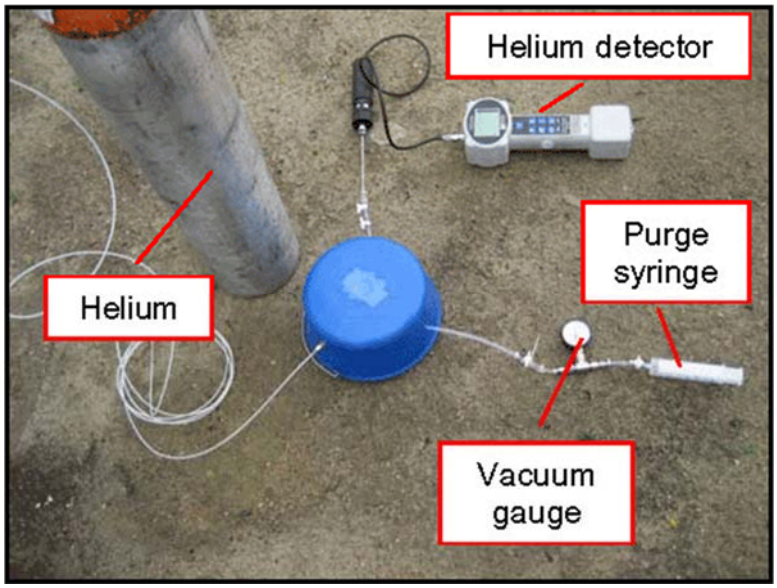


Figure 7-37: Example PVC Coupling "Water Dam" Sealed to Floor with Inert Putty for Leak Testing Slab-mounted Vapor Point. After Cox-Colvin 2013, b. The water level is filled to a level above the tubing connection to the vapor point and monitored during a vacuum test prior to and during sample collection.



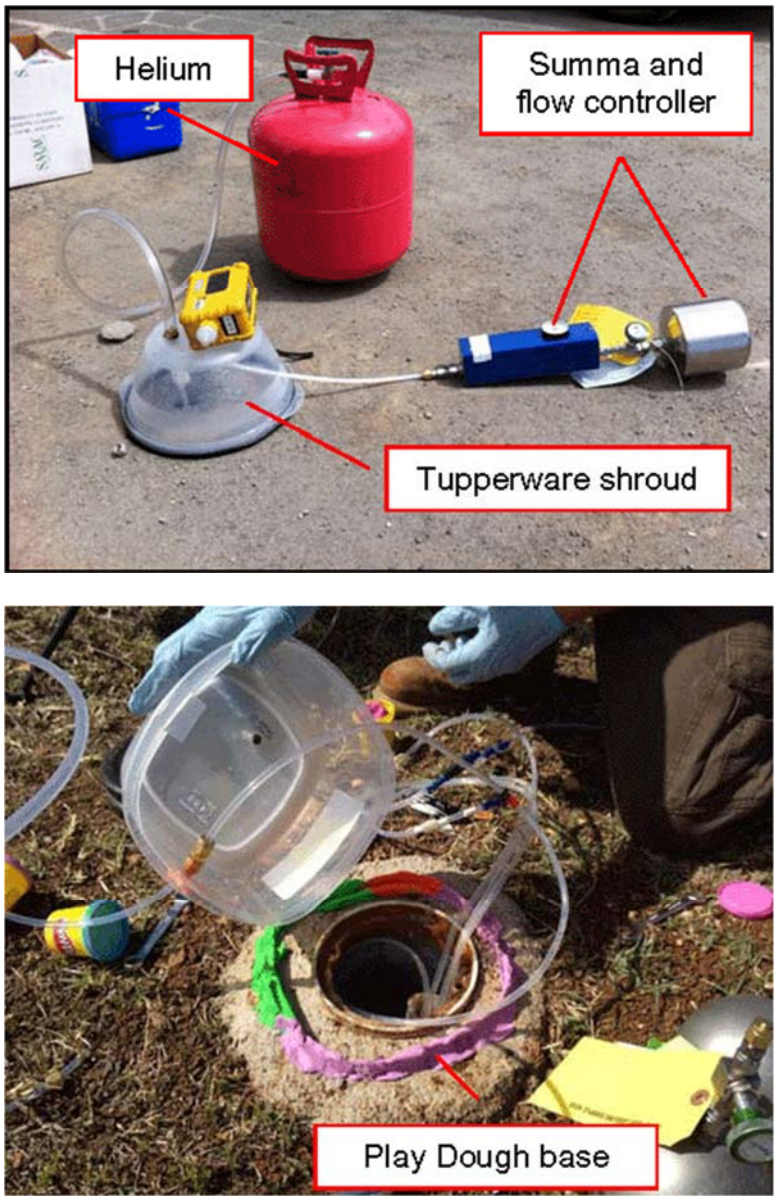


Figure 7-38: Shroud Over Vapor Probe Surface Completion. Upper Photo: System consists of shroud (blue bucket), industrial-grade helium cylinder, field helium detector to measure helium within shroud, and syringe with vacuum gauge for purging. Purged sample tested in field for helium. Sampling train not shown in example. Middle Photo: System consists of Summa and flow controller sampling train, Tupperware shroud (bottom lined with foam door seal), non industrial-grade helium cylinder. Option for use of field helium detector with shroud and field testing of purged sample for helium (not shown in example). Bottom System: Similar to above but Tupperware shroud set into a ring of Play-Doh on concrete base to provide a tighter seal around vapor point. Large Summa used to purge well point; smaller Summa used to collect sample (see also Figure 7-31).



Figure 7-39: Method 2 Helium Shroud Leak Testing Systems
Helium released into shroud and used as tracer to identify leaks in both sampling train and vapor probe annular seal. Upper left photo: Five-gallon bucket helium shroud placed over well point and Summa canister-flow controller sampling train (note two ports for injection and monitoring of helium inside shroud). Upper right photo: Use of garbage bag as shroud (helium injected under shroud to fill bag). Lower photos: Large Tupperware container converted to shroud, with fill ports for helium injection and monitoring, plus glove ports to open and close Summa canister for sample collection.

Table 7-9 Comparison of Leak Check Tracers

Compound	Advantages	Disadvantages
Isopropanol	• Inexpensive and readily available • Detected using method TO-14/15 and SW8260 • Can be used without a shroud • Denser than air	• Cannot be selectively measured in the field • High concentrations can interfere with laboratory analysis • Potential use in gasoline
Helium	• Can be selectively measured in the field	• More expensive • Requires valves and fittings for cylinder • Sample must be analyzed using a separate method

	• Will not interfere with TO-14/15 and SW8260 analysis	• Lighter than air
Difluoroethane	• Inexpensive and readily available • Detected using method TO-14/15 and SW8260	• Cannot be selectively measured in the field

The descriptions of active soil vapor sampling procedures in the following sections are general in nature and reflect commonly accepted designs and methods recommended by the USEPA (USEPA 1996c), industry standards (ASTM 2006f) and various other entities (e.g., MDNR 2005, SDC 20111, CalEPA 2012). Alternative designs may be more appropriate depending on sampling objectives

7.10.1 SOIL VAPOR SAMPLE TIMING AND FREQUENCY

Like sample location and depth, the timing and frequency of sample collection will necessarily be a site-specific decision and should be discussed with the overseeing HDOH project manager. General guidance is, however, presented below.

As discussed in Sections 7.2 and 7.5, the objective of the investigation is to develop a CSM that reflects the representative, *average* subsurface vapor concentrations and vapor intrusion conditions over time and during normal building operation over a period of many years (e.g., assumed exposure durations). Samples collected as part of an investigation should likewise be representative of assumed, long-term, average site conditions.

The collection of soil vapor samples from both the fill material immediately under the building slab *and* the suspected or known source area is recommended at sites where the distance to the source area is greater than 5 feet (but no closer than 2-3 ft to the water table) and a potentially significant source is present (see Section 7.6.2.3). This will help assess the need to seal cracks and utility gaps in the building floor as an added measure of precaution, in the event that nearby portions of the vapor plume exceed subslab, soil gas action levels even though VOCs meet action levels in subslab samples (see Section 7.14.1).

As discussed in Section 13.2 of the EHE overview, site-specific considerations regarding the timing and frequency of soil vapor sample collection include building HVAC system operation, seasonal weather variations and associated water table fluctuations and tidal effects on groundwater elevation. Multiple sampling events are recommended if the conceptual model identifies the VOC concentrations in source area vapors well above shallow soil gas action levels and the potential for significant, temporal fluctuations in soil vapor concentrations and or the potential for advective flow of vapors into overlying buildings. Recommendations include:

- Collection and comparison of subslab soil vapor samples (or crawl space samples) during periods of the year when air conditioning is and is not routinely used (e.g., summer versus winter months);
- Collection of deep and subslab soil vapor samples (or crawl space samples) during both the wet and dry season for sites where a significant smear zone is known or suspected to be present at the water table and exposure of contaminated soil in the smear zone could vary dramatically over the year.

The collection of seasonal soil vapor samples should be considered at sites where a substantial smear zone that could be exposed during falling water tables is known or suspected to be present. The collection of subslab soil vapor samples during periods of both falling and rising water table may be necessary on a site-specific basis to evaluate the effects of tidal pumping on subslab soil vapor concentrations at high-risk, coastal sites with significant free product on shallow groundwater.

At sites near the coast, the tides can affect groundwater levels, soil vapor samples should be collected at the same point in the tidal cycle in order to obtain data that are comparable from point-to-point and from sampling event to sampling event. The collection of subslab samples during both rising and falling tides (or more specifically water tables) may also be necessarily, especially if significant concentrations of vapor-phase contaminants have been identified in deeper, soil vapor samples.

A single round of soil vapor sample collection will generally be acceptable for sites that meet the following conditions (see HDOH, 2007c): 1) Minimal volume of contaminated, vadose-zone soil is suspected to be present within 30 feet of the building slab (e.g., 10m^3, not including capillary fringe zone soils), 2) Less than 30m^2 area of floating product on water table present, 3) Larger area of floating product present but greater than 30-foot vertical separation distance, and/or 4) Water table fluctuations unlikely to expose a smear zone greater than three feet thick within 30 feet of the building slab. A minimum of one round of samples should be collected at chlorinated solvent sites where groundwater action levels are approached or exceeded or a significant source is present in the vadose zone.

At least two rounds of soil vapor sampling, one during the “dry” season and one during the “wet” season, are recommended prior to negation of potential vapor intrusion hazards for sites that meet the following conditions: 1) Sites with widespread, heavy contamination in vadose-zone soil and/or floating on groundwater within 30 vertical feet or 100 lateral feet of a building slab that do not meet the above-noted conditions or 2) Confirmation of remedial actions at sites where potential vapor intrusion hazards have been documented in the past (e.g., concentrations of VOCs in subslab soil vapor greater than action levels and/or impacts to indoor air above action levels or expected background identified and tied to vapor intrusion).

If more than one round of soil vapor samples are collected, the field procedures (e.g., purge volume), sample containers, and analytical methods should be consistent from one sampling event to the next to allow comparison of the site data over time. The CSM model should be refined to reflect the data collected over multiple sampling events and used to determine the need for additional actions.

Short-term (minutes or days), temporal variation of concentrations in soil vapors due to changes in temperature, barometric pressure, and wind speed due to passing storms are likely to be nominal for uncovered areas at depths of 2 feet bgs or more (USEPA 2007e). Infiltration from rainfall can potentially impact soil vapor concentrations by displacing soil vapor, dissolving volatile organic compounds, and by creating a “cap” above the soil vapor. In practice, infiltration from brief, large storms only penetrates into the soil on the order of inches. Soil vapor samples collected at depths greater than 3 feet bgs are therefore unlikely to be significantly affected. Soil vapor samples collected closer to the surface (less than 3 feet) without surface cover may be affected.

If the wetting front has penetrated to the sampling zone, it typically can be recognized by high vacuums during purging. If high vacuums are encountered when collecting a sample or drops of moisture are evident in the sampling train or sample, a soil vapor sample should not be collected (e.g., vacuum greater than seven inches Hg or 100 inches of water; see Section 7.10.3.2). In addition to potential short circuiting to the surface, imposition of a high vacuum on the soil could cause non vapor-phase VOCs to be stripped in free product, sorbed to soil or dissolved in soil moisture and bias the resulting vapor sample. Measurement of soil moisture can also be useful if shallow sampling is performed during or shortly after significant rainfall (e.g., greater than 1 inch; SDC 2011

7.10.2 SOIL VAPOR PROBE EQUILIBRATION

Subsurface soil vapor conditions are disturbed during installation of soil vapor sampling probes. In general, temporary probes advanced with manual or direct push methods result in the least disturbance to soil vapor conditions and can be purged and sampled relatively soon after installation. Permanent probes result in greater subsurface disturbance and require a longer equilibration time.

Recent studies conducted by the USEPA have evaluated equilibration times for a variety of probe types (USEPA 2010c, USEPA 2010d). Data from these studies indicate that temporary probes (see Section 7.9.1) achieve approximately 80% equilibration within two hours of installation, while permanent probes installed in direct-push boreholes typically require eight to twenty-four hours to fully equilibrate. Probes installed in boreholes advanced with auger methods are expected to require up to 48 hours to equilibrate.

The time between probe installation and sampling will depend on the investigation objectives and the data quality requirements. For example, if a soil vapor survey is conducted using temporary points to map the extent of a vapor plume, and the sample data are not intended for use in risk assessment or site closure decisions, then sampling 30 minutes after installation would be acceptable. To obtain quality data for decision making, permanent soil vapor probes should be allowed to equilibrate for at least 24 (direct push) to 48 (augers) hours before sampling

As a default, the following equilibration times are recommended before proceeding with soil gas sampling (refer also to CalEPA 2012):

1. For soil gas wells installed with the direct push method, do not conduct the purge volume test, leak test and soil gas sampling for at least two hours following completion of vapor probe installation;
2. For soil gas wells installed with hollow stem or hand auger drilling methods, do not conduct the purge volume test, leak test and soil gas sampling for at least 48 hours following completion of vapor probe installation.
3. For subslab soil gas probes installed in soil beneath the slab, do not conduct the purge volume test, leak test and soil gas sampling for at least two hours following completion of vapor probe installation
4. For vapor collection pins installed directly into the slab, do not conduct the purge volume test, leak test and soil gas sampling for at least twenty minutes following completion of vapor probe installation (e.g., see Cox-Colvin 2013);

Cap the vapor pins immediately after they are installed in order to minimize the potential for cross slab air movement, including the potential migration of indoor air into the subslab area (e.g., air conditioned buildings under positive pressure).

7.10.3 SOIL VAPOR PROBE PURGING

Vapor probes should be purged of stagnant or ambient air in tubing and other equipment and filled with soil vapor prior to collection of a sample. The volume of air space in sand packs installed with the vapor point should be included in purging if less than 24 hours has lapsed since installation of the probes. The amount of time between purging and sample collection should be minimized.

The system volume is approximated as the sum of the volume of the open borehole interval (for temporary probes) or the sand pack porosity (for permanent probes) and the volume of tubing from the probe tip to the sample collection device.

Tables 7-6 and 7-7 show the sand pack volume (does not include tubing) and tubing volumes, respectively, for common borehole and tubing sizes.

Opinions vary on the optimum volume of vapor to be purged from a vapor point prior to the collection of a sample. Several published studies for relatively coarse soils indicated only minimal differences in VOC concentrations with different purge volumes (refer to SDC 2011). For the purposes of this guidance, it is recommended that temporary probes be purged of one to three system-volumes immediately prior to sampling. Permanent probes should be purged of three system-volumes after installation and then allowed to equilibrate.

Following equilibration, it is only necessary to purge three tubing-volumes prior to sample collection, as the sand pack is assumed to be in equilibrium with the surrounding native soils. The volume purged between different vapor points set at similar depths at a site should be approximately the same.

For in-slab, pin-type vapor points (e.g., Vapor PinsTM), minimal purging is required due to the small volume of air associated with the pin and tubing. Purging and monitoring prior to collection of a sample can be carried out until VOC and other target parameters (e.g., O2) appear to stabilize (e.g., using a PID). A minimum 30 second purge at a rate of 200ml/minute is recommended as a default.

Attempting to purge tight soils using a PID or similar instrument can induce an undesirably high vacuum on the soil, lead to inaccurate readings and even damage the instrument. Under these circumstances, an alternative is to collect an adequate volume of gas in a separate container to allow for field testing (e.g., use of a lung box and Tedlar bag; see Section 7.10.3.2). For example, a five-minute purge at 200mL/min can be used to fill a one-liter, Tedlar bag, which can then be tested using a multi-gas instrument as well as a landfill gas analyzer and/or helium detector, as needed. This approach also avoids the need to attach an instrument directly to the sample train tubing.

Probe purging can be accomplished using a syringe equipped with a three-way valve or a pump (Figure 7-31, see also Figures 7-24 and 7-26). Large Summa canisters can also be used for purging well points (ASTM 2006f; see Figure 7-31). Syringes are an inexpensive and simple approach for purging small volumes up to one liter. For larger purge volumes, a pump with variable flow rates and a flow meter should be used. The pump flow rate should not exceed 200 ml/minute unless it can be demonstrated that the vacuum imposed on the subsurface soil does not exceed seven inches of mercury. A PID can also be used to purge a well point provided that it does not cause an excess vacuum on the soil. Typical flow rates for PIDs range from 100 to 300 ml/minute.

Over purging a well point can have several drawbacks (SDC 2011). The larger the quantity of soil vapor drawn, the greater the uncertainty in the location of the collected sample. Large purge volumes also create a risk of short circuiting to atmospheric air along the outside of the probe body. Large purge volumes can also create vacuum conditions in the soil that could cause contaminant partitioning from soil or free product into the gas phase or cause a large volume of ambient air to be drawn into the formation after the purging equipment is removed.

7.10.3.1 FLOW RATE

A flow rate of 200 milliliters per minute or less is recommended during purging and sampling (SDC 2011, CalEPA 2012). This is intended to keep the vacuum imposed on the soil to below seven inches Hg (100 inches of water) and avoid migration of otherwise sorbed VOCs into the air-filled pore space (see following section). Lower permeability soils may require lower flow rates in order to control the vacuum. A maximum flow rate of 200 ml/minute also helps to minimize the chance of breakthrough during the collection of sorbent-tube samples. Short circuiting to the atmosphere is of less concern for deep wells (e.g., >15ft bgs). A vacuum of seven inches Hg or less should be maintained during sampling, however, in order to minimize volatilization of sorbed VOCs (see below). Packers or other methods may also be required to isolate targeted depth zones.

Summa canisters should be used with flow controller devices supplied by the laboratory and calibrated to an appropriate flow rate. Flow rates are typically set for the flow controller by the laboratory and cannot be adjusted in the field. For example, a flow rate of 200 ml/minute equates to a five minute draw time for a one-liter canister. When purging a well point or collecting a vapor sample with a syringe, the flow rate is maintained by drawing the plunger back at a steady rate. When purging or collecting with a pump, a flow meter should be used to control and measure the flow rate. The flow rate should be read and recorded periodically (e.g., every five minutes or less).

7.10.3.2 VACUUM CONDITIONS AND TIGHT SOILS

The purging and sample collection vacuum should be less than seven inches Hg (100 inches of water; SDC 2011, CalEPA 2012). Increasing the vacuum on the sampling system (e.g., resulting from low permeability soils, high purge or sample flow rates, or high soil moisture) can result in a biased sample. Imposition of a high vacuum on the soil could cause non vapor-phase VOCs in free product, sorbed to soil or dissolved in soil moisture to be stripped and bias the resulting vapor sample. As flow rates and vacuum levels increase, the risk of leakage in the sampling probes increases. High vacuums for sample points within a few feet of the water table can also cause water to be pulled into the sample container. This not only causes potential problems for the laboratory, but also compromises the integrity of the sample data since vapor-phase compounds could partition into the water during storage and shipment of the sample. If water is drawn into a sample container then the sample should be recollected (preferred) or the resulting sample data should be flagged and qualified in the site investigation report.

The vacuum should be measured and documented during purging and sample collection using a vacuum gauge placed between the probe and sample container (Figure 7-32). Note that the gauge on the flow controller for the Summa canister measures the vacuum in the canister, not the vacuum applied to the soil vapor probe.

A qualitative method to quickly determine if the permeability of the soil could lead to an excessive vacuum is to hook up a 20cc to 50cc gas-tight, plastic syringe to the probe and pull on the plunger (SDC 2011). If the plunger is difficult to pull (compare to pulling outside air) or if the plunger is pulled back towards the probe after released, then there is likely too little permeability to get an uncompromised sample. When sampling in relatively permeable soils (e.g., sands, or silty sands) using a syringe, a vacuum gauge is not typically needed as the sampler can feel the vacuum while drawing gas into the syringe.

If the purging or sampling vacuum exceeds seven inches Hg during sample collection, the sample collection flow rate should be reduced. This might be able to be accomplished by progressively closing the valve to the Summa canister. If this doesn't work, then an alternative flow controller with a lower flow rate (e.g., <100ml/minute) might be necessary. The potential need for a low-flow controller should be assessed prior to the collection of samples based on the geology of the site and prior sampling experience, if available.

If a continued reduction in the flow rate does not reduce the sampling vacuum, then an alternative vapor point would be installed with a large sand pack emplaced in the zone of interest (SDC 2011). The sand pack should have an interstitial void volume of approximately three liters, which implies the use of approximately ten liters of sand for the pack. A vapor point is installed in the pack and completed at the surface. The top of the sand pack should be at least five feet below surface grade. The pack should be capped with bentonite to prevent break though to ambient air.

A vapor sample should only be collected after the sand pack has reached equilibrium with the surrounding, native soil. This can be expected to take approximately two weeks (SDC 2011). Only one purge volume equating to one tubing volume should be removed. Tubing size should be selected so that the purge volume does not exceed 200 milliliters. Purging 200 milliliters is unlikely to induce a significant vacuum in the probe given the substantially larger void volume in the sand pack. Sample size should be limited to one liter. The vacuum within the vapor probe should be measured during sampling to ensure that seven inches Hg is not exceeded during the purging and sample collection

7.10.4 SOIL VAPOR SAMPLING TRAINS

A variety of sampling systems can be used to collect representative soil vapor samples. Individual laboratories typically provide guidance on recommended designs of sampling trains (e.g., Air Toxics 2012, Air Toxics 2012b). The system should be selected based on the type of sample container, the sampling probe, and the overall sampling objectives. The primary requirements are that the system forms a gas-tight sample train from the probe to the sample container, with a means of controlling the sample flow rate and gauging the vacuum in the system.

Tedlar bags can also be filled using a lung box. A lung box is an air-tight container with ports for the soil vapor probe tubing and separate tubing to a pump. The Tedlar bag is connected to the vapor probe tubing and then placed inside the lung box. A pump is used to evacuate the lung box, which causes the Tedlar bag to expand, drawing in soil vapor (Figure 7-33).

A schematic diagram and photograph of a soil vapor sampling apparatus for collecting samples in Summa canisters is depicted in Figure 7-34 and includes the following major elements: the vapor probe tubing, a vacuum gauge, sample tubing (inert tubing such as Teflon, nylon, or stainless-steel), a flow controller, Summa canister, and gas-tight fittings.

The valves and gas-tight fittings must be closed at all times to prevent ambient air from entering the system except when actively purging or collecting a sample. This is especially critical if the sample collection vacuum is elevated (see Subsection 7.10.3.2).

Figure 7-35 shows several typical sampling apparatus in which soil vapor samples are being collected with a sorbent tube and Summa canisters.

In the bottom, right-hand photo of Figure 27, the dual vacuum gauges are used to read the vacuum in the Summa (gauge nearest Summa) and the vacuum imposed on the soil as the sample is being collected (gauge closest to well point). A small, pre-calibrated flow regulator is present between the gauges. The vacuum imposed on the soil will be near zero in highly permeable soils but could exceed 10 inches of mercury in tight, clayey soils. Both of these gauges should remain stable during the initial shut-in test of the sampling train (see Subsection 7.10.5.1).

7.10.5 SOIL VAPOR PROBE LEAK TESTING

Leak tests are an important part of quality assurance and are strongly recommended for each vapor sample. The nature of leaks tests carried out as part of a site investigation should be clearly presented and discussed in the resulting report. Leaks in sampling train fittings or leaks at the vapor point annulus can result in dilution of the soil vapor samples with ambient air and under reporting of actual contaminant concentrations. Most leaks occur in the sampling train, rather than in the annulus around the vapor probe surface seal. Excessive vacuum conditions resulting from low porosity soils or high moisture content soils can exacerbate the potential for ambient air leakage. The use of Teflon tape in Swagelok fittings can also cause leaks and should be avoided.

Three types of leak tests are described: 1) A “shut-in” test to determine the tightness of the sampling train in the field, 2) A “water dam” test for field testing of the integrity of the vapor point when installed into a slab or other relatively impermeable surface and 3) A tracer test to determine the presence or absence of gas introduced around the vapor point and/or the sampling train in the sample that is collected. Performance of a shut-in test of the sampling train is recommended prior to the collection of all soil vapor samples. As described below, this allows the tightness of the sampling train to be quickly evaluated in the field. A water dam test, as described below, or equivalent test is recommended for vapor points installed in intact slabs prior to sample collection. This allows the tightness of the annular space around the vapor point to be quickly tested in the field.

Tracer tests are recommended to test the tightness of vapor points installed in soil, cracked slabs, pavement or other cases where a bentonite seal is used to prevent the infiltration of ambient air during sample collection. Tracer gas leak tests are also recommended for high-risk or high public profile sites where where lab data are desired to confirm sampling chain and vapor point tightness. As described below, two tracer gas methods are recommended: (1) Application of a leak check compound to the vapor probe surface seal or (2) Application a tracer gas to the entire sampling apparatus. Table 7-8 provides a comparison of the two leak check methods using a tracer gas.

Use of one of the two tracer methods described above is recommended for vapor points with connections that cannot be included in a shut-in test and for all samples collected from a depth of 5 feet or shallower, due to the increased risk of a leak in the annular seal. This will help to verify that short circuiting is not occurring at surface connection points and/or that there is an adequate annular seal for shallow samples. As discussed below, field measurement for the presence or absence of the tracer in the initial sample drawn from the well point can be used to help verify the integrity of the vapor point prior to submittal of samples to a laboratory (e.g., collection of an initial sample in a Tedlar bag and testing for helium using a hand-held field meter).

A simple shut-in test will be adequate for the routine collection of soil vapor samples when the depth of the probe is greater than 10 feet and all connections in the sampling train can be included in the test. Testing the tightness of the vapor point connection with the ground surface is less critical in these cases given the depth to the sampling point, although a seal should still be placed around the point. A combination of a field shut-in test with a water dam (for intact slabs) and/or the Method 1 tracer test described above will be adequate for the majority of remaining samples. The use of a full shroud over both the sampling train and vapor point could, however, be recommended or even required for sites with a high public profile, sites involved in legal actions, or sites where the integrity of previously collected samples is in question.

Note that simple release of tracer gas around sampling train connections and the vapor probe seal at the ground surface in the absence of a shroud is not recommended, since the concentration of tracer gas around the test points can be difficult to maintain and lengthy release times may be required to draw an adequate amount of tracer gas into the sample container and identify a significant leak.

Be aware that consultants have reported false positives for some types of helium field detectors due to very high concentrations of C5-C12 hydrocarbons in vapors in soil gas. This can be assessed prior to purging and sample collection by connecting the helium detector directly to the vapor point and evaluating the response. Ultra high-purity helium (e.g., Grade 5) is recommended for leak tests due to potential petroleum and other contaminants in cheaper, “party-grade” helium

High levels of light-end, petroleum vapors have also been reported to cause false, elevated readings of methane in vapor samples using a standard, landfill gas analyzer. The use of a carbon trap is recommended when evaluating methane using field instruments at sites where high levels of petroleum may be present in soil gas (see also Subsection 9.4). A carbon trap will retain VOCs, but not methane, and can allow for a more refined estimation of the level of methane present. If a carbon trap is reused, it is recommended to always have gas flow through a carbon trap in the same direction.

7.10.5.1 SAMPLING TRAIN SHUT-IN TEST

A sampling train shut-in test is recommended prior to the collection of all soil vapor samples. The shut-in test is performed by isolating the sampling train from the vapor sampling point and applying a vacuum to the sampling train. The applied vacuum should hold steady (not decrease) for at least 60 seconds. The start and end vacuum should be recorded and reported.

Figure 7-36 depicts example sampling trains arranged for a shut-in test. The system consists of a gas tight 2-way valve at the vapor probe termination, a 3-way valve to connect the vapor probe to the sample container, and a vacuum gauge and syringe with shut-off valve. The 2-way valve is closed and the sample container valve is closed to seal the sampling train. A vacuum is then applied by drawing back the syringe plunger. The vacuum in the sampling train is then monitored for one to five minutes, with a longer time used for more complex trains that have multiple connections or that otherwise might be especially susceptible to leaks. The sampling train can be considered to be adequate "tight" if the apparent loss in vacuum is less than 0.5 in mercury. The second example in the figure consists of a more simple arrangement, with a clamp and short length of flexible tubing included at the well point and used to seal the sampling train. A vacuum is applied by opening the valve on the Summa canister. The vacuum is monitored using the gauge on the flow controller. If the sampling train does not hold a vacuum, then all connections should be rechecked and the shut-in test repeated.

7.10.5.2 WATER DAM VAPOR POINT TEST

A "water dam" offers a simple and inexpensive method to test for leaks around vapor points installed into a slab or other relatively impermeable surface (e.g., see Cox-Colvin 2013b). For a flush-mount installation, water is poured directly into the depression cut into the floor around the vapor point (see Figure 7-30). For a stick-up installation, a coupling can be sealed to the floor around with non-volatile putty and then filled with water (Figure 7-37).

Pour enough distilled water into the water dam containment or the annular space of a flush-mount depression to immerse the tubing connection to the vapor point. Note that water soluble clays such as Play-Doh might absorb too much water to be suitable for tests that last more than one hour. Assemble the sample train and connect it to the vapor point. Perform a shut-in test to verify that the sample train can hold a vacuum for one to five minutes with no more than 0.5 in Hg loss of vacuum (see previous section). Purge the vapor point and monitor the water level in the dam. The water level might drop slightly due to absorption into the concrete. A sudden drop in water level, the appearance of water in sample tubing or other indication of water entering the sub-slab is most likely indicative of a significant leak, however. If this occurs then remove the distilled water and reposition or reseal the vapor point to address the leak.

7.10.5.3 TRACER METHOD 1 – APPLICATION OF TRACER GAS TO SURFACE COMPLETION POINT ONLY

Under Tracer Method 1, once the shut-in test has been successfully completed, a leak check compound is applied to the surface completion of the probe. In the first example, the leak check compound is applied by wetting a towel with liquid compound (e.g., Isopropanol) and placing it around the probe tubing at the ground surface (see Figure 7-36). Isopropanol is included as a targeted VOC in the lab analysis of the sample. In the second example, a small shroud is placed over the surface completion and the shroud filled with a tracer gas like helium (Figure 7-38). Leaks around the probe seal can be tested in the field by drawing a purge sample with a syringe and testing it for helium, as depicted in the first example. As an alternative or as a second check, helium can be included as a targeted VOC in the lab analysis of the sample (see second example). A concentration of 10-30% helium is typically targeted and maintained in the shroud. Advantages and disadvantages of different tracer compounds are discussed in the following sections.

On uneven surfaces it may be useful to place the shroud in a ring of bentonite clay to obtain a better seal around the base of the shroud and minimize the escape of helium. In the lower photo of Figure 7-38 the consultant used a ring of Play-Doh to seal the base of the shroud. Play-Doh is a non-toxic mixture of flour, water, salt, boric acid and mineral oil. Volatile chemicals associated with the mineral oil are negligible and not expected to interfere with leak detection or samples collected.

7.10.5.4 TRACER METHOD 2 – APPLICATION OF TRACER GAS TO ENTIRE SAMPLING APPARATUS

Figure 7-39 depicts several alternative, shroud configurations for enclosure of the entire sampling apparatus (Method 2), including sample container, all tubing and connections, and the vapor probe surface completion in a shroud, which is filled with tracer gas.

A concentration of 10-30% helium is typically targeted and maintained in the shroud. A hand-held helium detector can be used to monitor helium concentrations within the shroud. Purge tests can be conducted in the field to test for annular seal leaks. In addition, the sample submitted to the laboratory is analyzed for the tracer gas.

Five-gallon buckets modified to include ports for sampling train tubing and helium injection and monitoring are currently the most commonly used for full shrouds. Note that a Summa canister sampling train that includes an older, flow controller may not generally fit under a five-gallon bucket shroud. A smaller, more compact flow controller should be used instead. Garbage bags offer a last, easy-to-find resort, but can be difficult to keep sealed and inflated in the field, especially on a windy day and are not recommended for routine sampling.

An advantage of the full-system shroud is the ability to document the lack of a leak in both the sampling train and the vapor point seal by testing for helium in the sample analyzed by the laboratory. Combination with a field shut-in test of the sampling train as described in the previous section is still strongly recommended. This will allow significant leaks in the sampling train to be identified and addressed at the time of sample collection. If helium is identified in the sample that is subsequently collected and analyzed then it can also be concluded that the leak occurred around the vapor point annular seal. A disadvantage of full-system shrouds is the volume of helium required, as well as the increased time and cost of sample collection in the field. Monitoring the vacuum gauge on the flow controller without opening the shroud and loosing the helium is only possible if a clear container or bag is used. This is one advantage of the large Tupperware shroud.

7.10.5.5 TRACER GAS CONCENTRATION MEASUREMENT

For both methods, the concentration of tracer gas in the shroud should ideally be measured and monitored in the field using a hand-held field meter. A concentration of 10-30% helium is typically targeted and maintained. If the field meter is selective for the tracer gas compound (e.g., a helium detector used with helium tracer), then a pre-sample can be collected and checked in the field for tracer gas prior to collecting the formal sample. The formal sample should be analyzed by the laboratory for the leak check compound.

The amount of leaking, if any, can be quantified by comparing the tracer gas concentration measured in the shroud to the concentration measured in the sample. If the leak is less than ten percent of the original concentration of the tracer gas in the shroud then the sample can be considered acceptable (i.e., sample concentration less than 1% to 3% for original concentration in shroud of 10-30%). This indicates that no more than ten percent of the sample submitted to the lab was ambient air and that reported concentrations of VOCs are within ten percent of the actual concentration of VOCs at the vapor point in the field at the time the sample was collected. If a field meter is not used to monitor the concentration of tracer gas in the field then the results of the leak test can only be qualitatively evaluated and any detection of helium will be flagged as a potentially significant leak. Fully document and discuss any detections of leak check compound in the soil vapor investigation report.

7.10.5.6 SELECTION OF LEAK CHECK COMPOUND

The selection of leak check compounds is site and analysis specific. Considerations include whether it is a known or suspected contaminant at the site or included in the laboratory's list of target analytes for the method being used, and whether it can be monitored with portable measurement devices. Common leak check compounds are isopropanol (2-propanol or “rubbing alcohol”), helium, and difluoroethane (found in “office duster” cans). Each of the compounds has a variety of advantages and disadvantages.

Isopropanol is readily available, inexpensive, and does not require the use of a shroud, as it can be applied to a towel placed around the vapor probe, although it can also be used with a shroud by placing the towel inside the shroud. Isopropanol is also more dense than air and may be particularly useful for testing leaks associated with the anular space of the vapor point (see Figure 7-43). A further advantage of isopropanol is that it can be detected using methods TO-14, TO-15 or SW8260.

A disadvantage, however, is that selective field meters for isopropanol are not readily available and leaks cannot be readily identified in the field, as can be done with helium. Because it is handled at high concentrations, a relatively small and otherwise minor leak (i.e., <10%) can also significantly interfere with the analysis and require reporting limits for VOCs to be raised above target action levels. Quantification of leaks is likewise difficult, since the original concentration of vapor-phase isopropanol under the shroud can at best be estimated based on its vapor pressure. Isopropanol is also sometimes used as an additive in gasoline. This could again lead to false leaks for sampling at gasoline-release sites.

When using liquid tracer compounds, extreme care also needs to be taken to not contaminate the sampling train parts with tracer compound. Gloves should always be worn when handling the tracer compound. A new pair of gloves should be worn when handling and assembling sampling train components. Ideally, one field technician will be assigned to handle the leak check compound and a second field technician will be assigned to handle and assemble the sampling train.

Helium is commonly used as a leak detection tracer, especially for sampling trains. Helium concentrations can be readily measured in the field using a selective hand-held meter. A further advantage of helium is that its presence in a sample, even at high concentrations, will not interfere with TO-14, TO-15 or SW8260 analysis for VOCs. This allows for a more reliable quantification of leakage. However, the laboratory must run a separate analytical method to analyze for helium. A potential disadvantage of helium is that it is lighter than air. This requires that care be taken to ensure adequate mixing under a shroud if it is used as a tracer for leak detection around vapor points.

Difluoroethane (in office duster cans) is readily available and simpler to handle than helium cylinders and can be analyzed using methods TO-14, TO-15 or SW8260. However, like isopropanol, selective field meters are not readily available.

Table 7-9 provides a comparison of these leak check compounds.

7.10.6 SOIL VAPOR SAMPLE COLLECTION STEPS

The following general steps should be followed when collecting soil vapor samples:

1. Allow the sampling probe to equilibrate with the subsurface (see Section 7.10.2).
2. Check all valves and fittings for integrity by either performing a vacuum leak test or applying a leak check compound during purging and sample collection (see Section 7.10.5).
3. Purge the sampling apparatus as discussed in 7.10.3.
4. Collect the soil vapor sample into the appropriate sample container.
5. Disassemble the sampling apparatus making sure to close the valves on the sample container and the soil vapor sampling probe.
6. Transport the sample to the analytical laboratory under appropriate conditions (based on the analytical method[s] employed) following standard chain-of-custody procedures.

7.10.7 SOIL VAPOR SAMPLE NOTES AND LOGS

Good field notes and logs are important components of soil vapor investigations. Take clear notes in the field. State the goals of each planned activity at the beginning of each day or shift. Document the names of personnel responsible for carrying out different activities, as well as site visitors. Be certain to include units of measurement. Note any nearby activities that could release chemicals to the air (e.g., smoking, recent painting, cleaning with solvents, generators, operation of motor vehicles, passing of cars on roadways, etc.).

Example information that should be included in a sample log includes:

- Sample identification;
- Names of sampling personnel;
- Date and time of sample collection;
- Sampling depth;
- Sampling methods and devices;
- Purging and sampling rates;
- PID readings;
- Soil vapor probe system volumes;
- Volume of soil vapor extracted prior to sampling;
- Sample volume;
- If canisters are used, vacuum of canisters before and after sample collection;
- Apparent moisture content of the sampling zone (e.g., dry, moist, etc.); and
- Chain of custody protocols and records used to track samples from the sampling points to the laboratory

Use field forms to help remind workers of the information that needs to be recorded. Complete every part of the form provided, even if the response is “N/A.” Record data on field logs/forms and sample container tags at the same time. Take photographs during the field work, including broad overviews of the work site and close ups of specific activities. Use a checklist to verify that all equipment has been staged and accounted for prior to initiation of sample collection. Calibrate the field meters and record the method and results in the field notes and on any applicable field forms.

The above represents a necessarily brief overview of requirements for proper documentation of field work. Training by experienced experts and preparation of a detailed work plan can help minimize unanticipated problems during field activities.

7.11 ACTIVE INDOOR AIR SAMPLE COLLECTION PROCEDURES

This section provides a general overview of recommended indoor and outdoor air sample collection procedures and is not intended to be comprehensive. More detailed guidance, including the references noted, should be reviewed prior to the preparation of an indoor air sampling work plan (see HDOH, 2016). Example guidance includes:

- Massachusetts: *Indoor Air Sampling And Evaluation Guide* (MADEP 2002b);
- DoD: *Tri-Services Handbook for the Assessment of the Vapor Intrusion Pathway* (DoD 2008);
- Massachusetts: *Vapor Intrusion Guidance* (MADEP 2010); and
- California: *Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air* (CalEPA 2011).

Due to potential complications from indoor and outdoor sources of VOCs, the collection of indoor air samples as part of a vapor intrusion study will rarely be practical or recommended (see Sections 7.2 and 7.3). The collection of indoor air samples is only recommended if concentrations in subslab soil vapor exceed 1,000 times (residential) to 2,000-times (commercial/industrial) anticipated background in indoor air, due to potential indoor sources of the same VOCs (see Section 7.7). When needed, however, active sampling of indoor air can be carried out in order to assess the risk posed by contaminants present within a building. Multiple lines of evidence in addition to indoor air data will be required to demonstrate a link between apparent impacts to indoor air and the intrusion of subsurface vapors (refer to Section 7.1 and HEER Office EHE guidance, HDOH, 2016). This includes the magnitude and nature of subsurface contamination (e.g., free product on shallow groundwater), concentrations of targeted VOCs in source area and subslab soil vapor samples, presence or absence of apparent pathways for vapor intrusion, building ventilation design and operation (e.g., likelihood to be over- or under-pressured) and the anticipated concentrations of targeted VOCs in indoor air due to known or suspected indoor and/or outdoor sources.

Discrete sampling approaches are still relied on for the collection of air samples, with six-liter Summa canisters or sorbent tubes most commonly used (see Subsection 7.8 and following sections). Alternative sampling approaches that provide better coverage of targeted, indoor areas and volume of air (i.e., “Decision Units (DU)”) are currently being reviewed (see TGM Sections 2 and 3). Although guidance has not yet been fully developed, this could include the placement of multiple, passive samplers in individual, targeted areas of a building (i.e., “DUs”) and combination of the samplers from individual areas for testing as a single sample. This could allow an improved coverage and resolution VOCs in indoor air, especially in areas of poor circulation or where distinct layering of VOCs in air might be possible (e.g., higher concentration of HVOCs near the floor).

Indoor air samples are typically collected under operational conditions representative of the use of the structure (i.e., doors open or closed depending on their typical condition and the type and operating status of the air conditioning/ventilating system in use in the building). From a risk perspective the objective is to determine the average, long-term concentration of targeted VOCs in the space or spaces occupied by an individual within the structure. As discussed in the following sections, samples collected from multiple locations within a building during different times of the year are usually required to establish a baseline health risk. Although not necessarily representative of long-term exposure conditions or risk, it may be also useful to collect a sample(s) directly from a point of suspected vapor entry, including bathrooms, utility rooms or other areas where utilities protrude through the building floor. As discussed in Sections 7.2 and 7.3, temporal changes due to differences in ventilation and other factors that could influence indoor concentrations of VOCs throughout the year should be evaluated and taken into consideration. For example, buildings may be more prone to vapor intrusion during periods of the year when air conditioning is not routinely used and the potential for the building to be under-pressured due to wind effects is increased. Buildings could also be more susceptible to vapor intrusion during dry periods of the year due to the exposure of subsurface smear zones as the water table falls.

If collecting a combination of indoor air samples, outdoor air samples, and sub-slab soil vapor samples for one project, the indoor and outdoor air samples should be collected concurrently, immediately followed by collection of the sub-slab soil vapor samples. The collection of sub-slab samples simultaneously with the indoor air samples it not recommended because the installation and purging of the probes could introduce site VOCs into the indoor air.

Concurrent outdoor, ambient air samples should be collected when conducting indoor air sampling as part of a vapor intrusion study. Ambient air samples are important for evaluation of potential outdoor sources of targeted VOCs. Like indoor air, ambient air can contain a number of VOCs typically targeted for vapor intrusion studies. Examples include TPH, BTEX and other

petroleum-related chemicals associated with auto exhaust as well as chlorinated solvents from nearby industrial activities. Concentrations of these VOCs in heavily populated or industrialized urban areas often exceed purely risk-based, indoor air action levels (HDOH 2016, USEPA 2011e, USEPA 2012, USEPA 2012b).

For residential structures, outdoor air samples should be ideally collected from a representative upwind location, away from wind obstructions such as trees and buildings. The intake should be at five feet off the ground and five to 15 feet away from the building. For commercial structures, outdoor air samples should be collected in representative locations for the intakes of the building HVAC systems.

Outdoor background samples should be collected at locations to minimize bias toward obvious sources of volatile chemicals (e.g., automobiles, lawn mowers, oil storage tanks, gasoline stations, industrial facilities). Outdoor air samples should be collected and analyzed by the same method as indoor air samples and generally for the same time periods as the indoor air samples.

7.11.1 INITIAL BUILDING SURVEY

The indoor environment in any building is a result of the interaction between the site, climate, building heating, ventilation and air conditioning (HVAC) systems, construction design, indoor VOC sources (building materials and furnishings, cleaning fluids, carpet glues, activities within the building, and outdoor sources) and building occupants (smoking, dry cleaning, etc.). An initial building survey is therefore an important part of the indoor air sampling event. This should include interviews with building occupants to assess exposure areas and duration, an evaluation of the building ventilation system and typical operating conditions, an inspection of the building to identify appropriate sampling locations, and an inventory of products or wastes in the building that could release VOCs into the indoor air (i.e., indoor sources). It is recommended that a checklist be used as a guide when conducting building surveys. Vapor intrusion assessment guidance manuals from the USEPA (USEPA 2004e), the Interstate Technology and Regulatory Council (ITRC 2007) and the California EPA (CalEPA 2011) contain example building survey checklists, as do several other state guidance documents (see also vapor intrusion discussion in HEER EHE guidance; HDOH, 2016).

As part of the building survey, potential preferential vapor intrusion pathways should also be evaluated. Utility corridors can act as contaminant migration pathways allowing VOCs to travel long distances. Primary entry points for subsurface vapors include bathrooms, kitchens and utility rooms where water, sewer, gas, electric and telecommunication lines penetrate the floor. Wall outlets for electrical fixtures can also serve as a vapor intrusion pathway.

Depending on the COPC, screening for VOCs using direct reading instruments, such as a high sensitivity PID (e.g. ppbRAE), field portable GC/MS (e.g. Hapsite by Inficon), or combustible gas meter (sometimes known as an explosivity meter) can be useful. These instruments have detection limits in the parts per billion (ppb) range, and are best used for screening at points of potential vapor entry, locating indoor VOC sources, or identifying acute exposure or potentially explosive situations. Note that petroleum vapors are dominated by aliphatic compounds. PIDs primarily target aromatic compounds and are not good indicators of total TPH levels in soil vapors without inclusion of a correction factor (ASTM 2006f; refer also to HDOH, 2012). This is especially important to remember for aromatic-poor vapors from diesel fuel of other middle distillate fuels.

7.11.2 INDOOR AIR SAMPLE LOCATIONS

The concentrations of contaminants in various locations within a building can vary substantially. Indoor air samples should be collected in a manner which represents this variability (see Section 7.7). The number of indoor air samples collected is dependent upon the size, layout, and use of the building. A typical single family residential dwelling (approximately 1,500 ft2) should have at least one indoor air sample collected from each floor and one from the basement or crawl space (if present). Initial samples should target rooms where utilities penetrate the floor or large cracks are obvious, including basements, bathrooms, kitchens, laundry rooms and utility rooms. Although these rooms are unlikely to be continuously occupied, they represent high-risk areas for initial screening of potential problems. Follow-up samples could include bedrooms and living rooms where occupants spend the majority of time in order to provide a better estimate of potential health risk. Larger dwellings in particular may require multiple samples per floor to adequately represent the targeted room or area, especially in areas of poor air circulation. Multi-family residential units and commercial or retail buildings will require a more careful review of the building features and typically warrant multiple sample locations. The sampling plan should take into account the different exposure scenarios (e.g., day care, medical facilities) that exist within the building and any sensitive populations that may be exposed to the contaminated vapors. In structures with basements, both the occupied living areas and basement areas should be sampled from a risk management perspective. Note that ambient concentrations of VOCs from indoor sources will typically be much higher in poorly ventilated rooms such basements and utility closets. For multi-storied residential buildings, consideration should be given to the collection of individual samples or sets of samples on each floor.

Samples are typically collected in the breathing zone of the primary living or working area, approximately three to five feet from the floor (Figure 7-40). If convenient, samples should be collected from the center of the room. The canister or sorbent tube inlet should be placed so that the airflow is unrestricted and the sampling location allows free airflow that is typical of normal

conditions. At a minimum, the inlet should have at least one to two meters of free space in an arc of at least 270 degrees around the inlet.

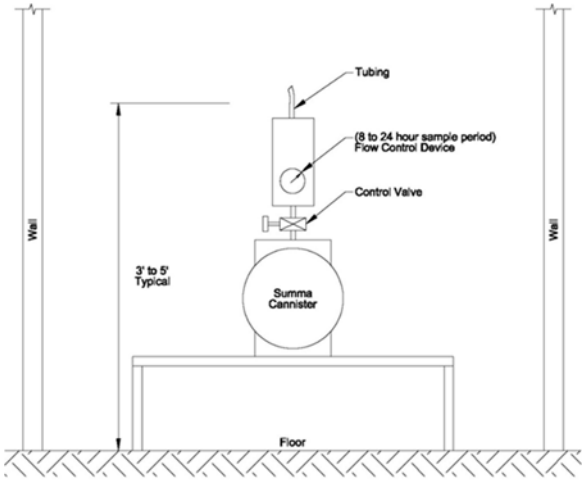


Figure 7-40: Typical Summa Canister Indoor Air Sampling Apparatus.

7.11.3 INDOOR AIR SAMPLE DURATION

The duration of indoor air sampling is typically matched to the type of building (see ITRC 2007, CalEPA 2011). In general, sampling duration is typically 24 hours for residential building samples and eight to ten hours for commercial/industrial building samples. Longer duration samples may be appropriate if significant variability in VOC concentrations is suspected. Summa canister flow controllers calibrated to seven-day collection periods are also available. Sorbent tubes can be used for longer duration or larger volume samples.

7.11.4 INDOOR AIR SAMPLE FREQUENCY

Sampling frequency is determined by the CSM, objectives of the study and the nature of the contaminants and should be discussed with the HEER Office on a site-specific basis (see ITRC 2007, CalEPA 2011). A single sampling event is unlikely to yield data that are representative of exposure concentrations over a chronic period of time (i.e., many years). If the contaminant source is non-constant, more frequent sampling should be considered in comparison to constant contaminant sources.

7.11.5 INDOOR AIR SAMPLE CONTAINERS AND ANALYTICAL METHODS

The most common methods for collecting indoor air samples are:

1. Use of Summa canisters equipped with a calibrated flow controller for VOCs (Section 7.8.1).
2. Use of sorbent tubes connected to a calibrated flow pump for VOCs and SVOCs (Section 7.8.2).

Currently available flow controllers and flow pumps enable collection periods ranging from less than 1 hour to 7 days.

Samples collected in Summa canisters should be analyzed for VOCs in the laboratory using USEPA method TO-14 or TO-15 (Section 7.13.1). Methods TO-14 and TO-15 are similar. Method TO-15 offers additional target analytes over TO-14, however, and has largely replaced the latter. Both methods use gas chromatography-mass spectrometry (GC/MS) instruments and can be operated in full-scan or SIM mode. Full scan mode offers a broader range of target analytes and is typically less costly than SIM mode, but has higher detection levels. SIM mode provides extremely low detection levels. Consultation with the analytical laboratory can assist in determining the most appropriate analytical method for a given air sample. Samples collected on sorbent tubes or passive samplers are typically analyzed using USEPA methods TO-1, TO-2, or TO-17, with the latter most commonly selected (see Subsection 7.13).

For vapor intrusion studies, the suite of VOCs targeted for Indoor and outdoor air samples should be identical to the suite targeted for soil vapor and identified in subslab soil vapor samples. Inclusion of additional VOCs can complicate the evaluation of impacts associated purely with vapor intrusion.

7.11.6 INDOOR-OUTDOOR AIR SAMPLE LOGS

A sample log should be maintained during indoor and outdoor air sampling. Information to be recorded can include:

- Sample identification;
- Names of sampling personnel;
- Date and time of sample collection;
- Weather conditions;
- Building conditions (e.g., HVAC on/off, windows/doors opened or closed);
- Sampling location;
- Sampling height;
- Sampling methods and devices;
- Depending upon the method used, volume of air sampled;
- If canisters are used, vacuum of canisters before and after sample collection;
- Chain of custody protocols and records used to track samples from the sampling points to the laboratory.

General information for field notes and logs presented in Subsection 7.10.7 are also applicable for indoor and outdoor air sampling.

7.12 PASSIVE SOIL VAPOR AND INDOOR AIR SAMPLE COLLECTION PROCEDURES



Figure 7-41: Installing a Passive Soil Vapor Sample Collector by Hand The hole is drilled using a roto-hammer. The soil vapor sample collector is installed using an insertion rod. The hole is then covered.

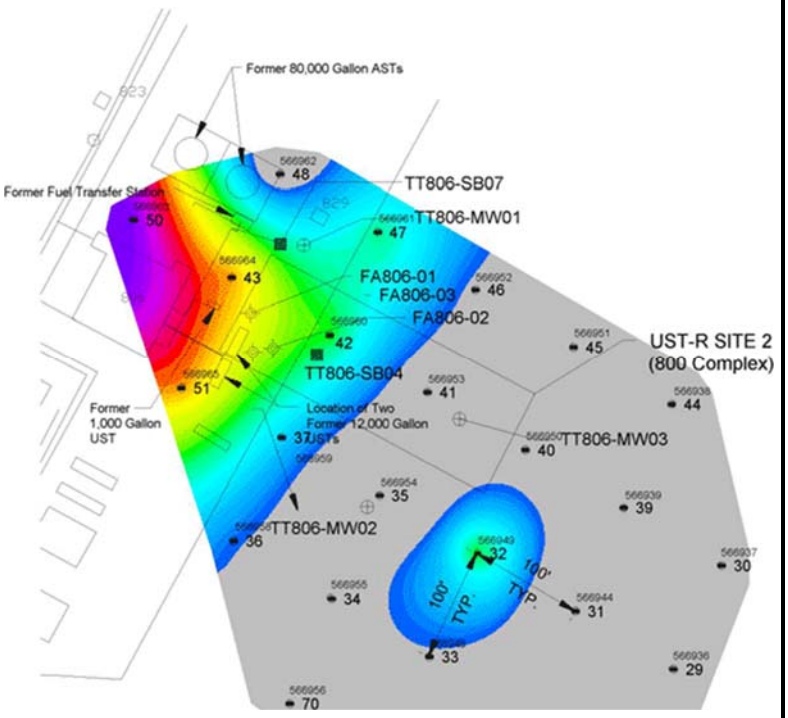


Figure 7-42: Example Plume Map from Grid-based Passive Soil Vapor Survey.

Passive sampling can be applied to either soil vapor or indoor air. Although the principle is the same in application to these media, the techniques for adsorbent placement, retrieval and analysis are different.

7.12.1 PASSIVE SAMPLING OF SOIL VAPOR

Implementing a passive soil vapor sampling strategy in the field requires careful consideration of the pertinent sampling variables, as described below.

Sample Spacing: The selection of sampling locations for passive sampling is based upon the same considerations as active soil vapor methods: project objectives and the need for adequate coverage. Predetermined and widely spaced grid patterns are most commonly used for reconnaissance work, while closely spaced, irregularly situated locations are commonly used for covering specific source areas.

Collection Depth: Although passive sample collectors have often been installed close to the surface (6 inches to 3 feet), that burial depth has been for convenience in deploying and retrieving the collector and not for technical reasons. In general, passive sample collectors should be deployed as near to the suspected soil or groundwater source as possible in order to reduce the chance of placing the sampler in a pocket of vapor-free soil in an otherwise contaminated area. In addition, collectors buried close to the surface will be very susceptible to air infiltration due to changes in barometric pressure and surface temperature. Therefore, at locations with uncovered soil, it is advisable to bury the collector to a depth of at least three feet. Placement of samplers at shallower depths may be acceptable for paved areas, depending on the objectives of the investigation. Check with the vendor for additional guidance.

Exposure Period: As with collection depth, the exposure period for passive collectors has often been generally selected more for convenience factors than for technical reasons. Typical exposure times have been a few days to a month.

In practice, the exposure period for a passive collector should depend upon the concentration of the contaminant of interest and desired detection levels. In areas of suspected high concentration, collectors can be left in the ground for shorter periods (1 to 5 days). In areas of suspected low concentrations, collectors are often left in the ground for two or more weeks. For areas of unknown concentration, the optimum approach is to determine the deployment time by burying a number of collectors in the same location and measuring them over a period of time.

The key assumption that is made when interpreting passive soil vapor data is that each collector is exposed to the same quantity of soil vapor. Therefore, it is most important that passive collectors within a sampling program be deployed for the same period of time in order for the data to be comparable.

QA/QC: The most important factors affecting the quality of passive soil vapor data is consistency of deployment and potential contamination of the samplers. Sampling teams should be trained in the deployment of the passive sample collectors to ensure consistent methodology is employed for each sample collector that is installed. To assess field contamination, analysis of field blanks and/or trip blanks is extremely important to verify that detected contamination was not from another source, such as the passive collector itself, or from handling and storage during transport to the laboratory.

There are several vendors of passive soil vapor sample collectors and those vendors should be consulted regarding specific installation procedures for their sample collectors and for any adsorbent-specific information, such as uptake rates. A time-sequence series of photographs that illustrates the installation of one vendor-supplied sample collector is shown in Figure 7-41. An example plume map from a grid-based passive soil vapor survey is shown in Figure 7-42.

7.12.2 PASSIVE SAMPLING OF INDOOR AIR

Passive sampling of indoor air is an evolving technique for evaluating potential indoor air impacts. VOCs are the most common target compounds but the technique is applicable to SVOCs as well. The primary advantage in comparison to active sampling is that passive sampling can be done over longer time periods and thereby reflect a longer-term average concentration. It may also be possible to deploy multiple passive samplers within a targeted floor or room and then combine them for extraction and analysis. This helps provide better coverage of targeted areas without increasing lab costs.

There are several vendors of passive indoor air sample collectors and those vendors should be consulted regarding specific applications and instructions for use. Data from passive samplers can be used to help focus the collection of whole air samples or sorbent tube samples.

7.13 SOIL VAPOR AND INDOOR AIR SAMPLE ANALYSIS

The analytical methods selected for analyzing soil vapor or indoor air samples depend on a number of factors. These include the targeted VOCs, desired detection and reporting limits and the manner in which the sample is collected. In Hawai'i, soil vapor or indoor air samples are in most cases forwarded to a fixed analytical laboratory on the mainland for analysis. Analytical methods should be consistent within each sampling event as well as for different sampling events to assist in the interpretation of the data.

7.13.1 AVAILABLE ANALYTICAL METHODS

7.13.1.1 VOLATILE ORGANIC COMPOUNDS (VOCS)

A variety of analytical methods are available to measure soil vapor samples all of which give accurate results. Table 7-10 gives a summary of the available methods. Table 7-11 summarizes the methods most commonly used on Hawai'i sites. Method versions denoted in the table by Roman letters (e.g., "A", "B", "C," etc.) are for example only and may not include recent updates to the method. Discussion of the most appropriate analytical methods to meet the objectives of an investigation with the laboratory is strongly recommended. Less expensive methods such as TO-3, 8015 and 8021 for VOCs are, for example, primarily used for screening or monitoring purposes. Method 8015 is a comprehensive method for TPH whereas Methods 8260, TO-15 and TO-17 measure individual VOCs by mass spectrometry. Both methods work well for TPH as comprehensive data but GC/MS methods are recommended for final, decision making.

As discussed in the following section, Total Petroleum Hydrocarbons (TPH) should be reported as the sum of C5 to C12 (Summa canister samples) and/or C5-C18 (sorbent tube samples) for vapors associated with all types of petroleum fuels, including diesel and other middle distillate fuels. Unlike soil or groundwater, reporting of TPH compounds as "gasoline-range" or "diesel-range" is not applicable to soil vapors. As discussed in Section 7.13.1.2, vapors associated with diesel and other middle distillate fuels could, in theory, include a large component of C12 and higher aliphatic and to a lesser degree aromatic compounds (see HDOH, 2012). Inclusion of heavier, vapor-phase compounds in the measurement of TPH will require the use of a sorbent method (e.g., TO-17). Recovery of aromatic compounds above C10 and aliphatic compounds above C12 is not currently practical for samples collected in a Summa canister (see Subsection 7.8.1). If a minimum one-liter sample cannot be drawn using a sorbent tube, for example due to potential saturation of the adsorbent material, then a concurrent Summa sample should be collected and used to report light-end VOCs and TPH (see Section 7.8.2). This will almost always be the case for soil vapors associated with petroleum. If initial sorbent data (or prior knowledge at a similar site) indicates that vapors are dominated (e.g., >90%) by C5-C12 compounds then subsequent TPH data can be obtained using Summa samples.

Other analytical methods not listed in Table 7-10 can be utilized on a site-specific basis. A description of the alternate analytical method, rationale for its selection, and analytical results should be fully documented in the final soil vapor or indoor air investigation report.

Table 7-10 Summary of Soil Vapor & Indoor Air Analytical Methods[1]

Method No.	Type of Compounds	Collection Device	Methodology	Detection Limit [2]	Reference
TO-1 [3]	VOC	Tenax® solid sorbent	GC/MS or GC/FID	0.02 – 200 µg/m^3 (0.01-100 ppbv)	USEPA 1999b
TO-2 [3]	VOC	Molecular sieve sorbent	GC/MS	0.2 – 400 µg/m^3 (0.1-200 ppbv)	USEPA 1999b
TO-3	VOC	Cryotrap	GC/FID	0.2 – 400 µg/m^3 (0.1-200 ppbv)	USEPA 1999b
TO-4A	Pesticides/ PCBs	Polyurethane foam	GC/MD	0.5 – 2 µg/sample	USEPA 1999b
TO-10A	Pesticides/ PCBs	Polyurethane foam	GC/MD	0.5 – 2 µg/sample	USEPA 1999b
TO-12	NMOC	Canister or on-line	FID	200 – 400,000 µg/m^3 (100-200,000 ppbv)	USEPA 1999b

TO-13A [3]	PAH, TPH	Polyurethane foam	GC/MS	0.5-500 µg/m^3 (0.6 – 600 ppbv)	USEPA 1999b
TO-14A	VOC (nonpolar)	Specially-treated canister	GC/MS	0.4 – 20 µg/m^3 (0.2-2.5 ppbv)	USEPA 1999b
TO-15 [4]	VOC	Specially-treated canister	GC/MS	0.4 – 20 µg/m^3 (0.2-2.5 ppbv)	USEPA 1999b
TO-15A	VOC	Specially-treated canister	GC/MS	0.005 µg/m^3-0.02 µg/m^3 (0.002-0 .04 ppbv)	USEPA 1999b
TO-17 [3,4]	VOC	Single/multi-bed adsorbent	GC/MS, FID	0.4 – 20 µg/m^3 (0.2-2.5 ppbv)	USEPA 1999b
Method 3C	N_2, O_2, CO_2, and CH_4	Canister	GC/TCD	20,000 – 150,000 µg/m^3 (10,000 ppbv)	USEPA 1999b
Method 16	H_2S	Tedlar® Bag, Canister	GC/FPD	100 - 700 µg/m^3 (50 ppbv)	USEPA 1999b
8015B/ 8015D	TPH/VOC	Tedlar® Bag, Canister, Glass vials	GC/FID	300 – 3000 µg/m^3 (100 – 10,000 ppbv)	USEPA 1998b
8021B	VOC	Tedlar® Bag, Canister, Glass vials	GC/PID	4.0 – 60.0 µg/m^3 (0.3 – 30 ppbv)	USEPA 1998b
8260B	VOC	Tedlar® Bag, Canister, Glass vials	GC/MS	10.0 – 50.0 µg/m^3 (0.6 – 25 ppbv)	USEPA 1998b
8270C	SVOC	Tedlar® Bag, Canister, Glass vials	GC/MS	1,000 µg/m^3 (20,000 – 100,000 ppbv)	USEPA 1998b
D1945-03(2010)	natural gases and mixtures	Tedlar® Bag, Canister, Glass vials	GC/TCD	800 – 29,000 µg/m^3 (10,000 ppbv)	ASTM 2010b
D1946-90(2011)	H_2, O_2, CO_2, CO, CH_4, C_2H_6, and C_2H_4	Tedlar® Bag, Canister, Glass vials	GC/TCD	800 – 18,000 µg/m^3 (10,000 ppbv)	ASTM 2011

Notes (Table adapted from API 2005):

1. This is not an exhaustive list. Some methods may be more applicable in certain instances. Other updated, proprietary or unpublished methods may also apply. Passive samplers can also be used for collection and qualitative assessment of some compounds.
2. Detection limits are compound specific and can depend upon the sample collection and the nature of the sample. Detection limits shown are for the range of compounds reported by the analytical methods.
3. Trapping-type sampling method used to achieve high sensitivity. TO-17 is a one-time thermal desorption method; TO-13 is an extraction method that can be reanalyzed as needed. TO-13 can be used to quantify heavier TPH in vapors but may not adequately capture light-end VOCs (consult the laboratory).
4. TO-15 or TO-17 recommended for final, decision making purposes.

GC - gas chromatography
MD - multi-detector
MS - mass spectrometry
NMOC - non-methane organic compounds
PAH - polycyclic aromatic hydrocarbons
FPD - flame photometric detector
FID - flame ionization detector
SVOC - semivolatile organic compounds
VOC - volatile organic compounds
TCD - thermal conductivity detector

Table 7-11 HDOH-Recommended Laboratory Analytical Methods for Soil Vapor or Indoor Air Contaminants and Leak Detection Compounds

.Analyte	Analytical Method	Reference
TPH	TO-3, TO-14, TO-15, TO-17, 8015	USEPA 1999b USEPA 1998b
BTEX, MTBE, naphthalene	TO-15, TO-17, 8012, 8260	USEPA 1999b USEPA 1998b

VOCs (including difluoroethane and isopropanol alcohol)	TO-14, TO-15, TO-1, TO-2, TO-17, 8260, 8021	USEPA 1999b USEPA 1998b
SVOCs (including PAHs)	TO-17, 8270 (sorbent methods)	USEPA 1998b
Oxygen, CO_2, Nitrogen, Methane, Helium	ASTM D-1946, 3C	USEPA 1996j
Polynuclear aromatic hydrocarbons (PAHs)	TO-13	USEPA 1999b

Notes:

1. According to discussions between HDOH and laboratory staff, The best laboratory method to test for TPH in soil vapors appears to be a combination of both TO-15 (Summa canister samples) and TO-17 (sorbent tube samples) (HDOH, 2012c). A sum of the individual carbon ranges can be more accurately determined from both methods. TO-3 can be far less sensitive than TO-15 and TO-17.

7.13.1.2 TOTAL VOLATILE PETROLEUM HYDROCARBONS

As discussed in Section 9 and the HEER Office EHE guidance (HDOH, 2016 and updates), testing of vapors associated with petroleum should include a short list of target indicator compounds (e.g., BTEX, naphthalene and methane) and Total Petroleum Hydrocarbons (TPH), also referred to as Total Volatile Petroleum Hydrocarbons (TVPH). The target indicator compounds recommended for analysis at petroleum contaminated sites are listed in Section 9, Table 9-5.

Total Petroleum Hydrocarbons represents the sum of the vapor-phase, aliphatic and non-targeted, individual aromatic compounds. This is sometimes subdivided into a “gasoline-range (“TPHg)” category characterized by a dominance of light-end, C5–C12 compounds and a “diesel-range (TPHd”) category characterized by heavier-end, C10–C26 compounds. This is appropriate for testing of soil and water samples, based on the known or assumed type of fuel released.

A distinction between TPHg and TPHd compounds is misleading for vapor-phase petroleum, however, since vapors from diesel and other middle distillate fuels or fuels that include middle distillates (e.g., JP-4, a mixture of gasoline and kerosene, and JP-8, similar to diesel fuel) can contain a significant proportion of lighter end compounds, especially C5-C8 aliphatics. Requesting the lab to report vapor-phase TPH as the equivalent of “TPHd” (i.e., sum of C10+ compounds) could significantly underestimate the actual concentration of TPH in soil vapors.

This issue was investigated and discussed in the HEER Office study Field Investigation of the Chemistry and Toxicity of TPH in Petroleum Vapors: Implications for Potential Vapor Intrusion Hazards (HDOH, 2012, 2012c; Brewer et al 2013). The study suggested that the proportion of C5-C8 aliphatic compounds in vapors associated with middle distillate fuels is highly variable but can be up to 50% or more of the total TPH. Excluding these vapors from the TPH analysis can significantly under-report the total TPH present in a vapor sample. The study also indicated that individual, targeted aromatic compounds such as BTEX typically make up less than 1% of the total petroleum vapors present.

Vapor intrusion risk associated with the TPH fraction of petroleum vapors has only recently begun to be investigated in detail (e.g., Brewer et al 2013; see also Section 9). Although “less toxic” with respect to toxicity factors and action levels, the higher proportion of TPH aliphatics in the vapors causes these compounds to be the primary risk driver with respect to potential vapor intrusion concerns. Ongoing evaluations of soil gas field data will help address the lack of published information on the relative risk of vapor intrusion (quantitatively considered) posed by TPH versus benzene and other individual compounds.

The HDOH study indicated that the ratio of TPH to other individual aromatic compounds, such as benzene, can vary within a study site and between sampling events. These spatial and temporal differences could reflect differences in weathering and biodegradation, subsurface migration and small-scale heterogeneity with the plume. This highlights the potential problems associated with one-time sampling events and limited vapor points (see Section 7.10.1).

For vapors associated with gasoline-only releases, TPH (or equivalent) should be reported as the sum of all compounds falling within the carbon range from C5 to C12 (non-BTEX aromatics typically reported to C10). **For vapors associated with middle distillate (and heavier) fuels, including diesel, TPH should be reported as the sum of all compounds falling within the carbon range from C5 to C12, if a summa canister is used, and C5 to C18 if a sorbent tube is used.** It is important to clarify this with the laboratory and document this in the report. The lab should not be requested to report “diesel range” TPH in the sample, since doing so excludes reporting of C5-C9 aliphatics in soil vapors and could significantly underestimate the total concentration of TPH-related compounds. As discussed in the HDOH EHE guidance, a more detailed analysis and evaluation of the carbon range makeup of TPH can be carried out on a site-specific basis as needed (e.g., development of more site-specific, TPH soil gas action levels; HDOH, 2016).

The concurrent collection of soil vapor samples using both a Summa canister and a sorbent tube is recommended for the investigation of subsurface vapors associated with diesel or other middle distillate fuels (see Section 7.8). This should be

incorporated into both traditional, small-volume vapor sampling methods as well as LVP methods. The draw volume for sorbent tube samples is typically limited to 50ml due to potential saturation of the sorbent media (see Section 7.8.2). The Summa canister sample is likely to be more representative of subsurface vapors, given its larger volume. This sample should be collected first, following purging, and tested for TPH as the sum of C5-C12 compounds, BTEX and other targeted compounds. The well point should then be closed (e.g., via a valve or tightly pinching the tubing) prior to unhooking the canister. This will prevent ambient air from entering the tubing if a vacuum has been imposed on the subsurface soil.

The sorbent tube sampling train should then be attached to the vapor point and a shut-in leak test performed. Following successful completion of a shut-in test, the well point should be opened and a minimum, 50ml sample drawn. The sorbent tube sample should be tested for TPH as the sum of C5-C18 compounds (e.g., using TO-17 methods). The resulting data should be compared to the reported level of TPH in the Summa canister sample. If the difference in minimal (i.e., ≤10%), then a conclusion can be drawn that a significant proportion of C12+ compounds are not present in the soil vapors and Summa canister samples can be used for future sample collection. A review of the TO-17 gas chromatograph for the sample can also be helpful to determine if a significant proportion of the TPH vapors consists of compounds greater than C12.

Vapor-phase TPH data for middle distillate release sites that do not include both light- and heavy-end compounds may not be accepted unless it can adequately demonstrated that heavier end compounds do not make up a significant proportion (e.g., >10%) of the total vapors. If the lab cannot report lighter-end compounds with their current setup then both “TPHg” and “TPHd” should be reported, and the sum of the two methods compared to target action levels (see also Section 7.13.2.

Targeted, individual compounds such as BTEX and naphthalene that are evaluated separately can be subtracted from the reported TPH for comparison to TPH indoor air or soil gas action levels. This can either be done by the laboratory (preferred) or based on the reported data if the compounds were included with the reported concentration of TPH (see Section 9). The approach used should be noted in the report.

The HEER Office indoor air and soil gas action levels for TPH action levels reflect assumptions regarding the toxicity-weighted sum of the individual carbon ranges. The action levels conservatively assume a mixture of a high proportion of more toxic, C9-C12 aliphatic compounds in petroleum vapors. These compounds are more typically associated with diesel and other middle distillate fuel vapors than vapors from gasoline. As a result, the default action levels may be excessively conservative for vapor intrusion evaluations of gasoline-only release sites. As discussed in the HDOH EHE guidance document, alternative action levels can be developed and proposed based on site-specific, TPH carbon range data (HDOH, 2016). Alternative toxicity factors for TPH carbon ranges can similarly be proposed in a site-specific risk assessment (HDOH, 2016).

As discussed in Appendix 1 of the HEER EHE guidance (HDOH 2016), the default action levels are likely to be too conservative for gasoline-only sites by a factor of three or more. For more site-specific evaluations, TPH can be reported in terms of the specific carbon ranges used to develop the action levels, including C5-C8 aliphatics, C9-C12+ aliphatics, and C9-C10+ aromatics. The concentration of individual TPH carbon ranges can be compared to indoor air or soil gas action levels presented in Appendix 1 of the EHE guidance. Site-specific TPH soil gas action levels can also be developed based on the average carbon range makeup of petroleum vapors (refer to HDOH, 2012). **Laboratory gas chromatograms should be obtained and included with site-specific evaluations of TPH carbon range chemistry and toxicity.**

Note that the cumulative, noncancer risk must be calculated if carbon range-specific concentrations and action levels are used. This is necessary to ensure that the total concentration of vapor-phase TPH does not pose an unacceptable health risk. This is done by dividing the reported concentration of an individual carbon range by its respective action level, referred to as the “Hazard Quotient,” and then summing the calculated Hazard Quotients for each carbon range, referred to as the “Hazard Index.” If the calculated Hazard Index is less than 1.0 then the TPH does not pose a cumulative risk. If it exceeds 1.0 then potential cumulative risk needs to be further evaluated. In practice, noncancer, Hazard Indices should also be calculated for individual, targeted compounds such as BTEX and naphthalene and added to the total Hazard Index.

A key issue influencing reported TPH concentrations is the calibration procedure used by the laboratory. Is calibration done using a liquid or a vapor standard? The latter will provide more accurate data. Were typical gasoline and diesel calibration standards used, or were separate aliphatic hydrocarbon component standards used? Results will vary between labs if different types of calibration standards are used. Therefore, the calibration procedure should be fully documented in the final soil vapor or indoor air investigation report.

7.13.2 CHOOSING THE ANALYTICAL METHOD

The primary criteria for choosing the appropriate method are:

- The compounds of concern;
- Required detection level and other data quality objectives (DQOs);
- Sampling logistics; and

- Cost.

The following questions should be considered prior to the selection of analytical methods for soil vapor or indoor air samples (API 2005):

- *What are the targeted chemicals of concern or other parameters (e.g., natural attenuation parameters)?* The specific analytes targeted for the site investigation should be identified and noted (e.g., TPH, benzene, naphthalene). Generally, these will be the volatile and semi-volatile chemicals of concern identified during the overall site investigation. If indoor air samples are to be tested, targeted chemicals should be limited to chemicals identified in subslab or subsurface vapor samples. The vapor intrusion risk calculated for indoor air data should be specific to the targeted, subsurface VOCs of concern and exclusive of other contaminants in the sample from indoor or outdoor sources. The lab method(s) selected should optimize the number of targeted COPCs that can be reported in a single analysis and limit overlap between different methods.

- *What analytical method reporting limits are required to adequately assess the potential exposures?* It is important to determine the lowest concentrations of chemicals of concern in soil vapor or other analytes that are expected to be required for evaluation of the subsurface vapor intrusion pathway and general site investigation needs. Refer to the EALs for indoor air and soil gas published in the HEER Office EHE guidance (HDOH 2016. Typical laboratory detection limits fall below action levels for soil gas but, in some cases, may be above purely risk-based action levels for indoor air. In this case the laboratory detection limit can be used as an alternative screening level (see also Volume 1 of the EHE guidance).
- *Do soil or groundwater analytical results, or other field data, indicate that concentrations of chemicals of concern in soil vapor will be high?* If concentrations of chemicals of concern or other analytes in soil vapor are anticipated to be high, then the analytical method selected should address high concentrations. It is important to notify the laboratory of anticipated, high concentrations of VOCs in samples so that sample processing can be optimized. Including a summary table of PID data for sample points can assist the lab in selection of the most appropriate lab methods and help them optimize detection limits.

  In cases where very high concentrations of VOCs are anticipated, solid waste program methods for analysis of soil vapor samples typically reserved for landfill gas samples may be appropriate (USEPA 1998b). There is some concern that the solid waste program methods might be biased low for some chemicals of concern. Studies have indicated, however, that the solid waste program methods and air toxics methods produce similar results for TPH, BTEX and chlorinated hydrocarbons (e.g., Hartman 2004).

- *How are the samples to be collected?* The analytical method selected, in many cases, will define the collection method (e.g., Summa canister) that should be used and typically the sample preparation that is required to analyze a sample (refer to Section 7.8).

- *Do the regulatory agencies require certification of the laboratory or that specific analytical methods be used?* Some state or federal regulatory agencies require that samples be analyzed by specific methods. They can also require the laboratory that is conducting the analysis to be certified under a state or national program. In some cases, this can limit the use of field analytical methods. HDOH does not currently require analysis labs in Hawai‘i to be certified for soil vapor analyses; however, the HEER Office recommends that lab certifications and/or other lab quality control measures be carefully considered when selecting an analysis lab. Be aware that work carried out at DoD facilities generally require use of certified laboratories.

- *Are there short turnaround times required for analytical results?* Turnaround times will be influenced by shipping requirements, holding times, laboratory backlog, and analytical methods. Depending on the objectives and priorities of the site investigation, field analysis using a mobile laboratory (if available) may be preferable to shipment to a laboratory. Field analysis can provide nearly real time results.

- *Are the analytical methods appropriate for the soil vapor samples?* Analytical methods are periodically updated with newer techniques. It is suggested that the user consult with the regulatory agency and a qualified analytical laboratory to identify analytical methods appropriate for the specific site.

As discussed above and in Section 9, it is important to also measure the total petroleum hydrocarbon concentration in soil vapor at petroleum hydrocarbon impacted sites. The total petroleum hydrocarbon measurement should be the full range of detectable hydrocarbons (i.e., C5 to C18), not of a specific product range of carbon numbers. Reporting of TPH as “gasoline range organics” or “diesel range organics” does not apply to indoor air or soil gas. This is because petroleum vapors from diesel can include a significant and even dominant proportion of lighter, aliphatic compounds even those these compounds make up only a small fraction of the fuel itself (refer to HDOH, 2012). The higher, relative volatility of these compounds causes these compounds to dominate vapors associated with diesel and other middle distillate fuels.

The currently preferred laboratory method to test for TPH in soil vapors for final decision making purposes is a combination of both TO-15 (Summa canister samples) and TO-17 (sorbent tube samples) (see HDOH, 2012, 2012c). Note that Methods TO-14 and TO-15 are similar. Method TO-15 offers additional target analytes over TO-14, however, and has largely replaced the latter. Based on discussions with laboratories, a sum of the individual carbon ranges can be more accurately determined using these methods. In theory, less expensive TO-3 methods can be far less sensitive than TO-15 and TO-17 to TPH. Data from the HDOH study do not indicate an obvious bias of TO-3 data for under reporting of TPH in soil gas samples, however. Alternative methods can be proposed on a site-specific basis.

A variety of issues, including low volatility and poor recovery from Summa canisters, make it problematic to quantify aromatic hydrocarbons greater than C10 and aliphatic hydrocarbons longer than C12 using methods TO-15 or SW8260. Sorbent tubes used in combination with Method TO-17 (or acceptable alternative) are capable of reporting the full range of vapor-phase, hydrocarbon compounds present in a sample, including aliphatics, aromatics and oxygenates. This is important because longer-chain hydrocarbons (C9+) are more toxic than shorter-chain hydrocarbons and their presence can significantly increase the vapor intrusion risk (HDOH, 2012, see also HDOH, 2016). Documenting the presence or absence of a significant proportion of these compounds in TPH vapors is necessary at the beginning of a site investigation.

The need to continue the collection of sorbent tube data at a site can be reviewed based on the results of the initial samples. It is reasonable to assume that this fraction of TPH, if present, is dominated by C12+ aliphatic compounds (refer to HDOH, 2012). If C12 or higher compounds make up less than 10% of the total TPH present in the samples (i.e., sum of C5-C18 compounds) then the concurrent collection of sorbent tube samples can be discontinued. Labeled, laboratory chromatograms should be included in the investigation report to support this conclusion.

Consult with the laboratory to determine the calibration standard used for the TO-17 method. Document that calibration procedure in the final soil vapor or indoor air investigation report.

Detailed TPH carbon range data will be necessary for more site-specific risk evaluation (see Section 7.13.1.2 and HEER Office EHE guidance, HDOH, 2016). The laboratory should be consulted to determine the most appropriate sample collection method (e.g., Summa vs sorbent tube) and lab method (e.g., TO-15 vs TO-17).

For vapors associated with diesel and other middle distillate fuels, sorbent tube methods that are able to report aromatic and aliphatic carbon ranges above C10 and C12 are preferred. Some labs may not be set up to report carbon range data using sorbent tube methods, however. In this case a combination of carbon range data (e.g., C5-C8 aliphatics, C9-C12 aliphatics and C9-C10 aromatics) and TPH data (e.g., TPH reported as sum of all compounds greater than C12, assumed to represent C12-C16 aliphatics and aromatics) may be necessary until it can be demonstrated that Summa data are adequate to evaluate TPH in general.

Many laboratories can quantify naphthalene using TO-15. Detection levels are normally adequate for soil vapor samples in comparison with correlative soil gas action levels (72 to 240 µg/m3), but may be too high for indoor air samples (action levels 0.072 to 0.12 µg/m3). Reporting naphthalene under TO-15 in combination with other targeted VOCs can avoid the need to for multiple samples and laboratory methods, especially for soil vapor samples. Check with the laboratory if indoor air sampling is to be carried out and naphthalene is a target compound.

7.13.3 FIELD ANALYTICAL METHODS

On-site analysis can be very beneficial for vapor intrusion assessments as real-time data enable detection of preferential vapor migration sources or pathways, allow additional sampling locations to be added (spatially or vertically), allow the identification of spurious or otherwise non-representative data and enable measurement of the leak-test tracer compound to ensure valid soil vapor samples are collected. Simple, portable instruments can provide both qualitative and quantitative data depending upon the compound and the required detection levels. Field screening with hand-held PIDs or FIDs enable rapid identification of vapor migration routes around and into structures; although most field screening instruments are limited to the ppmv range for VOCs, which often do not provide sufficient sensitivity for vapor intrusion investigations. [Note that PIDs are not very sensitive to aliphatic compounds, which dominate petroleum vapors (ASTM 2006f; see also HDOH, 2012).

Quantitative oxygen, carbon dioxide, and methane measurements also are possible using hand-held portable meters for concentrations in the percent range. Measurements of these compounds can help determine equilibration in newly installed wells, detect leaks in the sampling system, and also can be used to assess biodegradation of VOCs.

Mobile laboratories equipped with laboratory-grade instruments, including gas chromatographs and mass spectrometers, are capable of fully quantitative results meeting required QA/QC and detection limits as low as 1 ppbv. A field portable GC/MS (e.g. Hapsite by Inficon) is also available and gives quantitative soil vapor and indoor air analysis to levels as low as 1 ppbv.

7.13.4 QUALITY CONTROL SAMPLES

7.13.4.1 FIELD QUALITY CONTROL



Figure 7-43: Typical Duplicate Sampling Apparatus (see also Figure 7-35). Left photo: Stainless steel "T" manifold to simultaneously collect primary and duplicate soil vapor samples in 500-ml Summa canisters. Right photo: Laboratory-supplied duplicate sampling apparatus to simultaneously collect primary and duplicate soil vapor samples in sorbent tubes.

Replicates

The use of replicate sample data for the collection of Large Volume Purge (LVP) samples is discussed in Subsection 7.8.4. Concerns regarding the reproducibility and representativeness of small-volume soil vapor samples that represent very small volumes of vapor collected from a single location are discussed in Section 7.5. Random variability of VOC concentrations in soil vapor at the scale of traditional, small-volume soil vapor sample (e.g., one liter) limits the reliability of a single data point to represent the immediately surrounding area (Brewer et al. 2014). Large-scale patterns representing the core of a vapor plume can be reasonably identified using a sufficient number of small-volume sample points. Smaller-scale patterns identified within a vapor plume and based on single samples should be considered suspect, however, and could be artificial and unreproducible reflections of random heterogeneity. LVP sampling methods are intended to help address these limitations of traditional, small-volume vapor sample data. The collection LVP data from other than immediately beneath a building slab or otherwise sealed area is not currently feasible due to potential downward leakage of outdoor air into the sampling train.

Field replicates are not routinely collected for small-volume soil vapor sample investigations but should be considered to confirm plume patterns and VOC concentrations implied by data prior to initiating remedial actions. Replicate samples, normally triplicates, are collected to provide information on the reproducibility of a sample intended to represent a pre-specified volume of soil or more specifically the vapors held within that soil. Reproducibility is a function of both field and laboratory error. This is relatively straight forward for soil investigations, where a designated Decision Unit (DUs) is subsampled by collection of a single Multi Increment sample (refer to Subsection 7.6.2.2 and Sections 3 and 5). Replicates are collected to verify that the number of increments collected in the Decision Unit, typically thirty to fifty, adequately capture the contaminant heterogeneity and provide a representative mean of targeted chemicals.

As discussed in Section 7.6.2.2, approaches for the designation of DUs in terms of soil vapors and vapor intrusion are still being studied. At this time the primary purpose of replicate soil vapor samples, if collected, is to evaluate the reproducibility of data for individual sample point locations, rather than for a DU as a whole. More specifically, the replicates can provide some information on the spatial variability of VOC concentrations in soil vapor at the scale of the sample volume collected. Collecting larger samples also helps to ensure that the data are more representative of the targeted area (e.g., six-liter versus one-liter Summa sample). This can be challenging at sites with tight soils, however.

If desired or recommended, field duplicate samples can be collected at a minimum of 10% of the active soil vapor or indoor air samples collected per sampling day per laboratory (if more than one laboratory is used). If less than ten samples are collected during each day or sampling event, a minimum of one duplicate sample is recommended per sampling day or event.

A field duplicate is a second sample collected in the field simultaneously with the primary sample at a single location. The duplicate sample is collected in a separate sample container from the same location and depth as the primary sample (Figure 7-43). The results of the duplicate field sample can be used to calculate a relative percent difference to provide information on consistency and reproducibility of field sampling and lab analysis procedures.

Trip Blanks

A trip blank should be included at a minimum of one trip blank per sampling day or shipment cooler for vapor or indoor air samples collected using sorbent tubes or passive samples. Ensure that the laboratory includes at least one trip blank for each batch of sorbent tubes to be shipped back for analysis.

The trip blanks and media should be the same as the collection devices to be used in the field and prepared at the same time and in the same manner by the laboratory. The trip blank is included with sample collection devices to be used in the field and stored, shipped, processed and analyzed in the same manner as the actual samples. The results of the trip blank sample can be used to evaluate if the storage, shipping and handling procedures are introducing contaminants into the samples, or if the original packing material or the laboratory equipment was potentially contaminated.

Trip blanks are not necessary for Summa canister samples (e.g., an unused canister), since the blank would only indicate if that particular canister had leaked. A minimum, residual vacuum of 3-5 inches of mercury is instead recommended in order to determine if the canister leaks or is otherwise tampered with prior to analysis by the laboratory. Labs also have a rigorous certification process for Summa canisters and flow regulators prior to shipment for sample collection.

Equipment Blanks

An equipment blank should be collected as part of an indoor (or less commonly outdoor) air study when very low VOC action levels are being applied. An equipment blank is collected by passing clean air or nitrogen through the soil vapor probe parts (tubing, tips, sample train) into the sample container at the beginning of the sampling event. The blank is then analyzed with the actual indoor samples to determine if any contaminants are in the equipment. Equipment blanks are not generally necessary for soil vapor samples, since it is less likely that contamination in tubing or other equipment will in itself cause reported levels of VOCs to exceed the comparatively higher soil gas action levels (e.g., 1,000 times higher than indoor air action level for residential soil gas action levels; HDOH, 2016).

7.13.4.2 LABORATORY QUALITY CONTROL

The accuracy of an analytical method depends on sample handling and preparation and maintenance of the analytical equipment. Most analytical methods recommended by the USEPA include minimum quality control measures designed to assess the performance of the analytical procedures. Minimum quality control measures should include the calibration of instruments and an assessment of the analytical accuracy and precision (USEPA 2000d, API 2005). Analytical accuracy and precision are typically assessed through the use of method blanks and laboratory control samples (see Section 10). Additional details on quality control measures for analytical methods are included in the method documentation (USEPA 1998b; USEPA 1999b; USEPA 2004e).

7.14 DATA EVALUATION

Refer to the HEER Office Environmental Hazard Evaluation (EHE) document for guidance on the comparison of soil vapor and indoor air data to published action levels. The interpretation of data is a key element in planning the project as the data will drive the decision. When planning an investigation, project planners should agree on interpretation of the data before the samples are collected. Although not required, at least initial comparison of the data to HEER Office action levels will significantly expedite data evaluation and decision making.

7.14.1 SOIL VAPOR SAMPLE EVALUATION

The HEER Office EHE document provides risk-based, soil vapor action levels and additional guidance that can be used to screen sites for potential vapor intrusion hazards (HDOH 2017a; see also Sections 7.1 through 7.3). The collection of soil vapor data is recommended when the concentration of a VOC exceeds its action level for groundwater, or when a significant source of VOCs is suspected in vadose-zone soils (Section 13.2). Vapor intrusion action levels for soil are also provided in the HDOH EHE guidance document. Extrapolation of the concentration of a VOC in soil vapor from soil data is considered highly unreliable, however, due to the complexities of soil chemistry.

LVP subslab vapor data are directly comparable to HDOH (2017a) action levels for vapor intrusion risk. Comparison of small-volume soil vapor data, or data representative of only small-volumes of vapor collected at individual sample points, to soil vapor action levels should be done with caution and used in conjunction with other lines of evidence to assess potential vapor intrusion risk, especially if LVP data are not available. Be aware that random, small-scale variability in VOC concentrations within a vapor plume can hinder the interpretation of small-volume sample data (Section 7.5). Reliance on small-volume vapor sample data to estimate the approximate large-scale boundaries of a vapor plume is currently necessary, however.

Groundwater and soil vapor action levels for vapor intrusion are intended to be paired (HDOH 2017a). Empirical data and corresponding models suggest that the concentration of a VOC will not exceed the soil vapor action level at a distance of ten feet (three meters) from the top of the water table. Soil vapor data are therefore not normally necessary if vapor intrusion action levels for groundwater are not exceeded and groundwater data can reasonably be assumed to be representative of potential vapor emissions. Unexpectedly high concentrations of VOCs in soil vapor samples collected ten or more feet from groundwater can usually be attributed to some combination of the following scenarios:

1. Unidentified source in nearby, vadose-zone soils (most common);
2. Chemical present primarily in vapor phase (e.g., PCE vapors in dry soil beneath slab of a dry cleaner);
3. Groundwater source area closer than ten feet from soil vapor sample point (default depth to water table used in models);
4. Non-representative soil data (reliability of most soil VOC data from discrete samples is very low; see Section 4);
5. Non-representative groundwater data (e.g., heterogeneous plume with isolated “hot spots” nearby); or
6. Relict vapor plume associated with earlier migration of more heavily contaminated groundwater through area in past or post remediation of groundwater contamination.

The heterogeneity of contaminants in groundwater plumes has not been studied in detail. Heterogeneity can be expected to be significantly greater in sources areas in comparison to down-plume areas, although the latter could be characterized by discontinuous plugs of heavier contamination that reflect variability in source area releases over time.

As discussed in the EHE guidance document, soil vapor data may not be sufficient as a stand-alone tool to determine if a vapor intrusion hazard is present or absent. A “multiple lines of evidence” approach should be used to evaluate the vapor intrusion pathway. This includes consideration of the following factors, among others:

- Source area size and volume (e.g., free product on groundwater >100m^2 in area and/or >10m^3 contaminated soil present; refer to HDOH, 2007c);

- Mass of VOCs present in the source media (e.g., soil or groundwater) and associated volume of contaminated soil necessary to sustain long-term, vapor emissions over the assumed exposure duration (e.g., six to thirty years; see Section 7.5; can include use of mass-balanced vapor intrusion models);

- Design of potentially affected buildings and the completeness of possible vapor intrusion pathways (e.g., cracks, or gaps in the floor around utilities), including nature of the building ventilation system and the potential for the building to be consistently under-pressured, and thus more susceptible to subsurface vapors;

- Potential for intruding vapors to impact indoor air above known or anticipated background concentrations of targeted VOCs, due to emissions from unrelated, indoor or outdoor sources (note that this may not necessarily negate the need for remedial actions);

- Comparison of indoor air data, if collected, to anticipated, background levels of targeted VOCs.

The first two factors are sometimes referred to as “source strength.” For a long-term, vapor intrusion risk to be present, the source strength must be significant enough to sustain an average vapor flux rate above soil gas action levels for the assumed exposure duration (e.g., six to thirty years; see Section 7.5). The use of a multiple-lines-of-evidence approach allows investigators to more accurately assess the current or future completeness of the vapor intrusion pathway on a site-specific basis and determine if long-term, adverse impacts to indoor air are likely. Currently HEER Office guidance recommends a focus on subslab soil gas data for final decisions regarding potential vapor intrusion risks from multiple compounds, such as chlorinated solvents and petroleum. This is intended to target vapors at the point they could enter a building. This also takes into account attenuation from the source area and/or biodegradation.

Soil vapor sample analytical results should be initially compared to Shallow Soil Gas action levels for evaluation of potential vapor intrusion concerns, published in the EHE document (HDOH, 2016, Table C-2 in Appendix 1). The collection of Large Volume Purge (LVP) sample data immediately beneath the building slab is recommended (Section 7.4).At sites where the EALs for shallow soil gas are approached or exceeded, the need for the collection of additional soil vapor samples and a more thorough evaluation of potential vapor intrusion pathways should be evaluated. Indoor air samples may need to be collected if subslab data or other information suggests potential impact above anticipated background (see Section 7.7).

Based on past experience, scenarios where subslab soil vapor data does not suggest a potentially significant impact to indoor air (e.g., above indoor air action levels) but vapor sample data from relatively shallow source areas exceed action levels is fairly common, especially for petroleum. In these cases, sealing of gaps and cracks in floors and an evaluation of the adequacy of the building ventilation system is recommended as a precautionary measure, although not necessarily required.

As discussed in Section 7.7, the collection of indoor air samples is only recommended when concentrations of VOCs in subslab soil vapor or other information suggest that indoor air could be impacted above anticipated, background levels. As a general guide, testing of indoor air to evaluate potential vapor intrusion impacts is only recommended when concentrations of targeted chemicals in subslab soil vapor are more than one-thousand times typical indoor air concentrations for residences and two-thousand times typical indoor air concentrations for commercial/industrial buildings (assumed indoor air:subslab soil gas attenuation factors; see Subsection 13.2 and Table 7-2; see also HDOH, 2016).

7.14.2 INDOOR AIR SAMPLE EVALUATION

Determining the source of VOCs identified in indoor air can be challenging, if not impossible, unless reported concentrations are significantly above anticipated background levels, significant VOC levels have been documented in soil vapor samples collected immediately beneath the building slab, and clear entry points have been identified. If collected, indoor air data should be compared to both risk-based action levels and typical background concentrations (e.g., USEPA 2011d). A summary of action levels and typical background concentrations of common VOCs is provided in Table 7-2 in Subsection 7.7.1.

Data from air samples taken in various parts of a building can be reviewed and compared to help identify contaminant concentration gradients or specific vapor intrusion points. For example, data for basements, bathrooms, kitchens, utility rooms or elevator shafts that suggest VOC concentrations above anticipated background with decreasing concentrations higher in the building are suggestive of a subsurface source. However, the building should be inspected prior to sampling to eliminate the presence of other indoor sources, such as stored chemicals in a basement (see Subsection 7.7).

If impacts to indoor air above anticipated background are identified and subslab soil vapor data as well as other lines of evidence suggest a likely subsurface source, then actions will be *required*. Potential actions are briefly discussed in the next section.

If impacts to indoor air above anticipated background are *not* identified but subslab soil vapor concentrations exceed action levels, then measures to avoid potential future impacts to indoor air may be *recommended*, although not formally *required*. This will depend on site-specific circumstances. For example, sealing of floor cracks and gaps and a check of the building ventilation system may simply be *recommended* in cases where subsurface vapors are associated with a relatively small source area of

petroleum-contaminated soil or groundwater. In contrast, measures to eliminate potential vapor pathways might be *required* at a site where elevated concentrations of chlorinated solvents in soil vapors associated with a large source area are identified immediately beneath a building slab or in nearby, shallow soil vapor, even though adverse impacts to indoor air have not been specifically identified.

If impacts to indoor air above anticipated background are *not* identified and subslab soil vapor concentrations do not exceed action levels, then no further action will generally be *required* with respect to the subject home building. If subsurface data indicate a potentially significant vapor plume, however, then sealing of cracks and utility gaps in floors and an evaluation of the building ventilation system is *recommended* as a precautionary measure. Note that remediation of the source area may still be necessary regardless of the absence of clear impacts to existing buildings if source area soil, groundwater and/or soil vapor data suggest potential future vapor intrusion risks or other environmental hazards. Refer also to the HDOH technical memorandum *Long-Term Management of Petroleum-Contaminated Soil and Groundwater* (HDOH, 2007c).

As a general rule a home or building should *not* be flagged for potential vapor intrusion hazards unless this is supported by multiple lines of evidence, including indoor air data well above anticipated, background levels. Doing so could cause significant legal and financial problems for the property owner, even though no impact has been demonstrated. In such cases, it is more appropriate and responsible to state that "Conclusive evidence of adverse, vapor intrusion has not been documented" than an open-ended statement such as "Vapor intrusion into the home (or building) could not be discounted." Due to the sensitivity of testing indoor air in private residences and buildings, and the challenges posed by distinguishing indoor or outdoor sources of VOCs from subsurface sources, an "innocent until proven guilty" approach for the investigation of potential vapor intrusion hazards is recommended.

Precautionary measures are recommended, however, for sites where significant subsurface source exists even though adverse, vapor intrusion impacts have not been identified. As discussed above, this will typically include sealing of cracks and utility gaps in floors as well as an evaluation of building ventilation adequacy.

7.14.3 ADDITIONAL EVALUATION AND REMEDIAL ACTIONS

Assuming that the data are representative of long-term site conditions, and within the limitations described in the EHE document (HDOH, 2016), VOCs in groundwater or soil vapor below the corresponding Tier 1 EALs can be assumed to not pose a significant vapor intrusion threat.

If multiple lines of evidence such as those noted above indicate significant impacts to indoor air of existing or future buildings, then additional evaluation or remedial actions will be warranted. This will typically include the removal of vapor intrusion pathways for existing buildings (e.g., sealing of cracks and gaps in floors, etc.) and remediation of contamination in the source area to reduce soil vapor levels to below levels of potential concern. An evaluation of the adequacy of the building ventilation should also be carried out. Example guidance includes:

- *Building Air Quality, A Guide for Building owners and Facility Managers* (USEPA 1991d);
- *The Inside Story: A Guide to Indoor Air Quality* (USEPA 1995f);
- *Building Indoor Air Quality Action Plan* (USEPA 1998f);
- *Indoor Air Quality Building Education and Assessment Model* (USEPA 2008d).

A detailed review of site-specific vapor intrusion risks can also be carried out if desired and can include the preparation of site-specific human health risk assessments, vapor intrusion models and alternative action levels. This level of effort is unlikely to be necessary or cost-beneficial for typical, small sites, however.

A detailed discussion of source area remediation and vapor mitigation is beyond the scope of this section but will be included in future updates to the TGM. Proposed mitigation measures should be discussed with the HEER Office on a site-by-site basis. The extent and nature of source area remediation is dependent in part on extent and location of the contamination. For example, removal of the floor and excavation of contaminated soil might be the most cost- and time-effect means to address a localized area of solvent-contaminated soil beneath the floor of a former dry cleaner. Some combination of excavation, soil vapor extraction, in situ injections, or thermal treatment might be required for a site with extensive contamination.

At some point full remediation of a source area may not be practical from a cost or technical standpoint and engineered and/or institutional controls may be needed for existing or future buildings. Sealing of floors and/or improved ventilation may be required for existing buildings. In some cases the installation of a subslab ventilation system could be required. A vapor mitigation system for a new structure might include one or more of the following components (e.g., refer to USEPA 2008c, CalEPA 2011b):

- Base of permeable fill with collection system of perforated pipes and risers;

- Impermeable membrane beneath slab;
- Passive or active venting system above ground, or passive system with the ability to switch to active as needed (e.g., risers with wind-activated turbine vents and option for blowers, etc.); and
- Permanent soil vapor monitoring points through slab and within collection system.

Passive systems may need to be switched to active to address methane hazards or the buildup of very high levels of solvent or petroleum vapors beneath the slab. Monitoring points within the slab and collection system can be used to evaluate the effectiveness of remedial actions and natural attenuation, as well as to ensure flow in risers, and to support proposals to cease mitigation effects due to a reduced vapor intrusion risk.

7.15 DOCUMENTATION OF SOIL VAPOR OR INDOOR AIR SAMPLING

A soil vapor or indoor air investigation report should be submitted to the HEER Office for review following each sampling event. The investigation report is often prepared as a standalone document, although it can be included as an appendix in a larger investigation report. Information on recommended format and content requirements for Investigation Reports is included in Section 18. The submittal of a workplan for soil vapor and/or indoor air investigations is also strongly encouraged.

The soil vapor or indoor air investigation report should include a thorough description of all field operations, deviations from the approved work plan, data results (including data inconsistencies or laboratory analytical flags) and an analysis and interpretation of the data. All soil vapor or indoor air investigation reports should include a site plan map identifying soil vapor or indoor air sampling locations. The relative location of soil and groundwater contamination with respect to locations of sampling probes and all current or proposed future buildings should also be depicted on the figures. Field activities during vapor point installation and sample collection should be fully documented in the final investigation report. For sites where soil vapor or indoor air samples are collected from permanent probes, the probe construction details should be included in the investigation report. All field data including flow rates and pressure readings (from a vacuum gauge) during sample collection should also be included in the investigation report. Additional information that should be presented for the collection and interpretation of LVP sample data is summarized in Section 7.8.4.

The soil vapor or indoor air analytical data should be summarized and presented on a table that facilitates a review of the spatial and temporal trends as well as the relationships between lateral and vertical sampling locations.

SECTION 7 REFERENCES

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SECTION 8
FIELD SCREENING METHODS

Interim Final - July, 2017

State of Hawai'i
Department of Health
Office of Hazard Evaluation and Emergency Response
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SECTION 8 ACRONYMS AND ABBREVIATIONS

°F	Degrees Fahrenheit
µg/g	Micrograms per Gram
µg/L	Microgram per Liter
2,4-D	Dichlorophenoxyacetic Acid
BTEX	Benzene, toluene, ethylbenzene, and total xylenes
CAS	Chemical Abstract Service
COPC	Chemicals (or Contaminants) of Potential Concern
CPT	Cone Penetrometer Technologies
DNAPL	Dense Non-Aqueous Phase Liquid
DPT	Direct Push Technologies
DSITMS	Direct Sampling Ion Trap Mass Spectrometry
DU	Decision Unit
eV	Electron Volt
FFDs	Fuel Fluorescence Detectors
FID	Flame Ionization Detector
GC/MS	Gas Chromatography-Mass Spectrometry
HDOH	Hawai'i Department of Health
HDX	Octahydro-1,3,5,7-Tetranitro-1,3,5,7-Tetrazocine
HEER Office	Hazard Evaluation and Emergency Response Office
IDW	Investigation-Derived Waste
LIF	Laser-Induced Fluorescence
LNAPL	Light Non Aqueous Phase Liquid
mg/kg	Milligrams per kilogram
MI	Multi Increment
MIP	Membrane Interface Probe
MIS	Multi Increment sample(s)
mL	Milliliter
mm	Millimeter
PAH	Polynuclear Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
PCDDs/PCDFs	Polychlorinated Dibenzodioxins and Polychlorinated Dibenzofurans
PCE	Tetrachloroethylene
PCP	Pentachlorophenol
PID	Photo Ionization Detector
ppm	Parts per million
ppmv	Parts per Million by Volume
QA/QC	Quality Assurance and Quality Control
QAPP	Quality Assurance Project Plan
RDX	Hexahydro-1,2,5-Trinitro-1,3,5-Triazine
ROST™	Rapid Optical Screen Tool
SAP	Sampling and Analysis Plan

SOP	Standard Operating Procedure
SSCS	Site Specific Calibration Standard(s)
TCE	Trichloroethylene
THMs	Trihalomethanes
TNT	2,4,6-Trinitrotoluene
TPH	Total Petroleum Hydrocarbons
TPH-D	Total Petroleum Hydrocarbons-diesel range
TPH-G	Total Petroleum Hydrocarbons-gasoline range
USEPA	United States Environmental Protection Agency
UV	Ultra Violet
XRF	X-Ray Fluorescence

8.0 FIELD SCREENING METHODS

The Hawai'i Department of Health (HDOH) Hazard Evaluation and Emergency Response Office (HEER Office) supports the use of field screening methods to help streamline the site investigation or remediation process. This Section provides a general overview of selected field screening methods that have been approved by USEPA or other state environmental protection programs and is not intended to be comprehensive. A number of companies market field screening kits or instruments based on the methods described below or similar methods developed by a specific company. Alternative methods should be discussed with the HEER office on a site-by-site basis. Periodic updates on field screening methods will be included in this TGM Section. Detailed information is not provided on analytical systems used in conjunction with field screening on direct-push field platforms, including laser-produced fluorescence, membrane interface probes and fiber-optic chemical sensors. Refer to the USEPA link for Field Analytic Technologies noted in Table 8-2 for more detailed information on these methods.

The use of field screening methods is consistent with the "Triad" approach to site investigations promoted by the USEPA (USEPA, 2010e, Triad Resource Center, 2011). This includes the use of real-time field measurements to guide an investigation or remedial action, and optimize available resources as well as reduce the need for multiple remobilizations. Field screening should follow the same systematic planning steps outlined in Section 3 of the TGM. Site investigation objectives and decision statements should be developed to guide the investigation. This should include a thorough review of the site history to identify areas for targeted collection of field data, in addition to visual clues such as soil staining, obvious disposal areas, etc. Fixed laboratory data are generally collected for final decision making purposes. As described in this section, benefits of field screening include:

- Identification of contaminants of potential concern;
- Identification of areas of relative higher and lower contamination and the general magnitude of contamination in order to assist in initial site evaluation and Decision Unit (DU) designation for more detailed characterization;
- Rapid identification for removal of heavily contaminated soil prior to confirmation sampling using DU and Multi-Increment Sample (MIS) investigation approaches;
- Assessment of contaminant variability at the scale of individual sample points in order to estimate and optimize the mass and number of increments for Multi Increment (MI) sample collection;
- Selection of samples for initial laboratory analysis;
- Pre-screening of samples to optimize selection of laboratory analysis method (e.g. identification of low- or high-concentrations samples for the laboratory); and
- Carry out health and safety monitoring to determine possible worker hazards or exposures (generally not overseen by HDOH).

Field screening methods generate qualitative data (e.g., presence or absence),semi-quantitative data (e.g., above or below a pre-specified concentration), or quantitative data (specific concentration of targeted chemicals), depending on the method employed. It is important to understand both the advantages and limitations of the methods discussed. Field screening can be carried out *in situ*, without disturbing the targeted soil, or *ex situ*, on samples collected from targeted areas. *Ex situ* screening has traditionally been carried out on discrete samples but may also be used to screen MI samples (e.g., field XRF). The time and cost required to meet necessary data quality requirements for final decision making purposes utilizing field screening methods should be considered as part of the site investigation planning and site data quality objectives.

Note that a single test on a small mass of soil (e.g., one to ten grams) is unlikely to generate a representative mean concentration for either the bulk sample collected or the soil immediately surrounding a sampling point (refer to TGM Sections 3 and 4). Screening data for individual sample points should be used in a semi-quantitative manner, with the understanding that concentrations of the targeted COPCs in immediately surrounding soils could vary by up to an order of magnitude or more. The objective of screening is not to identify the "maximum" concentration of the COPC in the bulk sample or DU, since this is entirely dependent on the volume/mass of soil tested. Testing a small number of the likely millions of potential small masses of soil at a site will not identify the maximum concentration of the COPC present, and doing so is not relevant to investigation objectives.

The quality of field screening data will depend on representativeness of the sample tested and the method used. Higher quality field screening that generates concentrations of targeted contaminants is sometimes referred to as is “Field analysis” (see Subsection 8.2). Field screening should always be carried out in terms of “DUs” and well-thought-out DU questions and objectives, even if MI samples will not be collected at this point in the investigation (refer to Section 3). Testing of small masses of soil from unprocessed discrete samples, for example, are highly prone to error due to random small-scale distributional heterogeneity and variability of contaminant concentrations within any given mass of soil, including individual samples (see Subsection 4.1.1). This and other factors discussed below (e.g., soil moisture, particle size differences) can lead to “false negatives” or erroneous “cold spots” that lead to an underestimation of the extent and magnitude of contamination. Processing samples prior to screening when practical (e.g., drying and sieving prior to field XRF analysis) can help address these types of errors. However, the data are still subject to small-scale variability and erroneous decisions regarding apparently isolated “hot spots” and “cold spots.” At the other end of the spectrum, field XRF analysis of processed MI samples with accompanying field QA/QC by trained and experienced persons can generate high-quality data that rivals or exceeds laboratory data (refer to case study in Subsection 8.4.1). High quality data can also be obtained using field Gas Chromatography (GC). This could include the preservation of MI samples from excavation sidewalls or targeted intervals within borehole cores in methanol and analysis in the field to guide additional remediation or testing.

While large-scale patterns might be discernable from grid point sample data, boundaries between areas of “clean” and “contaminated” soil can be difficult to accurately establish based on traditional soil data (see Section 4). The zone between clean and heavily contaminated soil in particular is typically marked by scattered seemingly isolated “cold spots” and “hot spots” at the scale of a discrete sample (refer to XRF case study in Subsection 8.4.1. It is highly probable that this reflects random, small-scale variability of contaminant concentrations in the soil. If a new and independent set of discrete samples was collected across the same area, a similar pattern of cold spots and hot spots may appear, but in different locations. It is therefore important not to over interpret individual “cold spots” and “hot spots” identified with discrete sample data. Removal of soil in the immediate vicinity of apparent “hot spots” identified by a single or even a small number of discrete sample points is unlikely to reduce the average concentration across the area as a whole (see Section 4 for more detail on discrete sample variability). Properly designated DU-MIS soil samples are necessary to confirm initial estimates of the extent and magnitude of contamination based on grid point screening data.

This same type of random, distributional heterogeneity can introduce error in attempts to collect “splits” of samples for comparison of field screening data and fixed-laboratory data. Laboratory data may not necessarily be more accurate or representative of the original bulk sample if the sample handling and processing are not conducted appropriately. A significant and random variability between field and lab data could simply reflect inadequate processing of a sample before the splits were prepared. Refer to TGM Section 4 for additional information on subsampling of bulk samples for separate analyses.

When understood in this context, even qualitative and semi-quantitative screening data based on testing of samples from grid points designated across a targeted area could still be useful for the initial estimation of “clean” and “contaminated” areas, and improve the efficiency of more detailed followup investigations. Use of a field XRF by experienced personnel as discussed below is one example. Multi Increment samples tested at a fixed-laboratory are recommended to confirm initial decisions (see Section 4). Final confirmation could in theory be accomplished with field screening data provided that the following criteria are met: 1) An adequate number of increments (for MI samples) or alternative types of samples (e.g., discrete) of proper shape and mass are collected (see TGM Section 4 discussion of increment mass and shape), 2) The samples are assigned to well-thought-out DUs that include consideration of risk to human health and the environment as well as potential removal or remedial actions (refer to TGM Section 3), 3) Field QA/QC methods are comparable to QA/QC methods that are used at a fixed laboratory, 4) An adequate correlation of field screening data versus fixed-laboratory data is accomplished, and 5) Data for a subset of DUs are verified by replicate/independent sets of samples (refer to TGM Subsection 4.2.7).

The USEPA maintains a detailed overview of Field Analytic Techniques (USEPA, 2007). Refer to EPA's web page for additional information. New methods are constantly being developed and can be discussed with HDOH for site application. Field screening methods for site investigation and cleanup are typically followed by or used in conjunction with laboratory analysis testing for decision-making. Used in concert with laboratory analysis measurements, field screening data can serve to expedite site characterization or site remediation activities and reduce overall costs.

8.1 SELECTING A FIELD SCREENING METHOD

There are a number of important considerations that must be taken into account when proposing a field screening method. This list includes items that should be evaluated (at a minimum) for each project:

- Target Analytes: Field screening methods generally provide results for either a specific compound or a specific class of compounds. For example, if the site contaminant is petroleum, but the specific concern is polynuclear aromatic hydrocarbons (PAH), select a method that targets PAHs, not just petroleum hydrocarbons. Additionally, the available field screening methods may not have adequate selectivity to test for specific compounds within a class of chemicals (e.g., individual PAHs or PCB isomers).

- Action Levels: Field screening methods may have higher detection limits than laboratory methods and some methods may not be sensitive enough to meet applicable action levels. Field methods should have adequate sensitivity to meet the goals and objectives established in the site SAP/QAPP.

- Matrix Effects: Some field screening methods may have limited usefulness with certain sample matrices. An example of matrix effects is soil with a high clay or organic carbon content, which can cause an immunoassay test to be biased low. Other examples of matrix effects include moisture or the presence of large pebbles in soil being screened with a field XRF. A preliminary study using soil from the targeted site is recommended prior to the beginning of field work in order to evaluate potential limitations of the proposed field screening methods. Calibration of equipment with site-specific or soil type-specific samples/standards and other methods recommended by the field screening test kit or instrument manufacturer can compensate for some of these effects.

- Data Use: Field screening methods generate a wide range of data quality, from purely qualitative data (e.g., presence or absence) to quantitative data that rivals or even exceeds laboratory data depending on the sample type, processing and QA/QC (e.g., field XRF). The HEER Office currently requires laboratory-quality confirmation data for final decision making, especially for clearance of “clean” areas from further investigation. Field screening can be used to designate DUs (see TGM Section 3) for more detailed characterization and/or guide initial removal/remediation actions (refer to XRF case study in this Section). Field screening is best employed when the site contaminants of concern are known and a better understanding of the nature and extent of the contamination is needed for site characterization or for a removal or remediation response action. Particular attention should be focused on those portions of the site characterization and/or removal/remediation action that require documentation of contaminant levels below applicable EALs for final clearance (i.e., “Perimeter DUs”). Laboratory confirmation data will generally be required for these areas.

- Training: Many field screening methods employ specific kits or special field equipment, which requires properly trained personnel to conduct the testing. Standard operating procedures for the use of any field screening method(s) should be included as an Appendix to site-specific Sampling and Analysis Plans.

More information on topics discussed in this section can be found in Site Investigation Design and Implementation (see TGM Section 3) and in Data Quality Assurance and Quality Control (see TGM Section 10).

8.2 DATA QUALITY CONTROL AND DOCUMENTATION

Table 8-1 summarizes the data quality levels and objectives of "field screening." and "field analysis" data. Field analysis is used to discuss data quality control for quantitative field methods that can approach and even exceed laboratory quality data, though in many situations the cost of field analysis level data (with laboratory confirmation analyses) could exceed the cost of DU-MIS sampling with laboratory analysis.

Table 8-1 Data Quality Levels for Field Screening and Field Analysis Methods

Data Quality Level	Purpose of Testing (Examples)	Example Methods
Screening – Qualitative or Semi-Quantitative	• Approximating known contaminate magnitude • Assist in identification of DUs • Initial estimates of excavation limits • Health and safety evaluations	Portable PID, VOC headspace analysis, *in situ* XRF, colorimetric analyses, and *in situ* sensor or probe equipment.
Field Analysis – Quantitative (with QC similar to a fixed laboratory analysis)	• Site characterization • Excavation delineation	*Ex situ* XRF, and many immunoassay, colorimetric, and turbidimetric kits, with laboratory confirmation data

Field screening results can be presented in terms of presence or absence or in terms of relative concentration, for example above or below a pre-specified limit. The Photo Ionization Detector (PID), used to identify the presence and relative abundance of volatile organic chemicals (VOCs) in soil, is one of the most common field screening tools (see Subsections 8.4.2 and 8.4.5). Some PIDs can be used to measure both total VOCs in vapors emitted from soil as well as concentrations of a limited number of individual compounds (e.g., benzene). Another example of a field screening tool is a colorimetric field test kit for petroleum that is pre-set to a target concentration of TPH (e.g., 500 mg/kg). In some cases, screening may identify the total concentration of a family of contaminants but not concentrations for targeted, individual compounds needed for final decision making. This is true for some PAH field test kits. Due to potential matrix effects from moisture and large particles, the *in situ* use of a field XRF is considered "screening" level data, even though it reports specific concentrations of metals in soil.

Quality control procedures for the field screening methods typically consist of:

1. Familiarity with the instrument operation and operations manual;
2. Instrument calibration consistent with operations manual instructions; and
3. Written documentation of calibration(s), any instrument maintenance, and data collected in the field.

Field analysis results are, in contrast, intended to match quantitative data that would be obtained from a laboratory. The objective of field analysis is to estimate the mean concentration of a targeted contaminant in a specific area and volume of soil (i.e. DU) and/or for an individual sample. Examples include immunoassay kits to test for PCBs or the use of an XRF to test processed, ex situ soil samples for metals. In the case of the immunoassay kits the mass of soil tested is similar to the correlative method used by a laboratory (e.g., ten grams). A single test may be adequate to represent the sample in terms of sampling theory, assuming that the sample is adequately processed and subsampled (see representative sampling information in TGM Section 4). Averaging multiple tests of a single sample will be required with use of a field XRF, however, since the mass tested during a single reading is relatively small (e.g. approximately one gram).

Data for discrete samples, while accurate for the specific mass of soil tested, are difficult to extrapolate to bulk sample submitted for testing or identify localized areas of contamination due to random, small-scale heterogeneity (see TGM Section 4 and XRF case study in Subsection 8.4.1). The collection of grid point samples of sufficient mass (e.g., 300+g) from multiple points within a small area (e.g. 1-2m^2), rather than from single locations can help improve data representativenes and reduce this uncertainty. Note that such samples are sometimes referred to as "composites" by field workers, although in a strict sense of sampling theory (and in some regulatory applications) this term specifically infers the mixing of soil from otherwise separate DUs and its use as described above is discouraged (refer to Subsection 4.4.11). While potentially useful to help identify large-scale patterns of contamination and plan more detailed investigations or for initial identification and removal of areas of contaminated soil, HDOH considers this type of data to be adequate for screening purposes only. The designation of DUs and collection of MI sample data as described in Section 3 and Section 4 is recommended for final decision making.

Use of field analysis methods requires more attention and quality control in the field than screening methods, including:

1. Calibration of instrument;
2. Preparation of field standards using soil from the site or same soil type from near the site;
3. Preparation of comparibility curves (e.g., XRF vs lab extraction data; updated as the project proceeds);
4. Documentation of representative sampling/analysis methods
5. Field replicates;
6. Blank data;
7. Documentation of data printouts or read-outs; and
8. Field-laboratory data correlation.

Most field analysis method documentation includes a section that describes method precision and accuracy, as well as method limitations. These aspects of the method should be consistent with the goals established in the QAPP. The method of laboratory confirmatory analysis should also meet the project data quality objectives.

Traditional laboratory data are currently relied upon for final decision making purposes. Correlation analyses can be performed for field and laboratory confirmation data to utilize in data interpretation and decisions (if correlations are good). This might include, for example, correlation of the concentration of arsenic reported through use of *ex situ* field XRF analyses to USEPA Method 6010B (ICP) laboratory analyses (e.g., refer to discussion of Field XRF below). A minimum of ten to twenty samples should be submitted for laboratory analysis in order to carry out a comparability analysis of field screening data versus laboratory method data (see Subsection 8.2). Selected samples should span the range of metal concentrations estimated for the field samples and be processed and subsampled at the laboratory using MI procedures (see Subsection 4.2.6). Additional samples should be collected as needed to generate an acceptable correlation. Prediction lines that reflect 95% UCL and LCL confidence interval (or alternative values) should be added to the regression curve in order to assess the precision of an estimated value with respect to the target action level. For example, prediction lines might allow the ICP-equivalent concentration for a field XRF data point to be estimated within a range of +/- 25 mg/kg with a 95% confidence level. If the range of potential ICP concentrations predicted for an XRF data point spans both above and below the action level then a conclusion regarding the presence or absence of a potential environmental hazard (e.g., direct exposure risk) cannot be made for the specified degree of confidence. Certified laboratories are preferred or laboratories with equivalent documentation of QA/QC protocols. The proportion of field samples selected for laboratory confirmation will depend in part on project-specific data quality objectives.

Samples submitted to the laboratory for development of field versus laboratory data correlation analysis must be the same as used in the field or representative splits of the same material (see Subsection 4.2.2 on laboratory sub-sampling for guidance). Submittal of the entire sample that was analyzed in the field is preferable for cases where non-destructive field analysis methods are used (e.g., field XRF). Using a rigorous method to prepare any representative splits of samples is important in order to minimize subsampling error. This can greatly affect the correlation of field data to the laboratory data. Error due to variability in contaminant concentrations at the mass of soil analyzed may be unacceptable unless the same minimum (and representative) mass of soil is analyzed for both tests.

Because the minimum subsampling and analysis mass necessary to reduce fundamental subsampling/analysis error to a reasonable level is related to the maximum particle size in the sample, it is also important that the maximum particle sizes in the sample are known (to select the appropriate minimum subsampling/analysis mass) or that the samples are dried and sieved to a target maximum particle size before analysis in the field and lab, so a target subsampling/analysis mass can be selected. Typically, samples are air-dried and sieved to the < 2 mm particle size, before analysis in the field (e.g. *ex situ* XRF analysis) and laboratory, resulting in a target minimum subsampling/analysis mass of 10 grams. Due to the small mass typically measured by XRF analysis (~ 1 gram), averaging of multiple field XRF analyses (e.g. 10-20 analyses) across the same bulk sample will be

necessary for comparisons to laboratory analyses that use a minimum of a 10 gram representative subsample mass for analysis (< 2 mm particle size samples). This same consideration for minimum subsampling/analysis masses for the maximum particle sizes in the sample may also be a significant issue for other types of field screening or field analysis methods, depending on the typical mass of sample the particular method/instrumentation utilizes, and the data quality objectives for the site investigation (see Section 4 for more information on representative subsampling issues).

Details of the sample processing, subsampling mass, and analytical mass used for the field and laboratory samples should be included in the reporting of field and laboratory sample correlation analyses, and uncertainties discussed. Replicate subsamples should also be used to assess the precision of data and subsampling error. Samples used in the correlation analyses should be selected from the lower, middle, and upper range of concentrations measured in the field analyses, as well as samples with contaminant concentrations at or near the site action levels, if any are found.

A comparison of laboratory and field analysis data can be carried out through either a simple correlation analysis or through a regression analysis, depending on the project objectives (e.g., refer to Yates et al, 2003). A correlation coefficient (r) is used to evaluate the strength of the relationship between field and laboratory data, within the limitations described above for error associated with subsampling of the parent sample. The correlation should be positive. The association between the two data sets strengthens as the coefficient approaches 1 (see Yates et al, 2003; Taylor, 1990). Coefficients less than 0.35 are generally considered to represent low or weak correlations. Coefficients values between 0.36 and 0.67 are considered to reflect modest or moderate correlations. Values between 0.68 and 1.0 are considered to be strong, with r coefficients at or above 0.90 considered to be very high.

The data plots should be reviewed to further interpret the nature of the correlation. A strong correlation but consistent variability in field versus laboratory data (e.g., field data consistently lower or higher) can be interpreted to indicate a true difference in the methods. A strong correlation with random variability (e.g., field data randomly higher or lower than laboratory data) could reflect heterogeneity in the soil and difficulty in obtaining representative splits of a sample for field versus laboratory analysis. The lack of a strong correlation between field and laboratory data does not necessarily indicate that the field screening data are “wrong.” This could instead simply reflect the presence of significant short-scale heterogeneity within the samples and error associated with processing and subsampling and/or variability and error in one or both test methods. Determining the exact source or sources of error will require additional studies and may or may not be cost and time beneficial for the subject site investigation.

Laboratory data are preferred for comparison to action levels or for use in risk assessments. If a strong, linear correlation exists between data sets (i.e., $\geq$0.68) then a regression analysis can be carried out to quantify this relationship and predict the laboratory-equivalent concentration of a chemical in soil based on field screening data (Yates et al 2003; see also Cutler 2009, 2011). This can significantly improve interpretation of field screening data and confidence in initial decision making. Combined with the use of DU and MIS investigation approaches and associated field and laboratory QA/QC this level of effort could be used to complete a site characterization investigation and/or site cleanup action based on field screening/analysis approaches alone, and avoid the delay and added cost associated laboratory data. The HEER Office may, however, recommend DU-MIS with laboratory analyses for final confirmation samples (after cleanup actions) in these cases. The use of field screening/analysis data in conjunction with or in lieu of laboratory confirmation data should be discussed with the HEER Office project manager on a site-specific basis and documented in the site investigation or removal/remediation report.

8.3 FIELD SCREENING METHODS AND DOCUMENTATION

Field screening methods with supporting documentation equivalent to that published by the USEPA for standard laboratory methods typically offer a higher level of data quality and reliability (e.g., SW-846, USEPA 2010). Documentation for the field screening methods describes the intended use, proper application, interferences, and overall performance in comparison to laboratory methods. The methods also list the required equipment, supplies, reagents and standards as well as information on safety, pollution prevention, and waste disposal. In addition, the methods typically provide a procedure that outlines required quality control, calibration, data analysis and result calculation. As described in Subsection 8.4 below and in the links to USEPA methods, documentation has been published by the USEPA for many but not all field screening methods. Field screening methods from a source other than the USEPA methods would ideally cover the same level of detail, but at a minimum, documentation for field screening methods should cover the following:

1. Method Description: A summary of the method and instrumentation, including a list of target analytes and detection limits.
2. Calibration: Typically the HEER Office prefers a daily 3-point initial calibration, although some methods may only require a monthly initial calibration. A mid-level continuing calibration standard which is analyzed every 20 samples is recommended; however, some methods may only require one such standard at the beginning and end of daily sample analysis. The method should include criteria as to what constitutes an acceptable initial and continuing calibration.
3. Blank: The HEER Office prefers a baseline or a blank every 20 samples; however, some methods may only require a blank at the beginning of daily sample analysis. The method should include criteria as to what constitutes an acceptable blank.
4. Corrective Action: The method should include corrective actions for failure to meet the criteria for initial calibration, continuing calibration and/or blanks.

Field screening method information should be presented in the form of a standard operating procedure (SOP) and included in the QAPP. Documentation of the field use of a field screening method should be recorded on established field data sheets which at a minimum include:

1. Instrument: Type, maintenance, initial and continuing calibrations, blanks, and any failure to meet criteria along with the corrective action taken.
2. Sample analysis: Date and time of analysis, sample identification, instrument reading, including data analysis and result calculation if applicable.

Example sources for field screening methods are provided in Table 8-2:

Table 8-2 Sources for Field Screening Methods

Source/Website	Comments
USEPA's Field Analytic Technologies (USEPA, 2007), http://clu-in.org/characterization/technologies/	Overview of multiple field analytic techniques, with links to the majority of documents included on the Clu-in web page
USEPA's SW-846 Methods: http://www3.epa.gov/epawaste/hazard/testmethods/sw846/online/	Use search function to locate specific field screening methods
USEPA's Expedited Site Assessment Tools For Underground Storage Tank Sites (1997):http://www.epa.gov/sites/production/files/2014-03/documents/esa-ch6.pdf	1997 overview of field methods for petroleum

USEPA ETV Program: http://www.epa.gov/etv/	View information under subheading "Verified Technologies"; includes links to supporting documents.
ASTM International: http://www.astm.org/Standard/standards-and-publications.html	Use search function to look for specific method information.
Interstate Technology and Regulatory Council (ITRC): http://www.itrcweb.org/Guidance	See field measurement methods in the Triad Approach and Site Characterization and Monitoring topics
California Environmental Technology Certification (ETC) Program: http://www.dtsc.ca.gov/TechnologyDevelopment/TechCert/index.cfm Due to state funding shortfalls, these certifications are no longer current; however, the website is still a potential resource on field screening methods.	See ETC "Hazardous Constituents" List for substance-specific technologies

8.4 FIELD SCREENING METHODS FOR SELECT CONTAMINANTS AND MEDIA

Information is provided below for examples of field screening methods (USEPA methods or state environmental program methods) that may be applicable for site investigations or removal/remediation work. For USEPA methods, check for the latest applicable method editions at the SW 846 methods website (USEPA, 2010). Other sources of field screening methods may be acceptable, as discussed in Subsection 8.3. Site investigation typically includes both horizontal and vertical delineation of contaminants and this should be considered when selecting applicable field sample collection and screening or analysis methods.

8.4.1 METALS

Type of Contamination		Applicable Methods	
		Method Reference	Method Name
Metals	Soil and Sediment	USEPA 6200	Field Portable X-Ray Fluorescence (XRF) Spectrometry for the Determination of Elemental Concentrations in Soil and Sediment



Figure 8-1 *In situ* and *ex situ* analysis of soil using portable XRF unit.

Method 6200 (USEPA 2007g): **Field Portable XRF Spectrometry for the Determination of Elemental Concentrations in Soil and Sediment**

Method: XRF uses either sealed radioisotope sources or X-ray tubes (more current technology) to irradiate a soil sample. This incident radiation dislodges electrons from the innermost electron shells creating vacancies, which are filled by outer shell electrons. This rearrangement of electrons results in emission of X-rays (or X-ray fluorescence) that is characteristic of a specific atom and can be quantified. A single reading typically tests up to one-gram of sample, depending on the XRF being used. Source radiation and detector performance may vary by manufacturer and model. Field calibration standards, and calibration standards (or standard reference materials) should be employed for calibration and QA/QC measures. Those involved in sampling and testing should be trained in the use of the device and in radiation safety in accordance with manufacturer specifications and state radiation safety policy.

Detection limits vary from <10 to >200 milligrams per kilogram (mg/kg) depending on the instrument type and settings, the acquisition time used to collect a reading and the target element. The analyst should be trained in the use of the device, including XRF theory, instrument operation and calibration, detection limits, sample collection and processing, potential interferences and biases, QA/QC and data interpretation, and radiation safety (Kalnicky 2001; see also Geotek 2013,b). An overview of these issues is provided below but is not intended to serve as a replacement for formal training.

Due to advances in X-ray tube technology and difficulties in transporting radioactive materials, most field-portable XRF instruments currently use X-ray tubes. Some simple instruments have a few operating modes (i.e. alloy analysis, soil analysis, etc.) and built-in software, which provides real-time numeric concentrations for various elements. More advanced instruments allow flexibility in operational settings (tube voltage and current settings; filters for conditioning x-ray source, etc.) and collection of XRF spectra for later processing and analysis. Note that XRFs used in Hawai'i must be registered in the State of Hawai'i through completion of a Department of Health Radiation Facility License (http://health.hawaii.gov/irhb/radforms/). A copy of the XRFs license should be maintained by the user in the field, along with contact information for the specific entity that the XRF is registered under. Consultants who intend to bring XRF equipment in from out-of-state must ensure that the equipment is first registered and that a copy of the RFL license is included. If the specific type and model of equipment to be imported is unknown, then this can be noted on the form as "to be determined".

XRF technology can provide comparable or higher quality data for total metal concentrations in soil in comparison to standard laboratory extraction/analysis methods, even when highly quantitative and accurate methods such as Inductively Coupled Plasma (ICP) are used by the laboratory to analyze the extract. This is primarily due to the incomplete extraction and corresponding under reporting of metals at the laboratory using common acid digestion methods (e.g., 3050B acid digest). For example, a comparison of XRF versus ICP data (Method 6010B) for soil samples collected as part of an internal HDOH project (HDOH, 2015) indicated consistently higher concentration of arsenic, copper, iron and zinc for the XRF data (average 30-60%). In some cases, however, the XRF reported a consistently lower concentration of a metal in comparison to the ICP data. In the cited example, reported concentrations of lead were similar but slightly lower (average -7%) for the XRF, possibly due to interference from moisture in the soil. The precision of laboratory data can be improved by using a more vigorous extraction method such as Method 3051A (microwave digestion). Both XRF and ICP methods have spectral overlap limitations that must be evaluated by an experienced operator of the analytical equipment.

The common laboratory USEPA 3050B acid digest method, though not as complete a digestion as stronger acid digest methods, could be considered by some to more accurately reflect "available metal" exposures for site receptors. Higher total metal analysis results for XRF and strong acid digestion methods in the laboratory can be due, in part, to metal concentrations that are bound tightly in the matrix of the soil particles and not readily bioavailable, even if the soil was ingested by a site receptor. Therefore, the choice of laboratory sample digestion methods for comparison to in situ or ex situ XRF metals data will affect the resulting correlation analysis and data interpretation, and should be considered/addressed in the site investigation DQOs and discussed with the laboratory. As in any investigation, systematic planning and clear site investigation objectives are an important part of field XRF screening investigations (refer to Sections 3 and 4 for further information). USEPA Method 6200 provides information relevant to data quality objectives specific for use of an XRF (USEPA 2007g).

Target Analytes: The number of metals that can be tested depends on the type of XRF used. Target elements of potential environmental concern at sites in Hawai'i are typically limited to lead, arsenic and mercury (refer to Section 9). Lead is commonly found in soil impacted by lead-based paint, lead shot, and fill material that includes incinerator ash. Arsenic contamination is associated with the use of arsenic-based herbicides and can be very localized (e.g., at former pesticide mixing sites or from historic weed control around electrical substations) or widespread (e.g., due to past use for weed control in sugarcane fields). Mercury can be encountered at former sugar cane seed dipping facilities.

The need to test for and report other metals as potential contaminants of concern should be examined as part of the Systematic Planning process (TGM Section 3) and included in the site investigation work plan. Anthropogenic-related soil contamination associated with metals other than lead, arsenic, and mercury above levels of potential concern is rare in Hawai'i. Note that naturally occurring concentrations of heavy metals in the iron-rich, volcanic soils of Hawai'i can be significantly higher than typically found on the mainland US (e.g., cadmium, chromium, titanium, vanadium and zinc; see HDOH, 2012). These background concentrations of metals are tightly bound to soil particles (e.g., iron hydroxides) and do not pose a risk to human health and the environment (see also HDOH, 2016). Binding of arsenic residues to soil also significantly reduces the bioavailability and potential health risk posed by this contaminant (e.g., see Cutler 2011) and Cutler et al. 2013). In the case of arsenic, bioaccessibility testing data rather than total concentration data are used for human health risk and removal/remediation decision making purposes (HDOH, 2011c).

Advantages of Field-based XRF:

- *In situ* or *ex situ* analysis can be performed.
- Samples can be analyzed in minutes.
- Samples can be analyzed for multiple elements (metals) simultaneously.
- Many XRF instruments are portable and can operate in the field on battery power.
- Samples are not destroyed and can be re-analyzed or further analyzed in the lab by other methods.
- Simple sample preparation means little to no waste generation (i.e., no acids, solvents, etc.).

Limitations of Field-based XRF:

- Detection limits may vary significantly depending on the type of XRF instrument, x-ray sources, detection resolution, sample matrix, moisture content, and the metal being measured. Detection limits, depending on conditions and operating parameters can be higher than laboratory-based analytical methods, so project specific reporting limits should be evaluated to determine if XRF is appropriate, and what XRF instrumentation and operating parameters would work best.

- Physical matrix effects result from variations in particle size, uniformity and sample surface (ideally flat and smooth). If it is determined that physical matrix effects are impacting XRF measurements, these limitations can be managed by proper *ex situ* sample preparation including sample drying, sieving and increasing the number of points tested within a sample in order to both reduce and better represent variability within the sample.

- Moisture content can affect sample results. Field studies have indicated that the XRF fluorescence signal and calculated element concentration can be reduced by as much as 1 percent for every 1 percent increase in soil moisture (Cutler 2009). This limitation can be initially evaluated by pre-testing soil samples from the site under both field-moist and dried conditions. Potential interference from moisture can also be managed by uniformly drying (*ex situ*) samples before analysis (air or oven drying at ≤40°C preferred). Alternatively, moisture content can be determined in samples after field XRF analysis in field-moist condition, and results corrected for moisture effect (analogous to a laboratory reporting concentration in dry weight basis after applying a moisture correction). To perform such moisture correction, a calibration curve between XRF response and moisture content for each element of interest is required.

- Different metals can produce XRF spectral responses that interfere with one other because of peak overlap or absorption/enhancement phenomena. Most of these interferences are corrected automatically by modern XRF instrument software or post-acquisition software; however, they are best handled by calibration using site-specific calibration standards (SSCS), as described below. Hawaiian soils derived from volcanic materials contain high concentrations of iron (up to 20% by weight), titanium (up to 5%) and other heavy metals. The presence of these metals can greatly reduce fluorescence intensity of other elements (e.g., refer to Geotek 2013). For example, high iron can interfere with the accurate analysis of cobalt. Reported chromium concentrations can be falsely elevated in the presence of iron. High titanium can interfere with analysis for barium. Obtaining accurate element concentrations in high-iron soils (or sediments) requires use of calibration standards with similar atomic density, or better yet the use of SSCSs.

- Quantification of arsenic with elevated lead can be problematic due to fluorescence peak interference (USEPA 2007), as the dominant lead peak (L-alpha) emits at the same energy as the dominant arsenic peak (K-alpha). Lead concentrations can be readily determined from an alternate (secondary) peak; however, the arsenic secondary peak, depending on the instrument, might be too weak for quantification at concentrations of interest (e.g., below the Hawai‘i background concentration of 24 mg/kg). Newer XRF instruments and their robust built-in analysis software do an excellent job of quantifying lead and arsenic based on analysis of multiple fluorescence peaks. If analyzing samples for arsenic in the presence of lead, a subset of samples should be analyzed by laboratory methods to confirm XRF accuracy.

- A specific license, including a radiation safety course, is required to operate some XRF instruments that have radioactive source materials (hence most portable units now utilize x-ray tubes). Follow instrument-specific instructions to ensure proper operation of equipment. Persons using the instrument, or working in the vicinity of the instrument, should be trained on x-ray safety as per instrument guidance.

HEER Office recommendations (see also Geotek 2013b):

Calibration Standards

- Calibration standards (standard reference materials [SRMs]) are materials with similar chemical and physical properties as site samples, but with known concentrations of the elements of interest, analyzed in conjunction with site samples (unknowns) to allow calculation of element concentrations in unknowns. SRMs are often provided with rental XRF instruments, or can be obtained through entities such as National Institute of Standards and Technology (NIST).

- Some XRF instruments have pre-defined calibrations for “typical” soil materials built into “canned” instrument software (“fundamental” calibration). Results using these calibrations should be verified with laboratory testing of the same sample, taking into account potential laboratory processing/extraction error.

- Site-specific calibration standards (SSCSs) are also recommended in order to address differences in commercial SRMs (Standard Reference Materials) and local soils. Samples of soils from the study site (or a site with similar soil type) are collected prior to field work. Elements of interest are determined by laboratory analysis using EPA analytical methods (e.g., for most metals, acid digestion by 3050B [often incomplete digestion] or 3051 [more complete digestion since it

employs microwave heating] and ICP analysis of digest by 6010 [ICPES] or 6020 [ICPMS]). Either contaminated site samples (unspiked) or spiked (element of interest added at known concentration) samples can be used as SSCSs. Spikes can be prepared, for example, by drying and sieving a sample (typically a site sample screened by XRF to have low concentrations of the element of interest) to an appropriate grain size (<2mm for most site assessments), spiking the sample with the element(s) of interest to generate a desired screening concentration, and then analyzing the sample by laboratory methods for verification of the spiked concentration. High-quality SSCSs can be prepared at the laboratory and analyzed using a nearly complete acid extraction (e.g., USEPA Method 3051) and Inductively Coupled Plasma Mass Spectrometry analysis (ICP-MS). Two or more spiked samples that cover the potential range of contamination anticipated are typically prepared for use as SSCSs in the field (e.g., 50 mg/kg, 200 mg/kg and 1000 mg/kg for arsenic). These SSCSs can subsequently be used throughout a study to either: 1) confirm instrument performance in the field or 2) create a calibration curve to correct instrument readings to final reported concentrations.

- The XRF should be calibrated daily during field work per manufacturer specifications using commercially available Standard Reference Materials (SRMs) such as those supplied by National Institute of Standards and Testing (NIST) or SSCSs. This typically includes soil standards with known metal concentrations (e.g., NIST 2010) but can also include manufacturer-provided stainless steel coins and other materials. Include a known, low-concentration sample to check the instrument reporting level for targeted metals (e.g., a lab-supplied sample or preferably a SSCS). Following the calibration, a blank should be analyzed to confirm negative control (e.g., NIST silicon blank). These materials are typically provided along with an XRF instrument if rented from a commercial vendor. The NIST metal standard or preferably a SSCS should then be used to confirm positive control.

- More detailed, calibration curves to improve the accuracy of field data can be developed by comparison of XRF and laboratory analysis data for splits of multiple samples across a range of metal concentrations (e.g., see Cutler 2009). The resulting data can be used to develop algorithms for adjustment of XRF-generated concentrations to equivalent laboratory method concentrations. A minimum of 3-4 SSCSs are recommended for initial development of a calibration curve (more if a good linear calibration curve is not achieved over the measurement range of interest).

- Caution is advised for comparison of field XRF data against laboratory data. Sample preparation (e.g., drying, sieving and subsampling), sample heterogeneity (e.g., inadequate number of sample points analyzed in field), and laboratory acid digestion methodology (e.g., Method 3050B versus 3051A) are far more likely to be the cause of conflicting results than the analytical method used to test the sample (XRF versus ICP).

- Samples from the site (or a site with similar soil type and climate setting) should also be collected (prior to the primary investigation) to test for matrix suitability and potential interferences. For example, soil moisture is known to interfere with XRF readings. Prior to the investigation, samples can be collected during rainfall conditions similar to anticipated conditions during the actual investigation. Tests made on both moist and dried samples can provide information on potential moisture interferences in the field. This can be used to calibrate the XRF prior to field screening to account for moisture interference.

***Ex situ* XRF Screening**

- *Ex situ* screening of soil is likely to provide more representative and useful data than *in situ* analysis. In situ testing is prone to error due to small-scale random, small-scale variability of metal concentrations in soil as well as matrix interferences (refer to Subsection 4.1.2).

- A Decision Unit (DU) should be designated for a specific area of interest (e.g., suspect Spill Area DU or targeted Exposure Area DU; refer to Subsection 3.4). A Multi Increment sample consisting of 30-75+ increments should then be collected from the targeted DU and tested in the field using a portable XRF (see Subsection 4.2 and Section 5).

- Alternatively, a grid of "discrete" sample points can be used to help identify large-scale patterns of contamination and designate DUs for more detailed characterization (refer to Subsection 4.3). The collection of traditional 100-200g discrete soil samples from a single location is not recommended due to the uncertainty imposed by potential random, small-scale variability of contaminant concentration around individual grid points (see Subsection 4.1.2). As an alternative, large-mass discrete samples can be prepared by the collection of a minimum of 300g of soil from multiple points (e.g., 5-10+) within a short distance (e.g., one meter) of a grid point (see Subsection 4.3). This will improve the representativeness of the sample data for the subject grid point.

- Samples should be manually mixed to reduce variability prior to XRF testing, but be aware of separation of fines from coarser material. Coarse material should be removed prior to testing (e.g., >2 mm; plant roots, stones, etc.). If samples are dry enough, field sieving to the <2 mm size fraction and mixing can reduce small-scale variability and improve measurement accuracy. Potential interference from moisture can be addressed by drying samples before analysis (air or oven drying at ≤40°C preferred). Alternatively, the moisture content of field samples can be determined after analysis and results corrected, if a calibration curve between XRF response and moisture content for each element of interest has been determined.

- Spread the sample (typically in a plastic bag) to a thickness of 1 to 2 centimeters in order to allow equal access to all portions of the soil sample for X-ray analyses. A minimum of 10 to 20 random locations within the sample (representing a total of at least 10 grams of soil, assuming 0.5 to 1.0 grams tested per reading) should be tested until a reasonably consistent mean can be established that is unlikely to significantly change with additional testing (target a relative standard deviation of ≤20% to determine adequate number of readings). Test locations on both sides of the bagged, spread-out sample.

- Compare the *average* of the readings for a sample to action levels for decision making (refer to Subsection 3.2.1 and Subsection 3.4). Note that small-scale variability within an MI sample (or between discrete samples) is not important in terms of risk. HDOH EALs are likewise *not* intended for comparison to individual, discrete sample data for more than qualitative, screening level purposes (refer to Subsection 4.3).

- The following additional preparation and analysis procedures can be used to improve the quality and reliability of *ex situ* XRF data: 1) Prepare SSCSs to improve XRF measurement accuracy, 2) Inspect raw XRF spectra to ensure data acquisition is executed properly and assess potential interference from overlapping peaks (e.g., arsenic and lead), and 3) Grind (mill) samples to reduce variability if needed and practical for field screening (e.g., check variance of multiple analyses on subsamples of a larger sample to determine whether grinding may be necessary to reduce variability).

***In situ* XRF Screening**

- *In situ* XRF measurements can be used for collection of semi-quantitative data to: 1) Identify potential metals of concern in soils or sediments, 2) Approximate extent of contamination on the project site and aid in the designation of DUs, and/or 3) Aid in determining locations for collection of MI samples for *ex situ* measurements.

- *In situ* samples generally consist of exposed surface or subsurface soils (i.e. excavation sidewalls) and are analyzed by XRF in place. User's should be aware that single, *in situ* tests are highly prone to error associated with random, small-scale heterogeneity (i.e., variability over a few inches; refer to Subsection 4.1). Soil contaminant concentrations at the scale of an individual XRF reading can vary dramatically over short distances. Slightly offset, replicate measurements should be taken at each location to improve accuracy for the targeted sample location. Be aware that concentrations can also vary significantly and randomly over distances of a few feet, and patterns suggested by individual test points are also prone to error.

- Readings should be biased to areas of finer-grained soil (i.e., <2 mm particle size), and avoid taking readings on rocks or other large debris. Use a trowel or similar device to lift grass and organic material away from the targeted soil. A small piece of polyethylene film or similar material should be placed against the soil in order to protect the XRF detector. Detector window films (typically mylar) can easily rupture. The detector should not be used in any capacity with a ruptured window film. Care should be taken when replacing a window film to not allow soil or dust to enter the instrument.

- Ensure the XRF instrument can tolerate rain conditions, if encountered. Use a plastic bag or other rain protection for the instrument when needed in the field, or consider collecting *ex situ* samples and testing them at a fixed and protected location on- or off-site.

- Follow manufacturer specifications regarding acquisition time for the sample analysis (e.g., 30 second measurement typically recommended). Longer acquisition times can improve reporting levels, and may be desirable in certain situations.

- SSCSs are recommended if improved measurement accuracy is needed. If only relative element concentrations are required, default instrument calibrations or commercial standard reference materials (SRMs) can be used for calibration.

Additional Information:

Sample Type
Screening of Multi Increment samples can be useful for rapid assessment of contaminant levels in a targeted area (e.g., spill areas of suspected significant contamination or exposure areas for evaluation of direct-exposure risk, etc.) as well as guide designation of additional DUs for sample collection prior to demobilizing the field team. A minimum mass of 1 to 2 kilograms is recommended for MI samples. A minimum sample mass of several hundred grams is recommended for discrete samples. Sample collection for surface and subsurface soils is described in TGM Subsections 4.4 and 4.5.

Sample Drying
Air or oven dry (≤40°C) the entire sample (typically) to reduce interferences from moisture and improve the accuracy of the XRF readings. Air drying in humid settings could leave 5-10% moisture in samples, with resulting XRF compound peaks depressed by a similar amount. Oven drying at 40°C produces similar moisture content as air drying in a low-humidity room (although more quickly). In either case, constant sample weight over time will indicate that the sample has been sufficiently dried. After drying,

samples should be crushed or mixed by hand, as necessary, to break up aggregates and then sieved to collect the particle size fraction of interest (e.g., <2 mm particle size for most site investigation work).

Field Subsampling

If necessary, a subsample of the processed or unprocessed sample can be collected for ex situ XRF analysis. This will require additional sample handling and can increase the error in the estimated mean concentrations of metals in the original sample. However, subsampling before analysis may be desirable in some circumstances (e.g. to reduce drying time for very moist soils or minimize interference from large rocks or other debris in gravelly samples).

Physical mixing, drying, sieving and, if warranted, grinding a sample can help reduce variability, but complete "homogenization" of a bulk sample is rarely possible before subsampling and is difficult if not impossible to verify without extensive testing of the sample. Separation of fines during attempts to homogenize samples can lead to further bias in the collection of subsamples for testing. A representative subsample is collected with the use of Multi Increment sampling methods: approximately 30 small increments are collected from systematic random locations across the bulk field sample which has been spread out to a thin layer (see Subsection 4.2.6). Subsampling error (precision) should be estimated from the variance of replicate subsample analyses in terms of relative standard deviation (refer to Section 4). When the original bulk sample has been subsampled for XRF testing, that subsample should be returned to the bulk sample prior to the collection of additional (replicate) subsamples for testing.

XRF Analysis

Concentrations of elements of interest in site soils are best determined using empirical calibration and SSCSs. Known concentrations of elements and their spectra are entered into instrument software, or post-acquisition spectra processing software, and regression equations (calibration equations) are utilized to calculate concentrations of elements in unknowns (site samples). If there are only one or two elements of interest, and site samples and SSCSs are all similar, calibration equations and determination of concentrations can be handled "manually" in a spreadsheet program. This approach has been shown to be effective for analyzing arsenic in Hawaiian soils (Cutler 2011).

Site samples and SSCSs should be analyzed for elements of interest by optimizing acquisition parameters (if the instrument allows) including tube voltage and current, target X-ray conditioning filters and acquisition time. Multiple readings should be carried out on each sample until the user is confident of the range of targeted metal concentration present at the scale of the mass tested, with the average of the readings used for comparison to action levels. The minimum of readings necessary to estimate a mean metal concentration for a sample is site-and sample-specific. Based on HEER office staff experience a minimum of ten points is recommended in order to assess a target RSD of ≤20%. Significantly more readings might be necessary for soils with a high variability in contaminant concentration. Increasing the number of readings decreases errors in estimate of concentration means for the sample as a whole. Raw XRF spectra should be inspected to ensure data acquisition was executed properly. Software that allows overlay of multiple spectra can help flawed spectra to be identified and discarded prior to analysis for elemental concentrations.

Samples can be analyzed in various sample containers, such as plastic cups with mylar film windows or in thin plastic bags. If using plastic bags, the material should be analyzed with the XRF separately to confirm they do not contain elements of interest. Samples placed in plastic bags should not be later analyzed for phthalates or chemicals that the plastic could contain at significant concentrations.

XRF Field Analyses vs Laboratory Data Correlations

Multi Increment samples and fixed-laboratory data, including proper processing and subsampling of bulk samples, are normally required for final decision making purposes unless otherwise approved by HDOH. The entire bulk sample should be submitted to the laboratory for MIS-type processing and analysis. If a subsample is removed for XRF field screening then this should be placed back with the bulk sample before submittal for laboratory analysis.

A minimum of ten samples should be submitted for laboratory analysis in order to establish a correlation of field versus laboratory data (see Subsection 8.2. Selected samples should span the range of metal concentrations estimated for the field samples. Samples submitted to the laboratory to be processed and subsampled using MI procedures described in Section 4. This is the minimum number of samples recommended to establish the correlation of field versus laboratory data. For samples dried and sieved to a maximum particle size of < 2 mm, a 10-gram minimum mass should be representatively subsampled from bulk field XRF samples for laboratory correlation analyses (representative subsampling is typically conducted in the laboratory, but could be conducted in the field with a proper SOP). Samples to be used for XRF vs fixed-laboratory data correlation curves should be selected from the full range of concentrations measured by the XRF, and from different depth intervals, if applicable. They should also include samples with analyte concentrations at or near the site action levels, if present. For some projects, initial samples selected for field and laboratory correlation analysis could be used as the SSCSs during any subsequent phases of the investigation.

The results of the laboratory analyses and XRF analyses should be compared using linear regression analysis. If the measured concentrations span more than one order of magnitude, the data should be log-transformed to standardize variance, which is

proportional to the magnitude of measurements. The HEER Office considers a correlation coefficient (r) for the regression of 0.75 or greater to be considered good quality ($r^2 \geq 0.56$). If the r is 0.9 or greater ($r^2 \geq 0.81$) the data indicates the correlation between the XRF data and the laboratory data are very strong (also see Shefsky, 1997). *Ex situ* XRF analyses are more likely to produce a strong correlation to laboratory analysis results than are *in situ* XRF analyses.

Concentrations of metals reported using an XRF are often higher than reported by laboratory extraction-based methods due to incomplete digestion of the soil at the laboratory. Metals in un-weathered igneous mineral phases present in the soil, in particular silicate minerals, may not be completely dissolved by the commonly used EPA Method 3050B, and the resulting laboratory data will not be representative of the "total" concentration of metals present in the soil (as is represented by the XRF measurements). A more robust EPA digestion method (e.g. 3051 or 3052) can be considered to increase the likelihood that the laboratory and XRF data will be comparable. Also, laboratory matrix spikes run on Hawai'i volcanic soils when using Method 3050 may fail QC criteria due to strong binding to or interference from iron or other compounds. This increases the difficulty of assessing error associated with this digestion method and comparing field XRF vs laboratory results.

However, the use of alternative (stronger) lab digestion methods (e.g., Methods 3051 or 3052) and interpretation of the resulting data should be discussed with HDOH on a site-specific basis. The use of more stronger soil digestion methods could complicate comparison of the data to background metals in soils, since data reviewed for background levels were in part based on Method 3050 (see HDOH, 2012). In addition, the more commonly used digestion method (Method 3050) is also informally assumed by many risk assessors to represent worst-case estimates of the fraction of potentially bioavailable metals in soil. Bioavailability can be reassessed on a site-by-site basis for lead and arsenic through use of bioaccessibility tests, as described in Section 9 and the HDOH EHE guidance document (HDOH, 2016).

XRF Calibration Curves

Calibration curves for field XRF measurements based on site-specific calibration standards (SSCSs) as well as data comparisons to laboratory analyses of the same samples can be used to increase confidence in decision making in the field (see Cutler 2009). A relatively small number of SSCSs can produce a high-quality calibration curve in soils with a relatively low variability in terms of soil characteristics and metal concentrations. More samples (e.g., up to 10 or more) may be required to generate an acceptable regression line in some situations (e.g., USEPA 2007). If more than one soil type is present at a site (e.g., with different proportions of iron), separate sets of SSCSs for each soil type are recommended.

Use of XRF Data for Final Decision Making

It is feasible that the combined use of grids of samples to assist in DUs designation, thorough field QA/QC, replicate sets of data for select DUs, and strong correlation of field data with fixed laboratory data could allow final decision making at a site based primarily on grids of field XRF sample data in the absence of MIS confirmation data (refer to Section introduction). This is especially true for cases where random variability of contaminant concentrations in soil is anticipated to be low based on past experience at similar sites or previous studies at the subject site. The case study provided below approaches this idea, but uncertainty in the interpretation of seemingly isolated "hot spots" and "cold spots" and the mean concentration of arsenic in soil along the perimeter of heavily contaminated areas necessitates the collection of MIS confirmation samples prior to or following initial remedial actions. Although still considered "screening level" data, the thorough manner in which the data were collected significantly expedited the site investigation and allowed for initial remedial action plans to be developed. Conclusions drawn from the data and initial remedial actions are to be confirmed through a followup, DU-MIS investigation.

Investigation Report

The following information should be in included in a site investigation report when XRF data are collected:

- Printout of raw, XRF data for the project that includes calibration data and corresponding sample ID numbers (include as an appendix);
- Summary of *ex situ* sample collection methods including DU designation, number of increments collected, tools used, sample container, approximate sample mass, etc., and/or summary of *in situ* testing method used;
- Summary of field processing, including removal of large material, moisture testing, drying and subsampling, as applicable;
- Preparation of site-specific calibration standards, if used;
- Summary of XRF instrument utilized, including maker, beam strength used, calibration method, and other pertinent information;
- Summary of XRF testing method, including targeted metals, XRF read time, number of points tested, problems encountered in the field, etc.,
- Summary of XRF data and laboratory data comparison and, if prepared, calibration curves based on site-specific samples;

- Discuss how the XRF data were used for decision making in the field and will be used for any subsequent investigation work, and other information pertinent to the project.

Case Study – Arsenic at a Pesticide Mixing Site (see also Cutler 2009):

Elevated arsenic was identified in MI samples collected from a nine-acre, former pesticide mixing area. The past history of the site suggested that contamination was likely to be localized in the northwestern area of the property. In order to confirm and expedite identification of this area, ninety discrete soil samples with a mass of a few hundred grams each were collected in a grid pattern across the property and analyzed for total arsenic with a field-portable XRF. A subset of these samples was analyzed offsite for both total arsenic (USEPA Methods 3050B/6020) and bioaccessible arsenic (environmental hazards from direct contact to arsenic-contaminated soil are managed in the State of Hawai'i by evaluating bioaccessible arsenic). From this data a correlation was developed between the total arsenic (measured by XRF) and bioaccessible arsenic. This allowed initial estimate of the area and volume of contaminated soil above bioaccessible arsenic thresholds, and better cost estimates for evaluation of remedial alternatives. Confirmation sampling using the DU/MIS process will be guided by the discrete sampling and field XRF analysis results.



Figure 8-2 Use of portable XRF for ex situ soil analysis at an industrial site in Hilo. Screening of soils for arsenic and lead in field-moist condition. Samples analyzed in sealable plastic bags.

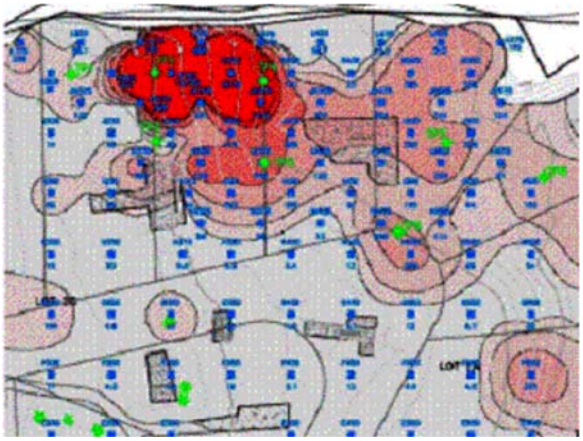


Figure 8-3 Map of total arsenic concentrations in discrete surface soil samples at a former pesticide-mixing site, measured by field-portable XRF. Red area indicates most contaminated soil.

The XRF data indicate a core area of arsenic contamination in the location of a known, former pesticide mixing area on the property. The model-generated sharpness of boundaries between "clean soil" and "contaminated" soil is misleading, however, and gives a false sense of resolution (see Section 4). As the mean concentration of arsenic in the soil situated between the heavily contaminated area and the apparently clean area begins to approach the target action level, smaller-scale variability in concentrations within the soil will begin to be exhibited in the form of seemingly isolated "hot spots" and "cold spots" above and below the target action level. These spots are "real" in terms of the soil samples tested, but cannot be accurately extrapolated beyond the mass of the soil tested with any degree of certainty, based on the discrete sample data alone. The identification of a hot spot or cold spot at any given location within this transition zone could instead be purely random in nature. If additional samples were collected a short distance away, then concentrations could be reversed, with "hot spot" areas turning "cold" and vice versa. Removal of isolated, sample-size hot spots is unlikely to reduce the overall, mean concentration of arsenic within this zone. Perimeter DUs should instead be designated for these areas and MI samples used to estimate mean contaminant concentrations for comparison to action levels (refer to Section 3).

This type of heterogeneity-derived variability is commonplace in attempts to generate isoconcentration maps from large amounts of discrete data. Such patterns are readily apparent in maps of background metals in soil published by the US Geological Survey (USGS 2014). As stated in that document:

"Soil geochemistry can vary considerably over (the distance between sample points), and this variation will not be accurately portrayed by the (isoconcentration) interpolation procedure. This study… (was) designed to reveal regional-, national-, and continental-scale geochemical and mineralogical patterns extending over thousands or hundreds of thousands of square kilometers. The resulting data sets are not appropriate for the accurate estimation of the concentration of a given element or mineral at a site (location) where a sample was not collected."

8.4.2 PETROLEUM

Type of Contamination		Applicable Methods	
		Method Reference	Method Name
Petroleum	Soil	USEPA 4030	Soil Screening for Petroleum Hydrocarbons by Immunoassay
Petroleum	Soil	USEPA 9074	Turbidimetric Screening Method for Total Recoverable Petroleum Hydrocarbons in Soil
Petroleum	Soil	RemScan (REMScan, 2014)	Infrared Spectrophotometry
Petroleum	Soil	USEPA Innovative Technology Verification Reports (USEPA, 2008)	Various (see reference), examples include Chemetrics, Inc. “Remediaid TPH Starter Kit”, and Sitelab Corporation’s “UVF 3100 TPH Analytical Test Kit”
PAHs	Soil	USEPA 4035	Soil Screening for PAHs by Immunoassay
Petroleum	Soil	Maine DEP-SOP:TS004	PID Bag Headspace Test
Petroleum	Soil	Maine DEP-SOP:TS004	Oleophilic Dye Test

Current field screening methods are not capable of separately reporting TPH aromatic and aliphatic fractions. If needed, contact the laboratory for more detailed information on these types of analyses.

USEPA 4030 (USEPA, 1996l): **Soil Screening for Petroleum Hydrocarbons by Immunoassay**

Method: Test kits are commercially available for this method and the manufacturer's directions should be followed. The soil sample is extracted, filtered, and the sample extract and an enzyme conjugate reagent are added to immobilized antibody. The enzyme conjugate competes with the TPH present in the sample for binding to the immobilized anti-TPH antibody. The test is interpreted by comparing the sample response to a reference response.

Target Analytes: Depending on the testing product selected, results can be used to determine relative levels of TPH (low, medium, high) or whether the sample exceeds a threshold concentration (5, 25, 100, or 500 mg/kg).

Advantages:

- Samples can be analyzed quickly and on-site.
- Method is not affected significantly by moisture content or pH.

Limitations:

- Small mass of soil tested;
- The sensitivity of any immunoassay kit depends on the binding of the target analyte to the antibodies used in the kit. These kits are most sensitive to small aromatic compounds (ethylbenzene, xylenes, and naphthalene), while petroleum fuels tend to be dominated by aliphatic compounds.
- Non-TPH compounds such as chlordane and toxaphene show cross reactivity and can cause false positives.
- The sensitivity of the test is influenced by the nature of the hydrocarbon contamination and any degradation processes at the site. Although the response of the test to different sites will vary, the results within a site should be consistent and could be interpreted with comparison to laboratory TPH data.
- Organic and clay-rich soils may limit the effectiveness of soil extraction and may require longer extraction times than other soil types.

HEER Office recommendations: The HEER Office recommends an initial site-specific evaluation of this method. Laboratory confirmation data required for final decision making.

USEPA 9074 (USEPA, 2007h): **Turbidimetric Screening Method for Total Recoverable Petroleum Hydrocarbons in Soil**

Method: A sample of soil is extracted with a solvent mixture (primarily methanol), filtered, and added to an aqueous emulsifier development solution. As a result the hydrocarbons precipitate out and become suspended in solution. The sample is measured in a turbidimeter using a beam of yellow light at 585 nanometers (nm). Commercially available turbidimetric kits include the PetroFLAG™ system (see also USEPA 2001f).

Target Analytes: Broad spectrum of petroleum hydrocarbons in the range of 10 to 2000 parts per million (ppm).

Advantages: Samples can be analyzed quickly on-site, and at low cost. Most test kits do not require power or use battery-operated components.

Limitations:

- Small mass of soil tested;
- Potential under reporting of TPH concentration due to evaporation of volatile petroleum hydrocarbon mixtures such as gasoline during test procedure.
- Organic-rich soils can cause a positive interference as naturally occurring compounds become suspended in solution and/or cause a negative interference due to a reduced effectiveness of the extraction.
- Extraction may be difficult with clayey soils.
- Higher moisture content will bias sample results lower because there is a resultant dilution of the extraction solvent.
- The response of individual PAHs varied greatly from compound to compound and therefore use of this method to quantify individual PAHs is not recommended although quantification of PAHs as part of a larger hydrocarbon fraction, such as diesel fuel is recommended.
- Temperature has an effect on the suspension and it is important to recalibrate if temperatures change more than 10 degrees.

HEER Office recommendations: The HEER Office recommends an initial site-specific evaluation of this method. Laboratory confirmation data required for final decision making purposes.

RemScan (REMScan, 2014): **Infrared Spectrophotometry**

Method: This hand-held instrument uses diffuse reflectance infrared spectrophotometry to measure non-volatile TPH compounds (C10 to C36) in soils (see Figure 8-4). It was developed in collaboration with the (Australian) Commonwealth Scientific Industrial Research Organization (Forrester et al., 2012)). It is portable, hand-held, designed for regular field use, and makes direct surface soil measurements (either surface soil or along the surface of soil cores). This device is especially useful to screen for middle distillate fuels (e.g., diesel, kerosene, etc.) and heavier hydrocarbons in soil. Carbonates and natural organic matter can interfere with the infrared signature but this can be accounted for with site-specific calibrations. Moisture contents greater than 5% can also interfere with readings. Air-drying of samples is recommended for best accuracy.

Data Use: Screening.

Target Analytes: Total petroleum hydrocarbons, (C10 to C36) in soils.

Advantages:

- Portable, samples can be analyzed quickly on-site.
- Easy to calibrate in the field
- Minimal sample preparation (primarily just air-drying the surface of the soil, if >5% moisture content.

Limitations:

- Small mass of soil tested. Affected by soil moisture content - air drying before measurement is recommended.
- High cost for purchase (rental may be a more affordable option for limited use)

HEER Office recommendations: The HEER Office recommends an initial site-specific evaluation of this method. Laboratory confirmation data required for final decision making.



Figure 8-4 RemScan handheld infrared spectrophotometry for testing of TPH in soil; produced by Ziltek Pty Ltd of Australia.

USEPA Innovative Technology Verification Reports (USEPA, 2008): Note: Various field testing methodologies are evaluated and detailed in "Verification Reports". For example, two field measurement technologies evaluated and judged reliable for TPH in soil include: 1) the **Remediaid TPH Starter Kit** (USEPA, 2001g) and 2) the **UVF 3100 TPH Analytical Test Kit** (USEPA, 2001g).

Remediaid TPH Starter Kit (USEPA, 2001g):

Method: Measurement based on a combination of the modified Friedel-Crafts alkylation reaction and colorimetry. Dichloromethane is used as a reactant and the solvent to extract petroleum hydrocarbons. Anhydrous aluminum chloride is used as another reactant. At least five grams of soil can be utilized per analysis.

Data Use: Screening.

Target Analytes: Aromatic petroleum hydrocarbons in soil. Includes analysis for a number of petroleum products/fractions, including gasoline, diesel, crude, lube oil, BTEX, and PAHs.

Advantages:

- Can measure a wide range of petroleum products
- Is not sensitive to common chlorinated solvents
- Portable and battery powered colorimeter
- Can be operated by one person with basic wet chemistry skills

Limitations:

- Provides little response for MTBE or Stoddard solvent
- Minor sensitivity to soil moisture

HEER Office recommendations: The HEER Office recommends an initial site-specific evaluation of this method. Laboratory confirmation data required for final decision making.



Figure 8-5 RemediAid Colorimetry test kit for TPH in soil.

UVF 3100 TPH Analytical Test Kit (USEPA, 2001h):

Method: Soil measurement utilizes an ultraviolet fluorescence spectrophotometer. The fluorometer uses a mercury vapor lamp as its light source. Petroleum compounds in soil sample are mixed and extracted with methanol, and the extract is transferred to a quartz cuvette that is placed in the fluorometer. 10 gram soil samples can be analyzed.

Data Use: Screening.

Target Analytes: The test kit can measure gasoline range organics (GRO) and extended diesel range organics (EDRO) separately, by selecting the appropriate emission filter that corresponds to the wavelength those fractions will fluoresce.

Advantages:

- Method detection limits below 10 mg/kg.
- Can be operated by one person with basic wet chemistry skills
- Non-petroleum compounds (e.g. chlorinated solvents, humic acid) do not interfere

Limitations:

- Portable, but needs power source (can use 110-volt or 12-volt outlet from automobile)
- Provides little response for MTBE or Stoddard solvent
- Minor sensitivity to soil moisture

HEER Office recommendations: The HEER Office recommends an initial site-specific evaluation of this method. Laboratory confirmation data required for final decision making.

USEPA 4035 (USEPA, 1996m): **Soil Screening for PAHs by Immunoassay**

Method: A sample of soil is extracted and filtered using a commercially available test kit. The sample extract and an enzyme conjugate reagent are added to immobilized antibody. The enzyme conjugate competes with the PAHs present in the sample for binding to the immobilized anti-PAH antibody. The test is interpreted by comparing the sample response to a reference response.

Data Use: Screening.

Target Analytes: The test is most sensitive to three (phenanthrene, anthracene, fluorene) and four (benzo[a]anthracene, chrysene, fluoranthene, pyrene) ring PAH compounds and also recognizes most of the five and six ring PAHs listed in USEPA Method 8310. This test detects PAHs present at concentrations above 1 mg/kg.

Advantages: Samples can be analyzed quickly, on-site, and at relatively low cost.

Limitations:

- Small mass of soil tested;
- The sensitivity of the test is influenced by the nature of the hydrocarbon contamination and any degradation processes at the site. Although the response of the test to different sites will vary, the results within a site should be consistent and could be interpreted with comparison to laboratory PAH data.
- Field extraction of PAHs may be less effective than the extraction methods used in a laboratory and excessive amounts of oil in soil samples will interfere with the analysis of PAHs.
- Alkyl-substituted PAHs, chlorinated aromatic hydrocarbons, and other aromatic hydrocarbons (dibenzofuran) have been demonstrated to be cross-reactive with the immobilized anti-PAH antibody. The presence of these compounds may contribute to false positives.
- Kits may be damaged if frozen or if exposed to prolonged heat.

HEER Office recommendations: The HEER Office recommends an initial site-specific evaluation of this screening method for each project. Given the uncertainties with the PAH analyses, laboratory confirmation is recommended.

Maine DEP (MEDEP, 2012): **PID Bag Headspace Test for Volatile TPH compounds**

Method: A photoionization detector (PID) uses an ultraviolet (UV) light source to break down chemicals into positive and negative ions that can then be measure with a detector (see USEPA Field Analytic Technologies link in Table 8-2; refer also to RAE Systems 2010). A soil sample is placed in an approved container and the volatile constituents are allowed to come to equilibrium. A minimum 200 gram sample is recommended. The headspace is measured with an isobutylene calibrated PID, and a result expressed in parts per million by volume (also see Subsection 8.6.4). Double layer, metalized polyester/low-density polyethylene bags are recommended as sample containers (e.g., Associated Bag Company Item #183-52) in order to minimize vapor loss during the recommended fifteen- minute equilibration period.

The Maine guidance recommends the following approach:

- Label and open the bags;
- Unfold the bottom gusset to facilitate a uniform headspace volume;
- Place appropriate mass of soil in metalized bag (recommended minimum 200 g);
- Close bag leaving uniform headspace.
- Knead samples (in closed bag) if needed to break up clumps;
- Shake bags for 30 seconds;
- Let stand for 10 minutes (out of direct sunlight) in order for the headspace to equilibrate with the soil;
- Knead/shake bags for additional 30 seconds;
- Let stand for 2 minutes
- Note: the PID reading must be made within 30 minutes of sampling to minimize loss;
- Open bag carefully and insert probe of calibrated PID one third to half way into bag (approximately 4 inches);
- Seal bag as much as possible around probe;
- Allow instrument to read until concentrations start to fall;

- Record highest sustained reading.

Headspace concentration readings must be kept within the PIDs linear range or use the data as minimum concentrations if over the linear range. Concentrations over the linear calibration range could saturate the detector and the instrument may not be able to distinguish between higher levels of volatile compounds. Readings above the linear calibration response range used for the particular PID should be estimated as above the upper calibration concentration utilized (different brands of PIDs could have different linear response ranges, or the documented linear response range could be limited by the calibration standards available).

Either MI or samples collected from individual points can be screened. The HEER office recommends that MI samples be screened when feasible, in order to ensure adequate coverage of the targeted DU area and better represent the results of final confirmation soil samples. If samples from single points are used, then soil should be collected and combined from multiple locations within the immediate vicinity of the sample point in order to reduce the effects of random, small-scale heterogeneity. An adequate number of samples to cover the targeted area should be screened based on professional judgment in the field.

The Maine guidance provides specific PID screening levels than can be used for final, site closure decisions. For example, based on studies conducted by that agency, 200 grams of soil with 25 mg/kg TPHg placed in a 2.5 liter bag should generate a headspace reading of approximately 40 ppmv (based on MiniRAE PID readings, other PIDs may differ). This may prove useful for general screening purposes in the field. Assuming a near linear correlation at low TPHg concentrations in soil, a PID reading of 160 mg/kg would presumably reflect the HEER office Tier 1 EAL of 100 mg/kg for TPHg. A lower PID screening level of 100 ppmv is recommended due to Hawaii's warmer climate (Maine study carried out under controlled temperatures of approximately 70ºF). A PID screening level of 10 ppmv is recommended for soils impacted with middle distillate fuels (e.g., diesel and JP-8) or when the fuel type is unknown. This corresponds to anticipated lower vapor emissions from soils containing 100 mg/kg TPHd in comparison to gasoline-contaminated soils, due to a lower proportion of light-end aromatics and aliphatic compounds in these fuels (assumed 10% of gasoline vapor emissions; see also HDOH, 2012). Consultants report that PID readings below 10ppmv are unreliable for screening purposes and can in particular be biased high due to moisture.

The Maine guidance recommends testing of very small discrete samples under some closure scenarios in order to obtain accurate readings for high PID readings. For example, the guidance recommends the use of a five-gram sample (approximately one teaspoon) and PID reading of 1,500 ppmv (using a MiniRAE PID) in order to assess potential direct-exposure risk to workers with respect to a target soil screening level of 5,000 mg/kg TPHg (the correlation of PID readings and soil concentrations are not strictly linear between low and high TPH concentrations in the Maine study.) Use of a small mass of soil in the 2.5L headspace bag is intended to ensure that the PID detector does not become saturated. At this time, the HEER office has not adopted PID screening levels for final decision making purposes, so concerns of PID saturation and the use of a small sample mass are not applicable and screening of larger and more representative samples continues to be preferred (e.g., MI sample collected from excavation floor or targeted core interval).

Data Use: Screening.

Target Analytes: Gasoline-related volatile aromatic compounds. PIDs are not good indicators of total TPH levels in soil vapors because they do not respond well to aliphatic volatile compounds, which dominate vapors from petroleum fuels (refer to Section 7 and Section 9).

Advantages:

- Samples can be analyzed quickly, on-site, and at low cost.
- Amenable to testing of large samples, including MI samples.
- PID reading cleanup levels presented in Maine DEP guidance can be used for general guidance but collection of soil confirmation samples and comparison to HDOH EALs is currently required for regulatory concurrence.

Limitations:

- Applicable only for soils contaminated with gasoline. Can also be used to screen for diesel, kerosene, JP-8 or other middle distillate fuels in soil but PID response is significantly lower than for an equivalent concentration of gasoline due to low, aromatic content of vapors.
- Requires use of a container that minimizes loss of volatile chemicals during the equilibration period.
- PID requires periodic calibration in field.

HEER Office recommendations: The HEER Office recommends an initial site-specific evaluation of this method. Laboratory confirmation data required for final decision making.

Maine DEP (MEDEP 2012): **Oleophilic Dye Test**

Method: Soil is added to a sample bottle with water and a rapidly dissolving red or blue oleophilic dye. Contents are shaken vigorously. Released petroleum attaches to a polystyrene bead or to the walls of the container. Bead will turn pink or blue, depending on the dye use, if the concentration of petroleum in the soil exceeds the method detection limit (e.g. 500 ppm). Kits tested by Maine DEP include Oil-In-Soil and Oil-Screen-Soil but similar kits may be available from other venders. Red dyes typically most visible. Indigo blue kits available if soil color interferes with interpretation of red dye test kits. Recommended for testing of diesel, kerosene, JP-8 or other middle distillate fuels in soil.

Data Use: Screening.

Target Analytes: Oleophilic, petroleum hydrocarbon compounds (see also petroleum discussion in Section 9).

Advantages:

- Samples can be analyzed quickly, on-site, and at low cost.
- Results can be assessed in terms of “saturated,” “positive,” “slightly positive” and “undetected.”

Limitations:

- Marketed kits only allow testing of small masses of soil (e.g., ten grams of soil placed in 50 ml bottle); may not be practical for screening of MI samples (30 g mass typically tested by laboratory).
- Not applicable for gasoline (only) contaminated sites, heavy crude oils (Bunker C), or bituminous materials like asphalt or waxes.
- Mineral oil and motor oils may be detectable, but detergents in some synthetic oils can interfere with color development in the kits (i.e., potential for false negatives).

HEER Office recommendations: The HEER Office recommends an initial site-specific evaluation of this method.

8.4.3 PCBS

Type of Contamination	Applicable Methods	
	Method Reference	Method Name
PCBs	USEPA 4020	Screening for PCBs by Immunoassay
PCBs	USEPA 9078	Screening Test Method for PCBs in Soil
PCBs	USEPA 9079	Screening Test Method for PCBs in Transformer Oil





Figure 8-6 (A) PCB test kit components and (B) RaPID Assay immunoassay PCB test kits (Method 4020) in use at Kure Atoll (photo courtesy of Element Environmental).

USEPA 4020 (USEPA, 1996n): **Screening for PCBs by Immunoassay**

Method: Test kits are commercially available for this method. A sample of soil and an enzyme conjugate reagent are added to immobilized antibody. The enzyme conjugate "competes" with PCB present in the sample for binding to immobilized anti-PCB antibody. The test is interpreted by comparing the response produced by testing a sample to the response produced by testing a standard(s) simultaneously.

Data Use: Screening.

Target Analytes: PCBs in soils and non-aqueous waste liquids present at concentrations above 5, 10, or 50 mg/kg.

Advantages: Samples can be analyzed quickly and on-site at a lower cost than typically charged by fixed laboratories.

Limitations:

- Small mass of soil tested (typically 5-10g);
- Detection limits for PCBs may not be adequate in either of the field screening methods to meet HDOH action levels. While useful in identifying areas of high concentration, areas with low-level concentrations may be overlooked.
- Poor extraction and correlation to laboratory sample data noted by some consultants for soils with a high clay or organic carbon content;
- Depending on the test kit used, chemically similar compounds (e.g., petroleum hydrocarbons) may exhibit cross-reactivity and produce a false positive test result.

This test method cannot differentiate between different Aroclor mixtures or individual congeners.

HEER Office recommendations: The HEER Office recommends an initial site-specific evaluation of this method. Laboratory comparison data required for final decision making purposes.

USEPA 9078 (USEPA, 1996o): **Screening Test Method for PCBs in Soil**

Method: This electrochemical method can be used to determine the amount of polychlorinated biphenyls (PCBs) contamination in soils if PCBs are known to be the sole organic halogens at the site. Chlorine is removed from the PCB molecule using an organo-sodium reagent. The method is designed to provide quantitative field results over a range of 2 to 2,000 microgram per gram (µg/g, equivalent to mg/kg) PCBs. The test can be useful when screening soil for disposal based on the TSCA-based limit of 50 mg/kg PCBs for municipal landfills. Caution should be used, however, when using results for decision making purposes on discrete samples rather than MI samples.

Data Use: Screening.

Target Analytes: PCBs in soils and non-aqueous waste liquids present at concentrations above 5, 10 or 50 mg/kg.

Advantages: Samples can be analyzed quickly and on-site. Most test kits do not require power or use battery-operated components.

Limitations:

- Small mass of soil tested (typically 5-10g);
- Reacts to all sources of organic chlorine and the presence of chlorine-containing compounds other than PCBs will cause the analyzer to produce false positive results (e.g., organochlorine pesticides such as Technical Chlordane).
- Iodine and bromine containing compounds will also affect results if present in significant quantities.

HEER Office recommendations: The HEER Office recommends an initial site-specific evaluation of this method. Laboratory comparison data required for final decision making purposes.

USEPA 9079 (USEPA,1996p): **Screening Test Method for PCBs in *Transformer Oil***

Method: Method 9079 uses a colorimetric test kit to screen for PCBs in transformer oil at preset levels of 20, 50, or 500 mg/kg based on total organic chlorine detection. Samples are extracted in the field using an organo-sodium reagent. The resulting chloride ions in the sample are measured using a colometric indicator. Test readings typically calibrated to Arochlor 1242 (a lower chlorine content Arochlor) to provide conservative results. The test can be useful when screening transformer oil for TSCA-based limits for disposal options.

Data Use: Screening.

Target Analytes: PCBs in transformer oil present at concentrations above 20 mg/kg.

Advantages:

- Samples can be analyzed quickly and on-site. Most test kits do not require power or use battery-operated components.
- Results considered conservative, so concentrations near (but under) the set points typically provide a positive result, and limit false negative results.

Limitations:

- Water in the sample above 2% will cause low readings and cause a noticeable reaction with the sodium reagent.
- Can only be used for transformer oil, not for PCB contamination in other types of oils.
- Reacts to all sources of organic chlorine and the presence of chlorine-containing compounds other than PCBs will cause the analyzer to produce false positive results (e.g., organochlorine pesticides such as Technical Chlordane).

HEER Office recommendations: The HEER Office recommends an initial site-specific evaluation of this method. Laboratory comparison data required for final decision making purposes.

8.4.4 DIOXINS

Type of Contamination	Applicable Methods	
	Method Reference	Method Name
Dioxins	USEPA 4025m	Screening for PCDDs/PCDFs by Immunoassay
Dioxins	USEPA 4435	Method for TEQ Determinations for Dioxin-like Chemical Activity with the Calux Bioassay

Dioxins is a term used to refer to polychlorinated dibenzodioxin and polychlorinated dibenzofuran (PCDD/PCDF) compounds.

USEPA 4025m (USEPA, 2014b): **Screening for PCDDs/PCDFs by Immunoassay**

Method: This method uses a commercially available enzyme immunoassay (EIA) kit based on a polyclonal antibody specific for PCDD/PCDFs. The kit response correlates with total sample TEQ because the antibody responds to the 17 targeted PCDD/F congeners in approximate correlation with their toxic equivalency factors (TEFs). The kit response to a sample is a single result representing the aggregate of the individual congener responses. Congener separation is not required to use this kit, nor is it possible to generate any congener specific data with the kit.

The sample extraction and one step cleanup specified in the original Method 4025 allowed for only semi-quantitative screening at roughly 500 pg/g. That method remains viable, but the performance of the immunoassay has been improved by substituting a more conventional extraction and a simple and rapid coupled column cleanup. Quantitative analysis is possible to low pg/g levels in soils using the modified method. Detailed information is available from the immunoassay kit manufacturer, which also makes the sample preparation columns. The quantitative performance of this method has been validated by the SITE Program in two separate phases (USEPA 2008f). The effectiveness of the rapid sample preparation (separate from the immunoassay) is indicated by the fact that it is used by numerous labs for cleanup of sample extracts prior to analysis by Method 8290/1613B. Because of these improvements the immunoassay method using the coupled column cleanup is referred to as Method 4025m by the kit manufacturer and most users, to distinguish it from the original Method 4025 (Cape Technologies 2009).

Although an extremely useful screening method, EPA 4025 or its modified version (and other dioxin methods) should not be mistaken for a readily used field method. Mobilization into the field would likely require infrastructure comparable to mobilizing for the field execution of laboratory methods such as 8260, 8015, 8270 etc. (excluding expensive analytical instrumentation).

Data Use: Quantitative data at preselected decision levels (requires comparability analysis with GC/MS data; see Subsection 8.2)

Target Analytes: PCDD/PCDFs in soil to 5pg/g (ppt)(pg/g; equivalent to ng/kg or parts per trillion).

Advantages:

- Rapid testing of samples and reduced cost in comparison to Methods 8280 (or 8290).
- Direct reporting of TEQ dioxin concentration avoids need to adjust results with respect to congener-specific TEFs;
- Qualitative data as TEQ, comparable to Method 8290 in the range of the kit standard curve;
- Effective removal of most interferences by use of the coupled column cleanup, including heavy oils, PAHs, and other problem organics;
- Reduced cost in comparison to GC/MS analyses allows for the inclusion of larger number of QC samples.

Limitations:

- Common organic solvents such as hexane, acetone, and toluene are required for sample preparation;
- Method requires fume hood but can be done in small field lab [note that no liquid acids such as fuming sulfuric are used in 4025m);
- Sample processing and cleanup procedures may limit field use of the kits, although use in a laboratory setting can reduce costs in comparison to GC/MS methods.

HEER Office recommendations: The HEER Office recommends that dioxin levels be confirmed on 10% of the samples using laboratory GC/MS analyses (but at least 3 samples, whichever is greater). The GC/MS analyses should be conducted on samples with the highest-reported, bioassay TEQ dioxins results.

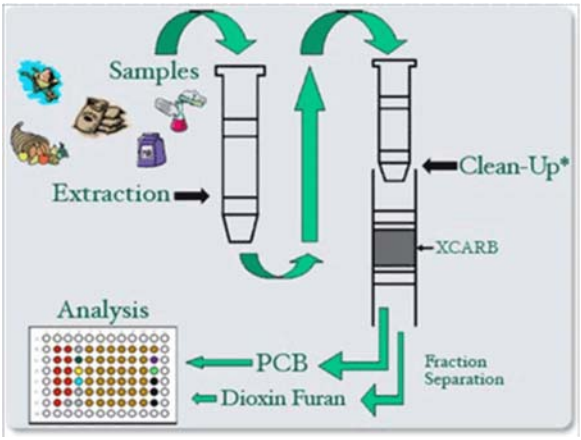


Figure 8-7. Schematic of sample processing steps for use of CALUX bioassay kit for Dioxins and PCBs (Xenobiotic Detection Systems, USEPA Method 4435).

USEPA 4435 (USEPA, 2014c): **Method for TEQ Determinations for Dioxin-like Chemical Activity with the CALUX Bioassay**

In order to evaluate the accuracy and precision of this dioxin bioassay kit for soils in Hawai'i, the HEER Office collected 25 multi-increment soil samples from a former sugar cane field in west O'ahu and tested the samples for toxic equivalent (TEQ) dioxins using both High Resolution GC/MS and CALUX, USEPA Field Screening Method 4435 (HDOH, 2007e). The study showed that

CALUX consistently over predicted TEQ dioxin concentrations in the soil in comparison to the GC/MS analysis. Dioxin TEQ concentrations estimated by CALUX ranged from 96% to 631% higher (average 297%) than Method 8290 data for splits of the MI samples. The difference was significantly higher for samples collected from an adjacent field, with CALUX data ranging from 416% to 1,346% higher (average 905%) than Method 8290 data for splits of the same samples (Tetra Tech 2012). Still other consultants have reported that CALUX produced slightly lower dioxin TEQ values in comparison to Method 8290 for soil with relatively low concentration of dioxins in soil (e.g., <50 ng/kg).

While the correlation of the CALUX test with the GC/MS data is somewhat low, the conservative nature of the CALUX test at concentrations above HDOH action levels supports its use as screening tool to estimate maximum levels of TEQ dioxins in soil. The consistency of the results suggests that the differences are more than random subsampling and laboratory error. This suggests that a pilot study on the use of CALUX methods and development of calibration curves prior to full-scale employment would be advisable.

Method: This method is a bio-analytical screening procedure for dioxin-like compounds in soils/sediments. This method is based on the ability of dioxin and related chemicals to activate the Ah receptor (AhR), a chemical-responsive DNA binding protein that is responsible for producing the toxic and biological effects of these chemicals. This method is a relatively rapid screening method capable of estimating the TEQs concentration for dioxin-like chemicals in a sample. A sample of soil is extracted in an organic solvent and fractionated through the sample processing procedure. An extract that contains the halogenated dioxins/furans is separated from an extract containing the halogenated biphenyls. These extracts are applied to monolayers of H1L6.1c3 cells and the amount of luciferase induction is measured after 20 to 24 hours. A standard dilution series of 2,3,7,8-TCDD is included on each plate of cells. Estimation of dioxin/2,3,7,8-TCDD-like TEQ activity present in the sample extract is performed by extrapolation to the 2,3,7,8-TCDD standard curve by least squares estimates with the 4 parameter Hill Equation. There are three modes by which the DIPS-CALUX bioassay is performed. These are the screening mode with historical recovery, screening mode surrogate recovery, and the semi-quantitative mode.

Data Use: Screening.

Target Analytes: PCDD/PCDFs in soil; a sample size of 2-10 g will typically give a detection limit of less than1 pg/g.

Advantages:

- Rapid testing of samples and reduced cost in comparison to Methods 8280 or 8290.
- Direct reporting of TEQ dioxin concentration avoids need to adjust results with respect to congener-specific TEFs.

Limitations:

- Small mass of soil tested (typically 5-10g).
- Field studies suggest overestimation of TEQ dioxins in comparison to GC/MS methods, especially at concentrations approaching or exceeding HDOH EALs;
- Samples expected to have extremely high levels of PAHs should be subjected to an additional cleanup step.
- Other contaminants in soil and sample extracts can be cytotoxic and impose a positive bias on the test (monitored as part of the method).
- Sample processing and cleanup procedures limit field use of the kits, although use in a laboratory setting can reduce costs in comparison to GC/MS methods.

HEER Office recommendations: The HEER Office recommends that dioxin levels be confirmed on 10% of the samples using laboratory GC/MS analyses (but at least 3 samples, whichever is greater). The GC/MS analyses should be conducted on samples with the highest-reported, bioassay TEQ dioxins results.

8.4.5 VOLATILES

Type of Contamination	Applicable Methods	
	Method Reference	Method Name
Volatiles	USEPA 3815	Screening Solid Samples for Volatile Organics



Figure 8-8 PID for VOC screening

USEPA 3815 (USEPA, 2007i): **Screening Solid Samples for Volatile Organics**

Method: A sample of soil is collected with minimal disturbance to minimize loss of volatile constituents using either a modified plastic syringe or commercially-available coring devices intended for this purpose. The sample is placed in a glass vial with organic-free reagent water, shaken, and a photoionization detector (PID) is used to measure the volatile organics found in the headspace over the sample/water mixture. This method may be especially suitable for screening of low levels of chlorinated solvents in soil. Refer also to field methods described for petroleum in soil in Subsection 8.4.2.

This method is strictly a screening procedure for estimating the total concentration of VOCs in soil and solid samples. This method can be used to estimate the relative concentration of VOCs in soil at a site prior to submittal to a laboratory and assist in the selection of low- or high-level analytical procedures at the laboratory (Hewitt and Lukash 1999). This can help ensure that adequate sensitivity can be achieved, while providing reasonable protection against overloading the analytical instrumentation used in quantitative purge-and-trap or headspace analyses. Use of this procedure may provide cost savings by minimizing the total number of aliquots of *each sample* that have to be collected for analysis by such quantitative laboratory-based techniques. Screening data can be compared to data for previously prepared, spiked soil standards from the site to estimate the concentration of VOC samples. The results of this screening procedure can also be used to guide other sample collection activities.

Data Use: Screening only.

Target Analytes: This method provides an estimate of the total concentration of volatile organics in soil. The method recommends using a standard at 200 ppb and using this standard to classify sample readings as “low” (below 200 ppb) or “high” (above 200 ppb).

Advantages: Samples can be analyzed in 5 minutes. Equipment is portable and battery operated. Sample analysis is cost effective.

Limitations:

- Small mass of soil tested (e.g., 5 grams);
- The type of volatile organics at the site must be known in advance and must be detectable by the PID. While PID responses to halogenated volatiles and aromatics may be fairly similar between compounds, the PID response to alkanes may be lower by an order of magnitude or more.
- As a screening method, this procedure is subject to a wide variety of potential interferences.
- False positives may occur if the PID is exposed to motor vehicle exhaust, solvents used for decontamination, or other sources of volatiles.

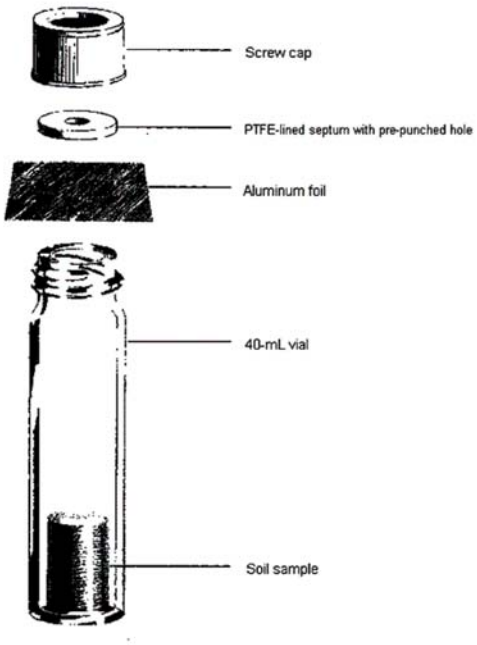


Figure 8-9 Container setup for headspace screening (Hewitt and Lukash, 1999)

HEER Office recommendations: Headspace screening for chlorinated solvents in soil should be performed as specified in this method. Samples for VOC analysis should be collected immediately after the surface to be sampled has been exposed to the atmosphere (Hewitt and Lukash 1999). This includes samples both for screening and subsequent laboratory comparison analyses. The native structure of the material being sampled should experience minimal disaggregation during the collection and transfer process. The collection and transfer process should take less than 30 seconds and the sample weight is approximately (10 ±2 g). The method specified sample container is shown above.

Immediately prior to analysis the vial should be hand shaken for 10-15 seconds for complete dispersion.

The most effective collection and handling protocols include either (a) the on-site, rapid transfer of discrete samples with a small coring tool to a hermetically sealable vessel that either already contains the appropriate dispersion/extractant solution or to which a solution can be added by puncturing the septum after a short period of storage (2 days at 4 degrees C) or (b) obtaining and temporarily storing (2 days at 4 degrees C) a sample in an EnCore sampler before transferring it to an appropriately prepared vessel.

Plastic bags or cores with plastic/Teflon on their end caps are not an acceptable substitution for the aforementioned sample collection methodology. Today it is recognized that past VOC sample collection and handling guidance often resulted in greater than 90 percent loss of VOCs from soil samples prior to laboratory analysis (Hewitt and Lukash, 1999).

8.4.6 PESTICIDES AND HERBICIDES

Type of Contamination		Applicable Methods	
		Method Reference	Method Name
Pesticides	Soil	USEPA 4041	Soil Screening for Chlordane by Immunoassay
Pesticides	Soil	USEPA 4042	Soil Screening for DDT by Immunoassay
Pesticides	Soil	USEPA 4040	Soil Screening for Toxaphene by Immunoassay
Pesticides	Soil, Water	USEPA 4015	Screening for 2,4-D (in Soil or Water) by Immunoassay
Pesticides	Water	USEPA 4670	Triazine Herbicides as Atrazine in Water by Quantitative Immunoassay

Pesticides	Soil, Water	USEPA 4010A	Screening for Pentachlorophenol (in Soil and Wastewater) by Immunoassay
Pesticides	Soil	USEPA 8540	Pentachlorophenol in Soil by UV-Induced Colorimetry

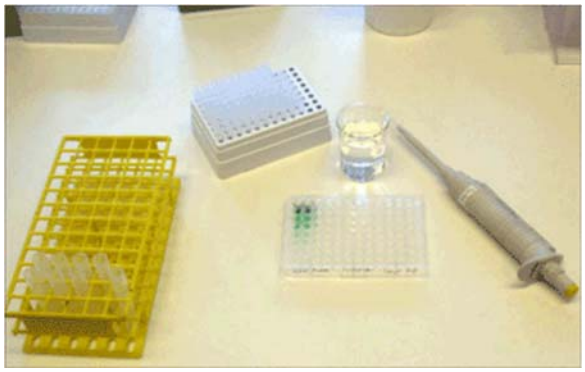


Figure 8-10 Pesticide immunoassay test kit components

USEPA 4041 (USEPA, 1996q): **Soil Screening for Chlordane by Immunoassay**

Method: The method is performed using an extract of a soil sample. Filtered extracts may be stored cold, in the dark. An aliquot of the extract and an enzyme-chlordane conjugate reagent are added to immobilized chlordane antibody. The enzyme-chlordane conjugate "competes" with chlordane present in the sample for binding to chlordane antibody. The enzyme-chlordane conjugate bound to the chlordane antibody then catalyzes a colorless substrate to a colored product. The test is interpreted by comparing the color produced by a sample to the response produced by a reference reaction.

Data Use: Screening.

Target Analytes: Method 4041 is a procedure for screening soils to determine whether technical chlordane (chlordane isomers, endrin, endosulfan 1 and II, dieldrin and heptachlor) is present at concentrations above 20, 100 or 600 µg/kg. This analyte list is consistent with the HEER Office recommendation to evaluate total chlordane (see Subsection 9.1.3.3).

Advantages: Samples can be analyzed quickly and on-site. Most test kits require minimal training and are portable with battery-operated components. Sample analysis can be cost-effective.

Limitations: Compounds that are chemically similar may cause a positive test (false positive) for chlordane. In particular lower concentrations of aldrin and higher levels of toxaphene can cause a positive interpretation.

HEER Office recommendations: The HEER Office recommends an initial site-specific evaluation of this method. Multi Increment or equivalent sample data and laboratory comparison samples required for final decision making purposes. If compounds known to cause false positives are also present at the site, this method may not be appropriate.

USEPA 4042 (USEPA, 1996r): **Soil Screening for DDT by Immunoassay**

Method: The method is performed using an extract of a soil sample. Filtered extracts may be stored cold, in the dark. An aliquot of the extract and an enzyme-DDT conjugate reagent are added to immobilized DDT antibody. The enzyme-DDT conjugate "competes" with DDT present in the sample for binding to DDT antibody. The enzyme-DDT conjugate bound to the DDT antibody then catalyzes a colorless substrate to a colored product. The test is interpreted by comparing the color produced by a sample to the response produced by a reference reaction.

Data Use: Screening.

Target Analytes: Method 4042 is a procedure for screening soils to determine whether 1,1,1-trichloro-2,2-bis(4-chlorophenyl) ethane (DDT) (CAS Registry 50-29-3) and its breakdown products (DDD, DDE, and DDA) are present at concentrations above 0.2, 1.0 or 10 mg/kg. Method 4042 provides an estimate for the sum of concentrations of DDT and daughter compounds by comparison against standards.

Advantages: Samples can be analyzed quickly and on-site. Most test kits require minimal training and are portable with battery-operated components. Sample analysis can be cost-effective.

Limitations: Compounds that are chemically similar may cause a positive test (false positive) for DDT and its daughter products. In particular low concentrations of chloropropylate, chlorobenzilate, and dicofol can cause a positive interpretation.

HEER Office recommendations: The HEER Office recommends an initial site-specific evaluation of this method. Multi Increment or equivalent sample data and laboratory comparison data required for final decision making purposes. If compounds known to cause false positives are also present at the site, this method may not be appropriate.

USEPA 4040 (USEPA, 1996s): **Soil Screening for Toxaphene by Immunoassay**

Method: The method is performed using an extract of a soil sample. Filtered extracts may be stored cold, in the dark. An aliquot of the extract and an enzyme-toxaphene conjugate reagent are added to an immobilized toxaphene antibody. The enzyme-toxaphene conjugate "competes" with toxaphene present in the sample for binding to the immobilized toxaphene antibody. The enzyme-toxaphene conjugate bound to the toxaphene antibody then catalyzes a colorless substrate to a colored product. The test is interpreted by comparing the color produced by a sample to the response produced by a reference reaction.

Data Use: Screening.

Target Analytes: Method 4040 is a procedure for screening soils to determine whether toxaphene (CAS Registry 8001-35-2) is present at concentrations above 0.5 µg/g.

Advantages: Samples can be analyzed quickly and on-site. Most test kits require minimal training and are portable with battery-operated components. Sample analysis can be cost-effective.

Limitations: Compounds that are chemically similar may cause a positive test (false positive) for toxaphene. In particular low concentrations of endrin, endosulfan I and II, dieldrin, and heptachlor can cause a positive interpretation.

HEER Office recommendations: The HEER Office recommends an initial site-specific evaluation of this screening method for each project. If compounds known to cause false positives are also present at the site, this method may not be appropriate. Laboratory comparison samples are required for final decision making.

USEPA 4015 (USEPA, 1996t): **Screening for 2,4-D in Soil or Water by Immunoassay**

Method: The method is performed using an extract of a soil sample, or directly on an aqueous sample. Filtered extracts may be stored cold, in the dark. An aliquot of the aqueous sample or extract and an enzyme-2,4-D conjugate reagent are added to immobilized 2,4-D antibody. The enzyme-2,4-D conjugate "competes" with 2,4-D present in the sample for binding to 2,4-D antibody. The enzyme-2,4-D conjugate bound to the 2,4-D antibody then catalyzes a colorless substrate to a colored product. The test is interpreted by comparing the color produced by a sample to the response produced by a reference reaction.

Data Use: Screening.

Target Analytes: Method 4015 is a procedure for screening soils and aqueous matrices to determine whether 2,4-dichlorophenoxyacetic acid (2,4-D) (CAS Registry 94-75-7) is likely to be present at concentrations above 0.1, 0.5, 1.0 or 5.0 mg/kg in soil, and 10 µg/L in water (ground water monitoring).

Advantages: Samples can be analyzed quickly and on-site. Most test kits require minimal training and are portable with battery-operated components. Sample analysis ican be cost-effective.

Limitations: Compounds that are chemically similar may cause a positive test (false positive) for 2,4-D. In general higher concentrations of chemically similar compounds are necessary to generate false positives and thus there are not significant interferences with this method.

HEER Office recommendations: The HEER Office recommends an initial site-specific evaluation of this method. Multi-increment or equivalent sample data and laboratory comparison data are required for final decision making purposes.

USEPA 4670 (USEPA, 2007j): **Triazine Herbicides as Atrazine in Water by Quantitative Immunoassay**

Method: This method uses a competitive immunoassay for the quantitative determination in water of triazine herbicides as atrazine. The method is performed using an aliquot of the water sample and an enzyme-atrazine conjugate reagent, which are added to an immobilized atrazine antibody. The enzyme-atrazine conjugate "competes" with triazine herbicides present in the

sample for binding to the immobilized atrazine antibody. The enzyme-atrazine conjugate bound to the atrazine antibody then catalyzes a colorless substrate to a colored product. The test is interpreted by comparing the color produced by a sample to the response produced by a reference reaction.

Data Use: Screening.

Target Analytes: Method 4670 is a procedure for screening water with an optimal quantification limit of 0.03 µg/L for drinking water samples. The actual method sensitivity may be highly dependent on the kit used and sample matrix and the 0.03 µg/L lower detection limit may not always be achievable.

Advantages: Samples can be analyzed quickly and on-site. Most test kits require minimal training and are portable with battery-operated components. Sample analysis can be cost-effective.

Limitations: Compounds that are chemically similar may cause a positive test (false positive) for triazine herbicides. This cross-reactivity varies between different manufacturers and should be carefully evaluated for each project. Additionally, because this method quantifies triazine herbicides as atrazine, the response for the different compounds also varies between different manufacturers and also needs to be carefully evaluated for each project.

HEER Office recommendations: The HEER Office recommends an initial site-specific evaluation of this screening method for each project. If compounds known to cause false positives are also present at the site, this method and/or specific kit for this method may not be appropriate. Laboratory comparison data is required for final decision making purposes.

USEPA 4010A (USEPA, 1996u): **Screening for Pentachlorophenol (in Soil and Wastewater) by Immunoassay**

Method: Method 4010A is a procedure for screening solids such as soil and sludge and aqueous media such as wastewater and leachate for pentachlorophenol (PCP) (CAS Registry No. 87-86-5). The method is performed using a water sample or an extract of a water sample. The sample/extract and an enzyme conjugate reagent are added to immobilized antibody. The enzyme conjugate "competes" with PCP present in the sample for binding to immobilized anti-PCP antibody. The test is interpreted by comparing the response produced by testing a sample to the response produced by testing standard(s) simultaneously.

Data Use: Screening.

Target Analytes: Method 4010A is recommended for screening samples to determine whether PCP is likely to be present at defined concentrations (i.e., kits are available which give positive results at 0.005 mg/L for aqueous samples, and at 0.5, 10 or 100 mg/kg in soil samples).

Advantages: Samples can be analyzed quickly and on-site. Most test kits require minimal training and are portable with battery-operated components. Sample analysis can be cost-effective.

Limitations:: Compounds that are chemically similar may cause a positive test (false positive) for PCP. In particular lower concentrations of 2,4,6-trichlorophenol and 2,3,5,6-tetrachlorophenol can cause a positive interpretation.

HEER Office recommendations: The HEER Office recommends an initial site-specific evaluation of this method. Multi Increment or equivalent sample data and laboratory comparison data are required for final decision making purposes. If compounds known to cause false positives are also present at the site, this method may not be appropriate.

USEPA 8540 (USEPA, 2007k): **Pentachlorophenol in Soil by UV-induced Colorimetry**

Method: The method was developed for wood treatment sites where PCP is the principal contaminant and other wood treatment chemicals, such as fuel oil and creosote are present. PCP is extracted from soil using methanol. An aliquot of the filtered methanol extract is added to acidified HPLC-grade water and the mixture is loaded onto a solid-phase extraction (SPE) column and eluted with hexane. The hexane eluate is mixed with basic water and is shaken. The aqueous solution is poured into a vial containing acidic water, octane, and cobalt chloride to facilitate separation. The mixture is shaken and allowed to separate. Approximately half of the octane is removed and added to a vial containing sodium sulfate. An aliquot of the octane is added to the vial containing the Quick Test® Reagent in an isopropyl alcohol solution. The mixture is placed in a plastic cuvette, mixed, and capped. The concentration of the PCP is determined using a dedicated colorimeter with the UV light exposure set at 260 nm.

Data Use: Screening.

Target Analytes: This method is recommended for analyzing soil samples to determine whether PCP is present at concentrations above 1.5 mg/kg. This method provides for the quantification of PCP relative to a three-point standard curve over a calibration range of 2 - 90 ppm.

Advantages: Samples can be analyzed quickly and on-site. Most test kits require minimal training and are portable with battery-operated components. Sample analysis can be cost-effective.

Limitations:

- Test reagents are highly sensitive to UV and have to be stored and used away from direct or indirect sunlight.
- The reagent can deteriorate slowly (based on post-exposure absorbance) but remains useful at 40 °C for up to 50 days. Deterioration at 60 °C occurred almost immediately, and post-exposure absorbance was significantly lower after 7 days. The reagent has been tested at 25 °C and remained stable for 4 months at that temperature.
- Compounds that are chemically similar may cause a positive test (false positive) for PCP; however, the clean-up steps in this method do eliminate most of this cross-reactivity and should not significantly impact this method.

HEER Office recommendations: The HEER Office recommends an initial site-specific evaluation of this method. Multi Increment or equivalent sample data and laboratory comparison data are required for final decision making purposes.

8.4.7 EXPLOSIVES

Type of Contamination		Applicable Methods	
		Method Reference	Method Name
Explosives	Soil	USEPA 4050	TNT Explosives in Soil by Immunoassay
Explosives	Soil	USEPA 4051	RDX in Soil by Immunoassay
Explosives	Soil	USEPA 8515	Colorimetric Screening Method for Trinitrotoluene (TNT) in Soil





Figure 8-11 Explosives immunoassay kit and explosives sample analysis using an immunoassay kit.

USEPA 4050 (USEPA, 1996v): **TNT Explosives in Soil by Immunoassay**

Method: The method is performed using an extract of a soil sample. Samples and an enzyme-trinitrotoluene (TNT) conjugate reagent are added to an immobilized TNT antibody. The enzyme-TNT conjugate "competes" with TNT present in the sample for binding to the immobilized TNT antibody. The enzyme-TNT conjugate bound to the TNT antibody then catalyzes a colorless substrate to a colored product. The test is interpreted by comparing the color produced by a sample to the response produced by a reference reaction.

Data Use: Screening.

Target Analytes: Method 4050 is a procedure for screening soil samples to determine when TNT (CAS No. 118-96-7) is present at concentrations above 0.5 mg/kg.

Advantages: Samples can be analyzed quickly and on-site. Most test kits require minimal training and are portable with battery-operated components. Sample analysis can be cost-effective.

Limitations: Compounds that are chemically similar may cause a positive test (false positive) for TNT. In particular lower concentrations of tetryl, 1,3,5-trinitrobenzene, and 2-amino-4,6-dinitrotoluene can cause a positive interpretation.

HEER Office recommendations: The HEER Office recommends an initial site-specific evaluation of this screening method for each project. If compounds known to cause false positives are also present at the site, this method may not be appropriate. Multi Increment or equivalent sample data and laboratory comparison samples are required for final decision making purposes.

USEPA 4051 (USEPA, 1996w): **RDX in Soil by Immunoassay**

Method: The method is performed using an extract of a soil sample. Samples and an enzyme conjugate reagent are added to immobilized hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) antibody. The enzyme-RDX conjugate "competes" with RDX present in the sample for binding to an immobilized RDX antibody. The enzyme-RDX conjugate bound to the antibody then catalyzes a colorless substrate to a colored product. The test is interpreted by comparing the color produced by a sample to the response produced by a reference reaction.

Data Use: Screening.

Target Analytes: Method 4051 is a procedure for screening soils to determine when RDX (CAS No. 121-82-4) is present at concentrations above 0.5 mg/kg.

Advantages: Samples can be analyzed quickly and on-site. Most test kits require minimal training and are portable with battery-operated components. Sample analysis can be cost-effective.

Limitations: Compounds that are chemically similar may cause a positive test (false positive) for RDX. In general higher concentrations of chemically similar compounds are necessary to generate false positives and thus there are not significant interferences with this method.

HEER Office recommendations: The HEER Office recommends an initial site-specific evaluation of this screening method for each project. Multi Increment or equivalent sample data and laboratory comparison samples are required for final decision making purposes.

USEPA 8515 (USEPA, 1996x): **Colorimetric Screening Method for TNT in Soil**

Method: The method is performed using an extract of a soil sample. The sample is treated with color-change reagents and is read in a portable spectrophotometer. The colorimetric nature of the test is based on the visual detection of the reaction product that is formed when polynitroaromatic compounds react with acetone by ketone substitution in the presence of a base. This substitution product is measured at 540 nm using a spectrophotometer. The concentration of 2,4,6-trinitrotoluene (TNT) and closely related nitroaromatic compounds (2,4-dinitrotoluene, 2,6-dinitrotoluene, and 1,3,5-trinitrobenzene) in an unknown sample is determined by evaluating the intensity of the color that is developed.

Data Use: Screening.

Target Analytes: Method 8515 is a procedure for screening soil samples to determine when TNT (CAS No. 118-96-7) is present at concentrations above 1 ppm. The test also has similar reactivity to 2,4-dinitrotoluene, 2,6-dinitrotoluene, and 1,3,5-trinitrobenzene.

Advantages: Samples can be analyzed quickly and on-site. Most test kits require minimal training and are portable with battery-operated components. Sample analysis can be cost-effective.

Limitations: This test has similar reactivity for TNT as well as 2,4-dinitrotoluene, 2,6-dinitrotoluene, and 1,3,5-trinitrobenzene. Results from this test should take this fact into consideration.

HEER Office recommendations: The HEER Office recommends an initial site-specific evaluation of this screening method for each project. Multi Increment or equivalent sample data and laboratory comparison samples are required for final decision making purposes.

8.5 FIELD SCREENING WITH CONE PENETROMETER AND SENSORS/PROBES

There are a variety of sensors and probes that can be used to optimize sampling and analyses at contaminated sites. Geotechnical sensors can provide an indication of where historical fill materials could be present, and they can be used to refine information for processing geophysical data. In addition, geotechnical methods like cone penetrometer technology (CPT) can be used to obtain detailed geologic information, and high-resolution sensors/probes on on direct push platforms (DPT) can be used to delineate a water table and even to predict where vertical gradients could be present.

Other types of probes and sensors used in combination with CPT are designed specifically to target the identification of contamination in the subsurface, like the membrane interface probe (MIP) or fluorescence tools that look for hydrocarbons. These instruments are generally stacked together such that the maximum amount of information for a particular portion of a site is collected as efficiently as possible. These tools can be extremely valuable, but are also selective in terms of the type of data they can generate and the requirements for collecting data under controlled conditions.

Mobilization costs for sensors and probes with CPT can be significantly more than other sampling/analysis strategies, especially for small numbers of samples. However, for large numbers of samples appropriate sensors or probes in combination with CPT may be more cost effective and a valuable assistance to site delineation efforts.

8.5.1 DESCRIPTION OF CONE PENETROMETER TECHNOLOGIES

CPT techniques include samplers and analytical devices (typically a steel cone) that can be deployed into the subsurface using a direct push platform. Direct push platforms use hydraulic pressure to push a steel rod into the ground. This creates a small borehole by pushing soil out of the way as opposed to removing soil as in drilling. The same method is used to advance the sampling devices, geotechnical sensors, or analytical sensors associated with CPT. The sensors (attached to the tip of the cone) are connected to electrical cable running inside the hollow push rods, enabling the collection of data by a computer acquisition system at the surface. As such, “real-time” data can be collected using CPT techniques.

Two platforms are used for direct push technology (DPT). The first advances the tool string by the weight of the truck and supplemental steel weights and is known as a CPT. The second uses the weight of the truck aided by a rotary hammer and is known as the rotary hammer system. The CPT system is usually mounted on a 10-30 ton truck, while the rotary hammer system is mounted on pick-up trucks. The use of the name cone penetrometer system for the larger platform is misleading since CPT technologies can be deployed from both the CPT and rotary hammer platform.

The two platforms differ in scale of application and, to some extent, in the types of instruments and tools that they deploy. The devices developed for these platforms are: samplers for soil, soil gas and groundwater; geotechnical sensors for soil texture and hydraulic conductivity; and chemical sensor sampling techniques to detect petroleum, volatile organic compounds, metals and explosives. The sensors are connected to data acquisition devices mounted on the trucks.

CPT techniques are utilized for field screening only. Use CPT data to guide the placement of boreholes and selection of sampling locations. Collect samples for laboratory analysis to verify contaminant plume extent and contaminant concentrations.

8.5.2 CONE PENETROMETER DATA VERIFICATION

Always verify interpretation of CPT data by correlating it to site data. Correlate CPT data for soil type to lithological samples collected from the site to allow accurate interpretation of the CPT data (USEPA 2005).

Correlate conductivity (resistivity) data collected by CPT techniques to samples collected from the site. Conductivity varies with grain size but also with soil water content and ionic strength of the pore water or groundwater. Ionic strength of the groundwater can change due to contaminant content. Dense non-aqueous phase liquids (DNAPL) have a very low conductivity and can thus be detected by conductivity measurements (USEPA 2004c and 2005). Light non-aqueous phase liquids (LNAPLs) can also be detected; however, other methods are more efficient in locating LNAPL plumes (USEPA 2005). Because conductivity is influenced by soil type, water saturation, solute type, solute concentration and presence of non-aqueous phase liquids, the interpretation of the data is not straight-forward and requires calibration against site samples.

8.5.3 CPT ADVANTAGES AND LIMITATIONS

Cone penetrometer technology is deployed through either of two platforms of direct push technology (DPT).The advantages of direct push technologies (DPT) are:

- Deployment of *in situ* instruments allows rapid, real-time collection of data, which may be used to guide further drilling and sampling efforts, avoiding laboratory turn-around times and remobilization.
- Sampling and data collection may be faster than with traditional drill rigs.
- DPT does not generate large quantities of soil cuttings, thus reducing the amounts of investigation derived waste generated during the course of an investigation.
- Installation of micro-wells or pre-packed wells is substantially lower in cost than installation of permanent monitoring wells using traditional drill rigs.
- The rotary hammer system is deployed using smaller rigs, often pick-up truck mounted, and are therefore more mobile than traditional drill rigs. Smaller rigs can often access buildings or difficult to reach off-road locations. Also small rigs can be used in areas with overhead wires or other overhead hazards.

Cone Penetrometer Technology (CPT techniques) have the following limitations:

- CPT techniques can be used only in unconsolidated formations. Hard layers, partially cemented sediments, rocks and boulders limit the penetration. However, rotary hammer systems have rotary capability and can be used to penetrate concrete or other thin hard layers.
- CPT can often be advanced to depths greater than 100 feet, but cannot advance boreholes as deep as traditional augers can.
- Vertical changes in formation density limit the method. Hard layers encountered under soft layers may cause refusal, bending or breaking of the drilling rod.
- When the CPT system is mounted on trucks that weigh 20 to 30 tons, they are limited to locations with firm ground (the rotary hammer system is mounted on pick-up trucks with fewer limitations).

8.5.4 OTHER CPT INSTRUMENTS

Piezocones can be used to determine the hydraulic conductivity of subsurface soils and the depth to groundwater. These data can be used to identify potential contaminant pathways in the subsurface, or to aid in the selection of sampling locations (USEPA 2005).

Available chemical analytical sensors include: laser-induced fluorescence (LIF) probes and fuel fluorescence detectors (FFD), which can identify PAHs; and membrane interface probes (MIP) and SCAPS Hydrosparge™ systems for the detection of volatile organic compounds in soil and groundwater (USEPA 2004 and 2005).

USEPA evaluation of chemical sensors used with CPT has revealed that the sensor output does not correlate well with results obtained from laboratory methods (USEPA 1998; USEPA 1995). The HEER Office considers chemical data collected with CPT techniques as qualitative. In addition, the chemical sensors often detect classes of analytes rather than specific analytes.

Induced Fluorescence Tools

There are two basic delivery systems that can be used to detect hydrocarbons in the subsurface. One is a laser-induced fluorescence (LIF) set of tools and another is the fuel fluorescence detection (FFD) systems. Both provide a method for real-time, *in situ*, field screening of hydrocarbons in subsurface soil and groundwater. The technologies are intended to provide highly detailed, qualitative to semi-quantitative information about the distribution of subsurface petroleum contamination. LIF and FFD sensors are generally deployed as part of integrated mobile CPT systems that are operated by highly trained technicians familiar with the technology and its application. See ASTM, 2010 for a standard describing characterization of petroleum contaminated sites with LIF.

LIF and FFD systems can, with relative degrees of success depending on the tool configuration, detect gasoline, diesel fuel, jet fuels, fuel oil, motor oil, grease, and coal tar in the subsurface. The data can be used to guide an investigation or removal action or to delineate the boundaries of a subsurface product contamination plume prior to installing monitoring wells or taking soil samples.

There are currently four major induced-fluorescence systems available to private sector clients: the rapid optical screening tool (ROST) systems, the ultraviolet optical screening tool (UVOST), the tar-specific green optical screening tool (TarGOST), and FFD. Also, the Site Characterization and Analysis Penetrometer System (SCAPS) LIF system is one of several CPT-mounted sensors developed through a collaborative effort of the Army, Navy, and Air Force under the Tri-Services Program, but it is only available for federal facility projects. The ROST system was developed by Loral Corporation and Dakota Technologies, Inc., and is available commercially through Fugro, Inc. The UVOST and the TarGOST are available commercially from several vendors including Dakota Industries. All of these systems, while differing in some respects, are similar in their theories and methods of operation.

Advantages:

- The primary advantage of using LIF systems is their ability to provide real-time chemical and geological information while in the field. This data can reduce and focus the amount of physical sampling and laboratory analysis, as well as optimize monitoring well placement.
- Systems are capable of achieving 200 to 300 feet of pushes in a 10-hour work day.
- The vertical spatial resolution is near 2.0 cm, which allows small zones of contamination to be delineated that might be missed by conventional sampling protocols.
- No drill cuttings are produced with the system, saving the logistical requirement of handling drums of cuttings and eliminating disposal costs.
- The sample holes can be grouted as the push rod is pulled from the hole. Also, the push rod can be decontaminated remotely as it is retracted from the hole. All the decontamination fluids are containerized in the process.

Limitations:

- The operation of the fluorescence system takes considerable experience. It takes many days and numerous projects to become familiar with the operation of the technology. Operation of the technologies is provided as services by their respective vendors for this reason.
- Although these sensors provide information regarding the relative degree of contamination that closely matches reference method data, little direct, quantitative correlation has been found to individual or classes of petroleum compounds.
- The cost of the large, truck-mounted versions of these systems may be prohibitive for small-scale projects. However, recent advancements in the delivery systems and laser electronics are making fluorescence systems capable of tackling almost any size job more economically.
- Some maintenance of the CPT tools and the LIF sensors is required, and breakdowns can be expected on long-term projects. For example, downtime due to breakage of fiber optic cables and push rods, fogging of the sapphire window, and problems with the grout pump or decontamination unit may occur.
- These systems can only be used where direct push is feasible, such as in unconsolidated sediments. The sensors are limited to a depth of 50 meters because of attenuation in the optical fiber umbilical cord.
- Minerals such as calcite, naturally occurring organic matter, and man-made chemicals also can fluoresce, which may cause interference problems. Smearing and a memory effect on the sensor may occur when pushing through fine-grained sediments such as clays.

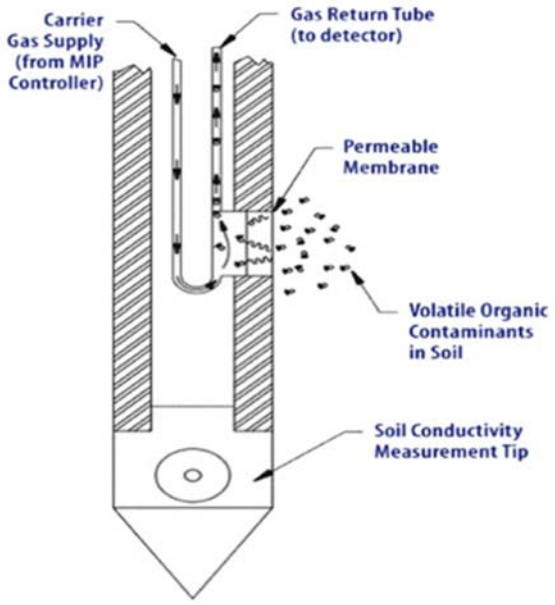


Figure 8-12 Membrane Interface Probe with Conductivity Probe Tip

A MIP is a semi-quantitative field screening device that can detect VOCs in soil and sediment. It is used in conjunction with a direct-push platform (DPP), such as a CPT testing rig or a rig that uses a hydraulic or pneumatic hammer to drive the MIP to the depth of interest to collect samples of vaporized compounds. The probe captures the vapor sample, and a carrier gas transports the sample to the surface for analysis by a variety of field or laboratory analytical methods. Additional sensors may be added to the probe to facilitate soil logging and identify contaminant concentrations. The results produced by a MIP at any location are relative and subject to analytic verification.

MIP technology is capable of sampling VOCs and some SVOCs from subsurface soil in the vadose and saturated zones. It is typically used to characterize hydrocarbon or solvent contamination. Its ability to rapidly locate and identify contaminants reduces uncertainty in management decisions associated with costly cleanup projects, such as those commonly involving source zones of dense non-aqueous-phase liquid (DNAPL) and light non-aqueous-phase liquid (LNAPL). MIP technology uses heat to volatilize and mobilize contaminants for sampling. Heating the soil and/or groundwater adjacent to the MIP's semi-permeable membrane volatilizes the VOCs, which then pass through the probe's membrane and into a carrier gas for transportation to the ground surface.

The MIP consists of a small polymer (tetrafluoroethene) port, or membrane, that is permeable to gas but impermeable to liquid. The port is secured onto a steel block that also contains a resistive heater coil and a thermocouple, allowing the temperature of the membrane to be controlled and monitored. The heater coil heats the soil near the membrane to 80 to 125 ºC (160 to 232 ºF), which allows VOCs in the soil and groundwater to partition across the membrane in saturated or unsaturated soil. The subsurface temperature needs to be at or above the boiling point of the target compound(s). Nitrogen is the most commonly used carrier gas, but helium has been used in some applications. The carrier gas sweeps across the back of the membrane, entrains the VOC sample, and carries the VOC to the detection device located at the surface.

Typically, the MIP probe includes a tip that measures soil or water conductivity at a known distance below the membrane. The conductivity measurements can help correlate contamination to known soil stratigraphy. The probe conductivity measurements cannot identify the specific type of soil (based on grain size) distribution that is encountered unless the conductivity measurements can be compared to actual site soil core data. In the absence of on-site data, the MIP conductivity measurements identify changes in the soil's electrical behavior that can be related to changes in stratigraphy or groundwater quality. Analytical devices commonly used with an MIP include gas chromatography (GC)-grade detectors (e.g., photo-ionization [PID], flame ionization [FID], electron capture [ECD], and dry electrolytic conductivity [DELCD] detectors) that establish the presence of VOC vapor, dissolved phase LNAPL, or DNAPL in soil. These detectors may be deployed singly or in line depending upon the site's contamination. PIDs are best used for detecting aromatic compounds, such as BTEX (benzene, toluene, ethylbenzene, and xylene isomers). FIDs are used to detect petroleum hydrocarbons (straight and branched chain alkanes). ECDs and DELCDs are used to identify chlorinated hydrocarbons (e.g., PCE, TCE, dichloroethene, carbon tetrachloride).

Speciation of the contaminants can be accomplished either by collecting the off-gas on carbon or Tenax traps and subsequently desorbing the contaminants into a GC/mass spectrometer (MS), or by direct injection into an on-site ion-trap mass spectrometer (ITMS). Since the ITMS lacks a GC, its ability to resolve complex mixtures of contaminants is limited. See ASTM 2007b for a standard describing use of DPT for volatile contaminant logging with the MIP.

Advantages

- Real time data.
- Limited investigation derived waste.

Limitations

- MIPs provide screening-level data that need to be supplemented with analytical soil or groundwater data to fully support human health risk assessments or remediation decisions.
- Determining the depth at which the sample was taken when the sampler is in a near-continuous operating mode and the push rate is variable can be difficult. Compounds may be found in the subsurface for which the detectors were not calibrated.
- As with all direct push devices, MIP is only useful for deployment in unconsolidated matrices. Speciation with the ITMS can be problematic when the gas stream contains a complex mixture of chemicals. In many cases, the detection limit of MIP equipment for specific contaminants is above the detection limit required for human health risk assessment.
- ITMS-MIP overestimates contaminant concentrations for most vadose zone soils when compared with validation results, and it underestimates contaminant concentrations for clay-type vadose zone soils.

8.6 FIELD SCREENING EQUIPMENT TO SUPPORT HEALTH AND SAFETY PROGRAMS

The HEER Office does not regulate Health and Safety plans required for work on contaminated or hazardous waste sites (see Subsection 3.6.3). However, the HEER Office does check to confirm that Health and Safety plans are included as part of the overall site Sampling and Analytical Plan or site Work Plans. Because field screening equipment is commonly used on contaminated sites to support protection of workers, summary information on field equipment that may typically be utilized is included in this section.

All personnel using field survey equipment for health and safety related monitoring should have training on its operation, limitations, and maintenance. Maintenance and internal or electronic calibration should be performed in accordance with manufacturer recommendations by individuals trained and familiar with the devices before and after their use in accordance with manufacturers' instructions. Repairs, maintenance, and calibration of these devices should be recorded in an equipment maintenance logbook. The equipment maintenance logbook for each instrument should be kept in that instrument's storage case. For rented monitoring equipment, routine repairs consisting of maintenance and calibration should be conducted by the rental company vendor prior to the equipment being available for rent. The rental company vendor should provide a copy of the equipment maintenance and calibration response certification within the equipment storage case. The results of the vendor's routine calibration and maintenance should also be recorded in the field logbook. For photoionization detector (PID) rentals, field personnel should ensure that the instrument contains the proper electron volt (eV) lamp.

Air monitoring equipment should be calibrated by field personnel before work begins and after each period of use, in accordance with manufacturers' instructions and standard industrial hygiene practices to ensure the accuracy of the air monitoring data. Field personnel should ensure that they have the correct calibration gases for the intended air monitoring equipment to be used. Only basic maintenance (such as changing/charging batteries) will typically be performed by on-site personnel. Any additional maintenance or repairs should be performed by a trained service technician.

No single instrument can provide sufficient information as each has its own strengths and weaknesses. Any health and safety monitoring strategy should employ a combination of devices, be documented in an accident prevention plan and site-specific health and safety plan that meets applicable state and federal regulations and has been reviewed and approved by a certified industrial hygienist. Weather conditions such as extreme heat or cold, humidity (water vapor), exposure to rain or other spilled liquids, and electromagnetic radiation can all affect the instrumental readings for the equipment. Real-time monitoring should take into account the applicable use, operating ranges and limitations for the instrument being used, equipment warm-up time, equipment response time, and equipment correction factor (equipment sensitivity). Pay attention to inconsistent or non-responsive readings and record them in the field logbook. Air monitoring instruments discussed in the following subsections are typically used during soil and groundwater investigations. Additional air monitoring, radiation monitoring or other specialized equipment may be required.



Figure 8-13 Combustible Gas Indicator

8.6.1 COMBUSTIBLE GAS INDICATOR (CGI)

This meter typically uses a platinum filament, which is heated by burning the combustible gas or vapor. The increase in heat is measured and reported as a percent of the lower explosive limit (%LEL). Generally if the gas is flammable, the Combustible Gas Indicator (CGI) reading is ±50 percent when the meter is calibrated to hexane. The CGI has multiple sensitivities and thus can read a wide range of atmospheric levels on one meter. This meter operates only at normal oxygen levels and is also subject to electronic noise and is not very accurate at very low levels.

Advantages

- Measures the presence of combustible gases/vapors
- Range : 0 – 100 % of LEL (units are % of the LEL or ppm depending on the instrument brand used)

Limitations

- Catalytic sensor poisoning
- Relative response
- Does not indicate mists or dusts
- Must have normal oxygen content (generally at least 16 %) to provide valid readings



Figure 8-14 Oxygen Meter

8.6.2 OXYGEN METER

This instrument uses an electrochemical sensor to measure the partial pressure of oxygen levels in the air and converts that reading to oxygen concentration. A deficient oxygen atmosphere (<19.5 percent) can indicate displacement by another gas or consumption. An oxygen atmosphere with a surplus (>23.5 percent) can indicate another source of oxygen. Either situation is potentially life-threatening and hazardous. It is important to understand that the meter only considers the effect of oxygen itself and not the presence of other materials. Any deflection on the oxygen meter should be treated as an abnormal situation. Neutralizing and masking gases can affect the accuracy of this instrumentation.

Advantages

- Measures oxygen levels in the air

Limitations

- Neutralizing and masking gases



Figure 8-15 Flame Ionization Detector

8.6.3 FLAME IONIZATION DETECTOR (FID)

This meter has low detection levels for a broad number of organic compounds and has a self-adjusting span for known compounds. The FID ionizes compounds by burning them in a hydrogen flame. Operations on site may result in variable background levels of airborne compounds. Airborne compounds may be released from vehicles, blowing dust, material transfers, and so on. These sources can complicate monitoring of contaminant emissions during project tasks. Therefore, several upwind and pre-work measurements should be taken to assess contributions to airborne contamination by other potential sources. The instrument can also flame out at 10,000 ppm and above.

Advantages

- Low detection levels for many organic compounds
- Self-adjusting span for known organic compounds
- Ionizes compounds by burning them in hydrogen flame
- Can detect compounds with high ionization energy vapors (such as methane).

Limitations

- Can flame out at 10,000 PPM
- Multiple sensitivities
- Does not differentiate between compounds detected



Figure 8-16 Photoionization Detector (MiniRAE)

8.6.4 PHOTOIONIZATION DETECTOR (PID)

This instrument detects atmospheric contaminants by ionizing them with UV radiation and producing a current that is proportional to the number of released ions. A PID with a 10.6 electron volt (eV) lamp should be sufficient for measuring VOCs and can be used for monitoring activities. A PID can determine compounds at very low concentrations with little electronic noise; the typical range is 0.5 to 2,000 ppm. The instrument is self-adjusting for known compounds but is blind to many common gases (methane, for example). Operations on site may result in variable background levels of airborne compounds. Airborne compounds may be released from vehicles, blowing dust, material transfers, and so on. These sources can complicate monitoring of contaminant emissions during project tasks. Therefore, several upwind and pre-work measurements should be taken to assess contributions to airborne contamination by other potential sources. This instrument is not accurate at high levels.

Advantages

- Can detect many analytes and organic compounds at very low concentrations

Limitations

- Not accurate when analytes and compounds are present in the air at high concentrations
- Does not differentiate between compounds detected
- Does not detect acid gases (HCl, HNO_3)
- Does not detect PCBs
- Humidity reduces accuracy
- Dusts / Mists reduce accuracy
- Extreme heat and cold may affect instrument response
- Does not detect methane and other vapors with high ionization energy
- Multiple sensitivities (multiple electron volt [eV] lamps may be needed)

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SECTION 9
SUPPLEMENTAL GUIDANCE FOR SELECT CONTAMINANTS OF CONCERN

Interim Final - April 2014

State of Hawai‘i
Department of Health
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µm	Micrometers (micron)
2,4,5-T	2,4,5-trichlorophenoxyacetic acid
2,4,5-TP	2,4,5-trichlorophenoxypropionic acid
API	American Petroleum Institute
ATSDR	Agency for Toxic Substances and Disease Registry
BTEX	Benzene, toluene, ethylbenzene, and total xylenes
CalEPA	California Environmental Protection Agency
cm^3/g	cubic centimeters per gram
D-D	A mixture of 1,2-dichloropropane; 1,3-dichloropropene; and 2,3-dichloropropene
DBCP	1,2-dibromo-3-chloropropane
DDT	dichloro-diphenyl-trichloroethane
EAL	Environmental Action Level
EDB	1,2-dibromoethane
EHE	Environmental Hazard Evaluation
GC/MS	Gas Chromatography-Mass Spectrometry
HDOA	Hawai'i Department of Agriculture
HDOH	Hawai'i Department of Health
HEER Office	Hazard Evaluation and Emergency Response Office
Koc	organic carbon sorption coefficient
m^3/mol	cubic meters per mole
MADEP	Massachusetts Department of Environmental Protection
mg/kg	Milligrams per kilogram
MSMA	monosodium methane arsenate
MTBE	Methyl tertiary butyl ether
NEIWPCC	New England Interstate Water Pollution Control Commission
NOAA	National Oceanic and Atmospheric Administration
NTP	National Toxicology Program
PCB	Polychlorinated Biphenyl
PCP	Pentachlorophenol
RSL	Regional Screening Level
SVOC	Semi-volatile organic compound
TCP	1,2,3-trichloropropane
TEF	Toxicity Equivalence Factor
Telone	1,3-dichloropropene
TEQ	Toxic Equivalency
TGM	Technical Guidance Manual
TPH	Total Petroleum Hydrocarbons
TVH	Total Volatile Hydrocarbons
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency

VOC	Volatile Organic Compound
WHO	World Health Organization

9.0 SUPPLEMENTAL GUIDANCE FOR SELECT CONTAMINANTS OF CONCERN

This section presents guidance for select contaminants frequently encountered in Hawai‘i, including target pesticides at former agricultural facilities/fields as well as non-agricultural sites, and of target petroleum-related contaminants. Additional guidance on these contaminants is provided in the fall 2011 edition (and updates) of the Hawai‘i Department of Health (HDOH) document *Screening for Environmental Hazards at Sites with Contaminated Soil and Groundwater* (Environmental Hazard Evaluation [EHE] guidance [HDOH, 2016]). In the EHE guidance, refer specifically to:

- Volume 1, Chapter 2, Subsection 2.6: Contaminants of Potential Concern at Petroleum Release Sites.
- Volume 1, Chapter 2, Subsection 2.7: Contaminants of Potential Concern for Former Agricultural Lands.
- Volume 1, Chapter 4: Advanced Environmental Hazard Evaluations.

Section 9 also includes information on methane, background metals in soils, and methamphetamine laboratory cleanup.

9.1 PESTICIDE CONTAMINATION AT FORMER AGRICULTURAL FACILITIES AND SITES

The Hazard Evaluation and Emergency Response (HEER) Office recommends that sites with known pesticide-related contamination and also those where pesticides were regularly applied be evaluated for residual contamination prior to re-development. "Pesticides" is a general term that includes any type of chemical mixture specifically formulated to kill "pests." Pesticides commonly used in Hawai'i include herbicides, fungicides and insecticides, the latter including termiticides and nematocides.

This section presents specific guidance regarding former sugarcane and pineapple operations because these were Hawai'i's most significant commercial agricultural crops during the 19th and 20th centuries. HDOH has created maps of former sugarcane lands in the Hawaiian islands in the early 20th century that can be accessed on the HEER Office soil arsenic information webpage. Between sugarcane and pineapple operations, these two industries cultivated as much as 250,000 acres of Hawai'i's farmlands (at the peak of production in the 1920s). However, it may be necessary to evaluate additional pesticides that could pose an unacceptable risk to human health and the environment. Large areas of former agricultural land are currently under consideration for residential and commercial development. Strategies for investigating former agricultural operations are discussed in Sections 3 and Section 4.

The criteria for selecting a target pesticide for a soil investigation is the potential for the pesticide to be present in soil at concentrations that pose potential direct-exposure hazards and/or leaching hazards. Factors that should be taken into account in selecting target pesticides for analysis include:

1. Known or suspected use
2. Application rate and duration of application
3. Environmental persistence (e.g., resistance to chemical and biological breakdown)
4. Nature of potential environmental hazards
5. Availability of toxicity and physiochemical data
6. Availability of commercial laboratory test methods

Investigations of former field areas should focus on pesticides and related contaminants that are persistent, toxic, and pose potential direct-exposure hazards for future residents and workers (e.g., dioxins, arsenic, organochlorine pesticides, etc.). Conditions in pesticide mixing and storage areas are much more uncertain, however. In addition to direct-exposure hazards, contamination could also pose leaching hazards and subsequent contamination of underlying groundwater resources (e.g., triazine pesticides and fumigants). This generally requires that the full range of pesticides be screened in these areas, and that all potential environmental hazards be fully evaluated in an Environmental Hazard Evaluation report (refer to Sections 3 and Section 13).

Although specifically directed to former sugarcane and pineapple operations, the approaches described in this section can be modified for investigation of lands that may have been impacted by cultivation of other agricultural crops, including macadamia nuts, coffee, and vegetables, as well as commercial pest control operations.

In 2011 the HEER Office prepared a summary of pesticide data for environmental investigations carried out for fields, mixing areas, seed dipping vats and various other sugarcane operations across Hawai'i (HDOH, 2011d). An overview of the report is provided in Subsection 9.1.4.

9.1.1 TARGETED OPERATIONS

Table 9-1 identifies specific areas of sugarcane and pineapple operations to target for investigation. Operations are divided into field areas and various non-field areas. Pesticide mixing and other areas that could contain localized but heavy contamination should be investigated separately from field areas (refer to Section 3). In this way, field areas may be quickly screened and,

ideally, cleared of contamination concern while closer investigation of smaller areas is carried out. Bagasse pile and cane wash discharge areas should be tested for the same suite of target pesticides as field areas.

Table 9-1 Example Target Areas for Investigation of Potential Pesticide Contamination

Areas of Concern	[1]Target Pesticide Groups
Sugarcane Operations	
[2]Fields	Heavy metals (arsenic only), organochlorine pesticides
Pesticide mixing areas	Carbamates, chlorinated herbicides, dioxins/furans, heavy metals (arsenic, lead, and total mercury), organochlorine pesticides, organophosphorus pesticides (known spill areas only), semivolatile organic compound (SVOCs), triazine pesticides, Total Petroleum Hydrocarbons (TPH) (middle distillates)
Seed dipping areas	Fungicides (benomyl and propiconizole [carbamates], total mercury)
[3]Settling ponds	Heavy metals (arsenic only), organochlorine pesticides
[3]Bagasse piles	Heavy metals (arsenic only), organochlorine pesticides
Pesticide container disposal areas	Carbamates, chlorinated herbicides, dioxins/furans, heavy metals (arsenic, lead, and total mercury), organochlorine pesticides, organophosphorus pesticides (known spill areas only), SVOCs, triazine pesticides, TPH (middle distillates)
Pineapple Operations	
[2]Fields	Heavy metals (arsenic only), organochlorine pesticides
Pesticide mixing areas	Carbamates, chlorinated herbicides, dioxins/furans, heavy metals (arsenic and lead), organochlorine pesticides, organophosphorus pesticides (known spill areas only), SVOCs, triazine pesticides, volatile organic compound (VOCs), TPH (middle distillates)
Seed dipping areas	Fungicides (benomyl and propiconizole [carbamates])
Pesticide container disposal areas	Carbamates, chlorinated herbicides, dioxins/furans, heavy metals (arsenic and lead), organochlorine pesticides, organophosphorus pesticides (known spill areas only), SVOCs, triazine pesticides, VOCs, TPH (middle distillates)
[3]Other Potential Areas of Concern	
Air Strip mixing and storage areas	Same as for pesticide mixing areas
Drainage ditches	Site specific depending on areas drained (e.g., pesticide mixing areas, seed dipping vats, cane wash, etc.)
Plantation camp	Site-specific
Maintenance facilities	Site-specific
Transformer pads	Polychlorinated biphenyls (PCBs); total petroleum hydrocarbons (TPH) as mineral oil
Rail lines	Same as fields

Notes
1. Categorized by laboratory method used for analysis. Refer to Appendix 9-B and Appendix 9-C for specific pesticides.
2. Dioxins removed as potential contaminant of concern for former sugarcane field areas based on 2011 HEER Office review (see Section 9.1.4).
3. See Tables 9-2 and 9-3. Testing for full suite of pesticides listed recommended for any areas that may have been impacted by runoff or discharges from a pesticide mixing area (e.g., mill ditches, settling ponds, areas of canewash discharges, bagasse piles, etc.).

9.1.2 TARGET PESTICIDES AND RELATED CONTAMINANTS

Categories of pesticides and related contaminants associated with sugarcane and pineapple cultivation in Hawai‘i are shown in Tables 9-2 and 9-3, respectively. These typically are grouped based on laboratory analytical methods, as follows, rather than by type of application:

- Organochlorine pesticides
- Organophosphorus pesticides
- Triazine pesticides
- Chlorinated herbicides
- Carbamates
- Fumigants
- Dioxins/furans
- Heavy metals (primarily arsenic, lead & mercury)
- Petroleum (e.g., Total Petroleum Hydrocarbons (TPH) (middle distillates), often used as a vehicle, or carrier oil, for application of pentachlorophenol, EDB, DBCP and other pesticides)
- Other (pentachlorophenol, etc.)

Appendix 9-A identifies pesticides (and related contaminants) known or suspected to have been used for agricultural purposes, and presents criteria for evaluating specific pesticides for further consideration. The list is based primarily on review of historical documents related to sugarcane and pineapple cultivation (e.g., Hanson 1959, 1962; HDOA 1969, 1977, 1987, 1989, USDA 2000). Few records exist prior to the late 1960s; therefore pesticide use prior to that time is uncertain. Rapid growth in the synthetic organic chemical industry began during the 1930s and 1940s. Prior to World War II, most pesticides were inorganic chemicals and naturally occurring plant extracts (Newman 1978), with the most common being arsenical compounds (Sheets 1980) and sulfur and mercury compounds (Newman 1978). In particular, arsenical compounds are known to have been used in sugarcane cultivation in Hawai‘i in the 1920s through the 1940s, when up to 200,000 acres of land in Hawai‘i was being used for sugarcane cultivation.

Several pesticides were banned or discontinued after the 1960s (e.g., dichloro-diphenyl-trichloroethane [DDT] in 1972). For the purposes of the target pesticide tables, it is assumed that use of these pesticides in Hawai‘i ended at that time. However, it is possible that these pesticides may have continued to be used at a given site (e.g., use of existing supplies, etc.). Additional pesticides may have been used in some areas, but the appended list is considered to capture pesticides that would drive the need for remedial actions. Petroleum products, such as diesel fuel (middle distillates), were used to prepare some pesticide mixtures as carrier oils and may need to be included in the site investigation. See also Subsection 9.2 for a discussion of petroleum contaminated sites.

Herbicides are the primary pesticide of potential concern for former sugarcane lands in Hawai‘i (i.e., weed killers). Insect control (i.e., insecticides) on sugarcane fields historically has been primarily through biological control methods (i.e., predator species). The overall use of insecticides by the Hawai‘i sugar industry historically has been very low (less than one half of one percent of total crop protection chemical usage), and it is unlikely that residues from past applications or handling/storage of insecticides would be of concern at a site used only to cultivate sugarcane. In many cases, the use of insecticides would have been counterproductive, since they could impact the desirable predator species as well as the target species.

Pesticides that are contaminants of potential concern in field and non-field areas are presented in Appendix 9-B and Appendix 9-C. For former field areas, the emphasis is on pesticides and related compounds that are persistent and primarily pose direct-exposure hazards (e.g., vs. leaching hazards).

The assumed persistence of other pesticides is based on published half lives in soil (refer to Appendix 9-A). A pesticide is considered to be highly persistent if the published half life exceeds one year or if the half-life exceeds 100 days and sorption coefficient is greater than 3,000 cubic centimeters per gram (cm^3/g) (default cutoff for "mobile" vs. "nonmobile" contaminants; HDOH, 2016). All metals, as well as organochlorine pesticides and dioxins/furans fall into this category.

A pesticide is considered to be moderately persistent if the published half-life is between 30 and 100 days. A pesticide is considered to have low persistence if the expected half-life in soil is less than 30 days. Existing field data support this breakdown

of anticipated pesticide persistence. The half-lives noted in Appendix 9-A are considered to be gross estimates only, but suitable for purposes of this guidance.

Information regarding pesticide application rates for field areas was not available for most pesticides at the time this guidance was prepared. Estimating long-term buildup of pesticides in soil was therefore not practical. Assumptions regarding likely application rates, likely persistence, and the time needed to exceed target action levels were used to screen out a small number of pesticides with relatively low toxicity from further consideration (refer to Appendix 9-B and Appendix 9-C).

Toxicity factors, physiochemical constants, and standard commercial laboratory test methods were not available for several pesticides at the time this guidance was published (refer to Appendix 9-A). These pesticides were excluded from further consideration. The majority of these pesticides were developed after the 1960s, when stricter regulations on pesticide formulations were put into effect. These pesticides are assumed to be less persistent and toxic than the broader list of pesticides selected for inclusion in site investigations and noted in the appendices.

Tables 9-2 and 9-3 summarize categories of pesticides that should be tested at former sugarcane and pineapple cultivation operations. The investigation of former field areas should focus on pesticides and associated contaminants that are highly persistent, as indicated, with an emphasis on arsenic and organochlorine pesticides (see Subsection 9.1.4). For non-field areas (mixing areas, storage areas, etc.), the investigation should focus on all pesticides with moderate to high persistence that may have been used or released at the site. Testing for the full suite of pesticides listed is recommended for any areas that may have been impacted by runoff or discharges from a pesticide mixing area (e.g., mill ditches, settling ponds, areas of canewash discharges, bagasse piles, etc.). Contaminants identified in initial, screening level investigations above laboratory reporting limits (e.g., neighborhood-size decision units) should be carried forward in more detailed investigations (e.g., lot-size decision units). Refer to Section 3 and Section 4 for additional information on sampling decision units and sampling strategies.

Table 9-2 Summary of Target Pesticide Categories for Investigation of Former Sugarcane Operations

Laboratory Analytical Group[1]	Laboratory Analytical Method	Field Areas	Non-Field Areas[2]	Notes
Carbamates	8321	No	Yes	Test for benomyl and propiconazole at seed dipping operations (fungicides).
Chlorinated Herbicides	8151 or 8321	No	Yes	
Dioxins/furans	8280 or 8290	No	Yes	See footnotes.
Heavy Metals (Arsenic, Lead)	6010B/ 6020	Yes	Yes	Arsenic only in field areas.
Mercury (elemental)	7471	No	Yes	Test for total mercury at seed dipping operations (fungicides).
Organochlorine Pesticides	8081 or 8270	Yes	Yes	Field areas: heptachlor Non-Field areas: heptachlor and trifluralin.
Organo- phosphorus Pesticides	8141 or 8270	No	No	Limited use. Include as contaminant of concern in known spill areas only.
Triazine Pesticides	8141 or 619M/ 8270	No	Yes	
Volatile Organic Compounds	8260	No	No	
Semi-Volatile Organic Compounds	8270	No	Yes	

Laboratory Analytical Group[1]	Laboratory Analytical Method	Field Areas	Non-Field Areas[2]	Notes
Total Petroleum Hydrocarbons	8015M	No	Yes	Petroleum (e.g., diesel fuel) used as a base for applying some pesticides.

Notes:

1. May differ from actual family of individual pesticides tested under noted laboratory method.

2. Testing for full suite of pesticides listed recommended for any areas that may have been impacted by runoff or discharges from a pesticide mixing area (e.g., mill ditches, settling ponds, areas of canewash discharges, bagasse piles, etc.).

Table 9-3 Summary of Target Pesticide Categories for Investigation of Former Pineapple Operations

Laboratory Analytical Group[1]	Laboratory Analytical Method	Field Areas	Non-Field Areas[2]	Notes
Carbamates	8321	No	Yes	Test for benomyl and propiconazole at seed dipping operations (fungicides).
Chlorinated Herbicides	8151 or 8321	No	Yes	
Dioxins/furans	8280 or 8290	No	Yes	See footnotes. PCP used to lesser extent in pineapple operations than sugarcane operations
Heavy Metals (Arsenic, Lead)	6010B/ 6020	Yes	Yes	Arsenic only in field areas.
Organochlorine Pesticides	8081 or 8270	Yes	Yes	
Organo- phosphorus Pesticides	8141 or 8270	No	No	Limited use. Include as contaminant of concern in known spill areas only.
Triazine Pesticides	8141 or 619M/ 8270	No	Yes	
Semi-Volatile Organic Compounds	8270	No	Yes	
Fumigants (Volatile Organic Compounds)	8260	No	Yes	

Laboratory Analytical Group[1]	Laboratory Analytical Method	Field Areas	Non-Field Areas[2]	Notes
Total Petroleum Hydrocarbons	8015M	No	Yes	Petroleum (e.g., diesel fuel) used as a base for applying some pesticides.

Notes:

1. May differ from actual family of individual pesticides tested under noted laboratory method.
2. Testing for full suite of pesticides listed recommended for any areas that may have been impacted by runoff or discharges from a pesticide mixing area (e.g., drainage ditches, settling ponds, etc.).

Soil action levels are provided in the EHE guidance for the majority of the pesticides listed in Appendix 9-C (HDOH, 2016). Follow the methodology presented in the HDOH EHE guidance to compile action levels for pesticides not currently listed in that guidance. At a minimum, site data should be compared to action levels for both direct exposure and leaching hazards. Soil action levels for a number of additional pesticides are included in the United States Environmental Protection Agency Regional Screening Level guidance (USEPA 2012b).

An evaluation of potential contaminant mobility in terms of vapor-phase or dissolved-phase (i.e., leachate) mobility in soil is important (refer to Appendix 9-B). Detailed discussions of contaminant mobility are provided in Volume 1 and Appendix 1 of the HDOH EHE guidance (HDOH, 2016); refer also to HDOH technical memorandum Use of laboratory batch tests to evaluate potential leaching of contaminants from soil (HDOH, 2007).

Pesticides classified as "volatile" in the HDOH EHE guidance are considered to be highly mobile in the vapor phase [Henry's number >0.00001 atmosphere cubic meters per mole (m^3/mol)] and molecular weight <200 (see HDOH, 2016). Pesticides with organic carbon sorption coefficients (Koc) values less than 100 cm^3/g are considered highly mobile in leachate. Pesticides with Koc values >100 cm^3/g but <3,000 cm^3/g are considered to be moderately mobile. Pesticides with Koc values greater than 3,000 cm^3/g are considered to be essentially immobile. Metals are given a default mobility ranking of low, although the need to evaluate potential leaching hazards posed by metals should be considered on a site-by-site basis (refer to Sections 3 and 13; see also Subsection 9.1.4).

9.1.3 DISCUSSION OF SELECT PESTICIDES

A summary of historical pesticide use for sugarcane and pineapple in Hawai‘i is provided in the appendices to this section, including primary references for more detailed information. A brief discussion of select pesticides and pesticide groups is provided below. Additional information on arsenic, dioxins, and technical chlordane is provided in the HDOH EHE guidance document (HDOH, 2016, Volume 1, Chapters 2 and 4).

9.1.3.1 FUMIGANTS

Fumigants used in pineapple cultivation to control nematodes began in the 1940s (HDOH 1985b; see Appendices 9-A and 9-B). Soil fumigants commonly used in Hawai‘i include:

- 1,2-dibromo-3-chloropropane (DBCP);
- 1,2-dibromoethane (EDB);
- 1,3-dichloropropene (Telone);
- D-D (a mixture of 1,2-dichloropropane; 1,3-dichloropropene; and 2,3-dichloropropene);
- 1,2,3-trichloropropene (TCP; an impurity associated with D-D).

Fumigants were typically injected from four to fourteen inches below ground surface. DBCP and EDB have been detected in groundwater wells on O‘ahu and Maui and have not been used since the mid-1980s (HDOH 1985, 1985c). 1,2,3-Trichloropropene (TCP) is an impurity associated with D-D and has also been detected in groundwater wells in the state (see HDOH 1985)

Fumigants are not likely to be persistent in field areas more than one year after use due to a propensity to volatilize into the atmosphere and degrade or be carried downward in leachate. Fumigants could, however, be a contaminant of concern in former

pesticide mixing, storage or disposal areas. Soil vapor data collection is strongly recommended when investigating for these areas.

9.1.3.2 ARSENIC

Appendix 9-E, Update to Soil Action Levels for Inorganic Arsenic and Recommended Soil Management Practices, contains detailed information on updated soil action levels for total inorganic arsenic, bioaccessible arsenic , and recommended soil management practices. Contact the HEER Office for further assistance if needed.

Historical Use

Arsenic-based pesticides are largely associated with sugarcane cultivation in Hawai'i during the 1910s through the 1940s. Various arsenic-based compounds were used as herbicides, insecticides and rodenticides in agricultural operations. The primary use was for weed control with respect to the overall volume stored, mixed and applied. The HEER Office has a dedicated webpage, Soil Arsenic Guidance and Information, which houses fact sheets, arsenic assessments throughout Hawai'i, maps and technical guidance for arsenic. Monosodium methane arsenate (MSMA) and sodium arsenite were used as herbicides during various stages of sugarcane cultivation (HDOA 1969). Arsenic was typically applied to surface soils by "poison gangs" using backpack sprayers. In addition, Canec, a building material made from sugarcane waste (i.e., bagasse) and used extensively in Hawai'i, was treated with calcium arsenate and arsenic acid as an anti-termite agent (NOAA 1990). The HEER Office fact sheet, Arsenic in Canec Ceilings and Wallboard in Hawai'i, provides an overview of the potential public health concerns associates with Canec (HDOH 2010b). Other arsenic-based pesticides include lead arsenite and lead arsenate, but it is unknown if these were used in Hawai'i.

Significantly elevated levels of total arsenic have been identified in a small number of former sugarcane fields in Hawai'i. Based on a review of pesticide data for former sugarcane operations, arsenic drives human health risk posed by residual pesticides in these fields (HDOH, 2011d, see Subsection 9.1.4). A brief discussion on public health concerns associated with arsenic is provided in HDOH's Arsenic in Hawaiian Soils: Questions and Answers on Health Concerns (HDOH, 2013).

Arsenic Bioaccessibility Tests

Because of extensive, historic use of arsenic-based pesticides in Hawai'i, soil samples collected at former agricultural sites should always be analyzed for total arsenic. The HEER Office recommends that a laboratory bioaccessibility test be carried out when the total arsenic concentration in the <2mm fraction of soil exceeds 24 mg/kg, the default, upper limit assumed for background arsenic in soil (see Appendix 9-E and HDOH, 2016). Soil action levels and categories specific to bioaccessible arsenic are included in Appendix 9-E. The bioaccessibility test and the associated action levels apply to the <250µm, fines fraction of soil.

Bioaccessible tests are used to estimate the fraction of total arsenic that could be stripped or "desorbed" from the soil following ingestion and thus made available for uptake. Arsenic that remains sorbed to the soil sample is considered to be unavailable for uptake and essentially non-toxic. Bioaccessibility should be tested and evaluated based on the gastric-phase, *in vitro* Solubility Bioaccessibility Research Consortium method ("SBRC" or "Drexler method"; Ruby 1996, 2001; Kelly 2002; Juhasz et al 2007). Studies have demonstrated that the SBRC assay method provides the best predictive capability to swine *in vitro* bioavailability testing in comparison to other in vitro methods, such as the Physiologically Based Extract Test (PBET) method or the In-Vitro Gastrointestinal Method (IVG).(Juhasz et al 2009; Juhasz et al 2011). These studies concluded that a 1:1 relationship between swine arsenic bioavailability and bioaccessibility using the SBRC gastric-phase method could be estimated, without the need for a correction factor. A direct correlation between SBRC data and in vivo data was also observed in soil from Hawai'i that was included in a cynomolgus monkey study overseen by the University of Florida (Roberts et al 2007). In this study an average of 5.4% bioavailability was determined in the in vivo tests compared with an average SBRC-gastric phase bioaccessibility of arsenic in the same soil of 6.5%.

A higher confidence in the SBRC-gastric method over other approaches was also observed in suite of twenty arsenic contaminated soil samples from Hawai'i that were submitted to a Canadian laboratory (RMC 2007). Three different bioaccessibility in vitro tests were evaluated, including SBRC, PBET and In Vitro Gastro-Intestinal (IVG) methods. The results demonstrated that the SBRC assay provided the highest estimate of bioaccessible arsenic of the gastric phase testing results, and consequently provides the most "protective" estimate of bioaccessibility of the three in vitro methods.

The SBRC bioaccessibility test is carried out on the <250µm fraction of dried soil separated from the original bulk sample by the laboratory. Under this method, one gram of the <250µm soil fraction is placed in 100ml of extraction solution intended to mimic human gastro-intestinal fluids and agitated for one hour. The concentration of bioaccessible arsenic in the soil sample is calculated by dividing the mass of arsenic that moves into the batch test solution by the mass of the sample. The percent bioaccessibility is calculated as the concentration of bioaccessible arsenic divided by the concentration of total arsenic reported for the same sample.

Both the total and bioaccessible concentrations of arsenic (mg/kg) in the <250µm fraction of the soil should be reported, even though the former may not be required as part of the bioaccessibility test. The percent bioaccessible arsenic, calculated as the concentration of bioaccessible arsenic divided by the concentration of total arsenic in the <250µm fraction, should also be reported. This will help confirm the test results and provide insight on possible enrichment of arsenic in the fine-grained fraction of contaminated soil.

The USEPA recommends a default bioavailability of 60% for arsenic in soil, based on a review of data for samples collected primarily on the mainland (USEPA 2012c). This default can be applied to the concentration of total arsenic reported for the <250µm soil fraction in lieu of a laboratory-based test if desired, provided that the total concentration of arsenic in this fraction does not exceed 160 mg/kg. This reflects the concentration of total arsenic in soil that would equate to the commercial/industrial action level for bioaccessible arsenic of 95 mg/kg and a bioaccessibility of sixty-percent. Laboratory-based bioaccessibility tests are recommended when the concentration of total arsenic in the <250µm soil fraction exceeds a concentration of 160 mg/kg.

Data compiled for Hawai‘i suggest that bioaccessibility as well as bioavailability is unlikely to exceed this threshold for soils with low to moderate concentrations of total arsenic, regardless of iron content and other factors (e.g., Cutler 2011, HDOH, 2011c, Cutler et al 2013). Note that this default value is highly conservative for iron-rich, volcanic soils, where bioaccessibility is more typically less than 30% and as low as 5%. The default factor should not be applied to total arsenic in the <2mm fraction of soil due to the potential for enrichment of metal concentrations in the fines.

9.1.3.3 TECHNICAL CHLORDANE AND OTHER ORGANOCHLORINE PESTICIDES

Technical chlordane is a mixture of chlordane isomers (50-75%) and over 100 related compounds, including heptachlor and heptachlor epoxide (ATSDR 1994). Technical chlordane was used in Hawai‘i in large quantities by pest control operators, lawn and garden services, and homeowners for the control of termites, armyworms, and other pests. The use of technical chlordane was discontinued in the 1980s. Soil contaminated with technical chlordane is highly likely to be present around and under the foundations of buildings constructed before this time. Technical chlordane was also used as an insecticide during pineapple cultivation (HDOA 1969).

The HEER Office recommends that soil samples be analyzed for technical chlordane rather than individual chlordane isomers and related compounds generally found in technical chlordane. The concentrations of chlordane isomers, heptachlor, and heptachlor epoxide do not need to be reported unless applied as a separate chemical. Laboratories should be directed to test for technical chlordane using USEPA Method 8081A or an equivalent method (USEPA 1996). This must be specifically requested prior to submitting the samples for analysis and noted on the chain of custody form. Laboratories also should be instructed to report any additional organochlorine pesticides that are not typically found in technical chlordane (e.g., DDT, dieldrin, endrin, etc.). Additional information on technical chlordane is presented in HDOH, 2011g, 2011h.

In addition to the approach noted for technical chlordane, concentrations of the following chemicals should be summed as indicated for comparison to HDOH EALs in a screening level EHE:

- Hexachlorocyclohexane ("BHC" as Lindane) = Alpha-BHC + Beta-BHC + Gamma-BHC (Lindane) + Delta-BHC;
- Endosulfan = Endosulfan I + Endosulfan II + Endosulfan sulfate;
- Endrin = Endrin + Endrin aldehyde + Endrin ketone.

These chemicals can be evaluated individually in a site-specific risk assessment as necessary.

9.1.3.4 DIOXINS AND FURANS

Appendix 9-F, Update to Soil Action Levels for TEQ Dioxins and Recommended Soil Management Practices, contains detailed information on updated soil action levels for TEQ dioxins and recommended soil management practices. Contact the HEER Office for further assistance if needed.

Dioxins and furans ("dioxins") should be included as chemicals of potential concern at former pesticide mixing areas associated with both sugarcane and pineapple operations. Although significant data are not currently available for the latter, dioxin contamination in soil well above HDOH action levels have been documented at numerous former pesticide mixing and storage areas associated with past, sugarcane operations (see following section).

Dioxins were created as a manufacturing byproduct in older formulations of several commonly used pesticides, especially pentachlorophenol (PCP), 2,4,5-trichlorophenoxyacetic acid (2,4,5-T), and 2,4,5-trichlorophenoxypropionic acid (2,4,5-TP or Silvex; NTP 2005). Soils in former pesticide mixing areas should be analyzed for dioxins if any the above-noted pesticides are known or suspected to have been stored, mixed or otherwise released in the area under investigation. These chemicals are not known to have been widely used in pineapple fields and dioxins are no longer considered a potential chemical of concern for

these areas (see Table 9-3). Organochlorine pesticides such as heptachlor, used for ant control, are instead considered to drive the need for investigation of former pineapple field areas.

Dioxins and furans are evaluated in terms of Toxicity Equivalent calculations or "TEQ "dioxins. Quantification of dioxins in soil for use in human health risk assessments requires conversion of congener-specific gas chromatography/mass spectrometry (GC/MS) data to TEQ dioxin concentrations by use of Toxicity Equivalence Factors (TEFs) (WHO, 2005). A summary of World Health Organization (WHO) TEFs is provided in Table 9-4. The TEQ concentrations for individual congeners are then added together to calculate a total TEQ dioxin concentration for the sample. Unless otherwise approved by HDOH, one-half of the Method Detection Limit (not the Reporting Limit) should be used for calculation of TEQ concentrations when the specific congener is reported as "Non Detect."

The HEER Office currently accepts the use of bioassay methods such as CALUX for testing of TEQ dioxins in soil provided that splits of 10% of the samples are tested using GC/MS methods such as Method 8280 or 8290, generally samples with the highest-reported concentration of TEQ dioxins (see Appendix 9-F). Bioassay data in studies carried out by the HEER Office consistently overestimated TEQ dioxin concentrations in soil in comparison with split samples that were tested using laboratory GC/MS methods (HDOH, 2007e). This suggests that the bioassay tests provide a conservative estimate of TEQ dioxin concentrations. Paired GC/MS and bioassay data for split samples can be used to develop a correction factor and adjust the bioassay data for actual comparison to HEER Office EALs.

Other investigations, however, suggest that bioassay tests may *underestimate* TEQ dioxin concentrations for very-low concentrations of dioxins in soil (e.g., <100 ng/kg; e.g., see TTEMI 2012). While this will not affect development of a correction factor based on paired, GC/MS data, it is important to be aware of for initial screening of sites, and emphasizes the need for Method 8280 or 8290 data.

Table 9-4 Summary of Toxicity Equivalence Factors for Dioxin

Compound	WHO 2005 TEF
chlorinated dibenzo-p-dioxins	
2,3,7,8-TCDD	1
1,2,3,7,8-PeCDD	1
1,2,3,4,7,8-HxCDD	0.1
1,2,3,6,7,8-HxCDD	0.1
1,2,3,7,8,9-HxCDD	0.1
1,2,3,4,6,7,8-HpCDD	0.01
OCDD	0.0003
chlorinated dibenzofurans	
2,3,7,8-TCDF	0.1
1,2,3,7,8-PeCDF	0.03
op2,3,4,7,8-PeCDF	0.3
1,2,3,4,7,8-HxCDF	0.1
1,2,3,6,7,8-HxCDF	0.1
1,2,3,7,8,9-HxCDF	0.1
2,3,4,6,7,8-HxCDF	0.1
1,2,3,4,6,7,8-HpCDF	0.01
1,2,3,4,7,8,9-HpCDF	0.01
OCDF	0.0003

WHO World Health Organization
TEF Toxicity Equivalence Factor

9.1.4 REVIEW OF PESTICIDE CONTAMINATION AT FORMER SUGARCANE OPERATIONS

In 2011 the HEER Office prepared a summary of pesticides identified in fields, mixing areas, seed dipping vats and various other sugarcane operations across Hawai‘i (HDOH, 2011d). An overview is provided below. Refer to references in the 2011 report, for examples associated with different operations.

9.1.4.1 PESTICIDE MIXING AREAS

Data reviewed for the pesticide and dioxin summary report (HDOH 2011d) confirm that pesticide mixing areas have the highest potential for significant contamination and maintain a high priority for identification and investigation. Identification of these areas through historical records, interviews with past employees and field reconnaissance is especially important as urban growth expands into former agricultural areas.

In order of potential risk to human health and the environment and presence at former mixing sites, the pesticide categories and pesticide-related chemicals can be generally prioritized as follows (see HDOH, 2011d):

- Arsenic and dioxins (chronic direct exposure),
- Ametryn and atrazine (leaching),
- Petroleum (vapor intrusion, gross contamination, leaching),
- Lead (chronic direct exposure),
- DDT (chronic direct exposure),
- Chlorinated herbicides (leaching),
- Carbamates (leaching),
- Organophosphates (acute direct exposure).

Arsenic, dioxins, ametryn, atrazine, and petroleum in particular drive the need for remediation at former mixing areas. Significant lead contamination is also identified at many mixing area sites, although this may in part be due to the use of lead-based paint, since lead-based pesticides are not known to have been widely used.

Although the remaining chemicals can also be present in the same soil at elevated levels, addressing potential environmental hazards posed by the former will almost always coincidentally address potential concerns posed by the latter. Organophosphates primarily pose a short-term, direct exposure risk during and immediately after application. These chemicals are not normally identified in abandoned, former mixing areas above levels of potential concern. Full testing of Decision Units within a former pesticide mixing area most suspected of heavy contamination is recommended. These observations, however, can be used to limit testing for these chemicals to areas suspected of the highest contamination in order to reduce investigation costs, if needed.

Heavy arsenic contamination due to the past use of water-based, arsenical herbicides has been identified to depths of greater than ten feet at former pesticide mixing areas. In some cases contamination can be so significant that soils will fail Toxicity Characteristic Leaching Procedure (TCLP) tests and require management as hazardous waste. It is important to determine this as part of the site investigation in order to help design future remedial actions. Fortunately, the strong binding capacity of iron-rich, volcanic soils in Hawai‘i limits this potential problem to sites with arsenic concentrations in excess of several thousand ppm or at sites where the soil is relatively iron-poor. Arsenic can expected to be much more mobile (and bioaccessible) at sites in coastal areas that are situated on low-iron, calcareous soils rather than volcanic soils.

Petroleum contamination is also present at many former pesticide mixing areas. This can be associated with the use of diesel for preparation of pesticide emulsions. Examples include the use of Concentrated Activated Diesel Emulsion or "CADE" that is "activated" with pentachlorophenol (PCP) for application as an herbicide. Long-term release of petroleum-based emulsions at mixing sites can lead to heavy contamination of underlying soils with dioxins to a depth of ten or more feet. The identification of diesel-contaminated soil at a mixing site should raise concerns about potential dioxin contamination.

Trace levels of PCP are typically identified at pesticide mixing areas operated prior to 1970, when the use of PCP for agricultural operations was banned (HDOA 1969, 1977). Most non-wood preservative uses of PCP were banned in 1987 and use of PCP for wood treatment was significantly restricted by the Federal government (USEPA 2008e; see also ATSDR 2001). The reported concentration of PCP in soil is often below or only marginally above the Tier 1 soil action level of 0.82 mg/kg (HDOH, 2016). Pentachlorophenol degrades relatively rapidly in the environmental and is only moderately persistent (see Appendix 9-A). The reported level of PCP in the soil is not a reliable indicator of the presence or absence of significant dioxin contamination. Heavy dioxin contamination, well over 10,000 to 100,000+ ng/kg, associated with the past use of PCP has been identified at sites where little to no PCP remains.

This highlights that the presence or absence of PCP in soil cannot be used as a stand-alone tool to screen for potentially significant dioxin contamination. Soils that could have been significantly impacted by past releases of PCP or similar, dioxin containing chemicals (e.g., 2,4,5 TP) should always be independently tested for dioxins in addition to the suspected parent chemical.

Soils in some, but not all, pesticide mixing areas are also heavily contaminated with ametryn and atrazine. While reported levels often do not exceed action levels for potential direct-exposure concern, these chemicals can still pose leaching threats to underlying groundwater. Comparison to screening levels that do not consider leaching is therefore not appropriate (e.g., USEPA Regional Screening Levels, USEPA 2012b). Reference to the more comprehensive HDOH EALs or equivalent is required. It is

important to indentify and remediate soils contaminated with these chemicals in order to prevent and/or cease long-term contamination of drinking water aquifers.

9.1.4.2 FORMER FIELD AREAS

With the local exception of arsenic, residual pesticides in former sugarcane fields are rarely detected above levels of potential concern (see Appendix 9-E). Arsenic has been identified in some fields at concentrations that are marginally above HDOH action levels for residential exposure. The distribution of former field areas with elevated arsenic is not uniform, but appears to be associated with specific sugarcane companies that operated from the 1910s through the 1940s and relied on arsenic-based herbicides for weed control in high-rainfall areas (see Subsection 9.1.3.2). Continued testing for arsenic in former sugarcane fields is recommended (see Table 9-2).

Data compiled over the past ten (and especially five) years indicate that dioxins in former sugarcane fields do not pose significant health risk should these areas be redeveloped for residential use in the future. Dioxins have subsequently been removed as a recommended contaminant of concern for former field areas (see Table 9-2). Trace levels of dioxins, reported in terms of Toxicity Equivalent or TEQ dioxins, are often below or slightly above expected, ambient background in many fields (≤20 ng/kg; refer to Appendix 9-F). In other fields the concentration of TEQ dioxins typically ranges between 50ng/kg and 100 ng/kg, below the HDOH residential action level of 240 ng/kg (e.g., see HDOH, 2007e). In relatively rare cases, the concentration of TEQ dioxins in soil at the scale of an individual, hypothetical, residential lot (e.g., 5,000 ft2; see Section 3), may slightly exceed the current action level but are still at or below past, residential action levels (e.g., 390 to 1,000 ng/kg; see Appendix 9-F; see also USEPA 1998g). This does not pose a significant risk to future residents when more site-specific exposure factors such as soil ingestion rates for urban areas are taken into consideration (see HDOH 2016).

9.1.4.3 SEED DIPPING VATS

Heavy mercury contamination has been identified at the outfalls of seed dipping vats that operated before the mid 1970s (see HDOH, 2011d). Contaminated sediment has also been identified in mill ditches that drain these areas, however contamination to date is primarily associated with arsenic and dioxins (see HDOH, 2011d). Earlier reports of mercury contamination in mill ditches that drained former seed dipping vats were not verified in followup sampling. This may have been due to misreporting of units in laboratory reports or investigation summaries. Laboratories in general report metal concentrations in soil or sediment in units of mg/kg. In the case of mercury, however, laboratories sometime report concentrations in units of µg/kg (1 mg/kg = 1000 µg/kg). Background levels of mercury in soil are typically less than 1.0 mg/kg (HDOH 2012b). It is important to review and confirm units for mercury at sites where apparent contamination is identified.

9.1.4.4 OTHER AREAS AND TARGET PESTICIDES

The review of data for former sugarcane operations did not identify a need to revise guidance for testing in other areas where pesticides may have been used or stored. Significant contamination with organochlorine pesticides (e.g., DDT, Technical Chlordane, aldrin-dieldrin) has not been identified at the majority of pesticide mixing areas or field areas (see HDOH, 2011d). Given their high toxicity and persistence in the environment, however, and past use for mosquito, termite and other pest control around former agricultural areas (e.g., around field margins), continued testing for these chemicals in both former mixing areas and in former field areas is still recommended.

Testing for thallium and barium in an area where rat poison was formerly stored and potentially mixed is currently underway (used in cakes, versus sprayed as a liquid), and data are anticipated in the future. Elevated levels of thallium have not been reported in mixing areas or fields. Due to its potential toxicity, anticipated background levels in soil are likely to be close to risk-based action levels for direct exposure (see HDOH, 2016, 2011d). Toxicity factors employed in the action levels assume that the thallium is highly soluble and bioavailable, however. Like arsenic, the actual bioavailability of both natural and pesticide-related thallium in soil is expected to be low.

9.2 PESTICIDE CONTAMINATION AT NON-AGRICULTURAL FACILITIES AND SITES

The HEER Office recommends safe management practices to limit potential exposure to and test soil for organochlorine (OC) termiticides found in and near wooden buildings built between the 1940s to the 1980s. The recommendations in this section are described in further detail in two HEER Office website fact sheets regarding the past use of OC termiticide, and soil testing for OC termiticides at residential sites (HDOH, 2011g, 2011h).

Termiticides is a general term that includes any type of chemical mixture specifically formulated to kill termites. Organochlorine termiticides are a group of persistent pesticides used for termite control in and around wooden structures from the mid-1940s to the late 1980s. Technical Chlordane and/or aldrin were applied in most instances (refer to Subsection 9.1.3.3). Dieldrin, a breakdown product of aldrin, is also commonly identified at these sites. The chemicals were used primarily by pest control operators in Hawai'i's urban areas, but also by homeowners, the military and counties to protect buildings against termite damage.

The USEPA banned all production and import of these and other OC pesticides in the 1970s (DDT) and 1980s (e.g., Technical Chlordane) due to concerns over potential long-term, ecological impacts as well as risks to human health.

Organochlorine termiticides were commonly applied directly to soil underneath foundations (e.g., around wooden piers or under slabs) and/or around the immediate perimeter of a building foundation. Application practices included pouring a liquid mixture into shallow (e.g., six inches) trenches excavated around the foundation, or by injection through holes drilled next to the foundation or in the flooring at the edge of foundation walls.

Reported concentrations of these compounds in treated soil can exceed HDOH soil action level for soil that is regularly contacted by residents or workers over many years. Typically the highest concentrations of termiticides in soil are found beneath the house or around the perimeter extending away from the building foundation up to 1 to 3 feet. The top six inches to one foot usually have the highest concentrations of OC termiticide. These chemicals were developed to be persistent and can be expected to remain in the soil for decades. Concentrations of OC termiticides under building slabs could be higher because the slab can act as a barrier or cap protecting the degradation of the termiticides in the soil over time. In some cases OC termiticides have been identified in open yard areas, apparently due to additional spraying, the existence of a former building in that area, or reuse of treated soil from former building foundations.

The HEER Office fact sheets discuss potential health concerns associated with OC termiticides in soil and recommend that contact with treated soils be minimized (HDOH, 2011g, 2011h). Termiticides applied more than two decades ago are not detectable by smell or sight. Soil testing is recommended to confirm the presence and level of these chemicals. Soil sampling techniques are described further in the HDOH fact sheet on soil testing for OC termiticides at residential sites in Hawai'i (HDOH 2011g, 2011h). This fact sheet provides an overview of the soil sampling techniques for construction or demolition contractors, homeowners, and others. Further information on soil sampling techniques can be found in TGM Sections 4 and 5.

If OC termiticides are confirmed by testing or suspected based on the age of the building then measures to minimize contact are recommended. This can include removal of treated soil or placement of gravel or landscaping around the perimeter of a house or building. Soil treated with termiticides should not be reused for other purposes without testing (refer to Clean Fill guidance, HDOH 2017d).

9.3 PETROLEUM CONTAMINATED SITES

A discussion of target chemicals of potential concern and the evaluation of petroleum releases is included in Volume 1 and Appendix 1 of the EHE guidance document (HDOH, 2016). This guidance is summarized and expanded below.

Petroleum is a complex mixture of hundreds of different compounds composed of hydrogen and carbon or "hydrocarbon" compounds (API 1994). The chemistry and toxicity of petroleum releases depends in part on the type of fuel released and the media tested. The bulk of the compounds are evaluated collectively under the all-inclusive category of Total Petroleum Hydrocarbons (TPH). The concentration of TPH in soil and groundwater is typically reported in terms of "carbon ranges," or the number of carbon molecules in individual hydrocarbon compounds based on the type of fuel released: 1) C5-C12 ("gasoline range" or "TPHg"), 2) C10-C24 ("diesel range" or "TPHd") and 3) C24-C40+ ("residual fuels" or "TPHo"). A number of different terms are applied to these ranges. As discussed below, reference to these ranges is less useful for air and soil vapor data.

"Gasoline-range" TPH is defined as a mixture of petroleum compounds characterized by a predominance of branched alkanes and aromatic hydrocarbons with carbon ranges of C6 to C12 and lesser amounts of straight-chain alkanes, alkenes, and cycloalkanes of the same carbon range (see also NEIWPCC 2003). Vapors from these fuels tend to be dominated by lighter-range, more volatile, C5-C8 aliphatics (HDOH, 2016, 2012). Although not studied in detail, dissolved-phase gasoline in groundwater is also likely to be biased towards more soluble, lighter-range compounds.

Petroleum compounds characterized by a wider variety of straight, branched, and cyclic alkanes, polynuclear aromatic hydrocarbons (PAHs, especially naphthalenes and methylnaphthalenes), and heterocyclic compounds with carbon ranges of approximately C9 to C25 are referred to as "Diesel Range" TPH. These compounds dominate the makeup of diesel and other middle distillates fuels (e.g., kerosene, diesel fuel, home heating fuel, JP-8, etc.). These fuels also contain a small but important amount of lighter, aliphatic compounds. Vapors from the fuels can somewhat counterintuitively be dominated by these "gasoline range," C5-C12, aliphatic compounds (HDOH 2012). As discussed in Subsection 9.3.1.2 below and in Section 7, it is important that these compounds be included in the analysis of TPH in air and soil vapor samples associated with releases of middle distillate fuels. Dissolved-phase, middle-distillate fuel in groundwater could also be biased towards more soluble, "gasoline-range" compounds. A dominance of "TPHg" in groundwater samples does not in itself indicate that the source of the contamination is associated with gasoline. A more detailed review of the chromatograph pattern and site history will be necessary to make this determination.

Residual fuels (e.g., Fuel Oil Nos. 4, 5, and 6, lubricating oils, mineral oil, used oils, and asphalts) are characterized by complex polar PAHs, naphthenoaromatics, asphaltenes, and other high-molecular-weight saturated hydrocarbon compounds with carbon ranges that in general fall between C24 and C40. Compounds associated with these fuels and related products are not considered to be volatile, although methane generated by degradation of the fuels could pose potential hazards at some sites.

Note that the breakdown of heavy petroleum can lead to an increase in volatile petroleum compounds (Chaplin 2002). This necessitates the collection of soil vapor samples at sites contaminated by heavier fuels, as well as gasolines and middle distillates.

Due to the number of sites with residual petroleum contamination, HDOH prepared a guidance document that outlines procedures for long-term management of residual petroleum contamination where full cleanup is not practicable. This guidance, Long-Term Management of Petroleum-Contaminated Soils and Groundwater (HDOH, 2007c) is included in TGM Section 19 as Appendix 19-A. The document includes three, supporting decision trees for determining the need for continued, HDOH oversight. Self-implemented, long-term management by the property owner and closure of the case in the HDOH database is possible in scenarios where the area and volume of contaminated soil and/or groundwater is minimal.

Table 9-5 Target Analytes for Releases of Petroleum Products

Petroleum Product	Media	[1]Recommended Target Analytes
Gasolines	Soil	TPH, BTEX, naphthalene, MTBE and appropriate additives and breakdown products (e.g., TBA, lead, ethanol, etc.)

	Soil Vapor	TPH, BTEX, naphthalene and MTBE plus other volatile additives and methane
	Groundwater	Same as soil
Middle Distillates (diesel, kerosene, Stoddard solvent, heating fuels, jet fuel, etc.)	Soil	TPH, BTEX, naphthalene, and methylnaphthalenes (1- and 2-)
	Soil Vapor	TPH, BTEX, naphthalene, and methane
	Groundwater	Same as soil
Residual Fuels (lube oils, hydraulic oils, mineral oils, transformer oils, Fuel Oil #6/Bunker C, waste oil, etc.)	Soil	TPH, [2]VOCs, naphthalene, methylnaphthalenes (1- and 2-), the remaining 16 priority pollutant PAHs, PCBs, and heavy metals unless otherwise justified
	Soil Vapor	TPH, VOCs, naphthalene, and methane
	Groundwater	same as soil

1. Include any additional volatile additives in soil vapor samples if suspected to be present.
2. VOCs includes BTEX and chlorinated solvent compounds.

9.3.1 RECOMMENDED TARGET ANALYTES

Recommended target analytes for petroleum contaminated soil and groundwater are provided in Table 9-5.

Petroleum contamination in soil, water or air/soil vapors should be evaluated in terms of both TPH and a short list of target "indicator chemicals" that are specific to the type of petroleum product released. As discussed in the previous section, non-specific compounds collectively reported as TPH typically comprise the bulk of petroleum fuels. Target indicator chemicals typically make up only a small fraction of the total petroleum present but are also important players in the assessment of environmental hazards posed to human health and the environment. The toxicity and fate and transport of these chemicals in the environment has been studied in detail.

9.3.1.1 TARGET INDICATOR COMPOUNDS

Target, indicator compounds for petroleum fuels include benzene, toluene, ethylbenzene, xylenes (total), methyl-tert butyl ether (MTBE), naphthalene and number of individual, polyaromatic hydrocarbon compounds (see Table 9-5). Separate evaluation of these chemicals is based on the availability of adequate toxicity data and the potential for the chemicals to drive risk and the need for remedial actions at contaminated properties in conjunction with TPH. Separate environmental action levels for these compounds are presented in the HEER Office EHE guidance (HDOH 2016).

All other petroleum compounds are collectively reported and evaluated under "TPH," as described above. Volatile components of petroleum that are not specifically identified as target indicator compounds in Table 9-5 but reported as separate compounds by the laboratory using EPA Method 8260 or similar methods do not need to be separately evaluated. Examples include trimethylbenzenes and other aliphatics and aromatics not specifically identified as target indicator compounds (refer to Subsection 2.11 in the EHE guidance document; HDOH, 2016). These compounds are included under the analysis and evaluation of the TPH component of petroleum.

Seventeen, semi-volatile PAHs are recommended as target, indicator compounds for releases of heavier petroleum fuels or waste oils:

- Acenaphthene
- Acenaphthylene
- Anthracene
- benzo(a)anthracene
- benzo(b)fluoranthene
- benzo(g,h,i)perylene
- benzo(a)pyrene
- benzo(k)fluoranthene
- chrysene
- dibenzo(a,h)anthracene
- fluoranthene
- fluorine
- indeno(1 ,2,3)pyrene,
- methylnaphthalenes (1 & 2)
- naphthalene
- phenanthrene
- pyrene

In practice, the need for remedial actions at sites impacted with PAHs is typically driven by benzo(a)pyrene. Naphthalene can be reported with either semi-volatile or volatile compounds (see Section 7). Separate Environmental Action Levels (EALs) for 1- and 2- methylnaphthalenes are presented in the EHE guidance document (HDOH, 2016).

The suite of PAHs that should be tested at a given site depends on the type of the petroleum product released (after MADEP 2002). As indicated in the Table 9-5, naphthalene is the only PAH that requires reporting for gasoline release sites. Both methylnaphthalenes and naphthalene should be reported at sites with releases of middle distillates (diesel, jet fuel, etc.). The full suite of PAHs should be considered at sites with releases of heavier petroleum fuels and waste oil, unless site-specific information on the product released justifies eliminating specific PAHs.

Methylnaphthalenes do not need to be reported for soil vapor samples as a default. Based on data reviewed by HDOH, these compounds are unlikely to drive potential vapor intrusion hazards at petroleum release sites over TPH or benzene due to their relatively low volatility and concentration in most middle distillates and residual fuels. Testing for these compounds in soil vapor also requires different sample collection and analytical methods (e.g., sorbent tubes and TO-1 analysis; see Subsection 7.8.2). Reporting of these compounds in soil vapor samples may, however, be required at sites impacted by Manufactured Gas Plant waste.

9.3.1.2 TOTAL PETROLEUM HYDROCARBONS

Soil, groundwater, and soil vapor samples must always be tested for TPH (or equivalent) in addition to targeted, individual chemicals. Laboratory analysis for TPH as gasolines and middle distillates is generally carried out using gas chromatography, modified for "gasoline-range" organics ("Volatile Fuel Hydrocarbons") and "diesel-range" organics ("Extractable Fuel Hydrocarbons"), respectively (e.g., EPA Method 8015). Analysis for TPH as residual fuels up to the C40 carbon range can be carried out by gas chromatography, infrared absorption, or gravimetric methods. The latter methods are rarely used, however, due to their inability to discriminate the type of the petroleum present and interference with organic material in the soil.

The concentration of TPH (or equivalent) in soil vapor should always be reported as the sum of C5-C12 compounds for whole air samples and C5-C18 for sorbent tube samples, regardless of the type of petroleum fuel involved. Refer to Appendix 1 of the HDOH EHE guidance for a detailed discussion on total volatile petroleum hydrocarbons (see also Brewer et al 2013). As discussed above and in Subsection 7.8.2, results from a petroleum vapor study carried out by HDOH study indicate that C5-C8 aliphatic compounds can make up a significant if not dominant fraction of the total TPH present in vapors associated with diesel and other middle distillate fuels (HDOH, 2012, 2012c). This is important, since current laboratory protocols typically require that they report "TPHdiesel" in any media as the sum of C10 to approximately C24 hydrocarbon compounds. Excluding the contribution of C5-C8 aliphatics to the total concentration of TPH reported in air or soil vapor samples associated with middle distillate fuels would be inappropriate, however.

To help address this issue, laboratories should be instructed to report TPH (or equivalent) in air or vapor samples as: 1) The sum of C5-C12 compounds for whole-air samples (e.g., summa canister samples and TO-15 lab methods, with the understanding that aromatics can only be confidently summed to C10) or 2) The sum of C5-C18 for samples collected using a sorbent media (e.g., sorbent tubes and TO-17 lab methods, with the understanding that aromatics can only be confidently summed to C16). This should be done regardless of whether the samples are associated with gasolines or middle distillates.

Laboratory methods for reporting of TPH in indoor air and soil gas are discussed in Subsection 7.13. A combination of both TO-15 (Summa canister samples) and TO-17 (sorbent tube samples) is currently recommended for initial investigation of petroleum-contaminated sites (see HDOH, 2012c). The collection of concurrent, sorbent tube samples can be discontinued if initial data indicate that C12+ compounds make up less than 10% of the total TPH present in vapors.

Designation of chromatogram patterns as "gasoline range" (e.g., C5-C12) or "diesel range" (e.g., C10-C24) with respect to traditional, laboratory methods for TPH in soil or water is not applicable to air and vapor samples and can be misleading. The reported concentration of TPH can then be compared to HDOH soil gas action levels. The sum of concentrations of individual, target analytes such as BTEX and naphthalene that will be evaluated separate can be subtracted from the reported concentration of TPH in order to avoid double counting, although this is not likely to make a significant difference in the final concentration.

As discussed in TGM Subsection 7.8, the initial collection of both Summa canister samples and sorbent tube samples is recommended for soil vapor investigations at diesel and middle distillate sites. This is due to limitations on the ability to extract >C12 compounds from Summa canisters (see Subsection 7.13.1.1). A minimum Summa canister size of one-liter is recommended, in order to help collect a representative sample (tested for both TPH and target, indicator compounds such as BTEX and naphthalene). A maximum, 50ml vapor draw might be required for sorbent tube samples due to limitations of the sorbent material (tested only for TPH). Sorbent tube data are used to evaluate the relative proportion of >C12 compounds associated with TPH.

If the relative fraction of >C12 is less than 10% of the TPH then the concentration of TPH reported for the Summa canister can be used for comparison to action levels and Summa canisters can be relied upon for the collection of future samples. If >10% of

the vapor-phase TPH is associated with >C12 compounds then a combined use of Summa data and sorbent tube data should be used to evaluate the site. For example, request that the laboratory report TPH for the sorbent tube sample as the sum of >C12 compounds. Add this to the concentration of TPH reported for the Summa sample (i.e., TPH as sum of C5-C12). The resulting, total TPH concentration can then be compared to soil gas action levels. This approach excludes the concentration of aromatic compounds greater than C10 but less than C12. Based on published information and data collected by the HEER Office, however, these compounds make up an insignificant (i.e., <10%) proportion of TPH vapors at typical, petroleum-release site.

Reported concentrations of unidentified hydrocarbons as gasoline, diesel or oil indicate that the chromatogram generated for the sample does not match standards used to quantify TPH. Reported concentrations of TPH should be considered approximate, but adequate for comparison to HDOH action levels. A more detailed evaluation through petroleum carbon range analysis can be carried out on a site-specific basis as warranted.

Silica gel cleanup of samples, in particular for surface water and groundwater, should not be carried out without consultation with HDOH. Two options are recommended: (1) Directly compare TPH data to HDOH EALs in the absence of silica gel cleanup, and/or (2) Report data both with and without silica gel cleanup. For the second option, compare the nonpolar, TPH fraction to HDOH EALs and evaluate potential hazards posed by TPH-derived, polar breakdown products to drinking water and aquatic habitats in a site-specific EHE (see HDOH, 2016).

Dissolved-phase TPH in water is composed of unaltered, nonpolar compounds originally in the parent fuel and polar compounds associated with the oxidation and biodegradation of the former (e.g., Zemo 1995, 2008, Lang et al 2009, Mohler et al. 2013). Polar compounds can be removed by passing the sample through silica gel prior to analysis, referred to as “silica gel cleanup (SGC).” A column SGC lab method should be used rather than a shake or funnel method (e.g., Method 3630C, USEPA 1996k). If polar compounds are removed, both non-SGC and SGC data should be reported.

In many cases silica gel cleanup will significantly reduce the concentration of TPH reported for the sample. The polar compounds, which can dominate the overall mass of TPH in groundwater at aged-release sites, are primarily organic acids/esters and alcohols with variable amounts of ketones, phenols and aldehydes. These compounds must be taken into account as part of a site investigation. From an environmental hazard standpoint, the sum of the polar compounds and nonpolar compounds (i.e., the concentration of TPH reported in the absence of a silica gel cleanup) represents the concentration of TPH that should be directly compared to HDOH Environmental Action Levels (refer to HDOH EHE guidance; HDOH, 2016).

Methods for development of separate EALs for TPH-related, polar compounds or evaluation of these compounds in a site-specific EHE or human-health risk assessment have not been fully developed. The toxicity of the polar fraction of the TPH to both humans and aquatic organisms has only recently begun to be studied (e.g., Zemo et al. 2013). As a default, and for the purposes of this guidance, the health risk and other potential environmental concerns associated with these compounds (e.g., toxicity to aquatic organisms, taste and odors in drinking water, etc.) is assumed at an initial screening level to be identical to the parent, nonpolar TPH compounds.

If silica gel cleanup of samples for a site is still desired (e.g., evaluation of degradation, fingerprinting of fuel releases, site-specific risk assessment, etc.), then the objectives and methodology to be implemented should be presented to HDOH for review and approval. A quantitative evaluation of potential threats to human health and the environment should be carried out in accordance with the HDOH EHE guidance document for a site-specific EHE. This includes addressing potential aquatic ecotoxicity concerns as well as gross contamination concerns (e.g., drinking water taste and odors). Alternative action levels for each environmental hazard should be presented and supported for comparison to data. In most cases, it is anticipated that long-term management of groundwater contaminated primarily with polar, TPH breakdown compounds above HDOH action levels will still be required due to potential nuisance and aquatic toxicity hazards, even in the absence of apparent risk to human health (e.g., via impacts to drinking water resources).

Comparison of data for groundwater samples tested with and without silica gel cleanup could be useful for assessing the state of natural biodegradation within a plume of petroleum-contaminated groundwater and optimizing remedial and monitoring actions. For example, no further active remediation may be appropriate for areas of the plume where the majority of dissolved-phase hydrocarbons have degraded into polar compounds (i.e., significant reduction of reported TPH concentration in samples processed with silica gel cleanup). Active remediation could focus on areas of the plume where a comparison of data indicates that significant, natural degradation is not occurring. Data can also be used as one line of evidence to support a recommendation for no further monitoring and site closure following the HEER office guidance for long-term monitoring of petroleum-contaminated sites (HDOH, 2007c; see TGM Section 19, Appendix 19-A).

9.3.2 PETROLEUM CONTAMINATION ENCOUNTERED DURING SUBSURFACE SOIL EXCAVATION

Unanticipated petroleum (free product) or petroleum-contaminated soil is sometimes encountered during construction work where subsurface soil is being excavated. The HEER Office has a Guidance Fact Sheet, consistent with the Hawai‘i Environmental Response Law (HRS 128D; HDOH 1990), to assist project managers, contract workers, safety and health personnel or anyone involved in construction and excavation of soils when petroleum is encountered on a site. This document,

"Guidance Fact Sheet for Use When Petroleum Contamination is Encountered During Subsurface Soil Excavation", is provided in Appendix 9-D.

In rare cases the reported concentration of TPH in soil with strong petroleum odors could fall below HEER Office EALs for gross contamination (refer to HDOH, 2016). This could be due to sampling error in the field, laboratory sample processing error, or the inability of the laboratory method to accurately quantify the amount of TPH in the soil. Even so, soil with an obvious petroleum odor should be considered grossly contaminated and managed appropriately. Removal and/or treatment of vadose-zone soil that exceeds the HEER Office EAL for subsurface gross contamination (e.g. 5,000 mg/kg) is typically recommended at a minimum when complete cleanup cannot be achieved. The HEER Office should be contacted regarding the on-site management or re-use of additional, petroleum contaminated soil. Refer also to the HEER Office Clean Fill Guidance for additional information (HDOH 2017d).

9.3.3 PAHS IN ASPHALT, TAR AND WASTE OIL

Understanding the potential source of polyaromatic hydrocarbon compounds (PAHs) in soil is important for decision making. Benzo(a)pyrene, the most potent of the PAHs, is almost always the risk driver in soils contaminated with PAHs. With the possible exception of naphthalene and methylnaphthalenes, these compounds are not present in significant amounts in gasolines and middle distillate fuels or soils impacted by these fuels (API 1994, TPHCWG 1998). They are present, however, in asphalt, waste oil and coal tar.

Samples of soil impacted with waste oil can have concentrations of benzo(a)pyrene and related PAHs in the tens of parts-per-million, well above Tier 1 EALs for potential direct-exposure concerns. Correlative concentrations of TPH up to approximately C40 are usually in the thousands of parts-per-million range (e.g., see API 1994). The concentration of PAHs in Bunker C and similar, residual fuels can also contain similar levels of BaP and other PAHs. Investigation and remediation of these soils is necessary for the protection of human health and the environment.

Soils impacted with asphalt can express similar concentrations of PAHs (e.g., see API 1994). An asphalt source of the PAHs is usually readily identifiable by relatively low concentrations of TPH, usually in the low hundreds of parts-per-million range. The bioavailability of PAHs in asphalt is relatively low and the presence at these levels does not pose a significant health risk. Asphalt is also regulated as an "inert waste" under Hawai‘i Revised Statutes 342H-1 and does not fall under HEER Office oversight, even if BaP concentrations exceed EALs. If the source of PAHs identified in soil can reasonably be attributed to asphalt, then no further action is required. The inclusion of small particles of asphalt in soil from heavily developed areas or previously paved areas may be unavoidable. The reuse or import of asphalt as fill material is not recommended at remediation sites overseen by the HEER Office (HDOH, 2017d).

Relatively low concentrations of <C40 TPH are also often reported for soils impacted with coal tar, including manufactured as plant waste, older clay pigeons used at skeet ranges and petroleum-based patching material for roads or roofing (API, 1994; EPRI, 1993). The concentration of PAHs associated with these materials is often in the hundreds of parts-per-million range, however, highlighting coal tar or similar material as the likely source of the PAHs. Concentrations of PAHs in soil at these levels could pose potential direct-exposure concerns, even if the bioavailability of the PAHs is relatively low. Investigation and remediation of sites impacted with coal tar and similar material is essential.

In addition to asphalt, parts-per-billion to low, parts-per-million range concentrations of PAHs in soil in urban environments in combination with relatively low concentrations of TPH can also be associated with exhaust from vehicles, ash from fires and other source of combustion (Mauro et al., 2006). Recognition of anthropogenic background as part of a site investigation is necessary in order to correctly define the extent of contamination associated with releases of waste oil, manufactured gas plant waste or other sources that might require remediation.

9.4 METHANE

Figure 9.1 Methane Mitigation Decision Matrix

Distance to structure	Methane Concentration in Soil Gas			
	<1000 ppm (<0.1%, <2% LEL)	1000 - 5000 ppm (0.1% - 0.5% 2% LEL - 10% LEL)	5000 - 12,500 ppm (0.5% - 1.25% 10% LEL - 25% LEL)	> 12,500 ppm (> 1.25% > 25% LEL)
0 ft (beneath structure)	No Controls Recommended	Methane Monitoring Conduit Seals and Utility Trench Dams	Methane Monitoring Conduit Seals and Utility Trench Dams Vapor Mitigation	Methane Monitoring Conduit Seals and Utility Trench Dams Vapor Mitigation
0 - 100ft	No Controls Recommended	Methane Monitoring	Methane Monitoring Conduit Seals and Utility Trench Dams	Methane Monitoring Conduit Seals and Utility Trench Dams Vapor Mitigation
100 - 300ft	No Controls Recommended	No Controls Recommended	Methane Monitoring	Methane Monitoring Conduit Seals and Utility Trench Dams
>300ft	No Controls Recommended	No Controls Recommended	No Controls Recommended	Methane Monitoring

1. Decision matrix modeled after Geonsyntec 2011.
2. Actions listed in this decision matrix assume soil gas pressure is < 2 in-H2O. If soil gas pressure is greater than 2 in-H2O, then the need for enhanced mitigation measures should be evaluated.
3. This mitigation matrix does not preclude site-specific evaluation of engineering controls. Engineering control requirements can be reduced if additional indoor/sub-slab monitoring is conducted following construction of building or if site conditions are in the more conservative end of the listed criteria (i.e., lower end of methane concentration and upper end of distance criteria). If reduced controls are utilized, a mitigation decision matrix for soil gas and indoor air data should be developed.
4. Methane Monitoring can include testing of exterior soil gas, sub-slab, and/or indoor air. A specific monitoring program should be proposed prior to building construction.

Methane is a colorless, odorless and highly flammable gas generated by the anaerobic biodegradation of organic material, including petroleum. Methane can pose explosion and fire hazards under some conditions. In order for methane to create hazardous conditions, three conditions must be met: 1) A sufficient concentration of methane; 2) A sufficient concentration of oxygen and 3) An ignition source. Potential safety risks should be assessed by considering concentrations of methane and oxygen in soil gas, significance of advective (i.e., under pressure) transport, and potential for methane attenuation between the soil gas and structure or enclosed space.

Advective flow of methane under pressure from a source area is primarily a concern at landfills. This creates a high risk for significant, offsite migration and potential intrusion into the lower floors of buildings or subsurface utility corridors. Methane can be present at high concentrations in vadose-zone soil at petroleum-contaminated sites but is rarely under significant pressure and typically migrates by diffusion rather than advection. While significant offsite migration is less likely, diffusion into subsurface utility corridors could pose localized flash explosion or fire concerns if the methane mixes with oxygenated air and is encountered during subsurface construction or utility work. Accumulation of methane in poorly ventilated rooms of buildings with cracked floors, gaps around utility penetrations in the floor or other vapor entry routes could also pose potential hazards.

Figure 9-1 presents a summary of recommended monitoring and mitigation actions for site where high levels of methane are detected in soil vapors (Geosyntec 2011).

Final monitoring and mitigation actions for potential methane hazards will necessarily be site specific, and depend in part on the estimated area and volume of the source area, planned remedial actions to address the source, the presence and use of existing buildings and the planned use or redevelopment of the site. Coordination with HDOH and submittal of a site-specific

workplan for review is recommended. Additional methane guidance can be found in the following document: Advisory on Methane Assessment and Common Remedies at Schools Sites (CalEPA 2005b).

Be aware that high levels of light-end (C5-C12), petroleum vapors can cause false, elevated readings of methane in vapor samples using a standard, landfill gas analyzer. The use of a carbon trap is recommended when evaluating for methane when using field instruments at sites where high levels of petroleum may be present in soil gas. A carbon trap will remove the majority of petroleum aliphatic and aromatic compounds from the soil gas and allow for a more accurate reading of methane.

Table 9-6 [1]Background Metals in Hawai'i Soils

Metal	Range (mg/kg)	[2]Upperbound Concentration (mg/kg)
Antimony	0.004-2.4	2.4
Arsenic	0.3-50	24
Barium	4.5-926	690
Beryllium	0.05-3.8	3
Cadmium	0.02-17	2.3
Chromium (Total)	8.52-3,180	1145
Cobalt	0.69-113	80
Copper	2.4-450	252
Lead	0.76-73	73
Mercury	<0.017-1.4	0.72
Molybdenum	0.06-4.0	4.0
Nickel	2.1-767	410
Selenium	0.24-12	7.1
Silver	0.02-1.5	1.5
Thallium	<0.25-15	0.25
Vanadium	0.25-1,090	770
Zinc	3.6-1,200	349

Reference: HDOH, 2012b

Notes:
1. Excludes samples with known or suspected anthropogenic contamination.
2. Upper Bound concentration selected based on evaluation of univariate sample data plots.
3. Background Threshold Value set to maximum-reported concentration, excluding samples with suspected anthropogenic contamination.
4. Background action level based on Upper Bound concentration unless otherwise noted.

9.5 BACKGROUND METALS IN SOIL

A review of background metals in soil is included in the HEER Office document Hawaiian Islands Soil Metal Background Evaluation (HDOH, 2012b). The results of this study were incorporated into the EHE guidance document and associated EALs. As discussed in the EHE guidance document, naturally occurring background concentrations of some metals in soil exceed risk-based action levels for these metals (see HDOH, 2016). This is especially true for arsenic, but can also occur for heavy metals such as thallium, vanadium and other metals associated with soils developed over basaltic bedrock. These metals in soils are tightly bound to iron hydroxide and other complexes and do not pose a health risk, however.

The upper bound concentration of the metal was selected for background screening purposes in the EALs. A summary of selected background concentrations is provided in Table 9-6. Risk-based action levels were replaced with the natural background concentration of the chemical if the background value was higher.

As discussed in the HEER EHE guidance, the risk-based action level for arsenic for soils in an unrestricted ("residential") land use scenario is 0.42 mg/kg based on a 10-6 excess cancer risk (see HDOH, 2016). This purely risk-based action level is based on an assumed bioavailability of arsenic in soil of 100%. This is unrealistic for most soils and especially iron-rich, volcanic soils in Hawai'i, since arsenic will tightly bind to iron in soil and not be available for uptake if the soil is incidentally ingested (e.g., Cutler et al 2013). Background concentrations of arsenic in soils in Hawai'i typically range from 5 mg/kg to 24 mg/kg (see above references). A default, upper bound background concentration of 24 mg/kg arsenic is incorporated into the EAL lookup tables. Soils with total arsenic that exceed this concentration should be tested for bioaccessible arsenic (see Subsection 9.1.3.2). Upper threshold background values of arsenic in soil can approach 40 to 50 mg/kg, especially in discrete samples.

Note that background concentrations of naturally occurring metals in soil should not be included in calculation of cumulative risk as part of a site-specific risk assessment. Additional guidance on site-specific risk assessments is included in the HEER Office EHE guidance document (HDOH, 2016).

Direct comparison of background metals concentrations to sediment samples should be done with caution. Although data are limited, concentrations and relative ratios of metals in sediment derived primarily from volcanic soils and rocks should be similar to those noted in the table. Separation and concentration of heavy metals during sediment transport is possible, however. This could lead to either elevated or decreased concentrations of heavy metals in sediment in comparison to the parent material. A high concentration of organic matter in sediment (e.g., >10%) will also "dilute" the reported concentrations of heavy metals in comparison to the parent material. This can be accounted for by adjusting reported metal concentrations with respect to the concentration of Total Organic Carbon (TOC) in the sample (i.e., Adjusted Concentration = Reported Concentration/(1-Fraction TOC). As discussed in the report, the background data also focus on volcanic soils are not directly applicable to either soils or sediments derived primarily from coral and limestone. Concentrations of heavy metals in these cases are likely to be considerable lower than those noted in the above table.

Further information on background metals in Hawaiian island soils can be found on the HEER Office website. This website also has a link to the HEER Office document *Hawaiian Islands Soil Metal Background Evaluation* (HDOH, 2012b).

9.6 METHAMPHETAMINE LABORATORY CLEANUP

9.6.1 BACKGROUND

Methamphetamine, also known as "meth," "speed," "crank," "crystal" and "ice," is a very powerful man-made drug that affects the central nervous system. Manufacture of methamphetamine is illegal. The product is often made in makeshift laboratories set up in rented property, including houses, apartments and hotel rooms. The majority of current operations in Hawai‘i are believed to be small scale.

Many of the chemicals used to produce methamphetamine are highly volatile and toxic. These chemicals can cause death or injury to the lab operators and other occupants, law enforcement officials and first responders to lab explosions.

The number of properties contaminated by illegal methamphetamine laboratories has been increasing through the years. After the operations move or are shut down, property owners are often left with unknown and not necessarily obvious levels of contamination. Carpeting, wall board, ceiling tile, wood and fabric and other materials in a building can absorb the chemicals used in meth labs. Furniture or draperies also can be contaminated. Contamination can spread to other areas of the building if residues enter the heating, ventilation and air-conditioning system. Soil or groundwater may become contaminated if chemicals are disposed of in a septic system or dumped outside.

Detailed information and guidance on methamphetamine laboratory cleanup can be found at the HEER Office meth labs webpage. The webpage contains fact sheets, policies, and useful links outside of the website. A brief overview is provided below.

9.6.2 HDOH GUIDANCE

In 2006, Act 170 was signed into law in response to concern over the potential health effects associated with residual methamphetamine and related contaminants at these operations. The Act required HDOH to establish administrative rules for the cleanup of these sites. These rules became effective in November 2007. Guidance was prepared and published in July 2010 (HDOH, 2010c).

The guidance discusses methamphetamine manufacturing in Hawai‘i, safety considerations during inspection and testing of former operations, hazardous materials disposal, decontamination procedures, reporting, and criteria that must be met before a No Further Action determination can be made by HDOH.

9.6.3 INVESTIGATION PROCESS

The HDOH HEER Office provides general oversight for the decontamination of methamphetamine manufacturing sites upon referral by the chief investigating law enforcement officer and coordination with the property owner. Testing is carried out prior to commencement of remediation activities.

The HEER Office reviews and approves the field sampling plan, quality assurance project plan, hazard assessment and recognition plan and health and safety plan submitted by the cleanup contractor(s). The contractor in most cases is hired by the property owner, unless a separate responsible party can be located to conduct sampling and decontamination. HDOH itself does not carry out sampling or decontamination activities.

Chemicals of potential concern to test for at former methamphetamine operations are necessarily site-specific. A number of methods are used to synthesize methamphetamine. The active ingredient is derived from one of three chemicals, ephedrine, pseudoephedrine, or phenylpropanolamine. Other chemicals used in the synthesizing process include iodine, red phosphorous , hydrochloric acid, ether, kerosene (e.g., Coleman fuel), paint thinner, acetone, drain cleaner, battery acid, lithium batteries, hydriodic acid, and anhydrous ammonia.

Table 9-7 includes a summary of chemicals that typically need to be included for testing for former methamphetamine labs and their associated hazards.

Table 9-7 Chemical Hazards Associated with Illegal Methamphetamine Labs

Typical Chemicals Found in Lab Sites	Common Legitimate Uses	Poison	Flammable	Toxic Vapors	Explosive	Corrosive	Skin Absorption	Common Health Hazards
Acetone	Fingernail polish remover, solvents	X	X	X			X	Reproductive disorders
Methanol	Brake cleaner fluid, fuel	X	X	X			X	Blindness, eye damage
Ammonia	Disinfectants	X		X		X	X	Blistering, lung damage
Benzene	Dye, varnishes, lacquers	X	X		X	X	X	Carcinogen, leukemia
Ether	Starter fluid, anesthetic	X	X		X			Respiratory failure
Freon	Refrigerant, propellants	X		X		X		Frostbite, lung damage
Hydriodic Acid	Driveway cleaner	X		X		X	X	Burns, thyroid damage
Hydrochloric Acid (HCL Gas)	Iron ore processing, mining	X		X		X	X	Respiratory, liver damage
Iodine Crystals	Antiseptic, catalyst	X	X		X	X		Birth defects, kidney failure
Lithium Metal	Lithium batteries	X				X	X	Burns, pulmonary edema
Muriatic Acid	Swimming pool cleaners	X		X		X		Burns, toxic vapors
Phosphine Gas	Pesticides	X		X			X	Respiratory failure
Pseudoephedrine	Cold medicines	X						Abuse: Heart damage
Red Phosphorus	Matches, fireworks	X	X	X	X			Unstable, flammable
Sodium Hydroxide	Drain cleaners, lye	X		X		X	X	Burns, skin ulcers
Sulfuric Acid	Battery acid	X		X		X	X	Burns, thyroid damage
Toluene	Paint, thinners, solvents	X	X	X	X		X	Fetal damage, pneumonia
Liquid Lab Waste	None	X	X	X	X	X	X	Unknown long term effects

Reference: HDOH, 2010c

Prior to issuance of a No Further Action determination, the HEER Office confirms that each remediation process has been completed according to the approved work plan, and that the property has been decontaminated to below state-approved levels of concern. Refer to the full guidance for additional details (HDOH 2010c).

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APPENDIX 9-A
GENERAL PESTICIDE INFORMATION

Chemical	Laboratory Analytical Group*	Standard Laboratory Method*	Availability of Toxicity Factors**	KoC (cm^3/g)	Half-Life in Soil (days)	Half-Life Refer-ence***	Notes
Ametryn	Triazine Pesticides	8141 or 619M	Yes	4.5E+02	1.8E+02	5	Moderately persistent herbicide. Used since the 1960s (possibly earlier).
Arsenic	Heavy Metals	6010B/ 6020	Yes	?	na	-	Highly persistent herbicide component.
Atrazine	Triazine Pesticides	8141 or 619M	Yes	2.3E+02	1.0E+02	3	Moderately persistent herbicide. Used since the 1960s (possibly earlier).
Benomyl	Carbamates	8321	Yes	5.2E+02	3.6E+02	6	Moderately persistent fungicide used for seed dipping. Used since the 1970s.
Bromodichloromethane	VOCs	8260	Yes	3.5E+01	1.5E+00	3	Fumigant with low persistence.
Bromomethane	VOCs	8260	Yes	1.4E+01	2.8E+01	2	Fumigant with low persistence.
Captafol	Organochlorine Pesticides	8081 or 8270	Yes	2.7E+03	7.0E+00	8	Fumigant with low persistence.
Captan	SVOCs	8270	Yes	8.6E+02	2.5E+00	8	Fumigant with low persistence.
Chlordane (Technical)	Organochlorine Pesticides	8081	Yes	8.7E+04	1.0E+02	8	Moderately persistent insecticide. Cancelled in 1988.
Chlorpyrifos	Organo-phosphorus Pesticides	8141	Yes	6.8E+03	8.4E+01	1	Moderately persistent insecticide used since the 1970s.
Dalapon	Chlorinated Herbicides	8151 or 8321	Yes	2.7E+00	3.0E+01	8	Low to moderately persistent herbicide used since the 1950s.
Diazinon	Organo-phosphorus Pesticides	8141	Yes	1.3E+03	4.0E+01	8	Moderately persistent insecticide broadly used since the 1960s (possibly earlier).
Dibromo-3-Chloropropane, 1,2-	VOCs	8260 or 8081	Yes	1.3E+02	1.8E+02	1	Moderately persistent (although volatile) fumigant broadly used from the 1940s through 1980s.
Dibromochloromethane	VOCs	8260	Yes	3.5E+01	1.8E+02	2	Moderately persistent pesticide; unknown if used in cultivation.

Table 9-A (continued)

Chemical	Laboratory Analytical Group*	Standard Laboratory Method*	Availability of Toxicity Factors**	KoC (cm^3/g)	Half-Life in Soil (days)	Half-Life Refer-ence***	Notes
Dibromoethane, 1,2-	VOCs	8260	Yes	4.4E+01	1.0E+02	8	Moderately persistent (although volatile) fumigant broadly used from the 1940s through 1980s.
Dicamba	Chlorinated Herbicides	8151 or 8321	Yes	2.9E+01	3.1E+01	7	Herbicide with low to moderate persistence.
Dichlorodiphenyl-dichloroethane (DDD)	Organochlorine Pesticides	8081 or 8270	Yes	1.5E+05	1.0E+03	8	Highly persistent impurity of DDT insecticide.
Dichlorodiphenyl-dichloroethylene (DDE)	Organochlorine Pesticides	8081 or 8270	Yes	1.5E+05	1.0E+03	8	Highly persistent impurity of DDT insecticide.
Dichlorodiphenyl-trichloroethane (DDT)	Organochlorine Pesticides	8081 or 8270	Yes	2.2E+05	1.2E+02	8	Moderately persistent insecticide. Used by State for mosquito control until banned in 1972.
Dichlorophenol, 2,4-	SVOCs	8270	Yes	7.2E+02	2.6E+00	1	Intermediate product of 2,4-D and other herbicides with low persistence.
Dichlorophenoxyacetic Acid (2,4 D)	Chlorinated Herbicides	8151 or 8321	Yes	7.2E+02	1.0E+01	8	Herbicide with low persistence.
Dichloropropane, 1,2-	Chlorinated Herbicides	8151	Yes	6.8E+01	3.6E+02	8	Moderately persistent (although volatile) fumigant used from the 1940s to 1974.
Dichloropropene, 1,3-	Chlorinated Herbicides	8151	Yes	8.1E+01	1.0E+01	8	Fumigant with low persistence.
Dioxins/Furans	Dioxins/furans	8280/8290	Yes	2.6E+05	3.7E+04	1	Highly persistent impurity of chlorinated phenol pesticides (pentachlorophenol; 2,4,5-T; 2,4,5-TP).
Diuron	Carbamates	8321	Yes	1.4E+02	9.0E+01	8	Moderately persistent herbicide. Used since the 1960s (possibly earlier).
Endosulfan	Organochlorine Pesticides	8081 or 8270	Yes	2.2E+04	1.5E+02	15	Pesticide with moderate persistence.

Table 9-A (continued)

Chemical	Laboratory Analytical Group*	Standard Laboratory Method*	Availability of Toxicity Factors**	KoC (cm^3/g)	Half-Life in Soil (days)	Half-Life Refer-ence***	Notes
Ethephon	SVOC	8270	Yes	3.6E+00	8.0E+00	7	Growth regulator with low persistence.
Glyphosate	Other	547	Yes	1.9E+01	4.7E+01	-	Herbicide with low to moderate persistence (beaks down in water).
Heptachlor	Organochlorine Pesticides	8081 or 8270	Yes	5.2E+04	2.5E+02	8	Moderately persistent insecticide and component of technical chlordane. Cancelled in 1988. Potentially used in fields with drip irrigation between 1979 & 1985.

Heptachlor Epoxide	Organochlorine Pesticides	8081 or 8270	Yes	5.3E+03	3.7E+02	-	Highly persistent component of technical chlordane.
Hexachlorocyclohexane, Gamma	Organochlorine Pesticides	8081 or 8270	Yes	3.4E+03	2.4E+02	12	Moderately persistent insecticide.
Hexazinone	Triazine Pesticides	8141	Yes	6.1E+02	2.2E+02	7	Moderately persistent herbicide used since the 1970s.
Lead	Heavy Metals	6010B/ 6020	Yes	?	na	-	Unknown if lead-based insecticides, herbicides, & rodenticides used in cultivation. Highly persistent.
Malathion	Organo-phosphorus Pesticides	8141 or 8270	Yes	3.1E+01	1.0E+00	7	Insecticide with low persistence. Used since the 1960s (possibly earlier).
Mercury	Heavy Metals	7471	Yes	1.7E+02	?	-	Highly persistent fungicide (seed dipping). All food uses cancelled in 1969.
Methyl Mercury	Heavy Metals	7471	Yes	?	?	-	Methylated form of mercury generated in reducing environments; potential byproduct.
Methyl Sulfanilcarbamate	Carbamates	8321A	Yes	1.2E+03	3.1E+01	-	Herbicide used since the 1970s. Low to moderate persistence.
Metribuzin	Triazine Pesticides	8141	Yes	1.2E+03	4.4E+02	7	Highly persistent herbicide used since the 1970s.

Table 9-A (continued)

Chemical	Laboratory Analytical Group*	Standard Laboratory Method*	Availability of Toxicity Factors**	KoC (cm^3/g)	Half-Life in Soil (days)	Half-Life Refer-ence***	Notes
Mirex	Organochlorine Pesticides	8081 or 8270	Yes	4.7E+05	3.7E+02	-	Highly persistent insecticide. Very limited use in Hawai'i. Not sold in US since 1978.
Oxamyl	Carbamates	8321	Yes	1.0E+01	2.7E+01	7	Insecticide with low persistence.
Parathion	Organo-phosphorus Pesticides	8141 or 8270	Yes	1.7E+03	7.3E+02	13	Highly persistent insecticide. Registration cancelled in 1992.
Pentachlorophenol	SVOCs or Chlorinated Herbicides	8270 or 8151	Yes	3.4E+03	3.0E+01	15	Herbicide used from 1960s (possibly earlier) until 1970. Low to moderate persistence.
Picloram	Chlorinated Herbicides	8151	Yes	1.8E+01	3.0E+02	7	Moderately persistent sugarcane herbicide used since the 1960s (possibly earlier).
Propiconazole	Carbamates	8321	Yes	5.6E+03	8.4E+01	7	Moderately persistent fungicide. Used since the 1980s.
Simazine	Triazine Pesticides	8141 or 619M	Yes	1.5E+02	2.5E+02	8	Moderately persistent herbicide. Used since the 1960s (possibly earlier).
Terbacil	Organonitrogen	633	Yes	7.8E+01	5.2E+02	7	Highly persistent herbicide. Limited used since the 1970s; not significantly toxic.

Tetrachlorophenol, 2,3,4,6-	SVOCs	8270	Yes	2.0E+03	3.0E+01	-	Component of pentachlorophenol with low to moderate persistence.
Trichlorophenoxyacetic Acid, 2,4,5- (2,4,5 T)	Chlorinated Herbicides	8151 or 8321	Yes	1.2E+03	3.0E+02	10	Moderately persistent herbicide. Limited possible use with sugarcane in 1960s. Suspended in 1985.
Trichlorophenoxypropionic Acid, 2,4,5- (2,4,5 Tp)	Chlorinated Herbicides	8151 or 8321	Yes	4.9E+01	1.7E+01	11	Herbicide with low persistence. Limited possible use with sugarcane in 1960s. Suspended in 1985.
Trichloropropene, 1,2,3- (TCP)	VOCs	8260	Yes	1.3E+02	3.1E+01	-	Impurity in 1,3 dichloropropene with low to moderate persistence.
Trifluralin	Organochlorine Pesticides	8081 or 8270	Yes	9.7E+03	6.0E+01	8	Moderately persistent herbicide. Used since the 1980s.

Table 9-A (continued)

Chemical	Laboratory Analytical Group*	Standard Laboratory Method*	Availability of Toxicity Factors**	KoC (cm^3/g)	Half-Life in Soil (days)	Half-Life Refer-ence***	Notes
Used But No Toxicity Data And/Or No Standard Laboratory Method							
Amitrole	Other	?	No	2.0E+01	2.6E+01	4	Herbicide used pre-1971 with low persistence.
Ammonium Sulfamate	Other	?	Yes	?	?	-	Herbicide used in the 1960s until possibly the 1980s; assumed low persistence.
Bromacil	Carbamates	8321	No	9.3E+00	2.4E+02	3	Moderately persistent herbicide. Used since the 1960s.
Chloropicrin	Other		No	5.1E+01	1.0E+00	8	Fumigant with low persistence.
Dichloropropene, 2,3-	Chlorinated Herbicides	8151	No	8.1E+01	1.6E+01	8	Fumigant with low persistence.
Diphacinone	Other	?	No	5.0E+03	3.7E+02	?	Rodenticide with moderate to high persistence.
Diquat	Other	?	Yes	1.9E+03	1.0E+03	8	Highly persistent growth regulator.
Endrin Aldehyde	Organochlorine Pesticides	8081 or 8270	No	1.1E+04	3.7E+02	8	Highly persistent impurity of Endrin.
Fenaminosulf	Other	?	Yes	1.0E+00	1.5E+01	8	Fungicide with low persistence.
Fenamiphos	Organo-phosphorus Pesticides	8141	No	2.3E+02	5.0E+00	8	Nematicide with low persistence.
Fenthion	Organo-phosphorus Pesticides	8141 or 8270	No	1.1E+02	3.4E+01	8	Moderately persistent insecticide used since the 1960s.
Fosetyl-Aluminum	Other	?	Yes	5.3E+03	1.0E-01	8	Fungicide with low persistence.
Hydramethylnon	Other	?	No	6.3E+08	?	-	Insecticide (ant control) with unknown persistence.
Mancozeb	Other	?	Yes	1.0E+01	2.0E+00	7	Fungicide with low persistence.

Monuron	Carbamates	8321	No	?	1.0E+02	-	Herbicide with moderate persistence. Registration cancelled in 1977.
Paraquat	Other	?	Yes	1.4E+03	7.3E+02	14	Highly persistent herbicide. Used since the 1960s.

Table 9-A (continued)

Chemical	Laboratory Analytical Group*	Standard Laboratory Method*	Availability of Toxicity Factors**	KoC (cm^3/g)	Half-Life in Soil (days)	Half-Life Refer-ence***	Notes
Pindone	Other	?	No	2.8E+01	?	-	Rodenticide with unknown persistence.
Quizalofop-P-Ethyl	Other	?	No	5.4E+02	6.0E+01	3	Moderately persistent herbicide. Used from the 1980s until present.
Sodium Chlorate	Other	?	No	1.0E+00	?	-	Herbicide with unknown persistence.
Sodium Monofluoracetate	Other	?	Yes	1.2E+00	?	-	Rodenticide with unknown persistence. Used in 1960s until unknown time.
Sodium Trichloroacetate	Other	?	No	1.0E+00	?	-	Herbicide with unknown persistence. Used in the 1960s until unknown time.
Sulfometuron-Methyl	Carbamates (modified)	8321Mod	No	7.8E+01	2.8E+01	7	Herbicide with low persistence.
Temephos	Other	?	Yes	1.6E+06	?	-	Insecticide with unknown persistence. Used in the 1960s until unknown time.

Table 9-A (continued)

Notes:

* Laboratory analytical method used to categorize pesticides may not match actual pesticide chemical category.

** Toxicity value availability noted as "Yes" if listed in May 2008 USEPA Regional Screening Levels guidance (USEPA, 2008). KoC values from same reference.

*** Half-Life References. The number in the column above corresponds to the references shown below.

1 Montgomery, J.H. 2000. Groundwater Chemicals. Desk Reference (3rd Ed).

2 Mackay, Shiu, Ma. 1992. Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals.

3 Extonet. Available online at: http://extoxnet.orst.edu/

4 USEPA. Reregistration Eligibility Decision - Amitrole. List A. Case 0095. (http://www.epa.gov/oppsrrd1/REDs/0095red.pdf)

5 Spectrum. Chemical fact Sheet - Ametryn (http://www.speclab.com/compound/c834128.htm)

6 Benomyl fact Sheet. Pesticides News No.35, March 1997, p20-21 (http://www.pan-uk.org/pestnews/actives/benomyl.htm)

7 ARS Pesticide Properties Database (http://www.ars.usda.gov/Services/docs.htm?docid=14199)

8 Knisel & Davis. 2000. Groundwater Loading Effects of Agricultural Management Systems.

9 Toxicological Profile for Pentachlorophenol. ATSDR 1991. http://www.atsdr.cdc.gov/toxprofiles/tp51.html

10 Spectrum Chemical fact Sheet - 2,4,5-Trichlorophenoxyacetic Acid. http://www.speclab.com/compound/c93765.htm

11 Spectrum Chemical fact Sheet - 2,4,5-Trichlorophenoxypropionic Acid. http://www.speclab.com/compound/c93721.htm

12 Extoxnet - Lindane (BHC). Available online at http://extonet.orst.edu/

13 Extoxnet - Parathion. Available online at http://extoxnet.orst.edu/
14 Extoxnet - Paraquat. Available online at http://extoxnet.orst.edu/
15 Toxnet HSDB. Available online at http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB

APPENDIX 9-B
Initial Shortlist of Pesticides Used in Sugarcane and Pineapple Operations and Selection for Further Consideration

Chemical[1]	Synonyms	Laboratory Analytical Grouping[2]	Period Used in Hawai'i[3]	Persistence[4]	Mobility[5]	Known Use in Sugar Cane Production?	Known Use in Pineapple Production?
Benomyl	Benlate	8321 (Carbamates)	1970s to present?	Moderate	Moderate	Yes	Yes
Diuron	Karmex	8321 (Carbamates)	1960s-present	Moderate	Moderate	Yes	Yes
Methyl Sulfanilcarbamate	Asulam	8321 (Carbamates)	1970s-present	Moderate	Moderate	Yes	Yes
Oxamyl	Vydate	8321 (Carbamates)	1980s-present?	Low	High	No	Yes
Propiconazole	Tilt	8321 (Carbamates)	1980s-present?	Moderate	Low	Yes	Yes
Dalapon		8151 or 8321 (Chlorinated Herbicides)	1953 - present?	Moderate	High	Yes	Yes
Dicamba		8151 or 8321 (Chlorinated Herbicides)	? to present	Moderate	High	Yes	No
Dichlorophenoxyacetic Acid (2,4 D)	2,4-D	8151 or 8321 (Chlorinated Herbicides)	1960s-present	Low	Moderate	Yes	No
Dichloropropane, 1,2-		8151 or 8321 (Chlorinated Herbicides)	1940s-1974	Moderate	High	No	Yes
Dichloropropene, 1,3-	Telone, D-D 92	8151 or 8321 (Chlorinated Herbicides)	1940s-present?	Low	High	No	Yes
Picloram	Tordon	8151 or 8321 (Chlorinated Herbicides)	1960s-present?	Moderate	High	Yes	No
Trichlorophenoxyacetic Acid, 2,4,5- (2,4,5 T)	2,4,5-T	8151 or 8321 (Chlorinated Herbicides)	1960s?	Moderate	Moderate	Yes	No
Trichlorophenoxypropionic Acid, 2,4,5- (2,4,5 Tp)	2,4,5-TP, Silvex	8151 or 8321 (Chlorinated Herbicides)	1960s?	Low	High	Yes	No

Table 9-B (continued)

Chemical[1]	Synonyms	Laboratory Analytical Grouping[2]	Period Used in Hawai'i[3]	Persistence[4]	Mobility[5]	Known Use in Sugar Cane Production?	Known Use in Pineapple Production?
Arsenic		6010B or 6020 (Heavy Metals)	1913 to 1960s	High	Site-specific	Yes	?
Lead		6010B or 6020 (Heavy Metals)	Unknown	High	Site-specific	Yes	No
Mercury	Phenylmercuric acetate	7471 (Mercury)	?-1969	High	Moderate	Yes	No
Methyl Mercury		7471 (Mercury)	?-1969	High?	High?	Yes	No
Captafol	Difolatan	8081 or 8270 (Organochlorine Pesticides)	1970s to ?	Low	Moderate	Yes	Yes
Chlordane (Technical)	Technical Chlordane	8081 or 8270 (Organochlorine Pesticides)	1960s to 1988	Moderate	Moderate	No	Yes
Endosulfan		8081 or 8270 (Organochlorine Pesticides)	1960s-1980s?	Moderate	Moderate	No	Yes
Heptachlor		8081 or 8270 (Organochlorine Pesticides)	1960s-1988	Moderate	Moderate	Yes	Yes
Heptachlor Epoxide		8081 or 8270 (Organochlorine Pesticides)	1960s-1988	High	Low	No	Yes
Hexachlorocyclohexane, Gamma	Lindane, BHC	8081 or 8270 (Organochlorine Pesticides)	1960s-present?	Moderate	Moderate	No	Yes
Trifluralin	Treflan	8081 or 8270 (Organochlorine Pesticides)	1980s-present	Moderate	Moderate	Yes	No
Chlorpyrifos	Dursban	8141 or 8270 (Organophosphorus Pesticides)	1970s to present?	Moderate	Low	Yes	Yes

Table 9-B (continued)

Chemical[1]	Synonyms	Laboratory Analytical Grouping[2]	Period Used in Hawai'i[3]	Persistence[4]	Mobility[5]	Known Use in Sugar Cane Production?	Known Use in Pineapple Production?
Diazinon		8141 or 8270 (Organophosphorus Pesticides)	1960s - present	Moderate	Moderate	Yes	Yes
Malathion		8141 or 8270 (Organophosphorus Pesticides)	1960s-present?	Low	High	Yes	Yes
Parathion		8141 or 8270 (Organophosphorus Pesticides)	1960s-1992	High	Moderate	No	Yes
Ethephon	Ethrel	8270 (SVOCs)	1980s-present?	Low	High	Yes	Yes

Captan	Ethyl Mercapton	8270 (SVOCs)	1960s to ?	Low	Moderate	No	Yes
Dichlorophenol, 2,4-		8270 (SVOCs)	1960s-present	Low	Moderate	Yes	No
Tetrachlorophenol, 2,3,4,6-		8270 (SVOCs)	1960s-1984?	Moderate	Moderate	Yes	Yes
Pentachlorophenol		8270 or 8151 (SVOCs or Chlorinated Herbicides)	1960s-1970	Moderate	Low	Yes	Yes
Ametryn	Evik	8141 or 8270 (Triazine Pesticides)	1960s to present	Moderate	Moderate	Yes	Yes
Atrazine	Astrex	8141 or 8270 (Triazine Pesticides)	1960s to present	Moderate	Moderate	Yes	Yes
Hexazinone	Velpar	8141 or 8270 (Triazine Pesticides)	1970s-present	Moderate	Moderate	Yes	Yes
Metribuzin		8141 or 8270 (Triazine Pesticides)	1970s-present	High	Moderate	Yes	No
Simazine		8141 or 8270 (Triazine Pesticides)	1960s-present	Moderate	Moderate	Yes	Yes

Table 9-B (continued)

Chemical[1]	**Synonyms**	**Laboratory Analytical Grouping**[2]	**Period Used in Hawai'i**[3]	**Persistence**[4]	**Mobility**[5]	**Known Use in Sugar Cane Production?**	**Known Use in Pineapple Production?**
Bromodichloromethane		8260 (VOCs)	1960s to ?	Low	High	No	Yes
Bromomethane	Methyl Bromide	8260 (VOCs)	1960s to present	Low	High	No	Yes
Dibromo-3-Chloropropane, 1,2-	DBCP	8260 (VOCs)	1940s-1985	Moderate	Moderate	No	Yes
Dibromochloromethane		8260 (VOCs)	Unknown	Moderate	High	No	Yes
Dibromoethane, 1,2-	EDB	8260 (VOCs)	1940s-1983	Moderate	High	No	Yes
Trichloropropene, 1,2,3-	TCP	8260 (VOCs)	1940s-1978	Moderate	Moderate	No	Yes
Dioxins/Furans		8280/8290 (Dioxins/furans)	1960s-1985?	High	Low	Yes	Yes
Glyphosate	Roundup, Rodeo, Polado	547		Low	High	Yes	Yes
Terbacil	Sinbar	633 (Organonitrogen Pesticides)	1970s-present	High	High	Yes	No

Table 9-B (continued)

Notes:

1 Refer to Appendix 9-A. Pesticide retained for consideration if toxicity data and standard laboratory analytical method available. Includes pesticide likely to drive environmental hazards at former agricultural sites.

2 Laboratory analytical method used to categorize pesticides may not match actual pesticide chemical category.

3 For sugarcane and pineapple agricultural purposes, reported or estimated dates of use in Hawai‘i.

4 Persistence ranking based on chemical and biological degradation potential.

- Metals all given persistence of "high"
- Scale for persistence for chemicals with half-life data:
  High = >1 year
  Moderate = one month to one year
  Low = <one month
- Where multiple values reported, highest value used to make determination. Soil degradation rates used are used preferentially.
- Data for one isomer used to estimate persistence of other isomers, as necessary.

5 Mobility ranking based on sorption coefficient, solubility and volatility.

- Sorption coefficient (Koc):
  High = KoC<100
  Moderate = 100<Koc<3,000
  Low KoC>3,000
- KoC values from USEPA May 2008 RSL guidance when available; otherwise as complied as noted in Appendix 9-A.
- If no KoC was available, but water solubility was high, pesticide was assumed to have high mobility.
- All volatiles given a mobility of High. Volatiles = Henry's law constant (unitless) >1E-4 and molecular weight <200
- All metals given a mobility of Low

VOC Volatile Organic Compounds

SVOC Semi-Volatile Organic Compounds

APPENDIX 9-C
Summary of Pesticides Used in Sugarcane and Pineapple Operations and Selection for Further Consideration

Chemical	Synonyms	Laboratory Analytical Grouping[1]	Retained as COPC for Sugar Cane? (Field Areas)[2]	Retained as COPC for Sugar Cane? (Non-Field areas)[2]	Retained as COPC for Pineapple? (Field Areas)[2]	Retained as COPC for Pineapple? (Non-Field areas)[2]	Notes
Benomyl	Benlate	8321 (Carbamates)	No	**Yes**	No	**Yes**	Fungicide used in seed dipping operations.
Diuron	Karmex	8321 (Carbamates)	No	**Yes**	No	**Yes**	
Methyl Sulfanilcarbamate	Asulam	8321 (Carbamates)	No	No	No	No	Limited use and not significantly toxic.
Oxamyl	Vydate	8321 (Carbamates)	No	No	No	No	
Propiconazole	Tilt	8321 (Carbamates)	No	**Yes**	No	**Yes**	Fungicide used in seed dipping operations.
Dalapon		8151 or 8321 (Chlorinated Herbicides)	No	**Yes**	No	**Yes**	
Dicamba		8151 or 8321 (Chlorinated Herbicides)	No	**Yes**	No	No	
Dichlorophenoxyacetic Acid (2,4 D)	2,4-D	8151 or 8321 (Chlorinated Herbicides)	No	No	No	No	
Dichloropropane, 1,2-		8151 or 8321 (Chlorinated Herbicides)	No	No	No	**Yes**	
Dichloropropene, 1,3-	Telone	8151 or 8321 (Chlorinated Herbicides)	No	No	No	No	
Picloram	Tordon	8151 or 8321 (Chlorinated Herbicides)	No	No	No	No	Limited use and not significantly toxic.

Table 9-C (continued)

Chemical	Synonyms	Laboratory Analytical Grouping[1]	Retained as COPC for Sugar Cane? (Field Areas)[2]	Retained as COPC for Sugar Cane? (Non-Field areas)[2]	Retained as COPC for Pineapple? (Field Areas)[2]	Retained as COPC for Pineapple? (Non-Field areas)[2]	Notes
Trichlorophenoxyacetic Acid, 2,4,5- (2,4,5 T)	2,4,5-T	8151 or 8321 (Chlorinated Herbicides)	No	**Yes**	No	No	
Trichloro-Phenoxypropionic Acid, 2,4,5- (2,4,5 Tp)	2,4,5-TP, Silvex	8151 or 8321 (Chlorinated Herbicides)	No	No	No	No	
Arsenic		6010B or 6020 (Heavy Metals)	**Yes**	**Yes**	**Yes**	**Yes**	Include arsenic for pineapple operations.
Lead		6010B or 6020 (Heavy Metals)	No	**Yes**	No	**Yes**	Lead-based pesticides not used in sugarcane field areas.
Mercury	Phenyl-mercuric acetate	7471 (Mercury)	No	**Yes**	No	No	
Methyl Mercury		7471 (Mercury)	No	**Yes**	No	No	Investigate only if total Hg contamination identified.
Captafol	Difolatan	8081 or 8270 (Organochlorine Pesticides)	No	No	No	No	
Chlordane (Technical)	Technical Chlordane	8081 or 8270 (Organochlorine Pesticides)	No	No	No	**Yes**	
Endosulfan		8081 or 8270 (Organochlorine Pesticides)	No	No	**Yes**	**Yes**	

Table 9-C (continued)

Chemical	Synonyms	Laboratory Analytical Grouping[1]	Retained as COPC for Sugar Cane? (Field Areas)[2]	Retained as COPC for Sugar Cane? (Non-Field areas)[2]	Retained as COPC for Pineapple? (Field Areas)[2]	Retained as COPC for Pineapple? (Non-Field areas)[2]	Notes
Heptachlor		8081 or 8270 (Organochlorine Pesticides)	**Yes**	**Yes**	**Yes**	**Yes**	Only used in fields with drip irrigation between 1979 & 1985. Cancelled in 1988.

Heptachlor Epoxide		8081 or 8270 (Organochlorine Pesticides)	No	No	**Yes**	**Yes**	
Hexachlorocyclohexane, Gamma	Lindane, BHC	8081 or 8270 (Organochlorine Pesticides)	No	No	**Yes**	**Yes**	
Trifluralin	Treflan	8081 or 8270 (Organochlorine Pesticides)	No	**Yes**	No	No	
Chlorpyrifos	Dursban	8141 or 8270 (Organophosphorus Pesticides)	No	No	No	No	Limited use in small amounts.
Diazinon		8141 or 8270 (Organophosphorus Pesticides)	No	No	No	No	Limited use in small amounts.
Malathion		8141 or 8270 (Organophosphorus Pesticides)	No	No	No	No	Limited use in small amounts.
Parathion		8141 or 8270 (Organophosphorus Pesticides)	No	No	No	No	Limited use in small amounts.

Table 9-C (continued)

Chemical	**Synonyms**	**Laboratory Analytical Grouping[1]**	**Retained as COPC for Sugar Cane? (Field Areas)[2]**	**Retained as COPC for Sugar Cane? (Non-Field areas)[2]**	**Retained as COPC for Pineapple? (Field Areas)[2]**	**Retained as COPC for Pineapple? (Non-Field areas)[2]**	**Notes**
Ethephon	Ethrel	8270 (SVOCs)	No	No	No	No	
Captan	Ethyl Mercapton	8270 (SVOCs)	No	No	No	No	
Dichlorophenol, 2,4-		8270 (SVOCs)	No	No	No	No	
Tetrachlorophenol, 2,3,4,6-		8270 (SVOCs)	No	**Yes**	No	**Yes**	
Pentachlorophenol		8270 or 8151 (SVOCs or Chlorinated Herbicides)	No	**Yes**	No	**Yes**	Banned for use in agricultural fields in 1970
Ametryn	Evik	8141 or 8270 (Triazine Pesticides)	No	**Yes**	No	**Yes**	
Atrazine	Astrex	8141 or 8270 (Triazine Pesticides)	No	**Yes**	No	**Yes**	
Hexazinone	Velpar	8141 or 8270 (Triazine Pesticides)	No	No	No	No	Limited use in small quantities
Metribuzin		8141 or 8270 (Triazine Pesticides)	No	No	No	No	Limited use in small quantities
Simazine		8141 or 8270 (Triazine Pesticides)	No	**Yes**	No	**Yes**	
Bromodichloromethane		8260 (VOCs)	No	No	No	No	
Bromomethane	Methyl Bromide	8260 (VOCs)	No	No	No	No	

Dibromo-3-Chloropropane, 1,2-	DBCP	8260 (VOCs)	No	No	No	**Yes**	
Dibromochloromethane		8260 (VOCs)	No	No	No	**Yes**	
Dibromoethane, 1,2-	EDB	8260 (VOCs)	No	No	No	**Yes**	
Trichloropropene, 1,2,3-	TCP	8260 (VOCs)	No	No	No	**Yes**	

Table 9-C (continued)

Chemical	Synonyms	Laboratory Analytical Grouping[1]	Retained as COPC for Sugar Cane? (Field Areas)[2]	Retained as COPC for Sugar Cane? (Non-Field areas)[2]	Retained as COPC for Pineapple? (Field Areas)[2]	Retained as COPC for Pineapple? (Non-Field areas)[2]	Notes
Dioxins/Furans		8280/8290 (Dioxins/furans)	No	**Yes**	No	**Yes**	
Glyphosate	Roundup, Rodeo, Polado	547	No	No	No	No	
Terbacil	Sinbar	633 (Organonitrogen Pesticides)	No	No	No	No	Limited use and toxicity.

Notes:

1 Laboratory analytical method used to categorize pesticides may not match actual pesticide chemical category.

2 Retained as chemical of potential concern (COPC) if: any of the following:

- Known past use.
- Commercial lab method available.
- Toxicity factors & physiochemical constants available.
- Non-field areas are moderately or highly persistent or field areas are highly persistent (see text for details).

APPENDIX 9-D
Guidance Fact Sheet for Use When Petroleum Contamination is Encountered during Subsurface Soil Excavation

PURPOSE: The purpose of this Guidance Fact Sheet is to provide guidance for construction projects when petroleum or petroleum contaminated soil (PCS) is encountered. These guidelines apply to construction projects that involve soil excavation, except associated with underground storage tank (UST) removal. These guidelines are consistent with Hawai'i Revises Statutes Chapter 128D, Hawai'i Environmental Response Law. Administrative procedures must be in place within your organization, so that project managers, contract workers, field workers, health and safety personnel, and essentially anyone who might be involved in construction and the excavation of soils follow these basic guidelines:

When must notification to the HEER Office be made?

The reportable quantity for petroleum is one of the following:

a. Any amount of oil which when released into the environment causes a sheen to appear on surface water, or any navigable water of the State.
b. Any free product that appears on groundwater.
c. Any amount of oil released to the environment greater than 25 gallons.
d. Any amount of oil released to the environment, which is not contained and remediated within 72 hours. Note: The HEER Office interprets this criteria to require petroleum-stained soil encountered during excavation work to be reported.

Who must notify?

Any person who has any knowledge of a release of a reportable quantity must immediately notify the HEER Office. Failure to notify the HEER Office of a release is subject to a civil penalty not to exceed $10,000 for each day of failure to report.

What is the number to call?

Hawai'i State Department of Health, Hazard Evaluation and Emergency Response Office (HEER Office):
(808) 586-4249 during working hours, Monday – Friday, 7:45 a.m. – 4:30 p.m.
or
(808) 247-2191 during non-working hours including holidays.

What information is required to be provided to the HEER Office?

The information gathered should be sufficient to answer the following, but notification shall not be delayed due to incomplete notification:

1. Name of the observed chemical released
2. Approximate quantity observed
3. The location and an address of the release. The location may be determined by either surveying by a licensed surveyor or the use of a Global Positioning System (GPS) unit, which provides latitude and longitude. The latitude and longitude of the contaminated area should be accurate to within 25 feet of the actual position. A detailed map should be submitted to the HEER Office at a later date
4. The name, address, and telephone number of the caller
5. The name, address, and telephone number of the owner/operator of the site where the release has occurred

6. The name, address, and telephone number of the contact person at the site where the release has occurred
7. Measures taken or proposed to be taken in response to the release at the time of the notification
8. Any other information, including but not limited to, potential on-site worker and public or environmental impacts

Who else should be notified?

If a party other than the landowner is conducting the project, then a separate notification needs to be made to the landowner to allow them to determine their liability and the next course of action.

What additional steps must be taken?

1. When petroleum or PCS is discovered during construction activities, an immediate determination is needed as to whether it may be a threat to the health and welfare of on-site workers or the nearby public.

   If a combustible hazard is identified, an Emergency Response Plan should be put into effect. No work may continue until the area is determined to be safe.

   [Note: A Combustible Gas Indicator may be used to determine if there is a flammable or explosive potential. Each combustible gas has its own Lower Explosive Level (LEL) and its Upper Explosive Level (UEL). For example, methane gas has a LEL of 5 percent (%) by volume and an UEL of 15% by volume. Between 5 to 15% by volume, a spark could cause an explosion. If the atmosphere has less than 5% methane, an explosion cannot occur even if a source of ignition is present. Likewise, if the atmosphere has greater than 15% methane, the air-fuel mixture is too rich to burn. Gasoline has a LEL of 1.4% by volume and an UEL of 7.4% by volume.

2. The project may continue with implementation of a Health and Safety Plan in accordance with applicable occupational safety and health regulations. This plan should address exposure issues and include appropriate air monitoring.

3. If free-floating petroleum product is encountered during the project, the product is to be recovered and either re-used or disposed of appropriately.

4. Petroleum-contaminated water encountered during dewatering projects must be tested and treated as necessary prior to discharge into a storm drain or other pathway that leads to surface water bodies. At a minimum, this will usually require that the water be passed through an oil/water separator. The water should also be tested for dissolved-phase petroleum contaminants prior to discharge (at least initially). The water should be treated to meet HDOH Environmental Action Levels for discharges to surface waters or a more site-specific assessment of potential impacts to aquatic habitats carried out. The HEER Office Environmental Hazard Evaluation (EHE) guidance can be consulted for applicable surface water environmental action levels, or call the HEER Office (808) 586-4249 during business hours for assistance.

   <u>Groundwater Management:</u>

   Groundwater that contains free product or a sheen can assumed to be contaminated with dissolved analytes. Re-infiltration, reinjection, treatment, disposal, or discharge are all acceptable options for the disposition of groundwater generated during subsurface excavation that encounters contaminated groundwater. Of these choices, re-infiltration within the Work Area where the water was extracted is the least expensive and easiest way to manage contaminated groundwater; however this option may not be feasible at all project locations.

   A. Groundwater should be reused within the Work Area and within the same aquifer where it was removed. Reuse in other areas could spread unidentified contamination or cause existing plumes in those areas to migrate.
   B. Removal and reuse must meet existing Federal and State permit requirements.
   C. If discharged to storm sewers or surface water bodies:
      1. National Pollution Discharge Elimination System and State permit requirements also apply. Prior to dewatering, clearance and/or permits from the CWB are required.
      2. Removal of floating product via an oil water separator and/or passage of the water through settling ponds or sand filters may not be adequate to reduce dissolved-phase contaminant concentrations to below action levels. Therefore, in addition to analytical screening required in applicable Federal and State permits, the HEER Office recommends:
         a. At a minimum, all groundwater discharged to storm sewers must be analyzed for constituents related to petroleum and solvents.
         b. Additional analytical data may be required based on knowledge of contamination within the vicinity of the work area.
         c. The groundwater must be analyzed for known or suspected contaminants and the results must be screened against the Estuarine EALs for Surface Water Bodies, in Table D of Volume

1 of *Screening for Environmental Hazards at Sites with Contaminated Soil and Groundwater*, Fall 2011 Updates, Revised January 2012 (and updates)

d. For some site-specific locations, the HEER Office analytical requirements may be adjusted with advance approval. Permit requirements will not be adjusted.

D. If discharged to sanitary sewers, contractors must follow the requirements of all permits.

E. If discharged to a re-infiltration trench:
   1. The trench must be within the Work Area, especially if the groundwater is extracted from a Work Area in the vicinity of known or observed contamination.
   2. The trench must not be an underground injection control (UIC) well by SDWB definitions. If some part of the trench system is deemed to be a UIC well, then the whole system is considered an injection well.
   3. Advance clearance from SDWB is required if a re-infiltration trench is deeper than 10 feet.

F. UIC wells may be used, but advance planning and approval are required. SDWB permit requirements must be met for well construction, placement, use, and closure.

G. In instances where "oily water" is disposed, the receiving facility must be permitted for that type of waste.

5. Petroleum contaminated soil is to be excavated and segregated from clean soils. Excavated contaminated soil must be placed under a liner and covered. Contaminated soil must be treated or disposed of in accordance with all applicable local, state and federal requirements.

   On-Site Management of Contaminated Soils:

   When deciding whether to re-deposit contaminated soil, the time saved by proceeding with the project immediately should be weighed against the possible increase in cost caused by deferring remedial action to a later date. If re-deposition is chosen, be advised that this does not absolve any party from liability should the actions taken exacerbate potential health and environmental impacts. If the option of re-depositing is chosen, excavated soils should be stored under cover before re-deposit into the excavation. Excavated soil that is contaminated should not be placed into an excavation that is clean, i.e., an excavation other than that from which the soil was removed, otherwise the soil should be treated as in No. 5 above. Excavated soil with petroleum contamination that is re-deposited into the excavation should be provided with a cover of clean soil or cap of asphalt/concrete once the work has been completed.

6. Detailed records of the investigation, any re-deposited contaminated soils, and any other clean-up activities are to be maintained and submitted to the HEER Office.

7. In cases where a site assessment and evaluation is to be conducted, the HEER Office Technical Guidance Manual, Environmental Hazard Evaluation (EHE) Guidance, and the State Contingency Plan are accessible through the HEER Office website:

   http://hawaii.gov/doh/heer

If uncertain of the action to take, call the HEER Office at 808-586-4249

APPENDIX 9-E
Update to Soil Action Levels for Inorganic Arsenic and Recommended Soil Management Practices

(see PDF file)

APPENDIX 9-F
Update to Soil Action Levels for TEQ Dioxins and Recommended Soil Management Practices

(see PDF file)

APPENDIX 9-A

GENERAL PESTICIDE INFORMATION

Table 9-A
General Pesticide Information

Chemical	Laboratory Analytical Group*	Standard Laboratory Method*	Availability of Toxicity Factors**	KoC (cm^3/g)	Half-Life in Soil (days)	Half-Life Refer-ence***	Notes
Ametryn	Triazine Pesticides	8141 or 619M	Yes	4.5E+02	1.8E+02	5	Moderately persistent herbicide. Used since the 1960s (possibly earlier).
Arsenic	Heavy Metals	6010B/ 6020	Yes	?	na	-	Highly persistent herbicide component.
Atrazine	Triazine Pesticides	8141 or 619M	Yes	2.3E+02	1.0E+02	3	Moderately persistent herbicide. Used since the 1960s (possibly earlier).
Benomyl	Carbamates	8321	Yes	5.2E+02	3.6E+02	6	Moderately persistent fungicide used for seed dipping. Used since the 1970s.
Bromodichloromethane	VOCs	8260	Yes	3.5E+01	1.5E+00	3	Fumigant with low persistence.
Bromomethane	VOCs	8260	Yes	1.4E+01	2.8E+01	2	Fumigant with low persistence.
Captafol	Organochlorine Pesticides	8081 or 8270	Yes	2.7E+03	7.0E+00	8	Fumigant with low persistence.
Captan	SVOCs	8270	Yes	8.6E+02	2.5E+00	8	Fumigant with low persistence.
Chlordane (Technical)	Organochlorine Pesticides	8081	Yes	8.7E+04	1.0E+02	8	Moderately persistent insecticide. Cancelled in 1988.
Chlorpyrifos	Organo-phosphorus Pesticides	8141	Yes	6.8E+03	8.4E+01	1	Moderately persistent insecticide used since the 1970s.
Dalapon	Chlorinated Herbicides	8151 or 8321	Yes	2.7E+00	3.0E+01	8	Low to moderately persistent herbicide used since the 1950s.
Diazinon	Organo-phosphorus Pesticides	8141	Yes	1.3E+03	4.0E+01	8	Moderately persistent insecticide broadly used since the 1960s (possibly earlier).
Dibromo-3-Chloropropane, 1,2-	VOCs	8260 or 8081	Yes	1.3E+02	1.8E+02	1	Moderately persistent (although volatile) fumigant broadly used from the 1940s through 1980s.
Dibromochloromethane	VOCs	8260	Yes	3.5E+01	1.8E+02	2	Moderately persistent pesticide; unknown if used in cultivation.

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Table 9-A (continued)

Chemical	Laboratory Analytical Group*	Standard Laboratory Method*	Availability of Toxicity Factors**	KoC (cm^3/g)	Half-Life in Soil (days)	Half-Life Refer-ence***	Notes
Dibromoethane, 1,2-	VOCs	8260	Yes	4.4E+01	1.0E+02	8	Moderately persistent (although volatile) fumigant broadly used from the 1940s through 1980s.
Dicamba	Chlorinated Herbicides	8151 or 8321	Yes	2.9E+01	3.1E+01	7	Herbicide with low to moderate persistence.
Dichlorodiphenyl-dichloroethane (DDD)	Organochlorine Pesticides	8081 or 8270	Yes	1.5E+05	1.0E+03	8	Highly persistent impurity of DDT insecticide.
Dichlorodiphenyl-dichloroethylene (DDE)	Organochlorine Pesticides	8081 or 8270	Yes	1.5E+05	1.0E+03	8	Highly persistent impurity of DDT insecticide.
Dichlorodiphenyl-trichloroethane (DDT)	Organochlorine Pesticides	8081 or 8270	Yes	2.2E+05	1.2E+02	8	Moderately persistent insecticide. Used by State for mosquito control until banned in 1972.
Dichlorophenol, 2,4-	SVOCs	8270	Yes	7.2E+02	2.6E+00	1	Intermediate product of 2,4-D and other herbicides with low persistence.
Dichlorophenoxyacetic Acid (2,4 D)	Chlorinated Herbicides	8151 or 8321	Yes	7.2E+02	1.0E+01	8	Herbicide with low persistence.
Dichloropropane, 1,2-	Chlorinated Herbicides	8151	Yes	6.8E+01	3.6E+02	8	Moderately persistent (although volatile) fumigant used from the 1940s to 1974.
Dichloropropene, 1,3-	Chlorinated Herbicides	8151	Yes	8.1E+01	1.0E+01	8	Fumigant with low persistence.
Dioxins/Furans	Dioxins/furans	8280/8290	Yes	2.6E+05	3.7E+04	1	Highly persistent impurity of chlorinated phenol pesticides (pentachlorophenol; 2,4,5-T; 2,4,5-TP).
Diuron	Carbamates	8321	Yes	1.4E+02	9.0E+01	8	Moderately persistent herbicide. Used since the 1960s (possibly earlier).
Endosulfan	Organochlorine Pesticides	8081 or 8270	Yes	2.2E+04	1.5E+02	15	Pesticide with moderate persistence.

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Table 9-A (continued)

Chemical	Laboratory Analytical Group*	Standard Laboratory Method*	Availability of Toxicity Factors**	KoC (cm^3/g)	Half-Life in Soil (days)	Half-Life Refer-ence***	Notes
Ethephon	SVOC	8270	Yes	3.6E+00	8.0E+00	7	Growth regulator with low persistence.
Glyphosate	Other	547	Yes	1.9E+01	4.7E+01	-	Herbicide with low to moderate persistence (beaks down in water).
Heptachlor	Organochlorine Pesticides	8081 or 8270	Yes	5.2E+04	2.5E+02	8	Moderately persistent insecticide and component of technical chlordane. Cancelled in 1988. Potentially used in fields with drip irrigation between 1979 & 1985.
Heptachlor Epoxide	Organochlorine Pesticides	8081 or 8270	Yes	5.3E+03	3.7E+02	-	Highly persistent component of technical chlordane.
Hexachlorocyclohexane, Gamma	Organochlorine Pesticides	8081 or 8270	Yes	3.4E+03	2.4E+02	12	Moderately persistent insecticide.
Hexazinone	Triazine Pesticides	8141	Yes	6.1E+02	2.2E+02	7	Moderately persistent herbicide used since the 1970s.
Lead	Heavy Metals	6010B/ 6020	Yes	?	na	-	Unknown if lead-based insecticides, herbicides, & rodenticides used in cultivation. Highly persistent.
Malathion	Organo-phosphorus Pesticides	8141 or 8270	Yes	3.1E+01	1.0E+00	7	Insecticide with low persistence. Used since the 1960s (possibly earlier).
Mercury	Heavy Metals	7471	Yes	1.7E+02	?	-	Highly persistent fungicide (seed dipping). All food uses cancelled in 1969.
Methyl Mercury	Heavy Metals	7471	Yes	?	?	-	Methylated form of mercury generated in reducing environments; potential byproduct.
Methyl Sulfanilcarbamate	Carbamates	8321A	Yes	1.2E+03	3.1E+01	-	Herbicide used since the 1970s. Low to moderate persistence.
Metribuzin	Triazine Pesticides	8141	Yes	1.2E+03	4.4E+02	7	Highly persistent herbicide used since the 1970s.

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Table 9-A (continued)

Chemical	Laboratory Analytical Group*	Standard Laboratory Method*	Availability of Toxicity Factors**	KoC (cm^3/g)	Half-Life in Soil (days)	Half-Life Refer-ence***	Notes
Mirex	Organochlorine Pesticides	8081 or 8270	Yes	4.7E+05	3.7E+02	-	Highly persistent insecticide. Very limited use in Hawai'i. Not sold in US since 1978.
Oxamyl	Carbamates	8321	Yes	1.0E+01	2.7E+01	7	Insecticide with low persistence.
Parathion	Organo-phosphorus Pesticides	8141 or 8270	Yes	1.7E+03	7.3E+02	13	Highly persistent insecticide. Registration cancelled in 1992.
Pentachlorophenol	SVOCs or Chlorinated Herbicides	8270 or 8151	Yes	3.4E+03	3.0E+01	15	Herbicide used from 1960s (possibly earlier) until the mid-1980s. Low to moderate persistence.
Picloram	Chlorinated Herbicides	8151	Yes	1.8E+01	3.0E+02	7	Moderately persistent sugarcane herbicide used since the 1960s (possibly earlier).
Propiconazole	Carbamates	8321	Yes	5.6E+03	8.4E+01	7	Moderately persistent fungicide. Used since the 1980s.
Simazine	Triazine Pesticides	8141 or 619M	Yes	1.5E+02	2.5E+02	8	Moderately persistent herbicide. Used since the 1960s (possibly earlier).
Terbacil	Organonitrogen	633	Yes	7.8E+01	5.2E+02	7	Highly persistent herbicide. Limited used since the 1970s; not significantly toxic.
Tetrachlorophenol, 2,3,4,6-	SVOCs	8270	Yes	2.0E+03	3.0E+01	-	Component of pentachlorophenol with low to moderate persistence.
Trichlorophenoxyacetic Acid, 2,4,5- (2,4,5 T)	Chlorinated Herbicides	8151 or 8321	Yes	1.2E+03	3.0E+02	10	Moderately persistent herbicide. Suspended in 1985.
Trichlorophenoxypropionic Acid, 2,4,5- (2,4,5 Tp)	Chlorinated Herbicides	8151 or 8321	Yes	4.9E+01	1.7E+01	11	Herbicide with low persistence. Suspended in 1985.
Trichloropropene, 1,2,3- (TCP)	VOCs	8260	Yes	1.3E+02	3.1E+01	-	Impurity in 1,3 dichloropropene with low to moderate persistence.
Trifluralin	Organochlorine Pesticides	8081 or 8270	Yes	9.7E+03	6.0E+01	8	Moderately persistent herbicide. Used since the 1980s.

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Table 9-A (continued)

Chemical	Laboratory Analytical Group*	Standard Laboratory Method*	Availability of Toxicity Factors**	KoC (cm^3/g)	Half-Life in Soil (days)	Half-Life Refer-ence***	Notes
Used But No Toxicity Data And/Or No Standard Laboratory Method							
Amitrole	Other	?	No	2.0E+01	2.6E+01	4	Herbicide used pre-1971 with low persistence.
Ammonium Sulfamate	Other	?	Yes	?	?	-	Herbicide used in the 1960s until possibly the 1980s; assumed low persistence.
Bromacil	Carbamates	8321	No	9.3E+00	2.4E+02	3	Moderately persistent herbicide. Used since the 1960s.
Chloropicrin	Other		No	5.1E+01	1.0E+00	8	Fumigant with low persistence.
Dichloropropene, 2,3-	Chlorinated Herbicides	8151	No	8.1E+01	1.6E+01	8	Fumigant with low persistence.
Diphacinone	Other	?	No	5.0E+03	3.7E+02	?	Rodenticide with moderate to high persistence.
Diquat	Other	?	Yes	1.9E+03	1.0E+03	8	Highly persistent growth regulator.
Endrin Aldehyde	Organochlorine Pesticides	8081 or 8270	No	1.1E+04	3.7E+02	8	Highly persistent impurity of Endrin.
Fenaminosulf	Other	?	Yes	1.0E+00	1.5E+01	8	Fungicide with low persistence.
Fenamiphos	Organo-phosphorus Pesticides	8141	No	2.3E+02	5.0E+00	8	Nematicide with low persistence.
Fenthion	Organo-phosphorus Pesticides	8141 or 8270	No	1.1E+02	3.4E+01	8	Moderately persistent insecticide used since the 1960s.
Fosetyl-Aluminum	Other	?	Yes	5.3E+03	1.0E-01	8	Fungicide with low persistence.
Hydramethylnon	Other	?	No	6.3E+08	?	-	Insecticide (ant control) with unknown persistence.
Mancozeb	Other	?	Yes	1.0E+01	2.0E+00	7	Fungicide with low persistence.
Monuron	Carbamates	8321	No	?	1.0E+02	-	Herbicide with moderate persistence. Registration cancelled in 1977.
Paraquat	Other	?	Yes	1.4E+03	7.3E+02	14	Highly persistent herbicide. Used since the 1960s.

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Table 9-A (continued)

Chemical	Laboratory Analytical Group*	Standard Laboratory Method*	Availability of Toxicity Factors**	KoC (cm^3/g)	Half-Life in Soil (days)	Half-Life Refer-ence***	Notes
Pindone	Other	?	No	2.8E+01	?	-	Rodenticide with unknown persistence.
Quizalofop-P-Ethyl	Other	?	No	5.4E+02	6.0E+01	3	Moderately persistent herbicide. Used from the 1980s until present.
Sodium Chlorate	Other	?	No	1.0E+00	?	-	Herbicide with unknown persistence.
Sodium Monofluoracetate	Other	?	Yes	1.2E+00	?	-	Rodenticide with unknown persistence. Used in 1960s until unknown time.
Sodium Trichloroacetate	Other	?	No	1.0E+00	?	-	Herbicide with unknown persistence. Used in the 1960s until unknown time.
Sulfometuron-Methyl	Carbamates (modified)	8321Mod	No	7.8E+01	2.8E+01	7	Herbicide with low persistence.
Temephos	Other	?	Yes	1.6E+06	?	-	Insecticide with unknown persistence. Used in the 1960s until unknown time.

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Table 9-A (continued)

Notes:

* Laboratory analytical method used to categorize pesticides may not match actual pesticide chemical category.

** Toxicity value availability noted as "Yes" if listed in May 2008 USEPA Regional Screening Levels guidance (USEPA, 2008). KoC values from same reference.

*** Half-Life References. The number in the column above corresponds to the references shown below.

1 Montgomery, J.H. 2000. Groundwater Chemicals. Desk Reference (3rd Ed).

2 Mackay, Shiu, Ma. 1992. Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals.

3 Extonet. Available online at: http://extoxnet.orst.edu/

4 USEPA. Reregistration Eligibility Decision - Amitrole. List A. Case 0095. (http://www.epa.gov/oppsrrd1/REDs/0095red.pdf)

5 Spectrum. Chemical fact Sheet - Ametryn (http://www.speclab.com/compound/c834128.htm)

6 Benomyl fact Sheet. Pesticides News No.35, March 1997, p20-21 (http://www.pan-uk.org/pestnews/actives/benomyl.htm)

7 ARS Pesticide Properties Database (http://www.ars.usda.gov/Services/docs.htm?docid=14199)

8 Knisel & Davis. 2000. Groundwater Loading Effects of Agricultural Management Systems.

9 Toxicological Profile for Pentachlorophenol. ATSDR 1991. http://www.atsdr.cdc.gov/toxprofiles/tp51.html

10 Spectrum Chemical fact Sheet - 2,4,5-Trichlorophenoxyacetic Acid. http://www.speclab.com/compound/c93765.htm

11 Spectrum Chemical fact Sheet - 2,4,5-Trichlorophenoxypropionic Acid. http://www.speclab.com/compound/c93721.htm

12 Extoxnet - Lindane (BHC). Available online at http://extonet.orst.edu/

13 Extoxnet - Parathion. Available online at http://extoxnet.orst.edu/

14 Extoxnet - Paraquat. Available online at http://extoxnet.orst.edu/

15 Toxnet HSDB. Available online at http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB

APPENDIX 9-B

INITIAL SHORTLIST OF PESTICIDES USED IN SUGARCANE AND PINEAPPLE OPERATIONS AND SELECTION FOR FURTHER CONSIDERATION

Table 9-B
Initial Shortlist of Pesticides Used in Sugarcane and Pineapple Operations and Selection for Further Consideration

Chemical[1]	Synonyms	Laboratory Analytical Grouping[2]	Period Used in Hawaii[3]	Persistence[4]	Mobility[5]	Known Use in Sugar Cane Production?	Known Use in Pineapple Production?
Benomyl	Benlate	8321 (Carbamates)	1970s to present?	Moderate	Moderate	Yes	Yes
Diuron	Karmex	8321 (Carbamates)	1960s-present	Moderate	Moderate	Yes	Yes
Methyl Sulfanilcarbamate	Asulam	8321 (Carbamates)	1970s-present	Moderate	Moderate	Yes	Yes
Oxamyl	Vydate	8321 (Carbamates)	1980s-present?	Low	High	No	Yes
Propiconazole	Tilt	8321 (Carbamates)	1980s-present?	Moderate	Low	Yes	Yes
Dalapon		8151 or 8321 (Chlorinated Herbicides)	1953 - present?	Moderate	High	Yes	Yes
Dicamba		8151 or 8321 (Chlorinated Herbicides)	? to present	Moderate	High	Yes	No
Dichlorophenoxyacetic Acid (2,4 D)	2,4-D	8151 or 8321 (Chlorinated Herbicides)	1960s-present	Low	Moderate	Yes	No
Dichloropropane, 1,2-		8151 or 8321 (Chlorinated Herbicides)	1940s-1974	Moderate	High	No	Yes
Dichloropropene, 1,3-	Telone, D-D 92	8151 or 8321 (Chlorinated Herbicides)	1940s-present?	Low	High	No	Yes
Picloram	Tordon	8151 or 8321 (Chlorinated Herbicides)	1960s-present?	Moderate	High	Yes	No
Trichlorophenoxyacetic Acid, 2,4,5- (2,4,5 T)	2,4,5-T	8151 or 8321 (Chlorinated Herbicides)	1960s-1985?	Moderate	Moderate	Yes	No
Trichloro- Phenoxypropionic Acid, 2,4,5- (2,4,5 Tp)	2,4,5-TP, Silvex	8151 or 8321 (Chlorinated Herbicides)	1960s-1985?	Low	High	Yes	No

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Table 9-B (continued)

Chemical[1]	Synonyms	Laboratory Analytical Grouping[2]	Period Used in Hawaii[3]	Persistence[4]	Mobility[5]	Known Use in Sugar Cane Production?	Known Use in Pineapple Production?
Arsenic		6010B or 6020 (Heavy Metals)	1913 to 1960s	High	Site-specific	Yes	?
Lead		6010B or 6020 (Heavy Metals)	Unknown	High	Site-specific	Yes	No
Mercury	Phenylmercuric acetate	7471 (Mercury)	?-1969	High	Moderate	Yes	No
Methyl Mercury		7471 (Mercury)	?-1969	High?	High?	Yes	No
Captafol	Difolatan	8081 or 8270 (Organochlorine Pesticides)	1970s to ?	Low	Moderate	Yes	Yes
Chlordane (Technical)	Technical Chlordane	8081 or 8270 (Organochlorine Pesticides)	1960s to 1988	Moderate	Moderate	No	Yes
Endosulfan		8081 or 8270 (Organochlorine	1960s-1980s?	Moderate	Moderate	No	Yes
Heptachlor		8081 or 8270 (Organochlorine Pesticides)	1960s-1988	Moderate	Moderate	Yes	Yes
Heptachlor Epoxide		8081 or 8270 (Organochlorine Pesticides)	1960s-1988	High	Low	No	Yes
Hexachlorocyclohexane, Gamma	Lindane, BHC	8081 or 8270 (Organochlorine Pesticides)	1960s-present?	Moderate	Moderate	No	Yes
Trifluralin	Treflan	8081 or 8270 (Organochlorine Pesticides)	1980s-present	Moderate	Moderate	Yes	No
Chlorpyrifos	Dursban	8141 or 8270 (Organophosphorus Pesticides)	1970s to present?	Moderate	Low	Yes	Yes

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Table 9-B (continued)

Chemical[1]	Synonyms	Laboratory Analytical Grouping[2]	Period Used in Hawaii[3]	Persistence[4]	Mobility[5]	Known Use in Sugar Cane Production?	Known Use in Pineapple Production?
Diazinon		8141 or 8270 (Organophosphorus Pesticides)	1960s - present	Moderate	Moderate	Yes	Yes
Malathion		8141 or 8270 (Organophosphorus Pesticides)	1960s-present?	Low	High	Yes	Yes
Parathion		8141 or 8270 (Organophosphorus Pesticides)	1960s-1992	High	Moderate	No	Yes
Ethephon	Ethrel	8270 (SVOCs)	1980s-present?	Low	High	Yes	Yes
Captan	Ethyl Mercapton	8270 (SVOCs)	1960s to ?	Low	Moderate	No	Yes
Dichlorophenol, 2,4-		8270 (SVOCs)	1960s-present	Low	Moderate	Yes	No
Tetrachlorophenol, 2,3,4,6-		8270 (SVOCs)	1960s-1984?	Moderate	Moderate	Yes	Yes
Pentachlorophenol		8270 or 8151 (SVOCs or Chlorinated Herbicides)	1960s-1984?	Moderate	Low	Yes	Yes
Ametryn	Evik	8141 or 8270 (Triazine Pesticides)	1960s to present	Moderate	Moderate	Yes	Yes
Atrazine	Astrex	8141 or 8270 (Triazine Pesticides)	1960s to present	Moderate	Moderate	Yes	Yes
Hexazinone	Velpar	8141 or 8270 (Triazine Pesticides)	1970s-present	Moderate	Moderate	Yes	Yes
Metribuzin		8141 or 8270 (Triazine Pesticides)	1970s-present	High	Moderate	Yes	No
Simazine		8141 or 8270 (Triazine Pesticides)	1960s-present	Moderate	Moderate	Yes	Yes

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Table 9-B (continued)

Chemical[1]	Synonyms	Laboratory Analytical Grouping[2]	Period Used in Hawaii[3]	Persistence[4]	Mobility[5]	Known Use in Sugar Cane Production?	Known Use in Pineapple Production?
Bromodichloromethane		8260 (VOCs)	1960s to ?	Low	High	No	Yes
Bromomethane	Methyl Bromide	8260 (VOCs)	1960s to present	Low	High	No	Yes
Dibromo-3-Chloropropane, 1,2-	DBCP	8260 (VOCs)	1940s-1985	Moderate	Moderate	No	Yes
Dibromochloromethane		8260 (VOCs)	Unknown	Moderate	High	No	Yes
Dibromoethane, 1,2-	EDB	8260 (VOCs)	1940s-1983	Moderate	High	No	Yes
Trichloropropene, 1,2,3-	TCP	8260 (VOCs)	1940s-1978	Moderate	Moderate	No	Yes
Dioxins/Furans		8280/8290 (Dioxins/furans)	1960s-1985?	High	Low	Yes	Yes
Glyphosate	Roundup, Rodeo, Polado	547		Low	High	Yes	Yes
Terbacil	Sinbar	633 (Organonitrogen Pesticides)	1970s-present	High	High	Yes	No

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Table 9-B (continued)

Notes:

1 Refer to Appendix 9-A. Pesticide retained for consideration if toxicity data and standard laboratory analytical method available. Includes pesticide likely to drive environmental hazards at former agricultural sites.

2 Laboratory analytical method used to categorize pesticides may not match actual pesticide chemical category.

3 Dates are based on available historical records and should not be considered exact. Synthetic pesticides generally became available in the 1930s and 1940s. Most available records date back to the only to the 1960s, but may have begun prior.

4 Persistence ranking based on chemical and biological degradation potential.

- Metals all given persistence of "high"
- Scale for persistence for chemicals with half-life data:
  High = >1 year
  Moderate = one month to one year
  Low = <one month
- Where multiple values reported, highest value used to make determination. Soil degradation rates used are used preferentially.
- Data for one isomer used to estimate persistence of other isomers, as necessary.

5 Mobility ranking based on sorption coefficient, solubility and volatility.

- Sorption coefficient (Koc):
  High = KoC<100
  Moderate = 100<Koc<3,000
  Low KoC>3,000
- KoC values from USEPA May 2008 RSL guidance when available; otherwise as complied as noted in Appendix 9-A.
- If no KoC was available, but water solubility was high, pesticide was assumed to have high mobility.
- All volatiles given a mobility of High. Volatiles = Henry's law constant (unitless) >1E-4 and molecular weight <200
- All metals given a mobility of Low

VOC Volatile Organic Compounds

SVOC Semi-Volatile Organic Compounds

APPENDIX 9-C

SUMMARY OF PESTICIDES USED IN SUGARCANE AND PINEAPPLE OPERATIONS AND SELECTION FOR FURTHER CONSIDERATION

Table 9-C
Summary of Pesticides Used in Sugarcane and Pineapple Operations and Selection for Further Consideration

Chemical	Synonyms	Laboratory Analytical Grouping[1]	Retained as COPC for Sugar Cane? (Field Areas)[2]	Retained as COPC for Sugar Cane? (Non-Field areas)[2]	Retained as COPC for Pineapple? (Field Areas)[2]	Retained as COPC for Pineapple? (Non-Field areas)[2]	Notes
Benomyl	Benlate	8321 (Carbamates)	No	**Yes**	No	**Yes**	Fungicide used in seed dipping operations.
Diuron	Karmex	8321 (Carbamates)	No	**Yes**	No	**Yes**	
Methyl Sulfanilcarbamate	Asulam	8321 (Carbamates)	No	No	No	No	Limited use and not significantly toxic.
Oxamyl	Vydate	8321 (Carbamates)	No	No	No	No	
Propiconazole	Tilt	8321 (Carbamates)	No	**Yes**	No	**Yes**	Fungicide used in seed dipping operations.
Dalapon		8151 or 8321 (Chlorinated Herbicides)	No	**Yes**	No	**Yes**	
Dicamba		8151 or 8321 (Chlorinated Herbicides)	No	**Yes**	No	No	
Dichlorophenoxyacetic Acid (2,4 D)	2,4-D	8151 or 8321 (Chlorinated Herbicides)	No	No	No	No	
Dichloropropane, 1,2-		8151 or 8321 (Chlorinated Herbicides)	No	No	No	**Yes**	
Dichloropropene, 1,3-	Telone	8151 or 8321 (Chlorinated Herbicides)	No	No	No	No	
Picloram	Tordon	8151 or 8321 (Chlorinated Herbicides)	No	No	No	No	Limited use and not significantly toxic.

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Table 9-C (continued)

Chemical	Synonyms	Laboratory Analytical Grouping[1]	Retained as COPC for Sugar Cane? (Field Areas)[2]	Retained as COPC for Sugar Cane? (Non-Field areas)[2]	Retained as COPC for Pineapple? (Field Areas)[2]	Retained as COPC for Pineapple? (Non-Field areas)[2]	Notes
Trichlorophenoxyacetic Acid, 2,4,5- (2,4,5 T)	2,4,5-T	8151 or 8321 (Chlorinated Herbicides)	No	**Yes**	No	No	
Trichloro- Phenoxypropionic Acid, 2,4,5- (2,4,5 Tp)	2,4,5-TP, Silvex	8151 or 8321 (Chlorinated Herbicides)	No	No	No	No	
Arsenic		6010B or 6020 (Heavy Metals)	**Yes**	**Yes**	**Yes**	**Yes**	Include arsenic for pineapple operations.
Lead		6010B or 6020 (Heavy Metals)	No	**Yes**	No	**Yes**	Lead-based pesticides not used in sugarcane field areas.
Mercury	Phenyl-mercuric acetate	7471 (Mercury)	No	**Yes**	No	No	
Methyl Mercury		7471 (Mercury)	No	**Yes**	No	No	Investigate only if total Hg contamination identified.
Captafol	Difolatan	8081 or 8270 (Organochlorine Pesticides)	No	No	No	No	
Chlordane (Technical)	Technical Chlordane	8081 or 8270 (Organochlorine Pesticides)	No	No	No	**Yes**	
Endosulfan		8081 or 8270 (Organochlorine Pesticides)	No	No	**Yes**	**Yes**	

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Table 9-C (continued)

Chemical	Synonyms	Laboratory Analytical Grouping[1]	Retained as COPC for Sugar Cane? (Field Areas)[2]	Retained as COPC for Sugar Cane? (Non-Field areas)[2]	Retained as COPC for Pineapple? (Field Areas)[2]	Retained as COPC for Pineapple? (Non-Field areas)[2]	Notes
Heptachlor		8081 or 8270 (Organochlorine Pesticides)	**Yes**	**Yes**	**Yes**	**Yes**	Only used in fields with drip irrigation between 1979 & 1985. Cancelled in 1988.
Heptachlor Epoxide		8081 or 8270 (Organochlorine Pesticides)	No	No	**Yes**	**Yes**	
Hexachlorocyclohexane, Gamma	Lindane, BHC	8081 or 8270 (Organochlorine Pesticides)	No	No	**Yes**	**Yes**	
Trifluralin	Treflan	8081 or 8270 (Organochlorine Pesticides)	No	**Yes**	No	No	
Chlorpyrifos	Dursban	8141 or 8270 (Organophosphorus Pesticides)	No	No	No	No	Limited use in small amounts.
Diazinon		8141 or 8270 (Organophosphorus Pesticides)	No	No	No	No	Limited use in small amounts.
Malathion		8141 or 8270 (Organophosphorus Pesticides)	No	No	No	No	Limited use in small amounts.
Parathion		8141 or 8270 (Organophosphorus Pesticides)	No	No	No	No	Limited use in small amounts.

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Table 9-C (continued)

Chemical	Synonyms	Laboratory Analytical Grouping[1]	Retained as COPC for Sugar Cane? (Field Areas)[2]	Retained as COPC for Sugar Cane? (Non-Field areas)[2]	Retained as COPC for Pineapple? (Field Areas)[2]	Retained as COPC for Pineapple? (Non-Field areas)[2]	Notes
Ethephon	Ethrel	8270 (SVOCs)	No	No	No	No	
Captan	Ethyl Mercapton	8270 (SVOCs)	No	No	No	No	
Dichlorophenol, 2,4-		8270 (SVOCs)	No	No	No	No	
Tetrachlorophenol, 2,3,4,6-		8270 (SVOCs)	No	**Yes**	No	**Yes**	
Pentachlorophenol		8270 or 8151 (SVOCs or Chlorinated Herbicides)	No	**Yes**	No	**Yes**	
Ametryn	Evik	8141 or 8270 (Triazine Pesticides)	No	**Yes**	No	**Yes**	
Atrazine	Astrex	8141 or 8270 (Triazine Pesticides)	No	**Yes**	No	**Yes**	
Hexazinone	Velpar	8141 or 8270 (Triazine Pesticides)	No	No	No	No	Limited use in small quantities
Metribuzin		8141 or 8270 (Triazine Pesticides)	No	No	No	No	Limited use in small quantities
Simazine		8141 or 8270 (Triazine Pesticides)	No	**Yes**	No	**Yes**	
Bromodichloromethane		8260 (VOCs)	No	No	No	No	
Bromomethane	Methyl Bromide	8260 (VOCs)	No	No	No	No	
Dibromo-3-Chloropropane,	DBCP	8260 (VOCs)	No	No	No	**Yes**	
Dibromochloromethane		8260 (VOCs)	No	No	No	**Yes**	
Dibromoethane, 1,2-	EDB	8260 (VOCs)	No	No	No	**Yes**	
Trichloropropene, 1,2,3-	TCP	8260 (VOCs)	No	No	No	**Yes**	

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Table 9-C (continued)

Chemical	Synonyms	Laboratory Analytical Grouping[1]	Retained as COPC for Sugar Cane? (Field Areas)[2]	Retained as COPC for Sugar Cane? (Non-Field areas)[2]	Retained as COPC for Pineapple? (Field Areas)[2]	Retained as COPC for Pineapple? (Non-Field areas)[2]	Notes
Dioxins/Furans		8280/8290 (Dioxins/furans)	No	**Yes**	No	**Yes**	
Glyphosate	Roundup, Rodeo, Polado	547	No	No	No	No	
Terbacil	Sinbar	633 (Organonitrogen Pesticides)	No	No	No	No	Limited use and toxicity.

Notes:

1 Laboratory analytical method used to categorize pesticides may not match actual pesticide chemical category.

2 Retained as chemical of potential concern (COPC) if: any of the following:

- Known past use.
- Commercial lab method available.
- Toxicity factors & physiochemical constants available.
- Non-field areas are moderately or highly persistent or field areas are highly persistent (see text for details).

APPENDIX 9-D

GUIDANCE FACT SHEET FOR USE WHEN PETROLEUM CONTAMINATION IS ENCOUNTERED DURING SUBSURFACE SOIL EXCAVATION

GUIDANCE FACT SHEET
FOR USE WHEN PETROLEUM CONTAMINATION IS ENCOUNTERED
DURING SUBSURFACE SOIL EXCAVATION

PURPOSE: The purpose of this Guidance Fact Sheet is to provide guidance for construction projects when petroleum or petroleum contaminated soil (PCS) is encountered. These guidelines apply to construction projects that involve soil excavation, except associated with underground storage tank (UST) removal. These guidelines are consistent with Hawaii Revises Statutes Chapter 128D, Hawaii Environmental Response Law. Administrative procedures must be in place within your organization, so that project managers, contract workers, field workers, health and safety personnel, and essentially anyone who might be involved in construction and the excavation of soils follow these basic guidelines:

When must notification to the HEER Office be made?

The reportable quantity for petroleum is one of the following:

a) Any amount of oil which when released into the environment causes a sheen to appear on surface water, or any navigable water of the State.

b) Any free product that appears on groundwater.

c) Any amount of oil released to the environment greater than 25 gallons.

d) Any amount of oil released to the environment, which is not contained and remediated within 72 hours. Note: The HEER Office interprets this criteria to require petroleum-stained soil encountered during excavation work to be reported.

Who must notify?

Any person who has any knowledge of a release of a reportable quantity must immediately notify the HEER Office. Failure to notify the HEER Office of a release is subject to a civil penalty not to exceed $10,000 for each day of failure to report.

What is the number to call?

Hawaii State Department of Health, Hazard Evaluation and Emergency Response Office (HEER Office):

(808) 586-4249 during working hours, Monday – Friday, 7:45 a.m. – 4:30 p.m.

or

(808) 247-2191 during non-working hours including holidays.

What information is required to be provided to the HEER Office?

The information gathered should be sufficient to answer the following, but notification shall not be delayed due to incomplete notification:

1. Name of the observed chemical released
2. Approximate quantity observed
3. The location and an address of the release. The location may be determined by either surveying by a licensed surveyor or the use of a Global Positioning System (GPS) unit, which provides latitude and longitude. The latitude and longitude of the

contaminated area should be accurate to within 25 feet of the actual position. A detailed map should be submitted to the HEER Office at a later date

4. The name, address, and telephone number of the caller
5. The name, address, and telephone number of the owner/operator of the site where the release has occurred
6. The name, address, and telephone number of the contact person at the site where the release has occurred
7. Measures taken or proposed to be taken in response to the release at the time of the notification
8. Any other information, including but not limited to, potential on-site worker and public or environmental impacts

Who else should be notified?

If a party other than the landowner is conducting the project, then a separate notification needs to be made to the landowner to allow them to determine their liability and the next course of action.

What additional steps must be taken?

1. When petroleum or PCS is discovered during construction activities, an immediate determination is needed as to whether it may be a threat to the health and welfare of on-site workers or the nearby public.

   If a combustible hazard is identified, an Emergency Response Plan should be put into effect. No work may continue until the area is determined to be safe.

   [Note: A Combustible Gas Indicator may be used to determine if there is a flammable or explosive potential. Each combustible gas has its own Lower Explosive Level (LEL) and its Upper Explosive Level (UEL). For example, methane gas has a LEL of 5 percent (%) by volume and an UEL of 15% by volume. Between 5 to 15% by volume, a spark could cause an explosion. If the atmosphere has less than 5% methane, an explosion cannot occur even if a source of ignition is present. Likewise, if the atmosphere has greater than 15% methane, the air-fuel mixture is too rich to burn. Gasoline has a LEL of 1.4% by volume and an UEL of 7.4% by volume.
2. The project may continue with implementation of a Health and Safety Plan in accordance with applicable occupational safety and health regulations. This plan should address exposure issues and include appropriate air monitoring.
3. If free-floating petroleum product is encountered during the project, the product is to be recovered and either re-used or disposed of appropriately.
4. Petroleum-contaminated water encountered during dewatering projects must be tested and treated as necessary prior to discharge into a storm drain or other pathway that leads to surface water bodies. At a minimum, this will usually require that the water be passed through an oil/water separator. The water should also be tested for dissolved-phase petroleum contaminants prior to discharge (at least initially). The water should be treated to meet HDOH Environmental Action Levels for discharges to surface waters or a more site-specific assessment of potential

impacts to aquatic habitats carried out. The HEER Office Environmental Hazard Evaluation (EHE) guidance can be consulted for applicable surface water environmental action levels, or call the HEER Office (808) 586-4249 during business hours for assistance.

Groundwater Management:

Groundwater that contains free product or a sheen can assumed to be contaminated with dissolved analytes. Re-infiltration, reinjection, treatment, disposal, or discharge are all acceptable options for the disposition of groundwater generated during subsurface excavation that encounters contaminated groundwater. Of these choices, re-infiltration within the Work Area where the water was extracted is the least expensive and easiest way to manage contaminated groundwater; however this option may not be feasible at all project locations.

A. Groundwater should be reused within the Work Area and within the same aquifer where it was removed. Reuse in other areas could spread unidentified contamination or cause existing plumes in those areas to migrate.

B. Removal and reuse must meet existing Federal and State permit requirements.

C. If discharged to storm sewers or surface water bodies:

    1. National Pollution Discharge Elimination System and State permit requirements also apply. Prior to dewatering, clearance and/or permits from the CWB are required.

    2. Removal of floating product via an oil water separator and/or passage of the water through settling ponds or sand filters may not be adequate to reduce dissolved-phase contaminant concentrations to below action levels. Therefore, in addition to analytical screening required in applicable Federal and State permits, the HEER Office recommends:

        a. At a minimum, all groundwater discharged to storm sewers must be analyzed for constituents related to petroleum and solvents.

        b. Additional analytical data may be required based on knowledge of contamination within the vicinity of the work area.

        c. The groundwater must be analyzed for known or suspected contaminants and the results must be screened against the Estuarine EALs for Surface Water Bodies, in Table D of Volume 1 of *Screening for Environmental Hazards at Sites with Contaminated Soil and Groundwater*, Fall 2011 Updates, Revised January 2012 (and updates).

        d. For some site-specific locations, the HEER Office analytical requirements may be adjusted with advance approval. Permit requirements will not be adjusted.

D. If discharged to sanitary sewers, contractors must follow the requirements of all permits.

E. If discharged to a re-infiltration trench:

1. The trench must be within the Work Area, especially if the groundwater is extracted from a Work Area in the vicinity of known or observed contamination.
2. The trench must not be an underground injection control (UIC) well by SDWB definitions. If some part of the trench system is deemed to be a UIC well, then the whole system is considered an injection well.
3. Advance clearance from SDWB is required if a re-infiltration trench is deeper than 10 feet.

F. UIC wells may be used, but advance planning and approval are required. SDWB permit requirements must be met for well construction, placement, use, and closure.

G. In instances where "oily water" is disposed, the receiving facility must be permitted for that type of waste.

5. Petroleum contaminated soil is to be excavated and segregated from clean soils. Excavated contaminated soil must be placed under a liner and covered. Contaminated soil must be treated or disposed of in accordance with all applicable local, state and federal requirements.

   On-Site Management of Contaminated Soils:

   When deciding whether to re-deposit contaminated soil, the time saved by proceeding with the project immediately should be weighed against the possible increase in cost caused by deferring remedial action to a later date. If re-deposition is chosen, be advised that this does not absolve any party from liability should the actions taken exacerbate potential health and environmental impacts. If the option of re-depositing is chosen, excavated soils should be stored under cover before re-deposit into the excavation. Excavated soil that is contaminated should not be placed into an excavation that is clean, i.e., an excavation other than that from which the soil was removed, otherwise the soil should be treated as in No. 5 above. Excavated soil with petroleum contamination that is re-deposited into the excavation should be provided with a cover of clean soil or cap of asphalt/concrete once the work has been completed.

6. Detailed records of the investigation, any re-deposited contaminated soils, and any other clean-up activities are to be maintained and submitted to the HEER Office.

7. In cases where a site assessment and evaluation is to be conducted, the HEER Office Technical Guidance Manual, Environmental Hazard Evaluation (EHE) Guidance, and the State Contingency Plan are accessible through the HEER Office website:

   http://hawaii.gov/doh/heer

   If uncertain of the action to take, call the HEER Office at 808-586-4249

APPENDIX 9-E

UPDATE TO SOIL ACTION LEVELS FOR INORGANIC ARSENIC AND RECOMMENDED SOIL MANAGEMENT PRACTICES

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GOVERNOR OF HAWAII

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In reply, please refer to:
File: EHA/HEER Office
2011-690-RB

November 2011 (updated September 2012)

To: Interested Parties

From: Roger Brewer, Ph.D., Environmental Risk Assessor, HEER

Through: Barbara Brooks, Ph.D., Toxicologist, HEER

Subject: Update to Soil Action Levels for Inorganic Arsenic and Recommended Soil Management Practices (updates default, background arsenic soil action level presented in 2010 guidance to 24 mg/kg; arsenic exposure units in Section 3.0 table corrected to ug/day September 2012)

1.0 Introduction

This technical memorandum presents an update to the 2008 Hawai'i Department of Health (HDOH) action levels and corresponding guidance for inorganic arsenic in soil (HDOH 2008a, attached). Categories for management and evaluation of arsenic-contaminated soil have been revised and simplified. Soil action levels for arsenic presented in the 2008 technical memorandum have not been adjusted. This guidance serves as an addendum to the Hazard Evaluation and Emergency Response (HEER) office document *Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater* (EHE guidance; HDOH 2008b).

Refer to the June 2010 dioxin technical memorandum for additional guidance on issues common to both dioxin- and arsenic-contaminated soil, including (HDOH 2010a):

- Site characterization;
- Disposal of contaminated soil;
- Engineering controls;
- Institutional controls;
- Management of Category C Soils at Commercial/Industrial Sites;
- Environmental Hazard Management Plans and management of Category C soils at commercial/industrial sites;
- Inclusion of soil above surrounding background in remediation of Category D soils; and

- Hazardous Waste Considerations.

The soil action levels presented herein are not promulgated regulatory standards or required cleanup levels. Alternative proposals may be presented in a site-specific risk assessment.

2.0 Arsenic Soil Management Categories

Updated categories for the evaluation and management of arsenic-contaminated soil are summarized below and in Table 1. These categories replace the scheme presented in the 2008 HDOH technical memorandum (HDOH 2008a):

Category A Soils (natural background): Soils exhibit concentrations of total arsenic <24 mg/kg, and do not appear to have been impacted by local, agricultural or industrial releases of arsenic; not impacted. The natural, background concentration of arsenic in soils in Hawai‘i is typically less than 24 mg/kg (<2mm soil fraction; upperbound background level, HDOH 2011). A summary of background concentrations of heavy metals in soil in Hawai'i is in preparation. In the interim, refer to documents published by the Air Force (USAF 2005) and Navy (USN 2006) environmental programs in Hawai‘i. A summary of background concentrations of metals in various soil types on the mainland US has been published by the University of California (UCR 1996) and U.S. Geological Survey (USGS 2001).

Category B Soils (minimally impacted): Total arsenic >24 mg/kg but bioaccessible arsenic <23 mg/kg, indicating probable anthropogenic impacts but at levels within acceptable health risks for long-term exposure; Unrestricted Land Use. Bioaccessible arsenic determined for 250 micron soil fraction. HEER expects Category B soils to be generally associated with agricultural fields where arsenic- based herbicides were used for weed control between the years 1915 to 1950. Arsenic levels between individual fields can vary with respect to the location of the field (e.g., high- versus low-rainfall area) as well as the weed control preferences of the sugar companies that managed the fields. Reported concentrations of bioaccessible arsenic are typically below 23 mg/kg in field areas, although exceptions have been identified in some areas. This action level can be easily exceeded in former pesticide storage and mixing areas. In general, bioaccessibility is higher in iron-poor, coralline sands in comparison to iron-rich volcanic soils.

Although not necessary from a health risk standpoint, owners of existing homes where pesticide-related, Category B soils are identified may want to consider measures to minimize exposure to arsenic in the soil as summarized in Table 1 and discussed in the HDOH fact sheet *Arsenic in Hawaiian Soils: Questions and Answers on Health Concerns* (HDOH 2010b; see also 2008c).

HDOH discourages the use of Category B soils with greater than 100 mg/kg *total* arsenic in the fines sol fraction (< 250µm) as fill material in offsite areas without further consultation, even if bioaccessible arsenic meets action levels for unrestricted use. This

is intended to limit the movement of contaminated soil to otherwise un-impacted areas, as well as address a potential increase in bioaccessibility with the addition of phosphate fertilizers in lawns or gardens in new developments. Investigations carried out by HDOH in several heavily-impacted community garden soils on the Big Island (>400 mg/kg total arsenic in the fines soil fraction; HDOH 2007) suggested an increase in bioaccessible arsenic (15-20%) in comparison to equally-contaminated soils in the surrounding areas (1-10%). A limit of total arsenic to 100 mg/kg in fines is intended to approximate the target Category B limit of 23 mg/kg under a worst-case, 25% bioaccessibility for arsenic in iron-rich, volcanic soils.

Category C Soils (moderately impacted): Bioaccessible arsenic between 23 mg/kg and 95 mg/kg; Commercial/Industrial Land Use Only. Category C soils are exemplified by contamination at former pesticide storage and mixing areas and wood treatment facilities. Category C soils have also been identified in community gardens associated with former sugarcane plantations (with elevated arsenic also identified in the adjacent field areas), at the site of a former Canec manufacturing site (see HDOH 2010c), and in some industrial areas believed to have been historically treated with arsenic herbicides for weed control.

Category D Soils (heavily impacted): Bioaccessible arsenic greater than 95 mg/kg; Remedial Actions Required. Category D soils have been identified at a small number of former pesticide mixing areas (e.g., sugarcane operations), former plantation housing areas and wood treatment facilities. Concentrations of total arsenic in soil typically exceed several thousand milligrams per kilogram. These soils are often co-located with heavy dioxin contamination (associated with use of pentachlorophenol) and in some cases triazine pesticides. Pentachlorophenol and triazine pesticides successively replaced the use of arsenic-base herbicides in the 1930s and 1970s, respectively (see HDOH 2010a; refer also to Section 9 in the HEER office Technical Guidance Manual, HDOH 2009).

A site-specific, Environmental Hazard Management Plan (EHMP) must pre prepared for all sites where Category C and D soils are to be left in place for long-term management (HDOH 2008b, 2009). Information to be provided in the EHMP includes:

- To-scale maps that specify the location, thickness and depth of Category C and D soils;
- Summary of the specific environmental hazards potentially posed by the contaminated soil;
- Required institutional and engineering controls (e.g., restricted use, capping requirements, etc.);
- Fugitive dust and storm water runoff control measure;
- Measures for protection of workers involved in future construction or trenching projects that might disturb Category D soils.

Inappropriate reuse of Category C or D soils in offsite areas is of particular concern when excess soil is generated during construction or trenching projects. Clean fill should be used in utility corridors to minimize worker exposure and inadvertent reuse of removed

soil in offsite areas. Refer to the HEER office *Environmental Hazard Evaluation* guidance (HDOH 2008b) and *Technical Guidance Manual* (HDOH 2009) for additional information. A copy of the EHMP should be retained by the property owner and lessees, as well submitted to HDOH for inclusion in the public record for the subject site.

3.0 Comparison of Soil Exposure to Dietary Exposure

The unrestricted (e.g., residential) soil action level of 23 mg/kg for bioaccessible, inorganic arsenic equates to a hypothetical, daily exposure dose for a 15kg child of approximately 4.0 micrograms (based on assumed soil ingestion rate, exposure duration and frequency, etc.; see HDOH 2008a). The commercial/industrial action level of 95 mg/kg equates to a daily exposure dose for a 70kg worker of 7.0 micrograms. Actual exposures to arsenic in soil for both children and adults are likely to be much lower due to the conservative nature of the exposure factors used in the calculations.

Exceeding the soil action level and the hypothetical exposure dose does not imply that an adverse health risk will occur, only that additional evaluation is warranted. This is because the Reference Dose (RfD) used to calculate the soil action level (i.e., 0.3 ug/kg-day; USEPA 2010a) incorporates an inherent uncertainty and margin of safety, due to the nature of toxicological risk assessment. As stated in IRIS summary for arsenic, "Risk managers should recognize the considerable flexibility afforded them in formulating regulatory decisions when uncertainty and lack of clear consensus (on toxicity factors) are taken into account."

Arsenic is a naturally occurring element in the earth's soil and water. As such it is naturally present in trace amounts in food. A comparison of exposure to inorganic arsenic in the diet to exposure from soil helps put the stated action levels into perspective, as shown in the table below (see Attachment 2 for detailed explanation):

	Exposure (ug/day)	
Receptor	*Soil	Dietary
Child (15 kg)	4.0	18
Adult (70 kg)	7.0	44

*Exposure to Category B (Child) and C (Adult Worker) soil.

Based on a typical Pacific-Asian diet that is rich heavy in rice and fish, dietary inorganic arsenic exposures are estimate to be as high as 18 ug/day for children (1.2 ug/kg-day for a 15 kg child) and 44 ug/day for adults (0.6 ug/kg-day for a 70 kg adult). Rice accounts for the majority of dietary, inorganic arsenic (see Attachment 2).

Dietary exposure to inorganic arsenic is therefore anticipated to far exceed exposure to arsenic in soil at the stated action levels. The majority of exposure to inorganic arsenic in the diet comes from rice (see Attachment 2), which naturally accumulates arsenic and other elements in the soil when grown under wet conditions. Regular consumption of rice has not been shown to pose a significant health risk due to the presence of arsenic or other metals. Fish contains a significant amount of relatively non-toxic, *organic* arsenic

("fish arsenic") but can also contribute to a small portion of total inorganic arsenic exposure.

4.0 Comparison to 2010 Draft USEPA Arsenic Toxicity Review

The USEPA published draft, proposed changes to the cancer slope factor for inorganic arsenic in February 2010 (USEPA 2010b). The draft USEPA document recommends an *increase* in current cancer slope factors for inorganic arsenic by more than an order of magnitude under some circumstances. In theory this could result in a *reduction* of cancer-based soil action levels by a similar magnitude. As stated in the draft USEPA document: "(This document) has not been formally disseminated by EPA. It does not represent and should not be construed to represent any Agency determination or policy."

The draft USEPA (2010b) cancer slope factors for arsenic are based on doses that are orders of magnitude higher than are typically associated with exposures to soils (e.g., 100s to 1,000s ug/day vs <5 ug/day for exposures to Category B soils. There is considerable debate among both regulators and private entities regarding the applicability of both current and proposed cancer slope factors to very low doses of inorganic arsenic typically associated with exposure to soil as well as rice and other foods (e.g., USSBA 2010, EPRI 2010). As described in the 2008 technical memorandum, HDOH places a higher level of confidence in the noncancer toxicity factors and feels that the use of these factors in the development of soil action levels is more technically supportable for regulatory decisions (HDOH 2008a).

The use of conservative exposure assumptions in conjunction with a comparison to anticipated dietary exposure to inorganic arsenic provide additional lines of evidence to support the adequacy of the soil action levels to help separate low-risk sites from high risk sites and prioritize HDOH resources. HDOH considers the current approach to develop soil action levels as outlined in the 2008 technical memorandum to be appropriate for use in Hawai‘i and does not anticipate the need to adjust them in the foreseeable future.

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Table 1. Summary of Inorganic Arsenic Soil Action Levels and associated soil management categories.

Soil Management Category	Action
Total Arsenic (< 2 mm size fraction)	
Category A Total Arsenic ≤24 mg/kg	**Background.** Within range of expected background conditions in non-agricultural and non-industrial areas (upperbound background noted, HDOH 2011). No further action required and no restrictions on land use.
Bioaccessible Arsenic (<250 µm size fraction)	
Category B Total Arsenic >24 mg/kg and Bioaccessible Arsenic ≤23 mg/kg	**Minimally Impacted-Unrestricted Land Use.** Exceeds expected background conditions but at levels anticipated for many agricultural fields where arsenic-based chemicals were used historically. Potential health risks considered to be within the range of acceptable health risks for long-term exposure. Include Category B soil in remedial actions for more heavily contaminated spill areas as practicable in order to reduce exposure (e.g., outer margins of pesticide mixing areas). Offsite reuse of soil for fill material not recommended for soil with >100 mg/kg total arsenic (see text). Use of soil for intermediate (e.g., temporarily inactive portions) or interim (e.g., daily or weekly) cover at a regulated landfill is acceptable, pending agreement by the landfill and barring hazardous waste restrictions. Although not strictly necessary from a health-risk standpoint, owners of existing homes where pesticide-related, Category B soils are identified may want to consider measures to reduce daily exposure to soil (e.g., maintain lawn cover, ensure good hygiene, thoroughly wash homegrown produce, etc) as described in the HDOH fact sheet *Arsenic in Hawaiian Soils: Questions and Answers on Health Concerns* (HDOH 2010c). For new developments on large, former field areas, notify future homeowners of elevated levels of arsenic on the property and recommend similar, precautionary measures (e.g., include in information provided to home buyers during property transactions, see also HDOH 2008b).
Category C (Bioaccessible Arsenic >23 but ≤95 mg/kg)	**Moderately Impacted-Commercial/Industrial Land Use Only.** Identified at several, former pesticide mixing areas and wood treatment facilities. May be co-located with pentachlorophenol, dioxin and triazine pesticide contamination at agricultural sites. Restriction to commercial/industrial land use is typically required in the absence of remediation or significant institutional and engineered controls and HDOH approval. Use of soil as soil as intermediate (e.g., temporarily inactive portions) or interim (e.g., daily or weekly) cover at a regulated landfill is acceptable, pending agreement by the landfill and barring hazardous waste restrictions. Preparation of a site-specific, *Environmental Hazard Management Plan* (EHMP) required if soil is left on site for long-term management (HDOH 2008b, 2009). Treatment to reduce bioavailability and/or removal of isolated spill areas is recommended when practicable in order to minimize future management and liability concerns. This includes controls to ensure no off-site dispersion (e.g., dust or surface runoff) or inadvertent excavation and reuse at

	properties with sensitive land uses.
Category D (Bioaccessible Arsenic >95 mg/kg)	**Heavily Impacted-Remedial Actions Required.** Identified at a small number of former pesticide storage and mixing areas (e.g., sugarcane operations), former plantation housing areas and wood treatment facilities. May be co-located with dioxin and triazine pesticide contamination. Remedial actions required under any land use scenario in order to reduce potential exposure. Potentially adverse health risks under both sensitive and commercial/industrial land use scenarios in the absence of significant institutional and/or engineered controls. Disposal of soil at a regulated landfill is acceptable, pending agreement by the landfill and barring hazardous waste restrictions. Preparation of site-specific EHMP required if left on site.

ATTACHMENT 1

2008 HDOH ARSENIC ACTION LEVEL GUIDANCE

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TO: Interested Parties

FROM: Roger Brewer
Environmental Risk Assessment
HEER Office

THROUGH: Barbara Brooks
Toxicologist
HEER Office

DATE: June 13, 2008

SUBJECT: Tier 2 Action Levels for Arsenic (update to August 2006 memorandum)

This technical memorandum presents Tier 2 action levels and corresponding guidance for arsenic-contaminated soils. The guidance serves as an addendum to the Hazard Evaluation and Emergency Response (HEER) office document *Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater* (HDOH 2008a). The guidance updates and takes precedence over guidance published in August 2006 (HDOH 2006). The update primarily addresses recommendations for the management of Category 2 soils in former agricultural fields. Similar guidance has been prepared for dioxin-contaminated soils (HDOH 2008b)

The guidance is especially intended for use during the redevelopment of former agricultural areas, although it is applicable to any site where releases of arsenic may have occurred. The action levels should be used to help determine the extent and magnitude of arsenic-contaminated soils and help guide the scope of remedial actions needed. The action levels are intended to serve as guidelines only, however, and do not represent strict, regulatory cleanup requirements. Alternative action levels may be proposed for any site in a site-specific, environmental risk assessment.

Overview

The action levels presented are based on concentrations of *bioaccessible* arsenic in soil. *Total* arsenic data are considered appropriate for comparison to anticipated background levels of arsenic in soil but not for use in human health risk assessment or for setting risk-based action levels. An action level of 4.2 mg/kg bioaccessible arsenic is recommended for residential sites. For commercial/industrial sites, an action level of 19 mg/kg bioaccessible arsenic is recommended. Remediation of sites to permit future, unrestricted, residential land use is encouraged when technically and economically feasible. "Residential" use includes both single-family homes and high-density developments, where open spaces essentially serve as residential "backyards." Schools, parks, playgrounds, and other open public spaces that adult and child residents may visit on a regular basis should also be initially assessed under a residential use exposure scenario. Short- and long-term remedial actions in the latter areas may differ from

actions recommended for high-density and single-family residential properties, however, due to greater control over digging and other activities that may expose contaminated soil.

Additional guidance and action levels are provided for sites where the preferred action levels noted above cannot be reasonably met and continued use or redevelopment of the site is still desired. Three categories of arsenic-contaminated soil are defined for both residential and commercial/industrial sites. Residential, Category 1 soils (R-1) are not considered to pose a significant risk to human health under any potential site conditions and can be reused onsite or offsite as desired. Commercial/Industrial, Category 1 soils (C-1) can be used as needed on commercial/industrial sites but should not be used as fill material offsite without prior consultation with HDOH.

Category 2 Residential (R-2) and Commercial/Industrial (C-2) soils are not considered to pose a significant risk to human health under the specified land use. As a best management practice, however, HDOH recommends the removal or capping of Category 2 soils associated with easily identifiable, localized spill areas when feasible (e.g., past pesticide mixing or storage). HDOH does not consider capping or removal of Category 2 soils in large, former field areas to be necessary or practicable.

Category 3 Residential (R-3) and Commercial/Industrial (C-3) soils are considered to pose an unacceptable risk to human health and should be removed from the site or isolated onsite under permanent structures or properly designed caps, as described below.

Remediation of residential and commercial/industrial properties to action levels for Category 2 soils is recommended to the extent technically and economically feasible, however, and should be discussed with the HEER office on a site-by-site basis. Reuse of Category 2 Commercial/Industrial soil for daily cover at a regulated landfill may be acceptable but should be discussed with the landfill operator as well as the HDOH Solid and Hazardous Waste Branch.

Background

Significantly elevated levels of arsenic have been identified in soils from former sugar cane fields and pesticide mixing areas in Hawai‘i, as well as in and around former plantation camps. High levels of arsenic have also been identified in soil samples from at least one former golf course. The presence of the arsenic is believed to be related the use of sodium arsenite and other arsenic-based pesticides in and around the cane fields in the 1920s through 1940s. During this period, up to 200,000 acres of land in Hawai‘i was being cultivated for sugar cane. The arsenic is generally restricted to the upper two feet of the soil column (approximate depth of plowing). Alternative action levels and approaches may be acceptable for contaminated soils situated greater than three feet below ground surface and should be discussed with HDOH on a site-by-site basis.

Current studies have focused on the Kea‘au area of the Big Island. Soils in the area have been described as stony, organic, iron-rich Andisols (Cutler et al., 2006). Concentrations of total arsenic in soils from undeveloped former sugar cane lands in this area have been reported to range from 100-400 mg/kg in the $\leq$2mm size fraction of the soil and >500 mg/kg in the <250µm size fraction (report pending). Concentrations greater than 1,000 mg/kg have been reported in one former plantation camp area. Background concentrations of arsenic in native soils range from 1.0 mg/kg up to 20 mg/kg. The presence of the arsenic initially posed concerns regarding potential groundwater impacts, uptake in homegrown produce and direct exposure of residents and workers to contaminated soil. Maximum-reported concentrations of bioaccessible arsenic in

soil are far below levels that would cause immediate, acute health affects. Continued exposure to arsenic in heavily contaminated soils over many years or decades could pose long-term, chronic health concerns, however.

Arsenic has not been detected in municipal groundwater wells in the area. Testing of produce from gardens in the Kea'au area by the Department of Health in 2005 also did not identify levels of arsenic above U.S. norms, even though total arsenic in the garden soils approached or exceeded 300 mg/kg in the $\leq$2mm size fraction. Uptake of the arsenic in edible produce or other plants therefore does not appear to be a significant environmental health concern. These observations suggest that the arsenic is tightly bound to the soil and not significantly mobile. This is further supported by petrologic and leaching studies as well as "bioaccessibility" tests conducted on the soils (Cutler et al., 2006). Despite being relatively immobile, however, elevated levels of arsenic in some areas could still pose a potential chronic health risk to residents and workers who come into regular contact with the soil. The action levels and soil categories discussed below are intended to address this concern.

The evaluation of soil for arsenic has traditionally focused on the *total* amount of arsenic present and comparison to action levels based on a target excess cancer risk of one-in-a-million or 10^{-6}. This has always presented a dilemma in human health risk assessments. Natural, background concentrations of arsenic in soils are typically much higher than risk-based action levels for total arsenic. For example, the residential soil action level for arsenic presented in the HDOH document *Screening For Environmental Concerns at Sites With Contaminated Soil and Groundwater* is 0.42 mg/kg (HDOH 2008a, Appendix 1, Table I-1), while background concentrations of arsenic in soil in Hawai'i may range up to 20 mg/kg or higher. In addition, much of the arsenic in pesticide-contaminated soil appears to be tightly bound to soil particles and not *available* for uptake in the human body. This portion of the arsenic is essentially nontoxic. These two factors led to a need for further guidance, particularly with respect to the use of *bioaccessible* arsenic data in human health risk assessments and in the development of risk-based, soil action levels.

Bioavailable and Bioaccessible Arsenic

Risk to human health posed by exposure to a contaminant in soil is evaluated in terms of the average daily dose or *intake* of the contaminant for an exposed person (e.g., in milligrams or micrograms per day; USEPA 1989, 2004). Intake can occur through incidental ingestion of soils, inhalation of dust of vapors, and to a lesser extent (for most contaminants) absorption through the skin. Assumptions are made about the fraction of the contaminant that is available for *uptake* in a persons blood stream via the stomach and small intestine. This is referred to as the *bioavailability* of the contaminant (NEPI 2000). The most widely accepted method to determine the bioavailability of a contaminant in soil is through *in vivo* studies where the soil is incorporated into a lab test animal's diet. In the case of arsenic, the amount that is excreted in the animal's urine is assumed to represent the fraction that entered the animal's blood stream and was available for uptake.

In vivo bioavailability tests are time consuming and expensive, however, and not practical for routine site evaluations. As an alternative, faster and more cost-effective laboratory tests have been developed to estimate arsenic bioavailability in soil. These methods, referred to as *in vitro* bioaccessibility tests, utilize an acidic solution intended to mimic a child's digestive tract (typically a glycine-buffered hydrochloric acid solution at pH 1.5; Ruby 1999; Gron and Andersen, 2003). Soil with a known concentration and mass of arsenic is placed in the solution and allowed to equilibrate for one hour. An extract of the solution is then collected and analyzed

for arsenic. The concentration of arsenic in the solution is used to calculate the total mass of arsenic that was stripped from the soil particles. The ratio of the arsenic mass that went into solution to the original mass of arsenic in the soil is referred to as the *bioaccessible* fraction of arsenic.

The results of *in vitro* bioaccessibility tests for arsenic compare favorably with *in vivo* bioavailability studies (Ruby 1999; Gron and Andersen, 2003). This is supported by studies of arsenic-contaminated soils from the Kea'au area of the Big Island of Hawai'i. Samples of the soil were tested for bioavailable arsenic in an *in vivo* monkey study carried out by the University of Florida in 2005 and simultaneously tested for bioaccessible arsenic by *in vitro* methods (report pending publication). The concentration of total arsenic in the samples was approximately 700 mg/kg. The study concluded that the bioavailability of arsenic in the soil ranged from 3.2% to 8.9%. This correlated well with an *in vitro* test carried out on the same soil that yielded an arsenic bioaccessibility of 6.5%. The bioaccessibility of arsenic in soils from the same site was estimated to range from 16% to 20% in a separate study, suggesting that the *in vitro* test method may err on the conservative side in comparison to the more standard *in vivo* method (Cutler et al., 2006). This has been observed in other studies of bioavailability versus bioaccessibility. Bioaccessibility tests on soils from other areas around Kea'au yielded similar results and again indicated that 80% to >90% of the arsenic in the soil is so tightly bound to soil particles that it is essentially "nontoxic."

Bioaccessible arsenic was observed to increase with increasing total arsenic concentration (Cutler et al., 2006). This is probably because much of the arsenic in heavily contaminated soils is fixed to low-energy binding sites on soil particles and comparatively easy to remove. Continued stripping of remaining arsenic from progressively higher-energy binding sites requires greater effort (i.e., the arsenic becomes progressively less bioaccessible). Data from the study also indicate that arsenic bioaccessibility (and therefore toxicity) may increase with increasing phosphorous concentration in soil related to the use of fertilizers in gardens. This is because phosphorus is able to out compete arsenic for high-energy binding sites on soil particles. The relationship has not been fully demonstrated, however, and is still under investigation.

Based on a review of published literature and studies conducted to date in Hawai'i, HDOH considers arsenic bioaccessibility tests to be sufficiently conservative and an important tool in the assessment of arsenic-contaminated properties. Bioaccessible arsenic analyses should always be conducted on the ≤250µm size fraction of the soil since this is the fraction that is most likely to be incidentally ingested. Most soils only contain a small percentage of particles 250µm in size or less. This typically requires the collection of very large samples (several kilograms) to obtain the mass needed for bioaccessibility tests. Appropriate sample handling, processing, and sub-sampling by the lab conducting bioaccessibility testing is essential. Guidance on suggested procedures and quality control for bioaccessibility lab tests will be forthcoming from HDOH. For more information on this subject contact John Peard of the HDOH HEER office (john.peard@doh.hawaii.gov).

Basis of Soil Action Levels

Arsenic action levels and correlative soil categories for residential and commercial/industrial properties are presented in Tables 1 and 2 and summarized in Figure 1. An action level of 20 mg/kg total arsenic in the ≤2mm size soil fraction is recommended to screen out sites where naturally occurring ("background") concentrations of arsenic are not significantly exceeded (HDOH 2008a). Background total arsenic may approach 50 mg/kg in some areas but this is

considered rare. Analysis of soil samples for bioaccessible arsenic is recommended at sites where total arsenic exceeds anticipated background concentrations.

Action levels for bioaccessible arsenic are presented in Table 1 (residential land use) and Table 2 (commercial/industrial land use). The action levels are based on direct-exposure models used by USEPA to develop soil *Regional Screening Levels* (RSLs) (replace 2004 Preliminary Remediation Goals; USEPA 2008). The USEPA RSLs for arsenic for residential and commercial/industrial land use are 0.39 mg/kg and 1.6 mg/kg, respectively, based on a target excess cancer risk of $1x10^{-6}$ (one-in-a-million). Risk-based action levels for arsenic of 0.42 mg/kg and 1.9 mg/kg are presented in the HDOH document *Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater*, based on a similar target risk but assuming a slightly lower, dermal absorption factor (HDOH 2008a). Both the USEPA RSLs and the HDOH Tier 1 action levels assume that 100% of the soil arsenic is bioavailable.

The USEPA RSLs and HDOH Tier 1 action levels for total arsenic are far below typical background concentrations of arsenic in soils from Hawai'i, as well as most of the mainland US. To address this issue, action levels for Category 1 soils in Tables 1 and 2 are based on a target excess cancer risk of $1x10^{-5}$ (one-in-one-hundred-thousand) rather than $1x10^{-6}$. This generates residential and commercial/industrial action levels for bioaccessible arsenic of 4.2 mg/kg and 19 mg/kg, respectively. These action levels serve as useful starting points to help identify arsenic-contaminated sites that warrant further evaluation.

A second set of action levels is used to define soils that are most likely impacted above natural background levels but still may be acceptable for use in residential or commercial/industrial areas if adequate lawns and landscaping are maintained (Category 2 soils). An action level of 23 mg/kg bioaccessible arsenic was selected as an upper limit for soils in residential areas (Table 1). This reflects a noncancer Hazard Quotient of 1.0 and correlates to an excess cancer risk of approximately $5x10^{-5}$. Commercial/industrial action levels based on a similar excess cancer risk of $5x10^{-5}$ and a noncancer Hazard Quotient of 1.0 are 95 mg/kg and 310 mg/kg, respectively. Since the correlative action level for excess cancer risk is less than the action level for noncancer risk, the former (95 mg/kg) was chosen as an upper limit for soils in commercial/industrial areas (Table 2). These action levels are used to define the lower boundary of Category 3 soils.

At concentrations greater than 180 mg/kg, bioaccessible arsenic in soil begins to pose a potentially significant health risk to construction workers and utility workers (HDOH 2008a, refer to Table I-3 in Appendix 1, based on an excess cancer risk of $1x10^{-5}$). As discussed below, this is used as a "ceiling level" for soil that can be isolated under clean soil caps, buildings or paved areas.

The action levels for bioaccessible arsenic were used to group soils into three categories (see Tables 1 and 2). A discussion of potential remedial actions at each site that fall into these soil categories is provided in the following sections. The ultimate action taken at an individual site will be dependent on numerous site-specific factors, including current and planned land use, available options for onsite isolation or offsite disposal, and technical and economic constraints.

Soil Categories and Action Levels for use at Residential Sites

Category 1 Soils (R-1): Bioaccessible Arsenic $\leq$4.2 mg/kg, No Further Action

Long-term exposure to Category 1 (R-1) residential soils is not considered to pose a significant risk to residents. No further action is necessary at sites where the reported concentration of bioaccessible arsenic in soil is equal to or below 4.2 mg/kg.

Utility corridors should be backfilled with clean fill material (e.g., R-1 soils) or at a minimum R-2 soils in order to prevent excavation of contaminated soil and inappropriate reuse in other areas in the future. R-3 soils should not be placed in utility corridors.

Category 2 Soils (R-2): Bioaccessible Arsenic >4.2 mg/kg and ≤23 mg/kg, Consider Removal or Isolation of Localized Spill Areas

Long-term exposure to Category 2 (R-2) residential soils is not considered to pose a significant risk to residents. As a best management practice, however, HDOH recommends the removal or capping of Category 2 soils associated with easily identifiable, localized spill areas when feasible (e.g., past pesticide mixing or storage). HDOH does not consider capping or removal of Category 2 soils in large, former field areas to be necessary or practicable. These issues are discussed in more detail below.

At sites where R-2 soils are discovered in the vicinity of existing homes, residents should be encouraged to minimize exposure to the soil by taking the following precautions:

- Reduce areas of bare soil by planting and maintaining grass or other vegetative cover, or cover barren areas with gravel or pavement.
- Keep children from playing in bare dirt.
- Keep toys, pacifiers, and other items that go into childrens' mouths clean.
- Wash hands and face thoroughly after working or playing in the soil, especially before meals and snacks.
- Wash fruits and vegetables from home gardens before bringing them in the house. Wash again with a brush before eating or cooking to remove any remaining soil particles. Pare root and tuber vegetables before eating or cooking.
- Bring in clean sand for sandboxes and bring in clean soil for garden areas or raised beds.
- Avoid tracking soil into the house and keep the floors of the house clean. Remove work and play shoes before entering the house.

Testing of produce from gardens in the Kea'au area by the Department of Health in 2005 did not identify levels of arsenic above U.S. norms. Uptake of the arsenic in edible produce or other plants does not appear to be a significant environmental health concern in former sugar cane operation areas. Produce should be thoroughly cleaned before cooking or eating, however, in order to avoid accidental ingestion of small amounts of soil.

Category 3 Soils (R-3): Bioaccessible Arsenic >23 mg/kg, Removal or Isolation Recommended

Long-term exposure of residents to Category 3 (R-3) residential soils is considered to pose potentially significant health risks. As discussed above, maximum-reported concentrations of bioaccessible arsenic in soil from former agricultural areas are far below levels that would cause immediate, acute health affects. Continued exposure to arsenic in R-3 soils over many years or decades could pose long-term, chronic health concerns, however.

Offsite disposal of R-3 soils in a permitted landfill facility is recommended when technically and economically feasible. Reuse of some or all of the soil as daily cover at a landfill may also be possible. This should be discussed with the landfill in question as well as with the HDOH Solid and Hazardous Waste Branch. Offsite disposal of soil with bioaccessible arsenic in excess of 180 mg/kg is especially recommended (action level for construction/trench work exposure).

Soils that fall into this category but cannot be disposed offsite due to technical and/or cost constraints should be placed in *soil isolation areas*. Optimally, a soil isolation area would be created under public buildings, private roadways, parking lots and other facilities/structures that constitute a permanent physical barrier that residents are unlikely to disturb in the future. Isolation of R-3 soils under public roadways should be done in coordination with the local transportation authority. Isolation of R-3 soils under permanent structures is preferable to isolation in open areas, due to the increased potential for open areas to be inadvertently disturbed during future gardening, landscaping or subsurface utility work. Soil that cannot be placed under a permanent structure or disposed of offsite should be isolated in well-controlled common areas, rather than on individual residential lots. Contaminated soil should be consolidated in as few isolation areas as possible. Areas where R-3 soils are placed and capped for permanent onsite management must be clearly identified on surveyed, post-redevelopment map(s) of the property. These maps should be included a risk management plan that is provided to HDOH for inclusion in the public file for the site (see "Identification of Soil Isolation Areas" below). Utility corridors should be backfilled with clean fill material (e.g., R-1 soils) when initially installed or following maintenance work in order to prevent excavation and inappropriate reuse of contaminated soil in the future.

Depending on site-specific conditions, permanent covers or caps for soil isolation areas may be constructed of paving materials such as asphalt and concrete ("hard cap") or earthen fill material ("soil cap") that meets R-1 (preferred) or R-2 action levels. A soil cap thickness of 24 inches is recommended for areas where landscaping activities may involve digging deeper than one foot or where gardens may be planted in the future (based on USEPA guidance for lead-contaminated soils, USEPA 2003). A cap of twelve inches may be acceptable in high-density residential redevelopments where gardens will not be allowed and use of the area will be strictly controlled. A clearly identifiable, marker barrier that cannot be easily penetrated with shovels or other handheld digging tools (e.g., orange construction fencing or geotextile webbing) should be placed between the contaminated soil and the overlying clean fill material. A similar marker barrier should be placed below or above gravel, concrete or other hard material placed on top of contaminated soil in order to avoid confusion with former building foundations or road beds.

Permeable marker barriers may be necessary in areas of high rainfall in order to prevent ponding of water during wet seasons. Leaching tests should be carried out on R-3 soils in order to evaluate potential impacts to groundwater (see discussion below).

When R-3 soils are identified at existing homes, removal or permanent capping of the soils should be strongly considered. In the interim, residents should follow the measures outlined for residential R-2 soils to minimize their daily exposure. Children should avoid areas of bare soil and regular work in garden areas.

Soil Categories and Action Levels for use at Commercial/Industrial Sites

Category 1 Soils (C-1): Bioaccessible Arsenic >4.2 mg/kg and ≤19 mg/kg, No Further Action

Long-term exposure to Category 1 (C-1) soils is not considered to pose a significant health risk to workers at commercial or industrial sites. Remediation of soil that exceeds action levels for residential, R-1 (preferred) or R-2 action levels, however, will minimize restrictions on future land use and should be considered when feasible. Note that this may require a more detailed sampling strategy than is typically needed for commercial/industrial properties (e.g., decision units 5,000 ft^2 in size or less). Long-term institutional controls to restrict use of property to commercial/industrial purposes may be required if the site will not be investigated to the level of detail required for future, unrestricted land use to ensure that action levels for Category 2 Residential soils are not exceeded

Category 2 Soils (C-2): Bioaccessible Arsenic >19 mg/kg and ≤95 mg/kg, Consider Removal or Isolation

Long-term exposure to Category 2 (C-2) soils is not considered to pose a significant risk to workers provided that lawns and landscaping are maintained to minimize exposure and control fugitive dust or if the soils. Remediation of commercial/industrial properties to action levels approaching those for C-1 soils or lower is recommended when technically and economically feasible, however, and should be discussed with the HEER office on a site-by-site basis. When selecting remedial options, long-term effectiveness should be given increasing weight as concentrations of bioaccessible arsenic approach the upper boundary for C-2 soils.

For new developments, isolation of C-2 soils under buildings, private roadways and other areas with a permanent cap that workers are unlikely to disturb in the future is recommended when feasible. Isolation of C-2 soils under public roadways should be done in coordination with the local transportation authority. Offsite reuse of C-2 soil as fill material should be avoided. Reuse of some or all of the soil as daily cover in a regulated landfill may be feasible, however. This should be discussed with the landfill in question as well as with the HDOH Solid and Hazardous Waste Branch. Areas of the property where capped or uncapped C-2 soil is located must be clearly identified on surveyed, post-redevelopment map(s) of the property and included in a risk management plan that is documented in the HDOH public file for the site (see "Identification of Soil Isolation Areas" below). Care must be taken to ensure that soil from these areas is not excavated and inadvertently reused in offsite areas where residents could be exposed on a regular basis. Utility corridors should be backfilled with clean fill material (e.g., R-1 soils) when initially installed or following maintenance work in order to prevent excavation and inappropriate reuse of contaminated soil in the future.

At existing facilities, areas of bare C-2 soils should be minimized by maintaining grass or other vegetative cover or by covering bare areas with gravel or pavement. Workers should be encouraged to maintain clean work areas and thoroughly wash hands before breaks and meals.

Category 3 Soils (C-3): Bioaccessible Arsenic >95 mg/kg, Removal or Isolation Recommended

Long-term exposure to Category 3 (C-3) soils is considered to pose potentially significant health risks to workers at commercial or industrial sites. Offsite disposal of C-3 soils is recommended when technically and economically feasible. Offsite disposal of soil with bioaccessible arsenic in excess of 180 mg/kg is especially recommended (action level for construction/trench work exposure). Soil that cannot be removed from the site should be placed in designated isolation areas under public buildings, private roadways, parking lots and other facilities/structures that constitute a permanent physical barrier that residents are unlikely to disturb in the future. Contaminated soil should be consolidated in as few isolation areas as possible. Areas of the property where C-3 soil is located must be clearly identified on surveyed, post-redevelopment map(s) of the property and included in a risk management plan that is documented in the HDOH public file for the site (see "Identification of Soil Isolation Areas" below). Care must be taken to ensure that soil from these areas is not excavated and inadvertently reused in offsite areas where residents could be exposed on a regular basis. Utility corridors should be backfilled with clean fill material (e.g., R-1 soils) in order to prevent inadvertent excavation and reuse of contaminated soil in other areas in the future.

As discussed for residential sites, isolation of contaminated soil under buildings or other permanent structures is preferred over isolation in open areas. If placement of the soil in an open area is necessary, use of areas that are unlikely to be disturbed in the future is preferred. A

minimum cap thickness of twelve inches is generally acceptable for commercial/industrial sites where use of the area will be strictly controlled (USEPA 2003). A clearly identifiable marker barrier should be placed between the contaminated soil and the overlying clean fill material (e.g., orange construction fencing or geotextile webbing). Fencing, geotextile fabric or similar, easily identifiable markers should likewise be placed above any gravel, concrete or other hard material placed on top of contaminated soil in order to avoid confusion with former building foundations or road beds.

Use of Total Arsenic Data

Based on data collected to date, it is possible that a significant portion of former sugar cane land situated in areas of high rainfall (e.g., >100 inches per year) will fall into the R-2 or C-2 soil categories as described above and summarized in Tables 1 and 2. Some of these areas have already been redeveloped for residential houses. Determination of bioaccessible arsenic levels on individual lots with existing homes may not be economically feasible for some residents (current analytical costs $500 to $1000). If site-specific, bioaccessible arsenic data is not affordable for a private homeowner, HDOH recommends that the soil be tested for total arsenic (generally less than $100). The resulting data should then be adjusted using a default *bioavailability* value to estimate bioavailable arsenic concentrations. Based on data collected to date in the Kea‘au area, a 10% bioavailability factor (BF) is recommended for total arsenic values at or below 250 mg/kg. Measured concentrations of total arsenic should be multiplied by 0.1 and the adjusted concentration compared to the action levels in Table 1 or Table 2. For total arsenic above 250 mg/kg, a more conservative bioavailability factor of 20% (0.2) is recommended.

For residential sites, this approach corresponds to an upper limit of 42 mg/kg total arsenic for R-1 soils and 230 mg/kg total arsenic for R-2 soils (10% BF used). For commercial/industrial sites, this corresponds to an upper limit of 190 mg/kg total arsenic for C-1 soils (10% BF used) and 475 mg/kg total arsenic for C-2 soils (20% BF used). Soils that potentially fall into Category 3 for residential or commercial/industrial sites should be tested for bioaccessible arsenic if at all possible. In the absence of bioaccessibility data, it is recommended that children avoid playing or working in gardens or other areas where total arsenic action levels indicate the potential presence of R-3 soils. The default bioaccessibility factors presented were developed based on data from the Kea‘au region and are subject to revision as more data becomes available.

The total arsenic action levels proposed above should not be used for general screening purposes at sites where a formal environmental investigation is being carried out. As previously discussed and as noted in the summary tables, bioaccessible arsenic data should be collected at all sites where total arsenic concentrations exceed an assumed background concentration of 20 mg/kg unless otherwise approved by HDOH.

Soil Sampling Methods

The use of multi-increment field soil sampling and lab sub-sampling techniques is recommended over the use of discrete or traditional composite sampling techniques. This sampling approach allows for the determination of a statistically representative concentration of arsenic within a specific area of investigation or “decision unit.”, such as an individual yard, a park, a garden or a well-defined spill area. Additional guidance on the use of multi-increment and decision unit investigation strategies will be provided in the 2008 update to the HEER office *Technical Guidance Manual.*

Other Potential Environmental Concerns

A discussion of environmental hazards associated with contaminated soil is provided in the HDOH document *Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater* (HDOH 2008a). The arsenic action levels presented in this technical memorandum address human-health, direct-exposure hazards only. The action levels do not address potential leaching of arsenic from soil and subsequent impacts to underlying groundwater or potential toxicity to terrestrial flora and fauna. These issues should be evaluated on a site-specific basis as directed by HDOH. Arsenic is not considered to pose significant vapor intrusion or gross contamination hazards.

Based on data collected to date, leaching of arsenic from former sugar cane fields is not anticipated to pose a significant concern in Hawai‘i due to the apparent, relative immobility of the arsenic. Additional field data are needed to support this assumption, however, particularly for soils that exceed the upper action level for R-2 residential soils (i.e., >23 mg/kg bioaccessible arsenic). HDOH recommends that potential leaching of arsenic from soils that exceed 23 mg/kg bioaccessible arsenic be evaluated using the USEPA Synthetic Precipitation Leaching Procedure (SPLP) test or a comparable method. Refer to the HDOH technical memorandum *Use of Laboratory Batch Tests to Evaluate Potential Leaching of Contaminants from Soil* for additional guidance (HDOH 2007).

Assessment of additional pesticides and pesticide-related contaminants in agricultural areas should be carried out as needed based on the past use of the property. Refer to the 2008 update of the HEER office *Technical Guidance Manual* for additional information on target pesticides.

Environmental Hazard Evaluation Plans

Isolation areas where arsenic-contaminated soil is to be capped for permanent onsite management must be clearly identified on surveyed, post-redevelopment map(s) of the property. Areas of soil at commercial/industrial sites that exceed action levels for residential R-1, R-2 and R-3 soils should also be clearly surveyed and mapped. The maps identifying arsenic-impacted soils should be incorporated into an *Environmental Hazard Evaluation Plan* (EHMP, HDOH 2008a) that describes proper management, reuse and disposal of contaminated soil if disturbed during later redevelopment activities. A copy of the plan should be submitted to both HDOH and to the agency(s) that grants permits for construction, trenching, grading or any other activities that could involve future disturbance or excavation of the soil. The need to incorporate the risk management plan and specific land use restrictions in a formal covenant to the property deed should be discussed with HDOH on a site-by-site basis. Additional guidance on EHMPs will be provided in the 2008 update to the HEER office *Technical Guidance Manual*.

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Table 1. Soil categories and recommended actions for Residential Sites.

Total Arsenic (≤ 2 mm size fraction)	**Action**
≤20 mg/kg	Within range of natural background. No further action required and no restrictions on land use.
>20 mg/kg	Exceeds typical background. Re-evaluate local background data as available. Test soil for bioaccessible arsenic if background is potentially exceeded.
Bioaccessible Arsenic (≤250µm size fraction)	**Action**
R-1 Soils (≤4.2 mg/kg)	No further action required and no restrictions on land use.
R-2 Soils (>4.2 but ≤23 mg/kg)	Within USEPA range of acceptable health risk. Consider removal and offsite disposal of small, easily identifiable "hot spots" when possible in order to reduce potential exposure (not required for large, former field areas). Use of soil as daily cover at a regulated landfill may also be possible. For existing homes, consider measures to reduce daily exposure to soil (e.g., maintain lawn cover, ensure good hygiene, thoroughly wash homegrown produce, etc.). For new developments on large, former field areas, notify future homeowners of elevated levels of arsenic on the property (e.g., include in information provided to potential buyers during property transactions).
R-3 Soils (>23 mg/kg)	For existing homes, removal or onsite isolation of exposed soil is strongly recommended. Consider a minimum one-foot cover of clean fill material (two feet in potential garden areas) if soil cannot be removed. An easily identifiable marker barrier should be placed between the contaminated soil and the overlying fill (e.g., orange construction fencing or geotextile/geonet material). In the interim, take measures to reduce daily exposure to soil (e.g., maintain lawn cover, ensure good hygiene, thoroughly wash homegrown produce, etc.). Children should avoid areas of bare soil and regular work in gardens areas. For new residential developments, removal and offsite disposal of soil should be strongly considered. At a minimum, consider removal and offsite disposal of soil with concentrations of bioaccessible arsenic that approach or exceed 180 mg/kg (direct exposure action level for construction and trench workers). Use of soil as daily cover at a regulated landfill may be possible if concentrations of bioaccessible arsenic meet C-2 commercial/industrial soil criteria. If offsite disposal is not feasible but redevelopment of the property is still desired, consider use of soil as structural fill under public buildings, parking lots, private roads, or other paved and well-controlled structures. If capping in open areas is unavoidable, consider a one-foot minimum cap thickness with an easily definable marker barrier placed between the soil and the overlying clean fill (e.g., orange construction fencing or geotextile fabric). Capping of R-3 soils on newly developed, private lots is not recommended due to difficulties in ensuring long-term management of the soil. Backfill utility corridors with clean fill material (e.g., R-1 soils) to avoid excavation and inappropriate reuse of the soil in the future.

Table 1. Soil categories and recommended actions for Residential Sites (cont.).

R-3 Soils (cont.) (>23 mg/kg)	Require formal, long-term institutional controls to ensure appropriate management of soil in the future (e.g., Covenants, Conditions and Restrictions (CC&Rs), deed covenants, risk management plans, etc.). All areas of capped soil should be delineated on a surveyed map of the property to be subsequently included in the risk management plan.

The soil categories and arsenic action levels noted above are intended to be used as guidelines only and do not represent strict, regulatory cleanup requirements.

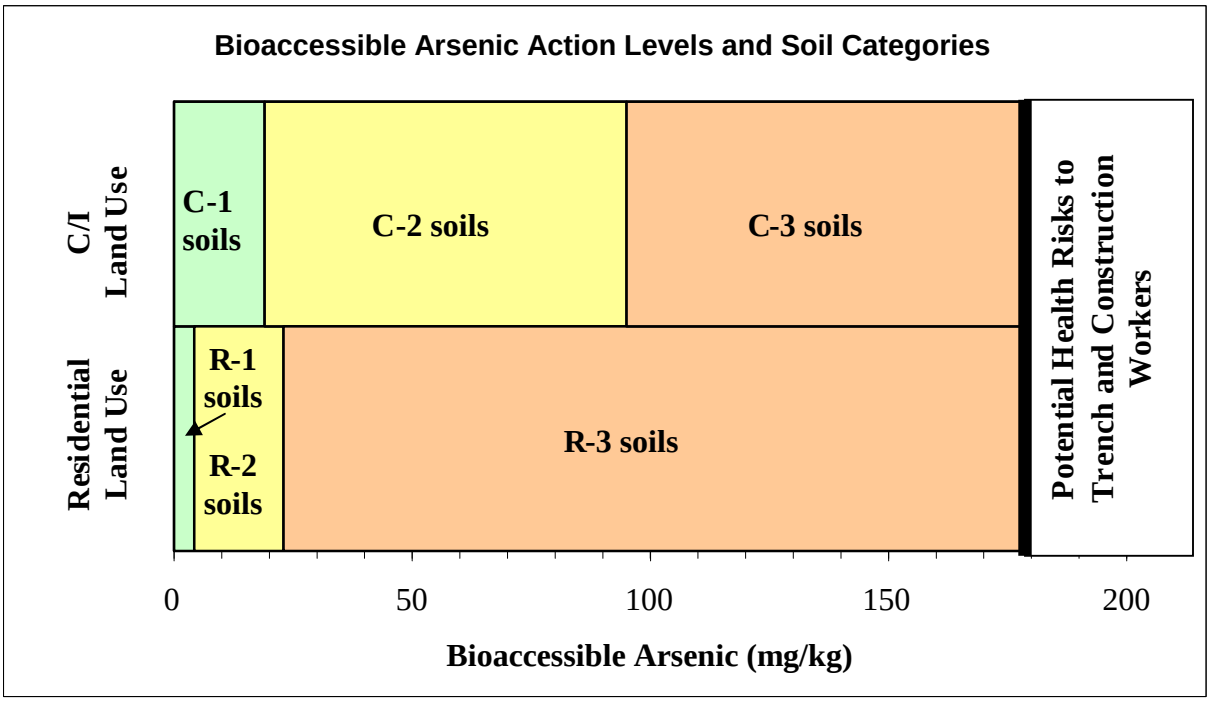
Table 2. Soil categories and recommended actions for Commercial/Industrial Sites.

Total Arsenic (≤ 2 mm size fraction)	**Action**
≤20 mg/kg	Within range of natural background. No further action required and no restrictions on land use.
>20 mg/kg	Exceeds typical background. Re-evaluate local background data as available. Test soil for bioaccessible arsenic if background is potentially exceeded.
Bioaccessible Arsenic (≤250µm size fraction)	**Action**
C-1 Soils (>4.2 mg/kg but ≤19 mg/kg)	No remedial action required. However, consider remediation of commercial/industrial properties to meet Residential R-1 (preferred) or R-2 action levels when feasible in order to minimize restrictions on future land use. Note that this may require a more detailed sampling strategy than typically needed for commercial/industrial properties (e.g., smaller decision units). Require formal, long-term institutional controls to restrict use of property to commercial/industrial purposes if the site will not be investigated to the level of detail required for future, unrestricted land use (i.e., inform potential buyers, deed covenants, risk management plans, etc.).
C-2 Soils (>19 but ≤95 mg/kg)	Remedial actions vary depending on site-specific factors, including current and planned use, available options for onsite isolation or offsite disposal, and technical and economical constraints (see text). Potential actions include: Consider removal and offsite disposal of small, easily identifiable "hot spots" when possible in order to reduce the average concentration of bioaccessible arsenic on the property. Use of C-2 soils as daily cover at a regulated landfill may also be possible. For sites that have already been developed, consider a minimum one-foot cover of clean fill material if the soil cannot be removed. If capping of soil is not feasible, consider measures to reduce daily exposure to soil (e.g., maintain lawn cover, ensure good hygiene, etc.). For new developments, consider isolation of soil under buildings, private roads or other permanent structures if technically and economically feasible. If isolation under permanent structures is not feasible, consider a minimum one-foot cover of clean fill material. Maintain landscaping and lawns in open areas where soil will not be capped. Backfill utility corridors with clean fill material (e.g., R-1 soils) to avoid excavation and inappropriate reuse of contaminated soil in the future. Require formal, long-term institutional controls to restrict use of site to commercial/industrial purposes only and ensure appropriate management of soil if exposed in the future (e.g., inform potential buyers, deed covenants, risk management plans, etc.). All areas of capped soil should be delineated on a surveyed map of the property to be subsequently included in the risk management plan.

Table 2. Soil categories and recommended actions for Commercial/Industrial Sites (cont.).

C-3 Soils (>95 mg/kg)	Removal of soil at existing commercial/industrial sites strongly recommended. At a minimum, consider removal and offsite disposal of soil with concentrations of bioaccessible arsenic that approach or exceed 180 mg/kg (direct exposure action level for construction and trench workers). If C-3 soils cannot be removed for technical or economic reasons, consider a minimum one-foot cover of clean fill material (two feet in potential deep landscaping areas) and placement of an easily identifiable marker barrier between the clean fill and the underlying soil (e.g., orange construction fencing or geotextile/geonet material). For new developments, removal and offsite disposal of soil should be strongly considered. At a minimum, consider removal and offsite disposal of soil with concentrations of bioaccessible arsenic that approach or exceed 180 mg/kg (direct exposure action level for construction and trench workers). If offsite disposal is not feasible but redevelopment of the property is still desired, consider use of soil as structural fill under public buildings, private roads, or other paved and well-controlled structures. If capping in open areas is unavoidable, consider a one-foot minimum cap thickness with an easily definable marker barrier placed between the soil and the overlying clean fill (e.g., orange construction fencing or geotextile/geonet material). Backfill utility corridors with clean fill material (e.g., R-1 soils) to avoid excavation and inappropriate reuse of contaminated soil in the future. Require formal, long-term institutional controls to ensure appropriate management of soil in the future (e.g., inform potential buyers, deed covenants, risk management plans, etc.). All areas of capped soil should be delineated on a surveyed map of the property to be subsequently included in the risk management plan.

The soil categories and arsenic action levels noted above are intended to be used as guidelines only and do not represent strict, regulatory cleanup requirements.



Residential Land Use Soil Categories		Commercial/Industrial Land Use Soil Categories	
R-1	≤4.2 mg/kg	C-1	≤19 mg/kg
R-2	>4.2 mg/kg to ≤23 mg/kg	C-2	>19 mg/kg to ≤95 mg/kg
R-3	>23 mg/kg	C-3	>95 mg/kg
>180 mg/kg: Potential risk to trench & construction workers			

Figure 1. Summary of bioaccessible arsenic action levels and correlative soil categories for residential and commercial/industrial (C/I) land-use scenarios.

ATTACHMENT 2

ESTIMATED DIETARY INTAKE
OF TOTAL AND INORGANIC ARSENIC FOR PACIFIC-ASIAN DIETS

Dietary Exposure to Arsenic

A review of dietary exposure to total and inorganic arsenic was carried out by estimating daily consumption of the following food groups and typical concentrations of arsenic associated with each group:

- cereals & cereal products;
- starch roots and tubers;
- sugars and syrups;
- fats and oils;
- fish, meat and poultry;
- eggs;
- milk and products;
- dried beans, nuts and seeds;
- vegetables;
- fruits; and
- miscellaneous (beverages, condiments, etc.).

Consumption rates of each food group in a typical Filipino diet were compiled based on information published by the Philippine government and used as a surrogate for a typical Pacific-Asian diet (FNRI 2003, see Tables 1 and 2). Data are provided for children (ages 1-5) and the population as a whole (essentially adults). The data are provided for "As Purchased" food (e.g., raw vegetables, uncooked rice, etc.). A summary of the data is provided in Table 1.

Typical concentrations of inorganic and total arsenic in each food group were taken from a study of dietary exposure to arsenic in US children (Schoof et al. 1999, as presented in Yost et al. 2004; refer to Table 2). The data are based on prepared food (i.e., cooked meats and vegetables, including rice). While this is unlikely to introduce significant bias for meats and raw vegetables, the arsenic data for cooked rice cannot be directly compared to consumption data for uncooked rice. As an alternative, the estimated concentration of arsenic in rice is based on the average of 11 types of uncooked rice tested in a separate study (Williams et al 2005, as presented in Juhasz et al. 2006; refer to Table 1). Estimated concentrations of inorganic and total arsenic in seaweed was taken from a study carried out by the United Kingdom Food Standards Agency (UKFSA 2004).

The estimated daily, dietary intake of total arsenic is summarized in Figure 1. The estimated daily intake of inorganic arsenic is summarized in Figure 2. For children age one to five, the average exposure to dietary inorganic arsenic is estimated to be 18 ug/day, with 95% of the arsenic coming from rice. For the mean population (assumed representative of adults in general), the average exposure to dietary inorganic arsenic is estimated to be 44 ug/day, with a similar proportion of the arsenic coming from rice.

Dietary total arsenic is significantly higher, due primarily to the anticipated high consumption of fish and seaweed and the relatively high levels of organic arsenic in these foods. As noted in Table 1 and Figure 1, the average dietary total arsenic for children ages 1-5 is estimated to be 176 ug/day and for the mean population 339 ug/day. The

consumption of fish provides approximately 75% of the total dietary arsenic, with the remainder of the total arsenic contributed by rice and seaweed (Nori seaweed assumed). Although organic arsenic is not considered to be significantly toxic, metabolism to DMA could complicate interpretation of the urine data collected for the target Filipino population.

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Table 1. Estimation of dietary exposure to total arsenic for a typical Filipino diet (surrogate for Pacific-Asian diet).

				Child (6mo-5yr)		Mean Population			
Food Group	**[1]Child Consumption (g/d)**	**[1]Mean Consumption (g/d)**	**Total Arsenic (ug/kg)**	**Daily Dose (ug/d)**	**Percent Total Arsenic Contribution**	**Daily Dose (ug/d)**	**Percent Total Arsenic Contribution**	**[2]Reference**	**Comments**
Cereals	**166**	**364**		**27.09**	**15.40%**	**65.4**	**19.28%**		
Rice & Products	122	303	208	25.4	14.42%	63	18.58%	Williams et al 2005	*in* Juhasz et al 2006
Corn and Products	17	31	38.6	0.66	0.37%	1.20	0.35%	Yost et al., 2004	
Other Cereals and Products	27	30	39.2	1.06	0.60%	1.18	0.35%	Yost et al., 2004	flour
Starch Roots and Tubers	**8**	**19**	**2.8**	**0.02**	**0.01%**	**0.05**	**0.02%**	Yost et al., 2004	potatoes
Sugars and Syrups	**15**	**24**	**23.8**	**0.36**	**0.20%**	**0.57**	**0.17%**	Yost et al., 2004	cane sugar
Fats and Oils	**6**	**18**	**1.8**	**0.01**	**0.01%**	**0.03**	**0.01%**	Yost et al., 2004	butter
Fish, Meat & Poultry	**95**	**185**		**135.61**	**77.08%**	**247.58**	**73.00%**	Yost et al., 2004	
Fish and Products	57	104	2356	134.29	76.34%	245.02	72.25%	Yost et al., 2004	Saltwater fish (Freshwater = 160 ug/kg)
Meat and Products	27	61	13.5	0.36	0.21%	0.82	0.24%	Yost et al., 2004	pork
Poultry and Products	11	20	86.40	0.95	0.54%	1.73	0.51%	Yost et al., 2004	chicken
Eggs	**8**	**13**	**0.98**	**0.01**	**0.00%**	**0.01**	**0.00%**	Yost et al., 2004	
Milk and Products	**179**	**49**		**0.39**	**0.22%**	**0.11**	**0.03%**	Yost et al., 2004	
Whole Milk	158	35	2.2	0.35	0.20%	0.08	0.02%	Yost et al., 2004	
Milk Products	21	14	2.2	0.05	0.03%	0.03	0.01%	Yost et al., 2004	
Dried Beans, Nuts & Seeds	**4**	**10**	**43.7**	**0.17**	**0.10%**	**0.44**	**0.13%**	Yost et al., 2004	
Vegetables	**23**	**111**		**12.08**	**6.87%**	**24.65**	**7.27%**	Yost et al., 2004	
Green Leafy & Yellow	10	31	6.1	0.06	0.03%	0.19	0.06%	Yost et al., 2004	spinach
Other Vegetables	3	80	5.8	0.02	0.01%	0.46	0.14%	Yost et al., 2004	average all other vegetables
Seaweed	0.5	1	24,000	12.00	6.82%	24.00	7.08%	UKSFA 2004	nori seaweed (1/2 MRL of 0.3 mg/kg)
Fruits	**31**	**54**		**0.16**	**0.09%**	**0.26**	**0.08%**	Yost et al., 2004	
Vitamin C-rich Fruits	4	12	2.5	0.01	0.01%	0.03	0.01%	Yost et al., 2004	oranges
Other Fruits	27	42	5.5	0.15	0.08%	0.23	0.07%	Yost et al., 2004	average all other fruits
Miscellaneous	**27**	**39**		**0.02**	**0.01%**	**0.03**	**0.01%**	Yost et al., 2004	
Beverages	26	26	0.8	0.02	0.01%	0.02	0.01%	Yost et al., 2004	tapwater used in cooking
Condiments & Others	1	13	0.8	0.001	0.0005%	0.01	0.003%	Yost et al., 2004	salt
Total Food Consumption:	562	886	**Total:**	**176**	**100.0%**	**339**	**100.0%**		

1. FNRI, 2003. Child = Average 6mo to 5 yrs. "As Purchased," cereals presumable dry weight.

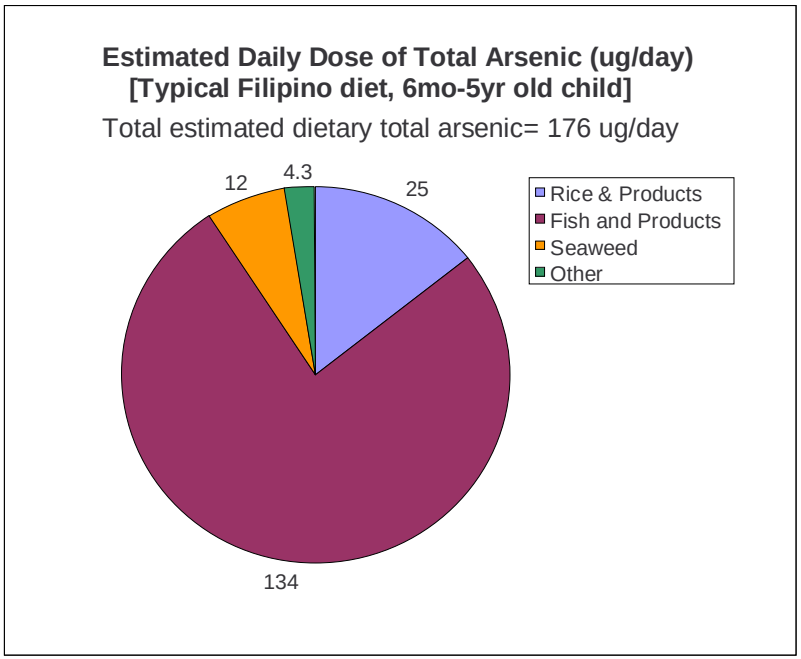
2. See text for full reference.

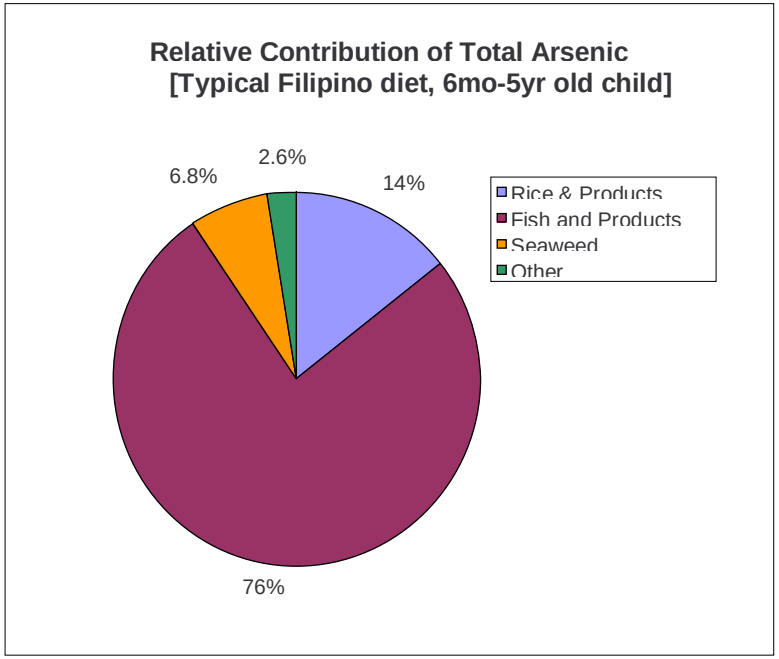
Table 2. Estimation of dietary exposure to inorganic arsenic for a typical Filipino diet (surrogate for Pacific-Asian diet).

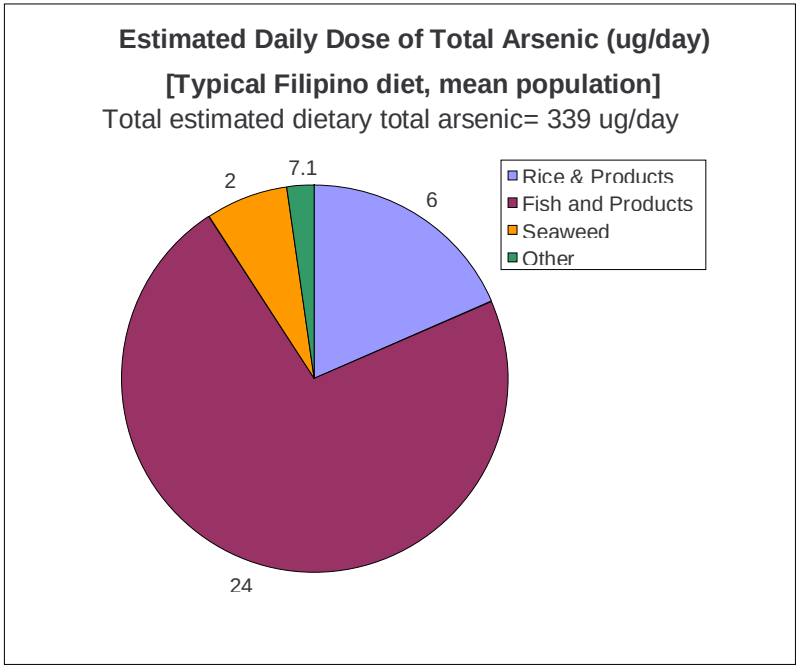
				Child (6mo-5yr)		Mean Population			
Food Group	**[1]Child Consumption (g/d)**	**[1]Mean Consumption (g/d)**	**Inorganic Arsenic (ug/kg)**	**Daily Dose (ug/d)**	**Percent Inorganic Arsenic Contribution**	**Daily Dose (ug/d)**	**Percent Inorganic Arsenic Contribution**	**Reference**	**Comments**
Cereals	**166**	**364**		**17.33**	**96.6%**	**42.6**	**97.5%**		
Rice & Products	122	303	139.0	17.0	94.6%	42	96.4%	Williams et al 2005	*in* Juhasz et al 2006
Corn and Products	17	31	4.4	0.07	0%	0.14	0%	Yost et al., 2004	
Other Cereals and Products	27	30	10.9	0.29	2%	0.33	1%	Yost et al., 2004	flour
Starch Roots and Tubers	**8**	**19**	**0.8**	**0.01**	**0.0%**	**0.02**	**0.0%**	Yost et al., 2004	potatoes
Sugars and Syrups	**15**	**24**	**4.4**	**0.07**	**0%**	**0.11**	**0.2%**	Yost et al., 2004	cane sugar
Fats and Oils	**6**	**18**	**1.2**	**0.01**	**0.0%**	**0.02**	**0.0%**	Yost et al., 2004	butter
Fish, Meat & Poultry	**95**	**185**		**0.08**	**0.5%**	**0.16**	**0.4%**	Yost et al., 2004	
Fish and Products	57	104	1.0	0.06	0.3%	0.10	0.2%	Yost et al., 2004	Saltwater fish (Freshwater = 160 ug/kg)
Meat and Products	27	61	0.67	0.02	0.1%	0.04	0.1%	Yost et al., 2004	pork
Poultry and Products	11	20	0.89	0.01	0.1%	0.02	0.0%	Yost et al., 2004	chicken
Eggs	**8**	**13**	**0.98**	**0.01**	**0.0%**	**0.01**	**0.0%**	Yost et al., 2004	
Milk and Products	**179**	**49**		**0.18**	**1.0%**	**0.05**	0.1%	Yost et al., 2004	
Whole Milk	158	35	1.0	0.16	0.9%	0.04	0.1%	Yost et al., 2004	
Milk Products	21	14	1.0	0.02	0.1%	0.01	0.0%	Yost et al., 2004	
Dried Beans, Nuts & Seeds	**4**	**10**	**4.7**	**0.02**	**0.1%**	**0.05**	**0.1%**	Yost et al., 2004	
Vegetables	**23**	**111**		**0.14**	**0.8%**	**0.54**	**1.2%**	Yost et al., 2004	
Green Leafy & Yellow	10	31	6.1	0.06	0.3%	0.19	0.4%	Yost et al., 2004	spinach
Other Vegetables	3	80	2.6	0.01	0.0%	0.21	0.5%	Yost et al., 2004	average all other vegetables
Seaweed	0.5	1	150	0.08	0.4%	0.15	0.3%	UKSFA 2004	nori seaweed (1/2 MRL of 0.3 mg/kg)
Fruits	**31**	**54**		**0.07**	**0.4%**	**0.12**	**0.3%**	Yost et al., 2004	
Vitamin C-rich Fruits	4	12	2.5	0.01	0.1%	0.03	0.1%	Yost et al., 2004	oranges
Other Fruits	27	42	2.1	0.06	0.3%	0.09	0.2%	Yost et al., 2004	average all other fruits
Miscellaneous	**27**	**39**		**0.02**	**0.1%**	**0.03**	**0.1%**	Yost et al., 2004	
Beverages	26	26	0.8	0.02	0.1%	0.02	0.0%	Yost et al., 2004	tapwater used in cooking
Condiments & Others	1	13	0.8	0.001	0.00%	0.01	0.02%	Yost et al., 2004	salt
Total Food Consumption:	562	886	**Total DD:**	**18**		**44**			

1. FNRI, 2003. Child = Average 6mo to 5 yrs. "As Purchased," cereals presumable dry weight.

2. See text for full reference.







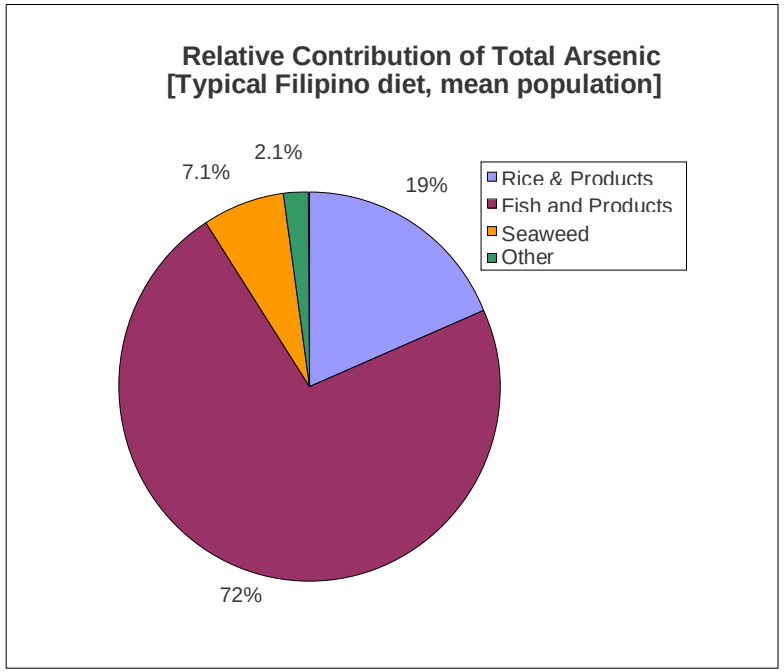


Figure 1. Estimated total arsenic intake based on a typical Filipino diet (surrogate for Pacific-Asian diet, refer to Table 1).

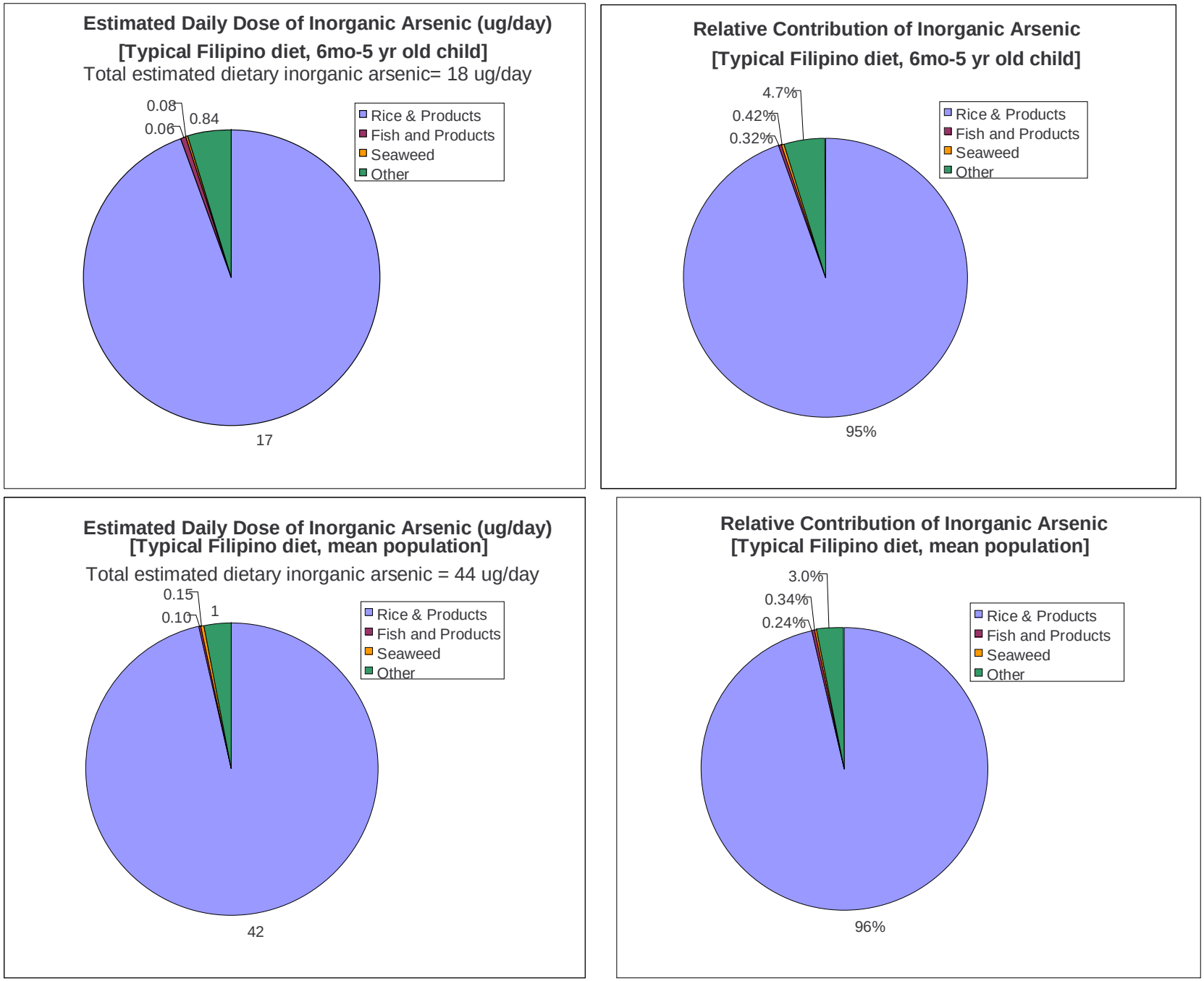


Figure 2. Estimated inorganic arsenic intake based on a typical Filipino diet (surrogate for Pacific-Asian diet, refer to Table 2).

APPENDIX 9-F

UPDATE TO SOIL ACTION LEVELS FOR TEQ DIOXINS AND RECOMMENDED SOIL MANAGEMENT PRACTICES

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In reply, please refer to:
File: EHA/HEER Office
2010-389-RB

June 2010

To: Interested Parties

From: Roger Brewer, Ph.D., Environmental Risk Assessor, HEER RB

Through: Barbara Brooks, Ph.D., Toxicologist, HEER BB

Subject: Update to Soil Action Levels for TEQ Dioxins and Recommended Soil Management Practices

1.0 Introduction

This technical memorandum presents an update to Hawai'i Department of Health (HDOH) action levels and corresponding guidance for dioxins and furans ("dioxins") in soil. This guidance serves as an addendum to the Hazard Evaluation and Emergency Response (HEER) office document *Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater* (EHE guidance; HDOH 2008a). A summary of the updated action levels and soil management categories is provided in Table 1. A detailed discussion of the development and support of the action levels is provided in Attachment 1 (Supplemental Information), Attachment 2 (Exposure Models) and Attachment 3 (Dietary Exposure to Dioxins).

This guidance supersedes and takes precedence over a technical memorandum on dioxins published by the HEER office in June 2008 and incorporated into the EHE guidance (HDOH 2008b). This memo also presents a modification of the HEER office soil categorization system, based on updates to dioxin action levels and a simplified approach for classification and management of dioxin-contaminated soils. The soil action levels presented herein are not promulgated regulatory standards or required cleanup levels. Alternative proposals may be presented in a site-specific risk assessment. However, the nature of the toxicity factors and exposure assumptions used to in this update are unlikely to allow significant flexibility for less stringent, site-specific action levels in the absence of institutional and/or engineering controls.

The soil action levels presented in this document are intended for comparison to soil data obtained through collection of multi-increment ("incremental") soil samples, as described in the HEER office *Technical Guidance Manual* (HDOH 2009). When combined with *Decision Unit* investigation approaches, multi-increment soil samples offer a more cost-effective and efficient

approach for characterization of a targeted area or volume of soil than traditional, discrete sample approaches. Studies have shown that a small number (e.g., less than <30) of discrete samples is unlikely to adequately capture contaminant heterogeneity and small "hot spots" of elevated contaminant concentrations within a targeted area (e.g., Ramsey et. al. 2005; Jenkins et al. 2005). This can lead to an underestimate of exposure point concentrations for risk assessment purposes, as well as an underestimate of contaminant mass for *in situ* or *ex situ* treatment. Alternative soil sampling schemes should be discussed with the HEER office on a site-by-site basis.

2.0 Updated HDOH TEQ Dioxin Soil Action Levels

The updated Toxicity Equivalent (TEQ) dioxin soil action levels are as follows:

2010 HDOH TEQ Dioxin Soil Action Levels	
≤240 ng/kg	No significant risk to human health under unrestricted (e.g., residential) land use.
≤1,500 ng/kg	No significant risk to human health under commercial/industrial land use (also used as the construction/trench worker action level).

As discussed in Attachments 1-3, the development and justification of the updated soil action levels are based on the following multiple lines of evidence:

- Predominance of less-toxic forms of dioxins in soil (tetrachlorodibenzo-*p*-dioxin or TCDD, generally <<1%);
- Reduced relative bioavailability of dioxins in soil in comparison to published toxicity studies (assumed 60%);
- Uncertainty in published and proposed cancer slope factors and noncancer reference doses for TCDD;
- HDOH preference for the World Health Organization (WHO) body burden approach to evaluate potential health risks posed by chronic exposure to dioxins;
- Comparability of WHO Permissible Tolerable Intake factors for TEQ dioxins to published and draft toxicity factors for health risks published by the U.S. Environmental Protection Agency (USEPA) and other parties;
- Use of WHO Toxicity Equivalent Factors to estimate health risks from non-TCDD dioxins and furans;
- Consideration of typical dietary intake of dioxins with respect to theoretical risk posed by exposure to soil;
- Lack of a significant, added health benefit from the use of lower action levels to further reduce exposure to dioxins in soil;
- HDOH's acknowledgment that remediation of large tracts of agricultural lands where trace levels of dioxins associated with the past use of pentachlorophenol and other agricultural practices have been identified is impractical and unnecessary from a health risk perspective; and

- Recommendation to remediate localized spill areas of heavy dioxin contamination to surrounding background when feasible rather than reliance on purely risk-based action levels.

The updated action levels are used in Section 3 of this technical memorandum to redefine the soil management categories originally presented in the 2008 HEER guidance. Reduction of the soil action level for unrestricted land use from 450 ng/kg, as presented in the 2008 HEER guidance, to 240 ng/kg is not considered to be a significant change from the standpoint of potential risk to human health. HEER does not foresee the need to reopen cases closed under the 2008 action levels or require additional sampling at sites where investigations carried out under the previous guidance have already been completed. For isolated spill areas at sites where remedial action plans have not been finalized or completed, however, parties are encouraged to include *all* soil contaminated above surrounding background in remedial actions to the extent practicable (refer to Section 4).

3.0 Dioxin Soil Management Categories

Updated categories for the evaluation and management of dioxin-contaminated soil are summarized below and summarized in Table 1. These categories replace the scheme presented in the 2008 HEER guidance:

Category A Soils (natural background): Soils exhibit concentrations of TEQ dioxins <20 ng/kg, and do not appear to have been impacted by local, agricultural or industrial releases of dioxin. These soils represent "background" dioxin levels in the absence of agricultural or industrial impacts. Data on dioxins in native, un-impacted soils in Hawai‘i are limited, especially when compared to data on metals (e.g., arsenic). However, based on recent investigations overseen by HEER, the background level of TEQ dioxins in soils in Hawai‘i that have not been impacted by modern agricultural or industrial activities appears to be <20 ng/kg.

Category B Soils (minimally impacted): Soils exhibit concentrations of TEQ dioxins between 20 ng/kg and 240 ng/kg, indicating anthropogenic impacts at levels that are detectable but not considered harmful. HEER expects Category B soils to be generally associated with agricultural fields where dioxin-bearing pesticides were routinely applied in the past. Dioxin levels measured in soils in former agricultural fields range from <20 ng/kg to 100 ng/kg, and up to 200 ng/kg in some areas. HEER believes these dioxins typically represent residues of past applications of pentachlorophenol as an herbicide in sugarcane fields although burning of the fields may have also contributed. At most sites, the pentachlorophenol has degraded to below detectable levels, leaving behind a low-level residue of dioxins. For further discussion, see Section 9 in the HEER *TGM* (HDOH 2009).

Category C Soils (moderately impacted): Soils exhibit concentrations of TEQ dioxins between 240 ng/kg and 1,500 ng/kg. Category C soils are exemplified by contamination at former pesticide storage and mixing areas that included the use of pentachlorophenol and similar pesticides. Soils associated with burn pits or impacted by incinerator ash are also likely to fall into this category.

Category D Soils (heavily impacted): Soils have dioxin concentrations exceeding 1,500 ng/kg. Category D soils are exemplified by heavy contamination at former pesticide mixing areas associated with the use of pentachlorophenol. Concentrations of TEQ dioxins in soil between 10,000 ng/kg and 100,000 ng/kg are not uncommon, with concentrations up to 1,000,000 ng/kg reported at some facilities (>500 mg/kg total dioxins/furans). Pentachlorophenol is typically present at significantly lower concentrations or even below laboratory reporting limits.

4.0 Management of Dioxin-Contaminated Soils

HEER offers the following observations and recommendations for the short-term and long-term management of dioxin-contaminated soil, based on experience with past dioxin response sites.

4.1 Site Characterization

Long-term management of soil with greater than 240 ng/kg TEQ dioxins (or other, approved action levels) will be required at all sites where treatment or removal of this soil is not carried out. Investigation of the site should characterize the lateral and vertical extent of soil contaminated above this action level to the extent practicable, regardless of the current land use of the site, unless otherwise approved by HEER. This includes the need to identify and include Category B soils at commercial/industrial sites in an *Environmental Hazard Management Plan* prepared for that property, even though these soils do no pose a significant health risk to site workers. This will help ensure that the soil is not inadvertently excavated and reused at a more sensitive, offsite location during future subsurface or redevelopment work (e.g., reuse as fill material for a school yard). Potential disposal and management requirements under State and USEPA hazardous waste regulations must also be evaluated and documented.

4.2 Remedial Options

Remedial options typically considered at dioxin response sites are, in order of descending preference, **treatment**, **off-site disposal**, **engineered controls** and **institutional controls**.[1] As discussed in Section 4.3, the added cost of long-term management and potential liability for inappropriate exposure or reuse of the soil in the future should be taken into consideration in the selection of a final remedy.

4.2.1 Treatment

In situ or *ex situ* thermal treatment is considered to be the state-of-the-art method for the destruction of dioxins in contaminated soils, although numerous other remedial options have also

[1] State regulations list remedial options for contaminated soils in the following order of descending preference, to the extent practicable: (a) reuse or recycling; (b) destruction or detoxification; (c) separation, concentration, or volume reduction, followed by reuse, recycling, destruction or detoxification of the residue; (d) immobilization; (e) on-site or off-site disposal, isolation, or containment at an engineered facility in accordance with applicable requirements; and (f) institutional controls or long term monitoring [Hawai‘i Administrative Rules 11-451-8(c)(2)].

been proposed (e.g., Haglund 2007, Kulkarni 2008). The number of companies and facilities that offer thermal treatment is very limited, however, and the cost of thermal treatment can far exceed the short-term costs for other remedial options. For example, the cost to excavate and ship 5,000+ tons of dioxin-contaminated soil from a former pesticide mixing area (PMA) site on O'ahu to treatment facilities in North America was recently estimated to exceed $3,000/ton. *In situ* thermal treatment of the soil was estimated to approach $1,000/ton. The initial cost to construct an engineered cap over the soil is approximately one-tenth of the total cost for *in situ* treatment.

Treatment of Category D, dioxin-contaminated soil will, in many cases, only be feasible as part of large-scale redevelopment projects that can generate adequate capital funds for this option, e.g., by amortization of cleanup cost, concessions on the land purchase price and/or marginal increases in sales prices of new homes. Capping of the soil at currently unused sites will be necessary in many cases (see *Engineered Controls*). If so, the soil should be capped in an area that will remain accessible for possible removal or *in situ* treatment should cheaper, on-island alternatives come become available in the future (e.g., under parking lots or other open areas, versus under a permanent building). This will allow the property owner and/or responsible party to access and treat the soil in order if they so desire, in order to remove liabilities and depreciation in property value posed by continued long-term management of the soil.

4.2.2 Disposal

Disposal of dioxin-contaminated soil in a permitted landfill is a potentially cost-effective option for remediation of isolated spill areas. As discussed in Section 4.4, however, dioxin-contaminated soil must be evaluated for potential Resource Conservation and Recovery Act (RCRA) Subtitle C hazardous waste restrictions prior to disposal. If the soil is determined to be a hazardous waste, then it cannot be disposed of in a local landfill. If the soil is determined to not be a hazardous waste, then it may be disposed in a municipal landfill or construction & demolition debris landfill, contingent upon acceptance by the landfill operator. Municipal landfills may also be reluctant to accept heavily contaminated soil for disposal due to worker exposure and future liability concerns.

4.2.3 Engineered Controls

The risk posed by dioxin-contaminated soils can be addressed via on-site construction of a physical barrier (a "cap") to protect the public and the environment from exposure. Containment-based remedies require long-term maintenance and monitoring to ensure the continued integrity of the cap and effectiveness of the remedy. Protocols for long-term management should be included in an *Environmental Hazard Management Plan* prepared for the site, as described in the HEER *Technical Guidance Manual* (HDOH 2009). Specific cap designs will vary depending on site-specific conditions and redevelopment plans.

A clearly identifiable marker barrier (e.g., orange plastic construction fencing) is generally placed between the contaminated soil and the overlying clean fill material. HEER also recommends that a grid of durable, detectable (metallic) and labeled underground warning tape

be placed on top of dioxin-contaminated soils as part of a long-term cap. Similar to the procedures used when burying natural gas pipelines, warning messages and contact information should be printed on the warning tape, for example: "**CAUTION – STOP DIGGING! DIOXIN-CONTAMINATED SOIL BELOW! CONTACT _____ at _____ FOR FURTHER INFORMATION**." The cost for this type of customized warning tape is approximately $200 per 1,000-foot roll; and is available from Safety Systems of Hawai'i among other vendors.

As discussed above, it is preferable that heavily contaminated soil be capped in an area that will allow access for removal or *in situ* treatment in the future should cheaper, on-island alternatives become available. For additional information, consult the HEER *Technical Guidance Manual* (HEER 2009) and contact HEER staff. HEER plans to update its capping guidance in the near future based on experience gained from current studies.

4.2.4 Institutional controls

Dioxin-contaminated sites may be addressed by the use of institutional controls (ICs) to protect the public and the environment from exposure. For example, use of the property for residences, schools, day care, medical facilities or other sensitive purposes can be restricted in a formal covenant to the deed. Excavation in contaminated areas or reuse of soil from the site without the express consent of HDOH can also be prohibited. Additional information on institutional controls is provided in the HEER *Technical Guidance Manual* (HEER 2009).

4.3 Management of Category C Soils at Commercial/Industrial Sites

Category C soils are not considered to pose health risks under commercial/industrial land use but could pose potential risks under residential or other sensitive land uses. Long-term management of these soils is therefore required if left in place at a commercial/industrial site. Specific issues associated with the long-term management of Category C soils are discussed below.

4.3.1 Include Institutional Controls in EHMPs

Category C soils can be managed in place at commercial/industrial sites with minimal engineering controls provided that care is taken to prevent offsite movement of the soils via windblown dust, storm water runoff and other processes. As discussed in above, however, a potential exists for the inadvertent excavation of these soils, transport to unrestricted/residential land use areas (e.g., schools or residential areas) and reuse of these soils as fill material in areas where the soil could then pose a health risk. Institutional controls should, therefore, be included as one part of the *Environmental Hazard Management Plan* prepared for a commercial/industrial site where Category C soils are left in place.

4.3.2 Include Soil Above Surrounding Background in Remediation of Category D Soils

From a purely risk assessment standpoint, redevelopment of a heavily contaminated site for commercial/industrial purposes only requires remediation of Category D soils, although Category C soils must be managed properly. The boundary between localized "hot spots" of

heavily contaminated soil and the surrounding soils is typically very sharp, however, with a rapid drop off in contaminant concentrations to background (i.e., <20 ng/kg for non-agricultural soils and 20-100 ng/kg for former field areas). The additional area and volume of marginally impacted soil that lies at the margins of the heavily contaminated area will, in many instances, be relatively minor. The inclusion of *all* soil contaminated by the release above the surrounding background in remediation actions is therefore recommended, to the extent practicable, even though the marginally contaminated soil may not pose a significant risk to future users of the site under commercial/industrial land use.

At sites where Category D soils are to be addressed via treatment, disposal, or containment, HEER recommends that the same remedy be used for the full area and volume of soil that is clearly above background for the surrounding area to the extent practicable, for the following reasons:

1. **The added cost of addressing less contaminated soils along with heavily contaminated soils is anticipated to be relatively small.** As described above, sites characterized by isolated spill areas of highly-contaminated soils are typically sharply defined. An expansion of the boundary of the remediation area to include Category C and even Category B soils that are clearly above the surrounding background may significantly increase the long-term reliability of the remedy without an excessive increase in short-term remediation cost and decrease the cost and liability associated with long-term management of the site.

2. **Engineered and institutional controls can be more expensive than initially estimated.** Low up-front capital costs for on-site, long-term management of moderately contaminated soil can mask costs associated with long-term maintenance and oversight of controls as well as future liability associated with inappropriate onsite or offsite reuse of inadvertently exposed soil. This underestimation of the total life-cycle cost can lead to the selection of a remedy that either (1) fails due to inadequately-funded implementation, or (2) ends up exceeding the costs of other remedial options that had been deemed too expensive during the initial evaluation. Full treatment of contaminated soil will also increase the future resale and development value of the property.

Short and long-term remedial actions for sites where Category D soils are identified should be discussed with the HEER office on a site-by-site basis.

4.4 Hazardous Waste Considerations

Hazardous waste issues associated with the long-term management of dioxin-contaminated soil should be discussed with HEER staff on a site-by-site basis and incorporated into an *Environmental Hazard Management Plan* prepared for the site. The burden and feasibility of long-term management of dioxin-contaminated soil at a site can vary greatly depending on the regulatory designation of the soil as a hazardous or nonhazardous waste under RCRA Subtitle C. Dioxin-contaminated soil that is designated as a hazardous waste (see below) cannot be disposed of in any of the permitted, municipal waste landfill or construction and demolition debris landfill

in Hawai‘i. The soil must instead be disposed of at an out-of-state hazardous waste facility, typically at a significantly greater cost and administrative burden. This issue should be considered in selection of a final remedy for a site.

A preliminary Land Disposal Restriction (LDR) determination under RCRA Subtitle C should be made for dioxin-contaminated soils identified in the course of a site investigation (e.g., USEPA 2005). Dioxins associated with the release of a listed waste under RCRA Subtitle C are considered to be hazardous waste at the point that the soil is excavated or “generated.” An example is dioxin-contaminated soil at a wood treatment facility that is associated with the release of pentachlorophenol. If the soil is not excavated then it is not considered to be "generated" and is therefore not subject to an LDR determination. If excavated, the soil is considered to be contaminated with a prohibited waste and must be managed in accordance with LDR restrictions.

Pesticide-contaminated soil associated with past agricultural practices is *exempt* from designation as a hazardous waste, provided that the pesticide was used as intended and containers were cleaned and disposed of in accordance with label information available at that time (40 CFR §262.70 Subpart G: Farmers; USEPA 1986, 2006). This exemption applies to both field areas and pesticide mixing areas. Dioxin-containing soil associated with these types of agricultural sites does not fall under RCRA Subtitle C regulation unless it otherwise fails a hazardous waste characteristics test for other contaminants in the soil (e.g., ignitability, corrosivity, reactivity or exceedence of Toxic Characteristics Leaching Procedure (TCLP) regulatory levels; 40 CFR §261). Note that this exemption will not generally apply to illegal dump sites where disposal of bulk pesticides (vs cleaned containers) occurred. Applicability of this exclusion should be clearly discussed in a site-specific *Environmental Hazard Management Plan* for dioxin-contaminated soil that is capped in place for long-term management, with reference made to the above documents (e.g., 40 CFR §262.70 Subpart G: Farmers; USEPA 1986, 2006) as well as other pertinent information (e.g., past use of subject site for agricultural purposes). Simple reference of this technical memorandum will not be adequate.

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Table 1. Summary of TEQ Dioxin Soil Action Levels and associated soil management categories.

Soil Management Category	Action
Category A (≤20 ng/kg)	**Background.** Within range of expected background conditions in non-agricultural and non-industrial areas. No further action required and no restrictions on land use.
Category B (>20 but ≤240 ng/kg)	**Minimally Impacted.** Exceeds expected background conditions but within range anticipated for agricultural fields. Potential health risks considered to be insignificant. Include Category B soil in remedial actions for more heavily contaminated spill areas as practicable in order to reduce exposure (e.g., outer margins of pesticide mixing areas). Offsite reuse of soil for fill material or as final cover on a decommissioned landfill is acceptable, pending agreement by the landfill and barring hazardous waste restrictions. For existing homes, consider measures to reduce daily exposure to soil (e.g., maintain lawn cover, ensure good hygiene, thoroughly wash homegrown produce, etc.). For new developments on large, former field areas, notify future homeowners of elevated levels of dioxin on the property (e.g., include in information provided to home buyers during property transactions).
Category C (>240 but ≤1,500 ng/kg)	**Moderately Impacted.** Typical of incinerator ash, burn pits, wood treatment operations that used pentachlorophenol (PCP), and the margins of heavily impacted, pesticide mixing areas associated with former sugarcane operations that used PCP. Restriction to commercial/industrial land use required with a formal restriction to the deed against sensitive land uses (e.g., residential, schools, day care, medical facilities, etc.) in the absence of significant institutional and engineered controls and HDOH approval. Use of soil as soil as intermediate (e.g., temporarily inactive portions) or interim (e.g., daily or weekly) cover at a regulated landfill is acceptable, pending agreement by the landfill and barring hazardous waste restrictions. Preparation of a site-specific, *Environmental Hazard Management Plan* (EHMP) required if soil left on site for long-term management. Removal of isolated spill areas recommended when practicable in order to minimize future management and liability concerns. This includes controls to ensure no off-site dispersion (e.g., dust or surface runoff) or inadvertent excavation and reuse at properties with sensitive land uses.
Category D (>1,500 ng/kg)	**Heavily Impacted.** Typical of former pesticide mixing areas that used PCP (e.g., sugarcane operations). Remedial actions required under any land use scenario in order to reduce potential exposure. Potentially adverse health risks under both sensitive and commercial/industrial land use scenarios in the absence of significant institutional and/or engineered controls. Disposal of soil at a regulated landfill is acceptable, pending agreement by the landfill and barring hazardous waste restrictions.

ATTACHMENT 1

SUPPLEMENTAL INFORMATION ON DEVELOPMENT AND JUSTIFICATION OF UPDATED TEQ DIOXIN ACTION LEVELS

1.0 Background Information on Dioxins

Dioxins are a group of chlorinated organic molecules whose specific members, referred to as "congeners," share similar chemical structures and mechanisms of toxicity (WHO 2001, 2002, 2006). Potential sources of dioxins in Hawai'i include deposition of airborne dioxins originating from off-site sources, application of dioxin-bearing pesticides to agricultural fields, spills of concentrated dioxin-bearing pesticides (e.g., at pesticide mixing areas) and combustion of organic materials in the present of chlorine (e.g., incinerators, burn pits, fire training pits, building fires, forest fires, etc.). In agricultural areas, the primary source of dioxins in soils is believed to be associated with manufacturing impurities in certain chlorinated pesticides, such as 2,4,5-T and, in particular, pentachlorophenol. Data on the concentration of dioxins in soils outside of agricultural areas area are limited. HEER is currently conducting research to collect additional soil data in various types of settings throughout the state.

The risk to human health posed by exposure to dioxins is evaluated based on 17 specific dioxin congeners: 7 polychlorinated dibenzo-p-dioxins (PCDDs) and 10 polychlorinated dibenzofurans (PCDFs). The majority of the published literature on dioxin toxicity is limited to 2,3,7,8-Tetrachlorodibenzo-*p*-dioxin (TCDD, USEPA 2010), considered to be the most toxic of the 17 congeners studied. The World Health Organization (WHO) assigns toxicity values, referred to as "Toxicity Equivalence Factors (TEFs)," to specific congeners relative to the toxicity of TCDD (WHO 2006). The reported concentration of each congener in a sample is multiplied by its respective TEF to calculate a "Toxicity Equivalent (TEQ)" concentration. The TEQ concentrations for individual congeners are then added together to obtain a total TEQ concentration for the sample. The U.S. Environmental Protection Agency (USEPA) and HEER office recommend the use of WHO's TEFs to calculate TEQ dioxin levels for use in human health risk assessments or for comparison to risk-based action levels (USEPA 2009a, HDOH 2009a).

2.0 2008 HEER Dioxin Guidance

Soil action levels published by the HEER office in 2006 and 2008 were based on potential excess cancer risk posed by long-term, direct exposure to dioxins in soil (HDOH 2008a,b). Noncancer health risks were not specifically considered but were presumed to be less significant than cancer risks. The soil action levels were based on the USEPA Regional Screening Levels (RSLs; USEPA 2009b), adjusted to a target excess cancer risk of 10^{-4} (i.e., one in ten thousand; see Attachment 2). Action levels based on a more conservative cancer slope factor published by the Minnesota Department of Health were also developed.

Cancer slope factors published by USEPA and other agencies for dioxins are not fully accepted by the toxicology community and considered by others to be excessively conservative (e.g., Cole

et. al 2003, Hayes and Aylward 2003, NAS 2006). Confidence in the slope factors is considered to be low (see Section 4.4). A target excess cancer risk of 10^{-4} was therefore deemed appropriate (refer to Attachment 2).

The 2008 HEER action levels were used to define three categories of soil each for unrestricted (e.g., "residential") and commercial/industrial land use scenarios. Specific guidance was then presented for the management of soil in each category. The final action levels and soil categories were defined as follows:

2008 HEER TEQ Dioxin Soil Categories		
Category	**Unrestricted/Residential Land Use [1]**	**Commercial/Industrial Land Use**
Category 1 [2]	<42 ng/kg	<170 ng/kg
Category 2 [3]	42 to ≤450 ng/kg	170 to ≤1,800 ng/kg
Category 3 [3]	>450 ng/kg	>1,800 ng/kg

Notes:
1. Includes schools, day care centers, medical facilities and other related sensitive land uses.
2. Action levels based on Minnesota Department of Health cancer slope factors.
3. Action levels based on California EPA cancer slope factors.

No further action was recommended for Category 1 soils under the noted land use. Efforts to minimize exposure (e.g., lawn maintenance) were recommended for Category 2 soils if the soil was associated with widespread, trace-level dioxin contamination in former agricultural fields. Removal or capping of small isolated "hot spots" of Category 2 soils to surrounding, background levels was recommended when feasible in order to minimize exposure, but not considered necessary from a purely health-risk standpoint. Removal or capping of Category 3 soils was recommended. Long-term management of soil at commercial/industrial sites that exceeded the upper action level for unrestricted/residential land use of 450 ng/kg TEQ dioxins was recommended to ensure that the soil was not inappropriately excavated and reused offsite in the future.

3.0 Basis of 2010 Updates to Dioxin Soil Action Levels

This technical memorandum updates the 2008 soil action levels for TEQ dioxin to take into account World Health Organization (WHO) Permissible Tolerable Intake factors for potential cancer and noncancer health risks. Exposure assumptions and model parameters used to develop the earlier action levels are otherwise identical. HDOH considers the WHO factors to be more defensible (e.g., lowest uncertainty factor) and appropriate for use in Hawai‘i in comparison to alternative factors, including cancer slope factors published by USEPA and other agencies, as well as noncancer toxicity factors published by the US Agency for Toxic Substances and Disease Registry (ATSDR) and more recently by USEPA.

A discussion of alternative toxicity factors is provided for comparison. The final, updated soil action levels fall within the range of action levels that could be developed by use of the alternative toxicity factors. A detailed discussion of model equations and assumptions used to generate the action levels is provided in Attachment 2.

3.1 Use of WHO PMTI Factors to Develop Soil Action Levels

This update incorporates the use of WHO Permissible Tolerable Monthly Intake (PTMI) factors (WHO 2001, 2002) to develop alternative soil action levels for TEQ dioxins. The WHO PTMI is intended to limit the long-term, body burden of TEQ dioxins to levels that are not believed to be associated with significant cancer or noncancer health risks. WHO concluded that body burden is a more appropriate measure of potential health risks than is a traditional approach based on daily dose, although the two parameters are closely related.

In 1998 WHO published a Tolerable *Daily* Intake (TDI) range for bioavailable TEQ dioxins of 1 to 4 picograms per kilogram of body weight per day (1-4 pg/kg-day; WHO 1998). The ATSDR published an identical range of TEQ dioxin "Minimal Risk Levels" in the same year (ATSDR 1998, 2008). WHO subsequently published an updated, Permissible *Monthly* Tolerable Intake (PTMI) factor range for TEQ Dioxins of 40 to 100 pg/kg-month, after further review of available studies (WHO 2001, 2002). The PTMI of 100 pg/kg-month is based on a No Observed Effects Level (NOEL, power model) for an equivalent human monthly intake (EHMI) of 330 pg/kg per month, adjusted by safety factor of 3.2 to account for inter-individual differences in toxicokinetics among humans (rounded downward to a value of 100). The PTMI of 40 pg/kg-month is based on a Lowest Observed Effects Level (LOEL, linear model) for an equivalent human monthly intake (EHMI) of 423 pg/kg per month, adjusted by safety factor of approximately 9.6 to account for both use of a LOEL (vs NOEL) and inter-individual differences in toxicokinetics (rounded downward to a value of 40).

The WHO PTMI levels were divided by a factor of 30.4 days/month in order to generate an equivalent, tolerable *daily* intake range of 1.3 pg/kg-day to 3.3 pg/kg-day and allow their use in risk-based models for development soil action levels (see Attachment 2). WHO presents monthly, rather than daily, intake ranges to emphasize that the PMTI range is applicable to long-term exposure only, and is well below levels that could pose immediate health effects. As stated in the WHO document:

> "The PTMI is not a limit of toxicity and does not represent a boundary between safe intake and intake associated with a significant increase in body burden or risk. Long-term intakes slightly above the (upper range of the) PTMI would not necessarily result in adverse health effects but would erode the safety factor built into the calculations of the PTMI."

The more rigorous, NOEL-based PMTI of 100 pg/kg-month (3.3 pg/kg-day) was selected for calculation of final dioxin soil action levels. The adjusted factor was incorporated into the USEPA Regional Screening Level (RSL) models for noncancer health risks. This generated a soil action level 240 ng/kg for unrestricted (e.g., residential) land use and 2,800 ng/kg for commercial/industrial land use (see Attachment 2). The calculated action level for unrestricted land use was retained for use in this guidance (refer to Sections 2 and 3 in main text). As discussed in the following section, the commercial/industrial action level was reduced by a factor of 1.9 to 1,500 ng/kg in order to limit theoretical exposure to dioxins in soil to approximately

50% of the estimated dietary intake for adults (refer also to Attachment 2). The HEER office believes that the final soil action levels are appropriate and practicable for screening of dioxin-contaminated sites in Hawai‘i.

Note that the WHO PTMI assumes a 50% bioavailability of TEQ dioxins in food (see footnote to Table 14, WHO 2002). This is similar to estimates of average dioxin bioavailability in soil, as recently reviewed by the Washington Department of the Environment (Washington DOE 2007a,b). In the absence of site-specific data, further adjustment of the WHO PTMI and soil action levels presented in the main text of this guidance based on assumed dioxin bioavailability in soil is not recommended.

3.2 Comparison of Dietary Exposure

A comparison of WHO PTMI factors to typical dietary exposure to TEQ dioxins is useful in order to put potential exposure to dioxins in soil at the action levels noted in perspective. The WHO estimates the mean, dietary intake of TEQ dioxins to be 15 to 160 pg/kg-month at the 90th percentile of mean lifetime exposure (WHO 2002). This equates to a daily dietary exposure of 0.5 to 5 pg/kg-day, or up to 75 pg/day for a 15 kg child and 350 pg/day for a 70 kg adult (default body weights typically used in human health risk assessments).

As summarized in Attachment 3, dietary intake of TEQ dioxins for Pacific-Asian diets heavy in fish and vegetables is estimated to range from 66 pg/day for children (4.4 pg/kg-day for a 15 kg child) and to 102 pg/day adults (1.5 pg/kg-day for a 70 kg adult), respectively. Food of animal origin is estimated to contribute to approximately 80% of overall human exposure to dioxins (USEPA 2010). Other studies have indicated a minimal contribution of TEQ dioxins from soil with respect to dietary intake (e.g., Kimbrough et al 2010).

For comparison, the HDOH soil action level for unrestricted (e.g., residential) land use of 240 ng/kg equates to a theoretical, TEQ dioxin average daily dose of approximately 23 pg/day for a 15 kg child and 12 pg/day for a 70 kg adult (assuming a soil ingestion rate of 200 mg/day for children and 100 mg/day for adults, a bioavailability of 50% and the additional exposure factors noted in Attachment 2). This represents approximately 35% of the estimated dietary exposure for a 15 kg child (USEPA default body weight for children, as averaged for ages 1-6; refer to Attachment 2).

The HDOH soil action level for commercial/industrial land use of 2,800 ng/kg equates to a theoretical, TEQ dioxin average daily dose of approximately 96 pg/day for a 70 kg adult. This is approximately equal to the estimated dietary exposure of adults to TEQ dioxins. As an added measure of safety, however, HEER decided to reduce the soil action level to 1,500 ng/kg in order to limit the theoretical exposure to dioxins in soil to 50 pg/day or approximately 50% of the estimated dietary exposure (added safety factor of 1.9; refer to Attachment 2). Actual exposure to dioxins in soil for both children and adults is likely to be much lower than exposure predicted by the models due to the conservative nature of the exposure factors assumed in the models.

3.3 Comparison to 2009 USEPA RSLs Adjusted for Relative Bioavailability

The 2009 USEPA Regional Screening Levels (RSLs; USEPA 2009b) do not consider the relative bioavailability of dioxins in soil (i.e., relative bioavailability of dioxins in soil in comparison to bioavailability of dioxins in laboratory-based studies). Guidance published by the Washington Department of Ecology (DOE) was used to adjust the USEPA RSLs for comparison to WHO-based action levels (Washington DOE 2007a,b; see Attachment 2). Washington DOE presents the following rationale for use of a gastrointestinal absorption adjustment (bioavailability) factor in the calculation of soil screening levels for cancer risk concerns:

- Available evidence suggests that soil-bound dioxins/furans are less bioavailable than dioxins/furans used to assess the health risks from bioassays, epidemiological studies or studies used to assess the toxicity of dioxins/furans in foods and drinking water.

- Although there is uncertainty in assigning congener-specific bioavailability estimates, the available evidence suggests that the higher-chlorinated dioxin/furan congeners (hexa-, hepta-, octa-) are less well absorbed and less bioavailable than the lower-chlorinated congeners (tetra- and penta-).

- Within a range of uncertainty and variability, available evidence suggests that congener-specific differences in bioavailability should be considered when evaluating the toxicity and assessing the risks for mixtures of dioxins/furans.

Based on a review of published studies, Washington DOE (2007a) recommended a default relative bioavailability 0.7 for the tetra- and penta-chlorinated dioxin/furan congeners, and 0.4 for the less available (but usually more abundant) hexa-, hepta-, and octa-chlorinated congeners (i.e., bioavailability in soil *relative* to the bioavailability in the food used in the animal studies, estimated to be between 80% ad 90%; USEPA 2010). Final guidance published by Washington DOE recommended a weighted, relative bioavailability or gastrointestinal absorption fraction for TEQ dioxins of 0.6, based on typical mixtures of dioxin/furan congeners identified in soil (Washington DOE 2007b). This was consistent with the default, relative bioavailability of TEQ dioxins in soil recommended by a majority of other State and international agency guidance reviewed by Washington DOE. Assuming a bioavailability of dioxins in the food used in animal studies of 80% to 90%, this equates to an ultimate bioavailability of dioxins in soil of approximately 50%, similar to the bioavailability of dioxins assumed in the WHO PMTI factors (refer to Section 3.1).

An internal HEER review of dioxin/furan congener soil data from former sugarcane operations in Hawai‘i indicated an average mixture of 2% tetra- and penta- dioxin/furan congeners and 98% hexa-, hepta-, and octa- congeners, with a worst-case instance of 20% tetra- and penta-dioxin/furan congeners and 80% hexa-, hepta-, and octa- congeners. Applying Washington DOE’s approachTo dioxin data from former sugarcane fields and pesticide mixing area in Hawai‘i, HEER calculated TEQ dioxin bioavailability factors from 0.41 (average) to 0.46

(worst-case). This suggests that the default, relative bioavailability of 0.6 published by the Washington DOE is adequately for modification of the USEPA RSLs.

Modification of the 2009 USEPA RSLs for relative bioavailability applies only to the incidental ingestion portion of the soil action level models. As indicated in Attachment 2, a separate absorption factor is used for dermal exposure. Relative bioavailability is not considered for inhalation of particulates. The latter two exposure pathways are relatively minor in comparison to incidental ingestion. Adjustment of the incidental ingestion portion of the soil model to reflect a relative bioavailability 0.6 and use of a target, excess cancer risk of 10^{-4} yields modified RSLs of 650 ng/kg and 2,400 ng/kg for unrestricted/residential land use and commercial/industrial land use respectively.

The updated TEQ dioxin soil action level for unrestricted land use presented in the main text (240 ng/kg) is more conservative than the USEPA RSL adjusted for relative bioavailability and a target excess cancer risk of 10^{-4}. The updated action level for commercial/industrial land use (1,500 ng/kg) is also lower than the adjusted RSL.

3.4 Comparison to 2009 USEPA TEQ Dioxin PRGs (Draft)

USEPA recently published a draft document entitled *Recommended Interim Preliminary Remediation Goals (PRGs) for Dioxin in Soil at CERCLA and RCRA Sites* (USEPA 2009a). Although the final PRGs are similar to the updated HDOH soil action levels presented above, the HEER office considers the approach presented in this technical memorandum to be more applicable for use in Hawai‘i.

The USEPA draft guidance proposes to retract screening levels for TEQ dioxins published in 1998 for use at CERCLA and RCRA sites, including the often cited screening levels of 1 µg/kg TEQ dioxins for residential soils and 5 to 20 µg/kg for commercial/industrial soils (USEPA 1998). The HEER office had previously discounted use of these action levels in Hawai‘i, after concluding that they may not be adequately protective of human health in some circumstances.

As an alternative, the draft USEPA document proposes use of the 1998 ATSDR Minimal Risk Level (MRL) to develop TEQ dioxin soil screening levels or “Preliminary Remediation Goals” (“PRGs”). The ATSDR document presents an MRL range for TEQ dioxins of 1 to 4 pg per kilogram bodyweight per day (pg/kg-day), identical to guidance published by the World Health Organization the same year (see above). This equates to an exposure of 15 to 60 pg/day for a 15 kg child (average child bodyweight used in noncancer risk assessments) or 60 to 280 pg/day TEQ dioxins for a 70kg adult (lifetime average bodyweight used in cancer risk assessments). Exposures below these levels are assumed to not pose a significant health risk. Note that the upper limit of the ATSDR MRL range is slightly less conservative than the range proposed by WHO (WHO 2002; see above).

Using the models and exposure assumptions presented in the draft guidance with the ATSDR MRL range for TEQ dioxins of 1 to 4 pg/kg-day yields a soil screening level range of 72 to 290 ng/kg for residential land use and 850 to 3,400 ng/kg for commercial/industrial land use. This is

comparable to the range of screening levels generated by use of the WHO PTMI guidance as described above and in the main text of this document. The draft USEPA document proposed a TEQ dioxin "Preliminary Remediation Goal" (PRG) of 72 ng/kg for residential soil and 950 ng/kg for commercial/industrial, based on use of the low end of the ATSDR MRL range, or 1 pg/kg-day. These action levels do not consider the relative bioavailability of dioxins in soil (see Section 3.2). Adjusting for a relative bioavailability of 0.6 would yield correlative PRGs of 120 ng/kg and 1,600 ng/kg, respectively. While the HEER office does not disagree that soils with concentrations of TEQ dioxins below the proposed PRGs levels do not pose a significant health risk, HEER feels that the PRGs are too conservative to be useful for initial screening purposes in Hawai'i. As discussed above, the HEER office also prefers use of the more recent, WHO PTMI guidance over the 1998 ATSDR guidance.

The draft USEPA document also notes that the proposed PRGs fall within the range of screening levels that would be generated using cancer slope factors published by the USEPA in the 1980s and a risk range of 10^{-6} to 10^{-4} (e.g., 4.5 to 450 ng/kg for residential soil and 18 to 1,800 ng/kg; based on the current USEPA RSLs; USEPA 2009b). Note that identical, noncancer screening levels for TEQ dioxins were calculated as part of the 2009 USEPA RSL guidance but ultimately not selected as the final RSLs, since the screening level for cancer concerns assumes a target risk of 10^{-6}.

As discussed below, HEER prefers to focus on remediation of *localized* areas of dioxin-contaminated soil (e.g., pesticide mixing areas) to meet the surrounding area background concentrations *as practicable* on a site-by-site basis, rather than deferring to a purely risk-based soil action level. Remediation of minimally impacted soils in large, former agricultural fields to natural background concentrations (e.g., <20 ng/kg) is considered to be impracticable and, from the standpoint of risk and added health benefit, unnecessary. This is supported by consideration of dietary intake of dioxins and furans, which is estimated to exceed the hypothetical intake associated with long-term exposure to soils with concentrations of TEQ dioxins at or below the updated action levels.

3.5 Comparison to 2010 USEPA TCDD Toxicity Review (Draft)

USEPA recently released a draft review of published literature on the health effects of tetrachlordibenzonedioxin (TCDD) and related compounds (USEPA 2010). USEPA focused on two studies of human exposure to TCDD to develop a draft, noncancer reference dose. A Lowest Observed Adverse Effects Level (LOAEL) of 20 pg/kg-day exposure to TCDD was ultimately selected for development of an oral reference dose (RfD).

The selected LOAEL of 20 pg/kg-day is well above the WHO Permissible Tolerable Intake of 3.3 pg/kg-day used to develop soil action levels in this technical memorandum (refer to Section 3.2). In the draft document, however, USEPA reduces the LOAEL by an uncertainty factor of ten due to the lack of a No Observed Adverse Effects Level (NOAEL) for TCDD. The LOAEL is further reduced by a factor of three to account for human inter-individual variability, for a total uncertainty factor of thirty. The document then proposes a final, draft, TCDD reference dose of 0.7 pg/kg-day.

The selected WHO tolerable intake factor of 3.3 pg/kg-day exceeds the final RfD of 0.7 pg-kg-day selected by USEPA in it's draft document. The WHO factor falls near the low end of the RfD and LOAEL low-risk range of TCDD exposure identified in the draft review, however (0.70 pg/kg-day to 20 pg/kg-day). Adjustment of the draft USEPA RfD to take into account a reduced relative bioavailability of dioxins in soil would further reduce the difference between action levels derived by either method. For example, use of the draft RfD in the USEPA RSL models would yield soil action levels of approximately 50 ng/kg and 600 ng/kg for residential and commercial/industrial land use, respectively (refer to Attachment 2). Adjustment for a relative bioavailability of dioxins in soil of 0.6 (see Section 3.2) yields action levels of 85 ng/kg and 1,000 ng/kg, respectively.

The draft USEPA document also presents an oral slope factor range of 1.1×10^5 $(mg/kg\text{-}day)^{-1}$ to 1.6×10^6 $(mg/kg\text{-}day)^{-1}$ for possible use in cancer risk assessments, depending on the selected target risk. As discussed above, the 2009 USEPA RSLs for 2,3,7,8 dioxins is based on a slope factor of 1.3×10^5 $(mg/kg\text{-}day)^{-1}$. Use of a more conservative slope factor would (e.g., 7.8×10^5 $(mg/kg\text{-}day)^{-1}$ based on target risk of 10^{-4}) would reduce the RSL by a factor of approximately six. As discussed above, the cancer slope factors incorporate a relatively high degree of uncertainty and confidence in their use to develop meaningful soil action levels is low.

HDOH does not feel that use of an RfD or cancer slope factor that equates to an exposure below anticipated dietary intake to derive soil action levels is practical. At this time, and in consideration of the multiple lines of evidence summarized in Section 2 of the main text, HDOH considers the WHO PTMI factors to be the most technically supportable and appropriate values for development of direct-exposure soil action levels for use in Hawai‘i.

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ATTACHMENT 2

EQUATIONS AND ASSUMPTIONS FOR DERIVATION OF TEQ DIOXIN SOIL ACTION LEVELS

1.0 Introduction

A summary of models and assumptions used to develop for human health, direct-exposure concerns is presented below. For addition information on the models, refer to the USEPA document *Screening Levels for Chemical Contaminants* (USEPA 2009). See also Appendix 1 of the HEER *EHE Guidance* (HDOH 2008b).

2.0 TEQ Dioxin Toxicity Factors and Bioavailability

The WHO Permissible Tolerable Monthly Intake (PTMI) upper limit of 100 pg/(kg-month) is used to calculate noncancer soil action levels (WHO 2002). The PTMI is converted to a Permissible Tolerable *Daily* Intake (PTDI) level of 3.3 pg/(kg-day) for use in the noncancer equations. Although not necessarily applicable, a default Hazard Quotient of 1.0 is also assumed in the equations. A Cancer Slope Factor (CSF) of 1.3E+05 $(mg/kg\text{-}day)^{-1}$ and an Inhalation Unit Risk Factor (IURF) of 38 $(\mu g/m^3)^{-1}$ were selected for calculation of cancer-based soil action levels (USEPA 2009; CSF adopted from CalEPA). Action levels are based on a target excess cancer risk of 10^{-4}.

The equations incorporate an additional Gastrointestinal Absorption Factor (GIABS) to adjust for the bioavailability of dioxins and furans in soil, as necessary. A default GIABS for dioxins and furans of 0.6 is assumed for soils (Washington DOE 2007a,b). This is used to adjust the incidental ingestion exposure portion of the cancer-based action level (see Table 1 and Equations 1 and 3). An assumed bioavailability of 0.5 is directly incorporated into the WHO PTMI; further adjustment of bioavailability for exposure to soil is therefore not warranted (GIABSnc = 1; see Table 1 and Equations 2 and 4).

3.0 Soil Action Levels Models

Human exposure assumptions are summarized in Table 1. With the exceptions noted, parameter values in Table 1 were taken directly from the USEPA Regional Screening Level (RSL) guidance document (USEPA 2009). Parameter values for the construction/trench worker exposure scenario are discussed in more detail in Appendix 1. Tables 2 and 3 summarize equations and parameter values used to develop the RSL Particulate Emission Factor and physiochemical constants assumed in the models for TEQ dioxins.

Carcinogenic risks under unrestricted/residential exposure scenarios were calculated using the following age-adjusted factors. Definition of terms and default parameter values used in the equations are presented in Tables 1, 2, and 3.

1) Ingestion [(mg·yr)/kg·d)]:

$$IFS_{adj} = \frac{ED_c \; x \; IRS_c}{BW_C} + \frac{(ED_r - ED_c) \; x \; IRS_a}{BW_a}$$

2) Dermal Contact [(mg·yr)/kg·d)]:

$$SFS_{adj} = \frac{ED_c \; x \; AF_c \; x \; SA_c}{BW_C} + \frac{(ED_r - ED_c) \; x \; AF_a \; x \; IRS_a}{BW_a}$$

3) Inhalation [(m^3·yr)/kg·d)]:

$$InhF_{adj} = \frac{ED_c \; x \; IRA_c}{BW_C} + \frac{(ED_r - ED_c) \; x \; IRA_a}{BW_a}$$

Direct exposure equations for soil are summarized as follows:

Equation 1: Combined Exposures to Carcinogenic Contaminants in Residential Soil

$$C(mg/kg) = \frac{TR \; x \; AT_c}{EF_r \left[\left(\frac{IFS_{adj} \; xGIABSc \times CSF_o}{10^6 \, mg/kg} \right) + \left(\frac{SF_{adj} \; x \; ABS \; x \; CSF_o}{10^6 \, mg/kg} \right) + \left(\frac{InhF_{adj} \; x \; CSF_i}{PEF} \right) \right]}$$

Equation 2: Combined Exposures to Noncarcinogenic Contaminants in Residential Soil

$$C(mg/kg) = \frac{THQ \times BW_c \times AT_n}{EF_r \times ED_c \left[\left(\frac{1}{RfD_o} \times \frac{IRS_c \times GIABSnc}{10^6 \, mg/kg} \right) + \left(\frac{1}{RfD_o} \times \frac{SA_c \times AF_c \; x \; ABS}{10^6 \, mg/kg} \right) + \left(\frac{1}{RfD_i} \times \frac{IRA_c}{PEF} \right) \right]}$$

Equation 3: Combined Exposures to Carcinogenic Contaminants in Industrial Soil

$$C(mg/kg) = \frac{TR \times BW_a \times AT_c}{EF_o \times ED_o \left[\left(\frac{IRS_o \times GIABSc \times CSF_o}{10^6 \, mg/kg} \right) + \left(\frac{SA_a \times AF_a \times ABS \times CSF_o}{10^6 \, mg/kg} \right) + \left(\frac{IRA_a \times CSF_i}{PEF} \right) \right]}$$

Equation 4: Combined Exposures to Noncarcinogenic Contaminants in Industrial Soil

$$C(mg/kg) = \frac{THQ \times BW_a \times AT_n}{EF_o \times ED_o \left[\left(\frac{1}{RfD_o} \times \frac{IRS_o \times GIABSnc}{10^6 \, mg/kg} \right) + \left(\frac{1}{RfD_o} \times \frac{SA_a \times AF_a \times ABS}{10^6 \, mg/kg} \right) + \left(\frac{1}{RfD_i} \times \frac{IRA_a}{PEF} \right) \right]}$$

Equation 5: Derivation of Particulate Emission Factor (residential & occupational)

$$PEF\,(m^3/kg) \;=\; Q/C\;x\;\frac{3600s/h}{0.036\times(1-V)\,(U_m/U_t)^3\times F(x)}$$

The USEPA RSL models incorporate a Volatilization Factor (VF) for emission of volatile chemicals to outdoor air. Volatile chemicals are defined as having a Henry's Law Constant of >1.0E-05 (atm·m^3)/mol and a molecular weight of <200 g/mol. Dioxin/furan mixtures do not meet this definition. The VF term in the soil equations is therefore replaced with the Particulate Emission Factor (PEF) term for non-volatile chemicals.

4.0 Calculated Soil Action Levels

4.1 Unadjusted Action Levels

Based on the models and model assumptions described above and in Table 1, a TEQ dioxin soil action level of 240 ng/kg is generated for unrestricted (e.g., residential) land use. This action level was retained for use in the final guidance (refer to Table 1 in the main text). A preliminary soil action level of 2,800 ng/kg is generated for commercial/industrial land use. As described below, this action level was adjusted by an additional safety factor of 1.9 in order to minimize exposure to dioxins in soil to approximately 50% of the estimated dietary exposure.

4.2 Adjustment of Commercial/Industrial Soil Action Level

The HDOH soil action level for commercial/industrial land use of 2,800 ng/kg equates to a theoretical exposure to TEQ dioxins of approximately 96 pg/day for a 70 kg adult (refer to Section 3.2 in main text). This is approximately equal to the estimated dietary exposure of adults to TEQ dioxins. As an added measure of safety, however, HEER decided to reduce the soil action level to 1,500 ng/kg in order to limit the theoretical exposure to dioxins in soil to 50 pg/day or approximately 50% of the estimated dietary exposure (added safety factor of 1.9). Actual exposure to dioxins in soil for both children and adults is likely to be much lower than exposure predicted by the models due to the conservative nature of the exposure factors assumed in the models.

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TABLE 1. HUMAN EXPOSURE PARAMETER DEFINITIONS AND DEFAULT VALUES

Symbol	Definition (units)	Value	Units	References (see USEPA 2002 for full references)
CSFo	Cancer slope factor, oral	1.3E+05	$(mg/(kg \cdot d))^{-1}$	USEPA 2009 (references California EPA 2008)
CSFi	Cancer slope factor, inhaled	38	$(ug/m^3)^{-1}$	USEPA 2009 (references California EPA 2008)
RfDo	Reference dose, oral	3.3E-09	mg/(kg·d)	WHO 2002, see text
RfDi	Reference dose, inhaled	-	mg/(kg·d)	-
TRr/o	Target cancer risk – residential or occupational exposure scenario	1.0E-04	Unitless	HDOH, see text
THQ	Target hazard quotient	1.0	Unitless	See text
BWa	Body weight, adult	70	Kg	USEPA 2009
BWc	Body weight, child	15	Kg	USEPA 2009
ATc	Average time, cancer risk	25,550	D	USEPA 2009
ATn	Average time, noncancer risk	ED × 365	d	USEPA 2009
SAar	Exposed surface area, adult residential	5.7E+03	cm^2/d	USEPA 2009
SAaw	Exposed surface area, adult occupational	3.3E+03	cm^2/d	USEPA 2009
SAc	Exposed surface area, child	2.8E+03	cm^2/d	USEPA 2009
AFar	Adherence factor, adult residential	0.07	mg/cm^2	USEPA 2009
AFaw	Adherence factor, occupational	0.20	mg/cm^2	USEPA 2009
AFc	Adherence factor, child	0.20	mg/cm^2	USEPA 2009
ABS	Skin absorption, chemical specific	0.03	unitless	USEPA 2009
IRAa	Inhalation rate, adult	20	m^3/d	USEPA 2009
IRAc	Inhalation rate, child	10	m^3/d	USEPA 2009
IRSa	Soil ingestion, adult	100	mg/d	USEPA 2009
IRSc	Soil ingestion, child	200	mg/d	USEPA 2009
IRSo	Soil ingestion, occupational	50	mg/d	USEPA 2009
GIABSc	Gastrointestinal Absorption Adjustment Factor, cancer risk	0.6	unitless	Washington DOE 2007b, see text
GIABSnc	Gastrointestinal Absorption Adjustment Factor, noncancer risk	1.0	unitless	No adjustment; 50% dioxin bioavailability assumed in food (WHO 2002), see text
EFr	Exposure frequency, residential	350	d/yr	USEPA 2009
EFo	Exposure frequency, occupational	250	d/yr	USEPA 2009
EDr	Exposure duration, residential	30	yr	USEPA 2009
EDc	Exposure duration, child	6	yr	USEPA 2009
EDo	Exposure duration, occupational	25	yr	USEPA 2009
IFSadj	Ingestion factor, soil	114	(mg·yr)/(kg·d)	USEPA 2009
SFSadj	Skin contact factor, soil	361	(mg·yr)/(kg·d)	USEPA 2009
InhFadj	Inhalation factor	11	$(m^3 \cdot yr)/(kg \cdot d)$	USEPA 2009
PEFres/oc	Particulate emission factor, residential/occupational exposure scenarios	1.32E+09	m^3/kg	USEPA 2009

Primary Reference: USEPA *Screening Levels for Chemical Contaminants* (USEPA 2009).

TABLE 2. PARTICULATE EMISSION FACTOR PARAMETER DEFINITIONS AND DEFAULT VALUES - RESIDENTIAL/OCCUPATIONAL SCENARIOS

Parameter	Definition	Default Value	Units
PEF *	Particulate emission factor	1.316E+09	m^3/kg
Q/C	Inverse of the mean concentration at the center of a 0.5-acre-square source	90.80	$g/(m^2 \cdot s)$ per kg/m^3
V	Fraction of vegetative cover	0.5	unitless
Um	Mean annual windspeed	4.69	m/s
Ut	Equivalent threshold value of windspeed at 7 m	11.32	m/s
F(x)	Function dependent on Um/Ut derived using Cowherd (1985)	0.194	unitless

* Equivalent to an airborne dust concentration, in mg/m^3, of (1,000,000 mg / 1 kg) / PEF = 0.0007 mg/m^3.

TABLE 3. DEFAULT PHYSIOCHEMICAL PARAMETERS FOR TEQ DIOXINS (USEPA 2009)

Parameter	Default Value	Units
Molecular weight	3.56E+02	g/mol
Koc	2.57E+05	l/kg
Solubility in water	1.2E-04	mg/l
Henry's Law Constant	2.2E-06	$(atm \cdot m^3)/mol$
Henry's Law Constant	9.0E-05	unitless

ATTACHMENT 3

ESTIMATED DIETARY INTAKE OF TEQ DIOXIN FOR PACIFIC-ASIAN DIETS

(see main text for full references)

Table 1. Estimated food consumption for a Pacific-Asian diet.

	Child (Ave 6mo-5yr)		Mean Population	
Food Group	**[1]Consumption (g/d)**	**Percent of Total**	**[1]Consumption (g/d)**	**Percent of Total**
Cereals & Cereal Products	**166**	**32%**	**364**	**43%**
Rice & Products	122	23%	303	58%
Corn and Products	17	3%	31	6%
Other Cereals and Products	27	5%	30	6%
Starch Roots and Tubers	**8**	**2%**	**19**	**4%**
Sugars and Syrups	**15**	**3%**	**24**	**5%**
Fats and Oils	**6**	**1%**	**18**	**3%**
Fish, Meat & Poultry	**95**	**18%**	**185**	**35%**
Fish and Products	57	11%	104	20%
Meat and Products	27	5%	61	12%
Poultry and Products	11	2%	20	4%
Eggs	**8**	2%	**13**	**2%**
Milk and Products	**179**	**34%**	**49**	**9%**
Whole Milk	158	30%	35	7%
Milk Products	21	4%	14	3%
Dried Beans, Nuts & Seeds	**4**	**1%**	**10**	**2%**
Vegetables	**13**	**2%**	**111**	**21%**
Green Leafy & Yellow	10	2%	31	6%
Other Vegetables	3	1%	80	15%
Fruits	**31**	**6%**	**54**	**10%**
Vitamin C-rich Fruits	4	1%	12	2%
Other Fruits	27	5%	42	8%
Total Food Consumption:	525		847	

	Consumption (kg/day)	
Combined Food Groups	**Child**	**Mean**
[1]Fuits & Vegetables	0.237	0.582
Dairy	0.179	0.049
[2]Meat	0.044	0.099
Fish	0.057	0.104
Eggs	0.008	0.013
Total:	0.525	0.847

1. Including cereals and cereal products, starch roots and tubers, dried beans, nuts and seeds.

2. Including fats, oil & poultry.

Reference: FNRI, 2003, The 6th National Nutrition Survey: Food, Philippine Department of Science and Technology, Nutrition and Research Institute, http://www.fnri.dost.gov.ph/index.php?option=content&task=view&id=1130

1. Raw as purchased (rice and cereals presumably dry weight).

Table 2. Estimated dietary intake of TEQ dioxins based on a typical Asian-Pacific diet (see also Table 1).

		[4]Child (6mo-5yr)			[5]Mean Population		
Food Group	**[1]TEQ Dioxins (pg/kg)**	**[2]Daily Dose (pg/d)**	**[3,4]Daily Intake (pg/Kg-d)**	**Percent TEQ Dioxins Contribution**	**[1]Daily Intake (pg/d)**	**[3,5]Daily Dose (pg/Kg-d)**	**Percent TEQ Dioxins Contribution**
Fruits and Vegetables	40	9.5	0.63	14%	23.3	0.33	23%
Dairy	100	17.9	1.19	27%	4.9	0.07	5%
Meat	130	5.7	0.38	9%	12.9	0.18	13%
Fish	560	31.9	2.13	48%	58.2	0.83	57%
Eggs	170	1.4	0.09	2%	2.2	0.03	2%
Total:		66	4.43	100%	102	1.45	100%

1. WHO, 2002, Safety Evaluation of Certain Food Additives and Contaminants: WHO Technical Report Series, Fifty-seventh report of the Joint FAO/WHO Expert Committee on Food Additives, WHO Technical Report Series 909, http://whqlibdoc.who.int/trs/WHO_TRS_909.pdf. Data for North America (vegetable data from Europe).

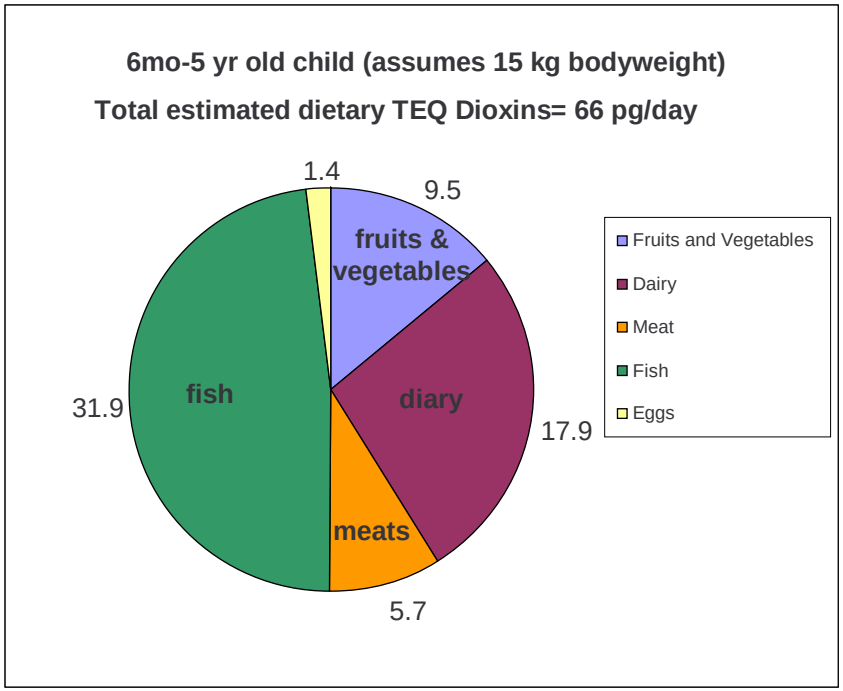
2. Calculated as: Daily Food Group Consumption (refer to Table 1; converted to kg/day) multiplied by the noted Food Group TEQ Dioxins concentration (converted to pg/kg).

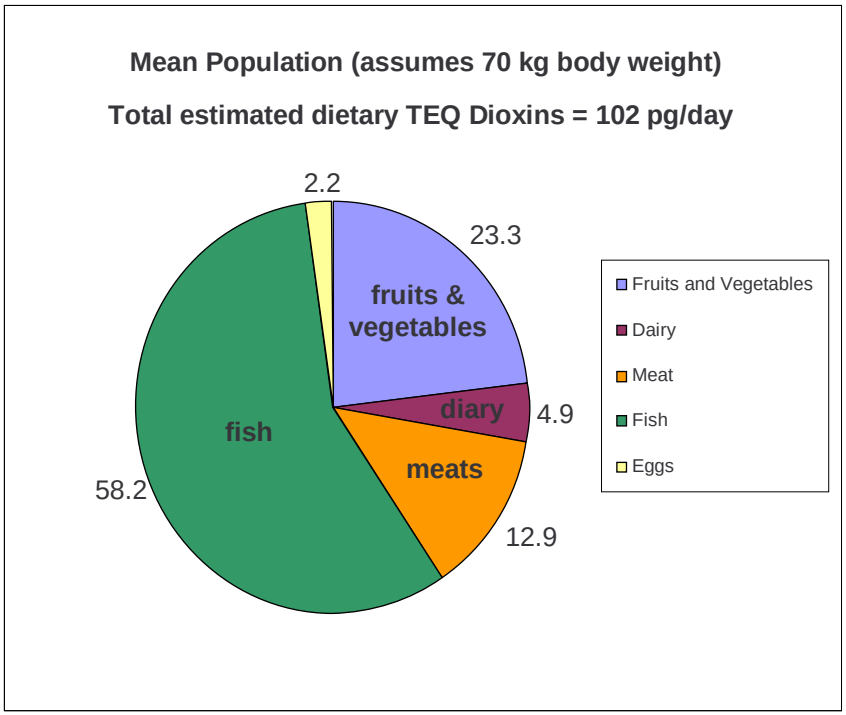
3. Calculated as: Estimated Daily Intake in pg/day divided by assumed weight in Kg.

4. Assumed Child Weight = 15 Kg (default in USEPA risk assessment guidance; e.g., USEPA 2009b).

5. Assumed Mean Population Weight =70 Kg (default in USEPA risk assessment guidance; e.g., USEPA 2009b).

Figure 1. Summary of estimated TEQ dioxin intake based on a Pacific-Asian diet [based on data reported by WHO for dioxin in food (WHO 2002)]





SECTION 10
DATA QUALITY ASSURANCE AND QUALITY CONTROL (QA/QC)

Interim Final-December 31, 2008

State of Hawai'i
Department of Health
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SECTION 10 ACRONYMS AND ABBREVIATIONS

%	Percent
COC	Chain-of-custody
COPC	Chemicals (or Contaminants) of Potential Concern
DQO	Data Quality Objective
DU	Decision Unit
EAL	Environmental Action Level
FID	Flame Ionization Detector
GC	Gas Chromatograph
HDOH	Hawai'i Department of Health
HEER Office	Hazard Evaluation and Emergency Response Office
LCS	Laboratory control sample
LCSD	Laboratory control sample duplicate
MIS	Multi Increment sample(s)
MS	Mass Spectrometer
MSD	Matrix spike duplicate
PARCC	Precision, accuracy, representativeness, completeness, and comparability
PCB	Polychlorinated Biphenyl
PID	Photo Ionization Detector
QA	Quality Assurance
QA/QC	Quality Assurance and Quality Control
QAPP	Quality Assurance Project Plan
QC	Quality Control
RL	Reporting Limit
RPD	Relative percent difference
RSD	Relative standard deviation
SAP	Sampling and Analysis Plan
SOP	Standard Operating Procedure
SVOC	Semi-volatile organic compound
UCL	Upper Confidence Level
USEPA	United States Environmental Protection Agency
VOA	Volatile organic analysis

10.0 DATA QUALITY ASSURANCE AND QUALITY CONTROL

The State of Hawai'i Department of Health (HDOH) Hazard Evaluation and Emergency Response Office (HEER Office) regards the quality of data as crucial to proper site characterization and evaluation of potential environmental hazards at a site. Data must be of sufficient quality to ensure that the overall site assessment objectives are met using the systematic planning approach (see Section 3). Ensuring that data is of sufficient quality begins during the initial planning and development of site investigation objectives and continues throughout the investigation to the final assessment of data quality. The HEER Office also regards evaluation of the suitability and usability of data as essential during both the site investigation and data quality documentation process.

The quality assurance and quality control (QA/QC) process should also be viewed as an approach to:

1. Ensure that site characterization data are adequate to accurately define site impacts and evaluate potential environmental hazards
2. Maximize the potential that any remedial actions at a site will be correctly selected
3. Ensure that site management decisions are arrived at with the correct information

Not devoting proper time and resources to QA/QC at any stage of investigation may result in uncertainly as to whether conclusions or actions are sufficiently protective of human health and the environment; this deficiency may be compounded by the need to make up for wasted time and resources.

10.1 PROJECT SPECIFIC QUALITY ASSURANCE PROJECT PLAN (QAPP) REQUIREMENTS

The Quality Assurance Project Plan (QAPP) is the formal project document that specifies the operational procedures and QA/QC requirements for obtaining environmental data of sufficient quantity and quality to satisfy site investigation objectives (see also Subsections 3.6 and 3.7). The QAPP is required for all data collection activities that generate data for use in decision-making. It contains information on project management, measurement and data acquisition, assessment and oversight, and data validation and usability. The QAPP integrates the Data Quality Objectives (DQO), the data collection design, and QA/QC procedures into a coherent plan to be used for collecting data of known quality and adequate for their intended use. The QAPP is typically presented as part of the Sampling and Analysis Plan (SAP) (Step 6 of systematic planning – See Subsection 3.2) and should include the following elements:

1. Quality assurance (QA) objectives for measurement
2. Sample chain of custody
3. Calibration procedures
4. Analytical methods
5. Data reduction, validation, and reporting
6. Internal quality control (field and laboratory checks)
7. Performance and system audits
8. Preventative maintenance
9. Data measurement assessment procedures (precision, accuracy, representativeness, completeness, and comparability)
10. Corrective actions

In addition, the QAPP should provide the contaminants of concern known or suspected to be present at the sampling location, the HEER Office Tier 1 Environmental Action Levels (EALs) (or other pertinent screening criteria) for those contaminants, and the quantitation limits needed to assess the EALs. The project-specific QAPP will also provide the required quantitation limits for these analytes in various matrices based upon their concentrations of concern. See Subsection 10.2.3 for additional information on quantitation limits.

More detailed information regarding the outline, format, and required content of the QAPP, is presented in Section 18.

10.2 QUALITY ASSURANCE OBJECTIVES

QA objectives and procedures are included in the sampling strategy to assess and evaluate a wide variety of concerns from sample collection through laboratory analysis. Defining QA/QC requirements is integral to the DQO process and is detailed in Section 3.0. The DQO must be developed well before any sampling or analysis and must be clearly defined in the SAP and QAPP for each project. QA objectives and procedures must also be defined in the SAP and the QAPP and will depend on the results of the project specific DQO processes.

10.2.1 DATA QUALITY OBJECTIVES

Data Quality Objectives are discussed in detail in Section 3.0 and summarized in this subsection. Environmental data must be of the appropriate type, quantity and quality to manage uncertainty and reach a defensible decision on appropriate response actions. To ensure that data obtained during a site investigation are adequate to identify or negate the presence of potential environmental hazards, the HEER Office recommends that the site investigation be developed using a **systematic planning approach**. This approach emphasizes using straightforward, clear questions to design and guide the site investigation. Consultation with the laboratory being utilized for sample analysis is also important to ensure the DQO can be met within their capabilities.

Systematic planning involves a series of well-thought-out steps that help ensure the investigation results are adequate to characterize potential environmental hazards posed by contamination and ultimately provide sufficient information to develop appropriate response actions. The recommended steps of the systematic planning approach, presented as Figure 3-1 in Section 3.0, function to establish the DQO for a site investigation.

DQO are established based on the expected end use of the data. For example, the data needed to perform a preliminary site screening assessment will differ significantly from the data needed to fully characterize a site and select an appropriate response action. DQO and the systematic planning approach in general are essential to developing a cost effective site investigation because they assure that resources devoted to sampling and analysis are not wasted on unnecessary or unreliable data.

10.2.2 QA OBJECTIVES

QA objectives must be specified in the project specific QAPP. For each sample matrix and environmental measurement type, define QA objectives in terms of the following information:

- Types of quality control (QC) samples and measurements involved
- Frequency of collection and analysis of QC samples and measurements
- How the QA objective is measured
- Acceptance criteria or QC limits for that measurement

For example, for soil samples analyzed for semivolatile organic compounds (SVOC), a project-specific QAPP might specify that the precision will be measured as the relative percent difference (RPD) between the results of matrix spike (MS) and matrix spike duplicate (MSD) samples. The QAPP might further specify that MS/MSD samples will be collected at a frequency of 1 MS/MSD sample for every 20 environmental samples, and that the QC limit for RPD is 20 percent for all spiking compounds.

Analytical data must be evaluated for compliance with QC limits. Typically, when analytical data do not meet the QC limits, corrective action must be initiated or the data will be qualified or rejected. Corrective action includes stopping the analysis; examining instrument performance, sample preparation, and analysis information; recalibrating instruments; preparing and reanalyzing samples. Examples of QC results indicating that corrective action may be necessary are provided in Subsection 10.8.

10.2.3 QUANTITATION LIMITS

A crucial QA objective is for sensitivity, which is generally expressed in the form of the method quantitation limit(s) (also commonly referred to as 'reporting limits') for the analytical method(s) selected. The concentrations of concern will be based on risk-based criteria, regulatory limits, and other similar guidelines. In Hawai'i, the default screening criteria on which to base quantitation limits are the HDOH HEER Office Tier 1 Environmental Action Levels (EALs) (HDOH, 2016).

Quantitation limits reflect the influences of the sample matrix on method sensitivity and are typically higher than detection limits. Quantitation limits provide a reliable indication of the amount of material needed to produce an instrument response that can be routinely identified and reliably quantified when applying a particular analytical method to real environmental samples.

The HEER Office requires analytical methods with sensitivities appropriate to the intended data use. Whenever possible, analytical methods should be specified such that matrix-specific reporting limits are lower than any contaminant concentrations of concern. In the event that the laboratory would not be able to achieve reporting limits below the screening criteria, the investigation team should first contact the HEER Office and present the proposed alternative laboratory reporting limit for the Chemical of Potential Concern (COPC) in a SAP or QAPP. Advance concurrence from the HEER Office for use of reporting limits above a relevant EAL must be obtained prior to initiation of field sampling. As part of the process for obtaining concurrence, the HEER Office will require that the investigation team document the proposed levels and provide well-documented evidence, rationale, and justification for using higher reporting limits.

10.3 DATA QUALITY ASSURANCE PROCEDURES

Table 10-1 Recommended QC Sample Frequency

QC Type	QC Sample	Default Frequency [1]
Field QC	Soil replicates/ triplicates	Depends on numbers of Decision Units (DU), COPCs, site characteristics. See Subsection 4.2.3 regarding field replicates (triplicates for MIS).
	Groundwater duplicates	1 per day for every 10 samples
	Equipment rinsate blank	Not required routinely when effective decontamination protocols are documented in the SAP. When required (e.g., investigations for trace levels), 1 per day per type of non-disposable sampling equipment
	Trip blanks	1 per shipping container containing volatile samples
	Source blanks	1 per water source per investigation, if used to decontaminate equipment for re-use.
Laboratory QC	Method blanks	1 per every 20 samples
	Sub-sampling replicates	1 per every 20 samples for soil analyses of non-volatile contaminants (triplicates preferred)
	MS/MSD percent recovery	1 per every 20 samples
	LCS/LCSD or blank spikes percent recovery	1 per every 20 samples
	Surrogate standard percent recovery	Every sample for organic analysis by gas chromatography

Notes:
LCS/LCSD Laboratory Control Sample/Laboratory Control Sample Duplicate
MS/MSD Matrix Spike/Matrix Spike Duplicate
MIS *Multi-Increment* sample
[1] Based on HEER Office guidance and SW-846 Method 8000C Guidance (USEPA, 2003a) pertaining to laboratory QC.

Implementing QA/QC procedures from start to finish in an investigation helps assure data that are usable and will meet and support the DQO. Procedures for Data Quality Assurance are presented within this subsection. Specifically, QA/QC parameters for precision, accuracy, representativeness, completeness, and comparability (commonly referred to as the "PARCC parameters") must be evaluated. The parameters of precision, accuracy, and completeness are quantitative measures, while representativeness and comparability are largely qualitative.

10.3.1 PRECISION AND ACCURACY

Precision and accuracy are evaluated quantitatively by collecting tPrecision and accuracy are evaluated quantitatively by collecting the types of QC samples listed in Table 10-1. While these QC samples are primarily intended for evaluation of precision and accuracy, the results are also used as necessary information for evaluating the other quality parameters.

The default, or preferred frequency, for these parameters is listed; however, different project-specific frequencies may be proposed to best meet project DQO. If proposing different QC sampling frequencies for a specific investigation, the proposed QC sampling program and the rationale should be presented in detail in the project-specific SAP or QAPP and should receive approval from the HEER Office prior to field investigation. More detailed descriptions of the individual types of QC samples and the modes of collection and handling are presented in Subsections 10.6 and 10.7.

Precision

Precision is the degree of mutual agreement between individual measurements of the same property under similar conditions. For soil samples, combined field and laboratory precision is typically evaluated by collecting and analyzing field triplicates and then calculating the variance between the samples as a Relative Standard Deviation (RSD) percent:

$$RSD\% = \frac{Standard\ Deviation}{Average} \quad x \quad 100\%$$

Groundwater field duplicates are evaluated by determining a RPD for the replicates, using RPD formula as noted below for laboratory MS/MSD precision determinations.

Laboratory analytical precision is evaluated by analyzing laboratory duplicates or MS and MSD, typically utilizing the following formula:

$$RPD = \frac{|A - B|}{(A + B)/2} \quad x \quad 100\%$$

where:

A = First duplicate concentration
B = Second duplicate concentration

The results of the analysis of each MS/MSD and sample duplicate pairs will be used to calculate an RPD for evaluating precision (USEPA, 2003a). These are default values that laboratories may use until they develop in-house QC limits for each method, in accordance with the guidelines established in SW-846 (USEPA, 2008a).

Laboratory sub-sampling poses the greatest potential for error in soil sample analyses for non-volatile contaminants; therefore, the HEER Office recommends laboratories perform triplicate sub-sampling analyses from at least one in every 20 of these soil samples (original sub-sample plus two additional sub-sample replicates collected independently from the entire mass of soil in the sample). Laboratory sub-sampling precision is typically calculated as RSD percent (for triplicates or more). The lab sub-sampling precision measure is also helpful to compare the degree of lab sub-sampling and analysis error to the total error (i.e. the field replicate precision data representing total error from field sampling plus lab sub-sampling and analysis). Soil sub-sample replicates (as well as sub-samples for any other soil analyses for non-volatiles) are collected by the laboratory from the entire mass of available sample using a sectorial splitter or by hand *Multi-Increment* sampling, as described in Subsection 4.2.2. This laboratory sub-sampling QC guidance applies to soil samples collected by *Multi-Increment* or discrete sampling approaches.

Accuracy

Sample spiking will be conducted to evaluate laboratory accuracy. This includes analysis of the MS and MSD samples, laboratory control samples (LCS) and laboratory control sample duplicates (LCSD), or blank spikes, surrogate standards, and method blanks. MS and MSD samples will be prepared and analyzed at a frequency of 5 percent. LCS or blank spikes are also analyzed at a frequency of 5 percent. Surrogate standards, where available, are added to every sample analyzed for organic constituents. The results of the spiked samples are used to calculate the percent recovery for evaluating accuracy (USEPA, 2003a).

$$\text{Percent Recovery} = \frac{S - C}{T} \quad x \quad 100$$

where:

S = Measured spike sample concentration
C = Sample concentration
T = True or actual concentration of the spike

Results that fall outside the project-specific accuracy goals will be further evaluated on the basis on the results of other QC samples. Table 10-1 summarizes recommended default frequencies for QC sample types. Example default precision and accuracy goals for laboratory analyses are described in Subsection 10.7.

10.3.2 REPRESENTATIVENESS

Representativeness is a qualitative measure that expresses the degree to which field data accurately and precisely represents a characteristic of a population, parameter variations at a sampling point, process condition, or environmental condition. For purposes of environmental investigation, representativeness is how well the media (e.g., soil) sampled represents impact (i.e., contamination) at the site. In the initial planning stages of an investigation, representativeness of data collected is first ensured by proper sampling design. Project planners account for the difficulty in knowing when, where, and how to collect representative samples by developing a statistical or random sampling approach; collecting adequate numbers of increments or samples to

determine a representative average COPC concentration in each decision unit; collecting samples at several different phases of natural or anthropogenic cycles; sampling at different locations within the project area; collecting *Multi-Increment* samples as opposed to grab samples; and verifying and validating the sampling techniques. The general strategies for ensuring representativeness are described in Section 3. The specific strategy used by the investigation team for each site is to be documented in detail in the project-specific QAPP or SAP.

One measurement of representativeness is the degree to which implementation of the sampling program has ensured that results reflect the site contaminant conditions and not outside impacts related to analytical preparation, field sampling, field decontamination, sample handling, sample shipping and other aspects of field investigation. The degree to which the sampling strategy has achieved representativeness can be measured as a qualitative parameter based on the proper implementation of the sampling program and laboratory analytical program (i.e., the QA/QC program set out in the QAPP). The results of field QC samples (i.e., replicates, trip blanks, field source blanks, or equipment blanks) may indicate that compounds have been introduced into the samples, possibly to an extent that would affect representativeness of the overall investigation.

Representativeness may also be measured by how well samples were delivered to the analytical laboratory within the described holding times and holding temperatures prescribed for individual analyses. Potential impacts to data quality measured by the QA/QC methods include (but are not limited to) the following:

- Insufficiency or lack of cleanliness of sample collection containers, materials or preservatives provided by the analytical laboratory prior to field work, to ensure that outside contaminants are not introduced into the analytical process
- Impurities detected in final decontamination rinse water that may not have originated from the site
- Contaminants originating from exposure during transport of samples from the field to the analytical laboratory
- Sample transport where delivery time to the laboratory exceeds holding time or sample temperature exceeds allowable temperature limits. Occurrence of either may indicate loss of contaminants during transport prior to extraction and analysis

Representativeness should be assessed for each matrix (media) and for each COPC. In addition to trip blanks for sites with volatile organics sampling (see Subsection 10.6.2.1) or equipment rinsate blanks and field source blanks (as described in Subsections 10.6.2.2 and 10.6.2.3), the following field QC procedures are used in evaluating representativeness:

- Temperature measurement, usually of the samples themselves and sometimes via separate temperature blanks. These blanks are containers of analyte-free water included with field samples, handled and transported in the same manner and measure for temperature upon delivery to the analytical laboratory. Trip blanks sometimes double as temperature blanks
- Chain-of-custody forms that document date and time of sampling and sample preservation for each sample

If analyses of field QC blank samples result in detected contaminants, the field procedures for decontamination, sample handling, and sample transport should be evaluated for how well procedures were followed, for any potential introduction of contaminants from outside sources, or for potential losses in the course of sample handling or transport.

10.3.3 COMPLETENESS

Completeness is a measure of the percentage of data that are valid. Data validation is performed by evaluating field and laboratory QC analyses combined with field QC logs, and chain-of-custody form information to determine how well field samples were collected and analyzed in accordance with QC procedures outlined in the QAPP. Field analytical data are acceptable if log and Chain-of-Custody (COC) information show that field QC procedures were properly followed, no significant level of analytes are detected in QC blank analyses, and when none of the QC objectives that affect data usability are exceeded. Data validation is also performed to determine when data should be rejected or declared unusable due to improper field QC, detection of analytes in blanks or laboratory QC limit exceedances. Completeness will also be evaluated as part of the data quality assessment process. This evaluation will help determine whether any limitations are associated with the decisions to be made based on the data collected.

Completeness is a percentage value, calculated to determine if an acceptable amount of usable data was obtained so that a valid scientific site assessment may be completed. The QAPP should present completeness goals (e.g., commonly 95%) to evaluate the degree of completeness. Percent completeness is calculated using the following equation:

$$\%C = \frac{T - R}{T} \times 100$$

where:

%C = percent completeness
T = total number of sample results
R = total number of rejected sample results

Completeness at a minimum should be determined for all field analytical results by method, but should also be determined by comparing the planned number of samples per method and specific matrix.

10.3.4 COMPARABILITY

Comparability is a qualitative parameter that expresses the confidence with which one data set can be compared with another. It is important that data sets be comparable if they are used in conjunction with other data sets. This type of comparison manifests itself most commonly (but not limited to) the following scenarios:

- Data from the same site but collected during different investigations.
- Data from the same site but collected during widely separated time-frames.
- Comparison of data from the same site and investigation, but analyzed by different laboratories.

Comparability of data can be achieved by consistently following standard field and laboratory procedures and by using standard measurement units in reporting analytical data. The factors affecting comparability include sample collection and handling techniques, matrix type, and analytical method. If these aspects of sampling and analysis are carried out according to standard analytical procedures and the procedures implemented properly, the data may be considered comparable. Comparability is also dependent upon other quality criteria, because only when precision, accuracy, and representativeness are known may data sets be compared with confidence. In some cases, additional care must be taken to evaluate comparability. For instance, groundwater samples handled in the exact same fashion, collected within the same sampling event, and analyzed by the same analytical method may not be directly comparable if one sample was filtered and the other was not.

10.4 QUALITY CONTROL

Field and laboratory QC samples and measurements must be used to verify that analytical data meet project-specific QA objectives. Field QC samples and measurements are used to assess how the sampling activities and measurements influence data quality. Similarly, laboratory QC samples are used to assess how a laboratory's analytical program influences data quality. How well a laboratory's QC program is set up, its past performance in implementing that program, and how well QC goals have been met also play a critical role in laboratory selection. The project-specific QAPP will provide a description of QC samples to be analyzed during the investigation for (1) each field and laboratory environmental measurement method and (2) each sample matrix type.

All laboratories that perform analytical work for investigations performed by or reviewed by the HEER Office must adhere to a QA program that is used to monitor and control all laboratory QC activities. Each laboratory must have a written QA manual that describes the QA program in detail. The laboratory QA manager is responsible for ensuring that all laboratory internal QC checks are conducted according to the laboratory's QA manual, and the requirements included within a project-specific QAPP or SAP. The most common (and default for projects conducted and reviewed by the HEER Office) QA/QC procedures are those outlined in the United States Environmental Protection Agency's (USEPA's) publication entitled: "Test Methods for Evaluating Solid Waste, SW-846" (USEPA, 2008a), and laboratory standard operating procedures (SOPs). Investigators should consult the USEPA SW-846 website under the following circumstances:

- During project planning to determine the most recent edition of any analytical method or SOP to cite in the work plan or QAPP.
- During selection of the analytical laboratory to ensure that they are employing the most recent method or SOP cited in the SAP or QAPP.
- If the investigation is utilizing multiple analytical laboratories.
- When significant time has elapsed between project planning and field investigation or between stages of field investigation to ensure that a previously cited or utilized method or SOP has not been modified or superseded.

For particulate (e.g., soil or sediment) samples, laboratories should follow the USEPA lab sub-sampling guidance (USEPA, 2003b) to ensure that representative lab sub-samples are obtained for subsequent analysis.

Many of the laboratory QC procedures and requirements are described in USEPA-approved analytical methods, laboratory method SOPs, and method guidance documents. If, however, laboratory QC requirements are not specified in an analytical method, or if additional requirements beyond those included in an analytical method are necessary to ensure that project QA objectives and DQO are met, the project-specific QAPP should identify the additional laboratory QC checks to be performed. The following types of information should be included:

- Laboratory analytical method(s) to which the internal QC check applies
- Complete procedures for conducting the internal QC check
- QC samples and QC measurements involved in the internal QC check
- Complete collection and preparation procedures for the QC samples
- Spiking analytes and concentrations
- Control limits for the internal QC check
- Corrective action procedures to be followed if the internal QC check is not done properly or results are outside control limits. Description of example instances that may require corrective action is presented in Subsection 10.8.

Laboratory QC procedures and requirements may include the preparation and analysis of sub-sampling replicates, method blanks, LCS, surrogate spikes, matrix duplicates, MS and MSD samples, and standard reference materials or independent check standards. Subsections 10.6 and 10.7 describe field and laboratory QC procedures respectfully. Subsection 10.7.7 includes information on data that the analytical laboratory should include in project analytical reports.

10.5 FIELD EQUIPMENT AND LABORATORY INSTRUMENT CALIBRATION

10.5.1 FIELD EQUIPMENT CALIBRATION

Investigations of soil, water, or gas phase matrices utilize variety of field equipment, such as a photo-ionization detector (PID) or flame-ionization detector (FID) to measure volatile constituents in soil sample, water quality measurement instruments, or a flow controller to limit or regulate the flow of gas.

In general, calibrate field equipment at least daily prior to its first use. Re-calibrate or check field equipment throughout the field day to verify that it is operating properly. Record field equipment calibration and equipment field checks in a field logbook and/or on a calibration log sheet accompanying the instrument. At a minimum, record:

1. Date and time of calibration
2. Type and identification number of equipment being calibrated
3. Reference standard(s) used for calibration
4. Name or initials of person performing the calibration.

10.5.2 LABORATORY EQUIPMENT CALIBRATION

For Method 8000 analyses, laboratory instruments are typically calibrated with a linear 5-point calibration curve prior to use. A calibration is considered valid if the 5-point linear curve meets a less than or equal to 20 percent RSD. Continual calibration verifications throughout the analytical day assess whether the calibration curve has drifted as a result of instrument use (USEPA, 2008a).

10.6 FIELD QA/QC

More than one type of field QA/QC sample may be collected simultaneously to provide a broad assessment of sample data quality. Field QA/QC sampling is typically used to evaluate the following, as well as other considerations:

- Accuracy of sample collection, processing and analysis procedures through the use of field replicates.
- Accuracy of sample analysis procedure through the use of field replicates sent to separate laboratories.
- Effectiveness of sample collection equipment decontamination procedures through the use of equipment blanks.
- Sample handling and transportation procedures through the use of trip blanks– for samples in aqueous media being analyzed for volatile chemicals.

The frequency of QA/QC sample collection is strongly dependent upon a variety of factors including the sample matrix (i.e., soil, water, or gas phase), COPCs, and QA/QC questions to be answered. The number of field QA/QC samples is site and project specific and needs to be addressed in detail in the SAP or QAPP for each project. A QA/QC sample should be analyzed for the same constituents and by the same method as the primary sample.

QA/QC samples should be labeled in a manner that does not allow the analytical laboratory to identify or correlate the QA/QC sample to the primary sample. This is often referred to as the submission of "blind" samples to the analytical laboratory. For example, if only one primary sample is collected, a replicate QA/QC sample label should not identify it as a duplicate (or other) QA/QC sample. If more than one primary sample is collected, the QA/QC sample name may indicate that it is a duplicate (or other) QA/QC sample as long as correlation to the primary sample is not possible (e.g., by indicating a sample collection date or time different from the primary sample).

10.6.1 FIELD REPLICATES

Field replicate samples are duplicate or triplicate samples collected from within the same decision unit or from the same groundwater well to evaluate the precision of the sampling effort. Replicates are to be collected, preserved, stored, transported, and analyzed in the same way as primary field samples. Duplicate or triplicate samples are collectively referred to as "replicate" samples unless specifically indicated. Replicates are intended to represent the same population and are taken to provide information on precision, accuracy, and representativeness for the data collection activity (e.g., replicates provide a measure of contaminant heterogeneity for a specific decision unit). If the degree of contaminant heterogeneity exceeds established DQO in the SAP, then additional sampling and/or steps to limit errors during sample processing and analysis are typically required to provide representative sample data. A field replicate precision of approximately 10-35% is generally established as a DQO, depending on the media and contaminant.

The method for collecting replicate QA/QC samples is strongly dependent upon the sample matrix, the COPCs, and the QA/QC questions to be answered, particularly when considering *Multi-Increment* sample (MIS) techniques as compared to discrete sampling.

10.6.1.1 DISCRETE SAMPLING REPLICATES

In general, for discrete sampling of groundwater or soil the HEER Office recommends collecting one replicate QA/QC sample per field day per sample matrix, or 10% of all field samples, whichever is greater. At least 10% replicate QA/QC samples should be collected in each decision unit or each area of known or suspected contamination. Consider both the horizontal and vertical dimensions when planning replicate QA/QC sample locations. If small scale heterogeneity is expected at the site, additional replicate QA/QC samples may be required to assess the scale of heterogeneity. Different project-specific frequencies may be proposed to best meet project DQO. If proposing different QC sampling frequencies for a specific investigation, the proposed QC sampling program and the rationale should be presented in detail in the project-specific SAP or QAPP and discussed with the HEER Office prior to field investigation.

Co-located duplicate samples

Co-located duplicates are samples collected at the same time from a location in proximity to the primary sample. Co-located duplicate soil samples are commonly collected due to sample volume factors (i.e., the volume of sample material retrieved in the sampler is less than the volume of sample required for laboratory analysis). Minimize the distance between the primary and

duplicate sample collection points; small scale heterogeneity in the contaminant distribution is more likely as the distance increases.

The co-located samples would be expected to have similar contaminant concentrations. Data quality objectives to evaluate the precision of co-located samples should be included in the SAP or QAPP, and co-located sample data compared to ensure these DQO are met.

Duplicate groundwater samples

For non-volatile groundwater contaminants collected in vials, generally two sample containers are "alternately" filled. For example, if a low-flow pump is used, the two containers would be filled by going back and forth with the discharge tubing.

For volatile groundwater contaminants, where multiple 40 ml vials are commonly used for each sample and loss of volatiles is an important concern, the primary and duplicate sets of samples are collected alternately. One vial is completely filled with the primary sample then a duplicate sample vial is filled until all vials (primary and duplicate sets) for that one sample are collected. It is also important to follow vial filling protocols appropriate to ensure minimal agitation and zero-headspace for the volatile samples.

Relative Percent Difference

In certain cases, particularly for discrete sampling, only duplicates rather than triplicates may be available to evaluate precision of sampling data, though triplicates are recommended wherever feasible. In those situations where only duplicates are able to be collected, the precision of the data would be evaluated by determining the RPD.

The RPD is calculated as described in Subsection 10.3.1.

10.6.1.2 *MULTI-INCREMENT* SOIL SAMPLING REPLICATES

The *Multi-Increment* soil sampling approach relies on collection of field replicate (triplicate) samples to estimate the sampling precision, as discussed in Subsection 4.2.3. Collecting and analyzing triplicate samples allows for statistical calculation of several important quantities including the standard deviation, RSD, and 95 percent (%) upper confidence level (UCL) of the mean. These statistical evaluations are utilized to determine the degree that the measured levels of contaminants vary from the (estimated) mean, and is taken into consideration when comparing site data to applicable HEER Office EALs (See Subsection 4.2.5).

The number of decision units where *Multi-Increment* sample replicates are collected will vary with each project, total number of decision units, and site characteristics. Consequently the number of DUs with replicates is site-specific and determined as part of the overall sampling strategy in the SAP. A batch-type replicate approach (similar to that used in the lab) may be applied in the field, if multiple decision units are similar (e.g., similar soil type, contaminants of concern, history of chemical use, topography, etc.). If multiple similar DUs are evaluated on a site, replicates in one DU may be used to evaluate that DU and up to 9 similar DUs. In this case, the precision data determined for contaminant(s) in one DU (e.g., RSD) would also be applied to the other DUs in the similar batch.

Standard Deviation, Relative Standard Deviation, and 95% Upper Confidence Limit of the Mean

The standard deviation is a statistical measure of the scatter, or variability, of several sample values around their mean (or average). The lower the standard deviation, the lower the variability of the sample values observed in the data. The standard deviation may be informally interpreted as the size of a "typical" deviation from the mean (or average) and may be calculated using standard equations presented in an introductory statistics book or included as software functions in programs such as Microsoft Excel.

The RSD, expressed as a percent, is a measure of precision among several sample values (the normal, duplicate, and triplicate samples in the case of *Multi-Increment* sampling). The RSD differs from the RPD in that it measures the precision among several sample values versus between just two sample values. The RSD can be calculated as the standard deviation of the sample replicates divided by the mean (or average) of the sample replicates, times 100%.

An RSD of 35% or less is typically a goal during environmental investigations. However, an RSD greater than 35% does not necessarily mean the data is not usable for the intended purpose. For example, an RSD somewhat greater than 35% may be acceptable if the estimated average level of contaminant(s) in the DU is much greater or much less than the relevant HDOH Tier 1 EAL.

The 95% UCL is another statistical measure of the precision for a series of sampling measurements. In this case, the normal, duplicate and triplicate samples are used to calculate a mean (or average) value and a standard deviation. The mean and

standard deviation are used to calculate, with 95% confidence, the mean value for the individual decision unit. Formulas and spreadsheets for calculating the 95% UCL are available through websites providing statistical analysis support.

10.6.2 BLANKS

Blank QA/QC samples are aliquots of the sample matrix that is known to be free of contaminants. The analytical data for blanks provides a measure of the cross-contamination that may have occurred during sample collection, sample storage and transport, or during laboratory preparation, extraction, and analysis. Compare the analytical results of the various types of blanks to each other to assess the degree to which contamination may have been introduced into the samples.

10.6.2.1 TRIP BLANKS

The purpose of a trip blank is to assess the possibility of cross contamination during sample collection, storage, and transport to the analytical laboratory. The trip blank is typically analyzed for volatile organic compounds in aqueous samples due to the high vapor pressure and potential for vapor migration. Non-aqueous samples collected using methanol preservation techniques may also require a trip blank.

Prepare trip blanks by filling sample containers with reagent grade water, then assuring that the trip blank sample containers accompany the main sample containers along every step to the analytical laboratory. Trip blanks are not opened in the field. Trip blank water should be from the same source as the method blank water used in the laboratory.

10.6.2.2 FIELD EQUIPMENT RINSATE BLANKS

The purpose of an equipment blank (also commonly referred to as a field equipment rinsate sample) is to place a mechanism of control on sample collection equipment (i.e., soil core samplers or sample tubing) that is decontaminated and reused in the field. Specifically, an equipment blank assesses sample collection equipment and/or related ambient conditions that may affect sample quality. Because the equipment blank is stored and transported with the primary samples, it is also representative of sample bottle preparation, storage, and transport conditions.

An equipment blank is collected by pouring reagent grade water over/through decontaminated equipment used in sample collection. The water is then collected in a sample container and analyzed for the contaminants of interest. Equipment blank water should be from the same source as the method blank water used in the laboratory.

The use of field equipment rinsate blanks is important for ultraclean and very low level (trace) contaminant investigations; however, in many general contaminant investigations it is not necessary as long as a specific and effective protocol (i.e., SOPs) for field decontamination of any re-used sampling tools is documented in the SAP and utilized. Collection of large *Multi-Increment* soil samples (rather than discrete samples) further decreases the potential for cross contamination with trace amounts of soil left on a sampling tool.

The protocol for decontamination should ensure that new sampling equipment is decontaminated (or certified clean and in original container until used) and any previously used equipment is decontaminated before reuse. The SAP or QAPP should clearly identify if the site investigation will or will not include equipment rinsate blanks, and discuss the rationale for this decision. Field (water) source blanks are required to be analyzed whenever equipment is decontaminated in the field. Where equipment rinsate blanks are included for trace level investigations or for other reasons, the HEER Office recommends collecting one equipment blank per matrix per sampling team per day.

10.6.2.3 FIELD SOURCE BLANK

Field source blanks are collected from the water source used for decontamination rinse of equipment, and are used to assess potential for contamination in the water used for decontamination. One source blank is collected from each source of water used for decontamination.

10.6.3 DOCUMENTATION

Document the following sampling information, as applicable, for primary and QA/QC samples in the field log:

- Time and date of sample collection
- Name of person(s) collecting the sample
- Location of sample
- Sampling procedure
- Sample identification
- Source of blank matrix
- Table that provides a cross reference of primary and replicate samples
- Equipment decontamination procedure

10.6.4 CHAIN OF CUSTODY

Attach a label to the sample jars and log each sample on a chain-of-custody (COC) form. Provide at a minimum the following information on the COC:

- Project identification
- Samplers name
- Sender - company name and address
- Destination - laboratory name and address
- Sample identification
- Number of sample containers per sample
- Preservation, if any
- Date and time of sample collection for each sample
- Requested analytes
- Special handling requirements, if any
- Shipping company
- Name and signatures of persons relinquishing custody
- Date and time when custody is relinquished
- Signatures of persons receiving custody
- Date and time when custody is received

The chain-of-custody must not be broken between the sampler and the laboratory sample receiving personnel. Enter the name of the shipping company into the received custody section, if the samples need to be shipped.

10.7 LABORATORY QA/QC

An accurate estimate of the precision or accuracy of analytical results is only possible if sample results are derived within laboratory reporting limits (RL) required by the DQO described in the SAP or QAPP. The RL represents the concentration of a specific analyte the laboratory can detect to a high degree of confidence for a particular sample.

The QAPP identifies DQO for the project; the laboratory report indicates RLs for each result. Variables that affect the laboratory's ability to achieve the RL conforming to the QAPP include: the sample matrix, naturally occurring background concentrations, and laboratory instrumentation. QA/QC requirements include following the referenced analytical method for each chemical of concern.

Most analytical data from laboratories are documented in computer records or on printouts generated by the instrument data-handling computer and transferred to a centralized acquisition server. Standard logs are maintained to document the preparation of standards. The identity and number of the parent material is recorded and each prepared standard is assigned a number that is traceable to the parent material. All data from analytical laboratories should be collected and documented in such a manner that allows the generation of data packages that can be used by an external data auditor to reconstruct the analytical process.

10.7.1 METHOD BLANKS

The laboratory analyzes method blanks for each analytical batch and uses results to assess laboratory background or reagent contamination. An aliquot (extraction blank) equal in mass to the sample and known to be free of the COPCs is used for method blank analysis. The matrix of the method blank is selected to represent the sample matrix as closely as possible. The method blank is taken through the whole analytical process and is analyzed exactly like the calibration standards, field samples, and field replicate samples. Method blank analytical results are included in the analytical report. Method blanks should be prepared and analyzed at a frequency of at least 1 per every 20 field samples (5%) of the same matrix (USEPA, 2003a).

10.7.2 LABORATORY CONTROL SAMPLES (LCS)

The laboratory analyzes an LCS to assess overall method performance; it is the primary indicator of laboratory performance. The LCS is commonly accompanied by an LCSD. The LCS and LCSD pairs should be prepared and analyzed at a frequency of at least 1 per every 20 field samples (i.e., 5%) of the same matrix (USEPA, 2003a). The LCS and LCSD are typically similar in composition to the primary samples, contain known concentrations of all analytes of interest, and undergo the same preparatory and determinative procedures as the primary samples. LCS and LCSD pairs are used to assess laboratory specific precision and accuracy or to assess the performance of an analytical method. Laboratories should have established internal QC RPD and Percent Recovery limits as defined in Subsection 10.3.1 for each method. The parameters should be developed in accordance with guidelines established in USEPA SW-846 (USEPA, 2008a). In the absence of established guidelines, RPD goals of 20% and Percent Recovery goal ranges of 70 to 130% should be used as default objectives (USEPA, 2003a).

When both an LCS and an LCSD are processed for a batch of samples, there is no significant physical distinction between the LCS and LCSD. Both the LCS and LCSD must satisfy the same recovery acceptance criteria, which is usually based on the laboratory specific control limits.

The LCS and LCSD are prepared by spiking an uncontaminated sample matrix with known amounts of analytes from a source independent from the calibration standards. Should the LCS and LCSD fail the acceptance criteria, the entire analytical batch must be re-analyzed with another LCS and LCSD pair.

10.7.3 MATRIX SPIKES (MS)

An MS sample is evaluated to assess the accuracy and precision of an analytical method with respect to the sample matrix. The MS is commonly accompanied by an MSD sample. The MS and MSD samples are prepared by adding known concentrations of analytes to the sample matrix prior to sample preparation. The MS/MSD pairs should be prepared and analyzed at a frequency of at least 1 per every 20 field samples (i.e., 5%) of the same matrix (USEPA, 2003a). The concentrations of analytes in the sample matrix are known prior to the addition of matrix spike analytes.

The MS and MSD are used to identify matrix interference peaks that may co-elute with target analytes. The MS and MSD are taken through the whole analytical process. Following the analytical process, the recoveries of the spike analytes are calculated and reported for assessment of accuracy. When an MSD is analyzed, the relative percent differences between the MS and the

MSD results will also be calculated and reported. The percent recoveries and the relative percent difference are used to evaluate the effect of the sample matrix on the accuracy and precision of the analysis. Matrix interference effects may result in the MS and MSD failing the acceptance criteria. However, the MS and MSD pair must satisfy their acceptance criteria for the analytical batch to be considered in control and acceptable.

10.7.4 MATRIX CLEANUP

Matrix cleanup methods are applied to the extracts prepared by one of the extraction methods to eliminate sample matrix interferences. Several cleanup methods may be employed depending upon the target analytes of interest. USEPA Method 3600 from SW-846 provides general guidance on selecting cleanup methods (USEPA, 2008a).

As indicated in USEPA Method 3600, the purpose of applying cleanup methods to extracts is to remove interferences and high boiling point material that may result in the following:

- Errors in quantitation [data may be biased low because of analyte adsorption in the injection port or front of the gas chromatograph (GC) column, or biased high because of overlap with an interference peak]
- False positives because of interference peaks falling within the analyte retention time window
- False negatives caused by shifting the analyte outside the retention time window

Most extracts of soil require some degree of cleanup. Highly contaminated extracts (e.g., soil containing oily residue) often require a combination of cleanup methods. Following extraction and cleanup, the extract is analyzed by one of the determinative methods. If interferences still preclude analysis for the analytes of interest, additional cleanup may be required.

10.7.5 SURROGATES

Surrogate spikes involve the addition of a known concentration of a non-target analyte prior to sample preparation and analysis. The surrogate is chemically similar to the target analyte(s) and behaves similarly during extraction and analysis. The surrogate spike recovery must meet the established acceptance criteria, and measures the efficiency of the steps of the analytical method in recovering the non-target analytes.

10.7.6 LABORATORY SUB-SAMPLING REPLICATES

Laboratory sub-sampling replicate QA/QC samples are generally employed for all soil, sediment, or other particulate samples analyzed for non-volatile contaminants (from *Multi-Increment* or discrete samples). The HEER Office recommends triplicate sub-sampling and determination of the RSD. Due to the typically smaller mass of discrete soil samples, there may be situations where only duplicate lab sub-samples may be feasible. This issue should be considered during the systematic planning phase of the investigation when determining DQO and coordinating with the laboratory.

The HEER Office recommends collecting laboratory sub-sampling replicate QA/QC samples at a frequency of at least one per 20 samples, or at least one if there are less than 20 samples. Replicate sub-samples are collected from the entire mass of sample available (e.g. the entire mass of sample available after drying and sieving to project-specific particle size, typically < 2mm). Sub-sampling should be performed using a sectorial splitter or by hand *Multi-Increment* sampling. The USEPA lab sub-sampling guidance (USEPA, 2003b) provides detailed information on sub-sampling procedures.

10.7.7 QA/QC REPORTS

The investigation team generating the data should include an experienced data reviewer or a third party data validator to review the analytical data to determine its validity and therefore usability.

The data reviewer or validator should review all QC-related information provided in the data package and project-specific laboratory report provided by the analytical laboratory. As part of the process of selecting the project analytical laboratory, the investigation team will ensure that the laboratory assigns a data analyst. The analyst should review the data to assess that:

- Sample preparation information is correct and complete.
- Analysis information is correct and complete.
- The appropriate SOPs were followed.
- Analytical results are correct and complete.
- Quality control samples were within established control limits.
- Documentation, including the case narrative is complete.

The analyst will then review the analytical data package to verify that:

- Calibration data are scientifically sound and method compliant.
- QC samples were within established guidelines.
- Qualitative and quantitative results are correct.
- Documentation and the case narrative are complete.
- The data package is complete and ready for document archiving.

The laboratory report must provide the following QA/QC information:

- Sample temperature at time of receipt
- Whether sample hold times were within method limits.
- Whether samples were received in good condition.
- Whether bubbles were present in volatile organic analysis (VOA) vials at time of receipt and size of bubbles if any.
- Description of corrective measures taken, if any QA/QC sample results were out of laboratory control limits.

10.8 CORRECTIVE ACTION

Whenever any QC parameters are outside of the control limits or DQO specified in the SAP or QAPP, the investigation team must identify the potential origin(s) of the problem(s), and initiate any appropriate corrective action. In some cases, the corrective action may involve evaluating potential impacts that these exceedances have on data quality and therefore usability of the data.

Any investigation should include a checklist of parameters or questions related to potential data quality issues potentially needing corrective action. Example issues include (but are not limited to) the following:

- Were any analytes, not on the initial SAP analyte suite, detected in laboratory blanks that could be attributed to laboratory contamination rather than field contamination? (e.g., solvents commonly used in analytical laboratories such as methylene chloride and acetone that were likely not used, handled, or stored at the site under investigation).
- Were any analytes of concern detected in the Method Blank? This may indicate contamination that is unrelated to the field sample.
- Were contaminants found in both the environmental sample and a blank sample? Such detections may be regarded as laboratory artifacts and not a result of contamination at the investigation site if the contaminant is detected in both and the concentration in the environmental sample is:
    - less than 10 times the blank value for common laboratory contaminants (e.g. methylene chloride, acetone, 2-butanone and phthalate esters)
    - greater than five times the blank value for other potential laboratory contaminants
- Did the RPD and Percent Recoveries for any of the QC analyses (e.g., LCS, MS/MSD) exceed the control limits initially specified in the SAP or QAPP? This may indicate sample preparation problems such as differences in spike solution preparation methods. If the control limits for a certain batch of samples being analyzed are exceeded and underlying issues not identified or resolved, the affected samples may need to be qualified or rejected.
- Was there any matrix interference suspected or determined that required dilution of the sample for reanalysis (e.g., did the dilution cause any reanalysis reporting limit to exceed the corresponding screening or regulatory criteria)? This may result in a degree of uncertainly for contaminants that may potentially mask each other on a chromatogram, such as pesticides and polychlorinated biphenyls (PCBs), or it may cause the reporting limit to exceed the HDOH Tier 1 EAL screening criteria or cleanup criteria.
- Were all calibration verification sample results within control limits? If any fail, recalibration of the instrument is necessary.

These parameters should be evaluated before accepting the data for use in the overall site investigation. Investigation reports should also include a data quality evaluation section that addresses these issues and provides documentation and justification for accepting the data. The HEER Office may reject data that does not meet the agreed upon level of data quality in the initially reviewed work plan or planning documents for the investigation. In more extreme cases, not evaluating data quality issues or initiating appropriate corrective action after an issue is identified may result in rejection of subsequent data sets.

SECTION 10 REFERENCES

Citation references for this TGM Subsection denoted with an “a”, “b”, “c”, etc… after the year of publication may not appear in sequence as these refer to the order placed in the Master References List for the entire TGM.

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SECTION 11
HANDLING AND ANALYSIS OF SAMPLES

Interim Final - July, 2017

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SECTION 11 ACRONYMS AND ABBREVIATIONS

°C	Degree Celsius
≤	Less than or equal to
A	Hold time after extraction until analysis
APHA	American Public Health Association
ASTM	American Society for Testing and Materials
BTEX	Benzene, toluene, ethylbenzene, and total xylenes
CFR	Code of Federal Regulations
CWA	Clean Water Act
Dioxins	Polychlorinated dibenzodioxins
DOT	U.S. Department of Transportation
DQO	Data Quality Objective
E	Hold time to extraction
EAL	Environmental Action Level
Furans	Polychlorinated dibenzofurans
HCl	Hydrochloric acid
HDOA	Hawai'i Department of Agriculture
HDOH	Hawai'i Department of Health
HEER Office	Hazard Evaluation and Emergency Response Office
HNO_3	Nitric acid
HVOCs	Halogenated Volatile Organic Compounds
L	Liter
MIS	Multi Increment sample(s)
mL	Milliliter
mm	Millimeter
MTBE	Methyl tertiary butyl ether
Na_2SO_4	Sodium bisulfate
NaOH	Sodium hydroxide
NaS_2O_3	Sodium thiosulfate
NELAC	National Environmental Laboratory Accreditation Conference
NIOSH	National Institute for Occupational Safety and Health
PAH	Polynuclear Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
PPE	Personal Protective Equipment
QA/QC	Quality Assurance and Quality Control
SAP	Sampling and Analysis Plan
SDWA	Safe Drinking Water Act
SOP	Standard Operating Procedure
SVOC	Semi-volatile organic compound
TGM	Technical Guidance Manual
TPH-D	Total Petroleum Hydrocarbons-diesel range
TPH-G	Total Petroleum Hydrocarbons-gasoline range

TPH-O	Total Petroleum Hydrocarbons-oil range
TSA	Transportation Security Administration
US Navy	United States Department of the Navy
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
VOA	Volatile organic analysis
VOC	Volatile Organic Compound

11.0 HANDLING AND ANALYSIS OF SAMPLES

This section presents appropriate methods for containing, preserving, shipping, and analyzing environmental samples for projects conducted under the guidance of this Technical Guidance Manual (TGM). Proper handling and analysis of environmental samples is an essential step to collecting representative, defensible data and to achieving Data Quality Objectives (DQO). The Sampling and Analysis Plan (SAP) documents necessary sample handling and analysis procedures and should identify the matrix to be sampled, the type and volume of proposed sample containers, preservatives (if any), and the proposed analytical methods for each sampling event.

This section focuses on soil and groundwater samples collected as part of an environmental investigation, which are sent to a fixed laboratory for analysis. Mobile laboratories used for field analysis may also be employed during an environmental investigation, but the use of mobile laboratories should be carefully planned and documented in the SAP prior to field activities and analysis. The State of Hawai‘i Department of Health (HDOH) Hazard Evaluation and Emergency Response Office (HEER Office) recommends the submittal of SAPs proposing the use of mobile laboratories for review prior to the initiation of sample collection activities.

During the collection, handling, and packing activities, personnel should use proper personal protective equipment (PPE). Typical PPE for use in sample collection, handling, and packing should include gloves and safety glasses, especially when employing chemical preservatives. Site-specific conditions may require the use of additional PPE (e.g., chemical protection clothing) based on the hazards present at the site, which should be documented in the site-specific Safety and Health Plan within the SAP.

Packing extra sample containers is recommended when planning fieldwork, in case additional sampling locations or areas are identified during execution of the fieldwork. Breakage, both prior to and after sample collection should be considered, particularly in light of challenges presented by remote field sites, as well as shipping requirements unique to performing investigations in Hawai‘i.

Guidance is presented on the use of soil sampling equipment in Section 5 and on the use of groundwater or surface water sampling equipment in Section 6. A discussion of gas phase samples is not included in this section; guidance on handling and analysis of soil vapor or indoor air samples is presented in Section 7. Quality assurance/quality control (QA/QC) considerations, such as trip blanks and equipment rinsate blanks, are discussed in Section 10.

11.1 SAMPLE CONTAINERS

Recommended sample containers for soil are presented in Table 11-A in the Appendix 11-A, while Table 11-B in the Appendix 11-B present the recommended sample containers for groundwater. The sample volumes for the containers listed in the tables represent the recommended size of container. More than one sample container may be required for the associated parameter and method. If soil or groundwater samples are to be analyzed for multiple contaminants, the sample volumes listed in the tables will require adjustment. Always consult with the laboratory when planning fieldwork to ensure that the proper sample containers and preservatives are used and sufficient sample mass/volume is collected for all intended analyses.

11.1.1 SOIL SAMPLE CONTAINERS

The types of sample containers used for the collection of soil samples is dependent upon the characteristics of media to be sampled as well as the specific analysis to be performed. Other factors, such as the anticipated concentrations of contaminants and the desired reporting limits are also important to consider when selecting appropriate soil sample containers.

In general, soil sample containers may be grouped into the following three broad categories: (1) non-volatile soil sample containers, (2) volatile soil sample containers, and (3) *Multi-Increment* soil sample containers (note that *Multi-Increment* samples may include both non-volatile and volatile analysis).

11.1.1.1 NON-VOLATILE SOIL SAMPLE CONTAINERS

Soil samples for non-volatile analysis are typically collected in wide-mouth glass jars sealed with Teflon-lined caps. Various volumes of wide-mouth glass jars, ranging from 2 ounces to 16 ounces, are employed in soil sample collection and are available as certified pre-cleaned prior to shipment to the end user. During sample collection, the soil is transferred directly from the sampling device (e.g., split-spoon sampler or acrylic tube liner) to the glass jar, which is sealed with a Teflon-lined cap.

Soil samples for non-volatile analysis may also be collected in stainless steel or brass tubes sealed with Teflon tape and plastic end caps, or in some cases in plastic bags. The stainless steel or brass tubes are typically 6 inches in length and vary between 1.5 and 3 inches or greater in diameter. The tubes are typically placed as a liner in a split spoon sampler driven by a drill rig. During sample collection, the soil is retained in the tubes following retrieval from the sampler, and Teflon tape and a plastic end cap is immediately placed over each end of the tube.

11.1.1.2 VOLATILE SOIL SAMPLE CONTAINERS

United States Environmental Protection Agency (USEPA) Method 5035 describes a closed-system purge-and-trap process for the analysis of volatile organic compounds in solid materials (e.g., soils, sediments, and solid waste) (USEPA, 1997g), which was subsequently updated with Method 5035A (USEPA, 2002h). The method is designed for use on samples containing low levels of VOCs, but procedures are also provided for collecting and preparing solid samples containing high concentrations of VOCs and for oily wastes. The procedures in EPA Method 5035 and 5035A may be used in conjunction with any appropriate determinative gas chromatographic procedure, including, but not limited to, EPA Methods 8015, 8021, and 8260.

Soil samples for volatile analysis can be collected using an EnCore® sampler, TerraCore® sampler, or similar sampling device capable of collecting a known mass of soil, approximately 5 grams, for preservation and analysis. The soil aliquot in the sampler may be chemically preserved by placing it into a glass jar containing a known quantity of preservative (see Subsection 11.2.3 for additional discussion of volatile soil sample collection).

The use of glass jars without the use of chemical preservatives when collecting soil samples for volatile analysis is not recommended.

The use of stainless steel or brass tubes when collecting soil samples for volatile analysis is not recommended.

11.1.1.3 *MULTI-INCREMENT* SOIL SAMPLE CONTAINERS

The collection of a 30- to 50-increment sample can result in approximately 500 to 2,000 grams of soil (i.e., the *Multi-Increment* sample) depending upon the mass of each increment. The sample container for a *Multi-Increment* sample must be large enough to accommodate this mass. For non-volatile analysis, a common method for collecting a *Multi-Increment* bulk sample is to place each increment into a dedicated, disposal plastic bag (such as a 2 gallon zip top or a heavy duty trash compactor bag) as each

increment is collected. The bag may be sealed, labeled and submitted directly to the laboratory for sub-sampling and analysis. There is a potential for some semi-volatile organic compounds (SVOCs), in particular, phthalates, to be transferred from plastic bags to samples, particularly if the soil has coarse or sharp particles that may abrade the bag surface. Therefore, when collecting *Multi-Increment* samples, the sampling team should consider the use of clean wide-mouth glass jars to collect and/or transport samples to be analyzed for SVOCs. These types of jars are available commercially and from Hawai'i-based analytical laboratories.

As discussed in Subsection 4.2.1, the *Multi-Increment* sample for non-volatile analysis may be sub-sampled in the field if an appropriate Standard Operating Procedure (SOP) has been developed for field sub-sampling and included in the SAP. In this case, the *Multi-Increment* sample would be collected in a dedicated, disposable plastic bag or wide-mouth jar, which is transferred to a pan for sieving and sub-sampling. The sub-sample is collected into a plastic zip top bag or glass jar and submitted to the laboratory for analysis. Field sub-sampling should follow procedures similar to those employed by the analytical laboratory as described in Subsection 4.2.2. Field sub-sampling of the *Multi-Increment* sample to collect a representative sub-sample may be difficult to perform due to conditions commonly encountered at field sites in Hawai'i (e.g., trade winds and/or rain). Laboratory sub-sampling to collect a representative sub-sample is generally preferable due to the controlled environmental conditions. Whenever samples are sub-sampled in the field, fully document the procedures, equipment, training requirements, and QA/QC measures employed during field sub-sampling in the SAP.

For laboratory sub-sampling, the most common QA/QC measure includes the collection of sub-sampling replicates (typically triplicates) to assess the error introduced by the sub-sampling routine. See discussion of replicates for laboratory sub-sampling in Subsection 10.7.6.

The recommended approach for the collection of *Multi-Increment* soil samples intended for volatile analysis is discussed in Subsection 4.2.7.

11.1.2 WATER SAMPLE CONTAINERS

The type of sample container used for collecting surface water or groundwater samples is dependent upon the specific analysis to be performed. Other factors, such as the anticipated concentrations of contaminants, the desired reporting limits, and the presence of free product are also important to consider when selecting appropriate water sample containers.

In general, water sample containers may be grouped into the following two broad categories: (1) non-volatile water sample containers, and (2) volatile water sample containers.

11.1.2.1 NON-VOLATILE WATER SAMPLE CONTAINERS

Water samples for organic non-volatile analysis are typically collected in 1 liter amber glass jars without the use of chemical preservatives. When collecting groundwater samples, fill the water sample containers by directing the outlet of the sampling device (i.e., pump tubing or bailer) toward the top and side of the sample container to allow the water to run down the inside of the bottle. Avoid agitation and the creation of bubbles when collecting water samples. To prevent cross contamination, avoid contacting the interior or top of the sample containers with either the sampling device or gloved hands.

Water samples for dissolved metals analysis are collected in 250 milliliter (mL) plastic bottles and preserved with nitric acid to a pH less than 2. Dissolved metals analysis also requires filtration prior to collection as discussed in Section 6.

11.1.2.2 VOLATILE WATER SAMPLE CONTAINERS

Water samples for volatile analysis are typically collected in 40 mL glass jars with septum-sealed screw caps and preserved with hydrochloric acid (HCl) to a pH less than 2. During sample collection, the screw caps should be carefully placed on the jars and sealed with zero headspace. When collecting groundwater samples for volatile analysis, fill the 40 mL jars by directing the outlet of the sampling device toward the top and side of the sample container to allow the water to run down the inside of the bottle. Adjust the flow rate of the water sampling device so that it does not cause the jars to rapidly overflow, causing loss of VOCs, sample volume, or any sample preservative. Avoid agitation and the creation of bubbles when collecting volatile water samples to prevent the loss of volatile constituents. To prevent cross contamination, avoid contacting the interior or top of the sample containers with either the sampling device or gloved hands.

The preservative HCl may react (effervesce) with turbid water containing calcareous particulates, resulting in a loss of volatile constituents. If a strong reaction is observed when filling the 40 mL jars containing HCl, collect the water samples for volatile analysis as unpreserved samples and note on the chain-of-custody. The collection of unpreserved water samples reduces the hold time of 14 days down to 7 days.

11.2 SAMPLE PRESERVATION AND HOLD TIMES

This section presents the recommended sample preservation for soil and water sample collection. Always consult with the laboratory when planning fieldwork to ensure that the proper sample containers and preservatives are used. Tables 11-A and 11-B, provided in the Appendices, present the recommended preservation and hold times for soil and groundwater, respectively.

Sample preservation consists of methods to assure the samples analyzed in the laboratory are representative of the field conditions. Preservation methods may include maintaining sample temperatures, analyzing the samples within recommended hold times or using chemicals (such as HCl or nitric acid [HNO3]) to stabilize the target contaminants by altering the sample chemistry.

Several potential difficulties associated with field preservation techniques include: sampling gravely soil matrix (if using EnCore® type samplers), spillage or evaporation of pre-weighed chemical preservatives, shipping restrictions involving chemical preservatives, or potential chemical reactions between calcareous particles and HCl preservative.

11.2.1 SAMPLE TEMPERATURE

Upon collection and sealing of sample containers, immediately begin the cooling process in the field by placing the sample containers in an insulated cooler containing water ice or frozen gel packs. Use of water ice is generally considered by the HEER Office to be more efficient to rapidly cool samples, and may be especially important for use with samples for volatile analyses, when feasible. Maintain the temperature of the sample containers at less than or equal to 6 degrees Celsius (°C) from the time of collection through the delivery to the analytical laboratory.

The National Environmental Laboratory Accreditation Conference (NELAC) states that samples which require thermal preservation shall be considered acceptable if the arrival temperature is within 2°C of the required temperature or the method specified range. For samples with a temperature requirement of 4°C, an arrival temperature from 0°C and 6°C meets specifications. Samples that are delivered to the laboratory on the same day that they are collected may not meet these criteria. In these cases, the samples are considered acceptable if there is evidence that the chilling process has begun, such as arrival at the analytical laboratory on ice.

11.2.2 CHEMICAL PRESERVATION

When employing chemical preservation, add the chemical reagents to the sample containers prior to mobilizing to the field, or request sample containers with pre-measured chemical reagents from the analytical laboratory. Carefully place the soil or groundwater samples into the sample containers to minimize loss of chemical preservative as well as volatile constituents in the sample (i.e., do not overfill water sample containers or leave the cap off a jar containing methanol for soil samples).

Some commonly used preservation chemicals may react with the sample media. For example, calcareous soil may react with sodium bisulfate; turbid groundwater collected from a coral aquifer formation may react with hydrochloric acid. If the sample media reacts with the chemical preservative, volatile organic constituents may be lost due to effervescence during sample collection, so an alternative preservation method or no chemical preservation may be needed.

The use of chemical preservatives for fieldwork in Hawai'i presents challenges when shipping preserved samples between islands or to the mainland (see Subsection 11.4 for additional details on shipping preservatives).

Some samples collected for specific analysis, such as dissolved metals in groundwater, may require pre-treatment prior to collection, as well as preservation (see Section 6.0).

11.2.3 SAMPLE HOLD TIMES

The soil and water samples should be analyzed as soon as possible after collection. Hold times are the maximum allowable times that a sample, or any subsample generated from the bulk sample, may be held before analysis. Several methods provide guidelines for both the hold time until extraction (denoted by "E" on Tables 11-A and 11-B in the Appendices) and the hold time after extraction until analysis (denoted by an "A" on the Tables).

Results from samples analyzed past the hold times may or may not be usable, depending upon the DQO set forth in the SAP. At a minimum, the results from analyses conducted past the recommending hold times should be interpreted as minimum concentrations.

Volatile Soil Samples

The use of Multi Increment sampling methods are recommended for testing of soil for VOCs (refer to Subsection 4.2.8.1). The use of discrete soil samples is discouraged, due to the small mass of soil represented by the laboratory data (e.g., five-grams). Sample containers, preservation, holding times and laboratory method for testing of VOCs in soil and water samples are described in EPA Method 5035 and 5035A and summarized in Appendices 11-A and 11-B, respectively (USEPA 1997g, 2002h).

The sample collection and preparation methods in EPA Method 5035 and 5035A include short hold times, ranging from 48 hours up to 14 days. The guidance recommends a number of potential methods including 1) preservation of soil samples in methanol, 2) freezing samples at low temperatures, 3) holding unpreserved samples for short time periods on ice, 4) preservation of soil with an acidic solution (sodium bisulfite), and 5) preservation of increments in reagent water. Preservation of calcareous, coralline soils with acidic solutions can cause the material to effervesce, resulting in a loss of VOCs. This could pose a problem in low lying coastal areas underlain by “caprock”, marine sediment, as well as fill material derived from these areas. The use of reagent-grade water has also come under question and is not recommended for use in Hawai‘i, due to concern about extraction efficiency as well as the short hold time of 48 hours (refer to Section 5). Preservation of MI samples with methanol is preferred and considered most reliable, although freezing of increments (e.g. using dry ice or water ice with salt) and shipment to the laboratory for extraction in methanol is unavoidable in some cases. This is especially true for projects on islands other than O‘ahu, due to logistical and safety issues associated with the air transportation and storage of methanol.

MI soil sample preservation methods and associated hold times for VOC testing are presented below (in order of preference) and summarized in Appendix 11-A and Subsection 4.2.8.1:

- Preserved soil samples collected with a sampling device capable of providing a pre-determined mass of soil and immediately extruded into a glass jar containing methanol must be analyzed within 14 days from the time of sample collection. This approach is recommended by the HEER Office when feasible in the field. Reporting limits achieved by the use of methanol might be elevated due to the need to dilute the solution for testing. If this is the case, the reporting limits can be used for general screening purposes in place of the applicable Environmental Action Levels (EALs; refer to HDOH, 2016). In this application, methanol acts as the preservative as well as the extraction solvent and a limited volume of methanol extract is introduced directly into the laboratory instrument. As such, the dilution and the reporting limits are higher than with some other preservation and extraction approaches. In some cases, the laboratory may be able achieve lower reporting limits for specific contaminants preserved in methanol by using additional analytical techniques, so consultation with the laboratory is recommended. The methanol preservation method may not be feasible due to the requirements or restrictions on hazardous material air shipments by the Department of Transportation (DOT) and/or the International Air Transportation Association (IATA). Consequently, applicable shipping regulations should be understood and carefully followed.
- Unpreserved soil increments collected in sealable, airtight sampling devices and immediately frozen in the field to less than negative 7°C must be analyzed within 14 days from the time of sample collection. Note that sealable, airtight coring tools or vials should not be frozen to less than -20°C to prevent problems with the integrity of the seals. Dry ice in direct contact with the sample containers may freeze them below -20°C, so dry ice needs to be used appropriately to achieve the desired temperature range (for example use a layer of insulating material between the dry ice and sample containers). Alternately, bags of water ice mixed with table salt may be used to freeze samples to below -7°C in the field.
- Unpreserved soil increments collected with a sealable, airtight coring device (e.g., EnCore® samplers or equivalent device) or in sealable, airtight vials and stored at 4°C must be extracted and analyzed within 48 hours from the time of sample collection. However, analysis time may be extended to 14 days of the sample collection date if the unpreserved soil increments are either placed in methanol or frozen to <-7°C by the lab within 48 hours from the time of sample collection in field.
- Preserved soil samples collected with a sampling device capable of providing a pre-determined mass of soil and immediately extruded into a glass jar containing sodium bisulfate preservative in reagent water must be analyzed within 14 days from the time of sample collection. This approach is appropriate for non-calcareous soils. A field check to determine whether the soil is calcareous is recommended (calcareous formations are commonly encountered in coastal areas when performing fieldwork in Hawai‘i). In addition, certain VOCs such as styrene, TCE, trichlorofluoromethane, cis- and trans 1,3-dichloropropene, 2-chloroethylvinyl ether, and vinyl chloride may be decomposed by the bisulfate leading to results biased low, so acid preservation should not be used for these contaminants of concern. The use of sodium bisulfate as a preservative should be discussed with the analytical laboratory since it may cause laboratory instrument problems requiring frequent recalibration.

11.3 SAMPLE CONTROL AND CHAIN-OF-CUSTODY PROCEDURES

Sample control and chain-of-custody procedures are extremely important for establishing that sample integrity was maintained from the time of collection through the time of analysis. Sample control procedures include the use of unique sample identifications, and sample labeling requirements. Chain-of-custody procedures include the use of chain-of-custody forms and custody seals.

11.3.1 SAMPLE IDENTIFICATION AND LABELS

Each sample collected in the field must be provided with a unique sample identification. In general, sample identification may include some or all of the following information:

- Project number (if samples collected by a consultant)
- Project location
- Sample location information (i.e., borehole or monitoring well identification)
- Depth of sample collection (for subsurface soil samples)
- Date/Time reference

A date/time reference is recommended if multiple samples are anticipated to be collected over the course of the project (such as during long-term monitoring projects).

Each sample collected in the field must be properly labeled using laboratory supplied (or equivalent) labels completed with indelible ink. The sample labels should contain the following information:

1. Sample identification number
2. Sampling date
3. Sampling time
4. Type of preservation
5. Analysis requested
6. Initials of sampler

Additional sample information should be documented in the field log including, but not limited to, the following:

- sample collection method (manual sampling, direct push drill rig)
- type of sample (e.g. *Multi-Increment* or discrete)
- significant observations noted during sample collection (petroleum odor or staining in soil, petroleum product or sheen on water surface)
- a cross reference of primary and replicate QA/QC samples

The peel and stick sample label should be securely affixed to the sample container. The outside of the sample container should be thoroughly cleaned and dried prior to affixing the label. Application of clear plastic adhesive tape over the label on the sample container provides a secondary means of securing the label to the container. Use of an indelible pen to mark the sample identification number on the container is a good backup method that can be used to identify a sample container in the event that it gets separated from the label.

Do not identify or cross-reference QA/QC samples on the sample labels or on the chain-of-custody form (see Section 10 for additional guidance on QA/QC samples).

11.3.2 CHAIN-OF-CUSTODY

Chain-of-custody is the process by which authorized custody of a sample is successively transferred from one person to another by the use of approved procedures and documents. If sample integrity is to be defensible, chain-of-custody procedures are necessary to document handling of samples from procurement through final analysis and disposal.

A sample is considered to be under a person's custody if:

- The sample is in the person's physical possession.
- The sample is in view of the person after that person has taken possession.
- The sample is secured by that person so that no one can tamper with the sample.
- The sample is secured by that person in an area where access is restricted to authorized personnel.

11.3.2.1 CHAIN-OF-CUSTODY FORMS

Chain-of-custody forms are used for tracking the samples from the time of collection in the field through the time of analysis. The chain-of-custody form contains the following information:

- Project identification
- Sampler's name
- Sender - Company name and address
- Destination - Laboratory name and address
- Sample identification
- Number of sample containers per sample
- Preservation, if any
- Date and time of sample collection for each sample
- Requested analyses
- Special handling requirements, if any
- Shipping company
- Printed name and signature of person relinquishing custody, and date and time when custody relinquished
- Printed name and signature of person receiving custody, and date and time when custody received.

Complete chain-of-custody forms at the time of sample collection and prior to leaving the field site. Analytical laboratories typically provide company-specific chain-of-custody forms, and sample labels, if sample containers are procured through the analytical laboratory. Complete chain-of-custody forms with indelible ink.

When transferring samples, the individuals involved must sign, date, and record the time in the relinquished/received-section on the form. The sampler retains one copy of the chain-of-custody form when relinquishing the samples following sample collection. Completely fill out all applicable sections of the form and numerically sequence the forms (i.e., page 1 of 3, etc.) if more than one chain-of-custody form is used for a sample batch. Consider grouping similar sample media in chain-of-custody batches for submittal to the laboratory (i.e., submit groundwater samples on one chain-of-custody batch separate from soil samples collected for the same project).

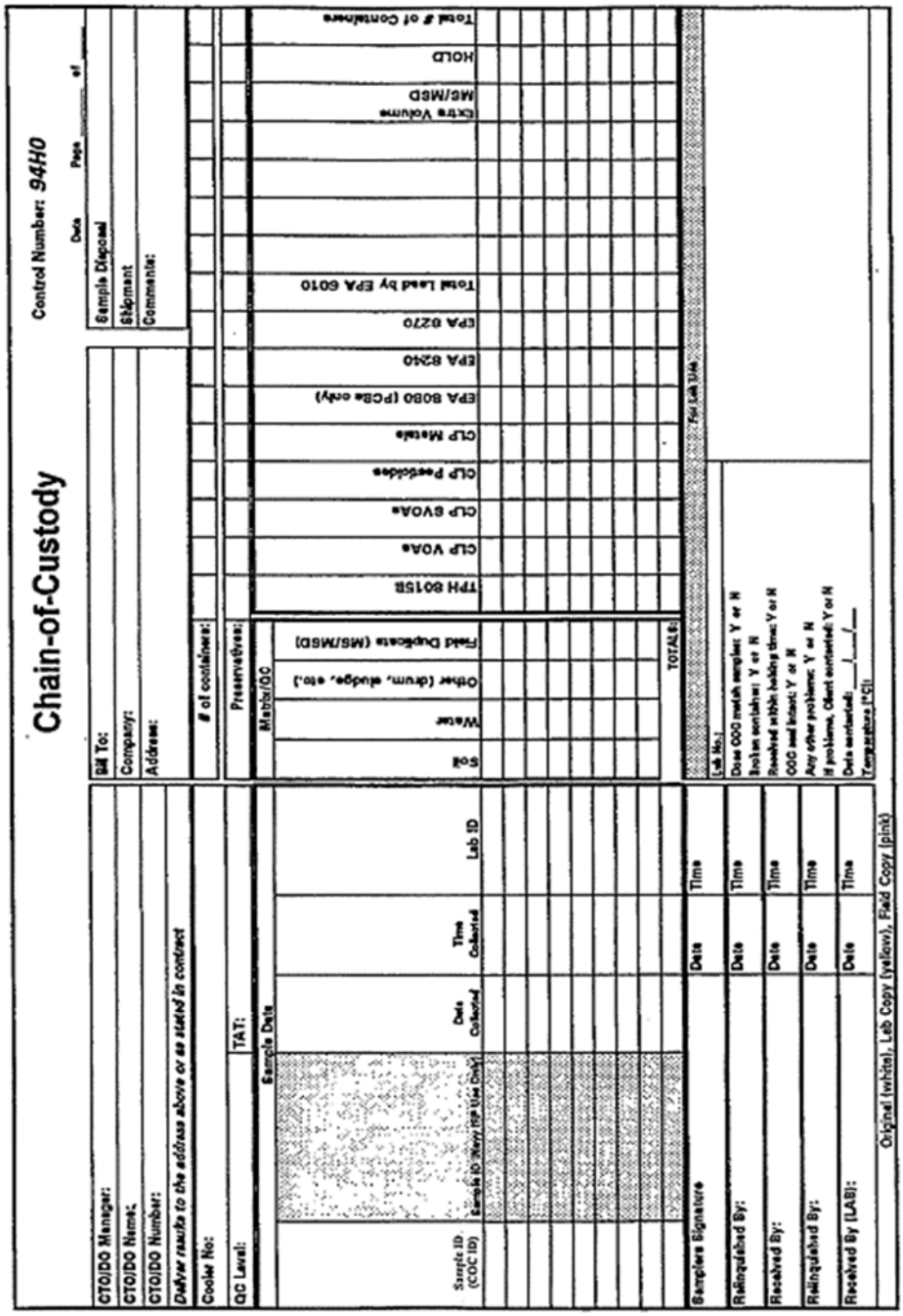


Figure 11-1. Example Chain-of-Custody Form.
[Source: US Navy, 2007]

Shipping companies (e.g. Federal Express, DHL, etc.) are not expected to sign the chain-of-custody form. However, complete shipping documentation, including tracking numbers, becomes part of the chain-of-custody record. When using shipping companies, the last person to have custody of the samples must fill in both the relinquished section (as normal) as well as the received section (identifying the shipping company's name and the date and time when the shipment was given into custody of the shipping company).

Once received at the laboratory, custody procedures shall apply. It is then the laboratory's responsibility to maintain custody records throughout sample preparation and analysis. An example generic chain-of-custody form is presented in Figure 11-1.

11.3.2.2 CHAIN-OF-CUSTODY SEALS

To ensure sample integrity when shipping samples, use custody seals. The custody seals must be dated and initialed by the personnel responsible for custody of the samples. Intact custody seals when the samples are logged into the laboratory indicate the physical integrity of the sample was not compromised during sample shipment.

Use custody seals on the outside of each container or cooler when shipping samples. Two seals are required, one at the front or opening edge of the cooler and one at the rear or hinged edge of the cooler. Clear tape can be applied over the custody seals when sealing the cooler or container for shipment.

Shipping sample coolers from the outer islands to O‘ahu or to mainland laboratories may require inspection by the Transportation Security Administration (TSA), which may break the chain-of-custody if custody seals are only used on the outside of shipping coolers. In this event, ensure individual sample integrity through the use of custody seals on individual sample container lids.

Custody seals may not be necessary if the sampling personnel retain custody of the samples from the time of collection to the time of delivery to the analytical lab, if the samples are delivered in person and a shipping company is not used.

11.4 SAMPLE SHIPPING

Upon completion of sample collection, shipment of samples to an analytical laboratory is typically required. This may include transport from an outer island to an O‘ahu-based laboratory or transport to a mainland laboratory. Properly pack the shipping containers to protect the individual sample containers, maintain the samples at temperature, and comply with all applicable transportation regulations.

Chain-of-custody forms are typically placed inside a sealed bag and adhered to the interior of the shipping container. The shipping paperwork is adhered to the outside of the shipping container and the container sealed for shipment. Shipping paperwork need only be attached to one cooler if multiple coolers are used in a single shipment, provided the shipping company concurs with this practice. When shipping multiple coolers in a single shipment, use additional labels to identify the cooler along with the total number of coolers in the shipment (e.g., cooler 2 of 3).

11.4.1 SAMPLE PACKING

Standard coolers are typically employed when packing samples for shipment although other shipping containers are acceptable. Interior packing materials include bubble wrap or foam sleeves encasing the individual sample containers and lining the cooler interior. Interior packing materials should be sufficient to prevent breakage during transport. After placing individually wrapped sample containers in the cooler, fill all empty space between sample containers with padding to minimize movement against each other.

Containers for water samples should be packed in an upright position and not stacked on their sides. When shipping water samples, line the bottom of the cooler with absorbent material to contain liquids in case of breakage.

The use of frozen gel ice is convenient to maintain the samples at a temperature of less than 6°C, but water ice may also be used. When using water ice, precautions to prevent spillage from the sample cooler (i.e., containing water ice in triple bags and sealing the cooler drain) are essential to expedient delivery of the shipment to the laboratory. Line the bottom of the cooler with absorbent material when using water ice in coolers.

Immediately prior to shipment, replace the ice or frozen gel packs in the coolers so that samples will be maintained at less than 6°C during transport to the analytical laboratory.

11.4.2 SHIPPING OR DELIVERY

If utilizing a mainland laboratory, consider shipping and delivery constraints resulting from Hawai‘i's geographic location, especially when collecting samples with a short hold time. Ensure sample delivery to the analytical laboratory so that there is sufficient time for analysis of the constituent with the shortest hold time. Samples preserved at less than 6°C using gel packs or ice should be shipped via overnight delivery. If samples are shipped on Friday, arrange for Saturday delivery with the analytical laboratory to ensure the correct temperature is maintained throughout shipping.

Errors in shipping and delivery risk exceeding either the required sample temperatures or analysis hold times. As noted previously, results from samples exceeding the required preservation temperatures or analyzed past the hold times may or may not be usable, depending upon the DQO set forth in the SAP. If the data are deemed usable, the results from the analyses should be interpreted as minimum concentrations.

When shipping air, soil, or water samples either inter-island or to the mainland, follow all appropriate U.S. Department of Transportation (DOT) regulations, specifically Title 49 of the Code of Federal Regulations (CFR), Parts 171 through 180 (Title 49 CFR). The DOT rules and regulations apply to all samples shipped including methanol, sodium bisulfate, and nitric acid preserved samples if a commercial carrier such as FedEx transports the samples. Personnel responsible for shipping soil and water samples in Hawai‘i should receive training and refresher training in these regulations. Specific packaging, labeling, and documentation are required by DOT regulations for most samples containing chemical preservatives. In addition, shipping dry ice is also subject to DOT regulations including, but not limited to, shipping container labeling requirements and restrictions on the weight of dry ice included in each shipping container.

Shipment of soil samples from Hawai‘i to the mainland is also subject to United States Department of Agriculture (USDA) inspection and regulation. The USDA does not need to inspect water sample shipments. A "USDA Soil Import Permit" is

required to prove that the receiving analytical laboratory is certified by the USDA to receive and properly dispose of soil. In addition, all soil sample coolers must be inspected by a USDA representative, affixed with a label indicating that the coolers contain environmental samples, and accompanied by shipping forms stamped by the USDA inspector prior to shipment (US Navy, 2007).

In Hawai'i, soil sample shipments are typically brought to the shipping company at the airport where the shipping company contacts a USDA representative to request an inspection. Alternatively, individuals or consulting firms may enter into an agreement with the USDA to ship soil samples. In this way, the USDA does not need to inspect each soil sample shipment. Consider USDA inspection requirements when planning sample shipments and employ custody seals on each individual sample container to ensure proper chain-of-custody control in the event coolers are opened by the USDA for inspection.

Inter-island shipment of soil in Hawai'i is subject to inspection and regulation by the State of Hawai'i Department of Agriculture (HDOA). Annual intra-state permits for shipping soil may be requested from the HDOA Plant Quarantine Branch in Honolulu.

Non-Hazardous Materials Shipment

Field personnel must state whether any sample is suspected to be a hazardous material. Samples may be shipped as non-hazardous based on previous site sample results, field screening results, or visual observations. In addition, environmental samples are currently exempt from Hazardous Goods regulations. Title 40 CFR, Part 261.40(d) states "A sample of solid waste or a sample of water, soil, or air which is collected for the sole purpose of testing to determine its characteristics or composition is not subject to this Part or Parts 262 through 267 or Part 124 of this chapter or to the notification requirements of Section 3010 of RCRA." (Title 40 CFR) Therefore, no special regulations are required to be followed for the shipment of environmental samples from the field. Note that this provision applies to unpreserved soil and water samples (i.e., no chemical preservatives added during collection).

For groundwater samples specifically, very small quantities of certain dangerous goods may be transported without certain marking and documentation requirements as described in Title 49 CFR Part 172 (Title 49 CFR). The Hazardous Materials regulations do not apply to the commonly utilized sample preservatives methanol, sodium bisulfate, hydrochloric acid, nitric acid, sulfuric acid, and sodium hydroxide added to water samples if their pH or percentage by weight criteria is met (USEPA, 1996; USACE, 1998b; US Navy, 2007). Standard preservative volumes in standard sample containers (e.g., HCl in 40 ml volatile organic analysis [VOA] jar) fall under this definition (USEPA, 1996; USACE, 1998b; US Navy, 2007).

It is extremely important to be aware that regulations may prohibit the shipment of chemically preserved soil samples (such as methanol or sodium bisulfate preserved soil samples intended for volatile analysis). The above paragraph references the shipment of chemical preservatives in water samples only.

11.5 APPROVED ANALYTICAL METHODS

Use the methods and standard operating procedures listed in EPA SW-846 (USEPA, 1991c and 2003b) for the analyses conducted under the guidance of this TGM. Consider the analytes of interest, the sample matrices, and the minimum detectable concentrations required to accomplish project DQO when selecting analytical methods. Tables 11-A and 11-B in the Appendices provide the recommended analytical methods for soil and groundwater analysis, respectively.

Use other EPA-approved methods (such as Methods for Chemical Analysis of Water and Wastes (USEPA, 1983) for analyses that measure parameters such as pH, specific conductance, dissolved oxygen, and temperature. Document any deviations from EPA-approved methods in the SAP.

When EPA-approved methods are not available or appropriate for project-specific requirements, other recognized standard analytical methods, such as those published by the American Society for Testing and Materials (ASTM) International or the National Institute for Occupational Safety and Health (NIOSH), may be used. Example guidance documents for other methods and procedures that may be proposed for site investigations include:

- American Public Health Association (APHA), American Water Works Association, Water Environment Federation. 2005. "Standard Methods for the Examination of Water and Wastewater." 21st Edition (APHA, 2005).
- ASTM. (updated yearly). "Annual Book of Standards." West Conshohocken, Pennsylvania (ASTM).
- NIOSH. 1994. NIOSH Manual of Analytical Methods, Fourth Edition. Publication No. 94-113 (NIOSH, 1994).

The published methods are updated at various time intervals. Unless otherwise stated, laboratories conducting work under the guidance of this TGM will use the most current version of any specified analytical method.

On occasion, project-specific conditions might require the use of analytical methods that are either a modification of an EPA-approved method or are not an EPA-approved method. These methods will typically be provided by the laboratory performing the analysis. Any laboratory using modified EPA-approved methods or non-EPA-approved methods must provide a detailed description of sample preparation, instrument calibration, sample analyses, method sensitivity, associated QA/QC requirements, and acceptance criteria, preferably during the planning phases and the creation of the SAP. The laboratory or method developer must provide method performance study information (e.g. detection, recovery, calibration data) to confirm the performance of the method for each applicable matrix. If previous performance studies are not available, they must be developed during the project and included as part of the project results.

An example of a modification of an EPA-approved method that is important for analysis of most soil and sediment samples for metals (whether *Multi-Increment* samples or discrete samples) is EPA Method 3050 for preparation of metals analyses. Soil or sediment samples are typically sieved to the <2 millimeter (mm) particle size before analysis, and an analysis of particles of this size requires a minimum extraction and analysis mass of 10 grams (rather than 1 gram generally recommended in Method 3050) to reduce fundamental error in the analysis (see discussion in Subsection 4.2.2 and USEPA, 2003b; ASTM, 2003). Laboratories conducting metals analyses of soils should therefore ensure they have conducted and documented method performance data for the extraction and analysis of these larger masses of soil or sediment.

11.6 FIELD-BASED MEASUREMENT TECHNOLOGIES

Field-based measurement technologies have advanced significantly in recent years in terms of quality and utility. Field-based measurement technologies include a broad range of options including devices capable of in-situ measurements, devices capable of providing ex-situ measurements on sampled media in the field, and mobile laboratories that can be transported to the field site.

Some field methods provide qualitative or semi-quantitative analyses that may be used as screening data. A growing number of field techniques, such as field assays and field colorimetric tests, are now available that are capable of providing quantitative, analyte-specific analyses typically associated with standard fixed-laboratory techniques.

Although the HEER Office supports the use of field measurement technologies whenever available and appropriate to enhance or help speed site investigations, these technologies must be augmented by the analysis of a subset of the field samples in a standard fixed analytical laboratory. The results from samples analyzed in the field should be correlated to the results from replicate samples analyzed in the fixed laboratory to assess the precision and accuracy of the field data.

Guidance on field assays and field screening methods is presented in Section 8.

SECTION 11 REFERENCES

Citation references for this TGM Section denoted with an “a”, “b”, “c”, etc… after the year of publication may not appear in sequence as these refer to the order placed in the Master References List for the entire TGM.

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HDOH, 2016b. Hawai’i Department of Health, Office of Hazard Evaluation and Emergency Response. Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater – Tropical Pacific Edition . Website URL: http://eha-web.doh.hawaii.gov/eha-cma/Leaders/HEER/ehe-guidance---pacific-basin-edition. Summer 2016 (and updates).

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Appendix 11-A

Laboratory Methods, Containers, Preservation, and Holding Times for Multi Increment Soil Samples

Parameter	Method[7]	Container	Preservation	Holding Time[1]
TPH-G	5035/8015 LUFT	[2]1 L Glass jar containing combined increments	Methanol and ≤6°C	14 days
		Individual soil plugs in sealable airtight coring tool or sealable airtight vial	[3]Immediately freeze to <-7°C	Within 14 days, combine in methanol at lab and test
		[4]Individual soil plugs in sealable airtight coring tool or sealable airtight vial	≤6°C	Within 48 hours, combine in methanol at lab or freeze to <-7°C in lab, and test within 14 days
		[5]1 L Glass jar containing combined increments	Na_2SO_4 in reagent water, ≤6°C	14 days
TPH-D	3550/8015 3550/8270 3540/8270 LUFT	Dedicated heavy-duty, sealable plastic bag	≤6°C	E: 14 days A: 40 days
BTEX, MTBE	5035/8015 5035/8021 5035/8260	[2]1 L Glass jar containing combined increments	Methanol and ≤6°C	14 days
		Individual soil plugs in sealable airtight coring tool or sealable airtight vial	[3]Immediately freeze to <-7°C	Within 14 days, combine in methanol at lab and test
		[4]Individual soil plugs in sealable airtight coring tool or sealable airtight vial	≤6°C	Within 48 hours,combine in methanol at lab or freeze to <-7°C in lab, and test within 14 days
		[5]1 L Glass jar containing combined increments	Na_2SO_4 in reagent water, ≤6°C	14 days
[6]PAHs, SVOCs	3540/8310 3550/8310 3540/8270 3550/8270 8100	Dedicated heavy-duty, sealable plastic bag	≤6°C	E: 14 days A: 40 days
HVOCs	5035/8021	[2]1 L Glass jar containing combined increments	Methanol and ≤6°C	14 days

Laboratory Methods, Containers, Preservation, and Holding Times for Multi Increment Soil Samples

Parameter	Method[7]	Container	Preservation	Holding Time[1]
		Individual soil plugs in sealable airtight coring tool or sealable airtight vial	[3]Immediately freeze to <-7°C	Within 14 days, combine in methanol at lab and test
		[4]Individual soil plugs in sealable airtight coring tool or sealable airtight vial	≤6°C	Within 48 hours, combine in methanol at lab or freeze to <-7°C in lab, and test within 14 days
		[5]1 L Glass jar containing combined increments	Na_2SO_4 in reagent water, ≤6°C	14 days
VOCs	5035/8260	[2]1 L Glass jar containing combined increments	Methanol and ≤6°C	14 days
		Individual soil plugs in sealable airtight coring tool or sealable airtight vial	[3]Immediately freeze to <-7°C	Within 14 days, combine in methanol at lab and test
		[4]Individual soil plugs in sealable airtight coring tool or sealable airtight vial	≤6°C	Within 48 hours, combine in methanol at lab or freeze to <-7°C in lab, and test within 14 days
		[5]1 L Glass jar containing combined increments	Na_2SO_4 in reagent water, ≤6°C	14 days
[6]SVOCs	3550/8270	Dedicated heavy-duty, sealable plastic bag	≤6°C	14 days
Metals (except Mercury and Chromium VI)	3050/6010 3050/6020	Dedicated heavy-duty, sealable plastic bag	None	6 months
Mercury	7471	Dedicated heavy-duty, sealable plastic bag	≤6°C	28 days
Chromium VI	7196	Dedicated heavy-duty, sealable plastic bag	≤6°C	E: 30 days A: 7 days
PCBs	3540/8082 3550/8082 8081 (Aroclors Only)	Dedicated heavy-duty, sealable plastic bag	≤6°C	none
Chlorinated Herbicides	8151	Dedicated heavy-duty, sealable plastic bag	≤6°C	E: 14 days A: 40 days
Organochlorine Pesticides	8081	Dedicated heavy-duty, sealable plastic bag	≤6°C	E: 14 days A: 40 days
Triazine Pesticides	8141	Dedicated heavy-duty, sealable plastic bag	≤6°C	E: 14 days A: 40 days
Organophosphorus Pesticides	8141	Dedicated heavy-duty, sealable plastic bag	≤6°C	E: 14 days A: 40 days

Laboratory Methods, Containers, Preservation, and Holding Times for Multi Increment Soil Samples

Parameter	Method[7]	Container	Preservation	Holding Time[1]
Carbamates	8321	Dedicated heavy-duty, sealable plastic bag	≤6°C	E: 14 days A: 40 days
Fumigants	5035/8260	[2]1 L Glass jar containing combined increments	Methanol and ≤6°C	14 days
		Individual soil plugs in sealable airtight coring tool or sealable airtight vial	[3]Immediately freeze to <-7°C	Within 14 days, combine in methanol at lab and test
		[4]Individual soil plugs in sealable airtight coring tool or sealable airtight vial	≤6°C	Within 48 hours, combine in methanol at lab or freeze to <-7°C in lab, and test within 14 days
		[5]1 L Glass jar containing combined increments	Na_2SO_4 in reagent water, ≤6°C	14 days
Pentachlorophenol	8270 8151	Dedicated heavy-duty, sealable plastic bag	≤6°C	E: 14 days A: 40 days
Glyphosate	EPA 547	Dedicated heavy-duty, sealable plastic bag	≤6°C	14 days
Cyanide	9013 EPA 335.3	Dedicated heavy-duty, sealable plastic bag	≤6°C	14 days
Dioxins/Furans	8290 8280	Dedicated heavy-duty, sealable plastic bag	≤6°C	none

Notes:

1. Holding times begin from the time of sample collection in the field
2. A methodology for the collection of *Multi-increment* samples for volatile analysis is discussed in Subsection 4.2.8. The sample container must be large enough to accommodate 30 to 50 soil increments, preserved with 1 milliliter of methanol per 1 gram of soil, and additional methanol to cover the sample as needed. Since methanol is toxic and flammable, DOT and IATA transportation regulations apply and must be considered in the selection of this preservation method, especially if samples need to be shipped by air to a laboratory for testing. Small quantity exemptions for shipping (where specific hazardous material containers, specific shipping containers, labelling, or other requirements do not apply) may be appropriate if the volume of methanol in each individual container inside a shipping package is limited (typically 30 mL), and the total quantity of methanol in each shipping package for air transport is limited (typically 500 mL). Always check with current DOT and IATA hazardous material shipping regulations to ensure compliance.
3. However, do not freeze samples below -20°C due to potential problems with seals on coring tool or vials. and subsequent VOC loss upon thawing samples.
4. Not recommended for aromatic hydrocarbons (e.g. BTEX) in biologically active soils (e.g. garden soils, fertilized soils).
5. Work with lab on appropriate ratio of Na_2SO_4 in reagent water for mass of multiple soil increments to be collected. Should be used only for non-calcareous soils (calcareous soils may be commonly encountered in coastal areas). Check with lab on other precautions for this acid preservation method, as some compounds within the olefins, ketones, esters, ethers, and sulfide classes may react and therefore results may not be representative of the soil sampled (e.g. generally not recommended for

VOCs such as styrene, TCE, or vinyl chloride). Sodium bisulfate is also a strong mineral acid, so there are associated shipping restrictions by DOT and/or IATA that must be considered.

6. Refer to Subsection 4.2.8, Appendix 4-B and Section 5 for discussions of soil samples to be tested for VOCs and SVOCs. Include naphthalene in VOC analyses. Subsample bulk multi increment sample immediately upon receipt without drying for testing of SVOCs.

7. Where the term “EPA" is used with a given method number the prefix indicates that the method comes from United States Environmental Protection Agency (EPA) wastewater and drinking water standards, both published and maintained by the EPA Safe Drinking Water Act (SDWA) and/or Clean Water Act (CWA). For methods that are presented without the “EPA" notation, the methods come from the guidance document “Test Methods for Evaluating Solid Waste Physical/Chemical Methods" (SW-846). Although SW-846 was written by the EPA originally, they are guidance documents and not prescriptive as the EPA prefix methods. Holding times are from SW-846 (USEPA 2007). A longer holding time may be appropriate if it can be demonstrated that the reported analyte concentrations are not adversely affected from preservation, storage and analyses performed outside the recommended holding times.

BTEX	Benzene, toluene, ethylbenzene, and xylene
Dioxins	Polychlorinated dibenzodioxins
DOT	Department of Transportation
Furans	Polychlorinated dibenzofurans
HVOCs	Halogenated volatile organic compounds
IATA	International Air Transportation Association
MTBE	Methyl-tert butyl ether
PAHs	Polynuclear aromatic hydrocarbons
PCBs	Polychlorinated biphenyls
SVOCs	Semi-volatile organic compounds
TPH-G	Total petroleum hydrocarbons as gasoline
TPH-D	Total petroleum hydrocarbons as diesel
TPH-O	Total petroleum hydrocarbons as oil
VOCs	Volatile organic compounds
≤	Less than or equal to
°C	Degree Celsius
g	Gram
L	Liter
mL	Milliliter
Na_2SO_4	Sodium bisulfate
MIS	*Multi-Increment* sample
E	Hold time to extraction
A	Hold time after extraction until analysis

References:

USEPA, 2007, *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods (Revision 5)* : U.S. Environmental Protection Agency, Office of Solid Waste, SW-846 Manual, Washington, D.C., February 2007 (and updates).

Appendix 11-B

Laboratory Methods, Containers, Preservation, and Holding Times for Groundwater Samples

Parameter	Method	Container	Preservation	Holding Time
TPH-G	5035/8015; LUFT	40 mL jar with septum cap	≤6°C	7 days
			HCl to pH<2 and ≤6°C	14 days
TPH-D	5035/8015; 3550/8270; 3540/8270; LUFT	1 L Amber Glass Jar	≤6°C<	7 day (4°C only)
TPH-O	8015; EPA 1664	1 L Amber Glass Jar	≤6°C	E: 7 days A: 40 days
			HCl to pH<2 and ≤6°C (1664 only)	
BTEX, MtBE	(BTEX only) 8260; EPA 602; EPA 624	40 mL jar with septum cap	≤6°C	7 days
	(BTEX and MTBE) 8260; EPA 524.2		HCl to pH<2 and ≤6°C	14 days
PAHs	8270; 8310; EPA 610; EPA 625	1 L Amber Glass Jar	≤6°C	E: 7 days A: 40 days
HVOCs	8260; EPA 601; EPA 608; EPA 624; EPA 625	40 mL jar with septum cap	≤6°C	7 days
			HCl to pH<2 and ≤6°C	14 days
VOCs	8260; EPA 624	40 mL jar with septum cap	4°C	7 days
			HCl to pH<2 and ≤6°C	14 days
SVOCs	8270; EPA 625	1 L Amber Glass Jar	≤6°C	E: 7 days A: 40 days
Metals (except Mercury and Chromium VI)	6010; 6020; EPA 200 Series	250 mL Plastic Container	HNO_3 to pH<2 and ≤6°C	6 months
Mercury	7470; EPA 245.1	250 mL Plastic Container	HNO_3 to pH<2 and ≤6°C	28 days
Chromium VI	7196	250 mL Plastic Container	≤6°C	24 hours
PCBs	8082; EPA 608	1 L Amber Glass Jar	≤6°C	E: 7 days A: 40 days
Chlorinated Herbicides	8151; EPA 615	1 L Amber Glass Jar	≤6°C	E: 7 days A: 40 days

Laboratory Methods, Containers, Preservation, and Holding Times for Groundwater Samples

Parameter	Method	Container	Preservation	Holding Time
Organochlorine Pesticides	8081; EPA 608	1 L Amber Glass Jar	≤6°C	E: 7 days A: 40 days
Triazine Pesticides	8141; 8270; EPA 619	1 L Amber Glass Jar	≤6°C	E: 7 days A: 40 days
Organophosphorus Pesticides	8141; 8270; EPA 622; EPA 614	1 L Amber Glass Jar	≤6°C	E: 7 days A: 40 days
Carbamates	8321; EPA 632	1 L Amber Glass Jar	≤6°C	E: 7 days A: 40 days
Fumigants	8260; EPA 504.1; EPA 524.2	40 mL jar with septum cap	≤6°C	7 days
			HCl to pH<2 and ≤6°C	14 days
Pentachlorophenol	8270; 8151; EPA 625	1 L Amber Glass Jar	≤6°C	E: 7 days A: 40 days
Glyphosate	EPA 547	1 L Amber Glass Jar	0.008% $Na_2S_2O_3$ (pH 5-8) and ≤6°C	14 days
Cyanide	9014; EPA 335.2/335.3	500 mL Plastic Container	NaOH to pH>12 and ≤6°C	14 days
Dioxins/Furans	8290; EPA 613; EPA 1613	1 L Amber Glass Jar	≤6°C	E: 30 days A: 45 days

Notes:

BTEX	Benzene, toluene, ethylbenzene, and xylene
Dioxins	Polychlorinated dibenzodioxins
Furans	Polychlorinated dibenzofurans
HVOCs	Halogenated volatile organic compounds
MTBE	Methyl-tert butyl ether
PAHs	Polynuclear aromatic hydrocarbons
PCBs	Polychlorinated biphenyls
SVOCs	Semi-volatile organic compounds
TPH-G	Total petroleum hydrocarbons as gasoline
TPH-D	Total petroleum hydrocarbons as diesel
TPH-O	Total petroleum hydrocarbons as oil
VOCs	Volatile organic compounds
≤	Less than or equal to
°C	Degree Celsius
g	Gram
L	Liter
mL	Milliliter
HCl	Hydrochloric acid
NaOH	Sodium hydroxide
NaS_2O_3	Sodium thiosulfate
HNO_3	Nitric acid
E	Hold time to extraction

A	Hold time after extraction until analysis
pH	A measure of the acidity or alkalinity of a solution.
EPA	Where the term "EPA" is used with a given method number the prefix indicates that the method comes from Environmental Protection Agency (EPA) wastewater and drinking water standards, both published and maintained by the EPA Safe Drinking Water Act (SDWA) and/or Clean Water Act (CWA). For methods that are presented without the "EPA" notation, the methods come from the guidance document "Test Methods for Evaluating Solid Waste Physical/Chemical Methods" (SW-846). Although SW-846 was written by the EPA originally, they are guidance documents and not prescriptive as the EPA prefix methods.

Appendix 11-A

Laboratory Methods, Containers, Preservation, and Holding Times for Multi Increment Soil Samples

Parameter	Method[7]	Container	Preservation	Holding Time[1]
TPH-G	5035/8015 LUFT	[2]1 L Glass jar containing combined increments	Methanol and ≤6°C	14 days
		Individual soil plugs in sealable airtight coring tool or sealable airtight vial	[3]Immediately freeze to <-7°C	Within 14 days, combine in methanol at lab and test
		[4]Individual soil plugs in sealable airtight coring tool or sealable airtight vial	≤6°C	Within 48 hours, combine in methanol at lab or freeze to <-7°C in lab, and test within 14 days
		[5]1 L Glass jar containing combined increments	Na_2SO_4 in reagent water, ≤6°C	14 days
TPH-D	3550/8015 3550/8270 3540/8270 LUFT	Dedicated heavy-duty, sealable plastic bag	≤6°C	E: 14 days A: 40 days
BTEX, MTBE	5035/8015 5035/8021 5035/8260	[2]1 L Glass jar containing combined increments	Methanol and ≤6°C	14 days
		Individual soil plugs in sealable airtight coring tool or sealable airtight vial	[3]Immediately freeze to <-7°C	Within 14 days, combine in methanol at lab and test
		[4]Individual soil plugs in sealable airtight coring tool or sealable airtight vial	≤6°C	Within 48 hours,combine in methanol at lab or freeze to <-7°C in lab, and test within 14 days
		[5]1 L Glass jar containing combined increments	Na_2SO_4 in reagent water, ≤6°C	14 days
[6]PAHs, SVOCs	3540/8310 3550/8310 3540/8270 3550/8270 8100	Dedicated heavy-duty, sealable plastic bag	≤6°C	E: 14 days A: 40 days

Laboratory Methods, Containers, Preservation, and Holding Times for Multi Increment Soil Samples

Parameter	Method[7]	Container	Preservation	Holding Time[1]
HVOCs	5035/8021	[2]1 L Glass jar containing combined increments	Methanol and ≤6°C	14 days
		Individual soil plugs in sealable airtight coring tool or sealable airtight vial	[3]Immediately freeze to <-7°C	Within 14 days, combine in methanol at lab and test
		[4]Individual soil plugs in sealable airtight coring tool or sealable airtight vial	≤6°C	Within 48 hours, combine in methanol at lab or freeze to <-7°C in lab, and test within 14 days
		[5]1 L Glass jar containing combined increments	Na_2SO_4 in reagent water, ≤6°C	14 days
VOCs	5035/8260	[2]1 L Glass jar containing combined increments	Methanol and ≤6°C	14 days
		Individual soil plugs in sealable airtight coring tool or sealable airtight vial	[3]Immediately freeze to <-7°C	Within 14 days, combine in methanol at lab and test
		[4]Individual soil plugs in sealable airtight coring tool or sealable airtight vial	≤6°C	Within 48 hours, combine in methanol at lab or freeze to <-7°C in lab, and test within 14 days
		[5]1 L Glass jar containing combined increments	Na_2SO_4 in reagent water, ≤6°C	14 days
[6]SVOCs	3550/8270	Dedicated heavy-duty, sealable plastic bag	≤6°C	14 days
Metals (except Mercury and Chromium VI)	3050/6010 3050/6020	Dedicated heavy-duty, sealable plastic bag	None	6 months
Mercury	7471	Dedicated heavy-duty, sealable plastic bag	≤6°C	28 days
Chromium VI	7196	Dedicated heavy-duty, sealable plastic bag	≤6°C	E: 30 days A: 7 days
PCBs	3540/8082 3550/8082 8081 (Aroclors Only)	Dedicated heavy-duty, sealable plastic bag	≤6°C	none
Chlorinated Herbicides	8151	Dedicated heavy-duty, sealable plastic bag	≤6°C	E: 14 days A: 40 days
Organochlorine Pesticides	8081	Dedicated heavy-duty, sealable plastic bag	≤6°C	E: 14 days A: 40 days
Triazine Pesticides	8141	Dedicated heavy-duty, sealable plastic bag	≤6°C	E: 14 days A: 40 days

Laboratory Methods, Containers, Preservation, and Holding Times for Multi Increment Soil Samples

Parameter	Method[7]	Container	Preservation	Holding Time[1]
Organophosphorus Pesticides	8141	Dedicated heavy-duty, sealable plastic bag	≤6°C	E: 14 days A: 40 days
Carbamates	8321	Dedicated heavy-duty, sealable plastic bag	≤6°C	E: 14 days A: 40 days
Fumigants	5035/8260	[2]1 L Glass jar containing combined increments	Methanol and ≤6°C	14 days
		Individual soil plugs in sealable airtight coring tool or sealable airtight vial	[3]Immediately freeze to <-7°C	Within 14 days, combine in methanol at lab and test
		[4]Individual soil plugs in sealable airtight coring tool or sealable airtight vial	≤6°C	Within 48 hours, combine in methanol at lab or freeze to <-7°C in lab, and test within 14 days
		[5]1 L Glass jar containing combined increments	Na_2SO_4 in reagent water, ≤6°C	14 days
Pentachlorophenol	8270 8151	Dedicated heavy-duty, sealable plastic bag	≤6°C	E: 14 days A: 40 days
Glyphosate	EPA 547	Dedicated heavy-duty, sealable plastic bag	≤6°C	14 days
Cyanide	9013 EPA 335.3	Dedicated heavy-duty, sealable plastic bag	≤6°C	14 days
Dioxins/Furans	8290 8280	Dedicated heavy-duty, sealable plastic bag	≤6°C	none

Notes:

1. Holding times begin from the time of sample collection in the field
2. A methodology for the collection of *Multi-increment* samples for volatile analysis is discussed in Section 4.2.8. The sample container must be large enough to accommodate 30 to 50 soil increments, preserved with 1 milliliter of methanol per 1 gram of soil, and additional methanol to cover the sample as needed. Since methanol is toxic and flammable, DOT and IATA transportation regulations apply and must be considered in the selection of this preservation method, especially if samples need to be shipped by air to a laboratory for testing. Small quantity exemptions for shipping (where specific hazardous material containers, specific shipping containers, labelling, or other requirements do not apply) may be appropriate if the volume of methanol in each individual container inside a shipping package is limited (typically 30 mL), and the total quantity of methanol in each shipping package for air transport is limited (typically 500 mL). Always check with current DOT and IATA hazardous material shipping regulations to ensure compliance.
3. However, do not freeze samples below -20°C due to potential problems with seals on coring tool or vials. and subsequent VOC loss upon thawing samples.
4, Not recommended for aromatic hydrocarbons (e.g. BTEX) in biologically active soils (e.g. garden soils, fertilized soils).

5. Work with lab on appropriate ratio of Na_2SO_4 in reagent water for mass of multiple soil increments to be collected. Should be used only for non-calcareous soils (calcareous soils may be commonly encountered in coastal areas). Check with lab on other precautions for this acid preservation method, as some compounds within the olefins, ketones, esters, ethers, and sulfide classes may react and therefore results may not be representative of the soil sampled (e.g. generally not recommended for VOCs such as styrene, TCE, or vinyl chloride). Sodium bisulfate is also a strong mineral acid, so there are associated shipping restrictions by DOT and/or IATA that must be considered.

6. Refer to Section 4.2.8, Appendix 4-B and Section 5 for discussions of soil samples to be tested for VOCs and SVOCs. Include naphthalene in VOC analyses. Subsample bulk multi increment sample immediately upon receipt without drying for testing of SVOCs.

7. Where the term “EPA" is used with a given method number the prefix indicates that the method comes from United States Environmental Protection Agency (EPA) wastewater and drinking water standards, both published and maintained by the EPA Safe Drinking Water Act (SDWA) and/or Clean Water Act (CWA). For methods that are presented without the “EPA" notation, the methods come from the guidance document “Test Methods for Evaluating Solid Waste Physical/Chemical Methods" (SW-846). Although SW-846 was written by the EPA originally, they are guidance documents and not prescriptive as the EPA prefix methods. Holding times are from SW-846 (USEPA 2007). A longer holding time may be appropriate if it can be demonstrated that the reported analyte concentrations are not adversely affected from preservation, storage and analyses performed outside the recommended holding times.

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Dioxins	Polychlorinated dibenzodioxins
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Furans	Polychlorinated dibenzofurans
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IATA	International Air Transportation Association
MTBE	Methyl-tert butyl ether
PAHs	Polynuclear aromatic hydrocarbons
PCBs	Polychlorinated biphenyls
SVOCs	Semi-volatile organic compounds
TPH-G	Total petroleum hydrocarbons as gasoline
TPH-D	Total petroleum hydrocarbons as diesel
TPH-O	Total petroleum hydrocarbons as oil
VOCs	Volatile organic compounds
≤	Less than or equal to
°C	Degree Celsius
g	Gram
L	Liter
mL	Milliliter
Na_2SO_4	Sodium bisulfate
MIS	*Multi-Increment* sample
E	Hold time to extraction
A	Hold time after extraction until analysis

References:

USEPA, 2007, *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods (Revision 5)* : U.S. Environmental Protection Agency, Office of Solid Waste, SW-846 Manual, Washington, D.C., February 2007 (and updates).

Appendix 11-B

Laboratory Methods, Containers, Preservation, and Holding Times for Groundwater Samples

Parameter	Method	Container	Preservation	Holding Time
TPH-G	5035/8015; LUFT	40 mL jar with septum cap	≤6°C	7 days
			HCl to pH<2 and ≤6°C	14 days
TPH-D	5035/8015; 3550/8270; 3540/8270; LUFT	1 L Amber Glass Jar	≤6°C<	7 day (4°C only)
TPH-O	8015; EPA 1664	1 L Amber Glass Jar	≤6°C	E: 7 days A: 40 days
			HCl to pH<2 and ≤6°C (1664 only)	
BTEX, MtBE	(BTEX only) 8260; EPA 602; EPA 624	40 mL jar with septum cap	≤6°C	7 days
	(BTEX and MTBE) 8260; EPA 524.2		HCl to pH<2 and ≤6°C	14 days
PAHs	8270; 8310; EPA 610; EPA 625	1 L Amber Glass Jar	≤6°C	E: 7 days A: 40 days
HVOCs	8260; EPA 601; EPA 608; EPA 624; EPA 625	40 mL jar with septum cap	≤6°C	7 days
			HCl to pH<2 and ≤6°C	14 days
VOCs			4°C	7 days

Laboratory Methods, Containers, Preservation, and Holding Times for Groundwater Samples

Parameter	Method	Container	Preservation	Holding Time
	8260; EPA 624	40 mL jar with septum cap	HCl to pH<2 and ≤6°C	14 days
SVOCs	8270; EPA 625	1 L Amber Glass Jar	≤6°C	E: 7 days A: 40 days
Metals (except Mercury and Chromium VI)	6010; 6020; EPA 200 Series	250 mL Plastic Container	HNO_3 to pH<2 and ≤6°C	6 months
Mercury	7470; EPA 245.1	250 mL Plastic Container	HNO_3 to pH<2 and ≤6°C	28 days
Chromium VI	7196	250 mL Plastic Container	≤6°C	24 hours
PCBs	8082; EPA 608	1 L Amber Glass Jar	≤6°C	E: 7 days A: 40 days
Chlorinated Herbicides	8151; EPA 615	1 L Amber Glass Jar	≤6°C	E: 7 days A: 40 days
Organochlorine Pesticides	8081; EPA 608	1 L Amber Glass Jar	≤6°C	E: 7 days A: 40 days
Triazine Pesticides	8141; 8270; EPA 619	1 L Amber Glass Jar	≤6°C	E: 7 days A: 40 days
Organophosphorus Pesticides	8141; 8270; EPA 622; EPA 614	1 L Amber Glass Jar	≤6°C	E: 7 days A: 40 days
Carbamates	8321; EPA 632	1 L Amber Glass Jar	≤6°C	E: 7 days A: 40 days
Fumigants	8260; EPA 504.1; EPA 524.2	40 mL jar with septum cap	≤6°C	7 days
			HCl to pH<2 and ≤6°C	14 days
Pentachlorophenol	8270; 8151; EPA 625	1 L Amber Glass Jar	≤6°C	E: 7 days A: 40 days
Glyphosate	EPA 547	1 L Amber Glass Jar	0.008% $Na_2S_2O_3$ (pH 5-8) and ≤6°C	14 days
Cyanide	9014; EPA 335.2/335.3	500 mL Plastic Container	NaOH to pH>12 and ≤6°C	14 days

Laboratory Methods, Containers, Preservation, and Holding Times for Groundwater Samples

Parameter	Method	Container	Preservation	Holding Time
Dioxins/Furans	8290; EPA 613; EPA 1613	1 L Amber Glass Jar	≤6°C	E: 30 days A: 45 days

Notes:

BTEX	Benzene, toluene, ethylbenzene, and xylene
Dioxins	Polychlorinated dibenzodioxins
Furans	Polychlorinated dibenzofurans
HVOCs	Halogenated volatile organic compounds
MTBE	Methyl-tert butyl ether
PAHs	Polynuclear aromatic hydrocarbons
PCBs	Polychlorinated biphenyls
SVOCs	Semi-volatile organic compounds
TPH-G	Total petroleum hydrocarbons as gasoline
TPH-D	Total petroleum hydrocarbons as diesel
TPH-O	Total petroleum hydrocarbons as oil
VOCs	Volatile organic compounds
≤	Less than or equal to
°C	Degree Celsius
g	Gram
L	Liter
mL	Milliliter
HCl	Hydrochloric acid
NaOH	Sodium hydroxide
NaS_2O_3	Sodium thiosulfate
HNO_3	Nitric acid
E	Hold time to extraction
A	Hold time after extraction until analysis
pH	A measure of the acidity or alkalinity of a solution.
EPA	Where the term "EPA" is used with a given method number the prefix indicates that the method comes from Environmental Protection Agency (EPA) wastewater and drinking water standards, both

published and maintained by the EPA Safe Drinking Water Act (SDWA) and/or Clean Water Act (CWA). For methods that are presented without the "EPA" notation, the methods come from the guidance document "Test Methods for Evaluating Solid Waste Physical/Chemical Methods" (SW-846). Although SW-846 was written by the EPA originally, they are guidance documents and not prescriptive as the EPA prefix methods.

SECTION 13
ENVIRONMENTAL HAZARD EVALUATION

Interim Final - September 19, 2017

State of Hawai‘i
Department of Health
Office of Hazard Evaluation and Emergency Response
919 Ala Moana Boulevard, Room 206
Honolulu, Hawai‘i 96814

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SECTION 13 ACRONYMS AND ABBREVIATIONS

BTEX	Benzene, toluene, ethylbenzene, and total xylenes
CalEPA	California Environmental Protection Agency
COPC	Chemicals (or Contaminants) of Potential Concern
CSM	Conceptual Site Model
DU	Decision Unit
EAL	Environmental Action Level
EHE	Environmental Hazard Evaluation
EHMP	Environmental Hazard Management Plan
HDOH	Hawai'i Department of Health
HEER Office	Hazard Evaluation and Emergency Response Office
HHRA	Human Health Risk Assessment
IEUBK	Integrated Exposure Uptake Biokinetic Model for Lead in Children
IRIS	Integrated Risk Information System
MLE	Maximum Likelihood Estimation
NCEA	USEPA National Center for Environmental Assessment
PCB	Polychlorinated Biphenyl
PCE	Tetrachloroethylene
PRGs	Preliminary Remedial Goals
RME	Reasonable maximum exposure
RSL	Regional Screening Level
TPH	Total Petroleum Hydrocarbons
TVH	Total Volatile Hydrocarbons
UCL	Upper Confidence Level
USEPA	United States Environmental Protection Agency

13.0 ENVIRONMENTAL HAZARD EVALUATION

This section provides an overview of the HDOH HEER Office approach to **Environmental Hazard Evaluation**, as described in the separate guidance document *Screening for Environmental Hazards at Sites with Contaminated Soil and Groundwater* (HDOH, 2016). Environmental Hazard Evaluation (EHE) is the link between site investigation activities and response actions carried out to address hazards posed by the presence of contaminated soil and groundwater, as shown in Figure 13-1.

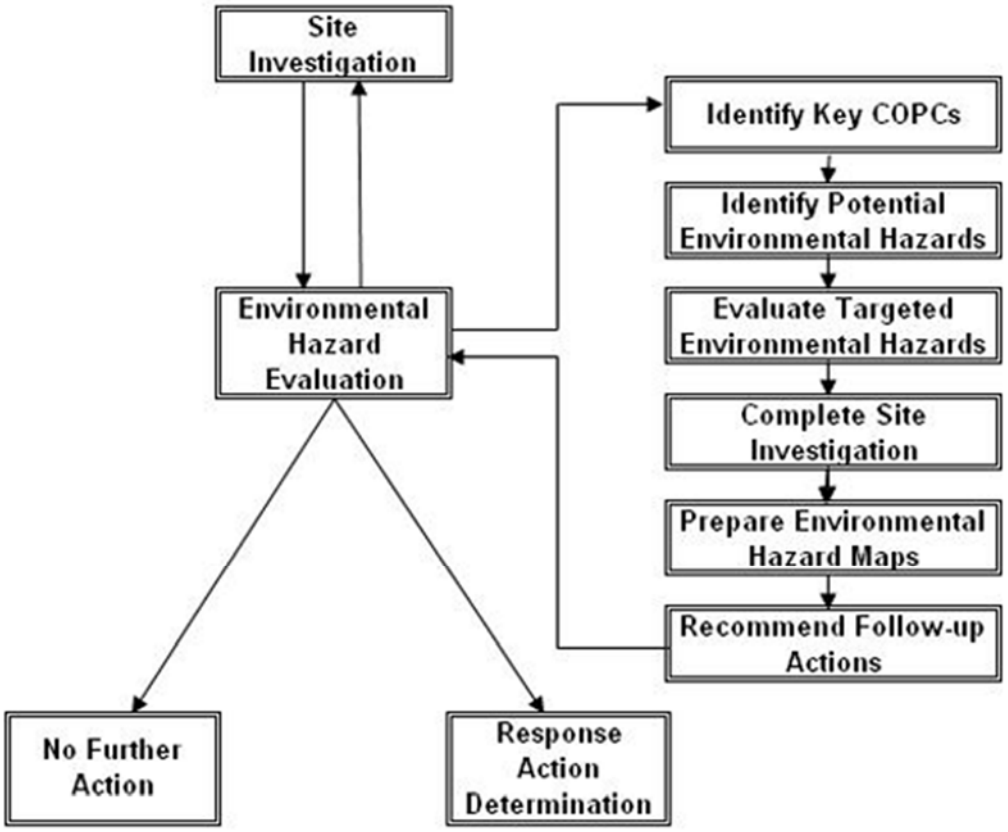


Figure 13-1. Expanded Overview of the Environmental Hazard Evaluation Process. Note: COPC = Chemicals of Potential Concern.

In this step of the site assessment process, the presence or absence of potential environmental hazards associated with contaminated soil and groundwater is determined and summarized in an EHE (i.e., a review of potential environmental hazards), which must be carried out for all sites. As discussed below, the level of detail needed in an EHE will vary, depending on the extent and nature of contamination. This is most easily done at a screening level by comparison of site data to HDOH Tier 1 Environmental Action Levels (Tier 1 EALs). When the presence of a potential hazard(s) is confirmed, the specific hazard posed by the contamination is identified and the scope of follow-up actions necessary to address the hazard(s) is determined.

Once the site has been adequately characterized and potential environmental hazards identified, an appropriate response action is determined. If contamination is not identified above HDOH Tier 1 EALs then no further action is necessary. For sites where the extent of contamination that exceeds Tier 1 EALs is minimal or time is of the essence, the most cost-effective response may simply be disposal or treatment of the contaminated media. The Tier 1 EALs are *not* strict, regulatory cleanup standards, however. The practicability of full remediation in terms of access, anticipated land use, use of engineered and institutional controls, public acceptance, cost and other factors should be considered before final remedial actions are developed (refer also to Sections 14, Section 16, and Section 19).

A more detailed evaluation of specific environmental hazards is usually warranted at sites where contamination is identified above HDOH Tier 1 EALs. This could include the need for additional site data (e.g., soil gas data, bioaccessible arsenic data, etc.), the development of more site-specific cleanup levels, identification of the most pressing hazards (e.g., discharges of free product into storm sewers, vapor intrusion into overlying buildings) and other site-specific considerations. Contamination left in place following remediation of the site to the extent practicable and the specific environmental hazards posed by the contamination are documented in the final Site Investigation and Environmental Hazard Evaluation reports. This information is then used to prepare an **Environmental Hazard Management Plan** that describes actions for long-term management of the contamination (see Sections 18 and Section 19).

Environmental Hazard Evaluation is therefore an integral part of both site investigations and response actions. Site investigations and response actions carried out in the absence of a basic understanding of environmental hazards posed by contaminated soil or groundwater run the risk of being incomplete, and require unanticipated, additional field work. This can result in unnecessary delays and costs in addressing contamination issues and bringing the property back into productive use. The guidance presented in this document is intended to help avoid these types of problems and make the site assessment process as effective and efficient as possible.

A summary of the Environmental Hazard Evaluation process is presented within this section. A detailed description of Environmental Hazard Evaluations and associated Tier 1 Environmental Action Levels is presented in a separate guidance document entitled *Screening for Environmental Hazards at Sites with Contaminated Soil and Groundwater* (HDOH, 2016). Readers unfamiliar with the concept of environmental hazard evaluation may be familiar with the concepts of human health risk assessment and ecological risk assessment. As discussed below, human health and ecological risk assessment are two important components of the broader concept of environmental hazard evaluation. Traditional risk assessments may not adequately address all potential environmental concerns at a site, and cannot be used as a replacement for Environmental Hazard Evaluation. Note that in earlier HEER Office guidance this process was referred to as Environmental Hazard *Assessment*. The term *assessment* has been changed to *evaluation* in this guidance to help avoid confusion with traditional health and ecological risk assessment.

Additional information on the evaluation of environmental hazards associated with petroleum contamination (as well as other contaminants) is discussed in Section 9 and the primary EHE guidance (HDOH, 2016; see also HDOH, 2007).

13.1 TARGET ENVIRONMENTAL HAZARDS

Table 13-1 Target Environmental Hazards by Media

Environmental Hazard	Description
Contaminated Groundwater	
Human Health Risk	
- Drinking Water	Toxicity concerns related to contamination of groundwater that is a current or potential source of drinking water
- Vapor Intrusion	Emission of volatile contaminants from groundwater and intrusion into overlying buildings
Aquatic Habitats	Discharges of contaminated groundwater and toxicity to aquatic organisms. Includes contamination of fish and shellfish used for human consumption.
Gross Contamination	Includes taste and odor concerns for contaminated drinking water supplies, free product, sheens and odors on surface water, general resource degradation, etc.
Contaminated Soil	
Human Health Risk	
- Direct Exposure	Exposure to contaminants in soil via incidental ingestion, dermal absorption and inhalation of vapors or dust in outdoor air.
- Vapor Intrusion	Emission of volatile contaminants from soil and intrusion into overlying buildings
Leaching	Leaching of contamination from soil by infiltrating surface water (rainfall, irrigation, etc.) and subsequent contamination of groundwater resources
Terrestrial Habitats	Toxicity to terrestrial flora and fauna
Gross contamination	Includes potentially mobile free product, odors, aesthetics, explosive hazards, general resource degradation, etc
Contaminated Soil Gas	
Explosions	An explosion hazard can exist if accumulation of unstable gases such as methane or Total Volatile Hydrocarbons (TVH) occurs in confined spaces.
Vapor Emissions	Emission of volatile contaminants from soil or groundwater into overlying buildings and/or outdoor air.

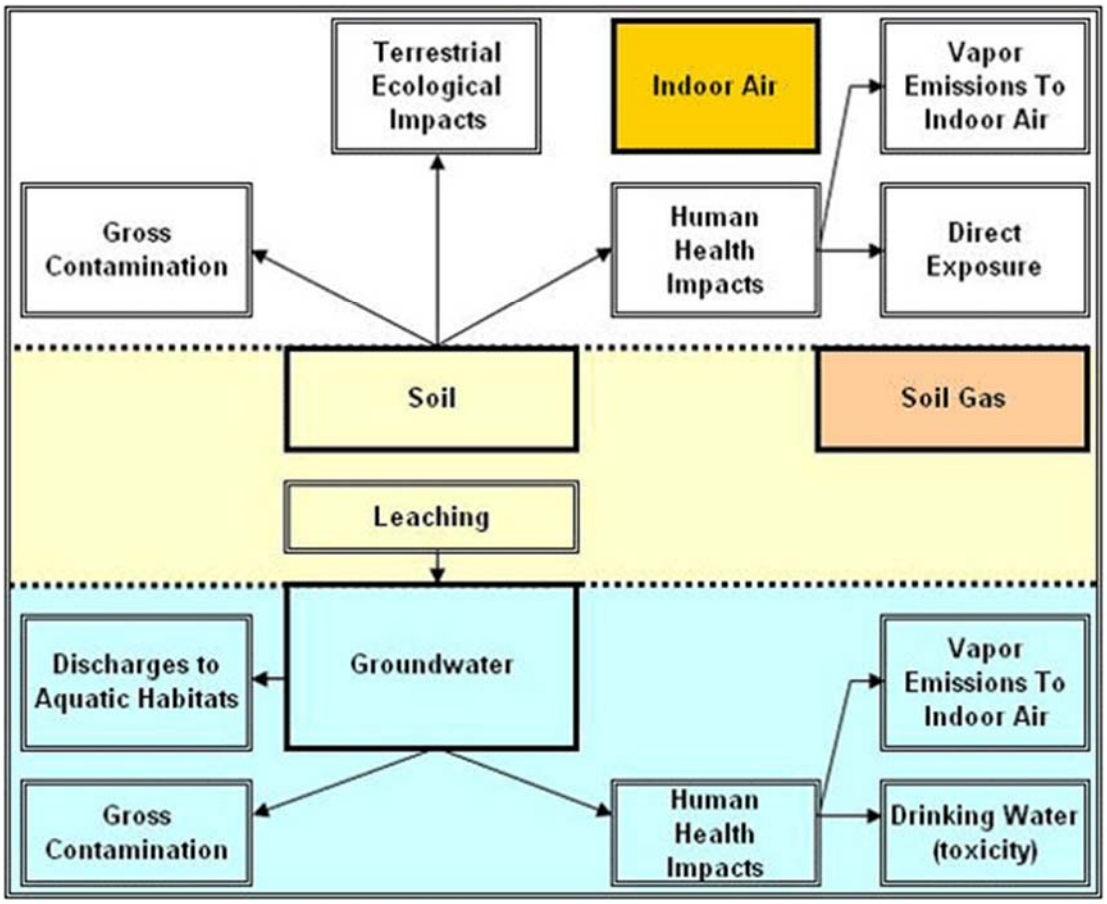


Figure 13-2. Summary of Environmental Hazards Considered in Action Levels. The four target media tested to evaluate these potential hazards are groundwater, soil, soil gas and indoor air.

A summary of common environmental hazards that should be initially screened for at contaminated sites is given in Table 13-1 (see also Figure 13-2)):

The potential for one of more of these environmental hazards to be present at a site should be evaluated in an EHE, which should include screening sample data if available. As discussed in Section 3, preparation of a conceptual site model that summarizes current site conditions is an important part of the EHE process.

Note that some of the environmental hazards listed above are not necessarily "risk-based," at least in the traditional toxicological use of this term with respect to dose and response. For example, soil that is grossly contaminated with petroleum may not pose a toxicological risk to future residents, but it could pose significant odor and nuisance concerns and in some cases even result in explosive levels of vapors in soil gas. Although it may seem counterintuitive, it is quite possible for soil that is flammable to be considered "nontoxic" in a standard human health risk assessment. Even so, the fact that the soil is flammable is important to call out in the Environmental Hazard Evaluation. Gross contamination can also complicate future construction or subsurface utility activities that require disturbance of heavily contaminated soil or groundwater.

Leaching of contaminants from soil is also important to consider, even though this is rarely included in traditional risk assessments. Discharges of contaminated groundwater or free product into nearby surface water bodies, either naturally or via leakage into storm sewers or through site dewatering activities, can pose significant environmental hazards to aquatic habitats. When large plumes of impacted groundwater threaten fisheries, the discharge of contaminated groundwater to surface water and subsequent uptake of contaminants into seafood may also be of concern. This includes the biomagnification of contaminants up the food chain and risks to human or ecological health if contaminated fish or shellfish is ingested.

The environmental hazard that drives the potential need for remedial action at a contaminated site is closely tied to the toxicity and mobility of the targeted contaminants. Concerns posed by soil contaminated with chemicals that are highly toxic to humans and relatively immobile are generally driven by direct exposure hazards (e.g., arsenic, lead, polychlorinated biphenyls [PCBs]). Vapor intrusion typically drives environmental hazard for soil contaminated with volatile carcinogens, although direct exposure and leaching hazards are not far behind (e.g., benzene, tetrachloroethylene [PCE], TPH gasoline, methane). Leaching hazards will often drive cleanup of soil contaminated with noncarcinogenic chemicals that are highly mobile (e.g., TPH gasoline or diesel,

toluene, xylenes, chlorinated herbicides). Soil contaminated with pesticides or metals that are relatively non-toxic to humans and immobile could still pose significant toxicity hazards to terrestrial flora and fauna (e.g., barium, copper, nickel).

Drinking water toxicity hazards are almost always identified for contaminated aquifers. Potential vapor intrusion hazards will also usually be identified for groundwater contaminated with carcinogenic, volatile chemicals. Chemicals that have a low taste and odor threshold may not pose toxicity concerns but can still pose gross contamination hazards for drinking water resources (e.g., TPH, ethylbenzene, toluene, xylenes). A number of pesticides pose aquatic toxicity hazards at concentrations well below drinking water standards. This can drive remedial actions if discharge of contaminated groundwater into a sensitive aquatic habitat is possible. Free product could pose both toxicity and gross contamination hazards if allowed to migrate offsite and discharge into a surface water body. Free product also poses potential vapor intrusion hazards for nearby buildings as well as potential explosive, subsurface vapor hazards.

Other potential environmental hazards may require attention at some sites, including exposure of construction workers to contaminated groundwater and the potential uptake of contaminants in garden produce. The need to include additional environmental hazards in the site assessment must be determined on a site-by-site basis.

13.2 DEVELOPMENT OF VAPOR INTRUSION SCREENING TOOLS

The collection of soil vapor samples as part of a site characterization and vapor intrusion investigation is discussed in Section 7. The technical background and development of soil vapor and indoor air action levels for assessment of potential vapor intrusion hazards is presented in the HDOH Environmental Hazard Evaluation (EHE) guidance (HDOH, 2016.). The guidance also presents soil and groundwater action levels for screening of potential vapor intrusion hazards. The collection of soil vapor data is recommended for all sites where potentially significant releases of volatile chemicals might have occurred.

A key factor in development of the action levels for potential vapor intrusion risks is the assumed attenuation of subsurface vapors as they intrude a building and mix with indoor air. Assumptions incorporated into the vapor intrusion models are discussed in Sections 2 and 3 of Appendix 1 of the EHE guidance and based on research published by Brewer et al. (Brewer et al., 2014b.). The research represents an important update to indoor air:subslab soil vapor attenuation factors initially proposed by USEPA researchers in the early 2000s and published for public review in 2012 (USEPA 2012b.).

The "empirical database" used to derive the 2012 USEPA attenuation factors was subsequently determined to be unreliable (Brewer et al. 2014b.). The database relied on a single, small-volume (e.g., one-liter), randomly located, subslab vapor sample to represent intruding vapors (attenuation = indoor air sample concentration/subslab vapor sample concentration). Attenuation factors derived from the database were an order of magnitude or more higher (i.e., less attenuation) than attenuation estimated from more rigorous databases of building leakage used by engineers to design heating and cooling and energy systems, and were called into question. Use of the excessively high ("conservative") attenuation factors caused large numbers of sites with relatively minimal VOC contamination to be unnecessarily flagged for potential vapor intrusion risks.

Reliability of the approach used by USEPA required a high degree of uniformity of VOC concentrations in vapors beneath building slabs. Collection of a vapor sample from another location under the building slab would otherwise generate a different attenuation factor, implying that any single attenuation factor estimated was random and unlikely to be representative of actual vapor intrusion conditions. As discussed by Brewer et al. (Brewer et al., 2014b.), subslab vapor plumes are in fact likely to highly heterogenous. This, in addition to uncertainty regarding actual vapor entry points into a building, negates the validity of the USEPA database for derivation of indoor air:subslab attenuation factors. As an alternative, Brewer et al. (Brewer et al., 2014b), refer back to the original approach proposed by USEPA (USEPA, 2004f.) based on better supported building leakage rates in various climate regions within the United States. Using this approach, attenuation factors estimated for tropical regions where buildings are not heated throughout the year were used to develop soil vapor action levels presented in the HDOH EHE guidance.

Two USEPA vapor intrusion guidance documents were being finalized for publication at the time that the Brewer at al. (Brewer at al., 2014b.) research was published, one for vapor intrusion in general (USEPA 2015c.) and one specific to vapor intrusion associated with petroleum (USEPA 2015b). The research published by Brewer et al. (Brewer et al., 2014b.) is referenced in the USEPA petroleum vapor intrusion guidance. The research is not, however, referenced in the general vapor guidance. This was due to completion of the final review of the guidance document prior to publication of the Brewer et al. (Brewer et al., 2014b.) paper (personal communication, Kapuscinski, 2016.):

> The (Brewer et al. 2014) paper… on subslab attenuation factors was published (Fall 2014) after the intra-agency vetting concluded for the (2015) OSWER Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air (OSWER Publication 9200.2-154). By contrast, the (2015) Technical Guide for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites (EPA 510-R-15-001) was prepared and revised somewhat independently.

Although publication of the USEPA vapor intrusion guidance documents postdate publication of the Brewer et al. (Brewer et al., 2014b.) research, presentation of indoor air:subslab vapor attenuation factors in the documents based on the 2012, USEPA "empirical database" should be considered invalid and not referred to for use in site-specific, vapor intrusion investigations.

13.3 TIER 1 ENVIRONMENTAL ACTION LEVELS

Tier 1 Environmental Action Levels (Tier 1 EALs) are concentrations of contaminants in soil, soil gas and groundwater below which the contaminants are assumed to not pose a significant threat to human health or the environment. Exceeding the Tier 1 EAL does not necessarily indicate that contamination at the site poses environmental hazards. It does, however, indicate that additional evaluation is warranted. This can include additional site investigation and a more detailed evaluation of the tentatively identified environmental hazards. For example, the Tier 1 EALs incorporate conservative, risk-based exposure assumptions that may not be applicable under current site conditions and warrant a more site-specific risk assessment (see also Subsection 13.5.3). The action levels, or approved alternatives, can be used to delineate specific areas of the site that require response actions. These actions can vary, depending on the hazard present and site conditions.

A detailed discussion of the development of the Tier 1 EALs is provided in the HDOH HEER Office document *Screening for Environmental Hazards at Sites with Contaminated Soil and Groundwater* (HDOH, 2016). The EALs described in the EHE document are not intended to establish policy or regulation. Use of the document and associated EALs is optional on the part of the party responsible for investigation and cleanup of a contaminated site. Reference to updated EALs will generally not be needed at sites where final cleanup levels have already been reviewed and approved by the HEER office, including sites that have already been closed. For sites where investigation is currently underway, referral to updated EALs is recommended.

13.3.1 DEFAULT CONCEPTUAL SITE MODELS

A conceptual site model (CSM) is a comprehensive representation of site environmental conditions with respect to contaminated soil and groundwater and related environmental hazards (see Subsection 3.4.3). Four default CSMs were used to develop The Tier 1 EALs (HDOH, 2016):

a. Groundwater affected or potentially affected by the release is a current or potential drinking water resource; site located within 150m of a surface water body.

b. Groundwater affected or potentially affected by the release is a current or potential drinking water resource; site *not* located within 150m of a surface water body.

c. Groundwater affected or potentially affected by the release is *not* a current or potential drinking water resource; site located within 150m of a surface water body.

d. Groundwater affected or potentially affected by the release is *not* a current or potential drinking water resource; site *not* located within 150m of a surface water body.

Only surface water bodies that are hydraulically connected to groundwater are considered to be potentially threatened by contaminated groundwater. For the purposes of the Tier 1 EALs, it is further assumed under each default CSM that contaminated soil is exposed at the ground surface or could otherwise become exposed in the future. Using this approach to initially screen site data clears the site for unrestricted land use if Tier 1 EALs are not exceeded and avoids the need for additional investigations if site conditions change. Refer to the HDOH document *Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater* for additional information on site conditions assumed for development of the Tier 1 EALs (HDOH, 2016).

The default CSMs can be modified and alternative action levels developed if necessary. Alternative soil action levels for direct exposure and gross contamination hazards at commercial/industrial sites are included in Appendix 1 of the detailed EHE document (HDOH, 2016). As discussed below in Subsection 13.3.3, the EAL Surfer has been modified to allow selection of land use on a site-by-site basis. Alternative action levels for deeper soils are also provided in the guidance (e.g., >3 meters below ground surface). Be aware, however, that the use of alternative CSMs and action levels could require that formal institutional or engineered controls be imposed on the property, especially for nonpetroleum-related contamination (see Section 19). **Site data should always be initially screened using the Tier 1 EALs (or approved, alternative action level) for unrestricted (e.g., residential) land use.** If the site passes this screen then there is no need to screen the data using an alternative CSM and assumed land use.

13.3.2 COMPILATION OF ENVIRONMENTAL ACTION LEVELS

Figure 13-3 summarizes the general use of the Tier 1 EALs. Approximately 150 chemicals are listed in the EAL lookup tables (HDOH, 2016). For each chemical, an action level was compiled to address each specific environmental hazard discussed above and noted in Figure 13-2, as applicable and available.

The lowest of the individual action levels for each hazard was selected for inclusion in the summary Tier 1 EAL lookup tables. This ensures that the EALs presented in these tables are protective of all potential environmental hazards. The detailed tables used to develop the Tier 1 EALs can be used to identify the specific environmental hazards that are potentially present at the site. The EAL Surfer makes this process relatively quick and easy (see Subsection 13.3.3).

An example of the selection of Tier 1 EALs for benzene is presented in Figure 13-4 (surface soils, drinking water resource threatened, unrestricted land use desired).

For soil, the action level for leaching hazards (0.22 mg/kg) is lower than the action levels for each of the other environmental hazards. This action level is therefore selected as the Tier 1 EAL [refer to lookup tables in HDOH EAL document (HDOH, 2016)]. For groundwater, the action level for drinking water toxicity concerns drives environmental hazards and is selected as the Tier 1 EAL (5 ug/L, the primary drinking water standard).

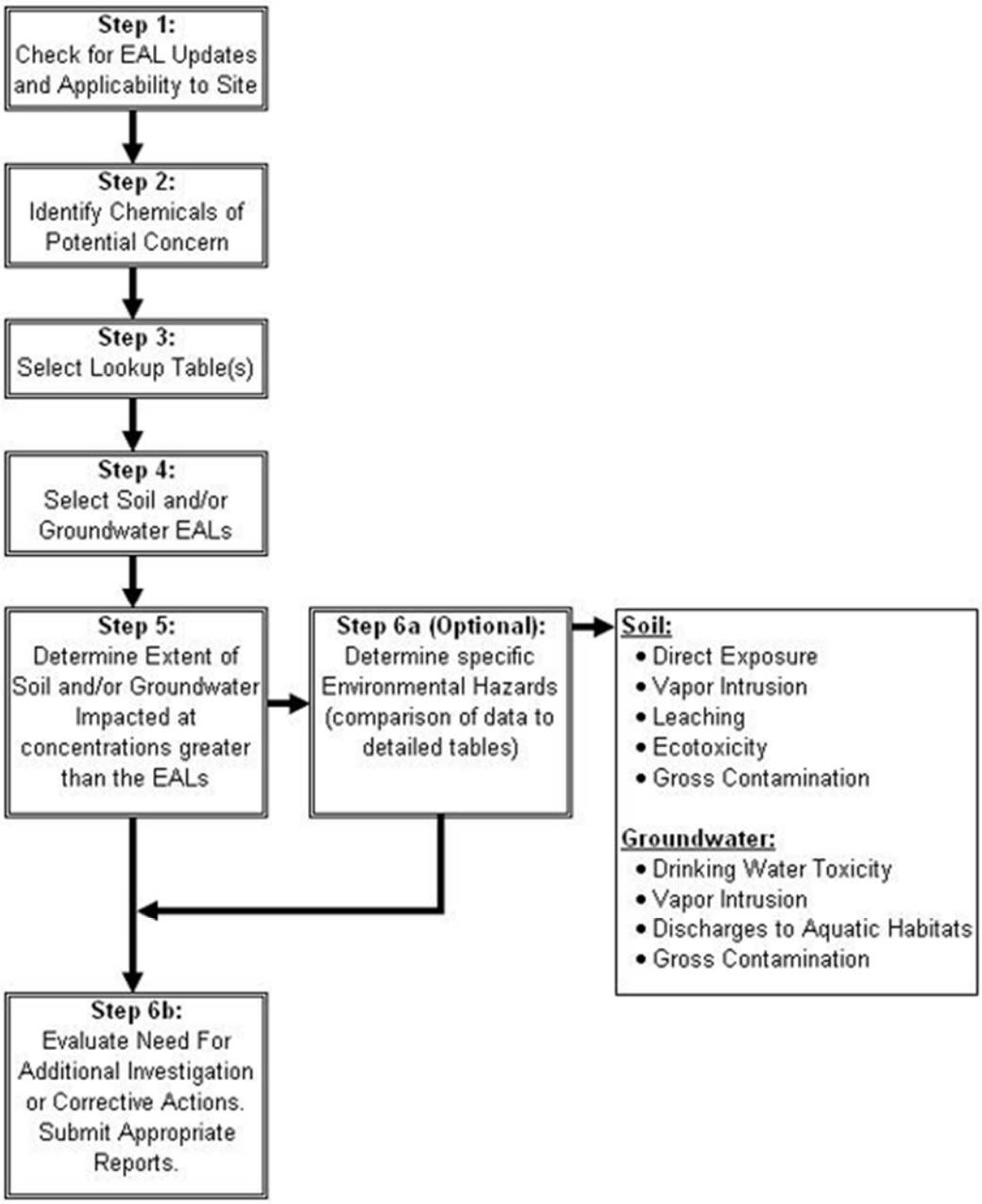


Figure 13-3 Summary of Steps for Use of Tier 1 EAL Lookup Tables.

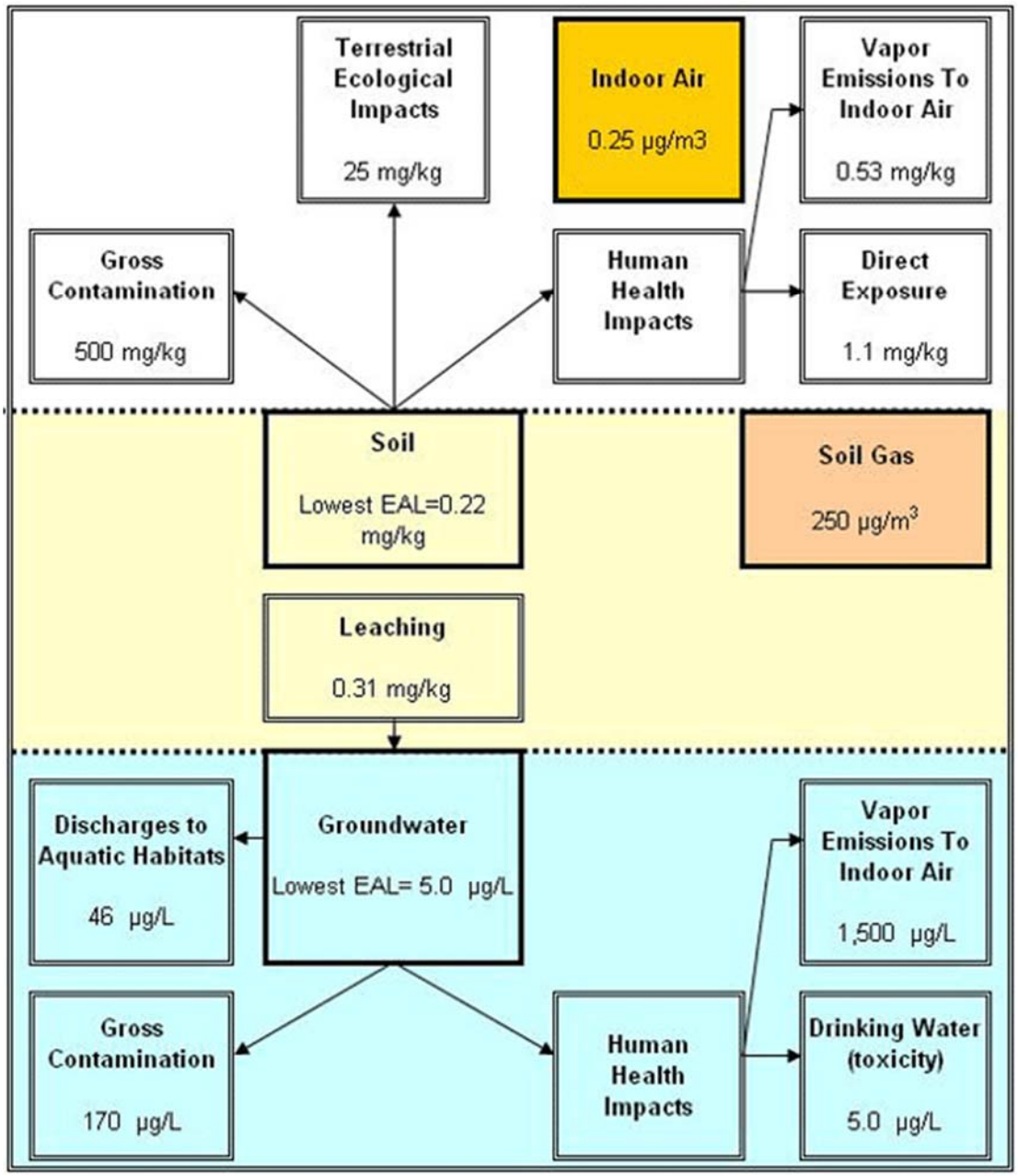


Figure 13-4. Summary of Action Levels Used to Select Tier 1 Soil and Groundwater EALs for Benzene. CSM A based on (1) groundwater is a drinking water resource, and (2) site within 150m of a surface water body. For soil and groundwater, the lowest action level for environmental hazards is selected as the final Tier 1 EAL.

13.3.3 USE OF THE EAL SURFER

The EAL Surfer, an Excel-based version of the lookup up tables, makes use of the EALs and the identification of potential environmental hazards at contaminated sites especially easy. The EAL Surfer is available for download from the HEER Office web page:

Use of the EAL Surfer in Environmental Hazard Evaluation reports is highly recommended. To use the Surfer, simply select the appropriate site scenario information from the pull-down list (groundwater utility, distance to nearest surface water body, land use, etc.), select the target contaminant, and (optional) input the representative concentration of the contaminant in soil and/or groundwater. If included, the input concentration is compared to action levels for specific environmental hazards and the Surfer flags hazards where the action level is exceeded. A separate, summary report is generated that can be printed and included in the Environmental Hazard Evaluation report.

The 2008 version of the EAL Surfer is modified from previous versions to allow selection of commercial/industrial land use, rather than residential/unrestricted land use as assumed in the default, Tier 1 CSMs and EALs. Soil action levels for direct exposure, vapor intrusion and gross contamination hazards are higher (i.e., less stringent) than correlative action levels for residential/unrestricted land use. Soil action levels for leaching hazards are unchanged because land use does not alter the threat to groundwater. Groundwater action levels for vapor intrusion hazards are also higher for a commercial/industrial land use scenario. Action levels for other hazards are unchanged.

Example printouts of the Surfer are provided in Figures 13-5a (data input form), 13-5b (detailed environmental hazards) and 13-5c (EHE summary report). The example is based on an assumed residential land use scenario. Contaminated soil is located within three meters of the ground surface ("shallow") and overlies groundwater that is a current or potential source of drinking water. The site is within 150 meters of a surface water body.

In the example (i.e., Figures 13-5a, 13-5b, and 13-5c), the input concentration of benzene in soil (5.1 mg/kg) causes direct exposure, vapor intrusion and leaching hazards to be flagged. Potential impacts to terrestrial ecological receptors and gross contamination are not flagged as potential hazards. The input concentration of 150 ug/L benzene in groundwater flags drinking water toxicity concerns and aquatic ecotoxicity concerns, but no other potential hazards.

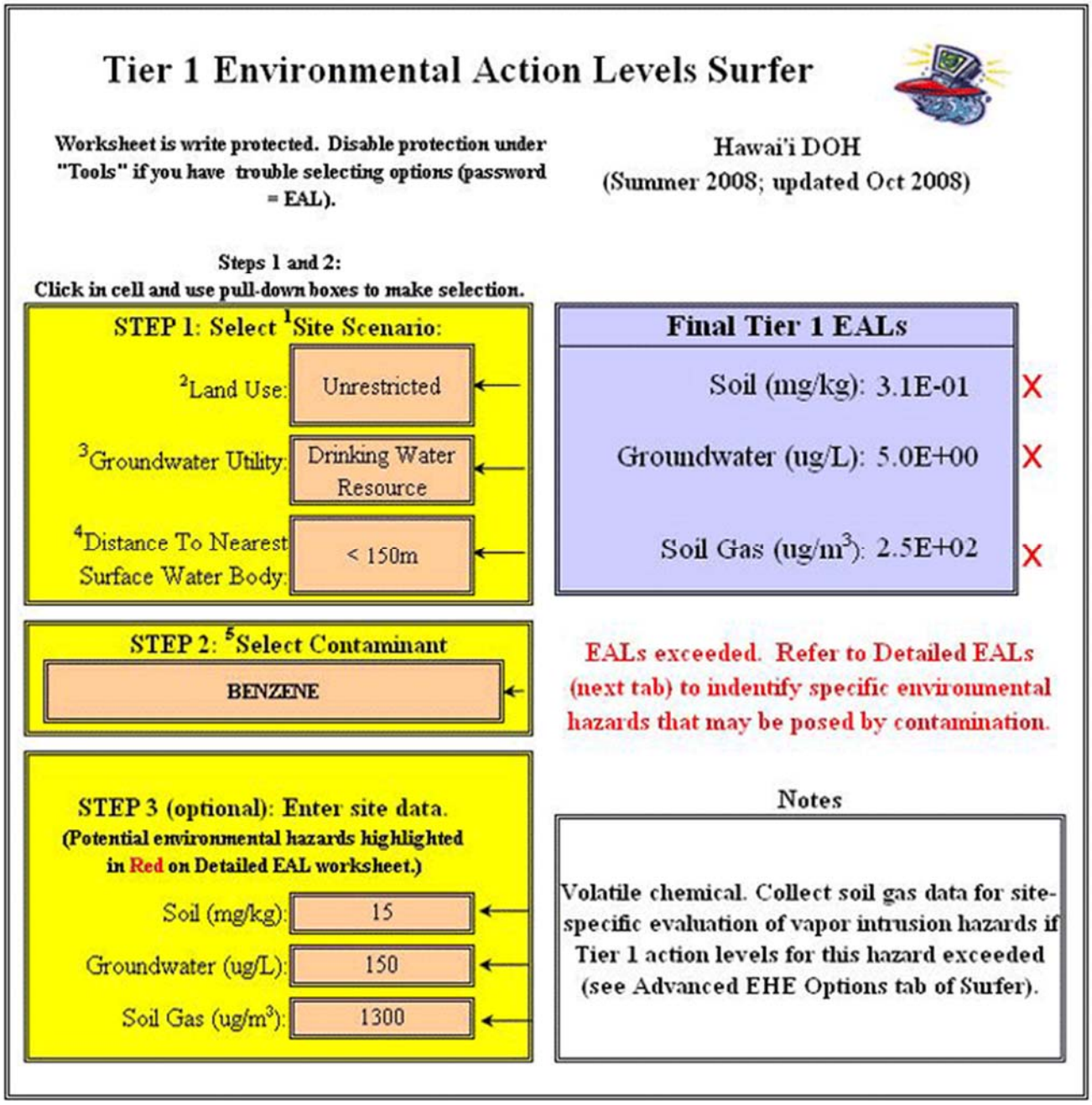


Figure 13-5a. Printout of EAL Surfer Input Page. Data used for this example was 5.1 mg/kg benzene in soil, and 150ug/L benzene in groundwater. Also, check for updates. The EAL Surfer is updated periodically and the page configurations may change.

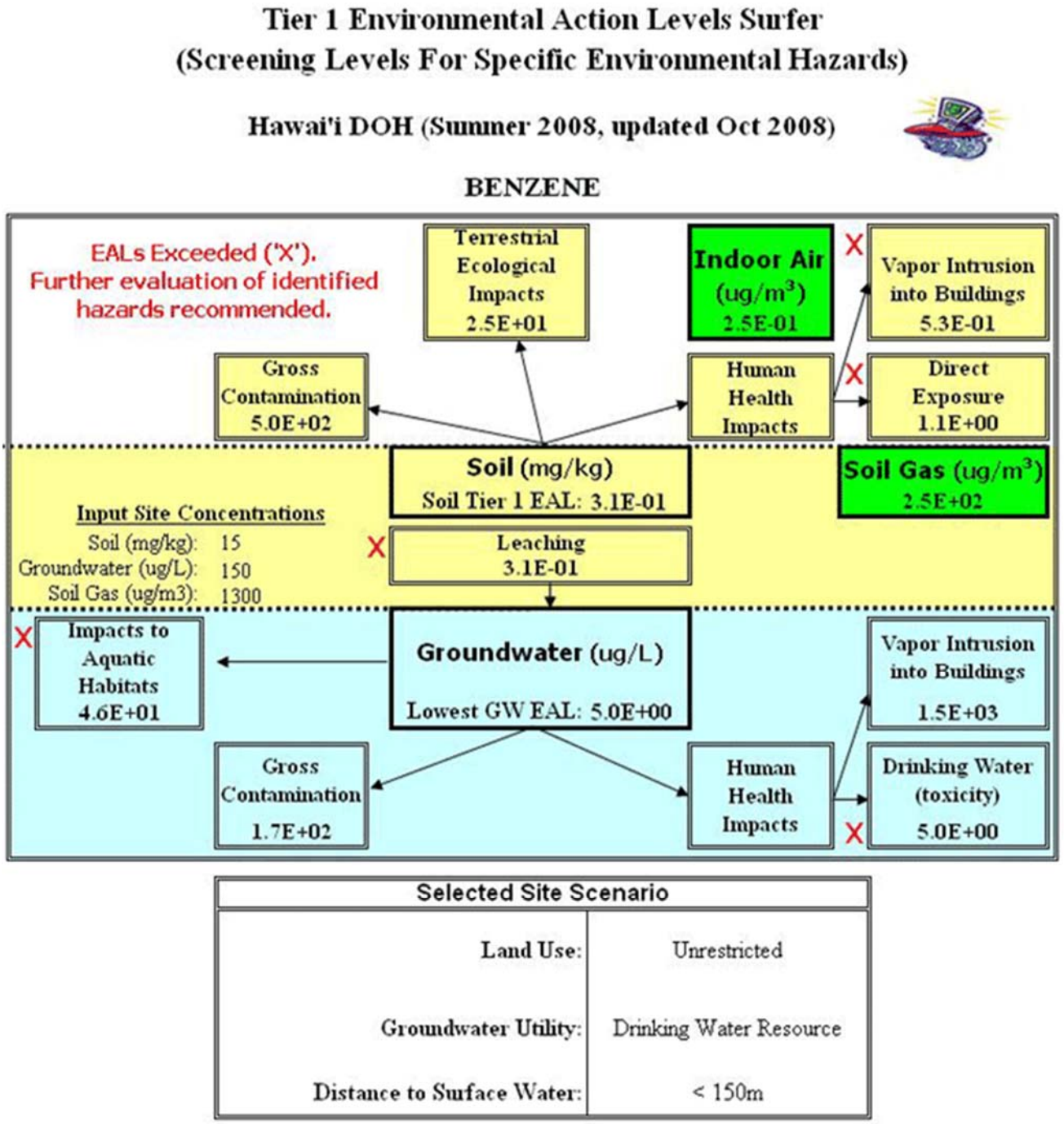


Figure 13-5b. Printout of EAL Surfer Detailed Environmental Hazard Identification Page, Using Benzene at Noted Concentration in Soil and Groundwater as an Example. Refer also to Figure13-5a.

[1]Tier 1 EAL SURFER SUMMARY REPORT
Hawai'i DOH (Summer 2008, updated Oct 2008)

Site Name:	
Site Address:	
Site ID Number:	
Date of EAL Search:	

Selected Site Scenario	
Land Use:	Unrestricted
Depth to Impacted Soil:	Drinking Water Resource
Groundwater Utility:	< 150m

Selected Chemical of Concern:	BENZENE

Input Site Concentrations	
Soil (mg/kg):	15
Groundwater (ug/L):	150
Soil Gas (ug/m^3):	1300

Soil Environmental Hazards	Units	Tier 1 Action Level	[2]Potential Hazard?	[3]Referenced Table
Direct Exposure:	mg/kg	1.1E+00	Yes	Table I-1
Vapor Emissions To Indoor Air:	mg/kg	5.3E-01	Yes	Table C-1b
Terrestrial Ecotoxicity:	mg/kg	2.5E+01	No	Table L
Gross Contamination:	mg/kg	5.0E+02	No	Table F-2
Leaching (threat to groundwater):	mg/kg	3.1E-01	Yes	Table E-1
Background:	mg/kg	-		
Final Soil Tier 1 EAL:	**mg/kg**	**3.1E-01**		
Basis:	**Leaching**			

Groundwater Environmental Hazards	Units	Tier 1 Action Level	[2]Potential Hazard?	[3]Referenced Table
Drinking Water (Toxicity):	ug/L	5.0E+00	Yes	Table D-1a
Vapor Emissions To Indoor Air:	ug/L	1.5E+03	No	Table C-1a
Aquatic Ecotoxicity:	ug/L	4.6E+01	Yes	Table D-4a
Gross Contamination:	ug/L	1.7E+02	No	Table G-1
Final Groundwater Tier 1 EAL:	**ug/L**	**5.0E+00**		
Basis:	**Drinking Water Toxicity**			

Other Tier 1 EALs:	Units	EAL	[2]Potential Hazard?	[3]Referenced Table
Shallow Soil Gas:	ug/m^3	2.5E+02	Yes	Table C-2
Indoor Air:	ug/m^3	2.5E-01	-	Table C-3

Figure 13-5c. Printout of EAL Surfer EHE Summary Report, Using Benzene at Noted Concentration in Soil and Groundwater as an Example. Refer also to Figure 13-5a. This page can be printed and included in the Environmental Hazard Evaluation report. Referenced tables are from Appendix 1 of the EHE guidance (HDOH, 2016).

13.3.4 USE OF EALS IN SITE INVESTIGATIONS

One of the most basic uses of the EALs is to determine the extent of investigation needed at a site where contaminated soil or groundwater is identified. The list of Chemicals of Potential Concern (COPCs) can be quickly narrowed down by direct comparison of soil and groundwater data to the Tier 1 EALs (HDOH, 2016). Further consideration of contaminants that do not exceed Tier 1 EALs is not necessary. This assumes that existing data are representative of overall site conditions.

Delineation of the narrowed list of target COPCs to non-detect levels is often impracticable and, from a hazard evaluation standpoint, unnecessary. The investigation can be considered complete once the extent of contamination is delineated to Tier 1 EALs (or approved alternatives). As data are received during the site investigation, the EALs can be used to determine areas where the extent of contamination has been adequately identified as well as areas where additional sampling is needed. The use of field screening methods, onsite mobile labs, and/or quick turnarounds in laboratory analyses will help reduce the need for remobilizations and expedite the completion of site investigation activities.

As the site investigation is underway, a comparison of site data to action levels for specific environmental hazards can also help identify the need for alternative types of site data that will help evaluate appropriate response actions to address the contamination. For example, if arsenic is reported in soil at concentrations above the Tier 1 EAL of 20 mg/kg, then laboratory arsenic bioaccessibility tests can be used to more accurately evaluate potential direct-exposure hazards (refer to Sections 3 and Section 9). If the reported concentration of volatile contaminants in soil or groundwater exceed action levels for vapor intrusion concerns, then soil gas data can be collected to more closely evaluate this potential hazard. Incorporating these decisions in the sampling and analysis plan for the site will help expedite completion of the site investigation as well as alert responsible parties to potentially significant environmental conditions at the site.

13.3.5 USE OF EALS IN ENVIRONMENTAL HAZARD EVALUATIONS

The most important use of the HDOH Tier 1 EALs is the rapid identification of potential environmental hazards associated with contaminated soil and groundwater (refer to Subsection 3.4). With the exception of gross contamination, most of the environmental hazards noted above are not obvious in the field. An initial comparison of site data to the Tier 1 EALs will only indicate if a potential hazard is present (i.e., "yes" or "no"). If the Tier 1 EAL is exceeded, site data should be compared to the detailed action levels used to develop the Tier 1 EALs to identify the specific potential environmental hazards present. As discussed above, use of the *EAL* Surfer will significantly expedite this process (see Subsection 13.3.3).

Potential environmental hazards identified in a basic screening level *Environmental Hazard Evaluation* can be evaluated on a more site-specific basis as needed. The information gained can be used to better define the need for additional site investigation as well as develop appropriate remedial options. Approaches for more advanced or site-specific evaluation of specific environmental hazards are briefly discussed in Subsection 13.5.4.

The level of effort required for advanced evaluations can vary greatly. For example, qualitatively discounting potential hazards posed to terrestrial ecological habitats will be relatively simple at highly developed commercial or industrial sites, based on the lack of significant habitat. The collection of additional soil gas data is very useful (and strongly recommended) for more detailed evaluations of vapor intrusion concerns. The inclusion of soil gas action levels in this guidance helps expedite this evaluation. A detailed review of groundwater data can sometimes be used in place of soil action levels to better evaluate leaching and groundwater contamination concerns. In other cases, additional laboratory tests and/or use of environmental models may be required (see Subsection 13.5.4).

13.3.6 USE OF EALS IN RESPONSE ACTIONS

The Tier 1 EALs are not strict cleanup standards. In cases where the extent of contamination is minimal and time is of the essence, however, it may be more cost-effective to simply remediate soil contaminated above the Tier 1 EALs (or acceptable, alternative action levels) without further evaluation. In other cases, use of the detailed action levels to identify site-specific environmental hazards posed by the contamination will play an important role in final response actions.

For example, placing a soil cap on contaminated soil may be acceptable in some cases (e.g., direct exposure to non-volatile contaminants) and not in others (e.g., vapor intrusion or leaching hazards). Using the detailed action levels to understand the specific environmental hazards posed by contaminated groundwater is especially important. Identifying toxicity hazards and taste and odor hazards in groundwater that is currently used as a source of drinking water is obviously important. Expeditious actions to address vapor intrusion hazards posed by contaminated soil are usually warranted. In contrast, long-term monitoring may be acceptable for groundwater that poses only gross contamination hazards (e.g., toxicity-based action levels for currently unused drinking water resources not exceeded) or potential aquatic toxicity hazards if it were to migrate offsite and discharge into a body of surface water.

Long-term management will be required for sites where soil and groundwater contaminated above levels of potential concern cannot be remediated in a relatively short time frame. In such cases, the detailed action levels presented in this guidance (or acceptable alternatives) should be used to delineate areas of contaminated soil and groundwater that will require long-term management as well as the specific environmental hazards posed by the contamination under uncontrolled site conditions.

Specific actions required to address these hazards should then be described in an Environmental Hazard Management Plan (EHMP). Refer to Sections 18 and Section 19 for additional details on EHMPs.

13.3.7 CHEMICALS WITH MRL THAT EXCEED EALS

Environmental Action Levels (EALs) for a number of chemicals can be below commercial laboratory Method Reporting Limits (MRLs) for a number of chemicals in groundwater. This is not generally the case for soil. As discussed in the EHE guidance, the laboratory MRL, or equivalent, should be used to screen site data (see HDOH, 2016).

Chemicals with laboratory MRLs that could exceed the HDOH EALs for groundwater are given in Table 13-2.

If the reported concentration of a chemical exceeds the MRL then the need for additional action should be discussed with the HEER office.

Table 13-2 Chemicals with laboratory reporting limits that could be higher than HDOH Environmental Action Levels.

Groundwater	Soil
Aldrin	Bis(2-chloroethyl)ether
Benzo(a)anthracene	Bromodichloromethane
Benzo(a)pyrne	Bis(2-chloroisopropyl)ether
Benzo(b)fluorene	p-Chloroaniline
Bis(2-chloroethyl)ether	Chloroform
Bis(2-chloroisopropyl)ether	2-Chlorophenol
Boron	3-Dibromo, 1,2-chloropropane
Bromodichloromethane	Dibromochloromethane
Chlordane(Technical)	1,2-Dibromomethane
2-Chlorophenol	3,3-Dichlorobenzidine
Cobalt	1,2-Dichloroethane
Cyanide(Free)	1,4-Dioxane
Dibenzo(a,h)anthracene	Methyl tert-Butyl Ether
3-Dibromo,1,2-chloropropane	Perchlorate
Dibromochloromethane	Phenol
1,2-Dibromoethane	tert-Butyl Alcohol
3,3-Dichlorobenzidine	1,1,1,2-Tetrachloroethane
Dichlorodiphenyldichloroethane (DDD)	1,1,2,2-Tetrachloroethane
Dichlorodiphenyldichloroethylene (DDE)	
Dichlorodiphenyltrichloroethane (DDT)	
1,2-Dichloroethane	
2,4-Dichlorophenol	
1,3-Dichloropropene	
Dieldrin	
Diethylphthalate	
Dimethylphthalate	
Endosulfan	
Endrin	
Heptachlor	
Heptachlor Epoxide	
Indeno(1,2,3-cd)pyrene	
Methoxychlor	
1-Methylnaphthalene	
2-Methylnaphthalene	
Polychlorinated Biphenyls (PCBs)	
1,1,1,2-Tetrachloroethane	
1,1,2,2-Tetrachloroethane	
Toxaphene	

13.4 CHEMICALS NOT LISTED IN LOOKUP TABLES

Soil, groundwater, soil gas and/or indoor air action levels should be developed and approved by HDOH for chemicals not listed in the current lookup tables but identified during a site investigation. A detailed discussion of the development of action levels presented in this guidance is provided in Appendix 1 of the EHE guidance (see HDOH, 2016). Preparation of the action levels should be coordinated with the HEER office.

An exception are petroleum compounds collectively measured under Total Petroleum Hydrocarbons (see Section 9), With the exception of the target, indicator compounds noted in Section 9, individual petroleum-related compounds that are captured and included in TPH analyses do not need to be evaluated separately in an EHE. Action levels for these compounds do not need to be developed. This includes a host of alkanes, alkenes, alkyl benzenes and other aromatics not specifically identified as target indicator compounds that could be reported separately in analytical methods for volatile organic compounds (e.g., trimethylbenzenes).

Action levels must be developed for all applicable, potential hazards (refer to Subsection 13.1; see also HDOH, 2016). **In particular, the USEPA Regional Screening Levels (RSLs, USEPA, 2012a and updates) *cannot* be used as standalone criteria for the evaluation of contaminated soil.** This is because the RSLs do not consider all potential environmental hazards posed by contaminated soil. In particular, the RSLs do not address potential vapor intrusion, leaching or gross contamination hazards and may not adequately address cumulative health risks.

13.5 STEPS TO ENVIRONMENTAL HAZARD EVALUATION

It is important to begin to identify potential environmental hazards at a site as soon as initial soil, groundwater and other data are received. As discussed above, this is used to guide completion of the site investigation as well as to identify hazards that may require additional attention. Questions that should be asked and addressed as part of the Environmental Hazard Evaluation include:

1. Of the initial list of COPCs, which contaminants could pose potential environmental hazards under uncontrolled site conditions?
2. What are the specific environmental hazards posed by the targeted COPCs?
3. Are additional site data needed to better define the extent and magnitude of contamination or the specific environmental hazards identified?
4. Is an advanced evaluation of a specific environmental hazard warranted?
5. What is the distribution of potential environmental hazards across the site?
6. Is a response action required to address identified hazards?

These questions are discussed in more detail in the following sections. As discussed in Section 3, the initial Conceptual Site Model should be continually refined as additional data are collected and a greater understanding of site conditions is gained.

13.5.1 IDENTIFY KEY COPCS

Preliminary COPCs are selected based on the known or assumed past use of hazardous chemicals at the site. This is an important part of the Phase I assessment of the site and the subsequent preparation of a sampling and analysis plan. For example, if gasoline was stored at the site then the target COPCs should be TPH-gasoline, benzene, toluene, ethylbenzene, and xylenes (BTEX), lead and fuel oxygenates. If the site was used to mix pesticides then the specific types of pesticides should be identified. Related contaminants such as arsenic, lead, mercury and dioxins should also be considered COPCs. Additional guidance for pesticide and petroleum contamination is provided in Section 9. Refer also to the HDOH *Screening for Environmental Hazards at Sites with Contaminated Soil and Groundwater* guidance document (HDOH, 2016).

The list of COPCs can be quickly narrowed down once initial data are obtained by a comparison of data to the Tier 1 EALs. If the representative concentration of a contaminant does not exceed the respective Tier 1 EAL, then it can be reasonably assumed the contaminant does not pose a significant environmental hazard. If the Tier 1 EAL *is* exceeded, then additional evaluation of that contaminant is warranted. Contaminants that exceed the Tier 1 EALs should continue to be considered COPCs and carried through the environmental hazard evaluation process.

13.5.2 DETERMINE REPRESENTATIVE CONTAMINANT CONCENTRATIONS

As discussed in Sections 3 and Section 4, sites should be subdivided into individual decision units (DU) and the representative concentration of target COPCs within each DU determined. For groundwater and soil gas samples, direct reference to reported concentrations of COPCs in single monitoring wells or soil gas collection points is appropriate.

For soil, the use of *Multi-increment* sample data to determine representative contaminant concentrations is preferred over discrete sample or judgmental sample data (see Section 4). *Multi-increment* samples provide better coverage of DUs and better estimates of representative contaminant concentrations in comparison to discrete sample data, especially in cases where only a limited number of discrete sample points (e.g., <30) are located within a target DU. *Multi-increment* is a registered trademard of Envirostat, Inc.

Discrete soil sample data can also inject an unnecessary distraction into the site investigation process due to a tendency to focus on "maximum" contaminant concentrations reported at a single sample point location. Identification of the maximum concentration of a contaminant at any given point within a DU is not an objective of the site investigation or environmental

hazard evaluation process. As discussed in Section 4, the concentration of a contaminant at any given sample point location in itself has little importance. This is because direct exposure or other potential environmental hazards must be evaluated for the DU as a whole, rather than at any given point within the DU. In typical environmental contaminant evaluations, the question is:

> "What is the *representative* contaminant concentration across the DU as a whole?" not "What is the *maximum* contaminant concentration across the DU as a whole?"

13.5.3 IDENTIFY POTENTIAL ENVIRONMENTAL HAZARDS

If the representative concentration of a contaminant is verified to exceed Tier 1 EALs then the specific environmental hazard(s) posed by the contaminant should be identified. A detailed, site-specific evaluation of each possible environmental hazard on a site-specific basis would be an arduous and time-consuming task. Fortunately, this level of effort will rarely be necessary. A simple comparison of site data to the detailed action levels used to develop the Tier 1 EALs offers a relatively rapid and cost effective alternative. As discussed in Subsection 13.3.3, use of the EAL Surfer to identify specific environmental hazards makes this process relatively simple and is highly recommended.

13.5.4 ADVANCED EVALUATION OF ENVIRONMENTAL HAZARDS

Potential environmental hazards flagged by comparison of site data to Tier 1 EALs (or approved alternative action levels) may or may not exist at the site. The Tier 1 EALs assume uncontrolled site conditions, with the potential for contaminated soil to be exposed at the surface at some point in the future under a residential land use scenario. The models used to develop the soil action levels assume a fresh release and maximum contaminant mobility. Screening soil data at this level allows unrestricted use of the property. Actual site conditions could differ and contaminants could pose a much lower threat to human health and the environment than a simple screening level evaluation might imply. If warranted by potential cleanup costs or other factors (including requirement by the HEER Office), a more advanced and site-specific evaluation of targeted hazards can be carried out.

Advanced approaches for evaluation of environmental hazards discussed earlier are presented in the HDOH guidance document *Screening for Environmental Hazards at Sites with Contaminated Soil and Groundwater* ["EHE guidance" (HDOH, 2016)]. A summary of commonly used approaches is provided in Tables 13-3 and 13-4.

The need to carry out more advanced evaluations of tentatively identified environmental hazards must be assessed on a case-by-case basis. Exceeding action levels for specific hazards does not necessarily indicate the contamination poses a significant threat to human health and the environment, only that additional evaluation is warranted (see Subsection 13.3). In many cases the most cost-effective action to address a tentatively identified environmental hazard is to simply remove all contamination that exceeds Tier 1 EALs (e.g., excavation and disposal of a small area of lead-contaminated soil). In cases where cleanup costs could be substantial or full cleanup is otherwise not technically feasible, a more detailed evaluation of tentatively identified environmental hazards may be warranted. For petroleum-related contamination in particular, soil gas data often indicate a much lower vapor intrusion hazard than predicted by simple comparison of soil or groundwater data to HEER Office action levels. The additional data could negate the need for remedial actions at some sites to address this hazard. In other cases, soil gas data can help identify the presence of contamination that was not detected in earlier soil and groundwater sample collection.

Preparing a traditional human health risk assessment or ecological risk assessment as described in the following sections *does not* fulfill the need to prepare an initial *Environmental Hazard Evaluation*. As discussed in Subsection 13.6, a traditional risk assessment focuses on toxicological risks associated with direct exposure to contaminated soil, groundwater, or air. While this is important, direct exposure is only *one* of several potential environmental hazards that must be addressed in a more comprehensive Environmental Hazard Evaluation. Action levels specifically developed to screen for potential direct exposure concerns are incorporated in the Tier 1 EALs. Exceeding Tier 1 EALs does not necessarily indicate that the contamination does in fact pose direct-exposure hazards, only that potential risks to human health need to be considered in subsequent actions at the site. This could include preparing a more detailed human health risk assessment (see Subsection 13.6).

Table 13-3 Commonly Used Approaches for Evaluating Environmental Hazards in Groundwater

Environmental Hazard	Example Site-Specific Evaluation Approaches
Contamination of drinking water resources	· Identification and monitoring of nearby, groundwater supply wells and guard wells · Long-term monitoring of groundwater to evaluate plume migration potential · Use of groundwater plume fate & transport models in combination with long-term monitoring to evaluate plume migration potential
Vapor Intrusion	· Collection of soil gas data (strongly recommended) and subsequent evaluation of risk to human health (site-specific vapor intrusion model)

Environmental Hazard	Example Site-Specific Evaluation Approaches
Impact to Aquatic Habitats	· Use of groundwater data to evaluate plume expansion and migration over time · Use of fate and transport models to predict long-term migration potential of groundwater contaminant plumes · Preparation of a site-specific, ecological risk assessment, which can include aquatic bioassay testing, an evaluation of species diversity and/or sediment studies
Gross contamination	· Check groundwater for free product · Check discharge areas for sheen and other gross contamination concerns

Table 13-4 Commonly Used Approaches for Evaluating Environmental Hazards in Soil

Environmental Hazard	Example Site-Specific Evaluation Approaches
Direct Exposure	· Use of *Multi-increment* sample data to evaluate direct exposure concerns in targeted decision units · Use of HDOH Tier 2 Direct Exposure Spreadsheet to calculate alternative action levels (available from HEER Office web page) · Use of laboratory arsenic bioaccessibility tests to better evaluate arsenic toxicity · Preparation of a site-specific human health risk assessment that considers engineered and institutional controls to eliminate or minimize exposure pathways, alternative exposure assumptions, alternative target risks, etc.
Vapor Intrusion	· Collection of soil gas data (strongly recommended) and subsequent evaluation of risk to human health risk (site-specific vapor intrusion model)
Leaching	· Collection of groundwater data · Use of HDOH laboratory batch test guidance to evaluate contaminant mobility and estimate concentrations in source area leachate
Impacts to terrestrial habitats	· Field inspection to determine the presence or absence of potentially significant terrestrial ecological habits · Preparation of a detailed ecological risk assessment.
Gross contamination	· Field inspection of petroleum-contaminated soil to evaluate potential gross contamination concerns (especially in existing or planned residential areas)

Additional guidance is provided in the HDOH EHE guidance document (HDOH, 2016).

13.5.5 COMPLETE THE SITE INVESTIGATION

The identification of potential environmental hazard(s) and completion of the site investigation is an iterative process. Basic site investigation activities can be considered complete when the vertical and lateral extent of contamination above Tier 1 EALs (or acceptable alternatives) is determined. In some cases (e.g., investigation of commercial/industrial areas with land use restrictions), the delineation of contamination to higher action levels will be acceptable. The need for additional site data to complete the investigation should be continually reviewed as initial data is screened for potential environmental hazards.

For example, if direct exposure to contaminated soil is flagged in the EAL Surfer as a potential hazard, then site data should be reviewed to ensure that the limits of contamination are adequately identified. Estimating representative contaminant concentrations across exposure areas (e.g., residential yards, commercial lots) rather than more specific areas is generally acceptable. This is because it is assumed a person would have equal access to all parts of the exposure area (i.e., decision unit), not just the contaminated areas. For large, industrial complexes, the property may need to be divided into smaller decision units based on specific exposure areas (e.g., specific work areas at an industrial site). The use of *Multi-increment*sampling to better estimate exposure point concentrations for specific exposure areas should be considered (see Section 4). The collection of arsenic bioaccessibility data for arsenic-contaminated soil is recommended when the concentration of total arsenic exceeds the Tier 1 EAL of 20 mg/kg. This is used to better evaluate direct exposure concerns.

If soil leaching hazards are identified then specific spill areas should be identified and treated as separate decision units. This is because the spill area, not the site as a whole, is the target where the "receptor" of concern is the groundwater directly underneath the contaminated soil. If Tier 1 soil action levels for leaching concerns are exceeded, then batch test data should be collected for the target contaminants and a more advanced evaluation of leaching concerns carried out. Keep in mind that soil data are not necessarily good indicators of potential groundwater contamination. This is especially true for chlorinated solvents. Releases of wastewater contaminated with solvents may not leave an identifiable smear zone in vadose-zone soil due to the low sorptive capacity of the solvent compounds, even though the release results in significant contamination of groundwater.

Soil or groundwater data flagged for potential vapor intrusion almost always indicates that soil gas samples should be collected at the site. The model used to develop the soil and groundwater actions levels for vapor intrusion hazards estimates the concentration of a volatile contaminant in shallow soil gas based on assumed chemical and soil properties. The models are considered to be conservative, especially for highly biodegradable chemicals like TPH and BTEX. Active soil gas data (e.g., collected in a summa canister) are much more reliable for evaluation of this hazard. The collection of methane data is also useful at sites with heavy petroleum contamination to address the potential for explosion hazards, especially where confined spaces are present or may occur after redevelopment.

The results of the site investigation should be summarized on to-scale maps and, as needed, cross sections of the site that clearly delineate the lateral and vertical extent of contamination above Tier 1 EALs (or approved alternative action levels). The same maps can be used to identify areas of specific environmental hazards and assist in development of appropriate response actions, as discussed below. A recommended format and content requirements for site investigation reports is presented in Section 18

13.5.6 PREPARE ENVIRONMENTAL HAZARD MAPS

Documentation of the distribution of environmental hazards across the site is an important step in the conceptual site model. Examples of issues to consider include: 1) What areas of the site pose potential direct exposure or vapor intrusion hazards? 2) What areas of the site pose potential leaching hazards? and 3) In what areas will grossly contaminated soil likely be encountered during future subsurface activities? Understanding the site in terms of environmental hazards rather than just contaminant concentrations is important because this serves as the basis for cleanup as well as long-term management plans. The most appropriate response action can vary, depending on the environmental hazards posed by the targeted contaminants.

Although not always needed or required, post-cleanup "as built" *environmental hazard maps* that clearly depict the extent and nature of environmental hazards at a site can be very useful. As discussed in the previous sections, this can be accomplished by comparison of site data to HEER Office action levels (or acceptable alternatives) for targeted hazards. Maps that summarize the extent and magnitude of contamination can be converted to environmental hazard maps by basing contaminant isoconcentration contours on action levels for specific hazards.

Example environmental hazard maps are provided in Figures 13-6 and 13-7.

In Figure 13-6, soil contaminated with dioxins and arsenic poses direct exposure hazards across a large portion of the site. Soil contaminated with chlorinated herbicides (e.g., ametryn, atrazine, diuron, etc.) in a smaller area of the site poses an additional leaching hazard. In a third area, soil contaminated with chlorinated solvents poses vapor intrusion hazard, a direct exposure hazard and a leaching hazard. In a fourth area, soil contaminated with heavy petroleum poses only gross contamination concerns. Note that highly toxic and mobile contaminants often pose a combination of several environmental hazards, including vapor intrusion, direct exposure and leaching (e.g., PCE).

The environmental hazard map in Figure 13-6 can now be used to guide selection of the most appropriate remedial alternative. Complete removal of contamination is obviously preferable. Assuming that this is not achievable for the example, a well-managed soil cap can be adequate to eliminate direct exposure hazards. Areas that pose a leaching hazard and cannot be cleaned up in a relatively short time frame will, in contrast, require some type of impermeable cap. Subslab vapor mitigation systems will be required for new buildings placed within the vapor intrusion hazard area. Indoor air studies may be needed for existing buildings located in this area.

Documenting where grossly contaminated soil and groundwater will be left in place at a site is also important (e.g., Figure 13-7). Gross contamination hazards often drive the cleanup of contaminated soil and groundwater, not direct exposure or even leaching hazards. Over time, grossly contaminated soil and groundwater can generate methane and related explosive hazards. Although the contamination may not pose environmental hazards under current site conditions, the unexpected discovery of grossly contaminated soil and groundwater during subsurface construction or utility activities can result in significant delays and project costs. Foreseeing and documenting these concerns in an Environmental Hazard Management Plan is important (see Sections 18 and Section 19).

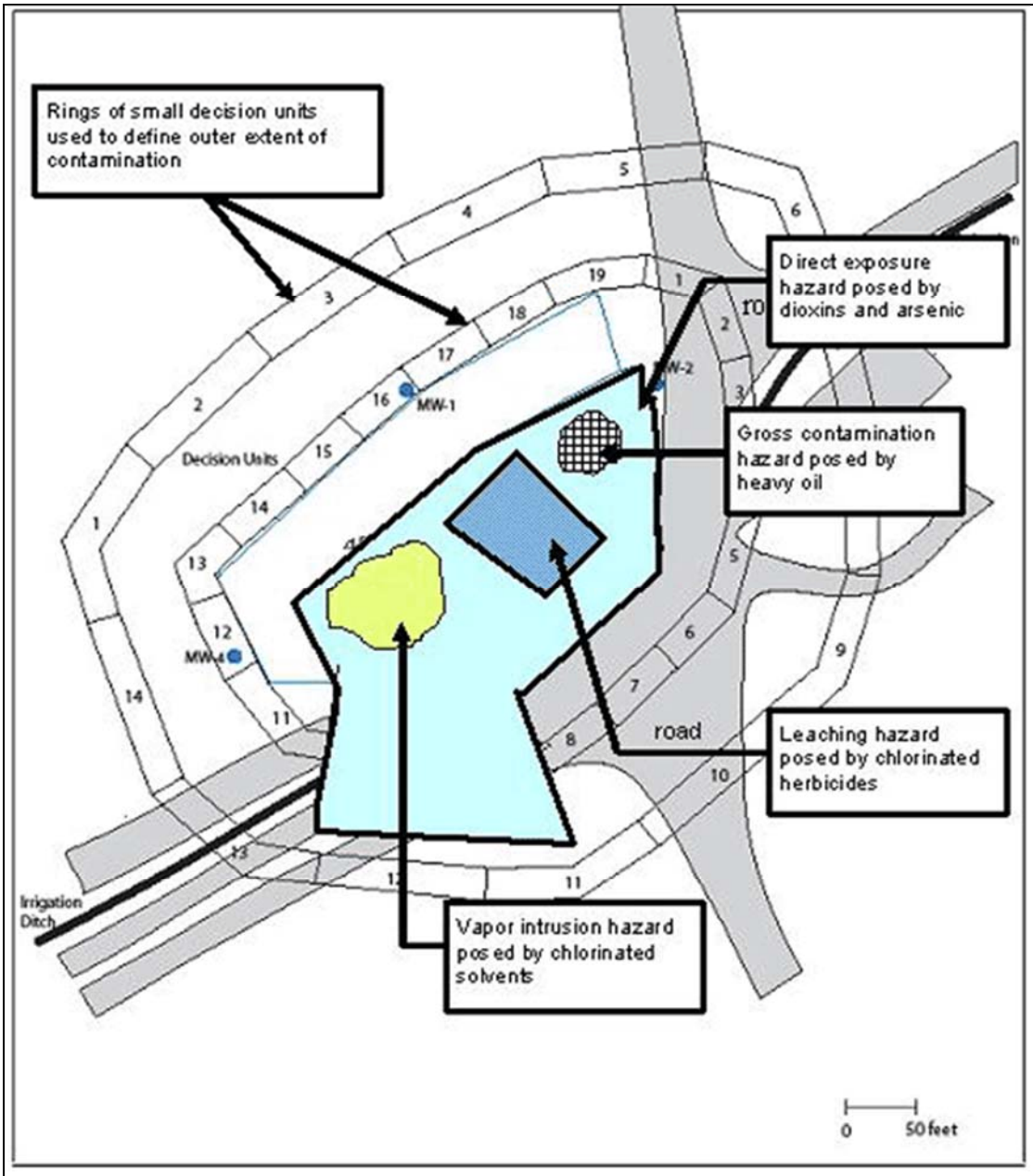


Figure 13-6. Environmental Hazard Map for Hypothetical Site with Soil Contamination. Hypothetical hazards include pesticides, dioxin, arsenic, solvents and heavy oil. Areas delineated by comparison of site data to HDOH action levels for the noted hazard (or approved alternatives). Remedial options could vary with respect to the specific environmental hazard(s) posed in a given area of the site including capping, vapor mitigation systems, offsite disposal, etc. (see text).

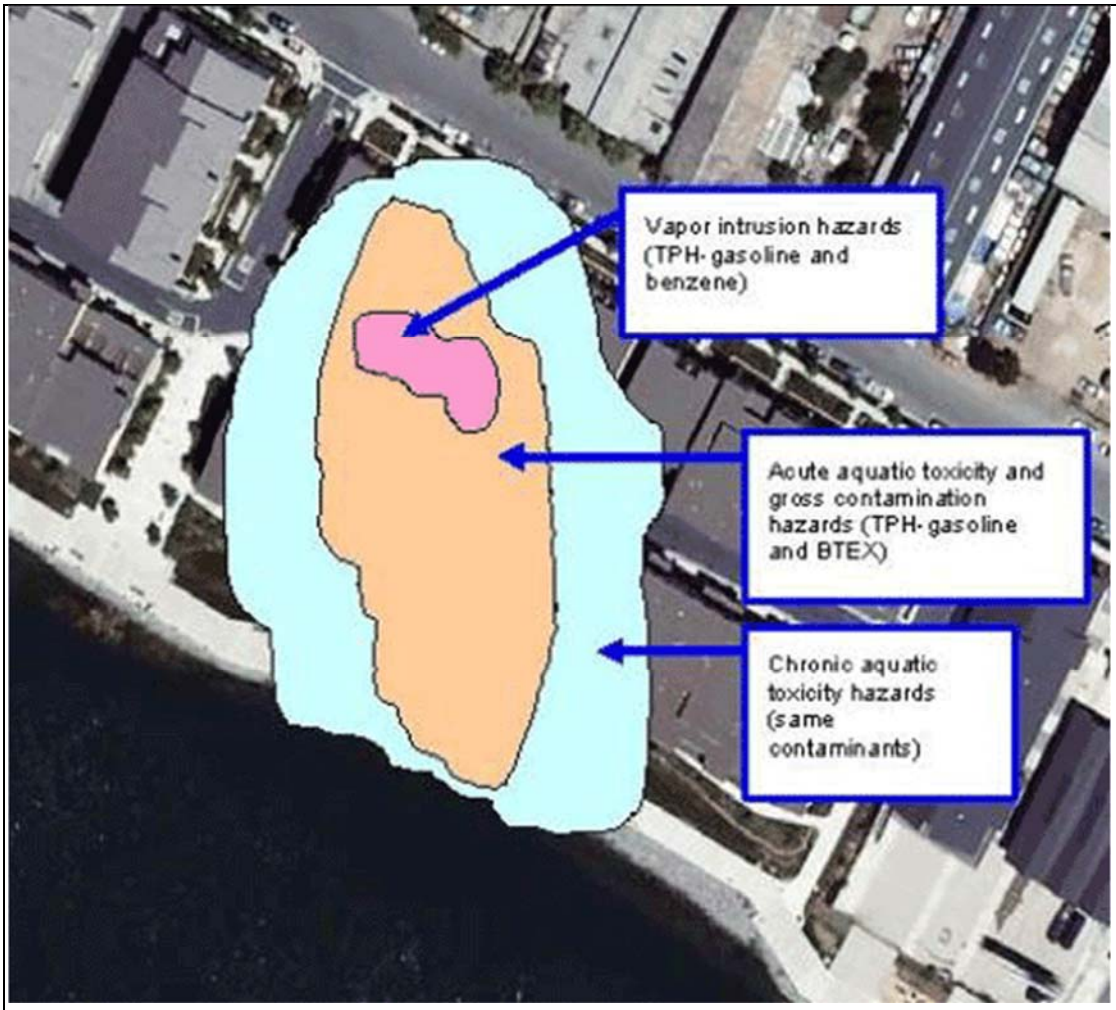


Figure 13-7. Environmental Hazard Map for Hypothetical Site with Groundwater Contamination. Hypothetical site contaminated with petroleum. Areas delineated by comparison of site data to soil screening levels for the noted hazard. Aggressive remediation should focus on removal of vapor intrusion hazard so property can be redeveloped. Aggressive remediation of groundwater that poses acute aquatic toxicity hazards and gross contamination (odors, sheens) within 50 meters of the shoreline is also recommended. Long-term monitoring of remaining groundwater contamination required (see text).

13.5.7 RECOMMENDED FOLLOW-UP ACTIONS

Based on the results of the Environmental Hazard Evaluation, provide recommendations for additional actions at the site. This could include additional fieldwork, additional analyses of existing samples, further evaluation of targeted environmental hazards, evaluation of remedial alternatives, preparation of an Environmental Hazard Management Plan, etc. If all contamination above Tier 1 EALs (or approved alternatives) is removed or if otherwise warranted by site conditions, then a recommendation of no further action should be made. The most appropriate response to address environmental hazards at contaminated sites depends on a number of site-specific factors, including the presence or absence of hazards under current conditions, planned future site use, the regulatory acceptability and cost-benefit of immediate cleanup as opposed to the use of engineered and institutional controls, natural attenuation of contaminants over time, etc. When practicable, full cleanup of contaminated soil and groundwater to permit future, unrestricted use of the property is desirable. A detailed discussion of site closure considerations is presented in Section 19.

When full cleanup is not feasible, the extent and magnitude of remaining contamination must be summarized and the potential environmental hazards posed by the contamination under uncontrolled conditions clearly described. The need for institutional and engineered controls must then be evaluated. This could include restrictions on future use of the property, installation of vapor mitigation systems under buildings, capping of contaminated soil to prevent exposure or leaching, long-term monitoring of groundwater, etc. These actions must be described in a site-specific EHMP. The preparation of an EHMP is discussed in more detail in Sections 18 and Section 19.

13.6 HUMAN HEALTH RISK ASSESSMENTS

In a very limited number cases a traditional Human Health Risk Assessment (HHRA) will be needed to more fully evaluate and document direct exposure concerns identified in the Environmental Hazard Evaluation (HDOH, 2016). An HHRA justifies and employs alternative models and assumptions to develop site-specific screening or final cleanup levels or quantitatively evaluate actual risk posed to human receptors. This type of Advanced Environmental Hazard Evaluation typically follows methodologies, assumptions, and risk assessment models for traditional, detailed HHRAs. Portions of the Tier 1 models still may be retained for some components of the Advanced Environmental Hazard Evaluation.

A HHRA can be described as a scientific process used to estimate the probability of adverse health effects resulting from human exposure to hazardous substances. In 1986, the USEPA established risk assessment guidelines to provide consistency and technical support between the USEPA and other regulatory agencies. The HEER Office recommends that HHRAs be prepared following USEPA risk assessment guidelines. The fundamentals of USEPA's HHRA methodology are presented in *Risk Assessment Guidance for Superfund. Volume I, Human Health Evaluation Manual (Part A)* (USEPA, 1989e).

A HHRA applies four evaluation components as the basis for characterizing potential health risks posed to current and/or potential future receptors at a site (USEPA, 1989e), as shown in Table 13-5.

Table 13-5 Evaluation Components for Characterizing Potential Health Risks to Current and/or Potential Future Receptors

1. Data Usability Evaluation/ Selection of COPCs • Collate the site investigation data • Evaluate the data • Select COPCs	**3. Toxicity Assessment** • Identify toxicity values for the COPCs
2. Exposure Assessment • Identify exposure scenario • Identify exposure pathways • Identify exposure factors for receptors • Quantify exposure point concentrations • Calculate exposure for each COPC/medium/pathway combination	**4. Risk Characterization** • Calculate the cancer risks and non-cancer hazard indices. • Summarize the site risks by COPC and medium for the receptors, exposure scenarios, and exposure pathways • Identify key uncertainties and evaluate their potential impacts on the results.

A summary of the basic components of a human heath risk assessment is provided below. Detailed guidance for preparing a HHRA is beyond the scope of this Section. Refer to the references provided at the end of this section for additional guidance and information.

It is vital to ensure that all potential environmental hazards have been considered at a site when conducting a site-specific human health risk assessment. Environmental Hazard Evaluations that only consider risk to human health (e.g., direct exposure to contaminted soil) will *not* be considered acceptable by the HEER Office.

13.6.1 COMPONENTS OF HUMAN HEALTH RISK ASSESSMENT

The components of a traditional HHRA are briefly reviewed below.

13.6.1.1 DATA USABILITY EVALUATION/SELECTION OF COPCS

Most of this task is completed during site investigation and presented in the site investigation report. Elements of data assessment are presented in Subsection 3.9. A preliminary list of COPCs is developed in the scoping process during site investigation planning (see Subsection 3.3). The COPCs are refined as the site investigation objectives are developed and the site investigation data are acquired (see Section 3).

To prepare a HHRA, it may be necessary to collate data from several site investigations and assess the collective data. Comparing the collated data to Tier 1 EALs is a good starting point for refining and finalizing the list of COPCs. It is important to remember that COPCs may be uniquely selected for individual decision units (see Subsection 3.6). In addition, COPCs may be uniquely selected for each environmental medium (e.g., COPCs for soil may be different that the COPCs for groundwater). The identified list of COPCs will be the focus of the HHRA.

13.6.1.2 EXPOSURE ASSESSMENT

Exposure scenarios, exposure pathways, and exposure factors for receptors are identified, exposure point concentrations quantified, and exposures calculated for each COPC/medium/pathway combination in the Exposure Assessment. The statistical evaluation of soil data to estimate representative contaminant concentrations within decision units (including exposure point concentrations for evaluation of direct-exposure hazards) is discussed in Section 4. The average concentration of exposure over the target exposure duration is used for estimation of risk.

Land use is a critical element in developing exposure scenarios because it determines potential receptor populations. Land use assumptions are based on a factual understanding of site-specific conditions and reasonably anticipated future use. Discussions with land owners and local land use planning offices are helpful in determining future land use. Typical land uses to consider include residential and commercial/industrial.

An exposure pathway describes the course that a chemical takes from a source to a receptor. Potential exposures are evaluated by considering the following four factors:

- A source of potentially hazardous substances
- A contaminated media, such as soil
- An exposure or contact point with the contaminated medium
- An exposure route for chemical intake by a receptor

An exposure pathway is considered complete when it has all four factors. Designation of an exposure pathway as complete indicates that human exposure is possible, but does not necessarily mean that exposure will occur nor that exposure will occur at the levels estimated in the HHRA. When any one of the factors is missing in the pathway, it is considered incomplete. Incomplete exposure pathways do not pose a health hazard and are not evaluated. The key step in analyzing exposure pathways is to determine whether there are any plausible routes of human exposure to chemicals detected at the site.

The hypothetical receptor that is typically evaluated in each exposure scenario is assumed to have a reasonable maximum exposure (RME) by any potential exposure route. The RME, as defined by the USEPA (USEPA, 1989e), is the "highest exposure that is reasonably expected to occur" and is intended to best represent "a conservative exposure estimate that is within the range of possible exposures." The assumption of exposure represents a conservative approach. This approach is recommended by regulatory risk assessment guidance in order to make the health risk assessment sufficiently protective of potential receptors.

Exposure factors, including exposure point concentrations for receptors are necessary to quantify exposures for each COPC/medium/pathway combination. Exposure factors are available in *Exposure Factors Handbook* (USEPA, 1997e), *Soil Screening Guidance: Technical Background Document* (USEPA 1996b), and *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites* (USEPA, 2002e), among other sources. An exposure point concentration is a reasonable estimate of the concentration likely to be contacted over time by potential receptors (USEPA, 1989e). A discussion of approaches to determine average contaminant concentrations for exposure areas or decision units is presented in Sections 3 and Section 4 .

The final step in the exposure assessment is quantifying the *Average Daily Intake* of COPCs for the identified potential receptors in the exposure scenarios. The daily intake equations are available in *Risk Assessment Guidance for Superfund. Volume I, Human Health Evaluation Manual (Part A)* (USEPA, 1989e).

13.6.1.3 TOXICITY ASSESSMENT

The purpose of the Toxicity Assessment is to weigh available evidence regarding the potential for the COPCs to cause adverse effects in exposed individuals and to provide, where possible, an estimate of the relationship between the extent of exposure to a COPC and the increased likelihood and/or severity of adverse effects (USEPA, 1989e). Because the USEPA has established values for the toxicity of most typically encountered COPCs, the toxicity assessment generally consists of locating and collating toxicity information and combining it with the exposure assessment information to calculate human health risks.

A cancer slope factor is a numerical estimate of potency of a chemical that is multiplied by the Lifetime Average Daily Intake to give a probability of an individual developing cancer over a lifetime. A reference dose is defined as an estimate (with uncertainty spanning perhaps an order of magnitude or greater) of a daily exposure level for the human population, including sensitive subgroups, that is likely to be without an appreciable risk of deleterious effects during a portion of a lifetime (USEPA, 1989e).

Refer to Appendix 1 of the HDOH EHE guidance for a summary of toxicity factors selected for development of environmental action levels. Except as noted, the toxicity factors for the EALs reflect those used for USEPA Regional Screening Levels guidance (USEPA, 2012).

13.6.1.4 RISK CHARACTERIZATION

For complete pathways, risk characterization combines the Exposure Assessment and Toxicity Assessment to produce quantitative estimates of potential health risks associated with the COPCs.

For carcinogens, cancer risks are calculated according to the following equation (USEPA, 1989e):

Incremental Lifetime Cancer Risk = Lifetime Average Daily Intake x Cancer Slope Factor

For non-carcinogens, hazard quotients are calculated according to the following equation (USEPA, 1989e):

Hazard Quotient = Average Daily Intake / Reference Dose

Incremental lifetime cancer risk probabilities may be compared to the USEPA acceptable risk levels. The USEPA has established a potentially acceptable range of 10^{-4} to 10^{-6} for lifetime cancer risk (USEPA, 1989e, 1991b). Remediation or risk management is almost always warranted at sites where the estimated cancer risk exceeds 10^{-4}. For sites where the estimated risk is between 10^{-4} and 10^{-6}, the need for active remediation or risk management is evaluated on a site-specific basis (i.e., risks within this range are "potentially acceptable", depending on site-specific considerations) (USEPA, 1991b). It should be noted that the calculated risk values are upper-bound estimates of excess cancer risk potentially arising from lifetime exposure to the chemical in question. A number of assumptions have been made in the derivation of the values, many of which are likely to overestimate exposure and toxicity. The actual incidence of cancer is likely to be lower than these estimates and may be zero.

The non-cancer hazard index is based on a comparison of the estimated site-related dose to the EPA acceptable dose. A hazard index of less than or equal to one indicates no potential for non-cancer health hazard (USEPA, 2001c).

13.6.2 REPRESENTATIVE CONTAMINANT CONCENTRATIONS

The concentration of a chemical reported for an Exposure Area Decision Unit (Subsection 3.4.2) based on Multi Increment sample data (Subsection 4.2) is used to evaluate the long-term, average exposure of residents or workers “receptors” to the chemical as part of a human health risk assessment. This was referred to as the “exposure point concentration” in past guidance (USEPA 1989e). Exposure “area” concentration is more precise of the intent of the data, however. Receptors are assumed to have random contact with soil within the targeted exposure area for a fixed number of days (“exposure frequency”) over a fixed number of years (“exposure duration”). The HDOH EALs for direct-exposure risks directly incorporate these exposure assumptions and represent the maximum concentration of the chemical for a given exposure area that does not pose a significant risk to users of the property. If this concentration is exceeded then additional evaluation is warranted, as described in this section.

The use of Multi Increment sample data is strongly recommended for estimation of exposure area concentrations. Early USEPA guidance relies on statistical tests for discrete sample data sets to estimate an exposure area concentration for a targeted chemical. Field research described in Subsection 4.1 of this guidance document point out the limitations of this approach and the inability to test the precision of estimated exposure area concentrations based on a single set of discrete soil samples. Multiple sets of discrete soil samples (minimum three) would be required to accomplish this. Uncertainty with respect to the representativeness of discrete sample data in terms of sample collection methods, minimum mass requirements under sampling theory and the lack of a systematic approach to laboratory processing further limit the reliability of discrete sample data in risk assessments. Proposals to use discrete sample data as part of a risk assessment should be discussed with the HEER Office. The collection of Multi Increment sample data to confirm initial conclusions based on discrete sample data will likely be required for high-risk areas.

13.6.3 LEAD RISK ASSESSMENTS

Special considerations must be made to conduct a human health risk assessment for sites at which lead is a COPC. For lead risk assessments, the EPA currently recommends two models to assess exposure, depending on the age of the receptor population. For children, exposure assessments should be performed using the Integrated Exposure Uptake Biokinetic Model for Lead in Children (IEUBK) (USEPA, 1994b). For adults, EPA's 1996 adult interim guidance should be used – the "Adult Lead Model" (USEPA, 1996e). These models are available for download free-of-charge from the USEPA web site.

Both models take into account intake and uptake components of lead exposure, allow the user to input site-specific data (exposure frequency, sources of lead, as well as others), and predict potential upper-bound blood lead concentrations. Predicted blood lead values provide one indication of the associated lead exposure for both current and potential future populations (USEPA, 2002, USEPA, 2002i).

USEPA guidance for lead-contaminated soil calls for the comparison of lead concentrations in the <250 micron soil fraction to action levels (USEPA, 2000e). The fine soil fraction is considered to be the particle size fraction most likely to stick to hands and, thus, potentially be incidentally ingested. This guidance also call for the use of the %lt;250 micron soil fraction in bioaccessibility tests (USEPA, 2000e). This also applies for bioaccessibility tests carried out on arsenic-contaminated soils. Concurrent data for the <2mm soil fraction can also be very useful in determining the distribution of lead (and arsenic) in the soil.

13.6.4 TARGET RISKS FOR PARKLANDS

In terms of human health risk assessment, parks and similar public recreational areas should be treated like residential backyards and indeed they serve this function in many densely populated areas of Hawai‘i (i.e., assumed residential exposure, screening level target excess cancer risk of 10^{-6} and target hazard index of 1.0). A purely toxicity-based, recreational-use exposure scenario could suggest that substantially higher concentrations of contaminants could be left in place at the site and not pose a threat to human health. This is because of the reduced exposure frequency and duration (e.g., 100 days per year for ten years) assumed in the models. Cleanup levels based on such scenarios can be higher (less stringent) than levels that would be allowed for commercial/industrial properties. This is counterintuitive to the intention of setting aside land for public use and puts an inherent public use restriction on the property (i.e., visitation and use limited to the assumed exposure frequency and duration).

The use of public parks should be unrestricted. Placing restrictions on the use of public parks due to contamination concerns would quite likely not be acceptable to the general public, one of the tenants required for consideration of final site remedial actions. Public parks are also frequented by children, young mothers, elderly people and other groups of people with potentially elevated sensitivities to environmental contaminants. Long-term, future uses of such properties are also difficult to predict.

In some cases, remediation of proposed parklands to unrestricted land-use standards may not be technically or economically practicable. This should be evaluated on a site-specific basis and receive approval from the overseeing regulatory agency as well as private and public stakeholders. In such cases, the appropriateness of allowing unrestricted access to the area should be carefully evaluated. This could include the need to impose access restrictions on the property (i.e., based on the exposure assumptions used in the risk assessment) and/or cap impacted soils with a minimal amount of clean fill. It may also be prudent to post signs at the property entrance that warn of potential health hazards (refer also to HDOH, 2016).

13.6.5 REFERENCES FOR HHRAS

Potentially useful reference documents for preparation of HHRAs include the following:

- Superfund Exposure Assessment Manual (USEPA, 1988c)
- Risk Assessment Guidance for Superfund. Volume I, Human Health Evaluation Manual (Part A) (USEPA, 1989e)
- Technical Support Document: Parameters and Equations Used in the Integrated Exposure Uptake Biokinetic Model for Lead in Children (USEPA, 1994b)
- Preliminary Endangerment Assessment Guidance Manual (CalEPA, 1994)
- Standard Provisional Guide for Risk-Based Corrective Action (ASTM, 2004b)
- Superfund Soil Screening Guidance: Technical Background Document (USEPA, 1996b)
- Supplemental Guidance For Human Health Multimedia Risk Assessments of Hazardous Waste Sites and Permitted Facilities (CalEPA, 1996b)
- Exposure Factors Handbook (USEPA, 1997e)
- Health Effects Summary Tables (USEPA, 1997)

- Assessing the Significance of Subsurface Contaminant Vapor Migration to Enclosed Spaces (Johnson et. al, 1998)
- Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites (USEPA, 2002e)
- USEPA Regional Screening Levels: (USEPA, 2012).

The 2012 USEPA Regional Screening Levels (RSLs) replace Preliminary Remediation Goals (PRGs) previously published by individual USEPA regions (e.g., USEPA, 2012). The USEPA RSLs have been incorporated into HDOH Environmental Action Levels for screening of potential direct-exposure hazards (HDOH, 2016).

The above list of references is not intended to be comprehensive. Additional HHRA guidance should be referred to as needed.

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SECTION 14
REMOVAL ACTIONS

Interim Final - June 21, 2009

State of Hawai‘i
Department of Health
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SECTION 14 ACRONYMS AND ABBREVIATIONS

EAL	Environmental Action Level
EHE	Environmental Hazard Evaluation
EP&R	HEER Office Emergency Preparedness and Response Section
HAR	Hawai'i Administrative Rules
HDOH	Hawai'i Department of Health
HEER Office	Hazard Evaluation and Emergency Response Office
HRS	Hawai'i Revised Statutes
NRDA	Natural resource damage assessment
OEQC	Office of Environmental Quality Control
RAR	Removal Action Report
SCP	Hawai'i State Contingency Plan
SDAR	HEER Office Site Discovery, Assessment and Remediation Section
TCLP	Toxicity characteristic leaching procedure
USEPA	United States Environmental Protection Agency

14.0 REMOVAL ACTIONS

If a hazardous substance release substantially endangers public health or the environment, an appropriate response action is required. The Hawai'i State Contingency Plan (SCP) [Hawai'i Administrative Rules (HAR), Title 11, Chapter 451 (HAR, 1995) defines two response action processes: removal and remediation. Due to the urgency of threats posed and the need for prompt action, emergency responses are typically conducted under the removal action process, which is also used for most responses to historic releases. In general, the removal action process can be used on a variety of releases ranging from simple to complex non-emergency cleanups.

Removal actions follow a limited process and typically may be conducted more quickly and simply than remedial actions. In addition, for site assessments and removal actions found eligible to participate, the voluntary Fast Track Cleanup Program can further streamline both assessment and removal actions by reducing the number of submittals to the State of Hawai'i Department of Health (HDOH) Hazard Evaluation and Emergency Response Office (HEER Office) (see Section 15).

Removal actions may include a range of activities including, but not limited to, the following:

- Monitoring, assessing, and evaluating a release or threat of a release
- Excavation and disposal of contaminated material
- Limiting access to the site with physical barriers such as fencing, walls, or barricades
- Evacuation of affected populations

As noted in the Hawai'i SCP [HAR 11-451-8(c) (HAR, 1995), all removal and remedial response actions should consider a hierarchy of response action alternatives in this descending order:

- Reuse or recycling
- Destruction or detoxification
- Separation, concentration, or volume reduction
- Immobilization of hazardous substances
- On-site or off-site disposal, isolation, or containment
- Institutional controls or long term monitoring

This hierarchy of response action alternatives should serve as a starting point when considering and selecting removal action cleanup alternatives (see Subsection 14.2.3).

The core decision-making process used in conducting removal actions is the same as used for remedial actions. However, for remedial actions key decisions are subject to a more intense level of review and scrutiny (see Section 2, Figure 2-2 for differences in required documentation). In both cases, decision-making should be conducted in a structured manner, following the same general hierarchy of response action alternatives as noted above. In the case of an emergency response removal action, where an on-scene coordinator may be making on-the-spot decisions based primarily on field observations, the decision-making process used will correspond in general terms to that used in non-emergency release responses.

Wherever a release constitutes a threat or potential threat to human health or the environment, the HEER Office will seek to identify a responsible party and request their cooperation in conducting and paying for site assessment and/or response action, as appropriate under Hawai'i Environmental Response Law [Hawai'i Revised Statutes (HRS 128D). If necessary, the HEER Office may enter into consent agreements or issue orders to require identified responsible parties to conduct any necessary response actions.

14.1 REMOVAL ACTIONS FOR EMERGENCY RESPONSE

Emergency responses are handled differently than responses for non-emergency environmental cleanups (see Subsection 2.3), and may have additional release notification requirements.

Emergency responses are typically conducted as removal actions due to the immediacy of the threats, as well as limited planning and implementation timelines for emergency responses. Emergency response removal actions are conducted when there is a release or threat of release of a hazardous substance that may pose an imminent and substantial danger to human health and the environment. In general, these include recent spills or releases of hazardous substances, or the discovery of abandoned containers of suspected hazardous substances that may have leaked or have the potential to leak into the environment.

During emergency response removal actions, the completion of a detailed site assessment is rarely feasible. Regardless of the nature of the emergency, it is critical to fully document the following information:

- Source and nature of the release or threat of release
- Magnitude of the threat to public health or welfare, the environment, or natural resources
- Whether a removal action is appropriate
- Whether another party is undertaking the proper response action

This assessment data is used to make decisions to protect human health and the environment, and to initiate release response removal actions, if appropriate. The removal actions may be carried out as soon as they may be safely conducted. In an emergency response removal action, the cleanup objectives should be clearly identified as soon as possible, and should be documented in the written incident action plan (or equivalent document) during the emergency response action.

In some cases, an emergency response removal action may address all immediate health threats, but leave a non-emergency environmental cleanup situation at the site (e.g. a surface spill is removed, but subsurface soil may be potentially contaminated). These cases are typically referred from the Emergency Preparedness & Response (EP&R) Section of the HEER Office to the Site Discovery, Assessment, and Remediation (SDAR) Section for additional evaluation and consideration for non-emergency cleanup action (either removal or remedial action).

A Removal Action Report (RAR) may be required to document an emergency response cleanup. An important consideration for the RAR would be the need for or the execution of confirmation sampling to (1) demonstrate that no immediate danger to human health or the environment remains, and (2) evaluate whether any additional non-emergency cleanup assessment or response may be appropriate (see Subsection 14.2.4).

14.2 REMOVAL ACTIONS FOR NON-EMERGENCY ENVIRONMENTAL CLEANUPS

Non-emergency environmental cleanups generally occur over a longer time frame, which allows for detailed site assessments to assist in identifying the specific environmental hazards, defining the extent of contamination, and determining if response actions are necessary to remediate the hazardous substances. Environmental cleanups conducted for non-emergency hazardous substance releases are often responding to historic or suspect past releases rather than to observable recent evidence, such as leaking containers, spilled materials, or other obvious sources of contamination at the site.

Historic releases generally do not present immediate threats needing an emergency response, as the contamination present does not pose a significant short-term hazard. However, they may commonly represent long-term hazards to human health or the environment. The HEER Office SDAR staff oversees these types of releases and recommends removal actions or remedial actions based on the following factors:

- Immediacy of threat
- Planning and implementation time
- Risks to public health and the environment
- Costs
- Community interest
- Site complexity
- Availability of other response options

Although removal actions may be appropriate under a variety of situations and each response action determination is site-specific, removal actions are generally effective where representative sampling and assessment have documented that significant soil contamination is limited in extent and within the reach of common excavation equipment.

14.2.1 DATA REVIEW AND DATA COLLECTION

Following the decision to conduct a non-emergency removal action, any existing data is reviewed and additional data is collected, as needed, to determine specific cleanup actions.

If a Site Assessment or an Environmental Hazard Evaluation (EHE) was performed for a particular site, they are reviewed to assess if sufficient information is available to evaluate and select among removal action alternatives. Missing data critical to the evaluation of removal action alternatives is identified and collected, as appropriate, preferably prior to the evaluation of alternatives. For example, if one of the removal alternatives is excavation and disposal, and representative toxicity characteristic leaching procedure (TCLP) testing of the contaminated soil has not been completed to determine whether the proposed disposal facility would accept the soil, this is an important data gap to fill to increase the reliability of the removal alternatives analysis.

14.2.2 ESTABLISHING CLEANUP OBJECTIVES

The HEER Office recommends that site owners and site consultants consult with the HEER Office early in the process for planned removal actions in order to ensure that the removal action's cleanup objectives are clearly stated and acceptable. Failure to mutually agree to cleanup objectives early in the process could lead to serious and costly disagreements over the adequacy of the response.

Cleanup objectives should be clearly stated as part of a non-emergency removal action work plan. For example, cleanup objectives for a contaminated pond may include:

- Achieving protective soil and surface water quality (e.g. representative samples with levels below Tier 1 EALs [HDOH, 2016] for soil and surface waters)
- Reducing possible future impacts to groundwater
- Restoring the pond to stable conditions where vegetation and animals may be re-established

Cleanup objectives for a removal action will vary depending on the plan for the overall response to a release. In many cases the objective of the removal action is to permanently address all threats posed by the release, so the goals/objectives of the work plan would be written accordingly. However, in some cases a removal action is planned only as an interim action as part of a

larger or longer-term response action and the cleanup objectives for these removal actions may have a narrower scope. For example, if a release poses imminent threats, such as acutely toxic exposure hazards posed by uncontrolled hazardous substances in surface soil, then a removal action of surface soils may be conducted with the objectives of eliminating these imminent, short-term threats. If longer-term threats posed by residual contamination of subsurface soils and non-drinking groundwater also exist, these less imminent hazards may be left for a non-emergency removal or remedial response action at a later date.

14.2.3 SELECTING A CLEANUP METHOD

Cleanup alternatives that include the on-site management of hazardous substances (above applicable HDOH Tier 1 EALs) are the least preferred of all response action alternatives. When persistent or high risk contaminants are involved, uncertainty over long-term effectiveness and possible lower levels of community acceptance may result in the selection of a remedial action versus a removal action. However, in some cases involving non-persistent contaminants and relatively low risk levels, permanent on-site management remedies may be implemented using the removal action process.

The cleanup method used for a particular removal action will depend on a number of factors, including the type and amount of hazardous substance released, physical setting in which the release occurs, and the type, number, and proximity of potentially affected human and ecological receptors. As noted earlier, multiple removal action alternatives are available; options to recover and reuse or detoxify or immobilize contaminants are generally preferred over other options. However, the simplest and most common form of removal action is excavation of contaminated soil and disposal in an approved landfill. The technological and cost feasibility of this option is typically more favorable for soil contamination at a site that is limited in extent and shallow enough to be accessible by excavation equipment than with a site with widespread soil contamination or with contamination at depths greater than approximately 15 feet below ground surface. A detailed discussion of common cleanup technologies is presented in Section 17.

A number of removal action alternatives should be considered in selecting a final cleanup method (typically a "no action" alternative is compared to several other removal action alternatives) and the rationale for proposing the final cleanup method for the site should be clearly documented. A comparison table depicting the various alternatives considered, practicality of implementation at the site, and costs associated with each option will assist in clearly documenting the removal action alternatives. The degree of thoroughness and detail required in the removal alternatives analysis, as well as the final cleanup method, depend on factors such as the urgency of the response and complexity of the release.

"Presumptive remedies" are available for several typical release scenarios (e.g., typical contaminants or disposal practices, or based on affects on environmental media). The United States Environmental Protection Agency (USEPA) provides guidance on presumptive remedies, which are preferred by the HEER Office where appropriate. When reviewing presumptive remedy guidance documents, confirm that cited methods are still considered to be best/good practices. Changes in cleanup technologies, scientific understanding, regulatory requirements, or public acceptance may affect whether a presumptive remedy is considered to be the preferred choice for a particular site.

14.2.4 REMOVAL ACTION REPORT

Removal actions require significantly less documentation than remedial actions (see Section 2, Figure 2-2). Non-emergency removal actions are documented by a Removal Action Report (RAR). The exact content and level of detail needed in a RAR varies depending on the nature and extent of the release, and the removal action alternative selected for the cleanup.

Documenting the Removal Action involves two steps:

1. The Removal Action Work Plan - Describe the site, relevant background information and the proposed cleanup action and alternatives considered.
2. The Removal Action Report (or sometimes referred to as the Removal Action Completion Report) – Includes information from the Removal Action Work Plan, plus a description of changes made in implementing the Work Plan, the resources expended on the cleanup, and the results of confirmation testing.

The Removal Action Work Plan should be prepared and submitted to the HEER Office prior to conducting the removal action (see flexibility for work plan submittals and reviews provided under the Fast Track Cleanup Program, Section 15). Key elements for the Removal Action Work Plan include:

- Introduction and Purpose
- Background, including site description, land use, applicable Tier 1 EALs
- Description of release/threat of release and environmental hazards
- Situation preceding decision to conduct removal
- Removal action alternatives considered
- Description/rationale for the planned removal action

- Removal action tasks, scope of work
- Description of sampling and analysis methods for confirmation testing of removal action
- List of equipment and supplies
- Planned schedule
- References

A more detailed recommended content guideline for the Removal Action Work Plan is provided in Section 18.

The RAR (or Removal Action Completion Report) is completed and submitted to the HEER Office after the planned removal action has been conducted. The RAR is typically a supplement to the Removal Action Work Plan, providing the following additional information:

- A description of the removal action as conducted (vs. planned)
- The resources expended to conduct the removal action
- The results of confirmation testing, including data quality evaluation
- A description of any hazardous substances and environmental hazards remaining on-site

After the cleanup has been completed, the environmental hazard evaluation (see Section 13)conducted before the removal action should be updated. The initial environmental hazard evaluation documented the threat posed prior to cleanup activities; the updated environmental hazard assessment documents the threats (if any) posed after cleanup activities.

A more detailed recommended content guideline for the RAR is provided in Section 18.

14.2.5 PUBLIC PARTICIPATION

Public participation serves two purposes: (1) to inform the public about the hazardous substance release and the proposed or selected response action; and (2) to obtain information from the public about the release, or about conditions in the community that may affect the release or the proposed response action.

Small removal actions, removal actions for contaminants that are judged very low risk, and/or removal actions in certain locations may not warrant significant public participation. However, large, extensive, highly visible, or highly toxic releases will warrant public participation, either because the release or the response has attracted public attention, or because the release or the response has affected or will significantly affect the public in some way. The HEER Office makes the determination regarding public participation requirements for each proposed removal action.

The public is required to be provided notice of a Removal Action Work Plan, and an opportunity for review and comment, if:

1. The HEER Office is conducting the removal action (e.g. when a responsible party cannot be identified) and expenditures on the site are reasonably expected to exceed, or have exceeded, $25,000
2. The HEER Office determines that significant concern has been expressed or is likely to be expressed by affected or potentially affected public or private interests, including local communities, as a result of the implementation of removal action activities
3. The HEER Office determines that public participation would be in the public interest

The minimum requirements of the public notice procedure, if selected for removal actions, consist of the following steps:

- A notice of the availability of the administrative record for the removal action is published in a newspaper of general circulation in the county affected by the proposed action, and if appropriate, in a newspaper of general circulation in the state, no later than 60 days after initiation of on-site removal activity. An example Public Notice for a Removal Action is provided in Section 18.
- A public comment period of at least 30 calendar days after relevant site documents are made available for review, to provide the public with a reasonable opportunity to submit written and oral comments on the removal action.

These public participation activities would be conducted by the HEER Office in the case of HEER Office-led removal actions, and required of potential responsible parties (with HEER Office oversight) in the case of removal actions carried out by those parties.

The public participation activities listed above are the minimum necessary to comply with the Hawai‘i SCP. When the HEER Office requires public participation elements, it is recommended that the following actions be conducted, where feasible:

- A public notice of the proposed removal action published in the newspaper and notice also distributed by other means well before the start of the on-site removal activity. An example Public Notice for a Removal Action is provided in Section 18.
- A digital copy of the public notice posted to the HEER Office website
- A copy of the public notice submitted for inclusion in the HDOH Office of Environmental Quality Control (OEQC) Environmental Notice semi-monthly newsletter
- Copies of the public notice should be provided to any interested parties identified, as a courtesy
- Courtesy copies of the public notice should be provided to state and local elected representatives or other representatives of the area affected by the removal action: state senator, state representative, county council member, and if applicable, neighborhood board.

For releases of significant public interest or impact, additional public participation and community involvement activities may be warranted (e.g. a public meeting). The HEER Office may conduct, or may require the potential responsible parties to conduct, additional public participation activities if they are determined appropriate.

14.2.6 NOTIFICATION OF NATURAL RESOURCE TRUSTEES

If a release affects or may affect natural resources (for example, endangered species, migratory birds, marine mammals, or other sensitive ecological resources), the HEER Office will notify the appropriate state and federal natural resource trustees. This notification may trigger a Natural Resource Damage Assessment (NRDA), which may result in cost recovery for damages in order to restore damaged natural resources identified in the assessment.

14.2.7 SITE CLOSURES FOR REMOVAL ACTIONS

A removal action may be conducted either as a stand-alone response action, or as an interim response action to be followed by further removal or remedial action at a later date. In addition, a removal action may result in long-term management of contamination on site. Each of these different types of removal actions has implications for site closure. See Section 19 for detailed guidance on site closures and for specific discussion on site closure implications of response action selection.

SECTION 14 REFERENCES

Citation references for this TGM Section denoted with an “a”, “b”, “c”, etc… after the year of publication may not appear in sequence as these refer to the order placed in the Master References List for the entire TGM.

HAR 11-451. Hawai'i Administrative Rules, Department of Health. Title 11, Chapter 451, State Contingency Plan (SCP). Local Copy (2.2mb). August 2, 1995.

HDOH, 2016. Hawai'i Department of Health, Office of Hazard Evaluation and Emergency Response. Screening for Environmental Concerns at Sites with Contaminated Soil and Groundwater. Website URL: http://eha-web.doh.hawaii.gov/eha-cma/Leaders/HEER/EALs. Summer 2016 (and updates).

HRS 128D. Hawai'i Revised Statutes. Hawai'i Environmental Response Law (HERL), Chapter 128D. Website URL: https://www.capitol.hawaii.gov/hrscurrent/Vol03_Ch0121-0200D/HRS0128D/.

SECTION 15
FAST TRACK CLEANUP

Interim Final - February 20, 2009

State of Hawai'i
Department of Health
Office of Hazard Evaluation and Emergency Response
919 Ala Moana Boulevard, Room 206
Honolulu, Hawai'i 96814

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SECTION 15 ACRONYMS AND ABBREVIATIONS

CERCLA	Comprehensive Environmental Response, Compensation & Liability Act (also known as the Federal Superfund Law)
EAL	Environmental Action Level
EHE	Environmental Hazard Evaluation
EHMP	Environmental Hazard Management Plan
FTC	Fast Track Cleanup
HAR	Hawai'i Administrative Rules
Hawai'i SCP	Hawai'i State Contingency Plan (HAR, Title 11, Chapter 451)
HDOH	Hawai'i Department of Health
HEER Office	Hazard Evaluation and Emergency Response Office
HERL	Hawai'i Environmental Response Law (HRS, Chapter 128D)
HRS	Hawai'i Revised Statutes
NFA	No Further Action
NPL	National Priorities List
RCRA	Resource Conservation and Recovery Act
SHWB	HDOH Solid and Hazardous Waste Branch
UECA	Uniform Environmental Covenants Act (HRS, Chapter 508C)
UST	Underground Storage Tank
VRP	HEER Office Voluntary Response Program

15.0 FAST TRACK CLEANUP

The Hazard Evaluation and Emergency Response Office (HEER Office) has instituted a process to streamline and clarify the site assessment and removal cleanup process for certain eligible sites. This streamlined process is known as **Fast Track Cleanup (FTC)**. In particular, FTC will help organize an increasing number of cases where site owners or their consultants approach the HEER Office and request approval of site conditions, sampling strategies, or no further action determinations without formally entering the Voluntary Response Program (VRP) or any other cleanup agreement.

FTC is intended to encourage and facilitate HEER Office involvement in these actions, as well as to help land owners achieve a determination of no further action at sites where a cleanup investigation may have already occurred.

15.1 FTC OVERVIEW

The purpose of Fast Track Cleanup is to enable landowners or other private parties to conduct a voluntary site assessment or cleanup under a simple agreement with the HEER Office, without requiring submittal of multiple work plans and interim reports, while still receiving concurrence on the final site status. The focus of FTC is to streamline and expedite site cleanup and the no further action determination at removal action sites. Figure 15-1 provides a simplified flow of a typical site under FTC.

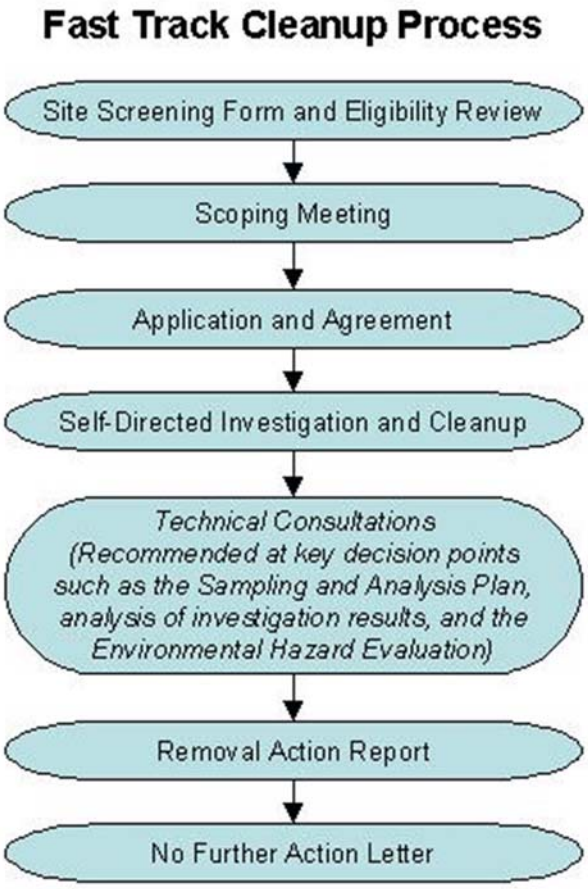


Figure 15-1. Fast Track Cleanup Process

FTC streamlines the review process by enabling a responsible party to conduct the site assessment and carry out cleanup actions without formal and rigorous HEER Office oversight or approval of each step. Project status and updates are instead conducted through scoping meetings or presentations, as needed.

Participants and their consultants who conduct the work under the FTC are expected to follow current environmental laws and HEER Office guidance for site assessment and cleanup activities, including guidance provided in this TGM and in the document entitled the "Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater" (HDOH, 2016).

15.1.1 DIFFERENCE FROM OTHER APPROACHES

While adhering to the State Contingency Plan, FTC offers a fundamentally different approach by placing a greater burden of technical justification on the participant, with less intermediate regulatory review and approval of sampling plans. If the HEER Office does not judge that the level and the quality of work meet current guidelines or expectations, they may direct work to be redone or terminate the agreement. This puts great responsibility on the participant to (1) hire a knowledgeable environmental consultant who understands the current environmental laws and guidelines, and (2) conduct an adequate and appropriate site

assessment and cleanup. The HEER Office offers and encourages periodic consultations, presentations, and informal updates, rather than the submittal of multiple work plan and interim report submittals. This frequent interaction between the participant and the HEER Office will help to reduce the delays encountered when awaiting approval of proposed actions. Such input, provided only upon request, serves to expedite the process by ensuring cleanup actions are consistent with applicable or relevant and appropriate laws and guidance.

15.1.2 FTC PROCESS COMPLETION

Following completion of a site assessment or cleanup, the HEER Office will review the FTC site assessment report or removal action report (including the environmental hazard evaluation) to determine if the response actions were completed to a level that is protective of human health and the environment according to State law (HRS 128D, Part I). In the event that site assessment results demonstrate site contaminant levels are below Environmental Action Levels (EALs) for unrestricted land use, the HEER Office will issue a "No Action" letter. If a removal action has occurred and no additional cleanup is deemed necessary, the HEER Office will issue a "No Further Action" (NFA) letter. For sites where cleanup decisions are based on commercial/industrial land use or other limited exposures, the HEER Office will issue a NFA Letter with Institutional Controls specifying the land use, property controls, or conditions required to support the NFA determination.

Fast Track Cleanup vs. Voluntary Response Program
FTC is different from the Voluntary Response Program (VRP) in that (1) the FTC application and agreement process is streamlined; (2) FTC does not require that the HEER Office approve each step of the investigation and cleanup process; and (3) FTC does not provide exemptions from future liability for prospective purchasers, as are provided in the VRP program.

15.2 LEGAL AUTHORITIES

FTC is implemented as a removal action policy with responsibilities and technical requirements provided under Hawai‘i Revised Statutes (HRS) §128D-4(a),17(f); and Hawai‘i Administrative Rules (HAR) §11-451-8(i), (j). Under these statutes and rules, the Hawai‘i State Department of Health (HDOH) has the authority to arrange, provide oversight, or assist with a cleanup action along with known responsible parties for the removal of any release or threatened release of a hazardous substance, pollutant, or contaminant at any time, provided such arrangements are consistent with the Hawai‘i State Contingency Plan (Hawai‘i SCP).

HDOH is also granted the responsibility of identifying or developing advisories, criteria, or guidance, such as FTC, considered useful in developing response actions (HAR §11-451-8(i)). The FTC program itself should withstand legal challenge (HRS §128D-17(f)), unless any actions taken under FTC are considered arbitrary and capricious, or an abuse of HDOH discretion.

FTC Site Screening Form Submittal
Send completed FTC screening forms to the FTC Coordinator in the HEER Office in Honolulu, Hawai‘i. The FTC Coordinator can be reached at:

Hawai‘i Department of Health
Office of Hazard Evaluation and Emergency Response
Attn: FTC Coordinator
919 Ala Moana Blvd Room 206
Honolulu, Hawai‘i 96814

or

Telephone: (808) 586-4249
Fax: (808) 586-7537
E-mail: heer@doh.hawaii.gov

15.3 SCREENING AND ELIGIBILITY

The first step of the process requires that the applicant complete a two-page Site Screening Form (provided in Appendix 15-A). The screening form is intended to present basic information regarding the site in a concise manner and to explain the purpose of entering FTC. The FTC screening forms must be submitted to the FTC Coordinator at the HEER Office, who will use the screening form to evaluate and confirm site eligibility and to guide discussions during the initial scoping meeting with the applicant.

Eligibility into FTC is not determined by the phase or status of the site assessment or cleanup. Sites may enter FTC during any phase of the assessment or cleanup process, such as:

- Following a known or suspected spill or release
- Following a Phase I Environmental Site Assessment where a Recognized Environmental Condition (REC) was identified
- Prior to, during, or following a site investigation
- Prior to, during, or following cleanup

HDOH has issued guidance regarding the investigation and assessment of residual pesticides in soils (see HDOH, 2016 and Section 9). The guidance focuses on the redevelopment of former agricultural land, but is also applicable to golf courses, nurseries, military housing complexes and similar, large-scale projects involving soils that may have been treated with pesticides. HDOH encourages the use of FTC for receiving a No Action Letter regarding residual pesticides at such sites.

FTC is intended to be inclusive of most sites, but there are some conditions that may eliminate a site from consideration:

- No known or suspected spills or releases
- Contamination that is known or likely to extend across a property boundary
- Groundwater contamination, especially in a drinking water aquifer
- Soil contamination that has a migration pathway to a drinking water aquifer
- Site is adjacent to sensitive communities or residences
- Site is adjacent to sensitive ecological receptors
- Site has sensitive current or future land use, such as a school or day care, or unrestricted access such as a public recreational area
- Site cleanup decisions would have a significant impact on the local community and thereby require public review or comment. (Public review or comment may be conducted under FTC, if the participant and the HEER Office believe it would be beneficial; however, this is not a required component of FTC.)
- Investigation or cleanup activities are already governed by a binding agreement, such as a cleanup order or state-led cleanup activity

Each of the above conditions will be assessed on a case-by-case basis. The HEER Office will make the eligibility determination in the application review process or in the scoping meeting.

The following sites are not eligible for participation in the FTC Program:

- A site listed or proposed to be listed on the National Priorities List (NPL) pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
- A site that has been issued an order or other enforcement action or has entered into an agreement under CERCLA that is still in effect
- A site where the United States Coast Guard has issued a federal Letter of Interest
- A site that is subject to corrective action under Subtitle C of the Resource Conservation and Recovery Act (RCRA) or Chapter 342J
- A site that poses an imminent and substantial threat to human health, the environment, or natural resources as determined by the Director of the HDOH
- A site that is under the jurisdiction or oversight of the HDOH Solid and Hazardous Waste Branch (SHWB), Underground Storage Tank (UST) Section

FTC Funding
The FTC initiative will be funded completely through cost recovery. HDOH will implement a cost recovery process consistent with cost recovery provisions of HRS 128D-5. The cost recovery framework, including hourly rates for HDOH review and consultation services, a fee schedule, estimated total hours for review services, and justification of rates, will be developed by HDOH and communicated to the public by June 30, 2009.

Sites entering FTC prior to June 30, 2009, will be provided HDOH oversight and consultation services at no cost through that date. Sites that have entered into but not completed FTC at that date will be given 60 days notice of the initiation of cost recovery. Applications received after June 30, 2009, will require a fee/deposit in order to initiate the process.

15.4 APPLICATION AND AGREEMENT

Following review of the screening form, the HEER Office will schedule a scoping meeting with the applicant to discuss the project goals, objectives, resources, plans, guidelines, and schedule. The meeting will also review the requirements of the Application and Agreement Form (provided in Appendix 15-B). The initial scoping meeting is conducted at no cost to the FTC applicant. A flow chart depicting the overall process and key decision points of the FTC is presented in Figure 15-2. Appendix 15-C provides responses to Frequently Asked Questions regarding FTC.

If the site meets eligibility requirements, and all parties concur that FTC will meet the applicant's goals, then the applicant will submit the FTC Application and Agreement. The application includes statements regarding the roles and responsibilities of all parties, known site conditions, project history, status of sampling plan or investigation report, review schedules, and an understanding of the HEER Office cost recovery process. The HEER Office will review the application for completeness and if no modifications are required, will return a signed version of the application constituting an agreement for the FTC. A follow-up meeting may be recommended to ensure understanding of the roles and responsibilities outlined in the agreement.

The agreement is non-binding; The HEER Office or the participant may terminate at any time. Participants may leave the program without cause. The HEER Office may terminate the agreement with cause if it believes that the quality of work is poor or adherence to State guidelines has not been adequately achieved.

Since FTC-eligible sites are without offsite impacts or immediate risks to human health or the environment, the HEER Office would not typically pursue the site as a State-led oversight project while the agreement is in effect.

Since FTC may be used at sites that already have been investigated or cleaned up, the scoping meeting may be used to discuss quality and completeness of existing data and any potential data gaps that would need to be addressed to meet the FTC requirements. The applicant still will be required to submit an application.

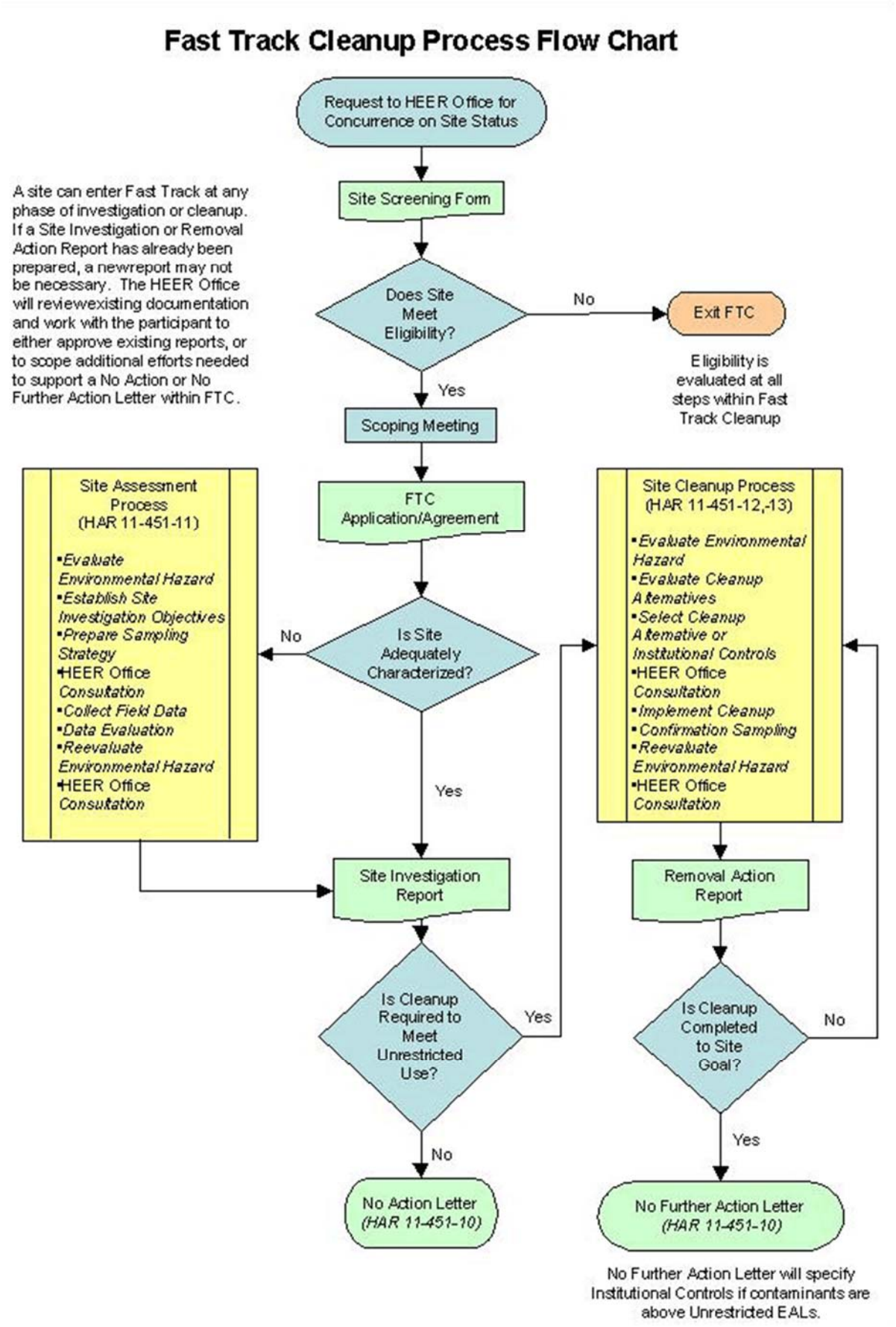


Figure 15-2. Fast Track Cleanup Process Flow Chart

15.5 SITE ASSESSMENT PROCESS

The goal of a site assessment is to characterize site conditions in order to identify the necessity for remediating soil or groundwater that poses unacceptable environmental hazards, either under current site conditions or under uncontrolled, future conditions. The site assessment is carried out by the collection and analyses of samples of soil, groundwater, soil gas, surface water, sediment, air and/or other media as needed. The EALs may be used to identify contamination above levels of potential concern. Information concerning site assessment strategies is included in Section 3.

When representative sampling at release sites demonstrate that contamination in areas of concern (i.e. decision units) are below the EALs, then a more comprehensive assessment or additional evaluation is not generally required. The presence of a contaminant at concentrations above the Tier 1 EAL indicates a potential environmental hazard. The nature and magnitude of tentatively identified hazards are described in the environmental hazard evaluation (EHE) portion of the site assessment report (see Section 13). For some FTC sites, the presence or absence of potential hazards may be identified and the contaminated soil or groundwater quickly remediated without further assessment. In cases where cleanup costs could be significant or the contamination cannot be easily remediated, a more advanced evaluation of specific environmental hazards may be necessary and advantageous to the FTC participant.

The site assessment and EHE are critical steps in the decision-making process to make FTC sites successful. HDOH recommends that participants consult with the HEER Office when developing site objectives, sampling strategies, and hazard evaluations. Coordination between the participant and the HEER Office may significantly improve the quality and timeliness of site assessment actions.

An overview of the critical steps and suggested questions to address in the site assessment process are discussed in Subsection 3.2. Additional details on site assessment procedures are provided in Subsections 3.3 through 3.9.

The FTC process does not require the HEER Office to review or approve the site assessment summary report unless no cleanup action is required. However, the participant is strongly advised to consult with the HEER Office at this step to ensure that the strategy for progressing into the cleanup process is clear. Information prepared for the site assessment report will be necessary for the removal action report provided following completion of the removal action.

For FTC sites where site conditions and contaminant levels are below the unrestricted EALs, the HEER Office does not recommend cleanup actions. For this scenario, the participant must provide a site assessment summary report for review and approval. The site assessment summary report must include a brief evaluation of site environmental hazards, but need not include a more detailed EHE as is required for sites where contamination exceeds EALs. The participant must provide 30 days (preferably 60 days) advance notice that the FTC site assessment report will be submitted for review. The HEER Office will commit to a 30-day review process and issue the No Action Letter following resolution of any outstanding items identified during the site assessment report review.

15.6 SITE CLEANUP PROCESS

The FTC route for removal actions provides a streamlined process to quickly address contaminant releases. Removal actions under the FTC process are typically effective where site assessment activities have clearly documented that significant contamination in soil is limited in extent and within the reach of common excavation equipment.

The nature of any cleanup action is generally very site-specific. For sites where the extent of contamination is very limited and/or time is of the essence, aggressive remediation of the contamination may be most cost effective. In these cases, the excavation and disposal of contaminated soil may be a practical and cost effective solution. In other cases, it may be appropriate to aggressively remediate contamination that is causing immediate environmental hazards (e.g. vapor intrusion into a building) and prepare an Environmental Hazard Management Plan (EHMP) to address long-term management of contamination that must be left in place.

The HEER Office will ultimately determine if sufficient data is available in the site assessment and EHE to support all removal action decisions, including the acceptability of any management actions in an EHMP. If data is insufficient for a decision, the HEER Office will require additional site investigation or revision of the EHMP. Section 14 provides additional information regarding removal action responses.

Removal actions are documented in a removal action report containing the following minimum elements:

- Location of release or threat
- Cause of release or threat
- Site history
- General site geology, hydrology, groundwater status, adjacent land uses
- Distance to surface water bodies
- Site investigation and environmental hazard evaluation
- Removal alternatives considered
- Removal action summary
- Sampling methods and data on confirmation testing of removal action
- Description of hazardous substances remaining on site
- Environmental hazard evaluation of final site conditions

The participant is encouraged to consult with the HEER Office prior to completion of the removal action report to ensure concurrence that the site goals have been met and that the cleanup has been completed according to the FTC agreement. If requested, the HEER Office can provide approval of a removal action work plan prior to the implementation of the cleanup action. The participant must provide advance notice that the removal action report will be submitted for review. Advance notice must be at least 30 days and preferably 60 days before the date of submittal; if 60 days' advance notice is received, the HEER Office will commit to provide review comments on the report within 30 days. The HEER Office will issue the No Further Action Letter following resolution of any outstanding items identified during the report review.

15.7 NO FURTHER ACTION DETERMINATION

Once the HEER Office concurs that no further action is necessary for a specific release or suspected release site, a no action or no further action letter will be sent to the FTC participant. The letter will only be issued when the HEER Office has determined that remaining contamination at the site does not pose an unacceptable threat to human health or the environment. The Hawai'i SCP (HAR, 1995), Hawai'i Environmental Response Law (HRS 128D), this TGM, the EALs (HDOH, 2016), or other HDOH policy documents will form the basis for all HEER Office determinations.

There are three types of letters that may be issued to finalize the FTC process:

- A *No Action Letter* is issued if no contamination above Tier 1 Unrestricted EALs is identified.
- A *No Further Action Letter* is issued if cleanup activities have resulted in contaminant concentrations that are below the Tier 1 Unrestricted EALs or alternate site-specific EALs approved by the HEER Office.
- A *No Further Action Letter with Institutional Controls* is issued if contaminant concentrations are acceptable for current land use (such as commercial or industrial) but not acceptable for all uses (such as residential). The letter will include specific institutional controls or site conditions that must be maintained in order to support the No Further Action designation.

A determination of no action is made after the HEER Office concurs that a site investigation report adequately documents that a release or threat of release has not occurred.

The determination of no further action is made after an appropriate cleanup action has been successfully completed and documented. The NFA letters will typically:

- Summarize the release or suspected release scenario
- Indicate that all pertinent information and data regarding the site assessment and response action(s) have been reviewed
- State that no further action appears necessary for the release
- State that if new information indicates that contamination is present at levels of concern, additional assessment and cleanup work (as necessary) may be required

In some cases, a response action may address the threat posed by a hazardous substance release by containing the hazardous substances on site so that exposures of human health and the environment are prevented. For example, a barrier cover might be used to prevent direct contact with contaminated soil. To ensure the continued effectiveness of such controls, institutional controls or other conditions are typically included in the no further action letter to assure the appropriate controls will continue to be implemented. The EHMP is typically used to address long-term management requirements associated with contaminated soil and to document any future requirements.

SECTION 15 REFERENCES

Citation references for this TGM Subsection denoted with an “a”, “b”, “c”, etc… after the year of publication may not appear in sequence as these refer to the order placed in the Master References List for the entire TGM.

HAR 11-451. Hawai'i Administrative Rules, Department of Health. Title 11, Chapter 451, State Contingency Plan (SCP). Local Copy (2.2mb). August 2, 1995.

HDOH, 2016. Hawai'i Department of Health, Office of Hazard Evaluation and Emergency Response. Screening for Environmental Concerns at Sites with Contaminated Soil and Groundwater. Website URL: http://eha-web.doh.hawaii.gov/eha-cma/Leaders/HEER/EALs. Summer 2016 (and updates).

HRS 128D. Hawai'i Revised Statutes. Hawai'i Environmental Response Law (HERL), Chapter 128D. Website URL: https://www.capitol.hawaii.gov/hrscurrent/Vol03_Ch0121-0200D/HRS0128D/.

HRS 128E. Hawai'i Revised Statutes. Hawai'i Emergency Planning and Community Right-To-Know Act, Chapter 128E. Website URL: https://www.capitol.hawaii.gov/hrscurrent/Vol03_Ch0121-0200D/HRS0128E/.

HRS 508C. Hawai'i Revised Statutes. Uniform Environmental Covenants Act (UECA), Chapter 508C. Website URL: https://www.capitol.hawaii.gov/hrscurrent/Vol12_Ch0501-0588/HRS0508C/. Local Copy (20kb).

APPENDIX 15-A
FAST TRACK CLEANUP
SITE SCREENING FORM

(see MS Word document)

APPENDIX 15-B
FAST TRACK CLEANUP
APPLICATION AND AGREEMENT FORM

(see MS Word document)

APPENDIX 15-C
FAST TRACK CLEANUP
FREQUENTLY ASKED QUESTIONS

HAWAIʻI DEPARTMENT OF HEALTH
HAZARD EVALUATION AND EMERGENCY RESPONSE OFFICE
FAST TRACK CLEANUP

FREQUENTLY ASKED QUESTIONS

Presented below is a list of frequently asked questions (FAQ) related to the Hawaiʻi Department of Health (HDOH) Hazard Evaluation and Emergency Response Office (HEER Office) Fast Track Cleanup (FTC) program.

Question/Topic	Answer
What are the advantages of FTC?	FTC streamlines the process by avoiding the submittal of multiple work plans and interim reports and therefore enabling the participant to move forward rapidly to cleanup actions. It communicates a straightforward process for receiving a NFA Letter.
How is FTC different than the VRP or other state-lead programs?	It does not require formal HEER Office reviews at each step (sampling plan or remedial alternatives plan). It does not provide prospective purchaser indemnities as does the Voluntary Response Program (VRP) Letter of Completion.
Are there disadvantages of FTC?	Yes. Risk or uncertainties associated with lack of formal HEER Office approval at each step could be considered a disadvantage. This places added responsibility on the consultant to understand all current guidance and technical policies if HEER Office consultations are not conducted.
Are the technical guidelines the same as any other program?	Yes. FTC operates under HDOH's removal authorities specified in Hawaiʻi Revised Statutes (HRS) 128D and Hawaiʻi Administrative Rules (HAR) 451. All actions conducted under FTC must be consistent with relevant and appropriate Hawaiʻi laws, the Technical Guidance Manual for the Implementation of the Hawaiʻi State Contingency Plan (HEER TGM), and other policy memoranda.
How is eligibility determined?	FTC is intended to be inclusive of most sites, but there are some conditions to evaluate when determining eligibility. Site conditions will be assessed on a case-by-case basis. The HEER Office will make the determination upon review of site screening form or at the scoping meeting.
Can a site that has already been investigated or cleaned up be included in FTC?	Yes. Eligibility is not determined by the phase or status of the investigation or cleanup. Sites can enter FTC during any phase of the investigation or cleanup process.
What if previous sampling did not incorporate current, state of the art sampling protocols, like *Multi-*	Previous sample results will be reviewed on a case-by-case basis. If a previous action has been conducted and the file information can support a NFA Letter, then the HEER Office would not require the participant to collect additional data or prepare updated reports.

***increment* sampling(MIS) & use of Decision Units (DUs)?**	
Will the HEER Office review a Phase I Environmental Site Assessment (ESA) report under FTC?	No. Site eligibility requires that a known or suspected release is present; therefore, if the Phase I ESA does not identify any recognized environmental concerns (REC), the site will not be eligible for FTC or HEER Office review. If sampling is proposed to address a REC, FTC may be a useful process to achieve HEER Office concurrence on environmental hazard(s) or a no further action determination.
If residential EALs are exceeded, can I still get a NFA Letter? Would I need an environmental covenant?	FTC may provide sites exceeding unrestricted Environmental Action Levels (EALs) a NFA Letter with Institutional Controls. If site contaminants and hazards have been substantially reduced, the HEER Office will not require an environmental covenant. The NFA Letter with Institutional Controls will serve as the documentation supporting the NFA determination.
If this is a new process, will new guidance or training be provided? Will regulations be required?	Yes. The HEER Office will conduct FTC trainings in Spring 2009. A primary goal of the trainings is to ensure that lenders, consultants, and participants understand the level of detail and effort required in order to receive a no further action determination. Currently, the HEER Office does not support new regulations to enhance FTC.
How does FTC fit within other existing guidance documents or policy statements, such as the HEER TGM, EALs, Environmental Hazard Evaluations (EHE), etc.	All activities under FTC must follow HAR 451-11 (Site Assessment) and HAR 451-12, 13 (Site Response and Cleanup). NFA Letters will be issued under the authorities identified in HAR 451-10.
What strength will the NFA letter have and is it legally defensible?	Yes. The NFA letter issued for a site within FTC will have the same legal standing as any determination of site status issued by HDOH.
Are there any costs?	The HEER Office will implement a cost recovery program by June 30, 2009, whereby it will recover its costs for review and consultation services from program participants. Sites entering FTC prior to this date will be provided HDOH oversight and consultation services without cost for services rendered through that date. Sites that have entered into FTC before June 30, 2009, and that continue to incur HDOH labor efforts beyond that date will be given 60 days' notice prior to the assessment of fees. Applications to the FTC program received after June 30, 2009, will require a fee/deposit in order to initiate the process.
What if I decide to leave the program?	The FTC agreement is non-binding; the HEER Office or the participant can terminate at any time. Participants may leave the program without cause. The HEER Office can terminate the agreement with cause if it believes that the quality of work is poor or adherence to State guidelines has not been adequately met. Since FTC-eligible sites are without offsite impacts or immediate risks to human health or the environment, the HEER Office would not typically pursue the site as a State-lead oversight project while the agreement is in effect.
What about public participation or notices?	FTC eligibility ensures that sites do not pose significant off-site risks or impacts to adjacent or sensitive communities. As a result, public participation or notice before or after the cleanup is not required. If institutional or site controls are necessary, these provisions will be included within the site closure letter which will be available to the public within HDOH files. Note that public review or comment can be conducted under FTC if both the participant and the HEER Office believe it would be beneficial, but it is not required.

How can a consultant guard against surprise comments from the HEER Office in the summary reports?	The HEER Office strongly recommends technical consultations at key decision points of the project, particularly regarding the sampling strategies, upon completion of data collection, and during the development of environmental hazard evaluations. Other states that have implemented similar programs report that the success of a site is based on the level of department consultation provided. They report that nearly one-third of the sites are supported with outstanding consultation, resulting in minimal or no agency comments during report review and approvals. Depending on the level of consulting provided, the remaining sites can require extensive revisions and frequently additional sampling. Judicious use of experienced consultants and HEER Office technical consultations is recommended to streamline the process and reduce the need for revisions or additional expense.

APPENDIX 15-A

FAST TRACK CLEANUP

SITE SCREENING FORM

HAWAI`I DEPARTMENT OF HEALTH
HAZARD EVALUATION AND EMERGENCY RESPONSE OFFICE
FAST TRACK CLEANUP

SITE SCREENING FORM

Fast Track Cleanup (FTC) is a Hawai`i Department of Health (HDOH) Hazard Evaluation and Emergency Response Office (HEER Office) program designed to enable landowners or other private parties to conduct a voluntary investigation or cleanup under a simple agreement with HDOH, without requiring multiple work plan and interim report submittals, while still receiving concurrence on the final site status of no further action. The focus of FTC is to streamline and expedite the assessment, cleanup, and no further action determination process at removal action sites.

The first step of the process requires that the applicant complete this site screening form. The HEER Office will use the screening form to confirm site eligibility and to schedule a scoping meeting with the applicant. Eligibility is not determined by the phase or status of the site assessment or cleanup; sites can enter FTC during any phase of the assessment or cleanup process.

GENERAL SITE INFORMATION

Participant Name **Phone** **Email**	
Site Name	
Site Address	
Site Status/Background	
Reason for Entering FTC	
Goal for Exiting FTC	
Estimated Start Date	
Estimated Completion Date	

FTC is intended to be inclusive of most sites; the eligibility criteria on the following page will enable the HEER Office to determine if the site is eligible for FTC. The following sites are not eligible for FTC:

- A site listed or proposed to be listed on the National Priorities List (NPL) pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA);
- A site with respect to which an order or other enforcement actions has been issued or entered under CERCLA and is still in effect;
- A site where the United States Coast Guard has issued a federal Letter of Interest;
- A site that is subject to corrective action under Subtitle C of the Resource Conservation and Recovery Act (RCRA) or Chapter 342J;
- A site that is under the jurisdiction or oversight of the HDOH Solid and Hazardous Waste Branch, including the UST Program.
- A site that poses an imminent and substantial threat to human health, the environment, or natural resources as determined by HDOH.

SITE ELIGIBILITY FACTORS

Eligibility Factors	Yes	No	Unknown
Is there a known or suspected contaminant release?	☐	☐	☐
Is an investigation or cleanup already governed by a current state, local, or federal agency?	☐	☐	☐
Is contamination known to or likely to cross property boundaries?	☐	☐	☐
Does soil contamination have a high likelihood of migrating to surface water or groundwater?	☐	☐	☐
Is groundwater contamination considered significant or is contamination in a drinking water aquifer?	☐	☐	☐
Is the site adjacent to sensitive communities or residences?	☐	☐	☐
Is the site adjacent to sensitive ecological receptors?	☐	☐	☐
Would site cleanup decisions have a significant impact on the local community and thereby require public review or comment?	☐	☐	☐
Does the site have sensitive current or future land use, such as a school or day care, or unrestricted access such as a public recreational area?	☐	☐	☐

Additional Comments or Notes:

Each of these conditions will be assessed on a case-by-case basis. The HEER Office will contact the applicant no later than 1 week following submittal of this screening form to schedule a scoping meeting to discuss site eligibility, project goals, objectives, technical resources and guidelines, and schedule.

Submitted by	***Signature***	***Date***

APPENDIX 15-B

FAST TRACK CLEANUP

APPLICATION AND AGREEMENT FORM

HAWAI`I DEPARTMENT OF HEALTH
HAZARD EVALUATION AND EMERGENCY RESPONSE OFFICE
FAST TRACK CLEANUP

APPLICATION AND AGREEMENT FORM

Fast Track Cleanup (FTC) is a Hawai`i Department of Health (HDOH) Hazard Evaluation and Emergency Response Office (HEER Office) program designed to enable landowners or other private parties to conduct a voluntary site assessment or cleanup under a simple agreement with HDOH, without requiring iterative regulatory oversight and approval, while still receiving concurrence on the final site status of no further action. The focus of FTC is to streamline and expedite the assessment, cleanup, and closure process at removal action sites.

The Hawai`i Department of Health and _____ [REQUESTING PARTY] hereby enter into this agreement, _____ [EFFECTIVE DATE], relating to the property identified in Item 5 below, and subject to the terms and conditions specified herein.

1. Introduction and Project Description

This agreement is made in accordance with Chapter 128D, Hawai`i Revised Statutes ("HRS"). FTC is implemented as a removal action policy and all HDOH responsibilities and technical requirements are presented under HRS §128D-4(a),17(f); and HAR §11-451-8(i), (j). Under these statutes and rules, HDOH has the authority to arrange, provide oversight, or take response with known responsible parties for the removal of any release or threatened release of a hazardous substance, pollutant, or contaminant at any time, provided such arrangements are consistent with the State Contingency Plan.

HDOH is also granted the responsibility of identifying or developing advisories, criteria, or guidance, such as FTC, to be considered useful in developing response actions (HAR §11-451-8(i)).

By participating in the program, the requesting party will conduct investigation and response activities with minimal oversight from the HDOH, Hazard Evaluation and Emergency Response Office ("HEER Office"). When the investigation summary or removal summary reports are completed to HDOH's satisfaction, the requesting party will receive a no action or no further action letter from HDOH.

The requesting party is the current owner or representative of the current owner of the property which has been found to be, or may be, contaminated. The requesting party is participating in Fast Track Cleanups and desires to complete the work described in Item 12. Completing this work may qualify the requesting party or site owner to receive a "No Action Letter", a "No Further Action Letter" or a "No Further Action Letter with Institutional Controls" as described in Section 4 of this Agreement.

2. Purpose of Agreement

The purpose of this Agreement is to set forth the terms and conditions of the investigation and response to address contamination at the Property, which upon completion will entitle the requesting party to a no further action letter from HDOH. This Agreement constitutes the final approval of HDOH for Requesting Party to conduct a cleanup action.

3. Authority to Enter into this Agreement

The signatories to this Agreement certify that they are fully authorized to execute this Agreement on behalf of the party each represents. No change in ownership, corporate, or partnership status of the Requesting Party shall alter its responsibilities under this Agreement.

EXAMPLE

4. Definitions

a. "Agreement" means this written agreement describing the cleanup action and all associated conditions in order for HDOH to issue a no further action letter for the contaminants, media, and property specified within.

b. "Contaminants" means those hazardous substances, contaminants and pollutants identified prior to, or during the course of the investigation or cleanup incorporated herein by this reference, cleaned up to the risk-based standard set forth in the provisions of Chapter 128D, HRS.

c. "No Action Letter" means the letter to be issued by HDOH, in accordance with §128D-10, HRS, subsequent to the satisfactory completion that site conditions are protective of unrestricted land use without cleanup action.

d. "No Further Action Letter" means the letter to be issued by HDOH in accordance with §128D-10, HRS, subsequent to the satisfactory completion of cleanup activities or site conditions are protective of unrestricted land use.

e. "No Further Action Letter with Institutional Controls" means the letter to be issued by HDOH, in accordance with §128D-10, HRS, subsequent to the satisfactory completion of cleanup activities or site conditions are protective of current property land use only.

f. "Property" means the property described in Item 5 that is subject to the cleanup action specified in this Agreement.

g. "Requesting Party" means the person or persons who have submitted an application to conduct a cleanup action. If the requesting party is not the property owner, then owner consent must be provided.

h. "Site Closure" means concurrence by HDOH through the issuance of any of the three letters defined in items c, d, or e above.

i. "Cleanup action" or "work" means the response action to be conducted voluntarily by the Requesting Party pursuant to the provisions of Chapter 128D, HRS, Chapter 11-451, Hawai`i Administrative Rules, this Agreement and the statement of work attached hereto.

5. Site Information and Description

Requesting Party **Name** **Company** **Address** **Phone** **Email**	
Property Ownership **Name** **Company** **Address** **Phone** **Email**	

EXAMPLE

Site Name	
Site Address	
Site Status, Background, History of Property	
Previous Investigations Conducted at Property	
Anticipated Chemicals of Concern	
Anticipated Scope of Work	
Purpose or Goal for Entering FTC	
No Further Action Letter Anticipated	
Estimated Start Date	
Estimated Completion Date	

EXAMPLE

6. Disclaimer of Admission

The Requesting Party has entered into this Agreement voluntarily. The Agreement is not to be construed as an admission of any liability under the Hawai`i Environmental Response Law, or any other law, whether municipal, local, state or federal, or as a waiver of any defense to such liability.

7. Finding of Eligibility

On [DATE], the Requesting Party submitted a FTC site screening form to HDOH; a scoping meeting was conducted on [DATE]. Site eligibility criteria are presented in the FTC site screening form. Based on the information presented in the screening form and scoping meeting, HDOH has found the Requesting Party and the Property eligible to participate in FTC. By signature at the end of this application and agreement form, HDOH formally approves the site eligibility and agreement in accordance with HRS 128D. Note that updates to site eligibility determinations can be reviewed at any phase of the process.

8. Payment of Fees

HDOH will develop a cost recovery framework pursuant to the cost recovery provisions of HRS 128D-5. The framework will be completed and communicated to the public by June 30, 2009. No fees will be required for a site entering FTC prior to June 30, 2009, for HDOH oversight and services related to site decisions rendered through that date. Sites that have entered into FTC before June 30, 2009, and that continue to incur HDOH labor efforts beyond that date will be given 60 days' notice prior to the assessment of fees. Applications received after June 30, 2009, will require a fee/deposit in order to initiate the process.

9. Right to Termination

Either party may terminate this Agreement in accordance with the provisions contained herein. The Requesting Party may choose to terminate the Agreement at any time. HDOH may terminate the

Agreement as specified in Chapter 128D, HRS, when: (1) there is an imminent and substantial threat to public health, the environment, or natural resources, (2) Requesting Party is not acting in good faith, (3) Requesting Party fails to comply with the terms of this Agreement (including if HDOH determines that the quality of work is poor or adherence to State guidelines has not been adequately met) and fails to commence such activities to cure such noncompliance within thirty days after HDOH issues to Requesting Party a notice of such non-compliance, (4) additional information is brought to the attention of HDOH which renders the cleanup action inadequate, (5) new information becomes available that necessitates a significant change in the statement of work or the priority with which HDOH must treat the project. For purposes of applying item (5), "the priority with which HDOH must treat the project" shall mean a decision made by HDOH, based upon new information about the Property, that had the new information been known by HDOH prior to entering into the Agreement, HDOH would not have proceeded to enter into the Agreement.

The party initiating termination of this Agreement shall immediately provide written notice to the other party of its intention to terminate the Agreement and the date upon which termination will be effective. Upon termination of this Agreement, HDOH may pursue any action related to the Property within its authority. Since FTC-eligible sites are without offsite impacts or immediate risks to human health or the environment, HDOH provides the general understanding that it would not pursue the site as a State-lead oversight project while the agreement is in effect.

HDOH represents to Requesting Party that it is committed to the cleanup action, intends to cooperate with Requesting Party in good faith in connection with those matters contained in this Agreement and agrees to issue a no further action letter upon reasonable satisfactory completion of the cleanup action.

10. Compliance with Applicable Laws, Rules, and Regulations

All work performed by the Requesting Party under this Agreement shall be performed in compliance with applicable federal, state, and local laws, ordinances and regulations. Requesting Party shall be responsible for obtaining all permits necessary to perform the work specified in this Agreement.

11. Roles and Responsibilities

The requesting party will provide 60 days advance notice that an FTC site investigation or removal summary report will be submitted for review. Documents and written submittals sent by the Requesting Party to the Project Manager will be reviewed by the Project Manager within 30 days from the date of receipt. Within that time, HDOH will provide the Requesting Party with written comments as to the acceptability of the submittal. If more time is needed, the Project Manager will notify the Requesting Party in writing of the need for additional time, the date by which the review will be completed, and the reason why the normal review period is being extended. While the Project Manager may provide informal advice, guidance, or comments, all approvals and decisions regarding the site investigation or removal summary report must be conveyed in writing by the Project Manager to be official. The Requesting Party agrees to perform and submit all work in accordance with state guidelines and policies. If any changes become necessary, the Requesting Party will notify the Project Manager describing the change needed. Verbal agreements for changes are acceptable when necessary and may be relied upon; however, major changes should be followed up in writing or via email by the party who initiated the change within 10 business days of verbal approval. Requests for extensions of time should be made in advance of the date on which the activity or document is due and should include a justification for the delay. All changes acknowledged and approved in writing shall be incorporated into this Agreement.

12. Statement of Work, Submittals, and Schedules

The work to be performed under this Agreement is specified in the statement of work prepared by the requesting party attached hereto as Exhibit A. This statement of work is estimated to be completed in accordance with the schedule provided in Exhibit A. HDOH formal review is expected to be limited to the removal action summary report. In the event that no cleanup actions are required in order to meet the site goals, then HDOH will provide a review of the site investigation report.

EXAMPLE

13. No Further Action Determinations

Within 30 days of satisfactory completion of the cleanup action as reasonably determined by the HDOH, HDOH will issue to the Requesting Party a no further action letter in accordance with Chapter 128D, HRS and this Agreement.

The letter documents that HDOH is satisfied that the cleanup is protective of human health and the environment and additional clean-up work is not needed at the site. The letter will identify the specific hazardous substances, pollutants, contaminants, media, and land area addressed in the response action. A no action or no further action letter does not provide the liability exemptions like those contaminants covered in a Letter of Completion under Chapter 128D, Part 2, HRS, Voluntary Response Program.

Three letters exist:

a. A No Action Letter will be issued subsequent to the satisfactory completion that site conditions are protective of unrestricted land use without cleanup action.

b. A No Further Action Letter will be issued subsequent to the satisfactory completion of cleanup activities or site conditions are protective of unrestricted land use.

c. A No Further Action Letter with Institutional Controls will be issued subsequent to the satisfactory completion of cleanup activities or site conditions are protective of current property land use only.

If contamination is left on the site above unrestricted land use levels, the letter shall identify land use restrictions and any required management plan at the Property. If any land use restrictions or management requirements that are part of the no further action letter are not subsequently complied with, the letter will be considered void and HDOH may re-open the site for additional investigation and/or action. The No Further Action Letter with Institutional Controls will be placed in the HDOH files and may be included in future HDOH site registries. The benefits and restrictions identified in the letter apply to all future purchasers of the Property.

14. Rights Reserved by HDOH

HDOH reserves the right to take action consistent with Chapter 128D, HRS, against responsible parties, and to exercise rights HDOH may have under any law including recovering costs and taking enforcement actions. Furthermore, HDOH may take enforcement action prior to completion of the cleanup action conducted pursuant to this Agreement and exercise other authorities of section 128D-4, HRS.

15. Site Access

Access During Conduct of Cleanup Action

During conduct of the cleanup action, Requesting Party agrees to provide HDOH access to the Property at all reasonable times and upon reasonable notice, for the purpose of allowing HDOH to perform its administrative oversight functions in connection with the work.

Access After Cleanup Action Is Completed

Requesting Party agrees to provide employees, contractors and other agents of HDOH access to the Property at all reasonable times and upon reasonable notice as specified below, solely for the purpose of possible follow-up activities associated with any conditions identified in a No Further Action Letter with Institutional Controls. Nothing in this Agreement is to be construed to limit HDOH's rights of access that it may have by operation of any law other than Chapter 128D, HRS.

HDOH shall give Requesting Party reasonable notice before entering upon the Property for any activity, unless HDOH is required to access the Property in the event of an emergency or court order and giving such notice is not possible. In the event of such emergency entry, delivery of

EXAMPLE

notice of the entry, along with an explanation of the emergency conditions, shall be given by HDOH to Requesting Party within five business days of HDOH entry onto the Property.

16. General Provisions

16.1. Dispute resolution

Requesting Party and HDOH agree to notify one another as soon as possible if a material disagreement becomes apparent to them. If this occurs, the party that identifies any such disagreement shall notify the representative of the other party. Initial notification will be by phone or in person, at which time the parties will attempt to resolve the disagreement. If the disagreement is successfully resolved, the situation will require no further action. If the disagreement continues, it will be discussed between the Manager of the HEER Office and a representative of Requesting Party. The Manager of the HEER Office will gather whatever additional information he/she feels is necessary and will render a decision in writing regarding the disagreement. If the decision is satisfactory, the parties will abide by the decision and no further action is necessary. If it is not satisfactory, Requesting Party or HDOH may terminate this Agreement.

16.2. Submittals

Requesting Party shall complete submittals as described in Item 12 and Exhibit B, and shall submit them to the following address in a manner that produces a record of submittal such as certified mail, overnight delivery service, facsimile, or courier hand delivery service:

Hawai'i State Department of Health
Office of Hazard Evaluation and Emergency Response
Attn: Fast Track Cleanups Coordinator
919 Ala Moana Boulevard, Room 206
Honolulu, Hawai'i 96814

16.3. Sampling, Data, and Document Availability

Requesting Party shall permit HDOH and its authorized representatives to inspect and copy all sampling, testing, monitoring, or other data generated by Requesting Party pursuant to the work being performed as part of this Agreement.

16.4. Record Retention

Requesting Party will retain all data, reports, and other documents for a minimum of five years after the conclusion of all activities under this Agreement. If HDOH requests that documents be preserved for a longer period of time, then Requesting Party will deliver the documents to HDOH, or permit HDOH to copy the documents prior to destroying them.

16.5. Governmental Liabilities

The State of Hawai`i shall not be liable for any injuries or damages to persons or property resulting from acts or omissions by Requesting Party, nor shall the State be held as party to any contract entered into by and between Requesting Party and a third-party contractor for services pertaining to the statement of work (Exhibit B) attached to this Agreement.

16.6. Modifications

This Agreement may be amended in writing by mutual agreement of HDOH and Requesting Party and shall be effective upon the date the change is signed by both parties and such amendment shall be deemed incorporated into this Agreement.

EXAMPLE

16.7. Counterparts

This Agreement may be executed and delivered in any number of parts, each of which shall be deemed to be an original and together constitute one and the same document.

16.8. Third-Party Actions

In the event that Requesting Party is a party to any suit or claim for damages or contribution relating to the Property to which HDOH is not a party, Requesting Party shall notify HDOH in writing within ten days after service of the complaint in the third-party action.

16.9. Governing law

This Agreement shall be construed and governed by the laws of the State of Hawai`i.

16.10. Transfer

With prior written approval of HDOH, all rights and benefits conferred upon Requesting Party under this Agreement may be assigned or transferred to any person. Requesting Party shall notify the Project Manager in writing of its intention to transfer its rights and benefits. Upon receiving the HDOH's approval, the transferee will be bound by all the terms and conditions of this Agreement.

16.11. Integration

This Agreement and its exhibits constitute the entire agreement between the parties hereto pertaining to the subject matter hereof, and the final, complete and exclusive expression of the terms and conditions thereof. All prior agreements, representations, negotiations and understandings of the parties hereto, oral or written, express or implied, are hereby superseded and merged herein.

17. Approvals

The undersigned hereby agree to the terms and conditions set forth above and to all attachments incorporated into this Agreement.

Requesting Party	**State of Hawai`i, Department of Health, HEER Office**
By:	**By:**
Name:	**Name:**
Company:	**HDOH HEER Office**
Title:	**Site Discovery and Remediation Manager**
Dated:	**Dated:**

EXAMPLE

APPENDIX 15-C

FAST TRACK CLEANUP

FREQUENTLY ASKED QUESTIONS

HAWAI`I DEPARTMENT OF HEALTH
HAZARD EVALUATION AND EMERGENCY RESPONSE OFFICE
FAST TRACK CLEANUP

FREQUENTLY ASKED QUESTIONS

Presented below is a list of frequently asked questions (FAQ) related to the Hawai`i Department of Health (HDOH) Hazard Evaluation and Emergency Response Office (HEER Office) Fast Track Cleanup (FTC) program.

Question/Topic	Answer
What are the advantages of FTC?	FTC streamlines the process by avoiding the submittal of multiple work plans and interim reports and therefore enabling the participant to move forward rapidly to cleanup actions. It communicates a straightforward process for receiving a NFA Letter.
How is FTC different than the VRP or other state-lead programs?	It does not require formal HEER Office reviews at each step (sampling plan or remedial alternatives plan). It does not provide prospective purchaser indemnities as does the Voluntary Response Program (VRP) Letter of Completion.
Are there disadvantages of FTC?	Yes. Risk or uncertainties associated with lack of formal HEER Office approval at each step could be considered a disadvantage. This places added responsibility on the consultant to understand all current guidance and technical policies if HEER Office consultations are not conducted.
Are the technical guidelines the same as any other program?	Yes. FTC operates under HDOH's removal authorities specified in Hawai`i Revised Statutes (HRS) 128D and Hawai`i Administrative Rules (HAR) 451. All actions conducted under FTC must be consistent with relevant and appropriate Hawai`i laws, the Technical Guidance Manual for the Implementation of the Hawai`i State Contingency Plan (HEER TGM), and other policy memoranda.
How is eligibility determined?	FTC is intended to be inclusive of most sites, but there are some conditions to evaluate when determining eligibility. Site conditions will be assessed on a case-by-case basis. The HEER Office will make the determination upon review of site screening form or at the scoping meeting.
Can a site that has already been investigated or cleaned up be included in FTC?	Yes. Eligibility is not determined by the phase or status of the investigation or cleanup. Sites can enter FTC during any phase of the investigation or cleanup process.
What if previous sampling did not incorporate current, state of the art sampling protocols, like *Multi-increment* sampling(MIS)[1] & use of Decision Units (DUs)?	Previous sample results will be reviewed on a case-by-case basis. If a previous action has been conducted and the file information can support a NFA Letter, then the HEER Office would not require the participant to collect additional data or prepare updated reports.
Will the HEER Office review a Phase I Environmental Site Assessment (ESA) report under FTC?	No. Site eligibility requires that a known or suspected release is present; therefore, if the Phase I ESA does not identify any recognized environmental concerns (REC), the site will not be eligible for FTC or HEER Office review. If sampling is proposed to address a REC, FTC may be a useful process to achieve HEER Office concurrence on environmental hazard(s) or a no further action determination.

[1] *Multi-increment® is a registered trademark of EnviroStat, Inc*

Question/Topic	Answer
If residential EALs are exceeded, can I still get a NFA Letter? Would I need an environmental covenant?	FTC may provide sites exceeding unrestricted Environmental Action Levels (EALs) a *NFA Letter with Institutional Controls*. If site contaminants and hazards have been substantially reduced, the HEER Office will not require an environmental covenant. The NFA Letter with Institutional Controls will serve as the documentation supporting the NFA determination.
If this is a new process, will new guidance or training be provided? Will regulations be required?	Yes. The HEER Office will conduct FTC trainings in Spring 2009. A primary goal of the trainings is to ensure that lenders, consultants, and participants understand the level of detail and effort required in order to receive a no further action determination. Currently, the HEER Office does not support new regulations to enhance FTC.
How does FTC fit within other existing guidance documents or policy statements, such as the HEER TGM, EALs, Environmental Hazard Evaluations (EHE), etc.	All activities under FTC must follow HAR 451-11 (Site Assessment) and HAR 451-12, 13 (Site Response and Cleanup). NFA Letters will be issued under the authorities identified in HAR 451-10.
What strength will the NFA letter have and is it legally defensible?	Yes. The NFA letter issued for a site within FTC will have the same legal standing as any determination of site status issued by HDOH.
Are there any costs?	The HEER Office will implement a cost recovery program by June 30, 2009, whereby it will recover its costs for review and consultation services from program participants. Sites entering FTC prior to this date will be provided HDOH oversight and consultation services without cost for services rendered through that date. Sites that have entered into FTC before June 30, 2009, and that continue to incur HDOH labor efforts beyond that date will be given 60 days' notice prior to the assessment of fees. Applications to the FTC program received after June 30, 2009, will require a fee/deposit in order to initiate the process.
What if I decide to leave the program?	The FTC agreement is non-binding; the HEER Office or the participant can terminate at any time. Participants may leave the program without cause. The HEER Office can terminate the agreement with cause if it believes that the quality of work is poor or adherence to State guidelines has not been adequately met. Since FTC-eligible sites are without offsite impacts or immediate risks to human health or the environment, the HEER Office would not typically pursue the site as a State-lead oversight project while the agreement is in effect.
What about public participation or notices?	FTC eligibility ensures that sites do not pose significant off-site risks or impacts to adjacent or sensitive communities. As a result, public participation or notice before or after the cleanup is not required. If institutional or site controls are necessary, these provisions will be included within the site closure letter which will be available to the public within HDOH files. Note that public review or comment can be conducted under FTC if both the participant and the HEER Office believe it would be beneficial, but it is not required.

Question/Topic	Answer
How can a consultant guard against surprise comments from the HEER Office in the summary reports?	The HEER Office strongly recommends technical consultations at key decision points of the project, particularly regarding the sampling strategies, upon completion of data collection, and during the development of environmental hazard evaluations. Other states that have implemented similar programs report that the success of a site is based on the level of department consultation provided. They report that nearly one-third of the sites are supported with outstanding consultation, resulting in minimal or no agency comments during report review and approvals. Depending on the level of consulting provided, the remaining sites can require extensive revisions and frequently additional sampling. Judicious use of experienced consultants and HEER Office technical consultations is recommended to streamline the process and reduce the need for revisions or additional expense.

SECTION 16
REMEDIAL ACTIONS

Interim Final - June 21, 2009

State of Hawai‘i
Department of Health
Office of Hazard Evaluation and Emergency Response
919 Ala Moana Boulevard, Room 206
Honolulu, Hawai‘i 96814

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- 16.1.3 Remedial Investigation and Remedial Investigation Report

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- 16.2.1 Threshold Criteria For Remedial Alternatives
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- 16.2.4 Remedial Alternatives Analysis Report

16.3 Selection of a Cleanup Remedy for the Remedial Action
- 16.3.1 Preparing a Draft Response Action Memorandum (Draft RAM)
- 16.3.2 Public Participation and Public Notices
- 16.3.3 Preparing a Final Response Action Memorandum (Final RAM)

16.4 Implementing the Cleanup Remedy Selected
- 16.4.1 Remedial Design Documentation
- 16.4.2 Remedial Construction Documentation
- 16.4.3 Operations and Maintenance (O&M) Documentation

16.5 Site Closure for Remedial Actions
- 16.5.1 Confirming Attainment of Remedial Objectives

References

SECTION 16 ACRONYMS AND ABBREVIATIONS

CERCLA	Comprehensive Environmental Response, Compensation & Liability Act (also known as the Federal Superfund Law)
COPC	Chemicals (or Contaminants) of Potential Concern
EAL	Environmental Action Level
EHE	Environmental Hazard Evaluation
EHMP	Environmental Hazard Management Plan
HAR	Hawai'i Administrative Rules
HDOH	Hawai'i Department of Health
HEER Office	Hazard Evaluation and Emergency Response Office
HRS	Hawai'i Revised Statutes
ITRC	Interstate Technology and Regulatory Council
LOC	Letter of Completion
NFA	No Further Action
O&M	Operation and maintenance
OEQC	HDOH Office of Environmental Quality Control
RAA	Remedial alternatives analysis
RAM	Response Action Memorandum
SCP	Hawai'i State Contingency Plan
U.S.	United States
USEPA	United States Environmental Protection Agency
VOC	Volatile Organic Compound
VRP	HEER Office Voluntary Response Program

16.0 REMEDIAL ACTIONS

If a hazardous substance release substantially endangers public health or the environment, an appropriate response action is required. The Hawai'i State Contingency Plan (SCP) [Hawai'i Administrative Rules (HAR), Title 11, Chapter 451 (HAR, 1995)]defines two response action processes: removal and remediation. The HDOH Hazard Evaluation and Emergency Response Office (HEER Office) may decide remedial action is appropriate for a complex release site, if site-specific data may be difficult to obtain, or when additional scrutiny, review, and feedback by third parties could be beneficial.

For example, the HEER Office may decide on a remedial action approach under the following conditions:

- Groundwater contamination, especially in a drinking water aquifer
- Soil contamination with a direct migration pathway to a nearby drinking water aquifer
- Contamination (soil or groundwater) crosses property boundaries
- Contaminants are present at high levels or consist of complex mixtures
- Soil contamination beyond the reach of conventional excavation equipment, and still presents exposure pathways for identified environmental hazards
- Site is adjacent to current or potential sensitive communities/residences (such as for schools, day care centers, or public recreational areas) and/or may impact sensitive/protected species

The voluntary Fast Track Cleanup Program (see Section 15), which provides an option for a more streamlined process for site investigations and cleanups, is intended for sites where removal actions, rather than remedial actions, will occur. Sites in the Voluntary Response Program (VRP) (see Subsection 1.3.2.5 and Section 20.3) for additional information on the VRP) are required to follow the public participation steps of the remedial action process whether the cleanup response is conducted as a removal or a remedial action.

The additional documentation and review steps provided by the remedial action process (see Section 2, Figure 2-2) are necessary to address the more complex or sensitive nature of these cleanups. Remedial actions may include physical, biological, or chemical methods to isolate or transform the contamination, as well as measures to protect human health and the environment.

Wherever a release constitutes a threat or potential threat to human health or the environment, the HEER Office will seek to identify a responsible party and request their cooperation in conducting and paying for assessment and/or response action, as appropriate under Hawai'i Environmental Response Law (HRS 128D). If necessary, the HEER Office may enter into consent agreements or issue orders to require identified responsible parties to conduct any necessary assessments or response actions.

Remedial response actions are intended to:

- Eliminate, reduce, prevent, minimize, mitigate, or control risks to public health or the environment
- Provide for efficient, cost effective, and reliable long-term cleanup remedies which protect human health and the environment

A remedial action consists of four broad phases:

- Remedial investigation
- Remedial alternatives analysis
- Remedy selection
- Remedy implementation

16.1 CONDUCTING A REMEDIAL INVESTIGATION

Remedial response actions are typically more complex than removal actions and often require additional site investigation to support appropriate decisions. The remedial investigation helps define and evaluate the nature and magnitude of the threat; but its primary goal is to collect data for use in analyzing remedial alternatives and selecting an appropriate alternative for the site.

16.1.1 REMEDIAL INVESTIGATION SCOPING

The first step in conducting a remedial investigation is investigation scoping. Existing information is assessed and analyzed, and data needs identified. It is not uncommon for additional site investigation to be required to support appropriate decisions in the remedial alternatives analysis.

The following steps should be conducted, as appropriate:

- Assemble and evaluate existing site data
- Identify and characterize the threat
- Develop a conceptual site model to represent the site
- Identify environmental hazards associated with contaminants that exceed State of Hawai'i Department of Health (HDOH) Tier 1 environmental action levels (EALs)
- Identify applicable requirements and guidance to be considered
- Identify data needed to support remedial alternative selection
- Notify natural resources trustees if natural resources are or may be affected
- Develop field sampling plan and quality assurance project plan
- Prepare site-specific health and safety plan

As discussed in Subsection 3.1, project scoping is a critically important step for developing a successful investigation. Inadequate scoping can lead to failures such as:

- Overlooking a significant contaminant
- Overlooking a significant contaminant transport pathway
- Overlooking a significant area of contamination
- Overlooking a sensitive receptor
- Collecting unusable data due to poor sample plan design
- Not collecting the data needed for remedial alternatives analysis
- Selecting an inappropriate cleanup method due to poorly collected data

16.1.2 PRELIMINARY IDENTIFICATION OF LIKELY AND/OR PRESUMPTIVE CLEANUP ALTERNATIVES

The identification and development of cleanup alternatives starts early and is dynamically revised as new data is collected. Based on the scoping phase and degree of site investigation data available, an initial set of potential remedial actions may be identified based on the type of contaminant, type of contaminated media, etc.

"Presumptive remedies" are available for several typical release scenarios (e.g., typical contaminants or disposal practices, or based on effects on environmental media). United States Environmental Protection Agency (USEPA) provides guidance on presumptive remedies, which are preferred by the HEER Office where appropriate. The USEPA Presumptive Remedies website.

When reviewing presumptive remedy guidance documents, confirm that cited methods are still considered to be best/good practices. Changes in cleanup technologies, scientific understanding, regulatory requirements, or public acceptance may affect whether a presumptive remedy is considered to be the preferred choice for a particular site.

The USEPA has developed specific presumptive remedy guidance documents pertaining to wood treatment sites, municipal landfills, volatile organic compounds (VOCs) in soils, and contaminated groundwater for Comprehensive Environmental Response, Compensation & Liability Act (CERCLA) sites. Other organizations such as the Interstate Technology and Regulatory

Council (ITRC) also publish documents on the testing, performance, and feasibility of selected remediation technologies and can be good sources of information when selecting or considering remedy alternatives. The ITRC website can be found at: www.itrcweb.org.

A detailed discussion of common cleanup technologies is presented in Section 17.

16.1.3 REMEDIAL INVESTIGATION AND REMEDIAL INVESTIGATION REPORT

The HEER Office will require submittal of a Remedial Investigation Report for sites following the remedial action process. The report compiles data collected from previous investigations (if relevant and representative of site conditions), plus supplemental investigation data collected to assist in characterizing the site and/or selecting remedial alternatives.

The Remedial Investigation should follow the guidance provided in Section 3 for site investigation design and implementation. The Remedial Investigation Report should be prepared according to the guidance provided in Section 18 on preparing Site Investigation Reports.

16.2 SETTING REMEDIAL ACTION OBJECTIVES AND CONDUCTING A REMEDIAL ALTERNATIVES ANALYSIS (RAA)

Identifying the primary remedial action objectives is the first step in the RAA process. The objectives are specific goals to be achieved by the selected remedy; these will include fulfilling applicable requirements (See Subsection 16.2.1.1>). The remedial action objectives should identify questions requiring answers, site characteristics, chemicals of potential concern (COPCs), and potential outcomes.

Examples of remedial action objectives for a site with soil contamination are:

- Remove exposure pathways between contaminants and receptors (either human or ecological receptors)
- Achieve cleanup of soil to below applicable HDOH EALs for a residential (unrestricted use) scenario
- Utilize USEPA presumptive remedies to the to the extent practicable
- While conducting the cleanup, follow all applicable federal, state, and local regulations pertaining to the site and the response actions
- Minimize potential adverse impacts to the community and the environment during implementation of the remedial action
- Properly dispose of waste streams generated by the remedial action

The Remedial Alternatives Analysis (RAA) Report is a formal presentation of the evaluation of different possible cleanup measures (remedial alternatives) that could be taken in response to a particular release. Therefore, the RAA Report:

- Identifies possible remedial alternatives
- Analyzes each remedial alternative's effectiveness, implementability, and cost
- Recommends a preferred remedial alternative

16.2.1 THRESHOLD CRITERIA FOR REMEDIAL ALTERNATIVES

All remedial alternatives evaluated must meet certain threshold criteria, described in subsections below. These are minimum requirements for a cleanup measure that may be considered for selection. If a cleanup measure cannot meet the threshold criteria, it is not an acceptable alternative and cannot be included in the remedial alternatives analysis.

16.2.1.1 APPLICABLE REQUIREMENTS

Remedial alternatives must comply with all applicable requirements, which are: any federal, state, or local requirements that are legally applicable to a hazardous substance, the response action, location, or other circumstance at a particular site. Examples of applicable requirements are:

- Air pollution emission limits on an on-site incineration process - regulated by the United States (U.S.) Clean Air Act and HRS 342B.
- Effluent discharge limits on wastewater discharges from an on-site treatment process - regulated by the U.S. Clean Water Act and HRS 342D.
- Grading, stockpiling, trenching - regulated by various county ordinances.

However, these actions may not require state or county permits if the activity controlled by an applicable requirement will be conducted entirely on site, and if the response action involving the activity is being conducted in compliance with HRS 128D. In these cases, the remedial alternative being applied must comply with all substantive requirements of the law authorizing the actions (e.g. grading permits), since the law is an applicable requirement.

16.2.1.2 HUMAN HEALTH AND ECOLOGICAL RISK LEVELS

All remedial alternatives considered must use cleanup levels meeting the following criteria:

Systemic toxicants: Cleanup levels must represent concentrations to which the human population, including sensitive subgroups, may be exposed without adverse effect during a lifetime or part of a lifetime (as appropriate), incorporating an

adequate margin of safety. Refer to the EALs provided in Evaluation of Hazards at Sites with Contaminated Soil and Groundwater (HDOH, 2016).

Known or suspected carcinogens: Cleanup levels should be concentrations that represent an excess upper bound lifetime cancer risk to an individual of between 10E-4 and 10E-6, using information on the relationship between dose and response. The 10E-6 risk level will be used as the point of departure for determining acceptable cleanup levels for remedial alternatives in most situations, and when (1) individual chemical-specific federal or state cleanup levels are not available, or (2) individual chemical-specific federal or state cleanup levels are not sufficiently protective due to the presence of multiple contaminants or multiple pathways of exposure. Refer to the EALs provided in Evaluation of Hazards at Sites with Contaminated Soil and Groundwater (HDOH, 2016).

Ecological receptors: Where these concerns are identified, cleanup levels should address impacts to ecological receptors. For example, on sites that have significant ecological risk concerns, the applicable HDOH Tier 1 EAL may be 200 mg/kg in soil rather than 400 mg/kg in soil for those sites where only human health concerns are being addressed. Alternatives for sites with ecological risk concerns must incorporate findings of any natural resource assessments conducted to address such impacts.

The HEER Office has developed an environmental hazard evaluation (EHE) process, presented in Section 13, to address these protectiveness criteria. Remedial actions that reduce contaminants below the appropriate HDOH Tier 1 EALs for the site will meet these criteria for protection of health and the environment. Information and lookup tables regarding HDOH EALs for specific contaminants is available in the guidance document (HDOH, 2016), and may be accessed quickly through the use of the on-line HDOH EAL "Surfer" tool

16.2.2 DEVELOPMENT OF REMEDIAL ALTERNATIVES

If possible, a preliminary list of likely cleanup alternatives developed earlier in the remedial action process should be used as a starting point for the detailed development of remedial alternatives (see Subsection 16.1.2).

16.2.2.1 HIERARCHY OF REMEDIAL ALTERNATIVE SELECTION

A primary objective of any remedial action is to reduce the toxicity, mobility, volume, and extent of released hazardous substances. As noted in the Hawai‘i SCP [HAR 11-451-8(c)] (HAR, 1995), all removal and remedial response actions should consider a hierarchy of response action alternatives in this descending order:

1. Reuse or recycling
2. Destruction or detoxification
3. Separation, concentration, or volume reduction
4. Immobilization of hazardous substances
5. On-site or off-site disposal, isolation, or containment
6. Institutional controls or long-term monitoring

When selecting and analyzing remedial action alternatives, this general hierarchy of response actions should be considered to help prioritize the alternatives.

1. **Reuse or recycling.** Released hazardous substances may sometimes be directly reused or recycled after recovery, depending on the quality of the recovered materials. Examples include:
    - Reuse or recycling of recovered petroleum "free product" as motor fuel or boiler fuel
    - Recycling of metallic lead fragments as recycled scrap metal
2. **Destruction or detoxification.** Organic hazardous substances can be destroyed or detoxified by altering their molecular structures, and, in principle, may be converted into carbon dioxide, water, and inorganic salts. Hazardous substances that pose a threat due to corrosivity or reactivity often can be neutralized. Examples include:
    - Biodegradation of organic hazardous substances
    - Combustion or incineration of organic hazardous substances
    - Neutralization of extremely acidic (low pH) or basic (high pH) corrosive substances
    - Detonation of unexploded ordnance or other explosive substances
3. **Separation, concentration, or volume reduction.** Contaminated material may be completely or partially separated from material that is not contaminated, or contamination may be reduced in a large volume of material by concentrating the contaminant in a smaller volume. Examples include:
    - Soil vapor extraction to extract volatile contaminants from subsurface soils
    - Groundwater extraction, filtration by activated carbon, and disposal of the carbon in an approved landfill
    - Soil particle size separation to reduce contaminated soil volume
4. **Immobilization of hazardous substances.** The physical state of a contaminant may be changed so it is no longer mobile in the natural environment. Examples include:
    - Binding of mobile heavy metals into low-mobility phosphates, sulfides, etc.

    - Chemical additives to reduce the bioavailability of contaminants
    - Vitrification of contaminated soil
5. **On-site or off-site disposal, isolation, or containment.** Contaminated material may be placed in an engineered facility or feature designed to minimize future release of hazardous substances and in accordance with applicable requirements. Examples include:
    - Off-site disposal at permitted landfills
    - On-site isolation of contaminated soil by covering the soil with a concrete cap
    - On-site containment of soil gas with vapor barriers or active ventilation systems
    - On-site containment of contaminated groundwater with sheet piles or slurry walls
    - Reducing mobility of free phase petroleum in soil or groundwater by removing petroleum to residual saturation or less
6. **Institutional controls or long-term monitoring.** Site uses may be restricted through administrative methods and/or long-term monitoring to assess changes in contaminant distribution over time. Examples include:
    - Environmental covenant to prohibit disturbance of contaminated soil
    - Establishment of a monetary trust to fund environmental response efforts if contamination left in place is disturbed in the future.
    - Long-term monitoring of a "stable" groundwater contaminant plume
    - Public notices and advisories against consumption of contaminated foodstuffs

16.2.2.2 PRELIMINARY SCREENING OF ALTERNATIVES

Initial identification of all potentially applicable remedial alternatives should be fairly broad. This initial list of alternatives can be narrowed by ruling out those alternatives that, while applicable in theory, will not work at the site due to factors such as site conditions or technology limitations. Typically, a minimum of five alternatives are considered initially, one of which is the null or "no action" alternative to use as a baseline.

A comparison table depicting the various alternatives considered, practicality of implementation at the site, and costs associated with each option will assist in clearly documenting the advantages and disadvantages of each alternative considered. Generally, at least 3 alternatives that have been screened and judged potentially feasible and practical for the site are carried forward for more in-depth review and analysis (see Subsection 16.2.3). In some cases, the remedy eventually selected will be a combination of remedial actions that are required to achieve the remedial action objective.

16.2.2.3 SOURCE CONTROL ACTIONS

A "source control action" prevents the continued release of hazardous substances into the environment, primarily from a source on top of or within the ground, or in buildings or other structures. Typical source control actions include:

- Removal of hazardous substances from drums, tanks, or pipelines to prevent leakage into the ground
- Removal of floating petroleum "free product" from the water table to prevent continued contamination of soil and groundwater
- Cleanup of contaminated soil to prevent direct exposure to the public
- Cleanup of contaminated soil to prevent leaching impacts to groundwater

When remedial alternatives for source control actions are developed, the remedial alternatives analysis should present:

- At least one alternative where the principal element is treatment that reduces the toxicity, mobility, or volume of the hazardous substances. As appropriate, a range of treatment alternatives should be presented, including:
    - An alternative that removes or destroys hazardous substances to the maximum extent feasible, eliminating or minimizing the need for long-term management.
    - Alternatives that vary in the degree of treatment used and the residuals and untreated wastes that must be managed.
- At least one alternative where protection is provided primarily by preventing or controlling exposure through engineering controls and, as necessary, institutional controls.

16.2.2.4 GROUNDWATER REMEDIAL ACTIONS

Analysis of remedial alternatives for groundwater contamination must assess varying restoration time periods utilizing different cleanup technologies.

16.2.3 EVALUATION OF CLEANUP ALTERNATIVES

Once all potential remedial alternatives are identified and screened to eliminate those that are not practical or technologically feasible at the site, the remaining alternatives are further evaluated relative to each other. The additional evaluation is based on three criteria:

- Effectiveness
- Implementability
- Cost

As noted previously, the evaluation of selected remedial alternatives should be presented in a table format. The table should be supplemented with detail provided in narrative form. For example, the narrative text could present the criteria used for detailed evaluation of remedial alternatives, and a table could summarize the main considerations in the detailed analysis of remedial alternatives selected. Concise summary presentation of remedial alternative comparisons is very helpful with respect to public participation requirements (see Subsection 16.3.2)

Based on the evaluation of these criteria, a preferred alternative (or combination or remedial actions) that meets the site's remedial objectives is selected by the responsible party/site consultant and identified in the results or summary portion of the RAA report (see Subsection 16.2.4)

16.2.3.1 EFFECTIVENESS

Effectiveness means the degree to which an alternative:

- Reduces toxicity, mobility, and volume through treatment
- Minimizes residual risks
- Affords reliable long-term protection
- Complies with applicable requirements
- Minimizes short-term impacts
- Quickly achieves protection

Effectiveness must consider both short-term and long-term elements.

16.2.3.2 IMPLEMENTABILITY

Implementability means the technical and administrative feasibility of the alternative:

Technical feasibility includes:

- Availability of equipment, facilities, and specialists needed
- Compatibility of the technology with site conditions

Administrative feasibility includes:

- Availability of necessary approvals
- Degree of community acceptance

16.2.3.3 COSTS

Each alternative must be considered in terms of total life-cycle cost, not just the up-front capital cost. This is especially important when evaluating alternatives that involve long-term operation and maintenance or other long-term costs that may be incurred by current or future responsible parties. Costs evaluated should include:

- Capital costs
    - Direct construction costs
    - Indirect costs
    - Opportunity costs imposed by the remedial alternative (for example, reduction in property value due to activity and use limitations)
- Annual cost of operation and maintenance (O&M)
    - Sampling and analysis, equipment maintenance, labor

    - Oversight costs (HEER Office or private consultant)
    - Opportunity cost (for example, reduction in annual revenue due to activity and use limitations)
- Contingency costs – possible cost of repairs / restoration in case of remedy failure

Costs should be presented in two formats: (1) as a lump-sum dollar amount in current dollars, with future costs amortized; and (2) as a graph showing projected costs over time.

16.2.4 REMEDIAL ALTERNATIVES ANALYSIS REPORT

The RAA report presents a concise discussion of the remedial alternatives identification and evaluation process for the site, including rationale for the preferred alternative. The content and level of detail in the RAA report will vary depending on the nature and extent of the release, as well as the remedial action or combination of remedial actions selected. The completed report is submitted to the HEER Office for review and comment. See Section 18 for an example outline of a RAA report.

16.3 SELECTION OF A CLEANUP REMEDY FOR THE REMEDIAL ACTION

Once the RAA has been completed adequately, and sufficient information has been gathered for public review and a remedy selection decision, the HEER Office will solicit public review and comment on the preferred remedy selection decision prior to making a final remedy selection. The final remedial alternative selection is approved by or chosen by the HEER Office.

16.3.1 PREPARING A DRAFT RESPONSE ACTION MEMORANDUM (RAM)

The Draft Remedial Action Memorandum (RAM) is a concise summary of site investigation and environmental hazard data, supplemental remedial investigation data (if applicable), the remedial alternatives analysis, and the preliminary remedial alternative selected for the site.

The Draft RAM is used to solicit public review and comment on the proposed remedial action. The Draft RAM may be assembled and finalized by the HEER Office, or alternately, the HEER Office may request or offer the responsible party/site environmental consultant an opportunity to prepare a "preliminary" Draft RAM. In this case, the preliminary Draft RAM would be carefully reviewed and edited, as necessary, for use as the HEER Office Draft RAM for public review.

Subsection 18.5.13 presents detailed content recommendations for the Final RAM, and all but the last several elements of these recommendations would also be applicable for the Draft RAM.

16.3.2 PUBLIC PARTICIPATION AND PUBLIC NOTICES

For remedial response actions, public notice and a minimum 30-day public comment period to review the Draft RAM and associated documents and provide comment are required under the Hawai'i SCP. This public notice and comment period must be completed prior to adopting the Final RAM and implementing the selected remedial alternative. A public meeting may also be held to review and discuss the Draft RAM, at the discretion of the HEER Office. VRP sites must follow the public participation steps of the remedial action process (see Subsection 20.3, VRP).

In some cases, public participation and community involvement activities should be started long before the Draft RAM is prepared. Site assessment and remedial investigation activities can identify the presence of off-site contamination, and potentially affected human and ecological receptors. Early contact with adjacent property owners as well as affected and interested groups, such as neighborhood boards, community groups, and environmental or public interest organizations, may be valuable in helping to identify site-specific issues relevant to the remedial action that otherwise might be overlooked. At a minimum, it is recommended that a public participation plan be developed concurrent with, or as soon as the Draft RAM is completed.

As part of the public participation process, a 2-page fact sheet typically is made available for interested parties. This fact sheet, which summarizes contaminants in the release, site environmental conditions, site environmental hazards, and the preferred remedial action selected for the site, can be posted on the HEER Office website and sent to interested parties via postal mail or e-mail. If the degree of public interest in the site is sufficient, the HEER Office may also decide to hold a public meeting. A public meeting generally would be scheduled in the evening on a weekday at a public meeting space near to the remediation site. The public meeting also generally would be held in the middle of the public comment period (e.g. two weeks from time notice published in the newspaper) to allow time for the public to review additional site information both before and after the meeting. A record of the public meeting, in the form of a transcript, recording, or minutes is prepared and made available to the public.

Public notices, where required or provided at the discretion of the HEER Office, primarily advertise availability of the administrative record for a particular site, the proposed response action, and the opportunity to review the record and submit public comment on the proposed response action within a specified comment period (at least 30 days). When a decision has been made by the HEER Office to hold a public meeting regarding the proposed response action, the meeting is also advertised in the public notice. Generally, public notices provide the following type of information:

- Location and size of site
- Hazardous substances and media being addressed
- Availability of key site documents such as the Draft RAM for a remedial response action - these key documents are made available in a local library, on the HEER Office website, and/or at the HEER Office in Honolulu
- Availability of the full administrative record for the site in the Honolulu HEER Office

- Availability of a "fact sheet" or an executive summary document containing concise summary information on the site and response action proposed, with contact number/e-mail to request
- Solicitation of written or oral comments on the proposed response action within the specified public comment period of at least 30 days, the address and e-mail to send comments; who to call for questions
- If a public meeting scheduled - date, time, and location of the meeting

Note: Publication date of the public notice is the official start of the public comment period (at least 30 calendar days).

Public notices are typically posted for one or two days in the “Public Notices” section of a general circulation newspaper in the county affected by the response action. An example Public Notice for a Draft RAM is provided in Subsection 18.5.13.

The HEER Office project manager for the site also will send a copy of the public notice to the HDOH Office of Environmental Quality Control (OEQC) bulletin editor for publication in The Environmental Notice. The OEQC publishes this bulletin every two weeks to inform the public of all projects being proposed in the State that are subject to public review and comment.

In some cases, the HEER Office project manager may send notice or request notice information be sent via direct mail or e-mail to directly inform known interested parties about the proposed response action, and to solicit their review and input.

- Known community groups in the site area (e.g., community/neighborhood associations or councils)
- Property owners surrounding the site
- Political representatives of the site area (i.e., City or County Council member(s), Legislative Senator/Representative from the site area)
- Public interest groups, if known and likely to have interest
- Other interested parties, if known

16.3.3 PREPARING A FINAL RESPONSE ACTION MEMORANDUM (FINAL RAM)

The HEER Office will consider all written, verbal, and e-mail comments on the Draft RAM and assess whether the preferred remedy selection decision is appropriate, make a final remedy selection decision, and document the decision by preparing a Final RAM for inclusion in the site administrative record. The Final RAM is HDOH's official decision on how the site is to be cleaned up. If the HEER Office decides there will be no changes to the preferred remedy identified in the Draft RAM, the Final RAM will be the same as the Draft RAM with the exception of the addition of the "Responsiveness Summary," a summary of HEER Office responses to public comments received on the Draft RAM.

In some cases, new information could be collected in the public comment period, after publication of the Draft RAM but before the HEER Office's final remedy selection decision that may substantially change the consideration of the performance or costs associated with the preferred remedy. In such cases, the HEER Office's choice of a final remedy may differ from the preferred remedy presented in the Draft RAM. If the changes to a Draft RAM selected by the HEER Office could be reasonably anticipated based on the information in the Draft RAM, the HEER Office may simply amend the Final RAM to include a discussion of the changes and the reasons for such changes.

If the selected remedy is significantly different from the preferred remedy in the Draft RAM, the HEER Office will provide additional public notice, and seek additional public comment on a revised Draft RAM, which includes a discussion of the changes and the reasons for such changes, before making a final remedy selection.

Additional public notice is not required when a final remedy selection decision is made. However, it is recommended that notice be given to interested parties as a courtesy.

Subsection 18.5.13 presents detailed contents recommendations for the Final RAM, which includes a "Responsiveness Summary" that provides specific HEER Office responses to the public comments received.

16.4 IMPLEMENTING THE CLEANUP REMEDY SELECTED

The issuance of a Final RAM only means that a decision has been reached as to how the cleanup of the site should be completed. The next step is to actually implement the selected remedy in the Final RAM. Typically, a responsible party conducts the remedial action voluntarily or under a VRP agreement with HDOH (see Subsection 1.3.2.5 and Subsection 20.3). In some cas). In some cases, the responsible party may conduct the cleanup under a formal consent agreement or an order from HDOH. Although rare, a remedial action cleanup may also be conducted by the HEER Office if a responsible party to perform necessary work cannot be identified.

In some cases, a remedial action can be implemented and completed in a relatively short time (e.g. less than a year). In these instances a concise Remedial Action Work Plan (see Subsection 18.5.14 and a final Remedial Action Report (see Subsection 18.5.15) approved by the HEER Office may be sufficient documentation for the cleanup. If the remedy did not involve continued long-term monitoring or engineering/institutional controls, an environmental hazard management plan (EHMP) for the site may be unnecessary (see Subsection 19.6 and Subsection 18.5.16).

However, depending on the nature and extent of the release as well as other factors, it could take multiple years to implement a remedial action after the Final RAM is issued. Complex cleanups may require construction and installation of specialized remedial systems, or collection of additional site data to optimize remedial design prior to remedial action implementation. In some cases, such as at groundwater cleanup sites, once the remedial system has been constructed and installed, it may operate for multiple years before the cleanup is completed.

Since it may be years before a final "no further action" or "letter of completion" may be issued for the more complex cleanup sites, the HEER Office recommends interim milestone documents to report the progress and completion of key remedial actions, in addition to the initial Remedial Action Work Plan (see 18.5.14)and the final Remedial Action Report (see 18.5.15). Interim milestone actions and associated documents should be identified in the Final RAM.

The initial Remedial Action Work Plan describes how the remedial action will be implemented. An important element of this work plan is a detailed description of representative confirmation testing to be conducted when remedial actions are complete, including the selection of appropriate decision units and the collection of field replicates to demonstrate the precision of confirmation testing.

The final Remedial Action Report presents detailed documentation of the completed remedial action(s), including documentation that remedial action objectives have been achieved and that representative confirmation testing has demonstrated that the remedy has been successful. Environmental hazards that had been identified on the site should no longer be present, or should be controlled through the remedial action and implementation of an EHMP.

For sites where the selected remedy involves the design, construction, and long-term operation of remedial systems, recommended "interim" documents include:

- Remedial design completed: Documents that the remedial system's design has been satisfactorily planned and completed. This report is the basis for HEER Office concurrence to initiate construction of the remediation system.
- Remedial construction completed: Documents that the remedial system's physical construction has been satisfactorily completed. This report is the basis for HEER Office concurrence to initiate operation of the remedial system.
- Remedial operation initiated: Documents that the remedial system has been demonstrated to be operating satisfactorily.

16.4.1 REMEDIAL DESIGN DOCUMENTATION

Remedial design documentation should be presented in a work plan for implementing the remedy selected in the Final RAM. For some types of remedies or in some circumstances, the description of the remedial action provided in the Remedial Action Work Plan may be adequate to develop the specific work plan for carrying out the remedy. However, in some cases the selected remedial action approach described in the Remedial Action Work Plan may not be detailed enough to ensure that the design is optimized. The remedial design work plan would provide the appropriate level of information and detail to initiate the remedy, and include procedures and criteria for determining that the site-specific remedial action objectives have been achieved.

16.4.2 REMEDIAL CONSTRUCTION DOCUMENTATION

A report may be prepared to documentation the actual work performed on site to implement the remedy: excavation of contaminated soil; installation and operation of extraction wells; construction of containment structures; etc. This data, as well as operations and maintenance data, if applicable, will be used to assess the performance of the remedy and determine whether and when the remedial action objectives have been achieved.

16.4.3 OPERATIONS AND MAINTENANCE (O&M) DOCUMENTATION

Operations and Maintenance (O&M) documentation is generated at sites where long-term cleanup or monitoring activities are planned, such as groundwater treatment and monitoring, or periodic inspections of engineered controls such as soil caps. Sites with on-going O&M activities may require periodic reporting to and review by the HEER Office. Long-term monitoring activities generally require the submission of periodic reports.

16.5 SITE CLOSURE FOR REMEDIAL ACTIONS

The goal of the entire remedial action is to achieve the remedial action objectives established in the Final RAM and the Remedial Action Work Plan. Upon documentation that the remedial action objectives have been achieved, the HEER Office can make a determination that no further action (NFA) is necessary (or provide a letter of completion [LOC] for VRP sites). In the case of remedies that employ on-going engineering or institutional control measures, the NFA or LOC determination will be contingent upon continued compliance with the activity and use limitations imposed by the designated engineering and/or institutional controls. See Section 19 for a detailed discussion on Site Closures, and Subsection 19.1.2 for guidance regarding remedy selection and site closure implications.

16.5.1 CONFIRMING ATTAINMENT OF REMEDIAL OBJECTIVES

The Remedial Action Work Plan should establish, and the HEER Office should approve, the procedures and criteria to be used for confirming that remedial action objectives are attained. Confirmation data is evaluated based on the data generated in the remedial construction and operations and maintenance stages, and summarized in the final Removal Action Report for the site.

After the cleanup has been completed, the environmental hazard evaluation (see Section 13) conducted as part of the Remedial Investigation should be updated. The initial environmental hazard evaluation documented the threat posed prior to cleanup activities; the updated environmental hazard evaluation documents the threats (if any) posed after cleanup activities.

SECTION 16 REFERENCES

Citation references for this TGM Section denoted with an “a”, “b”, “c”, etc… after the year of publication may not appear in sequence as these refer to the order placed in the Master References List for the entire TGM.

HAR 11-451. Hawai'i Administrative Rules, Department of Health. Title 11, Chapter 451, State Contingency Plan (SCP). Local Copy (2.2mb). August 2, 1995.

HDOH, 2016. Hawai'i Department of Health, Office of Hazard Evaluation and Emergency Response. Screening for Environmental Concerns at Sites with Contaminated Soil and Groundwater. Website URL: http://eha-web.doh.hawaii.gov/eha-cma/Leaders/HEER/EALs. Summer 2016 (and updates).

HRS 128D. Hawai'i Revised Statutes. Hawai'i Environmental Response Law (HERL), Chapter 128D. Website URL: https://www.capitol.hawaii.gov/hrscurrent/Vol03_Ch0121-0200D/HRS0128D/.

HRS 342B. Hawai'i Revised Statutes. Air Pollution Control, Chapter 342B. Website URL: https://www.capitol.hawaii.gov/hrscurrent/Vol06_Ch0321-0344/HRS0342B/HRS_0342B-.htm.

HRS 342D. Hawai'i Revised Statutes. Water Pollution, Chapter 342D. Website URL: https://www.capitol.hawaii.gov/hrscurrent/Vol06_Ch0321-0344/HRS0342D/.

SECTION 18
REPORT FORMATS AND CONTENT GUIDELINES

Interim Final - June 21, 2009

State of Hawai'i
Department of Health
Office of Hazard Evaluation and Emergency Response
919 Ala Moana Boulevard, Room 206
Honolulu, Hawai'i 96814

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SECTION 18 ACRONYMS AND ABBREVIATIONS

ARAR	Applicable or relevant and appropriate requirements
CAD	Computer-Aided Design
CD	Compact-disc
CFR	Code of Federal Regulations
CSV	Comma separated values
DQO	Data Quality Objective
DVD	Digital video disk
EAL	Environmental Action Level
EHMP	Environmental Hazard Management Plan
FTP	File Transfer Protocol
GIS	Geographical Information System
HAR	Hawai'i Administrative Rules
HASP	Health and Safety Plan
HAZWOPER	Hazardous Waste Operations and Emergency Response
HDOH	Hawai'i Department of Health
HEER Office	Hazard Evaluation and Emergency Response Office
HRS	Hawai'i Revised Statutes
ID	Identity
LEPC	Local Emergency Planning Committees
LIMS	Laboratory Information Management System
LOC	Letter of Completion
NAD83	North American Datum 1983
NFA	No Further Action
NRC	National Response Center
OSHA	Occupational Safety and Health Administration
PDF	Portable Document Format
PRP	Potentially Responsible Party
QA/QC	Quality Assurance and Quality Control
QAPP	Quality Assurance Project Plan
RAA	Remedial alternatives analysis
RAM	Response Action Memorandum
RAR	Removal Action Report
SAP	Sampling and Analysis Plan
SCP	Hawai'i State Contingency Plan
SDAR	HEER Office Site Discovery, Assessment and Remediation Section
TBC	To-Be-Considered
TGM	Technical Guidance Manual
TMK	Tax Map Key
UECA	Uniform Environmental Covenants Act (HRS, Chapter 508C)
USGS	United States Geological Survey

UTM	Universal Transverse Mercator
VRP	HEER Office Voluntary Response Program

18.0 REPORT FORMATS AND CONTENT GUIDELINES

This section presents recommended format and content guidelines for planning, documentation, decision-making, and management document submittals under the Hawai‘i State Contingency Plan (Hawai‘i SCP) (Hawai‘i Administrative Rules [HAR] 11-451). The objective of these guidelines is to produce clear, complete, easily-interpreted documentation of environmental response activities conducted under the Hawai‘i SCP. This guidance promotes consistency in reporting, which expedites the review and approval process conducted by the Hawai‘i Department of Health (HDOH) Hazard Evaluation and Emergency Response (HEER) Office.

In conjunction with this guidance, follow the **systematic planning approach** presented in Section 3. Reporting needs will vary depending on investigation and response complexity (e.g., remedial vs. removal actions) and other factors; report outlines presented in this Section should not be viewed as required "fill in the blank" templates. The HEER Office acknowledges a variety of existing report contents/formats used by environmental consultants and does not require a single specific report template. Rather, the detailed guidance presented throughout the Technical Guidance Manual (TGM) should be closely reviewed and followed during development of report submittals. Report outlines within this Section provide guidance to assure that necessary report elements are included in submitted reports.

18.1 GENERAL GUIDELINES AND TIPS

The following guidelines generally apply to all reports submitted to the HEER Office. Additional report-specific requirements follow in Subsections 18.4 and 18.5.

Signature: Final reports should be signed by the responsible consultant and the Potentially Responsible Part (PRP) (or their designated representative).

Page numbering and labeling: Number and label all document pages, especially when including pages from another document, for example when appending pages copied from another document.

Print quality: For printed documents, submit reports that are legibly and clearly printed. If using an image that was originally in color, then present it in color, not as a black-and-white copy. Label and caption all maps, figures, graphs, diagrams, and photographs, and indicate sources (filenames if applicable).

Paper size: For printed documents, where practicable, use 8.5"x11" sized paper. If larger sheets are used, they should be folded so that they can be stored within 8.5"x11" sized hard copies.

Binding: For printed documents, where practicable, use compact binding methods to optimize document storage capacity. For example, documents bound with three-ring binders do not fit into expandable file folders since they are wider and taller than the 8.5"x11" sheets they hold, whereas documents bound with same-sized report covers take up less space for storage.

Maps and Figures: Include a scale bar and a North arrow on all maps. Please orient maps so that North is at the top of the sheet where practicable.

When presenting multiple maps of the same area to show different data sets, such as different chemicals at a site, or the same chemical at different times at the site, use the same scale and extent for all maps to make it easier to compare one map to another (unless a detail view is intended).

When presenting a figure generated by software interpolation or extrapolation, for example contaminant concentrations generated by a contour mapping program, please identify the software program used on the figure or in the accompanying text.

18.2 ELECTRONIC DOCUMENTS

Electronic documents offer many advantages over paper, as they can be easily searched, indexed, analyzed, and transmitted. They also take up less room, conserving physical office space. The HEER Office is in the process of converting its existing printed document archives to electronic format.

Effective January 1, 2010, the HEER Office requests that all new detailed report documents be submitted in electronic format on permanent physical storage media [e.g., compact-disc (CD) or digital video disk (DVD)] where practical. Please check with the project manager to see if there are parts of the documents, such as large graphics, that should also be submitted in hard copy form. Document submittals via email or File Transfer Protocol (FTP) are also being considered by the HEER Office, and procedures will be announced when this is generally available.

18.2.1 GENERAL ELECTRONIC REPORT GUIDELINES

Where practicable, present the entire report as a single Portable Document Format (PDF) file, so that a complete and accurate duplicate of all pages of the original paper report can be reproduced solely from the PDF file, including all figures, graphs, pages with handwritten signatures or entries, etc. Geographical Information System (GIS) maps and other images should also be presented in their native formats as discussed below. Text in the PDF file should be searchable, where that option is available (depending on the underlying source). Reports may be split into multiple PDF files for practical reasons. For example, many email systems limit attachment size; also, it may be appropriate to separate the main body of a report from lengthy appendices.

18.2.2 MAP DATA

Electronic maps are managed by GIS software programs that link maps to computer databases. GIS software stores, manages, analyzes, and displays spatial data. Use of GIS to manage environmental cleanup site data can greatly improve report clarity and enhance data interpretation. The HDOH GIS platform is ArcGIS (currently version 9.3).

- Submit files in formats readable by ArcGIS 9.3, preferably as .mdx or .shp files. Project the data in North American Datum 1983 (NAD83) Universal Transverse Mercator (UTM) Zone 4N, in units of meters.
- Be sure to georeference all computer-aided design (CAD) files used for mapping purposes.
- Extensive basemap data, including coastlines, roads, aerial and satellite images, Tax Map Key (TMK) parcels, streams, aquifer classifications, etc. are available from the Hawai'i Statewide GIS Program and the United States Geological Service (USGS) Hawai'i Data Clearinghouse.

18.2.3 PHOTOGRAPHS, DIAGRAMS, AND OTHER IMAGES

Include photographs and similar images as separate files in their native formats as well as embedding them in the PDF report. Label and caption all photos. Image files should be named in a manner that matches the labeling in the report. For example, if a photograph is labeled "Figure 3" in the report, then the photo's corresponding image file might be "figure03.jpg".

18.2.4 CHEMICAL DATA

In addition to displaying tabular data (such as chemical data results tables) in the PDF report, include the tables as separate files in spreadsheet or comma separated values (CSV) formats as well, to facilitate data assessment. Name the data files in a manner that matches the labeling in the report.

Modern analytical laboratories generate and store environmental sample data using laboratory information management systems (LIMS). LIMS developed by different instrument manufacturers may be inconsistent and incompatible. Data standards to facilitate the exchange of chemical data are under development. The HEER Office is exploring the feasibility of developing a system to manage electronic data deliverables for chemical data at cleanup sites but has not yet established such a system for submittals.

18.3 TYPES OF DOCUMENTS, REPORTS AND FORMS

Several types of documents, reports, and forms are used during the Hawai‘i SCP release response process. In preparing documentation, several basic questions should be considered. For example, hazardous substance releases vary greatly in size, impact, and complexity, but the same essential questions are asked about every release and every response action:

- What hazardous substance was released? Where did it go in the environment?
- Did you look for the right things, in the right places, using the right methods?
- Could the release pose an environmental hazard? What kind of environmental hazard, and under what circumstances?
- What are the possible cleanup actions you could take to address these hazards?
- What cleanup action did you choose to do? Why did you choose that action?
- Was your cleanup successful? How did you measure your success? What was your cleanup objective, and did you meet it?
- Did you leave any hazardous substances onsite after completion of the cleanup? If so, what and where are they, and what should be done about them?

The documentation of a response action should address all of these questions. The level of detail needed to do so will vary greatly depending on the specific circumstances of each hazardous substance release.

In emergency response removal actions, due to the urgent threats posed by these releases, there is little opportunity for formal review and consultation with other parties prior to decision-making. Many of these questions are addressed informally, often with pre-established decisions for specific scenarios, and simply documented after the fact (see Subsection 2.3).

In non-emergency environmental cleanups (site investigations, removal actions, or remedial actions), these questions should be addressed in detail. Reports should explain the objectives, methods, and results in enough detail to be clearly understandable by the HEER Office and provide adequate documentation and support for investigation and cleanup decisions. If reports are poorly documented, decisions cannot be supported by the HEER Office regardless of how appropriate and well-executed the investigation or response may have been.

The primary Hawai‘i SCP reports and forms are listed below. Suggested outlines for each, as well as applicable forms, are presented in Subsection 18.5.

- Release Notification Report
- Site Prioritization Form*
- Response Action Determination Form*
- Removal Action Plan
- Removal Action Report
- Public Notice for Removal Action Report
- Sampling and Analysis Plan (SAP)
- Quality Assurance Project Plan (QAPP)
- Site Investigation Report
- Environmental Hazard Evaluation
- Remedial Investigation Report
- Remedial Alternatives Analysis (RAA) Report
- Response Action Memorandum (RAM)*
- Public Notice for Draft Response Action Memorandum
- Remedial Action Work Plan
- Remedial Action Report
- Environmental Hazard Management Plan
- "No Further Action" Letter*

- "No Further Active Remediation" Letter*
- Voluntary Response Program Letter of Completion*

* These forms, memoranda, or letters are the responsibility of the HEER Office to document official HEER Office decisions. However, they may be utilized by consultants/PRPs as planning tools.

Supporting Hawai‘i SCP documents and forms include:

- Soil Boring Log
- Monitoring Well Installation Log
- Monitoring Well Abandonment Form
- Voluntary Response Program Application
- Environmental Covenant
- Removal or Remedial Action Fact sheets

18.4 COMMON REPORT ELEMENTS

This section presents several common report elements to be included in many of the documents used in the Hawai‘i SCP release response process.

18.4.1 BASIC IDENTIFYING INFORMATION

Include basic identifying information in the various types of documents. Basic identifying information includes the following:

Document information

- Document title
- Document date
- Document preparer (include signature of preparer and PRP on Final Documents)

Facility/Site information

- Facility/Site name
- Administrative information
  - Facility/Site PRP: company name, mailing address
  - Facility/Site contact person: name, mailing address, phone, email
- Physical location
  - Facility/Site location address: street address, city, state, ZIP code
  - Facility/Site tax map key parcel(s)
  - Facility/Site map coordinates

Hazardous substance release information

- HEER release IDidentity (ID) Number (if applicable)
- Hazardous substance information
  - names of hazardous substances released
  - quantities (or estimates) of hazardous substances released

18.4.2 SITE BACKGROUND

Site background information is necessary in several of the documents. Site background information generally includes the following:

Site Description

- Climate
- Soils/Geology/Hydrology
- Surface Water
- Groundwater (including location of drinking water and other known wells on or near to the site)

Historic Land Use

Sources of information to determine historic land use, include, but are not limited to, aerial photographs, Sanborn fire insurance maps, street directories, title information, newspaper archives, and interviews.

Current Land Use

- Site Owners
- Site Occupants
- Site Zoning
- Conceptual Site Model

Conceptual Site Model

The Conceptual Site Model is prepared during the first step of **systematic planning** as a comprehensive representation of site environmental conditions with respect to recognized or potential environmental hazards. Exposure pathways to human and ecological receptors are indicated in the Conceptual Site Model. See Subsection 3.3 for a detailed discussion of Conceptual Site Models.

18.4.3 HEALTH AND SAFETY PLAN

Hawai'i SCP hazardous substance release sites generally fall under the definition of "uncontrolled hazardous waste sites" pursuant to Occupational Safety and Health Administration (OSHA) Hazardous Waste Operations and Emergency Response (HAZWOPER) Title 29 Code of Federal Regulations (CFR) Section 1910.120(a)(1). A health and safety plan (HASP) is required under Title 29 CFR, Section 1910.120, which includes a requirement for a hazard communication program meeting the requirements of 29 CFR 1910.1200, adopted by HAR Title 12, Chapters 60 and 203.1, Division of Occupational Safety and Health Standards. See Subsection 3.6.3 for more information regarding Health and Safety Plans.

18.5 DOCUMENT OUTLINES

This section presents suggested outlines for the documents and reports used in the Hawai‘i SCP release response process, as well as the applicable forms.

18.5.1 RELEASE NOTIFICATION REPORT (FOR EMERGENCY RESPONSES)

If a spill or release of hazardous substances exceeds a threshold quantity referred to as the "reportable quantity" (see Section 2, Appendices 2-A, through 2-D), you must immediately verbally notify the HEER Office, your County Fire Department, your local County Emergency Planning Committee (LEPC), and the National Response Center (NRC), as required by the Hawai‘i SCP. NRC notification is not required for releases of oil or for trichloropropane. See Subsection 2.3 for additional information regarding emergency response actions for sudden, accidental releases.

A written follow-up notice regarding the release must be sent to the state and county contacts noted above (written follow-up not required for the NRC), postmarked no later than 30 days after initial discovery and verbal notification of the release, and sent by certified mail or other means that provides proof of delivery.

The following information is required for both the initial verbal notification and follow-up written Release Notification Report:

- Chemical name of the released hazardous substance
- Approximate quantity released
- Reportable quantity that is basis for notification
- Location of release
- Media / pathway into which release occurred or is likely to occur (e.g. soil, storm drain, or stream)
- Source and cause of the release (what happened?)
- Date, time, and duration of the release
- Date and time that the person in charge became aware of the release
- Name, address and telephone number of the caller
- Name, address and telephone number of the facility owner
- Name and telephone number of a facility contact person
- Response actions taken or planned
- Facility owner's ability to pay for response actions
- Other government agencies that have been notified
- Health risks associated with the release
- Any other relevant information for assessing the hazard posed

The form in Section 2, Appendix 2-B can be used in preparing the written follow-up notice.

18.5.2 SITE PRIORITIZATION FORM

Sites that are not considered emergencies (e.g., historic releases) and sites that may have been stabilized but not entirely cleaned up following emergency response actions are prioritized by the HEER Office Site Discovery, Assessment and Remediation (SDAR) Section for evaluation and/or response action (HAR 11-451-9(d)). See Subsection 2.4.3 for additional information regarding site prioritization.

The Site Prioritization Form provides key information used by the HEER Office in evaluating the relative priority given to release or potential release sites. This information includes:

- Site identification information
- Documents or site information sources used for the evaluation
- Whether certain threshold hazard criteria are known or suspected to be exceeded at the site
- A description or discussion of the hazards exceeding threshold criteria

- Final determination of priority ranking (high, medium, low, or No Further Action)
- Name of HEER Office evaluator and date of evaluation

An example Site Prioritization Form is presented below. Note that other environmental hazard factors or considerations, in addition to those listed in the example form below, may be used by the HEER Office to establish a site priority ranking. In addition, the site priority ranking may change over time as additional information about the site is documented during site investigation.

Site Prioritization Form

Release Identifying Information (Facility/Site Name, Location, Etc.):

List of documents or site information sources used to make evaluation:

Determination:

- High Priority
- Medium Priority
- Low Priority
- No Further Action

Signature _____

Name _____

Date _____

Hazard Threshold Criteria	Check if Applicable
Actual or probable release to groundwater that is a drinking water supply	
Actual or probable release to surface water that is a drinking water supply	
Actual or probable release to air that poses a threat to public health	
Actual or probable release to and extensive contamination of soil that poses a direct contact hazard due to uncontrolled facility access	
Actual or probable existence of uncontrolled hazardous substances, pollutants, or contaminants, such as leaking containers or impoundments, that pose a direct contact hazard due to uncontrolled facility access	
Actual or probable adverse impact to natural resources	
Actual or probable imminent danger of fire or explosion	
A determination by the director that a facility or vessel poses a substantial endangerment to public health or welfare, the environment, or natural resources	

Discussion

18.5.3 RESPONSE ACTION DETERMINATION FORM

The HEER Office SDAR Section determines whether a proposed response action for environmental cleanups will be conducted as a removal action or a remedial action based on recommendations made by site environmental consultants, data provided in the site investigation and environmental hazard evaluation reports, and/or additional assessment that may have been required. See Subsection 2.4.5.1 for additional information regarding Response Action Determinations.

The Response Action Determination Form provides key information used by the HEER Office SDAR Section to determine whether a response action for environmental cleanups will be conducted as a removal action or a remedial action. This information includes:

- Site identification information

- Immediacy of threat, including threat of fire or explosion
- Presence of hazardous substances on-site
- Complexity of site, including extent of contamination, access to contamination, and feasibility of cleanup options
- Conditions that may results in releases of hazardous substances
- Actual/potential human exposures, drinking water contamination
- Name of HEER Office evaluator and date of evaluation

An example Response Action Determination Form is presented below. Determination factors or considerations other than those in the example may be used. In addition, the response action determination may change as additional information about the site is documented during site investigation.

Response Action Determination Form	
Release Identifying Information (Facility/Site Name, Location, Etc.):	
Determination: • Removal Action • Remedial Action	Signature: _____ Name: _____ Date: _____
Determination Factors	**Check if Applicable**
Immediacy of the threat	
Planning time (including site characterization)	
Implementation time	
Actual or potential exposure to nearby human populations, animals or the food chain from hazardous substances, pollutants or contaminants	
Actual or potential contamination of drinking water supplies or sensitive ecosystems	
Hazardous substances, pollutants, or contaminants in drums, barrels, tanks, or other bulk storage containers, that pose or may pose a threat of release	
High levels of hazardous substances, pollutants, or contaminants in soils largely at or near the surface, that may migrate	
Weather conditions that may cause a release of hazardous substances, pollutants, or contaminants to migrate or be released	
Threat of fire or explosion	
Cost, including the extent to which deferral from removal to remedial action will result in increased cost or increased risk to public health or welfare, the environment, or natural resources	
Community interest	
Site complexity (e.g. extent of release, accessibility, feasibility of cleanup options)	
Availability of other appropriate federal, state, county, or private response mechanisms to respond to the release	
Other situations or factors that may pose an imminent and substantial endangerment to public health or welfare, the environment, or natural resources	
Discussion	

18.5.4 REMOVAL ACTION WORK PLAN

The Removal Action Work Plan typically is completed prior to initiating a removal action; however, this may not be possible in the case of emergency response. See Subsection 2.3 and Section 14 for additional information on removal actions. The following is a suggested outline for a Removal Action Work Plan.

Outline for a Removal Action Work Plan	
1.0	**Introduction and Purpose**
2.0	**Background**
2.1	Site Description
2.1.1	Climate
2.1.2	Soils/Geology
2.1.3	Surface Water
2.1.4	Groundwater
2.2	Current/Future Land Use
2.3	Applicable Tier 1 Environmental Action Levels
2.4	Efforts by HDOH to Obtain Response by Other Parties (if appropriate)
3.0	**Description of Release/Threat of Release**
3.1	Situation Preceding Decision to Conduct Removal
3.2	Applicable Remedial Action Levels
4.0	**Removal Action Tasks**
4.1	Removal Action Alternatives Considered
4.2	Description of the Removal Action
4.3	Project Goal
4.4	Scope of Work
5.0	**Description of Sampling Methods for Confirmation Testing of Removal Action**
5.1	Soil Sampling Activities
5.2	Groundwater Sampling Activities
5.2	Laboratory Sample Preservation Procedures
5.3	Laboratory Analytical Procedures
5.4	Sample Chain-of-Custody and Transportation
5.5	Sample Identification
5.6	Decontamination Procedures
5.7	List of Equipment, Containers, and Supplies
6.0	**Schedule**
7.0	**References**

18.5.5 REMOVAL ACTION REPORT

The Removal Action Report (RAR) presents results of the removal action, based on the Removal Action Work Plan (typical for non-emergency environmental cleanups). Several RAR report elements are the same or very similar to the Removal Action Work Plan, which generally may be edited to include changes made to the planned work, a description of resources expended, results and documentation for confirmation testing. In the case that any hazardous substances remain on site after the removal action (above Tier 1 Environmental Action Levels), the RAR must describe these in detail. For emergency responses, the RAR may be required after the emergency response has been completed (see Subsection 2.3). A very important component of any RAR is a summary and analysis of confirmation testing conducted to demonstrate effectiveness of the removal action. See Section 14 for additional information on removal actions. A suggested outline for a RAR is presented on below.

Outline for a Removal Action Report	
1.0	**Introduction and Purpose**
2.0	**Background**
2.1	Site Description
2.1.1	Climate

	2.1.2	Soils/Geology
	2.1.3	Surface Water
	2.1.4	Groundwater
	2.2	Current/Future Land Use
	2.3	Applicable Tier 1 Environmental Action Levels
	2.4	Efforts by HDOH to Obtain Response by Other Parties (if appropriate)
3.0	**Description of Release/Threat of Release**	
	3.1	Situation Preceding Decision to Conduct Removal
	3.2	Applicable Remedial Action Levels
4.0	**Removal Action Tasks**	
	4.1	Removal Action Alternatives Considered
	4.2	Description of the Removal Action
	4.3	Project Goal
	4.4	Scope of Work
	4.5	Resources Expended
5.0	**Description of Sampling Methods for Confirmation Testing of Removal Action**	
	5.1	Soil Sampling Activities
	5.2	Groundwater Sampling Activities
	5.3	Laboratory Sample Preservation Procedures
	5.4	Laboratory Analytical Procedures
6.0	**Analytical Results of Confirmation Testing**	
	6.1	Analytical Results of Soil Samples
	6.2	Analytical Results of Groundwater Samples
	6.3	Analytical Results of Waste Samples
	6.4	Waste Profiling
7.0	**Description of Hazardous Waste Remaining On-Site (if applicable)**	
8.0	**Conclusions and Recommendations**	
9.0	**References**	

18.5.6 PUBLIC NOTICE FOR A REMOVAL ACTION

When a removal action option has been selected for environmental cleanups, the HEER Office may require public notice and a public comment period, particularly if significant public concern has been expressed, is likely, or is perceived by the HEER Office. In these cases, any public comment would be carefully considered and addressed, as appropriate, before making a final decision on the appropriate response action. In the case of emergency response removal actions, or if a non-emergency removal action has proceeded due to unique circumstances, the public notice is typically published after the removal action has been initiated or conducted. See Subsection 2.4.5.2, Subsection 2.4.6, and Section 14 for more information regarding Removal Actions.

The public notice provides key information to inform the public and assist in evaluating the proposed removal action, including:

- Site identification information
- Hazardous substances and media being addressed
- Availability of key site documents
- Availability of a "fact sheet" or an executive summary document containing concise information on the site and response action proposed, with contact number/e-mail to request
- Solicitation of written or oral comments on the proposed response action within the specified public comment period of at least 30 days, the address and e-mail to send comments; whom to call with questions
- Date, time, and location of public meeting, if scheduled

A sample public notice is presented below.

(Example Public Notice for a Removal Action)

Notice of Proposed Removal Action
SITE NAME
ADDRESS, CITY, STATE, ZIP
TMK

On or about **RELEASE DATE**, a release of **HAZARDOUS SUBSTANCES** to the environment as a result of **CAUSE OF THE RELEASE** occurred at the **SITE,** located at **ADDRESS, CITY, STATE, ZIP, TMK.** A removal action pursuant to HAR 11-451-13 was conducted to clean up contaminated **MEDIA** at the site.

[DETAILS OF THE CLEANUP]

Pursuant to Hawai'i Administrative Rules 11-451-13(f), a Removal Action Work Plan detailing the proposed Removal Action is available for public review and comment. HDOH is accepting comments on the Removal Action Work Plan for 30 days.

The Removal Action Work Plan, as well as supporting documentation, is available for review online at **URL**. The Removal Action Work Plan and supporting documentation may also be reviewed at HDOH offices at 919 Ala Moana Boulevard #206, Honolulu, HI 96814. To arrange for a review date, please contact **RPM NAME**, the HEER Office project manager for the site, at (808) 586-4249 or **RPM EMAIL**. Oral and written comments on the Removal Action Work Plan will be accepted through**COMMENT DEADLINE** . Written comments should be mailed to the Office of Hazard Evaluation and Emergency Response, Hawai'i Department of Health, 919 Ala Moana Boulevard #206, Honolulu, HI 96814, or faxed to (808) 586-7357.

18.5.7 SAMPLING AND ANALYSIS PLAN (SAP)

The Sampling and Analysis Plan (SAP) designates the types and quantities of samples or monitoring information to be collected; where, when and under what conditions they should be collected; the variables to be measured; and the Quality Assurance/Quality Control (QA/QC) procedures to ensure that sampling design and measurement errors meet the specified Data Quality Objectives (DQOs).

Sampling and Analysis Plans are prepared for a variety of environmental investigations ranging in complexity from preliminary to highly detailed. However, not every project will require submittal of a formal sampling plan and related reports prior to initiating site investigation activities; this should be discussed with a project manager in the HEER Office. See Subsection 3.6 for additional information regarding Sampling and Analysis Plans. A suggested outline for a Sampling and Analysis Plan is presented below.

Outline for a Sampling and Analysis Plan

1.0 Introduction and Purpose
2.0 Background
- 2.1 Site Description
  - 2.1.1 Climate
  - 2.1.2 Soils/Geology
  - 2.1.3 Surface Water
  - 2.1.4 Groundwater
- 2.2 Historic Land Use
- 2.3 Current/Future Land Use
- 2.4 Conceptual Site Model

3.0 Investigation History
4.0 Site Investigation Objectives/ Data Quality Objectives
- 4.1 Problem Statement

4.2 Identify Objectives and Chemicals of Potential Concern
4.3 Identify Data Information Needs
4.4 Define the Decision Units
4.5 Decision Statements
4.6 Statistics for Data Evaluation
5.0 Scope of Work
5.1 Surface Soil Investigation
5.2 Subsurface Soil Investigation
5.3 Groundwater Investigation
5.4 Soil Vapor Investigation
5.5 Summary of Environmental Samples
6.0 Description of Sampling Activities
6.1 Surface Soil Sampling Activities
6.2 Subsurface Soil Sampling Procedures
6.3 Groundwater Sampling Procedures
6.4 Soil Gas Sampling Procedures
6.5 Laboratory Sample Preservation Procedures
6.6 Laboratory Analytical Procedures
6.7 Sample Chain-of-Custody and Transportation
6.8 Sample Identification
6.9 Decontamination Procedures
6.10 List of Equipment, Containers, and Supplies
6.11 Investigation Derived Waste
7.0 Quality Assurance/Quality Control Plan
7.1 Quality Assurance/Quality Control Data Objectives
7.2 7.2 Chain of Custody Maintenance
7.3 Calibration Procedures and Frequency
7.3.1 Field Equipment Calibration
7.3.2 Laboratory Instrument Calibration
7.4 Data Reduction and Validation
7.5 Field Quality Control Checks
7.5.1 Field Replicates Collection
7.5.2 Field Replicates Evaluation
7.6 Laboratory Quality Control Checks
7.6.1 Method Blank
7.6.2 Laboratory Control Sample
7.6.3 Matrix Spike/Matrix Spike Duplicate
7.6.4 Surrogate Spike
7.7 Preventative Maintenance
7.8 Data Quality Assessment
7.8.1 Accuracy
7.8.2 Precision
7.8.3 Completeness
7.8.4 Determining if Data Meets DQOs
7.9 Corrective Action
8.0 Documentation and Reporting
8.1 Field Documentation
8.2 Investigation Report
9.0 Schedule
10.0 Health and Safety Plan

11.0	**References**

18.5.8 QUALITY ASSURANCE PROJECT PLAN (QAPP)

The Quality Assurance Project Plan (QAPP) specifies the operational procedures and QA/QC requirements for obtaining environmental data of sufficient quantity and quality to satisfy site investigation objectives. The QAPP is required for all data collection activities that generate data for use in decision-making. See Subsection 3.7 for additional information regarding QAPPs. The QAPP is typically presented as part of the Sampling and Analysis Plan. The suggested outline for the QAPP is presented as Section 7.0 of the Sampling and Analysis Plan outline in Subsection 18.5.7.

18.5.9 SITE INVESTIGATION REPORT

The Site Investigation Report presents accurate and thorough documentation of the sample plan design, sample collection and handling procedures, laboratory analyses, data assessment, and a summary of the data collected. See Subsection 3.9 for additional information regarding Site Investigation Reports. A suggested outline for a Site Investigation Report is presented below.

Outline for a Site Investigation Report	
1.0	**Introduction and Purpose**
2.0	**Background**
2.1	Site Description
2.1.1	Climate
2.1.2	Soils/Geology
2.1.3	Surface Water
2.1.4	Groundwater
2.2	Historic Land Use
2.3	Current Land Use
2.4	Conceptual Site Model
3.0	**Summary of Investigation History**
4.0	**Summary of Data Quality Objectives**
5.0	**Field Activities**
5.1	Selection of DUs
5.2	Surface Soil Sampling Activities
5.3	Subsurface Soil Sampling Activities
5.4	Groundwater Sampling Activities
5.5	Soil Vapor Sampling Activities
5.6	Summary of Environmental Samples
6.0	**Sample Control Procedures**
6.1	Sample Containers and Preservation
6.2	Chain of Custody
6.3	Laboratory Analytical Methods
7.0	**Field Observations during Sampling**
7.1	Surface Soil Sampling Observations
7.2	Subsurface Soil Sampling Observations
7.3	Groundwater Sampling Observations
7.4	Soil Gas Sampling Observations
6.5	Laboratory Sample Preservation Procedures
8.0	**Data Quality**
8.1	Laboratory Quality Control
8.1.1	Surface Soil Samples
8.1.2	Subsurface Soil Samples
8.1.3	Groundwater Samples
8.1.4	Soil Gas Samples
8.2	Field Quality Control

8.3 Field Replicates Analyses and Summary
8.4 Field Data Quality Assessment
8.5 Conclusions

9.0 Analytical Results

9.1 Surface Soil Sampling Analytical Results
9.2 Subsurface Soil Sampling Analytical Results
9.3 Groundwater Sampling Analytical Results
9.4 Soil Gas Sampling Analytical Res

10.0 Summary of Results and Extent and Magnitude of Contamination

10.1 & Surface Soil
10.2 & Subsurface Soil
10.3 & Groundwater
10.4 & Soil Gas

11.0 Environmental Hazard Evaluation

(see Subsection 18.5.10 below for details. This may be a separate document, especially for more complex sites)

12.0 Conclusions and Recommendations

13.0 References

18.5.10 ENVIRONMENTAL HAZARD EVALUATION

Environmental Hazard Evaluation is the link between site investigation and response action. The Environmental Hazard Evaluation may be prepared as a stand-alone document or as part of the Site Investigation or Remedial Investigation Reports. See Subsection 3.10 and Section 13 as well as the HDOH document *Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater* (HDOH, 2016) for a detailed discussion of Environmental Hazard Evaluation. A suggested outline is presented on the following page.

Outline for an Environmental Hazard Evaluation

1.0 Introduction and Purpose

2.0 Background

2.1 Site Description
2.1.1 Climate
2.1.2 Soils/Geology
2.1.3 Surface Water
2.1.4 Groundwater
2.2 Historic Land Use
2.3 Current/Future Land Use
2.4 Conceptual Site Model

3.0 Chemicals of Potential Concern

4.0 Decision Units

5.0 Summary of Data Representativeness

6.0 Magnitude and Extent of Contamination

7.0 Description of the Environmental Hazard Evaluation Process

8.0 Potentially Applicable Tier 1 Environmental Action Levels

9.0 Targeted Tier 1 EALs and Comparison to Site Data

9.1 Targeted Tier 1 Soil EALs
9.2 Comparison of Targeted Soil EALs to Site Data
9.3 Targeted Tier 1 Groundwater EALs
9.4 Comparison of Selected Groundwater EALs to Site Data
9.5 Targeted Tier 1 Soil Gas EALs
9.6 Comparison of Selected Soil Gas EALs to Site Data

10.0 Environmental Hazards

	10.1 Potential Human/Ecological Receptors
	10.2 Potential Exposure Pathways
	10.3 Potential Environmental Hazards
	10.4 Targeted Environmental Hazards
11.0	**Maps of Areas with Contaminants above Tier 1 EALs** (or acceptable alternative action levels) and Associated Environmental Hazards
12.0	**Conclusions and Recommendations**
13.0	**References**

18.5.11 REMEDIAL INVESTIGATION REPORT

A remedial investigation is typically an additional site investigation that focuses on more sampling to further delineate contaminant distribution, identify likely remedial action options and applicable technologies (including the presumptive remedies demonstrated to work well in similar circumstances), or fill data gaps related to remedial alternatives that are important for decision-making. Similar to a Site Investigation Report, a Remedial Investigation Report presents accurate and thorough documentation of the sample plan design, sample collection and handling procedures, laboratory analyses, data assessment, and a summary of the data collected. The Site Investigation Report outline presented in Subsection 18.5.9 also applies for a Remedial Investigation Report.

18.5.12 REMEDIAL ALTERNATIVES ANALYSIS (RAA) REPORT

The Remedial Alternatives Analysis (RAA) Report provides a comparison of various remedial strategies. Typically, at least five strategies (including a "no action" strategy) are initially selected and analyzed, with at least three of the strategies judged most appropriate then presented and compared in detail in the RAA report. Primary considerations in weighing the strengths and weaknesses of remedial alternatives include:

- Effectiveness
- Technological and Administrative Feasibility
- Cost

Based on these considerations, comparisons, and associated information, a preferred or preliminary remedial alternative is selected for the site and documented in the RAA Report. See Section 16 for additional information regarding RAA Reports. A suggested outline for a RAA Report is presented below.

Outline for a Remedial Alternatives Analysis Report	
1.0	**Introduction and Purpose**
2.0	**Background**
	2.1 Site Description
	2.1.1 Climate
	2.1.2 Soils/Geology
	2.1.3 Surface Water
	2.1.4 Groundwater
	2.2 Historic Land Use
	2.3 Current/Future Land Use
	2.4 Conceptual Site Model
3.0	**Magnitude and Extent of Contamination**
	3.1 Contaminant Fate and Transport
4.0	**Environmental Hazards Evaluation**
	4.1 Chemicals of Potential Concern
	4.2 Exposure Setting
	4.3 Potential Human/Ecological Receptors
	4.4 Exposure Pathway Analysis
	4.5 Environmental Hazard Evaluation Summary
5.0	**Establishing Alternatives**

5.1 Introduction
5.2 Potentially Applicable or Relevant and Appropriate Requirements (ARARs) and To-Be-Considered (TBC) criteria
5.2.1 Potential Chemical-Specific ARARs and TBCs
5.2.2 Potential Location-Specific ARARs and TBCs
5.2.3 Potential Action-Specific ARARs and TBCs
5.3 Remedial Action Objectives
5.4 General Response Actions
6.0 Detailed Analysis of Alternatives
6.1 Alternative 1: No Action
6.2 Alternative 2
6.3 Alternative 3
6.4 Alternative 4
6.5 Alternative 5
7.0 Comparative Analysis of Remedial Alternatives
7.1 Overall Protectiveness
7.2 Compliance with ARARs
7.3 Reduction of Toxicity, Mobility, and Volume through Treatment
7.4 Long-Term and Short-Term Effectiveness
7.5 Implementability
7.6 Estimated costs
8.0 Preferred Alternative

18.5.13 RESPONSE ACTION MEMORANDUM (RAM)

A Draft Response Action Memorandum (RAM) is written first, for public review and comment. The Draft Response Action Memorandum (Draft RAM) is a concise summary of site investigation and environmental hazard data, supplemental remedial investigation data (if obtained), the remedial alternatives analysis, and the preliminary remedial alternative selected for the site. See elements 1.0 through 5.0 in the Outline for Final Response Action Memorandum in Subsection 18.5.13.2 below for a recommended report format for a Draft RAM.

18.5.13.1 PUBLIC NOTICE FOR DRAFT RESPONSE ACTION MEMORANDUM

The Draft RAM is a HEER Office document intended for review and public comment. A public notice must be published regarding availability of the Draft RAM and a minimum 30-day comment period provided for review. See Section 16 for additional information regarding the Draft RAM and Subsection 2.4.6.1 for additional information regarding public notices.

The public notice (published in the newspaper and provided to interested parties) provides key information to inform the public and assist in evaluating the proposed response action, including:

- Site identification information
- Hazardous substances and media being addressed
- Availability of the Draft RAM (and other key site documents)
- Availability of a "fact sheet" or an executive summary document containing concise summary information on the site and response action proposed, with contact number/e-mail to request
- Solicitation of written or oral comments on the proposed response action within the specified public comment period of at least 30 days, the address and e-mail to send comments; whom to call for questions
- Date, time, and location of the public meeting, if scheduled

A sample public notice regarding the Draft RAM is provided below.

(Example Public Notice for Draft RAM)

Notice of Proposed Remedial Action
SITE NAME

ADDRESS, CITY, STATE, ZIP
TMK

The Hawai'i Department of Health (HDOH) is proposing a cleanup remedy for the **SITE** located at **ADDRESS, CITY, STATE, ZIP, TMK. MEDIA** at the site are contaminated with **HAZARDOUS SUBSTANCES** as a result of **CAUSE OF THE RELEASE**. **PRP NAME**, who operated the **SITE** and is responsible for the cleanup, has investigated the environmental contamination at the site and evaluated three potential remedies: (1) **REMEDY 1**, (2) **REMEDY 2**, and (3) **REMEDY 3**. Based on recommendations from the site environmental consultant, as well as a review of the site investigation and remedial alternatives reports, HDOH has tentatively selected the third remedial option, **REMEDY 3**.

Pursuant to Hawai'i Administrative Rules 11-451-15(i), a draft Response Action Memorandum detailing this proposed remedy is available for public review and comment. HDOH is accepting comments on the draft Response Action Memorandum for 30 days, after which HDOH will evaluate all comments received and make a final remedy selection decision for the site.

The Draft Response Action Memorandum, as well as supporting documentation, is available for review online at **URL**. The draft Response Action Memorandum and supporting documentation may also be reviewed at the **LIBRARY NAME** public library located at **LIBRARY ADDRESS** or at the HDOH offices at 919 Ala Moana Boulevard #206, Honolulu, HI 96814. To arrange for a review date at the HDOH offices, please contact **RPM NAME**, the HDOH remedial project manager for the site, at (808) 586-4249 or **RPM EMAIL**. Oral and written comments on the draft Response Action Memorandum will be accepted through **COMMENT DEADLINE**. Written comments should be mailed to the Office of Hazard Evaluation and Emergency Response, Hawai'i Department of Health, 919 Ala Moana Boulevard #206, Honolulu, HI 96814, faxed to (808) 586-7357, or emailed to **RPM EMAIL**

18.5.13.2 FINAL RESPONSE ACTION MEMORANDUM

A Final RAM documenting the final remedial alternative approved by the HEER Office for the site is provided after completion of the public comment period on the Draft RAM. All public comments are considered and addressed, as appropriate, in the Responsiveness Summary section of the Final RAM. See Section 16 for additional information regarding the RAM. A suggested outline for a Final RAM is provided below.

Outline for a Final Response Action Memorandum	
1.0	**Site Location and Description**
1.1	Site Description
1.2	Site Background
1.3	Investigation History
1.4	Magnitude and Extent of Contamination
1.5	Current/Future Land Use
2.0	**Environmental Hazard Evaluation**
2.1	Chemicals of Potential Concern
2.2	Exposure Setting
2.3	Potential Human/Ecological Receptors
2.4	Exposure Pathway Analysis
2.5	Environmental Hazard Evaluation Summary
3.0	**Remedial Strategy**
3.1	Development of Remedial Action Objectives
3.1.1	Applicable Remedial Action Levels
3.1.2	Remedial Action Objectives
3.2	Estimation of Soil Volumes Needing Remedial Action
3.3	General Response Actions

	3.4 Development of Remedial Alternatives
4.0	**Evaluation of Remedial Action Alternatives**
5.0	**Proposed Remedy**
6.0	**Descriptions and Rationale for Modifications from Proposed Remedy (if any)**
7.0	**Final Remedy Selected**
8.0	**Responsiveness Summary (specific responses to public comments)**
9.0	**References**

18.5.14 REMEDIAL ACTION WORK PLAN

A Remedial Action Work Plan is required to document the proposed approach to implement the selected remedial action. A very important component of any Remedial Action Work Plan is a detailed plan for representative confirmation testing to demonstrate effectiveness of the remedial action in reducing contaminant levels below Tier 1 EALs. See Section 16 for more information regarding Remedial Actions The suggested outline for the Remedial Action Work Plan is presented below.

Outline for a Remedial Action Work Plan	
1.0	**Introduction and Purpose**
2.0	**Background**
	2.1 Site Description
	2.1.1 Climate
	2.1.2 Soils/Geology
	2.1.3 Surface Water
	2.1.4 Groundwater
	2.2 Current/Future Land Use
	2.3 Conceptual Site Model
	2.4 Nature and Extent of Contamination
	2.5 Applicable Remedial Action Levels
3.0	**Summary of the Environmental Hazard Evaluation**
4.0	**Remedial Action Tasks**
	4.1 Description of the Selected Remedial Alternative
	4.2 Project Goal
	4.3 Remedial Approach
	4.4 Scope of Work
5.0	**Description of Confirmation Sampling Activities**
	5.1 Chemicals of Potential Concern
	5.2 Decision Units for Confirmation Sampling
	5.3 Field replicate sampling and evaluation
	5.4 Soil Sampling Activities
	5.5 Groundwater Sampling Activities
	5.6 Laboratory Sample Preservation Procedures
	5.7 Laboratory Analytical Procedures
	5.8 Sample Chain-of-Custody and Transportation
	5.9 Sample Identification
	5.10 Decontamination Procedures
	5.11 List of Equipment, Containers, and Supplies
	5.12 Investigation Derived Waste
6.0	**Schedule**
7.0	**References**

18.5.15 REMEDIAL ACTION REPORT

The Remedial Action Report presents accurate and thorough documentation of the Remedial Action. See Section 16 for additional information regarding remedial actions. A suggested outline for a Remedial Action Report is presented below.

Outline for a Final Remedial Action Report
1.0 Introduction and Purpose
2.0 Background
2.1 Site Description
2.1.1 Climate
2.1.2 Soils/Geology
2.1.3 Surface Water
2.1.4 Groundwater
2.2 Current/Future Land Use
2.3 Conceptual Site Model
2.4 Nature and Extent of Contamination
2.5 Applicable Remedial Action Levels
3.0 Summary of the Environmental Hazard Evaluation
4.0 Remedial Action Tasks
4.1 Description of the Selected Remedial Alternative
4.2 Project Goal
4.3 Remedial Approach/Design
4.4 Scope of Work
4.5 Construction Details
4.6 Field Observations during Remedial Action Activities
5.0 Operation and Maintenances
6.0 Confirmation Sampling Activities
6.1 Soil Sampling Activities
6.2 Groundwater Sampling Activities
6.3 Sample Control Procedures
6.3.1 Sample Containers and Preservation
6.3.2 Chain of Custody
6.3.3 Laboratory Analytical Methods
6.4 Data Quality
7.0 Confirmation Sampling Analytical Results
7.1 Field Replicates Evaluation
7.2 Laboratory QA/QC Data Evaluation
8.0 Post-Remedial Environmental Hazards
9.0 Conclusions and Recommendations
10.0 References

18.5.16 ENVIRONMENTAL HAZARD MANAGEMENT PLAN

If contaminated media is left on-site after the response action is completed, an Environmental Hazard Management Plan (EHMP) must be prepared to manage environmental hazards identified in the Environmental Hazard Evaluation over the long-term. An EHMP presents all necessary information in a single, stand-alone document that identifies the nature and extent of residual contamination, potential environmental concerns posed by the contamination, and appropriate measures to ensure that these concerns are adequately addressed. See Section 19 for additional information regarding EHMPs. A suggested outline for an EHMP is presented below.

Outline for an Environmental Hazard Management Plan
1.0 Introduction and Purpose
2.0 Background

	2.1	Brief Summary of the Site Background and History of Contaminant Releases
	2.2	Chemicals of Potential Concern
	2.3	Conceptual Site Model
3.0	**Clear Map Descriptions of the Extent and Magnitude of Remaining Contamination**	
	(to scale, with north arrow, and including footprints of any on-site buildings nearby contaminated areas)	
4.0	**Summary of Potential Environmental Hazards**	
5.0	**Long-Term Monitoring Requirements**	
6.0	**Engineering Controls Requirements**	
7.0	**Institutional Controls Requirements**	
8.0	**Implementation**	
9.0	**Soil and Groundwater Management for Future Site Activities Affecting On-Site Contamination**	
	9.1	Consultation with HEER Office
	9.2	Pre-Excavation Evaluation of Soils and Groundwater
	9.3	Soil Excavation and Handling
	9.4	Soil Stockpiling/Storage
	9.5	Soil Disposal
	9.6	Groundwater Handling
	9.7	Groundwater Disposal
10.0	**Exposure Management**	
	10.1	Awareness/Training for Contamination Managed On-Site
	10.2	Construction Worker Notifications and Protections
	10.3	Use Restrictions to Protect Site Workers, Guests
	10.4	Emergency Response for Chemical Exposure
		10.4.1 Eye and Skin Exposure to Chemicals
		10.4.2 Internal Exposure to Chemicals
		10.4.3 Inhalation Exposure to Chemicals
11.0	**References**	

18.5.17 "NO FURTHER ACTION" LETTER

An unrestricted site closure under the Hawai'i SCP (HAR 11-451) is granted as a No Further Action (NFA) letter. A restricted use site closure is granted as a NFA with Restrictions. Once the HEER Office decides that no further action is necessary for a specific release, suspect release, or the successful completion of a response action (either removal or remedial action), a NFA letter will be sent to the responsible party(s). See Section 19 for additional information regarding site closures.

A No Further Action letter includes the following information:

- Site identification information
- Hazardous substances and media being addressed
- List of key site documents reviewed
- Final determination of site (NFA or NFA with Restrictions)
- Description of restrictions (NFA with Restrictions)
- Description and requirement of an Exposure Hazard Management Plan (NFA with Restrictions)
- Name of HEER Office evaluator and date of evaluation

An example NFA Letter is presented below. After issuing the letter, the HEER Office may later require additional action if new information indicates a continuing threat to public health, the environment, or natural resources.

(Example: No Further Action Letter)

Dear [**RESPONSIBLE PARTY, TITLE, COMPANY, ADDRESS**]:
Reference: [**FACILITY/SITE NAME, ADDRESS (TMK)**]

Subject: No Further Action (NFA) Determination at
FACILITY/SITE, ADDRESS

Dear **POINT OF CONTACT:**

We have reviewed [**REPORT(S)**] regarding a release or suspected release of [**HAZARDOUS SUBSTANCE**] at the subject Facility/Site [**PROVIDE ADDITIONAL DETAILS TO IDENTIFY THE RELEASE - DATE, LOCATION, ETC.**].

Based on our review, we have determined that the site currently poses no threat to human health or the environment, and no further action is required in response to this release or suspected release. Please be aware that if future information indicates that contamination is present at the site at levels that pose a threat to public health, the environment, or natural resources, we may require additional investigative and response actions be performed. Thank you for your cooperation in this matter. Should you have any questions about this letter, please contact [**REMEDIAL PROJECT MANAGER**] at [**PHONE NUMBER**] or [**EMAIL ADDRESS**].

Sincerely,
[**SDAR SECTION SUPERVISOR**
HEER OFFICE]

18.5.18 "NO FURTHER ACTIVE REMEDIATION" LETTER

A No Further Active Remediation Letter is available for contaminated sites where potentially significant, environmental concerns remain but active remediation (e.g., excavation, soil vapor extraction, etc.) is no longer practical. This type of letter is often used when further excavation can jeopardize the structural integrity of on-site buildings. If needed, a letter can be requested from the HEER Office indicating that No Further Active Remediation is required at such a site.

A No Further Active Remediation status is not considered a type of site closure. The case will remain "open" in the HEER Office site records. The letter is intended to clarify that all major cleanup actions have been completed at the site and that the site has moved into a status of long-term monitoring and management. See Section 19 for additional information regarding site closures.

A No Further Active Remediation Letter is issued by the HEER Office and provides the following information:

- Site identification information
- Hazardous substances and media addressed
- List of key site documents reviewed
- Description of potential future hazards
- Description and requirement of an Exposure Hazard Management Plan
- Final determination of site (No Further Active Remediation)
- Name of HEER Office evaluator and date of evaluation

An example "No Further Active Remediation" Letter is presented below. Note that if future information indicates that contamination present at the site is posing a threat to public health, the environment, or natural resources, the HEER Office may require additional investigative and response actions.

(Example No Further Active Remediation Letter)

Dear [**RESPONSIBLE PARTY, TITLE, COMPANY, ADDRESS**]:
Reference: [**FACILITY/SITE NAME, ADDRESS (TMK)**]

Subject: No Further Active Remediation Determination at **FACILITY/SITE, ADDRESS**

We have reviewed [**REPORT(S)**] regarding a release of [**HAZARDOUS SUBSTANCE**] at the subject Facility/Site [**PROVIDE ADDITIONAL DETAILS TO IDENTIFY THE RELEASE - DATE, LOCATION, ETC.**].

Based on the site investigation and environmental hazard evaluation conducted in [**REPORT(s)**], the release at this site poses no current hazards to public health, the environment, or natural resources. However, potential future hazards may exist if [**DESCRIBE POTENTIAL FUTURE EXPOSURE SCENARIO**]. Implementing your Exposure Hazard Management Plan [**DATE, ATTACHED**] will monitor for and prevent, avoid, or mitigate these hazards.

We have determined that no further active remediation is required in response to this release, assuming that the Exposure Hazard Management Plan [**DATE**, **ATTACHED** is properly implemented at the site. However, you should note that if future information indicates that contamination at this site is posing a threat to public health, the environment, or natural resources, we may require additional investigative and response action to be performed. Thank you for your cooperation in this matter. Should you have any questions about this letter, please contact [**REMEDIAL PROJECT MANAGER**] at [**PHONE NUMBER**] or [**EMAIL ADDRESS**].

Sincerely,
[**SDAR SECTION SUPERVISOR**
HEER OFFICE
:attachment

18.5.19 VOLUNTARY RESPONSE PROGRAM LETTER OF COMPLETION

An unrestricted site closure under the Voluntary Response Program (VRP) (HRS[Hawai‘i Revised Statutes (HRS) 128D, Part II)II] is granted as a Letter of Completion (LOC). A restricted use site closure is granted as a LOC with Restrictions. The purpose of the Voluntary Response Program is to minimize environmental liability and assure timely HEER Office oversight in a way that will encourage prospective developers, lenders, and purchasers to voluntarily cleanup properties. See Section 19 for additional information regarding site closures.

A VRP Letter of Completion includes the following information:

- Site identification information
- Legal property description
- Requesting party and prospective purchaser
- List of contaminants and specific media
- Exemptions from future liability
- Final VRP determination of site (LOC or LOC with Restrictions)
- Description of restrictions and management conditions (LOC with Restrictions)
- Description and requirement of an Exposure Hazard Management Plan (LOC with Restrictions)
- Name of HEER Office evaluator and date of evaluation

An example VRP Letter of Completion is presented below. Note that HDOH may order a prospective purchaser receiving a LOC to re-open the site *only* if any institutional or engineering controls that are part of the LOC subsequently are not complied with, or future discoveries indicate contaminants present at concentrations exceeding Tier 1 EALs for contaminants and media *not listed* in the LOC and VRP Agreement. HDOH may not require prospective purchasers to perform additional work for contaminants and media covered in the VRP Agreement, as they have exemption from liability under HRS 128D, Part II.

Model Letter of Completion for
Prospective Purchaser as Requesting Party

NOTE: Actual letter issued may vary, and a LOC is different for a site owner conducting a voluntary cleanup rather than a prospective purchaser - please consult with the HEER Office.

Re: Letter of Completion Pursuant to the Voluntary Response Program Agreement Dated [**Insert date of the Voluntary Response Agreement**] between [**Insert Requesting Party name**] and the Hawai'i Department of Health

Dear [**Insert Requesting Party name**]:

I am sending this Letter of Completion ("Letter") in accordance with Chapter 128D, Hawai'i Revised Statutes, and the Voluntary Response Program Agreement ("Agreement") dated [Insert date of the Voluntary Response Agreement] between [Insert Requesting Party name] and the Hawai'i Department of Health ("Department"). The purpose of the law is to facilitate voluntary and timely responses to hazardous substance releases and provide relief from liability for eligible prospective purchasers who conduct voluntary response actions.

This Letter pertains to environmental contamination related to the real property located at [Insert Property Location Address] ("Property") and described in detail in Exhibit A, Attachment 1.

[Insert Requesting Party name] has completed the investigation and voluntary response action set forth in Exhibit B of the Agreement dated [Insert date of the Voluntary Response Agreement]. Pursuant to HRS 128D, Part II, carcinogens listed in Exhibit A, Attachment 2 do not pose an incremental cancer risk in excess of one in one million. Subject to the terms and provisions set forth herein, the Department hereby acknowledges satisfactory completion of the Voluntary Response Action in accordance with the Agreement and Hawai'i Revised Statutes (HRS), Chapter 128D.

These terms and provisions assure the long-term effectiveness of the Voluntary Response Action. The Department has determined that the Voluntary Response Action was an acceptable approach to managing the potential risks of exposure to the Contaminants at the Property, and that this Voluntary Response Action constitutes the "clean up" specified in HRS §128D-40(c).

Exemptions from Future Liability

Subject to the terms and provisions set forth herein, the Department hereby grants to [Insert Requesting Party name] and future prospective purchasers (as defined in §128D-32, HRS) of this Property exemptions from future liability to the Department and, to the extent authorized by law, third parties for the contaminants listed in Exhibit A, Attachment 2. Also, as provided for in §128D-40, HRS, §113(f) of the federal Comprehensive Environmental Response, Compensation, and Liability Act (P.L. 96-510), and to the fullest extent authorized by law, [Insert Requesting Party name] and future prospective purchasers shall not be liable for claims for contribution or indemnity regarding the provisions herein and Contaminants listed in Exhibit A, Attachment 2.

Exemptions from liability apply only to the Contaminants/media listed in Exhibit A, Attachment 2 that were documented and addressed in the response action on the property listed in Exhibit A, Attachment 1.

Exemptions from liability do not apply to any contamination released on the Property subsequent to the date of this Letter of Completion. [Insert Requesting Party name] and future prospective purchasers must comply with any land use restrictions or management conditions that are part of the Letter of Completion (Exhibit A, Attachment 3). Not complying with applicable land use restrictions or management conditions will void the Letter of Completion, and the Department may re-open the site for additional investigation and/or action.

The Department hereby exercises its administrative authority and holds [Insert Requesting Party name] and future prospective purchasers harmless from liability to the Department and, to the extent authorized by law, third parties for the Contaminants, Property, and specific media as addressed in the Voluntary Response Action.

Acknowledgement of land use restrictions or management conditions as part of the Letter of Completion

Note: If no land use restrictions or management conditions apply to the Letter of Completion, record this fact in this section and in Exhibit A, Attachment 3. Otherwise, provide the signature documentation below and details of any restrictions/conditions in Exhibit A, Attachment 3.

[Insert Requesting Party name] acknowledges and accepts the land use and/or management conditions as set forth in Exhibit A, Attachment 3. In the event these land use and/or management conditions are not followed, the Letter of Completion will be void and HDOH may initiate additional investigations and/or actions.

Signature: : Date
Title/Company:

In closing, I would like to thank [Insert Requesting Party name] for participating in the Hawai'i Voluntary Response Program and for taking actions to address contaminated property in the state.

Sincerely,
[**Director of Health**]
Exhibit A, Attachment 1

Legal Property Description

Note: This complete legal description must cover the specific land area(s) included in the Voluntary Response action taken as a result of the Voluntary Response Agreement. If the area of the Voluntary Response action is only a portion of a larger parcel, this must be clear in the description. Please include Tax Map Key number(s) and map(s), Certificate of Title and any associated documents, or other documents to ensure a complete legal description of the Property.
Exhibit A, Attachment 2

List of Contaminants and Specific Media

Contaminants:

Media:
Exhibit A, Attachment 3

Terms and Conditions

(List any Land Use Restrictions or Management Conditions that are tied to the LOC)

18.6 SUPPORTING FORMS AND OTHER DOCUMENTS

18.6.1 SOIL BORING LOG

Accurate boring logs are essential for evaluating and interpreting analytical results. Soil Boring Logs are included in Site Investigation Reports and Remedial Investigation Reports, as well as other reports, where appropriate. See Subsection 5.5.7 for additional information regarding Soil Boring Logs.

Recommend boring log contents include:

- Date, time (both starting and ending, if multiple days)
- Weather and site conditions
- Name(s) of field or sampling personnel
- Name of drilling contactor
- Drilling method
- Borehole coordinates - latitude and longitude
- Sketch showing the sampling location (including reference distances)
- Diameter and total depth of borehole
- Drilling fluid and angle (if applicable)
- Blow counts
- Site name and identification
- Boring location identification
- Sample identification number (if applicable)
- Depth to water and/or bedrock (refusal) when encountered
- Soil description
- Sample recovery (and portion submitted for analysis)
- Type of sample equipment used
- Field measurements (where appropriate)
- General comments (e.g., odor, staining, etc.)
- Planned sample analyses

A sample soil boring log is presented in Section 5, Figure 5-32.

18.6.2 MONITORING WELL INSTALLATION LOG

Throughout the drilling and well installation process, detailed observations are recorded in the Monitoring Well Installation Log. Prepare a well installation log for each monitoring well. See Subsection 6.2.1.5 for additional information regarding installation logs.

A recommend list of monitoring well installation log contents includes the following:

- Project name and location
- Well designation and location relative to contaminant source
- Date and time of well installation start and completion
- Environmental consulting company and on-site consultant
- Drilling company
- Drilling method
- Volume of drill fluid and/or pre-development fluid lost into well during installation
- A graphical depiction of the well
- Casing material type, diameter, joint type, and screen slot size
- Filter pack material, calculated and actual volume

- Annular seal material, calculated and actual volume
- Annular grout seal material, calculated and actual volume
- Placement method for filter pack, seal and grout (tremie, pumped, gravity)
- Borehole diameter
- Depth to bottom of borehole
- Depth to bottom of casing
- Depth to bottom and top of screen interval
- Depth to bottom and top of solid riser
- Depth to bottom and top of filter pack
- Depth to bottom and top of annular bentonite seal
- Depth to bottom and top of annular grout
- Depth to bottom of surface seal
- Depth to the water table
- Surface seal and well apron design
- Protective box/casing and cap designs
- Ground surface elevation
- Top of casing elevation

A sample Monitoring Well Installation Log is presented in Section 6, Figure 6-7.

18.6.3 MONITORING WELL ABANDONMENT FORM

A groundwater monitoring well that is no longer needed, sustains damage, or is determined to be improperly installed, must be properly abandoned so the well itself will not become a pathway for contamination. See Subsection 6.2.5 for additional information regarding well abandonment.

The monitoring well abandonment form (i.e., Abandonment of Monitoring Well Summary Report) must include the following:

- Location
- Owner Information
- Well Construction Information, including installation date, depth to groundwater, casing and screening material, etc.
- General Abandonment Information, including drilling firm and consulting firm contact information, etc.
- Well Abandonment Information, including date and reason for abandonment, sealing material, method for placement of sealing material, etc.

A sample Monitoring Well Abandonment Summary Report Form is provided below.

	Abandonment of Monitoring Well Summary Report **_____ (Monitoring Well ID)**
Submit form within 30 days of well abandonment or within 90 days if included in a site closure, monitoring, or investigation report. In addition, submit copies of the original boring log and well construction diagram for the monitoring well, a site map showing the location of the abandoned monitoring well, and the disposal documentation for wastes generated during the abandonment process. Submit all documentation to: Hawai'i Department of Health, Hazard Evaluation and Emergency Response Office, Attention: SDAR, 919 Ala Moana Blvd, Rm. 206, Honolulu Hawai'i 96814.	
Location Information	**Owner Information**
Facility Name:	Well Owner:
Facility Address:	Contact Person:
	Mailing Address:
Latitude:	
Longitude:	Phone Number: Fax Number:

TMK:	Land Owner:
Location Description:	Contact Person:
	Mailing Address:
Monitoring well location map attached: Y / N	Phone Number: Fax Number:
Well Construction Information	
Date of Installation:	Casing Material: Casing Diameter:
Drilling Company:	Casing Length: Casing Depth:
Total Depth:	Screen Material: Slot Size:
Depth to Water:	Screen Length: Screen Depth:
Was well set in an aquifer that is current or potential drinking water source? Y / N:	Annular Material: Depth:
Boring log / well construction diagram attached: Y / N	Annular Material: Depth:
General Abandonment Information	
Drilling Firm:	Consulting Firm:
Contact Person:	Contact Person:
Mailing Address:	Mailing Address:
Phone Number: Fax Number:	Phone Number: Fax Number:
Well Abandonment Information	
Date of Abandonment:	Sealing Material Depth:
Reason for Abandonment:	Volume/Weight/Bags Mixing Ratio:
Casing/Screen Removed: Y / N	Sealing Material: Depth:
If Yes, was annular material removed? Y / N	Volume/Weight/Bags Mixing Ratio:
If No, was casing cut off below surface? Y / N	Method of Sealing Material Placement:
Comments:	
Driller's Signature:	Date:
Consultant's Signature:	Date:

18.6.4 VOLUNTARY RESPONSE PROGRAM APPLICATION

An application is necessary to determine eligibility to participate in the Voluntary Response Program (VRP). A list of necessary application elements (no specific application form is required) can be found at the HEER Office web page (see How Can I Apply to Participate?). In addition, this website includes a "checklist" that can be downloaded that lists specific application elements that the HEER Office evaluates on new VRP applications.

18.6.5 ENVIRONMENTAL COVENANT

An environmental covenant is a legal device that restricts activities on sites where contaminated media is left on-site. The Uniform Environmental Covenants Act (UECA), HRS, 508C, was enacted by the Hawai'i State legislature in July 2006. The

UECA provides a regulatory mechanism for recording engineering or institutional controls on a property, and requires the creation of a publically accessible web-based registry to identify properties utilizing this mechanism. HDOH, at its discretion, may require UECA covenants. In general, these covenants are required for risk-based closures with extensive or highly persistent contamination. They may also be required where there are foreseeable future use changes that could expose sensitive populations.

Information in a UECA covenant includes the following:

- Site identification information
- Grantor and Owner information
- Site background
- Intent of environmental covenant
- Affected property
- Activity and use restrictions
- Obligations of the Grantor and all future owners and users of the Property
- Duration
- Effective date
- Representations and warranties
- Information regarding termination or modification of covenant
- Enforcement of covenant
- Rights of access to Property
- Recording and registry
- Execution

A sample environmental covenant has been developed by the HEER Office (below), however alternate formats may be acceptable on a case-by-case basis.

SAMPLE
STATE OF HAWAIʻI
ENVIRONMENTAL COVENANT

Return by Mail ( ) Pickup ( ) To:

Document contains ___ pages

Tax Map Key: Portions of [

Environmental Covenant # [ ]
[Covenant Name]

SITE _____

This Environmental Covenant (**Covenant"**) is made by and between _____(" **Grantor"**),_____(**"Owner"**), and the State of Hawaiʻi Department of Health (" **Holder"**). Grantor, Owner, and Holder are collectively the " **Parties"**to this Covenant.

1. Background.

1.1 On July 6, 2006, the Hawai‘i Uniform Environmental Covenants Act, Hawai‘i Revised Statutes Chapter 508C (**"UECA"**) became law in the State of Hawai‘i. The legislature found that there is a growing reliance on the risk-based cleanup of contaminated property when removal of contamination to unrestricted levels is infeasible, impracticable, or unnecessary. In such cases, certain land use restrictions, environmental monitoring requirements, and engineering controls known as Activity and Use Restrictions are required to protect the public and the environment from contamination that remains on the Property. The Hawai‘i Department of Health, Hazard Evaluation and Emergency Response (HEER) Office uses environmental covenants to ensure compliance with the terms and conditions of risk based cleanup projects under Hawai‘i Revised Statutes Chapter 128D.

1.2_____. (**"Owner"**) is the owner of real property consisting of: (a) a **[ ]** acre portion of TMK: _____located at _____more particularly described in Exhibit A attached hereto and incorporated herein (**the "Property"**).

1.3 Grantor and___ (Owner's predecessor-in-interest) entered into that certain **[ ]** filed in the Office of the Assistant Registrar of the Land Court of the State of Hawai‘i as Document No. **[ ]** and noted on Transfer Certificate of Title Nos., **[ ]** which affect the Property.

1.4 Pursuant to said Reciprocal Easement Agreement, Grantor undertook an environmental response project on the Property pursuant to Hawai‘i Revised Statutes Chapter 128D and the Voluntary Response Program Agreement between Grantor and Holder dated June 2001 (the " **Environmental Response Project** ").

1.5 The Environmental Response Project is described in the administrative record identified as **[FACILITY/SITE NAME, LOCATION, DATE]** which record is located at the Office of Hazard Evaluation and Emergency Response, State of Hawai‘i Department of Health ("HDOH").

1.6 In consideration of the Environmental Response Project, the Holder has issued a Letter of Completion under Hawai‘i Revised Statutes Section 128D-39 dated_____,**[YEAR]** ; attached hereto as Exhibit B, ("Letter of Completion") subject however, to the execution and delivery of an environmental covenant made in accordance with and pursuant to UECA.

2. Intent . The parties executing this Covenant intend it to be an "environmental covenant" created and executed pursuant to UECA. The State of Hawai‘i Department of Health is deemed to be a "holder" in accordance with the UECA. The property shall be burdened by the Activity and Use Restrictions described in paragraph 4 to the benefit of the Holder, and, in accordance with the Covenant, and use of this Property shall be subject to the Environmental Response Project or this Covenant. This Agreement is to be governed by and construed in accordance with Hawai‘i law, and courts sitting in the State of Hawai‘i, including the United States District Court for the District of Hawai‘i to the extent it has jurisdiction.

3. Affected Property . This Covenant applies to the Property.

4. Activity and Use Restrictions. The Grantor and Owner shall comply with the following Activity and Use Restriction:

4.1. [List applicable activity and use restrictions here]

5. **Obligations of the Grantor and all future owners and users of the Property .** The Grantor and Owner for themselves and on behalf of their heirs, successors, assigns and all persons acquiring or owning any right, title, or interest in the Property and their respective heirs, successors, assigns, lessees, licensees, executors, administrators, devisees and any users of the Property, now agree to comply with the Activity and Use Restrictions and incorporate either in full or by reference the restrictions of this Covenant in any deed, lease, license or other instruments granting a right to use the Property and any mortgage.

6. Duration. This Covenant shall be perpetual unless amended, terminated or modified pursuant to and in compliance with UECA.

7. Effective Date . This Covenant shall be effective at such time as all of Grantor, Owner, and the Holder have executed this Covenant.

8. Representations and Warranties. Each person signing this Covenant warrants that, to the best of his or her knowledge, he or she is the appropriate individual to represent his or her own interest or the interest of the entity on whose behalf the person is signing this Covenant in matters related to this Covenant. Each person signing also warrants that he or she possesses the proper authority to enter into this Covenant in the capacity stated in the applicable signature block. Additionally, the Grantor and Owner warrant that to their knowledge, there are no recorded or unrecorded interests in the Property that have not been disclosed.

9. Termination or Modification of this Covenant. This Covenant may be amended or modified or terminated only by a recorded document signed by the Grantor, Owner, and Holder and only in accordance with applicable provisions of UECA.

10. Enforcement. This Covenant is subject to the enforcement provisions of UECA.

11. Rights of Access to the Property. The Holder shall have the right to enter the Property at reasonable times without prior notice for the purpose of determining compliance with the terms of this Covenant. Nothing in this Covenant shall impair any other authority the Holder may otherwise have to enter and inspect the Property. No confidential information secured by an official, agent, or employee of the Holder within the scope and course of his or her inspection shall be disclosed by them except as it relates directly to Property contamination and then, only in connection with their official duties and employment.

12. Recording and Registry. This Covenant and any modification, amendment or termination instrument shall be recorded with the State of Hawai‘i Bureau of Conveyances or Office of the Assistant Registrar of the Land Court of the State of Hawai‘i or both as applicable. The Grantor shall provide a copy of the final recorded Covenant, any amendments, any termination documentation, and documentation of any other matters related to this Covenant to the Holder. The validity of this Covenant is not affected by failure to provide a copy of the Covenant. This Covenant is, however, subject to the laws of the State of Hawai‘i governing recording and priority of interests in real property. A copy of this Covenant and any modification, amendment or termination instrument shall be available at the Holder's Registry of Environmental Covenants.

19. Execution. This Covenant may be executed in any number of counterparts, each of which shall be deemed an original, but all of which together shall constitute one and the same instrument.

The Parties hereby execute this covenant as of this _____day of_____,**[YEAR]** .

By _____

Name: _____

Title: _____

Grantor

State of Hawai'i Department of Health

By _____

Name: _____

Title: _____

Holder

By _____

Name: _____

Title: _____

By _____

Name: _____

Title: _____

Owner

NOTARY SEAL FOLLOWS

EXHIBIT A

Insert Detailed Legal Description of Property where Covenant applies

18.6.6 REMOVAL OR REMEDIAL ACTION FACT SHEETS

To support public participation, a Fact Sheet may be necessary to summarize site information, the response action process, and the proposed response action. A Fact Sheet also presents information regarding the opportunity to review the record and submit public comment on the proposed response action within a specified comment period (at least 30 days). See Subsection 2.4.6 for additional information regarding public participation. The following outline is suggested for a Removal or Remedial Action Fact Sheet. Sample Fact Sheets are also available on the HEER Office Web page.

Example Outline for a Removal or Remedial Action Fact Sheet	
1.0	Introduction
2.0	Site and Vicinity Description
3.0	Site Characterization
4.0	Environmental Hazards
5.0	Removal or Remedial Action Development
6.0	Proposed Removal or Remedial Action

7.0	Next Steps (timetable)
8.0	Community Involvement
9.0	Information Repository
10.0	Agency Contact

SECTION 18 REFERENCES

Citation references for this TGM Subsection denoted with an “a”, “b”, “c”, etc… after the year of publication may not appear in sequence as these refer to the order placed in the Master References List for the entire TGM.

HDOH, 2016. Hawai’i Department of Health, Office of Hazard Evaluation and Emergency Response. Screening for Environmental Concerns at Sites with Contaminated Soil and Groundwater. Website URL: http://eha-web.doh.hawaii.gov/eha-cma/Leaders/HEER/EALs. Summer 2016 (and updates).

SECTION 19
SITE CLOSURES

Interim Final - April 2014

State of Hawai'i
Department of Health
Office of Hazard Evaluation and Emergency Response
919 Ala Moana Boulevard, Room 206
Honolulu, Hawai'i 96814

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SECTION 19 ACRONYMS AND ABBREVIATIONS

CERCLA	Comprehensive Environmental Response, Compensation & Liability Act (also known as the Federal Superfund Law)
DoD	United States Department of Defense
EAL	Environmental Action Level
HAR	Hawai'i Administrative Rules
HDOH	Hawai'i Department of Health
HDPE	High density polyethylene
HEER Office	Hazard Evaluation and Emergency Response Office
HRS	Hawai'i Revised Statutes
LOC	Letter of Completion
LUCIP	Land Use Controls Implementation Plan
LUCs	Land Use Controls
NFA	No Further Action
RCRA	Resource Conservation and Recovery Act
SCP	Hawai'i State Contingency Plan
UECA	Uniform Environmental Covenants Act (HRS, Chapter 508C)
USEPA	United States Environmental Protection Agency
VRP	HEER Office Voluntary Response Program

19.0 SITE CLOSURES

Under the Hawai‘i State Contingency Plan (SCP) [i.e., Hawai‘i Administrative Rules (HAR), Title 11, Chapter 451 (HAR Chapter 11-451)] an unrestricted site closure is granted as a "No Further Action", once the Hazard Evaluation and Emergency Response Office (HEER Office) of the State of Hawai‘i Department of Health (HDOH) decides that no further action is necessary for a specific release, suspected release, or upon the successful completion of a response action (either removal or remedial action). If contaminated media remains on site that necessitates land use restrictions, a "No Further Action with Restrictions" is granted. The HEER Office also may issue "No Action" determinations if sampling data indicate no evidence of a release, or the documented release is judged by the HEER Office as not warranting cleanup or restriction.

An unrestricted site closure approved under the Voluntary Response Program (VRP) is granted as a "Letter of Completion" (LOC). If contaminated media remains on site necessitating land use restrictions, a "Letter of Completion with Restrictions" is granted.

Note that a restriction is distinct from a *condition*. All LOCs have conditions, but they may not be "restrictions" (for example, a site with a LOC allowing unrestricted use will have a condition that requires the LOC be noted on the deed and sent to the County agency that issues building permits).

Thus, the available types of site closures include:

- No Action
- No Further Action
- No Further Action with Restrictions
- Letter of Completion (under VRP)
- Letter of Completion with Restrictions (under VRP)

The HEER Office may also issue a "No Further Active Remediation Letter;" however, this is not a type of site closure. No Further Active Remediation status is intended for contaminated sites where potentially significant environmental concerns remain, but active remediation (e.g., excavation, soil vapor extraction, etc.) is no longer practical. This status may be helpful to site owners, financial institutions, and potential purchasers to establish the "environmental liability" of a site with remaining contamination prior to formal site closure.

Within the various types of site closures a number of possible outcomes exist, ranging from clean closures with no land use restrictions to containment-based remedies addressing contaminated media left on site with monitoring requirements and stringent land use restrictions.

The type of site closure being sought must be selected prior to or during the response action selection stage. To ensure the restrictions and limitations that will result from the selected type of closure are feasible and/or acceptable to stakeholders, use systematic planning processes (see Section 3) to guide the site closure process, keeping long-term use of the site in mind.

19.1 SITE CLOSURE SCOPING

Site closure scoping is an important step that includes evaluating future land uses and determining site closure implications of the selected remedy. Site closure scoping can be part of the removal action work plan/removal action alternatives analysis (see Section 14), or the remedial alternatives analysis/response action memorandum (see Section 16).

19.1.1 EVALUATION OF FUTURE LAND USE

Planning or knowledge regarding future land use is crucial to evaluating site closure decisions. Evaluating future land use typically involves reviewing available records, determining current land use, inspecting the site and surrounding area, and discussing future uses with local government officials, current and future property owners, and the community. Further information about evaluating future land use is available from the United States Environmental Protection Agency (USEPA, 2001d).

19.1.2 REMEDY SELECTION AND SITE CLOSURE IMPLICATIONS

During the remedial alternatives analysis (for remedial response actions), remedies undergo a comparative analysis that focuses on the performance of each remedial alternative against three criteria: (1) Effectiveness, (2) Implementability, and (3) Cost (see Section 16). In addition, all potential remedial alternatives, except the required No Action alternative, must meet the threshold criterion of being protective of human health and the environment.

Considering the post-closure implications of each remedial option is essential to properly evaluating long-term effectiveness, implementability, and cost. Several issues must be considered to attain a site closure that is acceptable for the planned future site use and to the stakeholders involved.

Issues to consider during remedy selection and evaluation of post-closure implications include:

- Will the remedy restrict future land (or groundwater) use at the site?
- Will stakeholders concur with the land use restrictions?
- Will current and future property owners commit to implementing and maintaining the land use restrictions?
- What practices and safeguards will need to be implemented and maintained to ensure safe use of the property?
- Will the remedy compromise the architectural integrity of on-site structures?
- How will land use restrictions affect the property value? For example, will financial institutions be wary of loaning funds to prospective purchasers in future real estate transactions if contaminated soil and/or groundwater remains on site?
- What will be the long-term costs of institutional and engineering controls associated with managing contamination on site?
- What long-term effectiveness can be expected of the institutional and engineering controls? For example, will institutional controls (e.g., an environmental covenant) and engineering controls (e.g., a visible marker or boundary layer) be effective in preventing future site occupants from digging into contaminated soil or groundwater?
- What potential legal liabilities may be caused by managing contaminated soil or groundwater on site? Are landowners and other stakeholders willing to accept those liabilities?
- Will an exemption of liability for prospective purchasers granted for voluntary response actions (if the cleanup is completed under the VRP) increase the value of the property? Will an increase in value outweigh any additional costs associated with participating in the VRP?

Containment Remedies

Remedies that leave hazardous substances remaining on site as a permanent solution are known as containment remedies, because the hazardous substances are not removed or destroyed, but only contained. Containment remedies prevent hazardous substances from impacting public health or the environment only as long as they are maintained. Use of containment remedies will necessitate land use restrictions at the site.

If a containment remedy is being evaluated, the potential for it to fail over the long-term should be closely assessed. Several examples of potential remedy failures include:

- Failing to continue operation and maintenance of an active engineering control, such as an active vapor mitigation system.
- Failing to implement, maintain, and report on required monitoring.
- Failing to notify construction workers, tenants, etc. of use restrictions.
- Failing to prevent forbidden land uses, such as allowing residential use of land or soil cleaned up only to commercial/industrial Environmental Action Levels (EALs).
- Actively breaching a passive engineering control, such as digging through a protective soil layer, barrier, or visible marker into contaminated soil.
- Failing to incorporate protective systems designed to prevent exposure, such as constructing a new building on the site without the necessary vapor mitigation measures.
- Sale of the property without appropriate disclosures

Containment can be the least expensive remedy in terms of initial capital costs. However, when all of the associated costs are included (such as institutional control development, preparation and implementation of an Environmental Hazard Management Plan (EHMP), long-term monitoring costs, long-term operation of engineering controls, future incremental costs of managing contaminated materials, depreciation of land value, and maintenance costs), containment remedies typically have comparable costs to treatment remedies or removal actions. These long-term costs should be included in the Removal or Remedial Alternatives Analyses. The potential consequences of containment remedy selection include:

- Continued reporting
- Continued cost for monitoring and operation and maintenance
- May be ordered to take action under Hawai‘i Revised Statutes (HRS), Chapter 128D (HRS 128D) (the state government)
- May be ordered to take action under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (the federal government)
- Vulnerable to third-party torts if people claim harm
- Continued listing on state cleanup site lists
- Continued visibility to the community as a cleanup site with existing contamination
- Site flagged by Phase I Environmental Site Assessments
- Site listed as a liability on corporate balance sheets under Sarbanes-Oxley reporting
- Site property value decreased
- Less attractive to developers due to environmental protections needed for construction
- Engineering controls make future construction more difficult (e.g., concrete caps)
- Residual contamination may subject future construction workers to exposure hazards

In summary, remedial options must be thoroughly evaluated to determine the post-closure implications of each. Selection of a site closure option acceptable to the stakeholders involved will expedite the process and avoid costly and unnecessary delays.

19.2 UNRESTRICTED CLOSURES

If contaminated media is removed or treated to concentrations below the Tier 1 EALs or alternate action levels approved by the HEER Office, the site may be closed with unrestricted use (i.e., a No Action, a No Further Action, or a Letter of Completion).

19.2.1 NO ACTION

The HEER Office may, at its discretion, elect to review and provide determinations on sites where a property owner or prospective purchaser suspected a release that was disconfirmed by appropriate sampling data. In such cases, a No Action letter may be granted by the HEER Office. Examples include Phase II sampling to investigate an identified "recognized environmental condition" and appropriate screening of former agricultural fields for pesticide contamination. In cases where representative sampling indicates that contaminant levels are present above natural background levels but below applicable EALs, the HEER Office may elect to issue a No Further Action letter rather than a No Action letter.

19.2.2 NO FURTHER ACTION

An unrestricted site closure under the Hawai‘i SCP (HAR Chapter 11-451) is granted as a No Further Action (NFA). Once the HEER Office decides that no further action is necessary for a specific release, suspected release, or upon the successful completion of a response action (either removal or remedial action), a NFA letter will be sent to the responsible party(s) and the property owner. If the response action has resulted in either (1) removal of impacted media or (2) treatment of impacted media to concentrations below EALs for a residential land use scenario and any ecological concerns, the site closure is referred to as a "clean closure" or an "unrestricted closure." No land use restrictions are necessary and the site can be used for all potential future land uses. No further reporting requirements are necessary to HDOH. If new information indicates that contamination is present at levels of concern, the HEER Office may re-open the site and require additional assessment and cleanup work (as necessary) to be performed.

19.2.3 LETTER OF COMPLETION

An unrestricted site closure under the VRP (HRS 128D, Part II) is granted as a LOC. The purpose of the VRP is to minimize environmental liability and assure timely HEER Office oversight in a way that will encourage prospective developers, lenders, and purchasers to voluntarily clean up properties. The VRP facilitates the cleanup process and, in certain situations, provides relief from the strict liability provisions of the Federal CERCLA and Hawai‘i Environmental Response Laws. The greatest benefit to a site closure under the VRP is exemption of future liability for prospective purchasers and developers for the specific hazardous substances, pollutants, contaminants, media, and land area addressed in the voluntary response action, as specified in the LOC. An existing landowner does not receive relief from the strict liability provisions by undertaking a VRP cleanup; these protections extend only to prospective purchasers, future owners, operators, and tenants.

Following receipt of an unrestricted LOC, the site can be used for all potential future land uses. No further reporting to the HDOH is required. The LOC is noted on the property deed and is sent to the county agency that issues building permits. The LOC "runs with the land" and applies to all future owners of the property.

HDOH may only order a prospective purchaser who receives a LOC to re-open the site if future information indicates that contamination is present at levels of concern (above Tier 1 EALs) for contaminants and media *not listed in the LOC and VRP Agreement*, or if a new release of contaminants and media listed in the LOC and VRP agreement occurs after the LOC is signed.

19.3 CLOSURES WITH USE RESTRICTIONS

If contaminated media is left on site necessitating institutional or engineering controls to prevent potential future exposures, the site is closed with restricted use (i.e., a No Further Action with Restrictions or a Letter of Completion with Restrictions). The potential environmental hazards posed by leaving contaminated media on site must be assessed and documented in an Environmental Hazard Evaluation (EHE) (see Subsection 19.5). The mechanism to manage the environmental hazards posed by contaminated media left on site is called an EHMP (see Subsection 19.6).

A typical example of a restricted use closure is a petroleum-release site where petroleum-impacted soil cannot be fully excavated from the site (e.g., petroleum-impacted soil cannot be removed without jeopardizing structural integrity of a building). In the example, soil gas samples would need to be collected from beneath the slab, and resulting data may indicate a potential environmental hazard from subsurface vapor intrusion into indoor air spaces. The site may be closed with restricted use, but engineering controls (e.g., an active vapor mitigation system); institutional controls (i.e., an environmental covenant to restrict land use) may be necessary to prevent future exposures. An EHE would be required to assess potential hazards posed by the remaining petroleum contaminated soil. An EHMP would be required to document and manage the residual contaminated soil, engineering controls, and institutional controls. The EHMP typically would be attached to the closure document and, if applicable, the environmental covenant (see Subsection 19.8.1).

Another example of a restricted use closure is a case where only a land use restriction is required, with no engineering controls. This may be commonly applied in situations where representative contaminant levels are above the soil or groundwater "residential use" EALs, but below applicable "commercial/industrial use" EALs at a site zoned for commercial or industrial use. In this case, the site closure restriction would allow only a commercial/industrial use of the property, until such time as additional site investigation or site remediation demonstrates contaminant levels are below EALs for residential or unrestricted use. As noted in the example above, an EHPM typically would be attached to the closure document and, if applicable, the environmental covenant, to help document and manage the institutional controls at the site (e.g., the land use restrictions).

19.3.1 NO FURTHER ACTION WITH RESTRICTIONS

A restricted use closure under the Hawai‘i SCP (HAR Chapter 11-451) is granted as a NFA with Restrictions. If the removal or remedial action has resulted in leaving contaminated media on site, the site closure is referred to as a "restricted use closure." An EHE must be prepared to document and assess environmental hazards posed by the remaining contaminated media. Institutional and/or engineering controls are necessary to prevent future exposures; therefore, future land uses are restricted. An EHMP is necessary to manage the residual contamination, engineering controls, and/or institutional controls.

19.3.2 LETTER OF COMPLETION WITH RESTRICTIONS

A restricted use closure under the VRP (HRS 128D, Part II) is granted as a LOC with Restrictions. An EHE must be prepared to document and assess environmental hazards posed by the remaining contaminated media. Institutional and/or engineering controls are necessary to prevent future exposures; therefore, future land uses are restricted. An EHMP is necessary to manage the residual contamination, engineering controls, and/or institutional controls. Long-term (periodic) monitoring and reporting may be required to the HEER Office.

The LOC with Restrictions is noted on the property deed and is sent to the county agency that issues building permits. The restrictions on the LOC "run with the land" and apply to all future owners of the property.

HDOH may order a prospective purchaser receiving a LOC to re-open the site only if institutional or engineering controls that are part of the LOC are not being maintained, or contaminant concentrations are discovered at levels of concern (above Tier 1 EALs) for contaminants and media not listed in the LOC and VRP Agreement, or if a new release of contaminants and media listed in the LOC and VRP agreement occurs after the LOC is signed. HDOH cannot require prospective purchasers to perform additional work for contaminants and media covered in the VRP Agreement, as they have exemption from liability under HRS 128D, Part II.

19.4 NO FURTHER ACTIVE REMEDIATION LETTER

A No Further Active Remediation Letter is available for contaminated sites where potentially significant, environmental concerns remain but active remediation (e.g., excavation, soil vapor extraction, etc.) is no longer practical. This type of letter is often used when further excavation can jeopardize the structural integrity of buildings. If needed, a letter may be requested from the HEER Office indicating that No Further Active Remediation is required at such a site.

A No Further Active Remediation status is not considered a type of site closure. The case will remain "open" in the HEER Office site records. The letter is intended to clarify that all major cleanup actions have been completed at the site, but significant contamination remains and the site has moved into a status of long-term monitoring and management. This status may be helpful to site owners, financial institutions, and potential purchasers to establish the "environmental liability" of a site with remaining contamination prior to formal site closure. The No Further Active Remediation letter may also contain conditions of further work when (or if) the site is redeveloped. The need for on-going groundwater monitoring or soil gas monitoring may indicate a No Further Active Remediation Letter is not yet appropriate.

An EHE must be prepared to document and assess the remaining contamination. An EHMP must be prepared to manage the contamination, engineering controls, and/or institutional controls. The EHMP must include a description of conditions that must be met before the site can be formally closed with status of either No Further Action or a No Further Action with Restrictions.

Additional information regarding No Further Active Remediation letters is presented in HDOH guidance on Long-Term Management of Petroleum-Contaminated Soils and Groundwater (HDOH, 2007c; included as Appendix 19-A). This document outlines procedures for long-term management of residual petroleum contamination where a full cleanup is not practicable. The guidance document includes discussion and figures providing decision trees to address long-term oversight of residual petroleum contamination.

19.5 ENVIRONMENTAL HAZARD EVALUATION (EHE)

Environmental Hazard Evaluation (EHE) is the link between site investigation activities and response actions. In addition, if contaminated media is left on site under a restricted use closure, the EHE is necessary to assess and document potential environmental hazards posed by the contamination. Results of the EHE are crucial in selecting the appropriate measures, such as engineering and/or institutional Controls, to prevent future exposures. Section 13 presents a detailed discussion on the preparation of an EHE.

19.6 ENVIRONMENTAL HAZARD MANAGEMENT PLAN (EHMP)

If contaminated media is left on site under a restricted use closure, an *Environmental Hazard Management Plan (EHMP)* also must be prepared to manage environmental hazards identified in the EHE over the long-term. An EHMP presents all necessary information in a single, stand-alone document that identifies the nature and extent of remaining contamination, potential environmental concerns posed by the contamination, and appropriate measures to ensure that these concerns are adequately addressed. The EHMP is typically attached to the closure document, and if applicable, to the environmental covenant restricting site use.

In the EHMP, long-term environmental hazards must be clearly assessed and documented to ensure that in-place management of the remaining impacted media is viable and carried out properly. A discussion of the need for and management of institutional and/or engineering controls must be included. This could include restrictions on future use of the property, installation of vapor mitigation systems under buildings, capping of contaminated soil to prevent exposure or leaching, or long-term monitoring of groundwater, etc.

The EHMP must include the following at a minimum (also see Subsection 18.5.16):

- Brief summary of the site background and history of contaminant releases
- Identification of the Chemicals of Potential Concern
- Clear depiction of the extent and magnitude of remaining contamination in soil, groundwater and/or soil gas, presented on easily readable, to-scale maps with a north arrow
- Identification and discussion of all potential environmental hazards
- Requirements for long-term monitoring of contaminants in soil, groundwater, and/or soil gas
- Discussion of engineering and/or institutional controls needed to address identified environmental hazards to eliminate exposure pathways
- Guidance on proper handling, reuse and disposal of contaminated soil and/or groundwater that is encountered during future site activities
- Specific description of construction worker protections and notifications required
- Use restrictions to protect occupants, residents, guests, etc.
- Measures for repair or replacement of engineering controls that are disturbed or breached during future site activities
- Any other information required to adequately mitigate and manage remaining environmental concerns at the site

A brief Fact Sheet that summarizes key elements of the EHMP in simple, non-technical terms is required for large, complex sites where significant public review is anticipated.

19.7 INSTITUTIONAL AND ENGINEERING CONTROLS

Appropriate measures must be used to mitigate the environmental hazards posed by contaminated media left on site in restricted use closures. These measures are defined as institutional controls and engineering controls. *Institutional controls* are methods intended to prevent exposure to contaminated media by legal or procedural means (for example, environmental covenants), as opposed to *engineering controls*, which are methods of exposure prevention by physical means (for example, an active vapor mitigation system to prevent subsurface vapor intrusion into indoor air spaces).

Institutional controls alone are generally not sufficient to mitigate environmental hazards, with the exception of commercial or industrial zoned sites where representative sampling has demonstrated contaminant levels are above residential or unrestricted use EALs, but below applicable commercial/industrial use EALs. Engineering controls require institutional controls for their long-term management. Consequently, in most cases, institutional and engineering controls must be used together to adequately manage remaining environmental hazards at restricted use closure sites.

19.7.1 INSTITUTIONAL CONTROLS

Institutional controls are legal or administrative measures that prevent exposure by influencing human behavior through laws, rules, permits, requirements, contracts, warnings, and advisories. Institutional controls help to minimize the potential for human exposure to contaminated media by controlling activities that may affect exposure. Institutional controls also restrict land use and on-site activity that might interfere with the containment of contaminated media left on site. Examples of institutional control measures include:

- Prohibition on excavation of soil
- Prohibition on use of groundwater
- Prohibition on residential or other sensitive land use

HDOH's primary legal instrument for establishing institutional and/or engineering controls at a site is the site closure document. HDOH may, at its discretion, require an *environmental covenant* to provide additional long-term protection for sites with significant and persistent contamination (see Subsection 19.8.1).

19.7.2 ENGINEERING CONTROLS

Engineering controls are tangible measures that prevent exposure by physically preventing humans (or wildlife) from coming into contact with contaminated media left on site at restricted use closure sites. Institutional controls are required to ensure that engineering controls are properly managed. Examples of engineering controls include:

Soil Contamination

- Capping systems – contaminated soil is covered with a cap to reduce surface-water infiltration and leaching, control gas and odor emissions, improve aesthetics, provide a stable surface over the contaminated soil, and prevent human exposure from direct contact. Caps can range from a simple native soil cover to single layer caps (e.g., asphalt/concrete and soil/bentonite/clay) to multi-layer cover systems (e.g., Resource Conservation and Recovery Act [RCRA] caps) to buildings or structures.

  Consideration must be given to the type, magnitude, and extent of contaminated soil when selecting the appropriate cap. A cap for soils contaminated with highly toxic and persistent contaminants should be highly durable and long lasting, such as a multi-layer cover system.

  Soil caps may be appropriate at certain sites where future development/construction is highly unlikely and institutional controls are used to restrict such land use. The soil cap thickness is determined considering site-specific factors but must be adequate to reduce or eliminate the environmental hazard(s). A visible marker, such as orange construction fencing, is generally used to mark the top of the contaminated soil layer. Soil caps are typically used for non-volatile contaminants where leaching is not a concern.

  If a structure is used as a cap, the permanence of the proposed building must be considered. For example, a high-rise

structure designed and built for the long-term would be an appropriate "building cap" for significantly contaminated soils. The shorter life span of less durable structures must be taken into account when assessing long-term effectiveness of the cap.

- On-site Encapsulation/Repository – for potentially mobile contaminants, soil is consolidated and encapsulated into a lined subsurface on-site cell or vault. Such systems are designed to eliminate or reduce surface-water infiltration and leaching, control gas and odor emissions, improve aesthetics, and prevent human and ecological exposure from direct contact. On-site repositories range from High Density Polyethylene (HDPE) liner encapsulation to subsurface concrete vaults. For non-mobile contaminants, unlined borrow pits may be adequate for on-site management.

Groundwater Contamination

- Hydraulic Containment – measures are used to control the hydraulic gradient to minimize the spread of a groundwater plume. One example is the use of pumping wells to actively prevent the plume from spreading and reaching drinking water wells, surface water, or uncontaminated aquifers, etc. Another example is a slurry wall in which low permeability materials, such as grout, are injected into the subsurface to contain a groundwater plume. Institutional controls are necessary to restrict groundwater use.
- Alternative Water Source – an alternative water source can be provided to an area where groundwater is contaminated and not suitable for ingestion. Institutional controls are necessary to restrict groundwater use.

Sediment Contamination

- Capping systems - contaminated sediments are covered with a cap to eliminate erosion and dissolution into the water body, improve aesthetics, provide a stable surface over the contaminated sediment, and prevent human and ecological exposure from direct contact. An example is lining a streambed containing contaminated sediments with an impermeable material, such as HDPE liner, and then stabilizing the liner with highly durable materials, such as riprap and concrete.
- Dredging - An ongoing dredging program can be used as an engineering control of contaminated sediments, as well.

Soil Vapor Contamination

- Vapor barriers – impermeable materials are placed beneath a proposed building site to prevent subsurface vapor intrusion into indoor air spaces. Active vapor removal systems should be considered for sites with significant soil gas issues in which a gas collection system is placed beneath the barrier and connected to a suction fan, which may be vented above the roof of the building, or connected to a vapor treatment system such as a thermal oxidizer or granular activated carbon.

19.8 LEGAL INSTRUMENTS FOR RESTRICTED USE CLOSURES

The primary legal instrument for establishing engineering and/or institutional controls at a site is the HDOH closure determination. Environmental covenants and land use restrictions listed in a LOC with Restrictions and noted on the property deed for sites in the VRP are another legal instrument for establishing institutional controls. At Department of Defense (DoD) Installation Restoration sites, Land Use Controls (LUCs) are implemented through a Land Use Controls Implementation Plan (LUCIP).

19.8.1 UNIFORM ENVIRONMENTAL COVENANTS ACT (UECA) ENVIRONMENTAL COVENANT

The Uniform Environmental Covenants Act (UECA) is a Uniform Law that was approved by the Uniform Law Commission (also known as National Conference of Commissioners on Uniform State Laws) in 2003. The State of Hawai‘i adopted the UECA as Senate Bill 1167 in 2006 [Hawai‘i Revised Statutes (HRS), Chapter 508C (HRS 508C)]. The act is codified as HRS Chapter 508C. UECA establishes requirements for a new valid real estate document called an *environmental covenant* to control the future use of sites with contaminated media left on site when real estate is transferred from one person to another.

An environmental covenant is a legal device that restricts activities for sites where contaminated media is left on site. In such cases, institutional controls are needed to restrict land use to supplement the remedy and ensure safe land use. A UECA environmental covenant is based upon traditional property law principles and must be recorded in the local land records, thereby binding successive owners of the property. The State of Hawai‘i has clear rights to enforce the land use restrictions under UECA covenants, ensuring with greater certainty the protection of human health and the environment throughout the life of the land use restriction and through real estate transactions or legal actions.

HDOH, at its discretion, may require UECA covenants. In general, these covenants are required for risk-based closures with extensive or highly persistent contamination. They may also be required where there are foreseeable future use changes that could expose sensitive populations.

An example UECA environmental covenant is provided in Subsection 18.6.5.

19.8.2 VOLUNTARY RESPONSE PROGRAM (VRP) LETTER OF COMPLETION (LOC)

Site closure under the VRP (HRS 128D, Part II) is granted as a LOC. Under HRS 128D, Part II, a LOC is noted on the property deed and is sent to the county agency that issues building permits. The benefits and restrictions of the LOC "run with the land" and apply to all future owners of the property. Also see Subsections 19.2.3 and 19.3.2.

19.8.3 DOD LAND USE CONTROLS IMPLEMENTATION PLANS (LUCIPS)

Under DoD guidance (DoD, 2001), LUCs may be placed on DoD real property because of environmental restoration concerns. The Installation must then develop an implementation plan for the LUCs. A LUCIP is a DoD internal management tool that explains how LUCs will be established and identifies the individual(s) responsible for their maintenance and management. The LUCIP is incorporated in the DoD Installation Master Plan (DoD, 2001). DoD guidance (DoD, 2001) mandates that if a property subject to LUCs is transferred from federal ownership, the LUCs must be incorporated into the property transfer documents. Specifically, necessary language for the LUCs must be drafted, such as deed restrictions or restrictive covenants (DoD, 2001).

During the time the federal government owns a property subject to LUCs, the HDOH has agreed that DoD LUCIPs will be sufficient to comply with the UECA (HDOH, 2007b). In other words, as long as the DoD LUCs are clearly identified and observed pursuant to DoD policy (through the use of a LUCIP), the HDOH does not require that DoD place UECA covenants on federally owned property. For Installation Restoration sites, the DoD must, however, provide the HDOH with information including (1) the site location, (2) the specific LUCs at the site, and (3) other reasonably available information regarding the site requested by the HDOH. The site will then be included in the HDOH registry of sites with land use restrictions. This provision is not currently required for active installations (HDOH, 2007b).

If a property that is subject to LUCs is transferred from federal ownership, the DoD must execute a restrictive covenant regarding the LUCs in a form acceptable to the HDOH. The restrictive covenant must be recorded on the title of the property.

19.8.4 PROPERTY TRANSFERS AND SITE CLOSURES WITH USE RESTRICTIONS

All sites closed with restrictions require ongoing participation from the property owner to maintain safe use of the property, and prevent remedy failure. Therefore, HDOH strongly recommends that residual contamination and required institutional and/or engineering controls be freely disclosed to potential purchasers prior to property transfer.

SECTION 19 REFERENCES

Citation references for this TGM Subsection denoted with an “a”, “b”, “c”, etc… after the year of publication may not appear in sequence as these refer to the order placed in the Master References List for the entire TGM.

DoD, 2001. Department of Defense. Policy on Land Use Controls Associated with Environmental Restoration Activities. Local Copy (1.1mb). January 17, 2001.

HAR 11-451. Hawai'i Administrative Rules, Department of Health. Title 11, Chapter 451, State Contingency Plan (SCP). Local Copy (2.2mb). August 2, 1995.

HDOH, 2007b. Letter from the Laurence K. Lau, Deputy Director of Environmental Health, Hawai'i Department of Health to Rear Admiral Len R. Hering, Sr., Commander, Navy Region Southwest, DoD Regional Environmental Coordinator Region 9, United States Navy regarding Implementation of the UECA on DoD Owned Property. October 1, 2007.

HDOH, 2007c. Hawai'i Department of Health, Office of Hazard Evaluation and Emergency Response. Long-Term Management of Petroleum-Contaminated Soil and Groundwater. Website URL: http://www.hawaiidoh.com/tgm-content/1909a.aspx. Local Copy (161kb). June 2007

HRS 128D. Hawai'i Revised Statutes. Hawai'i Environmental Response Law (HERL), Chapter 128D. Website URL: https://www.capitol.hawaii.gov/hrscurrent/Vol03_Ch0121-0200D/HRS0128D/.

HRS 508C. Hawai'i Revised Statutes. Uniform Environmental Covenants Act (UECA), Chapter 508C. Website URL: https://www.capitol.hawaii.gov/hrscurrent/Vol12_Ch0501-0588/HRS0508C/. Local Copy (20kb).

USEPA, 2001d. United States Environmental Protection Agency. Reuse Assessments: A Tool to Implement the Superfund Land Use Directive. Office of Solid Waste and Emergency Response (OSWER) Memorandum 9355.7-06P. Website URL: https://clu-in.org/download/toolkit/thirdednew/reuseassesstool.pdf. Local Copy (87kb). June 4, 2001.

APPENDIX 19-A
Long-Term Management of Petroleum-Contaminated Soil and Groundwater.

(see PDF file)

APPENDIX 19-A

LONG-TERM MANAGEMENT OF PETROLEUM-CONTAMINATED SOIL AND GROUNDWATER

LINDA LINGLE
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CHIYOME L. FUKINO, M.D.
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In reply, please refer to:
File: EHA/HEER Office
2007-314-RB

June 27, 2007

TO: Interested Parties

FROM: Keith E. Kawaoka, D.Env., Program Manager
Hazard Evaluation and Emergency Response Office

Steven Chang, Chief
Solid & Hazardous Waste Branch

SUBJECT: Long-Term Management of Petroleum-Contaminated Soil and Groundwater

Attached for your information is a technical report that presents guidance on the long-term management of petroleum-contaminated soil and groundwater. This report serves as an addendum to the Hazard Evaluation and Emergency Response (HEER) Office document *Screening For Environmental Concerns at Sites With Contaminated Soil and Groundwater* (May 2005 and updates).

If you any questions, please contact Dr. Roger Brewer of the HEER Office at 1-808-586-4238 or contact him by email at roger.brewer@doh.hawaii.gov.

Attachment

Long-Term Management of Petroleum-Contaminated Soil and Groundwater

This technical memorandum outlines procedures for long-term management of residual petroleum contamination in soil and groundwater at sites where full cleanup is not practicable. Topics discussed include:

- Revisions to *Target Contaminants of Concern* for petroleum-contaminated media;
  - Addition of naphthalene for gasoline releases;
  - Reduction of target PAHs for diesel-only releases to naphthalene and methylnaphthalenes;
  - Inclusion of methane in soil gas samples;
- Identification of specific environmental concerns in an *Environmental Hazard Assessment* (formerly referred to as an Environmental *Risk* Assessment);
- Identification of long-term management needs and preparation of an *Environmental Hazard Management Plan*;
- Need for continued Hawaii Department of Health (HDOH) oversight*:*
  - Remaining contamination does not exceed action levels: *No Further Action* and case closure with no long-term monitoring or management requirements;
  - Remaining contamination exceeds action levels but very limited threat to human health and the environment: *No Further Action* and case closure with no requirement for continued monitoring; management of remaining contamination in accordance with the *Environmental Hazard Management Plan* required; or
  - Remaining contamination exceeds action levels and potentially significant threat to human health and the environment: Case remains open under continued HDOH oversight but responsible party may request concurrence that further active remediation is not practicable.

An important goal of the guidance is to allow closure of "low-risk" and low-priority cases. These are cases where remaining contamination is minimal and does not pose a significant risk to human health and the environment, even though a limited area of soil or groundwater is contaminated above HDOH environmental action levels. The remaining contamination must be properly managed in accordance with the *Environmental Hazard Management Plan* prepared for the site. No further reporting requirements will be imposed, although HDOH reserves the right to reopen the case if remaining contamination is not properly managed in the future. This allows HDOH to focus its resources on high-risk and high-priority sites. Formally closing low-risk sites also assists the owner in property transactions and redevelopment (which in some cases could assist in further cleanup). Clearly documenting post-remediation site conditions and remaining environmental concerns also reduces the chance that the owner could be inappropriately included as a "responsible party" for future, unrelated releases after the property has been sold.

The guidance draws from and adds to information presented in the Hazard Evaluation and Emergency Response (HEER) and Solid & Hazardous Waste Branch (SHWB) office *Technical Guidance Manual* documents (HDOH 1997, 2000). Guidance documents prepared by the USEPA and other state agencies are also referred to. In particular, this document incorporates guidance published by the State of California in 1996 to address what they termed "low-risk" petroleum-release sites (CalEPA 1996a). California's guidance is based on the premise that petroleum contamination does not pose a significant threat to human health and the environment

once the source of the release is stopped and gross contamination is removed from the immediate release area (irregardless of contaminant concentrations). While very practical, the discovery of extensive plumes of MTBE-contaminated groundwater from gas stations and leaking pipelines soon afterwards and the growing importance of vapor intrusion concerns reduced the usefulness of California's guidance. The guidance presented below helps address these gaps by requiring a full evaluation of potential environmental concerns and closer HDOH oversight of cases where soil and/or groundwater are contaminated with persistent and highly mobile chemicals like MTBE.

The guidance also serves as an update and addendum to the HDOH document *Screening For Environmental Concerns at Sites With Contaminated Soil and Groundwater* (HDOH 2005a). The guidance applies to both petroleum releases overseen by the HEER Office and releases overseen by the SHWB. Responsible parties with cases being overseen by the Underground Storage Tank section of the SHWB may continue to refer to action levels presented in 1995 HDOH Risk-Based Corrective Action guidance if they choose until such time that SHWB regulations pertaining to releases from underground storage tanks are updated (HDOH 2005b, regulations currently under review).

This guidance is intended to provide a starting point for discussion of possible case closure and removal from HDOH oversight. The guidance is *not* intended to represent strict requirements for closure and issuance of *No Further Action* letters to responsible parties. The information provided in this guidance will be updated as appropriate and will be included in future revisions of the HEER and SHWB *Technical Guidance Manual* documents (currently underway). Comments and suggestions are welcome and should be addressed to Roger Brewer of HDOH at roger.brewer@doh.hawaii.gov.

Overview

Responsible parties for sites where full cleanup of contaminated soil and groundwater has occurred and representative concentrations of contaminants in soil, soil gas and groundwater are below HDOH Tier 1 Environmental Action Levels (EALs) can petition HDOH for a *No Further Action* letter and case closure. Site conditions often limit the extent to which contaminated soil and groundwater can be aggressively remediated, however. This situation is especially common in heavily developed, urban areas. Excavation and removal of heavily contaminated soil and free product in the immediate area of the release is generally achievable. Concerns about building foundations, subsurface utilities and roadways coupled with high costs, however, often limit the feasibility of complete cleanup.

This guidance describes conditions where continued HDOH oversight of the site will be required (refer to Figures 1, 2 and 3). The guidance also presents conditions where a responsible party can petition for case closure under a *No Further Action* letter when contaminant concentrations exceeds Tier 1 EALs (or approved, alternative action levels) but the remaining threat to human health and the environment is minimal. When the remaining threat is still significant but further attempts to actively reduce contaminant levels via excavation, soil vapor extraction, direct groundwater treatment, etc., is not practicable, the responsible party can petition HDOH to concur that no further active remediation is required at the site. This allows current and future owners (as well as financial institutions) to better assess the monetary, environmental liability tied to the property and reduce financial uncertainty in property transfer or redevelopment plans.

Costs associated with long-term monitoring or engineered controls (caps, etc., if applicable) are, in contrast, relatively easy to project.

Continued HDOH oversight will likely be required at sites where Tier 1 EALs (or approved, alternative action levels) are exceeded *and* one or more of the following conditions exist (refer also to Figures 2 and 3):

- Sites where active remediation is still technically and economically practicable;
- A plume of contaminated groundwater is present that could threaten existing or future water supply wells;
- A plume of contaminated groundwater is present that could be acutely toxic to aquatic organisms if it discharges into a surface water body;
- Persistent chemicals such as lead, PCBs, chlorinated solvents, etc., are present above action levels for unrestricted/residential land use and no land use covenant/deed restriction in place;
- Remaining contamination poses direct-exposure and/or vapor-intrusion concerns for current and anticipated future land use in the absence of engineered controls;
- Greater than ten cubic meters of grossly contaminated soil are present within three meters of the ground surface (or above groundwater, if less than three meters deep).

Sites where each of the following conditions are met can petition for a *No Further Action* letter and case closure, provided that the remaining contamination is properly managed in accordance with the *Environmental Hazard Management Plan* prepared for the site (refer to Figures 2 and 3):

General:

- The release has been stopped and ongoing sources, including free product, have been removed or remediated to the extent practicable;
- Remaining contamination documented in an updated site assessment report, including maps that clearly define the extent and magnitude of remaining contamination above HDOH EALs (or other approved screening levels);
- Remaining environmental concerns are documented in an *Environmental Hazard Assessment* report;
- Requirements for long-term management of remaining contamination are presented in an *Environmental Hazard Management Plan;*

For soil:

- Representative concentrations of persistent chemicals do not exceed action levels (e.g., lead, PCBs, PAHs, etc.; multi-increment data preferred for surface and near surface samples, when practicable);
- Engineered controls (pavement, etc.) in place to prevent direct-exposure, vapor-intrusion or leaching concerns;
- Volume of contaminated soil within three meters (ten feet) of surface $\leq 10 m^3$ (approximately 15 cubic yards);

For groundwater:

- Body of groundwater that exceeds action levels is not expanding and/or or migrating (i.e., the plume is "stable" or shrinking);
- For impacted drinking water resources:
    - Plume is not within 300m (approximately1,000 ft) of an active water supply well and within the producing aquifer or within 150m of a surface water body that is a potential source of drinking water;
    - Persistent chemicals not present above drinking water goals (MTBE, chlorinated solvents, etc.);
    - Non-persistent, petroleum-related contaminants do not exceed drinking water goals by more than one order of magnitude;
- For plumes within 150m of an aquatic habitat (including drainage ways that lead to a surface water body):
    - Contaminant concentrations do not exceed action levels for chronic aquatic toxicity concerns for undeveloped waterfronts; or
    - Contaminant concentrations do not exceed action levels for acute aquatic toxicity concerns for developed waterfronts;
- For plumes not within 150m of an aquatic habitat:
    - Contaminant concentrations do not exceed action levels for acute aquatic toxicity concerns; and
- No vapor intrusion or methane buildup concerns in the absence of engineered controls.

The distance of 300m from a producing well to highlight "high-risk" plumes is subjective and is not necessarily reflective of groundwater flow rates in well capture zones. The two-year capture zone for municipal water wells installed in the basal, basalt aquifer can extend outward from the well head 3,000 meters or more (personal communication, HDOH Safe Drinking Water Branch). The upper few meters of the aquifer (where petroleum-contaminated groundwater is usually restricted), however, may not be included in the primary capture zone for wells that are screened well below the top of the water table. Unfortunately, detailed information on the design and construction of municipal water supply wells is not available to the general public. A more detailed evaluation will be required if HDOH determines that a water supply well is potentially at risk of being contaminated.

Sites where the above conditions are met can petition HDOH for case closure under a *No Further Action* letter. The burden and responsibility for long-term management of remaining contamination, as described in an *Environmental Hazard Management Plan*, is placed on the property owner (or other responsible party). HDOH reserves the right to reopen a case if it is determined that residual contamination is not being adequately managed.

Sites that do not meet these conditions will remain under the long-term oversight of HDOH, unless otherwise determined on a case-by-case basis. Responsible parties can, however, petition HDOH for a letter concurring that *No Further Active Remediation* is required. This lessens uncertainty regarding the financial "environmental liability" associated with the property and can assist in future property transfers and redevelopment.

Determining Need for Continued HDOH Oversight

A stepwise approach to determine the need for continued HDOH oversight of petroleum-contaminated sites is discussed below and summarized in Figures 1 through 3. Target contaminants of concern should be identified based on a comparison to HDOH Tier 1 EALs or approved, alternative action levels. The extent and magnitude of remaining petroleum contamination above action levels must be clearly documented in an updated site assessment report that summarizes post-remediation site conditions.

Potential environmental concerns posed by the contamination must be identified and discussed in an *Environmental Hazard Assessment* report. In most cases, this will involve a comparison of site data to HDOH EALs for specific environmental concerns or acceptable, alternative criteria (HDOH 2005a). A more detailed assessment of environmental concerns can be carried out on a site-by-site basis as needed.

This information should be used to develop an *Environmental Hazard Management Plan* that describes long-term monitoring and management of remaining contaminated soil and groundwater at the site. The report must discuss any engineered or institutional controls necessary to keep the contamination from spreading as well as to prevent adverse exposure of residents or workers and ensure proper reuse or disposal of soil and groundwater that is disturbed during future subsurface activities. Both the *Environmental Hazard Assessment* and *Environmental Hazard Management Plan* can be presented as part of the updated, site assessment report.

Step 1: Identify Target Contaminants of Concern

Table 1 provides an updated summary of contaminants of potential concern that must be included in environmental investigations at petroleum release sites. Petroleum contamination must be evaluated in terms of both Total Petroleum Hydrocarbon (TPH) and target "indicator chemicals" for the specific type of petroleum product released (e.g., benzene, toluene, ethylbenzene and xylenes or “BTEX”, methyl tertiary butyl ether [MTBE], polynuclear aromatic hydrocarbons [PAHs], etc.). Soil, groundwater and soil gas samples must <u>always</u> be tested for TPH in addition to the target indicator chemicals noted in Table 1 and discussed below.

Petroleum is a complex mixture of hundreds of different compounds composed of hydrogen and carbon (i.e., "hydrocarbon" compounds). The bulk of these compounds are evaluated under the all-inclusive category of “TPH.” Gasoline-range TPH is a petroleum mixture characterized by a predominance of branched alkanes and aromatic hydrocarbons with carbon ranges of C6 to C12 and lesser amounts of straight-chain alkanes, alkenes and cycloalkanes of the same carbon range (API 1994). Total Petroleum Hydrocarbon associated with middle distillates (e.g., kerosene, diesel fuel, home heating fuel, jet fuel, etc.) is characterized by a wider variety of straight, branched and cyclic alkanes, PAHs (especially naphthalenes and methyl naphthalenes) and heterocyclic compounds with carbon ranges of approximately C9 to C25. Residual fuels (e.g., Fuel Oil Nos. 4, 5, and 6, lubricating oils, mineral oil, used oils, asphalts, etc.) are characterized complex, polar PAHs, naphthenoaromatics, asphaltenes and other, high-molecular-weight, saturated hydrocarbon compounds with carbon ranges that in general fall between C24 and C40.

Laboratory analysis for TPH as gasolines and middle distillates is generally carried out using gas chromatography, modified for "gasoline-range" organics ("Volatile Fuel Hydrocarbons") and "diesel-range" organics ("Extractable Fuel Hydrocarbons"), respectively (e.g., EPA Method

8015). Analysis for TPH as residual fuels up to the C40 carbon range can be carried out by gas chromatography, infrared or gravimetric methods. The latter methods are rarely used, however, due to an inability to discriminate the type of the petroleum present and interference with organic material in the soil.

Environmental action levels for TPH are developed by assigning representative fate and transport properties and toxicity factors to each TPH category and applying the same models and approaches as used for the target, indicator compounds (HDOH 2005a). A more in-depth analysis of the specific components of the TPH can be carried out in a site-specific environmental hazard assessment as needed (e.g., TPHWG 1998, MAEDP 2002).

Target indicator chemicals typically make up only a small fraction of the total petroleum present but are important players in the assessment of environmental hazards posed to human and the environment. A brief discussion of target indicator chemicals for petroleum products is included in Chapter 2 of the HDOH document *Screening For Environmental Concerns at Sites With Contaminated Soil and Groundwater* (HDOH 2005a). The 2005 HDOH guidance recommends that the following PAHs be included as target indicator chemicals for soil and groundwater contaminated with middle distillates and residual fuels:

- acenaphthene
- acenaphthylene
- anthracene
- benzo(a)anthracene
- benzo(b)fluoranthene
- benzo(g,h,i)perylene
- benzo(a)pyrene
- benzo(k)fluoranthene
- chrysene
- dibenzo(a,h)anthracene
- fluoranthene
- fluorene
- indeno(1,2,3)pyrene,
- methylnaphthalenes (1- and 2-)
- naphthalene
- phenanthrene
- pyrene

Environmental Action Levels for these chemicals are included in the HDOH EAL lookup tables (HDOH 2005a). The list of target PAHs was taken from guidance prepared by the USEPA and various state agencies in the 1990s (e.g., CalEPA 1996b, USEPA 2004).

This technical memorandum reduces the PAHs that must be included as target indicator compounds for releases of middle distillate fuels to naphthalene and methylnaphthalene (Table 1, after MADEP 2002). A review of field data and discussions suggests that the majority of the PAHs are not present in middle distillate fuels at concentrations that would drive environmental concerns and cleanup actions. From an environmental hazard standpoint, cleanup of releases of middle distillate fuels is almost always driven by Total Petroleum Hydrocarbons (TPH) contamination, not PAHs. Naphthalene and methylnaphthalenes are two potential exceptions, since they can be present in middle distillate fuels at relatively high concentrations and are moderately volatile and mobile. Naphthalene is also an upcoming contaminant in vapor intrusion studies, although it is unlikely to be present in middle distillate fuels at levels that would pose vapor intrusion concerns when TPH itself does not exceed HDOH action levels.

Soil and groundwater contaminated with middle distillate fuels must also be tested for BTEX (Table 1). Although BTEX rarely drives cleanup for releases middle distillate fuels, their presence or absence is a useful indicator of past gasoline releases at the site or the migration of

gasoline-contaminated groundwater onto the property from offsite sources. Testing for naphthalene at gasoline release sites is also recommended (refer to Table 1).

Soil and/or groundwater contaminated with used oils, coal tar, asphalt and other heavy petroleum mixtures must be tested for the full suite of PAHs noted above. Releases of unused lube oil, transformer oils, mineral oils, virgin hydraulic oils, Fuel Oil #6 and similar products do not require testing for PAHs and other chemicals if it can be demonstrated that product released was never heated to high temperatures (potentially producing PAHs). Testing must also be carried out for volatile organic compounds (VOCs, including chlorinated solvents), PCBs and heavy metals unless otherwise justified.

Step 2: Prepare Updated Site Assessment Report

Site conditions following active remediation of contaminated soil and groundwater to the extent practicable must be clearly documented in an updated site assessment report. Information that should be provided in the report includes:

- Summary of Past, Current and Anticipated Future Site Activities and Uses:
    - Describe past and current site uses and activities;
    - Describe foreseeable future site uses and activities;
- Summary of Pre- and Post-Remediation Site Conditions:
    - Identify all types of impacted media;
    - Identify all sources of chemical releases;
    - Identify all chemicals of concern;
    - Delineate on to-scale maps the magnitude and extent of contamination above EALs (or other approved action levels) to extent practicable and applicable;
    - Identify nearby groundwater extraction wells, bodies of surface water and other potentially sensitive ecological habitats;
    - Ensure data are representative of site conditions.

Surveyed, to-scale maps of the site that clearly indicate the location of remaining contaminated soil and groundwater must be included in the report. This information will be necessary for both the assessment of potential environmental concerns or *hazards* posed by the contamination as well as the preparation of an *Environmental Hazard Management Report*, discussed in the following steps.

Step 3: Prepare Environmental Hazard Assessment

An *Environmental Hazard Assessment* is an evaluation of potential environmental concerns at sites where releases of petroleum or other hazardous chemicals have occurred (HDOH 2005a). Common environmental concerns that must be assessed at sites where petroleum-contaminated soil and/or groundwater are identified include:

Soil:

- Direct exposure to contaminants in soil (ingestion, dermal absorption, inhalation of vapors and dust in outdoor air);

- Emission of vapors to building interiors;
- Impacts to terrestrial ecological habitats;
- Leaching and impacts to groundwater resources; and
- General gross contamination and resource degradation (including generation of vapors and explosive hazards, potentially mobile free product, odors, general resource degradation, etc.);

Groundwater:

- Impacts to drinking water resources;
- Emission of vapors to building interiors;
- Impacts to aquatic habitats (discharges of contaminated groundwater to surface water); and
- Other gross contamination and resource degradation concerns (including intrusion of vapors into utility conduits, potentially mobile free product, sheens, etc.).

A more detailed discussion of common environmental concerns posed by contaminated soil and groundwater is provided in the HDOH document *Screening For Environmental Concerns at Sites With Contaminated Soil and Groundwater* (HDOH 2005a).

The presence or absence of potential environmental concerns is first evaluated in a brief, *Environmental Hazard Assessment*. This can be done by comparison of site data to the summary, Tier 1 EALs presented in Volume 1 of the HDOH document *Screening For Environmental Concerns at Sites With Contaminated Soil and Groundwater* (HDOH 2005a). The presence of chemicals at concentrations above an action level *does not* necessarily indicate that hazardous conditions exist at the site. It *does*, however, indicate that additional evaluation of identified, potential concerns is warranted.

When a Tier 1 EAL (or approved, alternative action level) is exceeded, specific environmental concerns can be identified by comparison of representative contaminant concentrations to detailed action levels presented in Appendix 1 of the HDOH EAL document. The Excel-based, EAL "Surfer" or electronic lookup tables can be used to expedite this process (available for download from the HDOH EAL webpage, see URL address in HDOH 2005a reference). The Surfer allows direct input of representative contaminant concentrations. Specific environmental concerns are identified if input contaminant concentrations in soil or groundwater exceed the primary Tier 1 EAL. The Surfer then generates a "Summary Report" that can be printed and included as supporting documentation for a basic *Environmental Hazard Assessment* report. Note that decision unit and multi-increment investigation strategies are preferred over the use of discrete sample data, when feasible (refer to HDOH 2007b).

An *Environmental Hazard Assessment* report must be prepared to document potential environmental concerns associated with remaining contamination at the site. This document should include the following information:

- Site Background;
- Summary of investigations (including to-scale maps with a north arrow);
- Applicability of HDOH EALs or alternative action levels;
- Selection of soil and groundwater categories;

- Selection of EALs & comparison to site data;
- Identification of specific environmental concerns if final Tier 1 EALs exceeded; and
- Recommendations for followup actions, including preparation of an *Environmental Hazard Management Plan* or, if needed, a more detailed assessment of identified environmental concerns.

A more detailed discussion of the preparation of *Environmental Hazard Assessment Reports* is provided in Volume 1 of the HDOH EAL document (HDOH 2005a). For relatively simple sites, the assessment can be included as a separate chapter in the post-remediation report, with EAL Surfer printouts, etc., included in the appendices. Maps that depict specific environmental concerns posed by contamination in various areas of the site can also be very useful, and in some cases required, for inclusion in the site *Environmental Hazard Management Report*, as discussed below (e.g., areas that pose direct-exposure, leaching or vapor intrusion concerns; areas of free product, grossly contaminated soil or methane buildup, etc.).

Conditions that pose immediate or short-term environmental concerns should be addressed as quickly as possible. This includes exposure of residents or workers to potentially harmful levels of contaminants in soil ("direct exposure"), impacts to water supply wells, intrusion of vapors or methane into overlying structures (including explosive hazards) and discharges of free product to surface water.

Note that the approach described above is referred to as *Environmental "Risk" Assessment* in the 2005 HDOH EAL document. The term "risk" is replaced with the term "hazard" in this guidance document. This was done to emphasize the fact that some environmental concerns are not necessarily toxicological in nature, as the term "risk" is often interpreted to indicate. Examples include explosive hazards, leaching of contaminants from soil and even general gross contamination concerns. Human health and ecological risk are of course an important component of an *Environmental Hazard Assessment*, but they cannot be used as stand-alone tools to assess the need for potential cleanup actions at sites where petroleum-contaminated soil and groundwater are identified. This change in terminology will be noted in upcoming revisions of HDOH environmental guidance documents.

Step 4: Prepare Environmental Hazard Management Plan

The purpose of an *Environmental Hazard Management Plan* (EHMP) is threefold: 1) document the extent and magnitude of contaminated soil and groundwater left in place at a site, 2) summarize identified environmental concerns posed by the contamination and 3) provide a framework for long-term management of the contamination. An EHMP must be prepared for all petroleum-release sites where residual soil and groundwater contamination is left in place above levels that could pose potential environmental concerns. A copy of the plan must be submitted to HDOH for inclusion in the public file.

An *Environmental Hazard Management Plan* is similar in intent to what are commonly referred to as *Risk Management Plans* or *Soil and Groundwater Management Plans*, as described in the current editions of the HEER Office and SHWB *Technical Guidance Manuals* (HDOH 1997, 2000; USEPA 2003). A *Risk Management Plan* or *Exposure Prevention Management Plan* typically focuses on the reduction or elimination of risks to human health posed by direct exposure to contamination in soil or groundwater or by the emission of vapors into buildings.

While important, other potential concerns such as leaching, explosive hazards and the simple need to properly manage grossly contaminated soil or groundwater are often ignored. A *Soil and Groundwater Management Plan* describes measures for handling, reusing and/or disposing of contaminated soil and groundwater that is encountered during future subsurface activities, including the repair of underground utilities or redevelopment of the property. Again, this information is important but these plans often fail to identify the specific environmental concerns posed by the contamination.

An *Environmental Hazard Management Plan* combines all necessary information into a single, stand-alone document that identifies the nature of the contamination present, the potential environmental concerns posed by the contamination, and appropriate measures to ensure that these concerns are adequately addressed. An *Environmental Hazard Management Plan* should include the following information, at a minimum:

- Brief summary of the site background and history of contaminant releases;
- Identification of specific contaminants of concern, including TPH, "Target Indicator Compounds" and any other contaminants associated with the release (refer to Step 1);
- Clear depiction of the extent and magnitude of remaining contamination in soil, groundwater and/or soil gas, presented on easily readable, to-scale maps with a north arrow (refer to Step 2);
- Identification and discussion of all potential environmental concerns (refer to Step 3);
- Requirements for long-term monitoring of contaminants in soil, groundwater, and/or soil gas;
- Discussion of engineered and/or institutional controls needed to address identified environmental concerns, including caps, barriers, etc., needed to eliminate exposure pathways;
- Guidance on the proper handling, reuse and disposal of contaminated soil and/or groundwater that is encountered during future site activities;
- Measures for repair or replacement of engineered controls that are disturbed or breached during future site activities; and
- Any other information required to adequately mitigate and manage remaining environmental concerns at the site.

A brief Fact Sheet that summarizes key elements of the *Environmental Hazard Management Plan* in simple, non-technical terms will be required for large, complex sites where significant public review is anticipated.

Long-term environmental concerns must be clearly assessed and documented to ensure that in-place management of the remaining petroleum contamination is viable and carried out properly. Examples of potential, long-term management actions include: 1) capping of grossly contaminated soil under paved areas or buildings, 2) installation of vapor barriers beneath buildings, 3) lining of utility corridors to prevent the migration of contaminated groundwater or vapors into storm drains, utility trenches or other subsurface conduits, 4) restrictions on subsurface activity in some areas without pre-approved work plans, 5) procedures for proper disposal or reuse of contaminated soil and groundwater disturbed during subsurface activities, 6) long-term monitoring of on-site groundwater and soil gas and, 7) installation of offsite "sentinel

wells" to monitor potential long-term impacts to more distant water supply wells or surface water bodies.

Additional guidance on engineered and institutional controls and the preparation of *Environmental Hazard Management Plans* will be provided in the upcoming revision of the HEER Office *Technical Guidance Manual* (anticipated late 2007, refer also to USEPA 2003). The complexity of the *Environmental Hazard Management Plan* for a given site will depend on the extent and nature of the specific contaminants released (mobility, toxicity, explosive hazard, etc.), the specific environmental concerns posed by the contamination and the current and future site use. For relatively simple sites, the *Environmental Hazard Management Plan* can be included as an appendix in the final site closure report.

Step 5: Determine Need for Continued HDOH Oversight

Figures 2 and Figure 3 provide flow charts to assist in determining an appropriate course of action for long-term oversight of petroleum-contaminated soil and groundwater, respectively. The flow charts, and related discussion below, should be considered general guidance only and not strict requirements that must be met before the status of a site can be updated to "closed" under a *No Further Action Letter*. As in any subject where the distinct lines between "yes" and "no" are difficult to draw, the use of sound, professional judgment is very important.

Cases where remaining contamination is minimal in extent and/or magnitude and not likely to pose significant environmental concerns under worst-case conditions can generally be closed under a *No Further Action* letter from HDOH. No further monitoring or reporting requirements will be imposed on these sites. Long-term management of remaining contamination must be carried out in accordance with the *Environmental Hazard Management Plan* prepared for the site. HDOH retains the right to reopen the case and impose enforcement actions if contaminated soil or groundwater is not properly managed.

Continued HDOH oversight will be necessary at sites where remaining contamination could pose significant environmental concerns if not appropriately managed. Sites where potentially significant, environmental concerns remain but active remediation (excavation, soil vapor extraction, etc.) is no longer practical can, and should, request a letter from HDOH clarifying that no *further active remediation* is required. The need for ongoing groundwater or in some cases soil gas monitoring should also be evaluated. The letter is intended to clarify that all major cleanup actions have been completed at the site and that the site has moved into a status of long-term monitoring and management. These letters help property owners, financial institutions and potential purchasers establish the "environmental liability" associated with the remaining environmental contamination and can greatly assist in future property transactions and redevelopment. The *Environmental Hazard Management Plan* should include a description of conditions that will need to be met before the case can be formally closed and a no further action letter issued.

<u>Long-Term Oversight of Petroleum-Contaminated Soil</u>

Continued HDOH oversight of cases with residual petroleum contamination in soil will be required if one of more of the following conditions exists and sufficient justification to close the case is not otherwise provided (see Figure 2):

- Additional remediation technically and economically practicable;
- Anticipated residential redevelopment in near future and representative contaminant concentrations exceed action levels for unrestricted land use;
- Persistent contaminants present above direct-exposure or vapor intrusion action levels for unrestricted land use and no deed restriction recorded (PAHs, MTBE, heavy metals, PCBs, chlorinated solvents, etc.);
- Direct exposure, vapor intrusion and/or leaching concerns under current or anticipated land use but engineered controls not in place prevent exposure or contaminant migration; and/or
- Nonpersistent contaminants only (e.g., TPH, BTEX, etc.) but volume of soil contaminated above action levels exceeds 10 cubic meters (approximately 15 cubic yards).

HDOH Tier 1 EALs are pre-approved for use at all sites and should be referred to in the absence of acceptable, site-specific, Tier 2 or Tier 3 action levels (refer to HDOH EAL document, HDOH 2005a).

For the purposes of this guidance, the term "soil" refers to any unconsolidated soil, sediment or fill material. HDOH Environmental action levels for soil are primarily intended for comparison with sample data collected above the water table. This is because residents, as well as commercial and industrial workers, are unlikely to come into regular contact with soil below the water table. The EALs also include consideration of vapor intrusion concerns and leaching concerns, both of which should not be applied to soils situated in groundwater. Direct collection of groundwater data is instead more pertinent to evaluate these concerns. The collection of soil sample data below the water table can sometimes assist in developing long-term management strategies for sites where residual contamination is to be left in place, however. Procedures for management of contaminated soil situated at or below the water table that is disturbed during future subsurface activities should also be included in the site *Environmental Hazard Management Plan.* Formal covenants that restrict land use and implement engineered controls to prevent exposure or leaching are required for sites where representative concentrations of persistent chemicals exceed action levels for unrestricted, residential land use.

Multi-increment sample data are preferred to establish representative contaminant concentrations within designated decision units over discrete sample data, although in practice this approach is most applicable for surface samples to be tested for non-volatile contaminants. The State of Alaska recently published guidance on the collection of multi-increment samples that area to be tested for volatile chemicals (ADEC 2007). The approach calls for the placement of soil increments in methanol in the field. Restrictions on airline transportation of methanol may limit the use of this approach in Hawai‘i, however. Additional guidance on this subject to be presented in the upcoming update of the HEER Office *Technical Guidance Manual* (anticipated Fall 2007).

Soil gas data are preferred over soil data for evaluation of potential vapor intrusion concerns. Leaching concerns should be evaluated based on comparison to HDOH action levels, the results of laboratory batch test (HDOH 2007a) and/or groundwater monitoring data for sites where the contaminated soil is not capped or in direct contact with groundwater. Closure of a case under a *No Further Action* letter with deeper, grossly contaminated soil that exceeds ten cubic meters in

volume is acceptable provided that the soil does not pose significant leaching and groundwater contamination concerns. This should be discussed on a case-by-case basis with HDOH.

Gross contamination action levels for soil address odor and aesthetic concerns and resource degradation in general (refer to Volume 1 of the HDOH EAL document). The action levels also help identify soil with mobile free product or explosive levels of vapors. Remaining gross contamination concerns at sites where active soil cleanup is no longer practicable should be evaluated by an inspection of soils that exceed action levels for TPH. Gross contamination action levels for soils contaminated with gasoline and middle distillate fuels (diesel, jet fuel, etc.) are based to a large degree on field experience. Action levels for shallow soils ($\leq$3m) are considered to be relatively accurate for odor concerns in a residential land use scenario (100 mg/kg and 500 mg/kg for gasoline and middle distillate fuels, respectively, refer to Appendix 1 of the HDOH EAL document for commercial/industrial action levels). Action levels for deeper soils are useful to identify the presence of potentially mobile, free product or the production of potentially explosive petroleum or methane vapors (2,000 mg/kg and 5,000 mg/kg, respectively).

Gross contamination action levels for the broad category of TPH "residual fuels" (motor oil, mineral oil, grease, etc.) are significantly more flexible. Used oil could in some cases pose nuisance concerns at concentrations as low as the default residential action level of 500 mg/kg for residual fuels but higher levels are acceptable on a case-by-case basis if it can be adequately demonstrated that the contamination does not pose adverse nuisance conditions. An in-house study using spiked soil samples indicated action levels of 5,000 mg/kg (shallow soils) and 25,000 mg/kg (deep soils) are appropriate for mineral oil (commonly used in electrical transformers), provided that the oil has not been heated to high temperatures, subjected to fire or contaminated with other chemicals. Similar gross contamination action levels may be appropriate for heavy greases.

Long-Term Oversight of Petroleum-Contaminated Groundwater

Continued HDOH oversight of cases with residual petroleum contamination in groundwater will be required if one of more of the following conditions exists and sufficient justification to close the case is not otherwise provided (see Figure 3):

- The area of the plume that exceeds action levels is still expanding and/or or migrating away from the original release area;
- The plume is within the capture zone of an active water supply well or within 150m of a potable surface water body and contaminant levels exceed drinking water action levels;
- The plume is not within the capture zone of an active supply well but within a potential drinking water aquifer and concentrations of TPH, BTEX and related petroleum compounds exceed action levels by an order of magnitude or more;
- The plume is not within the capture zone of an active supply well but within a potential drinking water aquifer and concentrations of MTBE, chlorinated solvents or other persistent compounds exceed action levels;
- The plume is within the capture zone of a nondrinking water, industrial or irrigation supply well and contaminant levels exceed action levels for impacts to surface water bodies or other environmental concerns;
- The plume is within 150m of an undeveloped water front or sensitive aquatic habitat and contaminants exceed action levels for chronic toxicity to aquatic organisms;

- The plume is within 150m of a highly developed waterfront area (e.g., wharf area) and contaminants exceed action levels for acute toxicity to aquatic organisms or potentially mobile free product is present;
- Storm sewers, abandoned pipelines or other subsurface utilities are located adjacent to or within plume and could serve as potential conduits for migration of free product or other contaminants to surface water bodies above the levels of concern noted above; and
- Free product on groundwater could pose a risk to on-site workers involved in excavation or dewatering activities, and/or long-term methane generation or vapor intrusion concerns.

A more detailed discussion of groundwater utility (e.g., drinking water supply, irrigation supply, etc.) is provided in Volume 1 of the HDOH document *Screening For Environmental Concerns at Sites With Contaminated Soil and Groundwater* (HDOH 2005a). The status of an aquifer as a potential source of drinking water is determined in part on the location of the groundwater with respect to the Underground Injection Control (UIC) Line and the state *Aquifer Identification and Classification* technical reports prepared by the University of Hawai'i. Groundwater in a viable aquifer that is situated inland ("mauka") of the UIC line or in the basal aquifer under coastal caprock sediments is generally considered by HDOH to be a potential water supply resource.

Once the source of a release has been removed (including vadose-zone soil that could act as a secondary leaching source), a minimum of two years of quarterly monitoring is generally required to establish that a plume is not expanding or migrating above levels of potential concern. This assumes that groundwater is not contaminated with MTBE and other persistent chemicals above levels of concern, in which case a plume may never become truly "stable" and long-term monitoring will be required. Long-term monitoring data can also be used to develop degradation trends for contaminants of concern (e.g., API 2007). If a convincing case can be made that contaminant levels will reach target goals within five years and currently used water supply wells are not threatened then closure of the case under a *No Further Action* letter will be considered.

If the source(s) of groundwater contamination has been gone for five or more years earlier, less data, in some cases even a single monitoring event, will be adequate to establish that a plume has reached it's greatest extent and is unlikely to spread further. Natural degradation and sorption of remaining contamination to soil particles quickly halt the spread and migration of petroleum-contaminated groundwater once the source has been removed. Plumes rarely extend more than 150 meters from the original release area in the absence of MTBE or other persistent and highly mobile chemicals. However, storm sewers, abandoned pipelines, other subsurface utilities or shallow irrigation wells could act as conduits for contaminated groundwater to reach more distant surface water bodies. Potential dewatering at construction sites must also be considered in areas of shallow groundwater, as should the potential for contaminated groundwater to enter an irrigation or industrial water supply well and ultimately be discharged into an irrigation canal, storm water drain or other direct conduit to a surface water body. These situations will require that the groundwater be screened against chronic rather than acute aquatic toxicity goals and must be evaluated on a site-by-site basis. HDOH NPDES requirements may also apply for surface discharges of contaminated groundwater.

Dilution of contaminated groundwater upon discharge to a surface water body is not taken into consideration for initial screening of potential impacts to aquatic habitats. This is because organisms living in the sediment that organisms living in the water column rely on as a food source could be exposed directly to the groundwater prior to discharge. Benthic habitats located along natural stream or channel banks or shoreline areas are particularly at risk. Groundwater in these areas should be screened against the more stringent, chronic, aquatic toxicity action levels included in Tier 1 EALs for areas within 150m of a surface water body (refer to Appendix 1 of the HDOH EAL document). Screening of groundwater data against acute aquatic toxicity action levels is considered adequate in highly developed waterfront areas (wharfs, seawalls, etc.) where significant benthic communities are generally absent in the area where contaminated groundwater may discharge and the primary risk is to aquatic organisms living in the water column. Impacts that result in a sheen on a surface water body must be avoided in all cases.

Other factors that can be considered in evaluating the need for continued HDOH oversight include the aerial extent of impacted groundwater and impacts to deep, non-potable groundwater. In commercial/industrial areas, petroleum-contaminated groundwater generally does not pose a significant threat to human health and the environment regardless of the actual concentrations of TPH or petroleum-related target indicator chemicals if the following conditions are met: 1) plume is not expanding or migrating away from the release area above final, target action levels, 2) area of remaining free product is less than approximately 100 square meters (assumed size of an existing or future building, minimal vapor intrusion and methane buildup concerns,) and 3) depth to groundwater is greater than five meters (unlikely to be encountered during future construction activity). This assumes the absence of conduits for offsite migration (storm sewers, etc.). Closure of such cases under a *No Further Action* letter with management of remaining contamination under an *Environmental Hazard Management Plan* should be considered. The primary concerns for deep (e.g., >5m), non-potable groundwater impacted with petroleum are offsite migration, the generation of methane and vapor intrusion into existing or future buildings. Closure of the case under *No Further Action* letter should be considered regardless of contaminant concentrations in groundwater if long-term groundwater monitoring data indicate that the plume is not migrating away from the release area above levels of concern and soil gas data rule out the potential for significant methane buildup or vapor intrusion concerns.

Wells that will no longer be used to monitor groundwater must be properly abandoned. Documentation on well abandonment must be submitted to HDOH for inclusion in the public file.

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Table 1. Recommended Target Analyte List For Petroleum Products

Petroleum Product	**Media**	**Recommended Target Analytes**
Gasolines	Soil	TPH, benzene, toluene, ethylbenzene, xylenes (BTEX), naphthalene, MTBE and appropriate additives and breakdown products (e.g., DBA, TBA, lead, etc.)
	Soil Gas	Same as soil plus methane
	Groundwater	Same as soil
Middle Distillates (diesel, kerosene, stoddard solvent, heating fuels, jet fuel, etc.)	Soil	TPH, BTEX, naphthalene, methylnaphthalenes (total 1- and 2-)
	Soil Gas	Same as soil plus methane
	Groundwater	Same as soil
Residual Fuels (lube oils, hydraulic oils, mineral oils, transformer oils, Fuel Oil #6/Bunker C, waste oil, etc.)	Soil	TPH, *VOCs, naphthalene, methylnaphthalenes plus remaining 15 priority pollutant PAHs, plus PCBs and heavy metals unless otherwise justified
	Soil Gas	TPH, VOCs, naphthalene, methylnaphthalenes, methane
	Groundwater	same as soil

*VOC: Volatile Organic Compounds, including BTEX and chlorinated solvent compounds

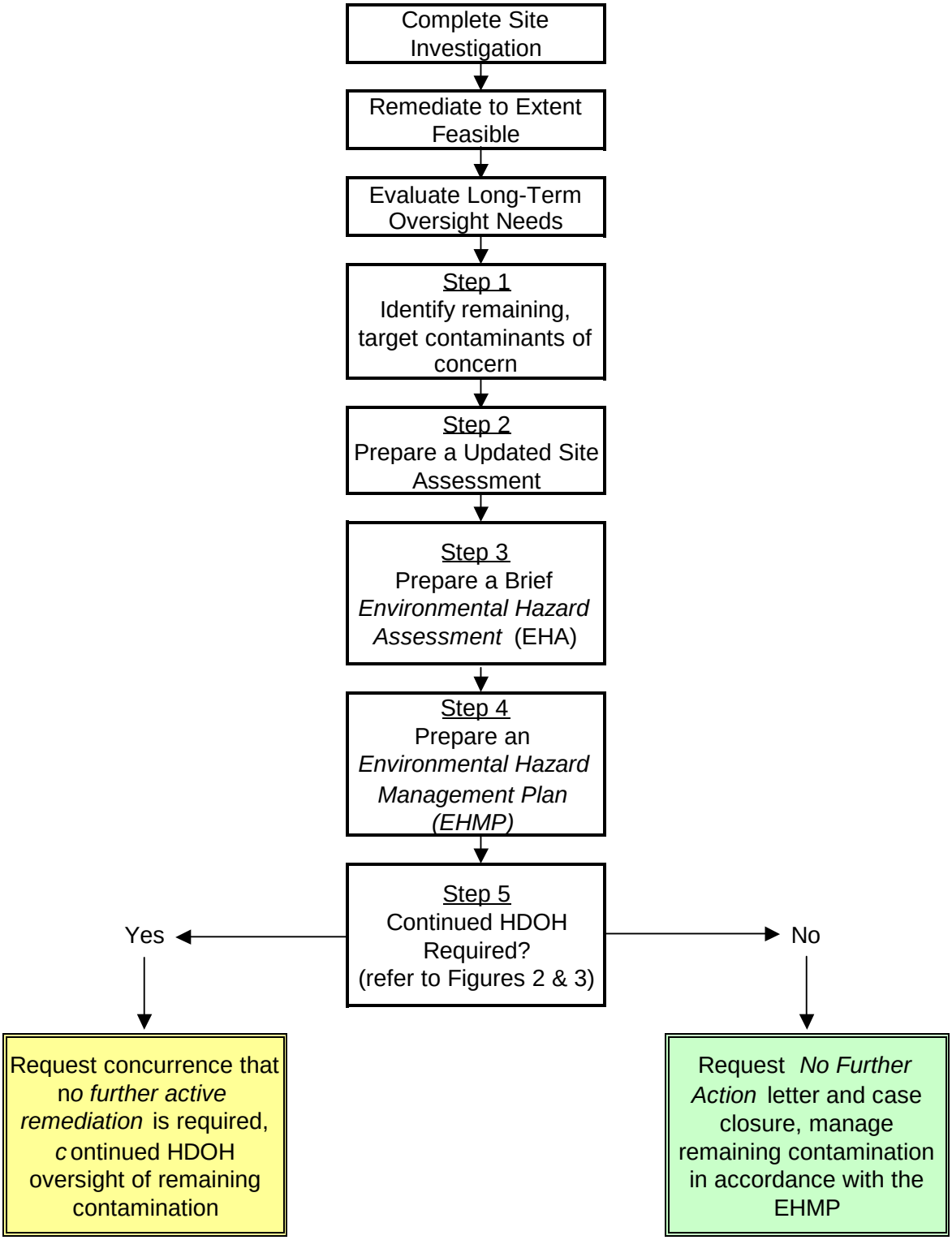


Figure 1. Overview of procedure to determine need for continued, HDOH oversight at sites with remaining petroleum contamination in soil or groundwater above HDOH EALs (or other approved action levels).

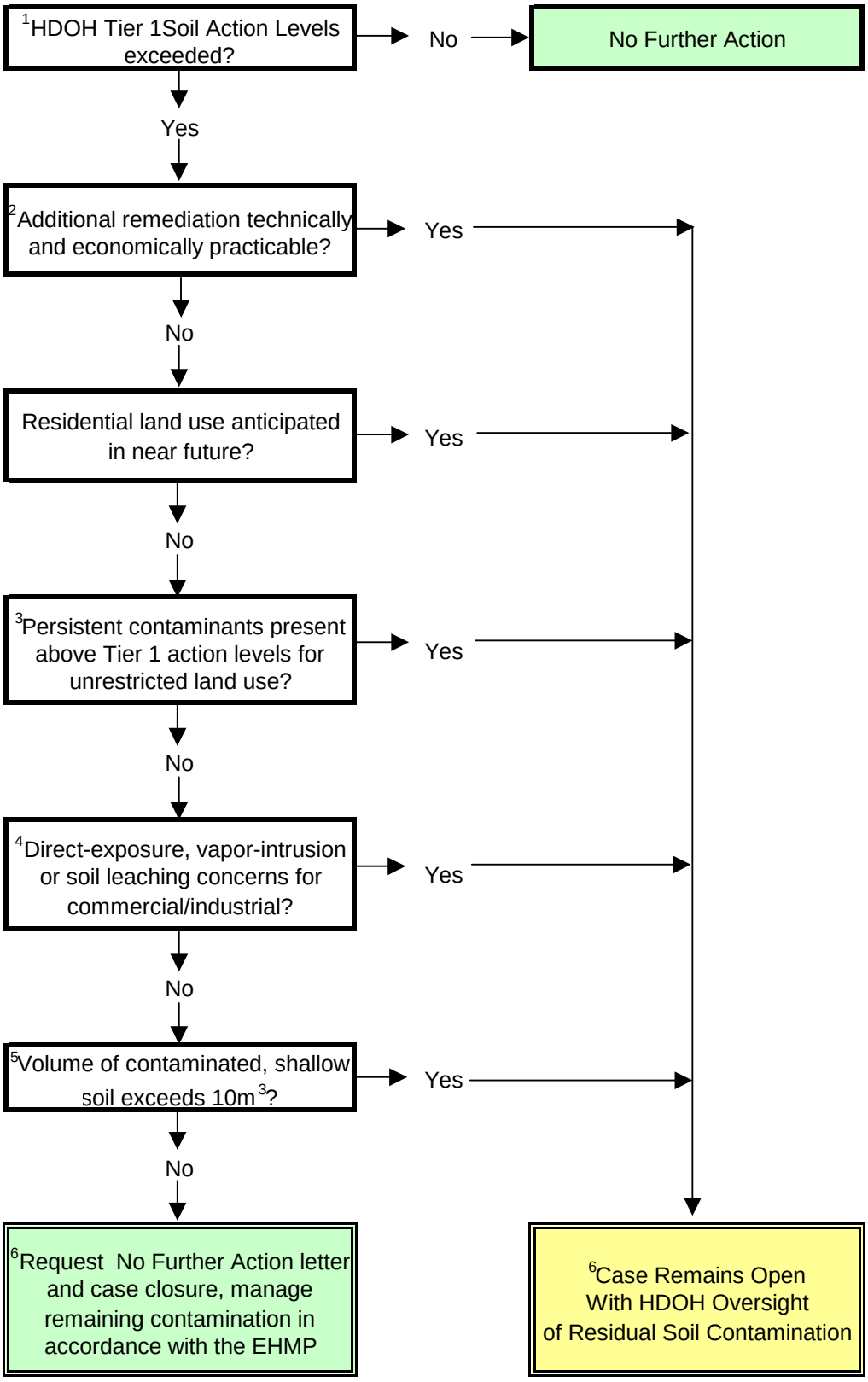


Figure 2. Decision path for long-term oversight of petroleum-contaminated soil following active remediation to extent practicable.

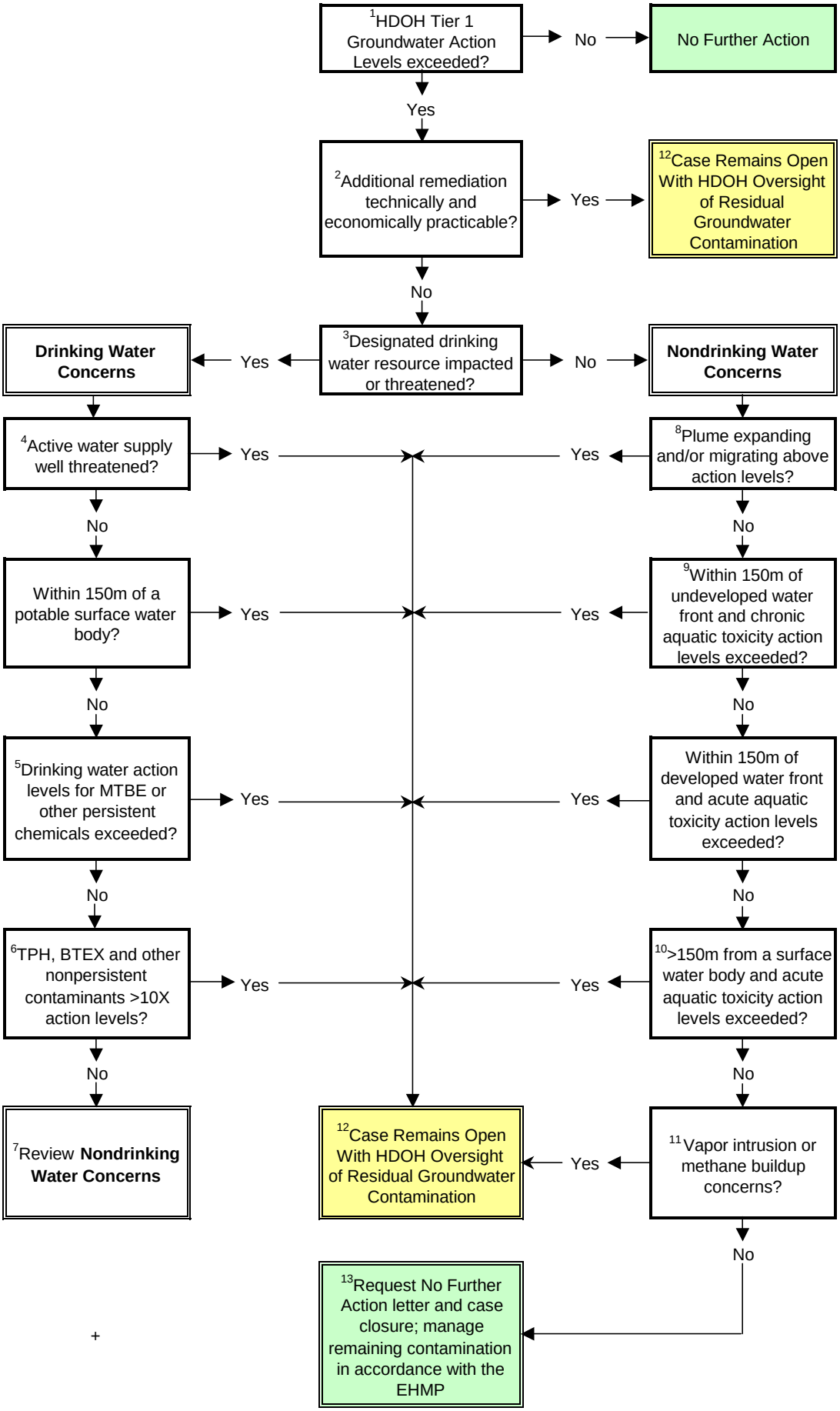


Figure 3. Decision path for long-term oversight of petroleum-contaminated groundwater following active remediation to extent practicable.

Figure footnotes

Figure 2 – Residual soil contamination:

1. Based on comparison of representative contaminant concentrations to HDOH Tier 1 EALs or approved, alternative action levels. "Soil" refers to any unconsolidated media situated above groundwater and does not include soil in the capillary fringe zone or in a smear zone associated with a fluxuating water table. Use groundwater data to evaluate potential concerns posed by soils situated below water table or within capillary fringe zone or groundwater smear zone.
2. Technical and economic practicability of additional cleanup should be discussed with HODH on a case-by-case basis.
3. MTBE, heavy metals, PCBs, chlorinated solvents, etc.
4. Commercial/industrial HDOH EALs for direct-exposure, vapor-intrusion exceeded and/or action levels for leaching concerns exceeded (or approved, alternative action levels) and engineered controls (pavement, etc.) not adequate to prevent exposure or leaching.
5. Shallow soils defined as soils within three meters (approximately ten feet) of the ground surface (HDOH 2005a). Closure of cases with greater volumes of contaminated soil left in place possible is based on a case-by-case review with HDOH.
6. No Further Action. Submittal of updated site assessment, *Environmental Hazard Assessment* and *Environmental Hazard Management Plan* required. Manage remaining contamination in accordance with the *EHMP*.
7. Case remains open under HDOH oversight. Submittal of updated site assessment, *Environmental Hazard Assessment* and *Environmental Hazard Management Plan* required. Option to petition HDOH for *No Further Remedial Action Required* letter.

Figure 3 – Residual groundwater contamination:

1. Based on comparison of representative contaminant concentrations to HDOH Tier 1 EALs or approved, alternative action levels.
2. Technical and economic practicability of additional cleanup should be discussed with HODH on a case-by-case basis.
3. Inland of UIC line or based on published groundwater resource reports.
4. Plume is within 1,000 feet in the upgradient direction of an active, producing water supply well and within producing aquifer (closer review of the potential threat to water supply wells may be required on a case-by-case basis).
5. Contaminants such as MTBE and chlorinated solvents that are known to degrade very slowly in the environment under natural conditions. Contaminant level as exhibited by current monitoring data or projected five-year degradation curve.
6. Contaminants such as TPH and BTEX that are known to rapidly degrade in the environment under natural conditions.
7. Refer to decision pathway for potential environmental concerns not directly related to drinking water.
8. Plume expanding and/or migrating above action levels, includes potential offsite migration via storm sewers, utility corridors, etc.
9. Within 150m of a sensitive aquatic habitat, generally including streams and shoreline areas that have not been significantly altered by culverts, shoreline development, etc., or otherwise protected habitat areas.
10. Consider No Further Action regardless of contaminant concentrations if plume is not migrating, area of remaining free product $<100 m^2$, no vapor intrusion or methane buildup concerns and depth to groundwater is greater than five meters (see text).
11. Vapor intrusion or methane buildup concerns in the absence of engineered controls.
12. Case remains open under HDOH oversight. Submittal of updated site assessment, *Environmental Hazard Assessment* and *Environmental Hazard Management Plan* required. Option to petition HDOH for *No Further Remedial Action Required* letter.
13. Case closed. Submittal of summary report, *Environmental Hazard Assessment* and *Environmental Hazard Management Plan* required. No further monitoring required. Manage remaining contamination in accordance with the EHMP.

SECTION 21
ENVIRONMENTAL RISK ASSESSMENT GUIDANCE FOR MARINE COASTAL ENVIRONMENTS

Interim Final October 2018

State of Hawai‘i
Department of Health
Office of Hazard Evaluation and Emergency Response
919 Ala Moana Boulevard, Room 206
Honolulu, Hawai‘i 96814

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SECTION 21 ACRONYMS AND ABBREVIATIONS

µg/kg	Micrograms per kilogram
ANZECC	Australian/New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
ASTM	American Society for Testing and Materials
AVS/SEM	Acid-volatile Sulfide and Simultaneously Extracted Metals
BERA	Baseline Ecological Risk Assessment
BSAF	Biota-to-Sediment Accumulation Factor
CBR	Critical Body Residue
CCME	Canadian Council of Ministers of the Environment
COPEC	Contaminant of Potential Environmental Concern
CSM	Conceptual Site Model
DQO	Data Quality Objective
DU	Decision Unit
EAL	Environmental Action Level
ER-L	Effects Range-Low
ER-M	Effects Range-Median
ERA	Ecological Risk Assessment
ESA	Endangered Species Act
FWS	Fish and Wildlife Service
GIS	Geographical Information System
HDOH	Hawai'i Department of Health
HEER Office	Hazard Evaluation and Emergency Response Office
HMW	High Molecular Weight
HQ	Hazard Quotient
ISQG	Interim Sediment Quality Guideline
LMW	Low Molecular Weight
LOAEL	Lowest Observed Adverse Effect Level
MC	Munitions Contaminants
mg/kg	Milligrams per kilogram
MHI	Main Hawaiian Islands
MIS	Multi Increment sample(s)
NAVFAC	Naval Facilities Engineering Command
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOAEL	No Observed Adverse Effect Level
NWHI	Northwest Hawaiian Islands
OC	Organic Carbon
PAH	Polynuclear Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
PDBE	Polybrominated Diphenyl Ether
ppb	Parts per billion

ppm	Parts per million
SAP	Sampling and Analysis Plan
SLERA	Screening Level Ecological Risk Assessment
SQG	Sediment Quality Guideline
SUF	Site Use Factor
SVOC	Semi-volatile organic compound
TBT	Tributyltin
TCDD	Tetrachlorodibenzo-p-dioxin
TEF	Toxicity Equivalence Factor
TEQ	Toxic Equivalency
TGM	Technical Guidance Manual
TOC	Total Organic Carbon
TRV	Toxicity Reference Value
UCL_{95}	95 percent upper confidence limit on the mean concentration
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VOC	Volatile Organic Compound

21.0 ECOLOGICAL RISK ASSESSMENT GUIDANCE FOR COASTAL MARINE ENVIRONMENTS IN HAWAIʻI

An investigation of contaminants in coastal marine and estuarine sediments in Hawaiʻi is necessarily influenced by the geophysical realities of the islands themselves and the dynamic Pacific Ocean. A brief introduction to the processes that create and redistribute sediments in Hawaiʻi provides a context for the specific guidance on conducting ecological risk assessments (ERAs) in Hawaiʻi.

The shield volcanoes that make up the main Hawaiian Islands are composed mainly of basaltic lavas. Erosion by wind and water break down these basaltic rocks into smaller particles that are transported into streams and ultimately deposited along the coast. At the same time, carbonate sediments derived from marine organisms in the surrounding waters are carried shoreward and deposited along the coast to form beaches (Fletcher et al. 2012). The processes of erosion and deposition of these two major sediment types creates a patchwork of unconsolidated substrates throughout coastal Hawaiʻi. Physical characteristics of the sediment particles, such as grain size and associated organic carbon, play a substantial role in the fate and transport, bioavailability, and toxicity of contaminants in the marine environment. These topics are introduced briefly below.

Grain size is a primary characteristic of sediment that influences the fate and transport of chemicals within the marine or aquatic environment. Geologists identify sediments by size fractions (gravel, sand, silt, and clay) and classify sediments based on the ratio of size fractions using the Wentworth grade scale (USGS 2006):

gravel	2 mm
sand	< 2 mm to > 62.5 µm
silt	< 62.5 µm to > 4 µm
clay	< 4 µm

Geological reports typically define the top 2 cm below the sediment/water interface as surficial sediment (USGS 2006). However, standard practice in ERAs is to focus on the top 10 to 15 cm (about 4 to 6 inches), the biotic zone, where exposure of ecological receptors is greatest.

Many chemicals that cause ecological effects (such as metals, pesticides, PCBs) are known to be associated most strongly with finer-grained sediment, especially silts and clays (also called “muds”) (Morrison et al. 2011). Fine-grained sediments generally accumulate in coastal bays and other sites where wave energy is low or absent. Contaminant concentrations are expected to be highest in such depositional areas where particles smaller than 62.5 µm accumulate (NRC 1989, Grabe and Barron 2004). In contrast, sites with predominantly sand or gravel are less likely to contain toxic levels of contaminants (Morrison et al. 2011).

One of the first studies to demonstrate the importance of grain size in sediment toxicity and bioavailability evaluations focused on PCBs in coastal marine sediments on the Mediterranean coast of France. The survey documented accumulation of low chlorinated PCB congeners with the sand-size fractions (> 63 µm) and of high chlorinated congeners with the silt-size fractions (< 63 µm). Greater bioavailability and toxicity were associated with the congeners in the fine-grained sediments (Pierard et al. 1996). Later studies in coastal marine harbors in the mainland United States corroborated these findings (Ghosh et al. 2003). Concentrations of dioxins and furans (PCDD/Fs) are also known to increase as grain size decreases in marine sediments (Lee et al. 2006). However, higher chemical concentrations may not accurately represent bioavailable fractions when chemicals are bound to finer-grained sediment.

The association of PCBs with fine-grained sediments has been demonstrated in tropical habitats, as well. In a highly-contaminated marine bay in Puerto Rico, PCB concentrations were shown to be influenced not only by grain size, but also by organic content. Moreover, microbiological characteristics (biofilm, bacteria levels, and microbial community composition) acted on the PCBs to reduce chlorination levels both in deeper anoxic sediment and shallow well-oxygenated sediments (Klaus et al. 2016). Toxic levels of lead are reported to be associated with fine-grained particulates carried by certain urban streams on Oʻahu, Hawaiʻi (Hotton and Sutherland 2016).

Coastal habitats in Hawai‘i may contain a mixture of sediment grain sizes from various sources, creating complex sediment profiles and challenging risk assessment scenarios. For example, Hanalei Bay on the north side of Kaua‘i receives fine-grained terrestrial basaltic sediment from taro fields delivered by the Hanalei River. Sand-sized sediment particles composed of calcium carbonate from nearshore coral reefs are transported into the bay by wave action. The Hanalei River carries so much suspended sediment that it often exceeds federal water quality standards for turbidity (Takesue et al. 2009). Despite the dominance of fine-grain sediments near the river mouth, organochlorine pesticides, PAHs, and metals were detected in sediment at very low levels. Concentrations of organic chemicals in Asian clam (*Corbicula fluminea*), giant mud crab (*Scylla serrata*), and Akupa sleeper fish (*Eleotris sandwicensis*) were also below ecological effect levels (Orazio et al. 2010). In contrast, sediment pore water was toxic to sea urchin fertilization (but not development) in clay and mud samples near the river mouth (Carr and Nipper 2007; Cochran et al. 2007). Further complicating the interpretation of ecological risk at this site is the seasonal influence of waves, which can flush out the finer-grained sediment from the bay during winter storms (Takesue et al. 2009).

The studies in Hanalei Bay illustrate the difficulty of drawing conclusions about ecological risk from a single line of evidence. Concentrations of chemicals in sediment of different grain sizes, surface water, pore water, and biota may all contribute to risk, but no single measure can adequately characterize the site. Actual exposure of ecological receptors to contaminant in sediment is influenced by both the presence and bioavailability of contaminated sediment and the absence of wave energy that removes sediment from the site. Although substantial deposition of fine-grained terrestrial sediment containing contaminants could indicate potential ecological risk, the regular winter flushing at this site reduced the risk to acceptable levels (Orazio et al. 2007, Takesue et al. 2009).

Beaches are eroding across Hawaiian Islands that have been evaluated (Kaua‘i, O‘ahu, Maui) more than accreting (Fletcher et al. 2012) and coastal erosion is expected to nearly double over the next few decades across areas studied, except Kailua Beach on O‘ahu. Nevertheless, sediment dynamics are spatially variable, and areas of erosion and accretion may be separated by only a few hundred meters. Each small embayment created by rocky headlands is influenced by local wave energy and terrestrial processes, creating a patchwork of erosion and accretion along the shore. The most recent data on coastal erosion and accretion of shorelines on Kaua‘i, O‘ahu, and Maui are available at (Fletcher et al. 2012). This USGS information should be consulted during the site characterization phase of the SLERA (See Subsection 21.3.3).

Data on grain sizes are site-specific; there is no comprehensive assessment for the state, as grain size on beaches changes seasonally due to wave energy. Most beaches are sand and thus less conducive to adsorbing contaminants compared with finer-grained silt and clay fractions (Storlazzi 2016, personal communication). The risk assessor should review available data on grain size at the site. If grain size has not been adequately characterized at the site (considering season and specific location), data collection should be considered prior to initiating an ERA. If the site is predominantly sand, the need for conducting additional chemical characterization in the area should be evaluated. Based on the CSM, additional chemical characterization may or may not be necessary. If the site has a patchy distribution of grain sizes, chemical characterization should focus on areas where silts and clays are dominant.

The HEER Office ERA program for marine coastal environments provides guidance for conducting screening level ERAs (SLERAs) and Baseline ERAs (BERAs) in these coastal habitats. Alternative approaches or methods to the guidance provided in this section may be acceptable but should be discussed with the HEER Office for approval. The ERA program is process-oriented in that a site progresses only as far as required by the site-specific characteristics. The level of effort devoted to preparing and submitting information to the HEER Office is determined by the level of risk posed by the site. A site may exit the process at any of several points marked by management decisions and supported by technical analysis.

An ERA at a marine sediment site typically begins as a SLERA, and then may proceed to a more site-specific and in-depth BERA, if necessary. In many cases, the ERA will be conducted as part of a larger site investigation, although some sites may be addressed as strictly ERA sites. In both instances, the overall approach to conducting an ecological site investigation should generally be consistent with guidance elsewhere in the TGM, particularly in the following sections:

- **TGM Section 3**: ***Site Investigation Design and Implementation***
- **TGM Section 4**: ***Decision Unit Characterization***
- **TGM Section 5**: ***Field Collection of Soil and Sediment Samples***

This ERA guidance is specific to the tropical marine environment of Hawai‘i, but draws on decades of technical development of ERA methods by federal agencies in the U.S. and their counterparts in Australia and New Zealand, individual state agencies, independent researchers, and universities. This guidance combines the widely-used U.S. EPA framework, which provides a logical step-wise approach to conducting ERAs, with a more regionally focused approach suitable for tropical marine ecosystems. The HEER Office has developed this regionally-focused guidance to efficiently evaluate exposure and effects using Hawai‘i-specific receptor and toxicity data wherever it is available. Readily available ecological exposure and effects data for 22 marine species in Hawai‘i are compiled in this guidance (see Appendix 21-A). As additional ERAs are prepared and more Hawai‘i-specific data become available, the on-line ERA TGM guidance will be updated to fill data gaps and refine exposure and effect default values and assumptions.

The HEER Office assumes that consultants and risk assessors using this guidance are familiar with the concepts and terminology of ERAs. Complete citations for references cited in this ERA guidance are provided in Section 21 References. Appendices to this guidance contain additional information, as follows:

APPENDIX 21-A Species Profiles and Exposure/Effects Data

APPENDIX 21-B ERA SCOPING CHECKLIST

APPENDIX 21-C DEFINING ECOLOGICALLY-BASED DECISION UNITS

APPENDIX 21-D HABITAT PROFILES

APPENDIX 21-E EVALUATING BIOACCUMULATING CHEMICALS

APPENDIX 21-F REFINING ASSUMPTIONS OF BIOAVAILABILITY

APPENDIX 21-G CONTENTS OF A BERA WP/SAP AND BERA REPORT

The risk assessor is responsible for providing technical justification for the methods and assumptions that underlie the ERA. All references cited in the ERA must be made available for review by the HEER Office upon request. The HEER Office maintains a large library of peer-reviewed literature and government reports that may be useful to the risk assessor. Close coordination with the HEER Office will provide opportunities to share references and ensure that the most current useful information is available throughout the ERA process.

21.1 FRAMEWORK FOR ECOLOGICAL RISK ASSESSMENTS

An ERA is a qualitative and/or quantitative appraisal of the actual or potential effects of one or more chemicals on plants and animals in the wild. At its simplest, risk can be defined as a function of the overlap in space and time of a stressor (a chemical) and a living organism (a receptor) where the stressor causes some adverse effect on the receptor. The process of risk assessment is designed to (1) identify the distribution and magnitude of chemical stressors; (2) identify the locations of living organisms that are sensitive to the chemical stressor; and (3) quantify the probability that the receptor will be exposed to the stressor *and* experience adverse effects related to the exposure.

This simple model of spatial and temporal overlap of a chemical and an organism is rarely encountered in the field, however. Instead, ERAs must often address sites where multiple chemicals have been released into several media (soil, groundwater, sediment, surface water) and numerous receptors are potentially exposed during all or part of their complex life cycles. Chemicals may be present but physically bound to media so that they do not exert a toxic effect on organisms. Concentrations of chemicals in background/ambient/reference samples may confound the interpretation of risk at the site. Information on the sensitivity of local organisms to the chemicals at the site may be unavailable. These and other difficult issues make the ERA process complex and add to the uncertainty of decisions based on ERA results.

In an effort to strengthen and streamline the ERA process, USEPA published an 8-step framework for ERAs that has been widely adopted, with modification, by national and state programs around the world (USEPA 1992e). Steps 1and 2 of the USEPA framework, generally referred to as the SLERA, are primarily based on limited site-specific sediment data and default assumptions about exposure and effects. Oftentimes, the SLERA incorporates the initial part of Step 3 (commonly referred to as Step 3a) in which the conservative default assumptions of Steps 1 and 2 are refined to focus the ERA process on the chemicals and receptors of greatest concern at the site. This HEER Office guidance includes Step 3a in the SLERA.

In addition to the USEPA framework, information and technical advances from the Australian/New Zealand Environment and Conservation Council / Agriculture and Resource Management Council of Australia and New Zealand (ANZECC/ARMCANZ) Guidance on ERAs will continue to be evaluated as they pertain to tropical marine sediments. Tables and data in the HEER Office TGM will be updated periodically as new information becomes available from sources relevant to tropical marine environments.

The risk assessor should realize that preparing an ERA is seldom a simple or linear process. More often, the risk assessor will work with data from many disciplines, including geologists, hydrologists, toxicologist, ecologists, and chemists to develop an understanding of the unique situation at the site. Some of the required elements may be available to the risk assessor from the start, while others may prove to be unobtainable within the time frame of the investigation. The steps and tasks can be approached in a different order; some processes may run concurrently and some may be repeated as the need for additional information becomes apparent. The risk assessor should maintain communication with the HEER Office and seek confirmation and clarification on the chosen approach whenever necessary.

21.2 DETERMINE THE NEED FOR A SLERA

An ERA is not required at every site where a release of chemicals has occurred. Sites where no ecological habitat exists or exposure pathways are incomplete are not required to be evaluated for ecological risk. Areas of coarse-grained sediment and high wave energy may require little or no investigation (see *ERA Scoping Checklist* in Appendix 21-B). To determine the need for an ERA, a person familiar with the site should complete the *ERA Scoping Checklist* (Appendix 21-B). The checklist is designed to help the risk assessor characterize the ecological setting of the target site and to identify complete and potentially important ecological exposure pathways. The checklist guides the risk assessor through the process of identifying relevant documents and organizing available information on the need for an ERA, referring to subsections of this HEER Office ERA Guidance when necessary. The *ERA Scoping Checklist* should be completed early in the investigation process to support a determination on the need for a SLERA at the site.

The preparer submits the *ERA Scoping Checklist* to the HEER Office for review. The HEER Office confirms that the checklist is complete and recommends future action, if warranted. If the *ERA Scoping Checklist* indicates that the site is excluded from ERA requirements, no other action is necessary. If the *ERA Scoping Checklist* indicates that exposure pathways are potentially complete and ecological habitat may be affected, then the risk assessor should initiate a SLERA in accordance with this guidance.

Sites where a potential ecological risk occurs may be evaluated using a SLERA, a BERA, or both. Most sites begin with the SLERA, although this is not strictly required. If the risk assessor believes that site conditions are relatively certain to warrant a BERA, then it is not necessary to conduct a separate SLERA. The conceptual elements of a SLERA will ultimately be incorporated into the BERA, but skipping the SLERA steps can save the risk assessor time and effort that can be better dedicated to the BERA. The risk assessor should consult with the HEER Office to obtain agreement on such an approach before initiating a BERA.

21.3 SCREENING LEVEL ECOLOGICAL RISK ASSESSMENT

Unlike the *ERA Scoping Checklist*, which can be completed by anyone familiar with the site, the SLERA should be prepared by a person or a team with knowledge of the chemicals, receptors, exposure pathways, and other ERA elements necessary to the investigation.

The purpose of the SLERA is to focus investigation and remediation on sites and chemicals that may pose an unacceptable risk to ecological receptors. The SLERA provides an opportunity for a site to exit the ERA Program with a minimum of effort if the site truly poses very little or no risk to ecological receptors. In cases where the entire site cannot be shown to pose a level of risk below applicable screening levels or alternate (approved) decision level based on a more a detailed evaluation, selected chemicals or receptors may still be identified for possible elimination from further investigation in later steps of the ERA.

21.3.1 PREPARING FOR A SLERA

If the ERA is being conducted as part of a larger site investigation, data collected for other purposes may be available to initiate the SLERA, as shown in Step 1b (Table 21-1). For example, sites where a chemical release happened some time ago may have been investigated for risk to human health. Sites where a discrete release of chemicals occurred may have been subjected to emergency removal actions and/or an investigation of residual risk. In such cases, the risk assessor should gather all available data from the site in preparation for the SLERA. Note that the existence of data from an umbrella investigation does not necessarily mean that no additional samples will be required. Available site-specific data are reviewed for usability during Step 1b and the need for additional data to adequately characterize current site conditions is determined. The risk assessor is encouraged to consult with the HEER Office if unsure about the need for additional data collection. Of special concern is the potential need for additional data collection in cases where existing data were based on a small number of discrete samples, which are not likely to be representative of the decision unit (see TGM Section 4). On the other hand, the risk assessor may have access to additional site-specific data not typically required for a SLERA (such as field-collected tissue samples). In such cases, the additional data can certainly be used in the SLERA to support a decision on the need for further investigation (see Step 2).

If the SLERA is being conducted outside the context of a larger investigation, then some additional steps will be necessary to initiate development of data collection suitable to support a SLERA. (Step 1a, Table 21-1). Guidance on conducting a general site investigation is provided in Sections 3.0, 4.0, and 5.0 of the TGM. Specifically, any field sampling and analysis plan (SAP) should be prepared in accordance with the decision unit (DU) and Multi Increment sampling (MIS) approach described in the TGM. Additional guidance on defining DUs for ERAs is in Appendix 21-C.

The risk assessor should review the pertinent subsections of the TGM, then consult with the HEER Office for assistance in developing a SAP that satisfies the requirements of a SLERA.

Table 21-1. SLERA Framework

Step 1A: Develop and Implement Screening Level Sampling and Analysis Plan (if available data are not adequate to support a SLERA)		
Only as Needed:	**Activities:** If site-specific data are not available, prepare a sampling and analysis plan (SAP) in accordance with site investigation guidance in Sections 3, 4, and 5 of the TGM, including clear data quality objectives (DQO). Once data are available, complete the outputs in Step 1B and then proceed to Step 2 below	**Outputs:** • DQOs • SAP • Maps or figures of site, including habitats and proposed sample locations • Data tables (if analytical data are available) • Preliminary Conceptual Site Model (CSM)

Step 1B: Screening Level Site Characterization Data and Ecological Effects Evaluation	
Activities: Task 1-1: Describe environmental setting (location, habitats, expected species, sources of chemicals, previous investigations) Task 1-2: Compile available site-specific and background, ambient, and reference analytical data (from *ERA Scoping Checklist* or other sources); include a description of ecotoxicity and bioaccumulative potential of target chemicals Task 1-3: Select assessment and measurement endpoints (see USEPA 1996za; 2016b) Task 1-4: Identify exposure pathways and ecological receptors Task 1-5: Develop preliminary CSM	**Outputs:** • Maps or figures of site • Data tables • Assessment and Measurement Endpoints identified • Preliminary CSM
Step 2: Estimate Preliminary Exposure Concentrations and Calculate Hazard Quotients	
Activities: Task 2-1: Compile screening levels for all media in your dataset. Sediment quality guidelines (SQG) are in Table 21-7. Surface water, groundwater, and sediment pore water should be screened against HEER Office Environmental Action Levels (EALs) for aquatic toxicity (aquatic habitat goals), surface water, and/or groundwater, as applicable and if included in this guidance (see HEER Office EAL Surfer tool). USEPA National Water Quality Criteria (USEPA 2016a, or current reference) can be referenced for chemicals not included in HEER Office EALs (if available). Tissue concentrations may be compared with critical body residues (CBR) reported in the literature). Toxicity reference values (TRV) for receptors evaluated through food chain modeling (e.g. mammals and birds) may be derived from published studies and reports. Task 2-2: Estimate average exposure concentrations that are representative for sediment and/or water decision units at the site (see TGM Sections 3, 4, and 5). Task 2-3: Calculate daily dose for higher trophic level receptors (birds and mammals). Task 2-4: Calculate hazard quotients (HQ) using *representative DU-MIS concentrations for sediments/no effect screening levels, representative pore water or surface water concentrations/no effect screening levels*, or *maximum tissue concentrations* to calculate daily doses for comparison with low TRVs. Task 2-5: Summarize HQs, identify chemicals of potential ecological concern [COPEC], and make a decision about the site. If risk is potentially unacceptable, continue to Step 3A), otherwise the ERA process can stop.	**Outputs:** • List of applicable screening levels (and source) for selected media and receptors • Estimated contaminant levels in site decision units/media compared with screening levels • Summary of HQs • Identification of COPECs • Decision Statements
Step 3A: Refine Screening Level Default Assumptions	

Activities:	Outputs:
Task 3-1: Compile available data representing background, ambient, or reference concentrations and submit to the HEER Office for concurrence. Compare the site sediment and/or water concentrations with background, ambient, and reference concentrations, as available. Task 3-2: Evaluate the magnitude of exceedance, frequency of detection, and distribution of exceedances in sediment (and water, if appropriate) at the site to determine whether any chemicals should be eliminated as COPECs. Task 3-3: Confirm that the data used are reasonably representative for decision units at the site. Evaluate the reasonableness of default conservative exposure assumptions (100 percent bioavailability of chemicals, 100 percent site use by receptors, maximum chemical concentrations, etc.) and adjust assumptions (if appropriate). Consider the influence of geophysical and geochemical parameters such as grain size, total organic carbon, pH, and other factors on bioavailability of chemicals. If the area is known to be erosional, consider the short-term and long-term fate of contaminated sediments. Task 3-4: Confirm with HEER Office that the Step 3a refinements are technically defensible based on site conditions. Task 3-5: Recalculate HQs using more realistic representative exposure concentrations. Task 3-6: Summarize HQs, evaluate uncertainty, and develop risk characterization to support a decision about the site. If risk is potentially unacceptable, continue to the baseline ERA (BERA); if not, the ERA process can stop.	• Data tables of background or reference concentrations • Technical justification for adjusting exposure assumptions and concentrations • Table of adjusted HQs • Technical justification for elimination of COPECs, if applicable • Decision Statements

21.3.2 COMPONENTS OF A MARINE SEDIMENT SLERA

In the interest of streamlining the SLERA process and promoting consistency among SLERAs, the HEER Office provides examples or templates for many of the common components of a SLERA. Additional examples/templates will be added to this TGM as they are developed.

Table 21-2. Components of a Marine Sediment SLERA

Required Information	Source of Information
Representative concentrations of chemicals in sediment from the site	Risk assessor (representing site owner/regulated community) compiles available site-specific data.
Sediment Quality Guidelines (SQG), HEER Office EALs and background/ambient/reference concentrations	HEER Office provides SQGs for most target chemicals (See Table 21-7); HEER Office provides EALs for aquatic toxicity, surface water, and groundwater (see EAL surfer; risk assessor supplements as needed.
Potential receptors (identified by habitat or exposure guild)	HEER Office provides species profiles and exposure/effects data (Appendix 21-A, habitat profiles (Appendix 21-D); risk assessor selects and augments as necessary.
Conceptual Site Model (CSM) (identifying pathways and representative receptors)	HEER Office provides examples for several habitats (Figures 21-2 through 21-7); risk assessor customizes to site and supplements when necessary.

Sediment dynamics (erosional or depositional)	Risk Assessor provides, based on US Geological Survey reports (Fletcher et al. 2012) or site-specific data
Toxicological profiles for COPECs	Risk Assessor provides; HEER Office may assist with reference materials.
Exposure factors for assessment endpoint receptors	HEER Office provides examples for some common receptors; risk assessor supplements as necessary (Appendix 21-A).

21.3.3 STEP 1B: SCREENING LEVEL SITE CHARACTERIZATION DATA

The screening-level site characterization, known as preliminary problem formulation, serves as an organizing foundation for the SLERA. It incorporates physical, chemical, and biological elements and features of the site that will guide the ERA process. Although each site is different, Step 1B usually includes five tasks, which are introduced below and discussed in more detail in the subsections below:

- Describe environmental setting (location, habitats, expected species, sources of chemicals, previous investigations) and summarize results of previous investigations [Step 1B, Task 1]
- Compile available site-specific, background, ambient, and reference analytical data (from *ERA Scoping Checklist* or other sources); include a description of ecotoxicity and bioaccumulative potential of target chemicals [Step 1B, Task 2]
- Select assessment and measurement endpoints [Step 1B, Task 3].
- Identify exposure pathways and receptors [Step 1B, Task 4]
- Develop preliminary CSM, [Step 1B, Task 5]

21.3.3.1 STEP 1B, TASK 1; DESCRIBE ENVIRONMENTAL SETTING

The environmental site setting includes a description of the location, habitats, expected species, sources of chemicals, and other site-specific information pertinent to the SLERA. The site setting should be based on information gathered during a site visit and/or readily available information.

The HEER Office has compiled a list of habitat types (see Table 21-3) and more detailed information on several key habitat types in Hawai‘i (see Appendix 21-D) to aid in developing the environmental setting and help foster consistency in ERAs across the state. Additional habitat profiles will be provided under subsequent phases of guidance development.

Habitat information in Appendix 21-D should be augmented by the following site-specific information whenever possible:

- Physical description of the site including:
    - Size (acres)
    - Potentially affected habitats (mudflats, coral reefs, seagrass beds, etc.) [Include map or figure of location and habitat types.]
    - Sediment type or grain size distribution (coral rubble, coarse sand, silt, etc.)
    - Wave environment (high energy, low energy, protected harbor, etc.)
    - Salinity, tidal range (intertidal, subtidal), bathymetry, etc.
    - Erosional/Depositional area (see Fletcher et al. 2012)
- Current and historical uses of the site (known or suspected)
- Potential ecological receptors present at the site (per habitat within site)
- Surrounding land use
- Any potential sources of contaminants not related to the site activities (storm water outfalls, stream discharge, nearby industries, recreational vessel traffic, etc.)
- Known or suspected threatened and/or endangered species or other protected species/habitats within or adjacent to the site
- Maps, photographs, and figures of the site (current and historical)
- Any site-specific studies conducted at the site or in adjacent habitats

A habitat is considered important if it comprises a substantial portion of the site or provides high-value areas for target receptors. Provide as much detail as is available about the relative distribution of habitats within the site. For example, at a site that is 90 percent soft-bottom and 10 percent coral rubble covered with algae, both soft-bottom and algae-covered rubble would be included as important habitat types. The soft-bottom is spatially dominant and the algae-covered rubble provides sheltering and foraging habitat likely to be used disproportionately by some receptors.

Table 21-3. Unique or Distinct Aquatic Habitat Types and Locations in Hawai‘i

Habitat Type	Description/ Example Locations
Mudflats/Coastal Wetlands/Lagoon (Appendix 21-D)	Significant mudflats occur in Mamala Bay, Pearl Harbor, and Kāne‘ohe Bay
Rocky Intertidal and Tidepools (Appendix 21-D)	Rocky intertidal habitat dominates most shorelines of all islands where constant wave action, currents, steep submarine slopes, and a lack of offshore sand reservoirs limit the accumulation of sand. ‘Īlio Point on Hawai‘i is a typical high-energy tidepool habitat.
Coastal Fishponds (Appendix 21-D)	Mamala Bay, Pearl Harbor, several around Kāne‘ohe Bay, and three on the southwestern coast of Kaua‘i.
Seagrass Beds (Appendix 21-D)	Significant seagrass beds are known from the inner reef flats of south Moloka‘i; ‘Anini (Kaua‘i); near Mamala Bay and Kāne‘ohe Bay; others exist but are not mapped
Mixed Sediment Bays and Harbors (Appendix 21-D)	Pearl Harbor; soft sediment overlaid on limestone platform of fossil reef origin; soft sediments often composed of carbonate grains derived from coralline algae, coral, mollusk fragments, foraminiferans, and tests of bryozoans and echinoderms
Young Volcanic Substrate; Little Sediment (profile not yet complete)	Big Island
Deep Channels (profile not yet complete)	‘Alenuihāhā Channel, between Hawai‘i and Maui
Soft Sediment Bays (profile not yet complete)	Hanalei Bay, Kaua‘i; no coral rubble
Sandy Beach (profile not yet complete)	Along the lagoon reaches of atoll islets and especially along the west and south sides of Kaua‘i, O‘ahu, Moloka‘i, Maui, Lāna‘i, and Hawai‘i; also along bays and coves on mature islands
Anchialine Pools (profile not yet complete)	Rocky shorelines on most islands, up to several hundred meters inland; The Kaloko-Honokohau Park on the western coast of Hawai‘i contains about 10% of Hawai‘i's anchialine ponds.
Stream-fed Estuarine Wetlands (profile not yet complete)	Mamala Bay and Kāne‘ohe Bay, O‘ahu
Mangroves (Introduced) (profile not yet complete)	In addition to invading coastal fishponds (see above), mangroves have spread to mud flats and estuarine waters around most of the Islands and to some rocky coastal areas around Hawai‘i Island.
Subtidal Hardbottom (profile not yet complete)	Hardbottom occurs on every island; shallow benthic communities occur in depths of up to 50 meters or more, on basalts, and on consolidated limestone (reef carbonates, beach rock). The distribution of benthic communities is determined by light penetration, temperature, wave action, availability of substrate, and movement and accumulation of sediments.
Coral Reef (profile not yet complete)	About 80% of coral reef habitat in Hawai‘i is in the Northwest Hawaiian Islands (NWHI), including atolls, islands, and banks. The high volcanic islands of the Main Hawaiian Islands (MHI)

	typically include non-structural reef communities, fringing reefs, and two barrier reefs (Kāneʻohe Bay and Moanalua Bay, Oʻahu).

Species at the Site

Species at the site should be grouped into two categories: (1) typical or common species and (2) threatened, endangered, or specially protected species. A list of typical or common species can be generated using Hawaiʻi-specific publications and websites cited throughout this guidance. Profiles of select species are in Appendix 21-A.

Information on threatened, endangered and otherwise protected species and habitats is widely available on websites published by state and federal resource agencies. The status of species and habitats may change over time. The risk assessor should check the websites below, and other websites, as necessary, to make sure the most current information is used in the ERA:

- The Hawaiʻi Department of Land and Natural Resources 700-page review, *Hawaiʻi's Comprehensive Wildlife Conservation Strategy*, describes habitats, species, and threats across the MHI and NWHI (Mitchell et al. 2005). This document lists and describes the distribution and abundance of species of "greatest conservation need," and provides locations and relative condition of key habitats; threats to species; conservation actions proposed; and plans for monitoring species and their habitats. Fact sheets address larger taxa or groups relevant to the marine ERA program, including waterbirds, seabirds, migratory shorebirds and waterfowl, anchialine pond fauna, marine mammals, marine reptiles, marine fishes, and marine invertebrates.
- Species *Recovery Plans*, critical habitat designations, and *5-Year Status Reviews* provide extensive information on life history and habitat requirements, as well as current threats to the species protected under the Endangered Species Act (ESA). Recovery plans for species under the jurisdiction of U.S. Fish and Wildlife Service (FWS), such as coastal birds, are available at (USFWS 2018). See (USFWS 2018b) for links to documents proposing and designating critical habitat for FWS species. Links to *5-Year Status Reviews* are on the species profile page for each species.
- The National Oceanic and Atmospheric Administration, Pacific Islands Regional Office of the National Marine Fisheries Service (NOAA 2018) provides information on ecological resources including protected species and unique habitats.
- The U.S. Navy has compiled data on Hawaiian species in the following documents:
    - U.S. Navy's most recent marine resource assessment for Hawaiʻi (Navy 2005).
    - Hawaiʻi-Southern California Training and Testing Environmental Impact Statement (EIS) and Overseas EIS (Navy 2017)
    - Hawaiʻi Range Complex EIS (Navy 2009)

Identify Potential Sources of Contamination

The site-specific data compilation activities of the SLERA should identify contaminants potentially present at the site and the sources of those contaminants based on the types of activities known or suspected to have taken place at the site. Typical point sources and COPECs are compiled in Table 21-4. While the information in Table 21-4 can be used as a starting point, it should not be assumed that these are the only chemicals associated with site activities. Activities specific to a particular facility may have resulted in different and/or additional chemicals being released into the environment. Also, because operations often change at a site over time, a thorough search of the site history is needed to determine which chemicals may be present at the site.

Table 21-4. Point Sources of Target COPECs in Hawai‘i

Type of Point Source	Chemicals	Example Locations	Documents
Harbors and marinas	Antifouling compounds (Irgarol and other copper-based compounds); polycyclic aromatic hydrocarbons (PAHs)	Ala Wai Marina, Kāne‘ohe Bay Yacht Club , Kāne‘ohe Bay Makani Kai Marina, Sand Island Ke‘ehi Marina, Waikīkī Yacht Club	(Knutson et al. 2012)
Former military installations or disposal sites	Metals, polychlorinated biphenyls(PCBs), munitions (energetics), pesticides	Wai‘anae, O‘ahu; Mākua Military Reservation, O‘ahu; Midway Atoll, Sand Island	(Garcia et al. 2009); (ACOE 2012); (Tetra Tech 2009); (Taylor et al. 2009)
Long Range Navigation (LORAN) stations	PCBs, lead	Kure Atoll, Cocos Island, Guam; ‘Īlio Point, Moloka‘i; Tern Island, French Frigate Shoals	(Element Environmental 2009); (Element Environmental 2010); (ESI 2012); (USCG 2000); Woodward-Clyde Consultants 1994)
Shipyards	Tributyltin (TBT), antifouling paints, copper, zinc	Pearl Harbor, O‘ahu	(Grovhoug 1992) (NAVFAC 2007)
Former shooting ranges on coast	Lead shot		
Estuaries	Metals, PAHs, pesticides, pharmaceuticals, polybrominated diphenyl ethers (PDBE), pathogens, PCBs		(Grovhoug 1992)(NAVFAC 2007)
Sugar mill or canec manufacture dumping areas	arsenic, herbicides	Waiākea Mill Pond, Wailoa River	(Hallacher et al. 1985) (HDOH 2005c)
Urban/ storm drains	PAHs	Various streams, O‘ahu	(Zheng et al. 2011)
Urban/ storm drains	Metals	Nu‘uanu watershed, O‘ahu	(Andrews and Sutherland 2004)
Urban Run-off	Microbial and nutrients	Hanalei Bay, Kaua‘i	(Boehm et al 2011)
Urban Run-off	Pesticides and metals	Various locations in O‘ahu and Kaua‘i	(Brasher and Wolf 2007)
Agricultural Run-off	Pesticides	Pineapple fields; Honolua Stream entering Honolua Bay, Maui	
Agricultural Run-off	Arsenic, herbicides, pesticides	Island of Hawai‘i sugar cane plantation	(Cutler et al. 2013)
Agricultural Run-off	Pesticides	Taro ponds; run-off to Hanalei River, Kaua‘i	(DLNR DAR 2012)
Golf courses	Herbicides; pesticides		
Sewage outfalls	Metals, PAHs, pharmaceuticals, pathogens		
Sediment disturbance			
Coastal marine construction sites	All chemicals associated with sediment in given location		

Dredging	All chemicals associated with sediment	Kūhīo and Hilo Bays, Hilo Commercial Harbor, Hawai'i Island	(ACOE 2008)
Shoreline erosion (landfill)	All chemicals associated with sediment; solid waste in landfills exposed to water and air		

21.3.3.2 STEP 1B, TASK 2; COMPILE AVAILABLE SITE-SPECIFIC AND REFERENCE DATA ON CHEMICALS AND ENDPOINTS

Step 1b, Task 2 requires the risk assessor to compile available site-specific and reference analytical data (from *ERA Scoping Checklist* or other sources), evaluate ecotoxicity screening levels, and identify bioaccumulative chemicals.

All analytical data collected at the site during current or previous investigations should be compiled and evaluated for use in the SLERA. Analytical data more than five years old may no longer be representative of site conditions and should be discussed with the HEER Office.

A list of site-related chemicals compiled during the scoping phase (see Subsection 21.2 and Appendix 21-B, Table B-1) will be evaluated in the SLERA. Chemicals that act primarily through direct toxicity are evaluated using a hazard quotient (HQ) approach in Step 2. Chemicals that are known or expected to bioaccumulate in living organisms are also evaluated separately because sediment and water screening levels do not typically incorporate risk due to bioaccumulation in tissues (see Appendix 21-E).

Site-specific and reference data compilations for the SLERA should describe the direct toxicity and bioaccumulation potential of COPECs at the site. Direct ecotoxicity of COPECs in sediment is evaluated by comparison of sediment concentrations with SQG designed to be protective of benthic invertebrates in direct contact with sediment (see Subsection 21.3.4 and Table 21-7). In the SLERA, the ecotoxicity evaluation may focus on groups of chemicals such as organochlorine pesticides, as opposed to specific pesticides. The risk assessor may augment the HEER Office SQG in Table 21-7 with data from the published literature to develop ecotoxicity profiles for COPECs whose primary mode of action is direct toxicity. HEER Office EALs (screening levels) for aquatic habitat goals, surface water, and groundwater can be referenced and used for data evaluation, as applicable. See the detailed table links in the EAL surfer tool for breakdown of the aquatic habitat goals and surface water EALs by marine, estuarine, or freshwater categories.

Separate from direct toxicity, some chemicals bioaccumulate in living organisms, meaning that they contain higher concentrations of a chemical in their tissues than in surrounding sediment or water. When bioaccumulated chemicals are transferred from one organism to another through the food web, the concentration may increase even more, in a process called biomagnification. Bioaccumulation of chemicals in tissues provides a pathway for chemicals to transfer to on-site and off-site receptors. The concentration of a bioaccumulating chemical in sediment may be considered safe for receptors in direct contact with sediment but not for receptors higher on the food web. Therefore, bioaccumulative chemicals require additional evaluation in the SLERA to determine whether they pose adverse risks to higher trophic levels that are not addressed by the SQGs.

21.3.3.3 STEP 1B, TASK 3; SELECT ASSESSMENT AND MEASUREMENT ENDPOINTS

A key task of the SLERA site characterization process is to identify the ecological resources to be protected at the site (known as **assessment endpoints**) and the measures used to evaluate risks to those resources (known as **measurement endpoints** or **measures of effect**). Assessment endpoints are explicit expressions of the environmental value that is to be protected. The selection of these endpoints is based on the habitats present, migration pathways of probable contaminants, and relevant exposure routes for the receptors. Suitable assessment endpoints species are characterized as follows:

- ecological relevance;
- susceptibility to known or potential stressors; and
- relevance to management goals (USEPA 1998).

For additional discussion of the selection of proper assessment endpoints, see the following:

- *Generic Ecological Assessment Endpoints (GEAEs) for Ecological Risk Assessment: Second Edition with Generic Ecosystem Services Endpoints added.* (USEPA 2016b)
- *Guidelines for Ecological Risk Assessment* (USEPA 1998i)

- *ECO Update: Identify Candidate Assessment Endpoints Ecological Significance and Selection of Candidate Assessment Endpoints* (USEPA 1996za)

Measurement endpoints are estimates of quantifiable biological features or processes (such as mortality, growth, and reproduction) that are believed to be linked to meaningful effects on the assessment endpoints selected at the site.

Assessment endpoints selected for the SLERA are typically carried through to the BERA, unless it is discovered during the SLERA that the species does not fit the requirements of an assessment endpoint (it is not present, not exposed to contaminated media, not valued by the community, or eliminated during earlier steps in the SLERA). Measurement endpoints selected for the SLERA are often augmented in the BERA by endpoints more focused on particular chemicals or pathways of interest at the site.

Example preliminary assessment and measurement endpoints for a coastal marine sediment site in Hawai'i are in Table 21-5. Measurement endpoints for the SLERA and the BERA are shown to illustrate the differences between the two phases of an ERA.

Table 21-5. Assessment and Measurement Endpoints: Coastal Marine Sediments

Ecological Guild	Assessment Endpoint	Typical Species	Measurement Endpoint
Seaweed (Limu)	Organism Level: Survival, growth, and reproduction Population/Community Level: Distribution and abundance within DU	• Sea lettuce (*Ulva fasciata*) • Limu kohu *(Asparagopsis taxiformis)*	**SLERA:** • Concentrations of chemicals in site MIS sediment samples compared with SQG protective of marine algae. • Estimates of tissue concentrations using biota-to-sediment-accumulation-factors (BSAFs) compared with tissue effect levels for marine algae (Tissue effect levels identified through literature review).
			BERA: Concentrations of chemicals in composite samples of tissues collected from the DU or estimates of tissue concentrations from sediment using BSAFs compared with tissue effect levels for marine algae (Tissue effect levels identified through literature review). • Comparison of tissue concentrations in site samples to tissue concentrations in reference areas • Laboratory toxicity test measuring survival and growth; laboratory bioaccumulation test to provide tissue concentrations (in place of field-collected organisms: see above) • Comparison of population metrics in DU (distribution and abundance) with reference area
Soft-bodied benthic invertebrates (macroinfauna)	Organism Level: Survival, growth, and reproduction Population Level/Community Level: Distribution and abundance within DU	• Polychaete (*Neanthes arenaceodentata*)	**SLERA:** Concentrations of chemicals in site MIS sediment samples compared with SQG protective of polychaetes.
			BERA: • Concentrations of chemicals in composite samples of whole body tissues collected from the DU or estimates of whole body tissue concentrations from sediment using BSAFs compared with CBR levels (effect levels) for

			polychaetes (CBRs identified through literature review). • Laboratory toxicity test measuring survival and growth; laboratory bioaccumulation test to provide tissue concentrations (in place of field-collected organisms: see above) • Comparison of population/community metrics in DU (distribution and abundance) with metrics at a reference area
Stony Corals	Organism Level: Survival, growth, and reproduction (of colony) Population/Community Level: Distribution and abundance within DU	• Lobe coral (*Porites lobata*)	**SLERA:** Concentrations of chemicals in site MIS sediment samples compared with SQG protective of corals. **BERA:** • Concentrations of chemicals in composite samples of coral tissues from the DU compared with CBR for corals and with reference areas • Comparison of tissue concentrations in site samples to tissue concentrations in reference areas • Direct toxicity test using coral test organisms • Comparison of relative percent cover, growth rates, external signs of health with corals in reference area
Epibenthic Invertebrate (macrofauna)	Organism Level: Survival, growth, and reproduction Population/Community Level: Distribution and abundance within DU	• Samoan crab (*Scylla serrata*) • Kona crab (*Ranina ranina*) • White crab (*Portunus sanguinolentus*) • Helmet urchin (*Colobocentrotus atratus*) • Hawaiian limpet (*Cellana exarata*) • Black sea cucumber (*Holothuria atra*) • Day octopus (*Octopus cyanea*)	**SLERA:** • Concentrations of chemicals in site MIS sediment samples compared with SQG protective of epibenthic macrofauna • Estimates of whole body tissue concentrations from sediment using BSAFs compared with CBR levels (effect levels) for surrogate benthic invertebrates. **BERA (Echinoderm only):** Laboratory toxicity test of effect of exposure to sediments and/or sediment pore water on sea urchin survival and development. **BERA (Other macrofauna):** • Concentrations of chemicals in composite samples of whole body tissues representing the DU or estimates of whole body tissue from sediment using BSAFs compared with critical body residues levels (effect levels) for surrogate epibenthic invertebrates. • Comparison of population metrics (distribution and abundance) with metrics at a reference area
Benthic Fish (herbivores,	Organism Level: Survival, growth, and reproduction	• Goatfish (*Mulloides vanicolensis*)	**SLERA:** • Concentrations of chemicals in MIS sediment samples compared with SQG protective of fish.

corallivores, carnivores)	Population Level: Distribution and abundance within DU	• Hawaiian flagtail (*Kuhlia sandvicensis*) • Pacific sergeant (*Abudefduf abdominalis*) • Mozambique tilapia (*Oreochromis mossambicus*) • Spectacled parrotfish (*Chlorurus perspicillatus*) • Yellowbar parrotfish (*Calotomus zonarchus*) • Moray Eel (Muraenidae)	• Estimates of tissue concentrations from sediment using BSAFs) derived from field studies on similar fishes compared with CBR (effect levels) for tropical fishes. **BERA:** • Concentrations of chemicals in composite samples representing the DU (whole body or organ tissues) or estimates of tissue concentrations from sediment using BSAFs derived from field studies on similar fishes compared with critical body residues levels (effect levels) for tropical fishes. • Comparison of population metrics (distribution and abundance) with metrics at a reference area
Pelagic Fish (piscivores)	Organism Level: Survival, growth, and reproduction Population Level: Distribution and abundance within DU	• Giant trevally (*Caranx ignobilis*) • Mahi mahi (*Coryphaena hippurus*)	**SLERA:** No direct link to sediment. Assume food web link to lower trophic levels in the DU. **BERA:** • Concentrations of chemicals in composite samples of tissues from decision unit compared with CBR levels (effect levels) for tropical fishes. • Concentrations of chemicals in composite samples of tissues from DU compared with reference area
Sea turtles	Organism Level: Survival, growth, and reproduction Population Level: Distribution and abundance within DU	• Green sea turtle (*Chelonia mydas*)	**SLERA:** Conservative estimate of daily ingested dose of contaminant within DU compared with no observed adverse effect level (NOAEL) TRVs for sea turtles (or surrogate reptiles). (TRVs identified through literature review). **BERA:** Realistic estimate of daily ingested dose of contaminant within DU compared with lowest observed adverse effect level (LOAEL) TRV for sea turtles (or surrogate reptiles). TRVs identified through literature review.
Piscivorous birds	Organism Level: Survival, growth, and reproduction Population Level: Distribution and abundance within DU	• Wedge-tailed shearwater (*Puffinus pacificus*) • Black-crowned night heron (*Nycticorax nycticorax hoactli*) • Hawaiian coot (*Fulica alai*)	**SLERA:** Conservative estimate of daily ingested dose of contaminant within DU compared with NOAEL TRV for piscivorous seabirds (or surrogate birds). (TRVs identified through literature review). **BERA:** Realistic estimate of daily ingested dose of contaminant within DU compared with LOAEL TRV for piscivorous seabirds (or surrogate birds). TRVs identified through literature review.

Marine mammals	Organism Level: Survival, growth, and reproduction Population Level: Distribution and abundance within DU	• Spinner dolphin (*Stenella longirostris*) • Hawaiian monk seal (*Monachus schauinslandi*) [endangered species: assess at the level of individual]	**SLERA:** Conservative estimate of daily ingested dose of contaminant within DU compared with NOAEL TRV for marine mammals (or surrogate carnivorous mammal). TRVs identified through literature review.
			BERA: Realistic estimate of daily ingested dose of contaminant within DU compared with LOAEL TRV for marine mammals (or surrogate carnivorous mammal).

21.3.3.4 STEP 1B, TASK 4; IDENTIFY COMPLETE EXPOSURE PATHWAYS AND POTENTIAL ROUTES OF EXPOSURE

Complete exposure pathways consist of contaminants, receptors, and routes (such as direct contact, sediment ingestion, and food chain transfer).

- ***Receptors:*** Living organisms present or potentially present at the site are the focus of the SLERA
- ***Exposure Medium:*** This part of the TGM addresses sediment as the primary exposure medium. Organisms in direct contact with the sediment may take up chemicals in their tissues and become sources of contaminants to animals that consume them. Exposure to contaminated food items (and ingested sediment) is evaluated using food chain models (see Subsection 21.3.4: Step 2, Task 3 below).
- ***Depth of Sediment Exposure:*** Benthic invertebrates typically live either on the surface of the sediment or within the top layer where water and oxygen exchange occur (the biotic zone). The default assumption of exposure depth for a SLERA is that benthic and epibenthic receptors are exposed to the top 10 cm of sediment. However, if receptors are known to burrow deeper in the sediment at a particular site, the exposure pathway to deeper sediment layers should be evaluated in the SLERA.
- ***Routes of Exposure:*** The SLERA should focus on routes of exposure most likely to be significant. Receptors living on or in the sediment are exposed primarily through direct contact; they may also be exposed to ingested sediment. Other receptors are indirectly exposed to sediment by consuming organisms that were in direct contact with the sediment.

The preliminary CSM for a SLERA relies on the published literature to predict occurrence of receptors and the trophic relationships among receptors at the site. Reports and publications written for purposes other than contaminant studies can be good sources of information on ecological processes and relationships in a given habitat type or location. For example, NOAA prepared a diagram of trophic linkages on the kaloko reef system for a report on energy flow on the Kona coastline (NOAA 2018b) (Figure 21-1). Although the NOAA project was not focused on contaminants, it provides valuable information on species occurrence and trophic relationships that could be incorporated into a SLERA in that location.

21.3.3.5 STEP 1B, TASK 5; DEVELOP THE SCREENING LEVEL PRELIMINARY CONCEPTUAL SITE MODEL

The CSM presents a description of predicted relationships between receptors and chemicals. It is an integrated model of contaminant sources, transport pathways, and receptors that represents potential contaminant dynamics at the site. CSMs range from simple diagrams to detailed illustrations of habitat emphasizing trophic transfer. To the extent possible, include expected effects of climate change, such as sea level rise, in the CSM.

Elements of a CSM

Regardless of the style, the CSM should depict how contaminants are believed to move across the site (fate and transport) and how receptors might be exposed to contaminants in various media (exposure pathways). The CSM should also identify assessment endpoints, which are the particular functional features of the ecological community to be protected, or representative surrogate species. Table 21-6 presents a list of required elements of the CSM.

Table 21-6. Elements of a Marine Sediment Ecological CSM

Sources of Chemical in Marine Sediments
• Terrestrial soils (via erosion, stream discharge)

- Spills into water body
- Surface water runoff
- Ground water infiltration
- Sediment “hot spots” (of unknown origin)
- Outfalls (combined sewer, storm water, industrial)
- Atmospheric deposition (including volcanic activity)

Contaminant Transport Pathways

- Sediment (including resuspension; natural or by human activity)
- Surface water transport
- Soil erosion
- Ground water advection
- Bioturbation
- Food chain transfer

Exposure Pathways to Ecological Receptors

- Direct contact with sediment (algae and invertebrates only)
- Intentional or incidental ingestion of sediment
- Direct contact with sediment interstitial water (pore water) (algae and invertebrates only)
- Direct contact with overlying surface water (primarily algae, invertebrates, bottom-dwelling fish, and pelagic fish)
- Ingestion of other organisms

Ecological Receptors

- Algae, seagrasses
- Benthic/epibenthic invertebrates
- Bottom-dwelling fish
- Pelagic fish
- Seabirds and shorebirds
- Marine mammals

Modified from (USEPA 2005f): *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites*

The preliminary CSM developed during the SLERA may include multiple chemicals and receptors to ensure that all potentially complete exposure pathways are included. The CSM is typically updated as more information is learned about the site. For example, if the risk assessor learns that a predicted pathway is incomplete because an expected receptor does not occur at the site, then the CSM is revised to eliminate that pathway and receptor.

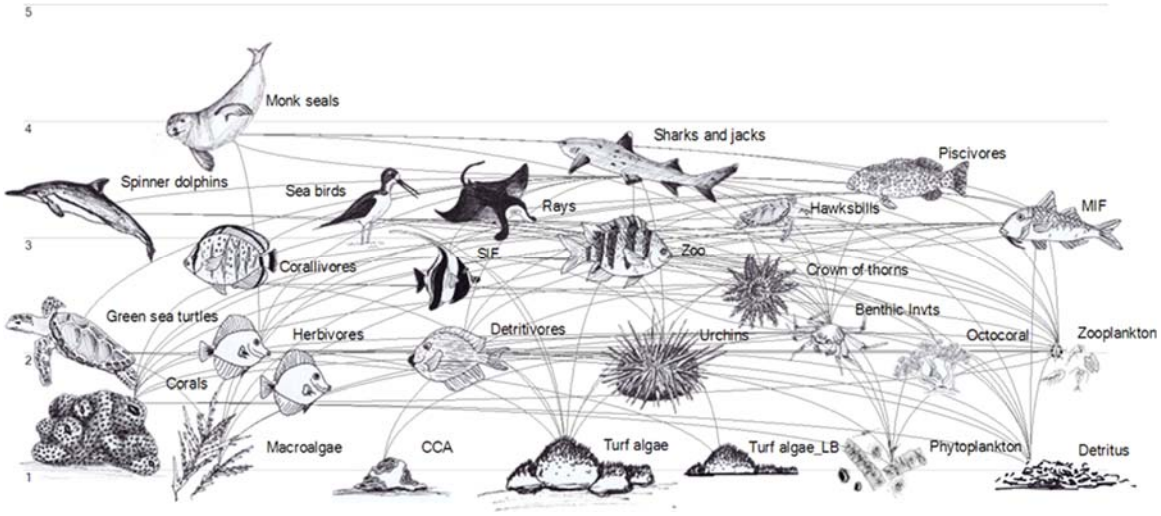


Figure 21-1. Food Chain Models Can Support Development of Conceptual Site Model
Graphical representation of the trophic linkages (i.e., who-eats-whom) within the Kaloko reef ecosystem. Each animal group within the system is identified here by an illustration (© M. Bailey); where relevant, an image of a species representative of its group is depicted. Images are not drawn to scale or proportional to the group's biomass. The light grey horizontal lines and associated numbers represent trophic levels (position in the food web); lines connecting individual groups represent trophic links. (NOAA 2018b)

Example CSMs

The HEER Office has prepared several examples to illustrate acceptable preliminary CSMs for a marine sediment SLERA. The risk assessor may adapt one of these CSMs or develop a new CSM incorporating the required elements from Table 21-6.

- Figures 21-2 and 21-3 present two types of CSM for the same site, a rocky intertidal site such as ʻĪlio Point on Molokaʻi. Figure 21-2 is a simple diagram and Figure 21-3 is a pictorial representation.
- Figure 21-4 is a CSM for a soft-bottom bay/harbor habitat (such as Hanalei Bay, Kauaʻi or Pearl Harbor) that illustrates both direct exposure to sediment and secondary exposure to contaminated prey. This CSM would be suitable to represent bioaccumulating COPECs (such as PCBs or organochlorine pesticides) that were originally released to soil, then washed into the marine habitat. In this scenario, ingestion of COPECs associated with sediment particles is considered the principal exposure pathway.
- Figure 21-5 is a CSM prepared for a BERA at Pearl Harbor. Note the multiple sources of COPECs that contribute to the existing load in the sediment.
- Figure 21-6 presents a focused CSM that illustrates the exposure of a single receptor group (water birds) to a single COPEC (arsenic) in sediments and surface water in Waiākea Pond on Hawaiʻi Island.
- Figure 21-7 is a CSM focused on a particular class of COPECs (energetic compounds associated with discarded munitions).

Other Features to Consider in CSMs

The following considerations should be taken into account when developing CSMs for marine sediment sites in Hawaiʻi:

- At intertidal sites, the CSM must capture both high tide and low tide exposure pathways. The intertidal habitat depicted in Figure 21-3 shows the inundated state, during which large pelagic fishes and sea turtles are present. At low tide, the large organisms move off shore and seabirds become the dominant predators. The CSM must account for exposure pathways under the full tidal cycle. See (Harborne 2013) for a discussion of foraging shifts between low and high tides on reef flats.
- At sites with stream discharge or other terrestrial inputs, the CSM must reflect the seasonal flux of contaminants entering the site. For example, in Hilo Bay, Hawaiʻi, the dominant exposure pathway to marine receptors varied throughout the year. Streams discharged heavy loads of soil/sediment as suspended particulate matter during the rainy season. Contaminants associated with terrestrial sources were transported to the bay along with the fresh water. Exposure of organisms in the bay to terrestrially-derived contaminants fluctuated from station to station, influenced by proximity to stream discharge and the time interval since the last major storm (Atwood et al. 2012). The CSM at a site with substantial terrestrial input must reflect this type of variability.

- At an anchialine pond site, the CSM must be developed specifically to reflect the relatively simple but unusual food web typical of this habitat. Apart from, or in addition to, effects mediated by contamination, any physical or biological perturbation of the food web can upset the balance of species in the pond, many of which are rare, endemic, or endangered. For background on anchialine ponds (see Dalton et al. 2013).
- The wave energy at a site must be considered in the CSM because waves are influential in sediment transport, deposition, and particle sorting processes that affect exposure of organisms to contaminants. Also, some receptors thrive in high energy environments while others prefer calmer environments. Many COPECs become bound to fine-grained sediment in the field, which tend to accumulate in areas where wave energy is dissipated by vegetation, such as seagrasses and mangroves, or around coastal protrusions such as jetties and piers. When fine-grained sediments are disturbed, either naturally by storms and erosion or purposefully by dredging or construction, metals can become remobilized from the sediments into the water column (Batley et al. 2013). Organic COPECs can become more bioavailable as fine sediment particles are suspended and ingested by receptors. The U.S. Geological Survey (USGS) has conducted numerous studies of natural processes that affect erosion and deposition in Hawai'i. Geophysical processes affect not only where sediments accumulate, but also how receptors are exposed to contaminated sediments. To assist risk assessors in describing the wave environment at a contaminated sediment site, the HEER Office has compiled a database of geophysical information provided in USGS reports, as well as in the primary literature, including descriptions and locations of high and low energy aquatic environments; erosional and depositional areas; and other features. The risk assessor should ensure that the influence of wave action is accurately represented in the CSM.

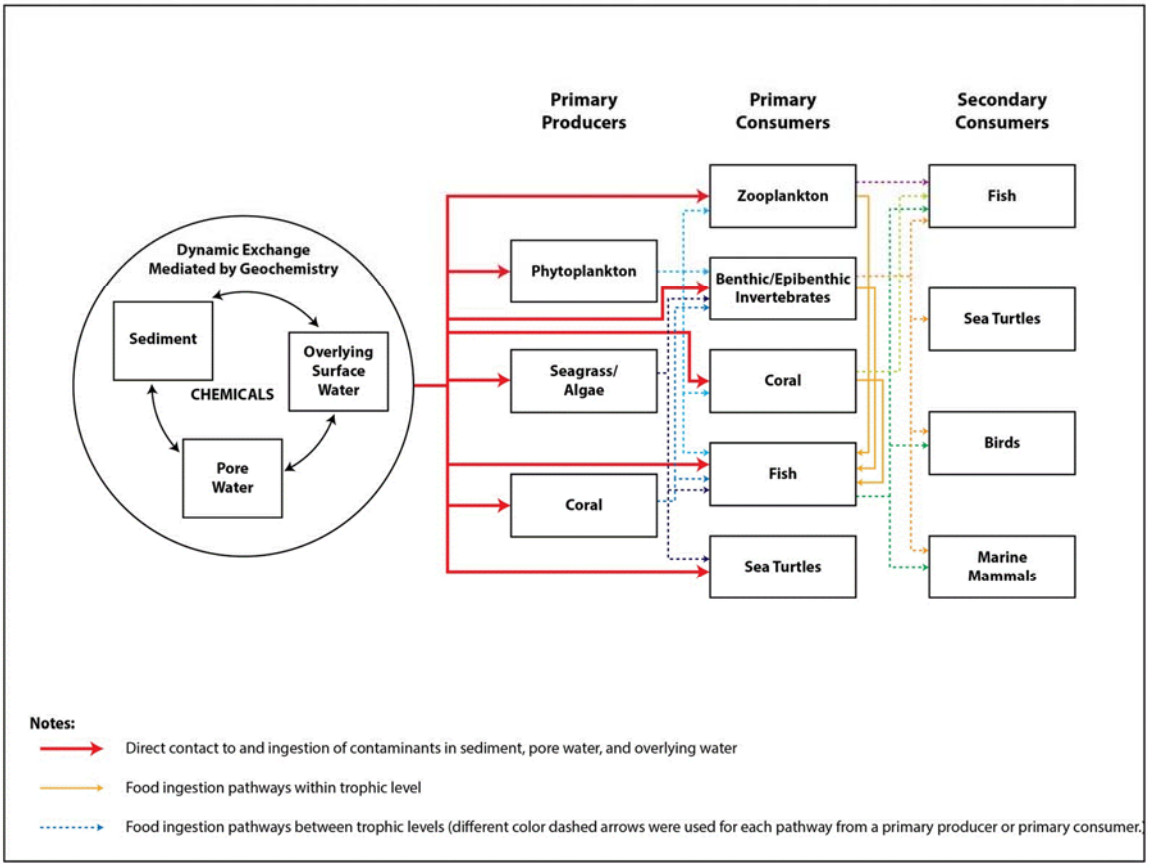


Figure 21-2. A Simple Diagrammatic Conceptual Site Model for a Rocky Intertidal Habitat with Hardbottom (such as ʻĪlio Point, Molokaʻi)

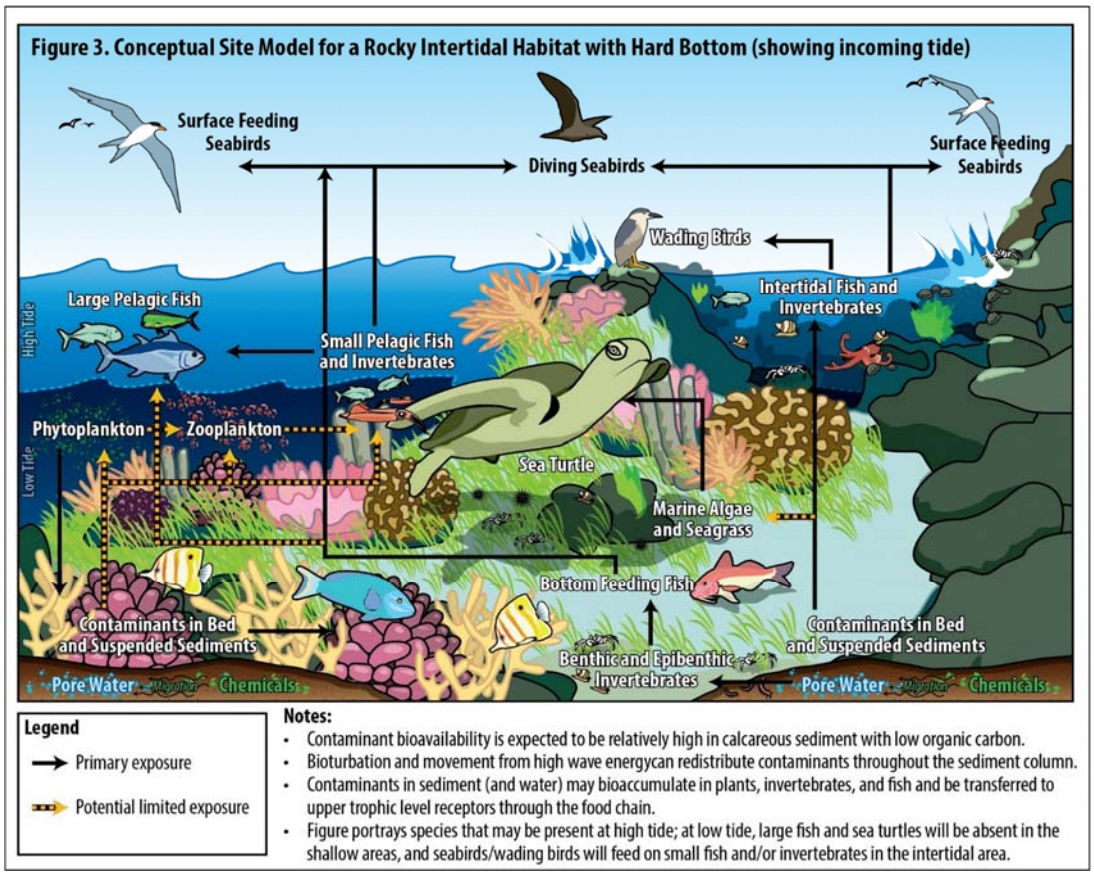


Figure 21-3. Conceptual Site Model for a Rocky Intertidal Habitat with Hardbottom

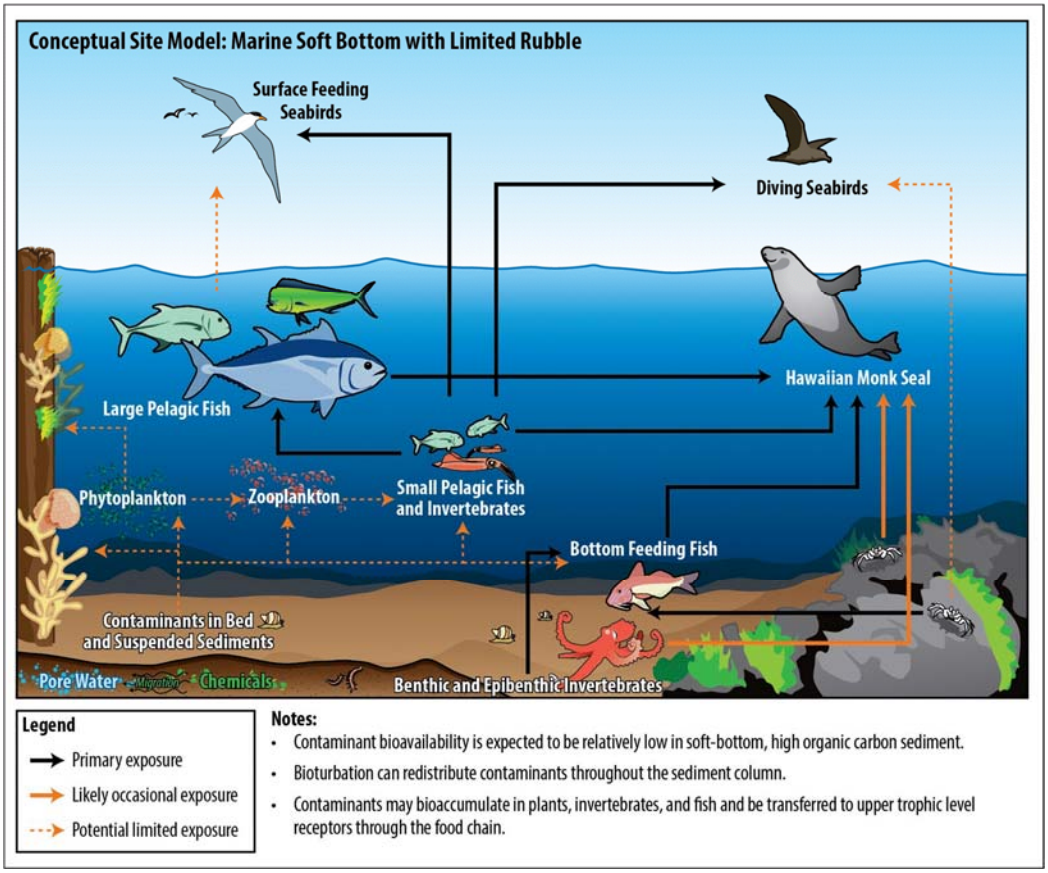


Figure 21-4. Conceptual Site Model for a Soft-Bottom Bay/Harbor Habitat (such as Hanalei Bay, Kaua'i, or Pearl Harbor, O'ahu)

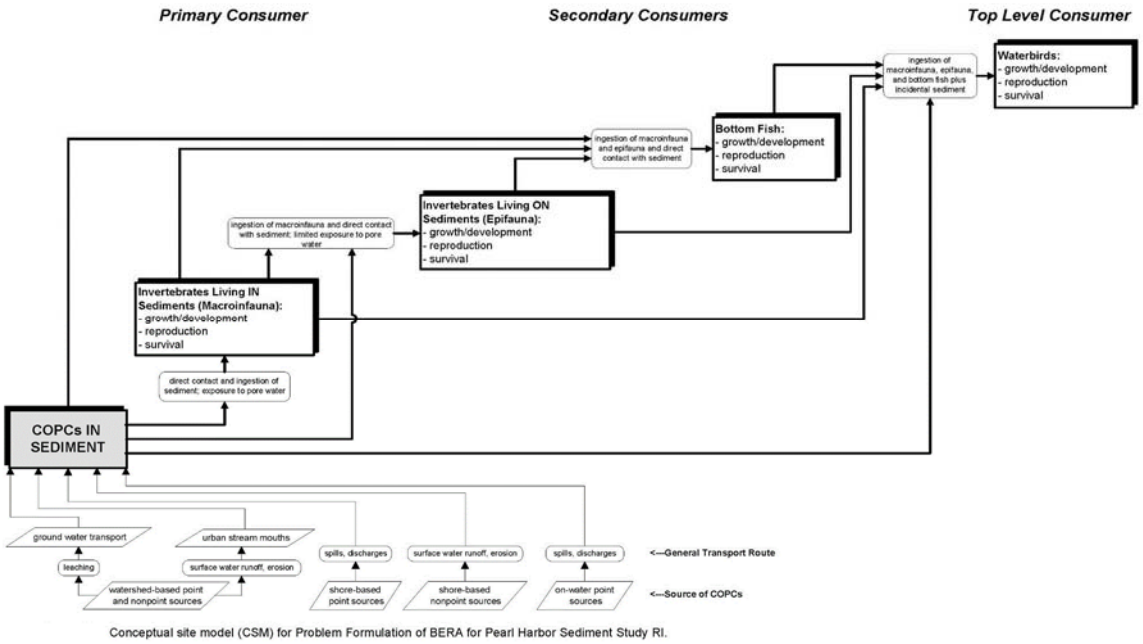


Figure 21-5. Conceptual Site Model Prepared for a BERA at Pearl Harbor
Source: (NAVFAC 2007), Figure 2-7
(Note the multiple sources of COPECs that contribute to the existing load in the sediment.)

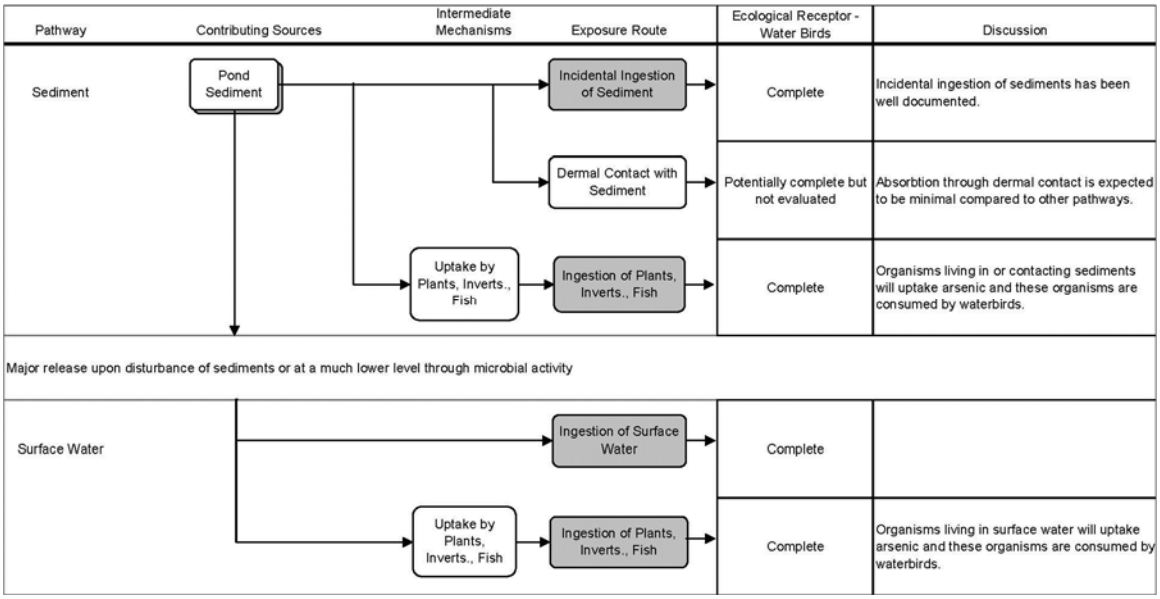


Figure 21-6. Conceptual Site Model Focused on Exposure of a Single Receptor Group (Water Birds) to a Single COPEC (Arsenic) in Sediments and Surface Water at Waiākea Pond on Hawai'i Island
Source: (HDOH 2005c), Figure 2-1

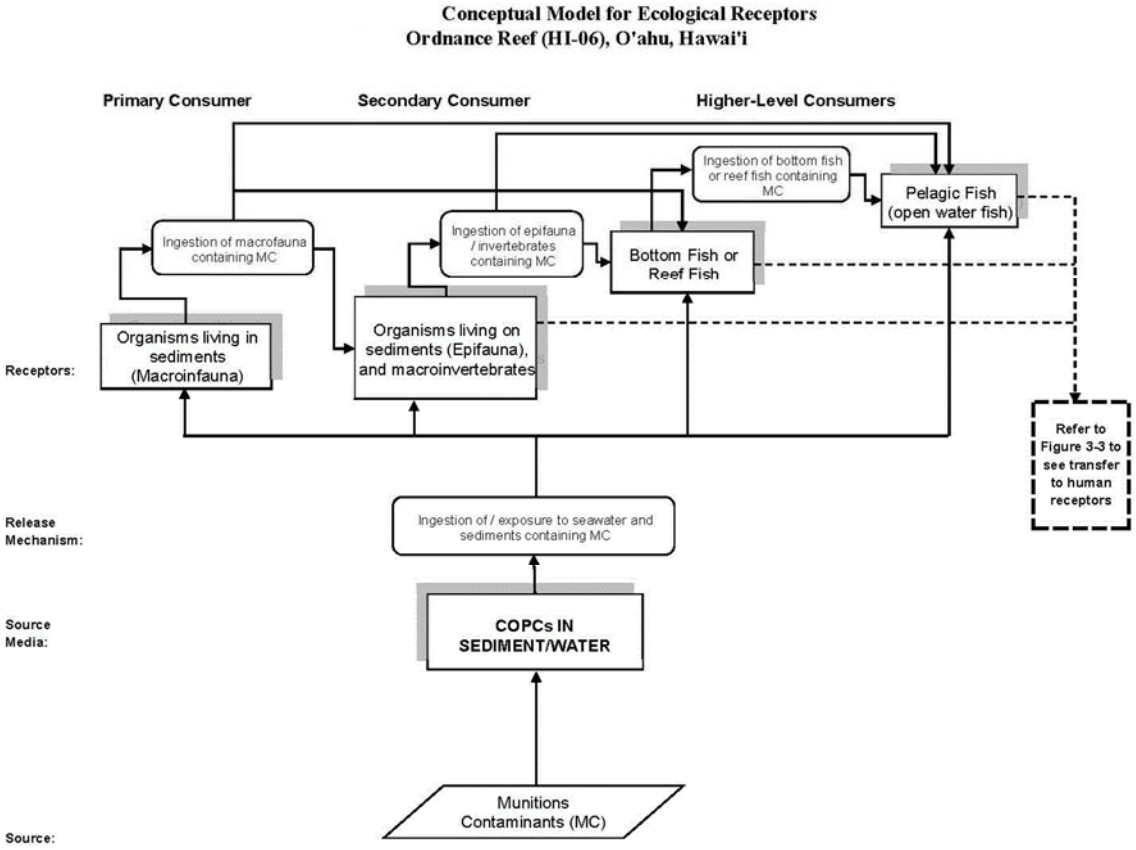


Figure 21-7. Conceptual Site Model Focused on a Single Class of COPECs (Energetic Compounds Associated with Discarded Munitions)
Source: (ACOE 2012) Figure 3-2

21.3.4 STEP 2: ESTIMATING EXPOSURE AND EFFECTS

In Step 2, available site-specific data are used to estimate conservative contaminant concentrations, which are then compared with screening levels to identify (1) chemicals that may pose potential risk and (2) chemicals that may be eliminated from further investigation.

21.3.4.1 STEP 2, TASK 1; COMPILE SCREENING LEVELS

SQGs and other screening levels are compiled as part of the *ERA Scoping Checklist* following the examples in Tables 21-B-1 through 21B-4. If additional analytical data or screening levels have become available, update the table. The HEER Office has developed screening levels for common COPECs at sediment sites in Hawai'i. Each of the screening levels is used to evaluate a different aspect of potential risk to receptors, as described below.

1. **Sediment quality guidelines (SQG)** are used to evaluate risks to receptors in direct contact with the sediment, especially benthic invertebrates. The SQGs were derived from large datasets on toxicity to benthic invertebrates under a variety of field conditions. Although the SQGs are not necessarily protective of seagrasses, marine algae, fish, or receptors that are not intimately exposed to sediment, they serve as surrogates during the SLERA. The HEER Office will add SQGs to this guidance as they become available. See Table 21-7 and see Appendix 21-E.
2. **HEER Office Environmental Action Levels (EALs)** used to evaluate aquatic toxicity (aquatic habitat goals), surface water, and groundwater are available for screening of chemicals in water (see EAL Surfer). See detailed Tables in the EAL Surfer tool for listings of aquatic toxicity and surface water EALs for marine, estuarine, or freshwater environments, as applicable.
3. **Toxicity reference values (TRV)** are daily doses of ingested chemicals used to evaluate risk to birds and mammals that are exposed to contaminants primarily through ingestion of contaminated food items (as well as sediment and water).
4. **Critical body residues (CBR)** are used to evaluate risk to receptors from chemicals accumulated by all routes into their tissues. CBRs are available for only a few receptors at this time.

HEER Office Interim Sediment Quality Guidelines

HEER Office SQGs are used to evaluate the potential for sediments to pose a risk to benthic invertebrates through direct exposure. The concentration below which sediments are considered safe for benthic marine organisms is called the interim "No Effect SQG." The concentration above which adverse effects are indicated on benthic marine organisms may occur is called the interim "Potential Effect SQG." Chemicals known or expected to bioaccumulate are indicated on Table 21-7 and may require additional evaluation, as described in Appendix 21-E.

The SQGs are considered interim because they are subject to revision as new data become available. The HEER Office anticipates that the HDOH interim SQGs will be revised as warranted by a review of new toxicity data reported from other tropical marine ecosystems, including the ANZEC/ARMCANZ ecotoxicology group. In the future, a range of revised SQGs will represent sediments that vary in percent organic carbon and grain size.

The HEER Office interim SQGs incorporate the Effects-Range Low (ER-L) and Effects-Range Median (ER-M) sediment levels published by (Long and Morgan 1990) and modified by (Long et al. 1995), as well as the ANZECC/ARMCANZ interim SQGs derived from other sources. Interim SQGs for 2,3,7,8-TCDD, which were not available from ANZECC/ARMCANZ or NOAA, were adopted from Canadian Council of Ministers of the Environment (CCME 2001).

The HEER Office considers the chemicals listed in Table 21-7 the most likely to be potential risk drivers at marine sediment sites in Hawai'i. Chemicals detected in sediment for which no HEER Office interim SQG is available should be screened using the most recent publicaly available literature available. Suggested sources are listed below:

- SQGs from (Simpson et al. 2013) and related documents
- Marine sediment screening levels from sources presented in the U.S. Department of Energy, Risk Assessment Information System - Ecological Benchmark Tool (USDOE 2018).
- Marine sediment screening levels from sources presented in the NOAA Screening Quick Reference Tables (Buchman 2008)

Table 21-7. HDOH HEER Office Interim Sediment Quality Guidelines for Selected Chemicals

Analyte	Recommended Interim Sediment Quality Guidelines for Direct Exposure	
	No Effect SQG	**Potential Effect SQG**
Inorganic Chemicals (mg/kg dry weight)		
Arsenic	20	70
Copper	34[a]	270
Lead	50	220
Mercury	0.15	1
Tributyltin (**µg/kg** Sn/kg dry weight)	5	70
Zinc	200	410
Organic Compounds		
***Pesticides/PCBs/Dioxins* (µg/kg dry weight)**		
4,4'-DDD	2	20
4,4'-DDE	2.2	27
Total DDTs	1.6	46
Total Chlordane	0.5	6
Dieldrin	0.02	8
Endrin	0.02	8

Total PCBs	23	180
TEQ Dioxins and Furans	0.00085	0.0215
***Semivolatile Organic Compounds* (µg/kg dry weight)**		
Acenaphthene	16	500
Acenaphthylene	44	640
Anthracene	85	1100
Benzo(a)anthracene	261	1600
Benzo(a)pyrene	430	1600
Chrysene	384	2800
Dibenzo(a,h)anthracene	63	260
Fluoranthene	600	5100
Fluorene	19	540
Naphthalene	160	2100
Phenanthrene	240	1500
Pyrene	665	2600
Sum HMW PAHs	***1700***	***9600***
Sum LMW PAHs	***552***	***3160***
Total PAHs	***4000***	***45000***

HMW	High molecular weight
LMW	Low molecular weight
µg/kg	Microgram per kilogram
mg/kg	Milligram per kilogram
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
SQG	Sediment quality guideline
TEQ	Toxic equivalent

Notes:

- The chemicals in Table 21-7 are also considered bioaccumulative and must undergo further evaluation for this hazard (see Appendix 21-E).
- Some local background/ambient/reference concentrations may exceed No Effect SQG.
- See Table 21-1, Required, Preferred, or Optional Data for Sediment ERAs, for addressing sediment contaminant levels greater than the No Effect SQGs but less than the Potential Effect SQGs.
- All organic SQGs are normalized to 1% organic carbon.
- If data are available for both total organic carbon and grain size fraction, the No Effect SQG for copper is organic carbon (OC)-normalized copper concentration of 3.5 mg Cu/g OC in the < 63 µm sediment fraction. The **copper** SQG is under review by both ANZECC/ARMCANZ (Simpson et al., 2013) and researchers in Hong Kong (Kwok et al. 2008) and is expected to be revised.
- The following individual PAHs are typically reported by laboratories using standard EPA analytical methods. This list may change, depending on which specific parameters are requested:
    - ***LMW PAH*** = acenaphthene, acenaphthylene, anthracene fluorene, naphthalene, phenanthrene, 1-methylnaphthalene, 2-methylnaphthalene.
    - ***HMW PAH*** = benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene, fluoranthene, indeno(1,2,3-cd)pyrene, and pyrene.

The chemicals on the HEER Office SQG table (Table 21-7) are also known as common bioaccumulating chemicals, based on a review of technical manuals prepared by USEPA, other states, and international organizations. Therefore, these chemicals should also be considered potential bioaccumulators, and evaluated accordingly using food chain models (see Step 1b, Task 3). The risk assessor should also consider other technical sources of information when determining whether chemicals detected in sediment at a site may be bioaccumulators. The *Bioaccumulation Testing and Interpretation for the Purpose of Sediment Quality Assessment, Status, and Needs* (USEPA 2000i) provides technical direction on identifying bioaccumulators. More detailed guidance on evaluating risk of bioaccumulating chemicals is in Appendix 21-E.

Toxicity Reference Values

A TRV is an ingested daily dose of a chemical associated with a designated effect level. A low TRV is a conservative value consistent with a chronic no observable adverse effect level (NOAEL). A high TRV is consistent with a lowest observable adverse effect level (LOAEL). When compared to site-specific doses ingested by receptors, the high TRV should be used to identify sites posing potential risk to birds or mammals. Conversely, the low TRV is a dose level below which no adverse effects are expected.

The HEER Office has not compiled a comprehensive list of TRVs for all receptors. The risk assessor may select TRVs based on site-specific receptors and exposure conditions and provide technical rationale for the TRVs selected. TRVs are available from several sources in the literature, including, but not limited, to the following:

- TRVs developed by the U.S. Navy for 20 chemicals common at San Francisco Bay area naval installations, including 12 metals and metalloids (arsenic, butyltins, cadmium, cobalt, copper, mercury, lead, manganese, nickel, selenium, thallium, and zinc), five pesticides (aldrin, DDT, heptachlor, lindane, and methoxychlor) and three other organic compounds (benzo(a)pyrene, naphthalene, and total polychlorinated biphenyls) (Navy 1998). Several of the Navy TRVs have been updated using more recent toxicological studies (CalDTSC 2009)
- Toxicological Benchmarks for Wildlife (Sample et al. 1996)
- FCSAP Supplemental Guidance for Ecological Risk Assessment Selection or Development of Site-specific Toxicity Reference Values (Azimuth 2010). This document does not present specific TRVs but list several sources of TRVs.
- Recommendations for the Development and Application of Wildlife Toxicity Reference Values (Allard et al. 2010). This document does not present specific TRVs but presents recommendations on the derivation and application of wildlife TRVs.
- EPA Ecological Soil Screening Level Documents (USEPA 2005g) and supporting documents). Although these documents pertain to soil, some of the toxicological literature cited within them is relevant to birds and mammals exposed to chemicals in surface water and sediment.
- Los Alamos National Laboratory, ECORISK Database (Release 4.1) (LANL, 2017). This database presents TRVs for several chemicals and receptors.

Note that TRVs used in ERAs in Hawai'i are provided in the species profiles, where available (See Appendix 21-A). The HEER Office does not necessarily endorse the use of the particular TRVs presented in earlier ERAs but does recommend that the risk assessor make use of existing literature to select and provide rationale for TRVs suitable to the site.

Critical Body Residues

The CBR can be used to evaluate risk to a receptor based on a chemical concentration in its tissue. However, CBR data are available for only a few chemicals and selected species from a limited number of locations. Few, if any, of the published CBRs cited are for native Hawaiian species. No standard CBR values have been developed by EPA or other national agencies. Limited CBR data are available from the following sources:

- *Linkage of Effects to Tissue Residues: Development of a Comprehensive Database for Aquatic Organisms Exposed to Inorganic and Organic Chemicals* (Jarvinen and Ankley 1999). Most of the available data are for freshwater species, although some marine and estuarine species are included.
- *Guidance for Assessing Bioaccumulative Chemicals of Concern in Sediment* provides freshwater and marine CBRs for metals, pesticides, PCBs, and 2,3,7,8-TCDD TEQs (ODEQ, 2017).
- *Environmental Residue Effects Database* (*ERED*) is a searchable compendium of CBRs derived by USEAP and the ACOE from literature published in the 1960s to 1990s. (US Army 2018)
- Dredged Material Evaluation and Disposal Procedures User Manual (DMMP) (ACOE 2016) lists target tissue concentrations for several chemicals.
- *Environmental Contaminants in Biota: Interpreting Tissue Concentrations*, Second Edition (Beyer and Meador 2011) summarizes data on CBR for numerous species and contaminants.

21.3.4.2 STEP 2, TASK 2; CALCULATING CONTAMINANT CONCENTRATION(S) IN SEDIMENT AND WATER

At a minimum, the SLERA requires site-specific sediment concentrations. The preferred approach to estimating exposure concentrations at a sediment site is to use MIS sampling to represent the typical exposure of receptors within a DU. The general guidance in the TGM on developing a sampling plan for a sediment investigation is applicable to an ERA (see TGM Sections 3, 4, and 5). However, the designation of DUs is more complex for an ERA because no single DU is appropriate for all ecological receptors at a site (See Appendix 21-C).

Stationary and relatively immobile species such as algae, benthic infauna, and coral are primarily exposed to chemicals in sediment through direct contact. The MIS concentration detected in a DU is used as the representative contaminant concentration in the SLERA. Assuming laboratory detection limits are lower than the SQGs, non-detects are treated as zero values. If the laboratory detection limit exceeds the SQG, the detection limit is used as the reported value for all nondetects. (In this case, the data should be scrutinized and laboratory methods reviewed so that detection limits appropriate for a SLERA can be achieved.)

If site-specific concentrations are available for surface water, sediment pore water, or groundwater discharging to the site, the MIS detected concentration is used as the contaminant concentration for the SLERA (given the protocol for estimating nondetects in the previous paragraph). Samples should be analyzed for dissolved concentrations for constituents that have WQC based on dissolved concentrations.

The SLERA is purposefully designed to be conservative, evaluating the worst-case exposure scenario and often overestimating contaminant concentrations in early steps. Subsequent steps allow refinement of conservative assumptions to reflect site-specific conditions that may reduce estimated contaminant levels or risk.

21.3.4.3 STEP 2, TASK 3; ESTIMATING DAILY INGESTED DOSE TO BIRDS AND MAMMALS

The SQG are considered protective of algae, benthic invertebrates, and fish exposed directly to sediment but cannot be used to evaluate risk to birds or mammals feeding on prey at a contaminated sediment site. Risk to birds and mammals ingesting sediment, water, and prey at a site is evaluated using food chain modeling to estimate the dose of a chemical ingested by these animals.

Tissue concentrations are a key component of dose estimates to birds and mammals, but are not always available during a SLERA. If tissue concentrations from organisms collected at the site or from organisms exposed to site-sediment in the laboratory are available, site-specific doses to birds and mammals can be estimated. Site-specific tissue concentrations (also known as CBRs) can also be used to estimate direct effects to the organisms from contaminant body burdens. If no tissue data are available, chemical concentrations in tissue may be estimated using concentrations in sediment, literature BSAFs, and parameter assumptions (see Appendix 21-F).

Ingested doses of bioaccumulative chemicals are estimated using food chain models. The dose estimate represents the mass of chemical ingested per day, indexed to the receptor's body weight (mg/kg-body weight/day). Daily ingested doses are estimated for higher trophic level receptors (birds and mammals) that are exposed to contaminants primarily through their diet rather than through direct contact with sediment. Where appropriate, the dose estimate should include incidental sediment ingestion. For example, the Hawaiian monk seal is reported to consume substantial amount of sediment when it hauls out on beaches. The risk assessor should review the relevant literature on key receptors at the site to determine the need to include sediment ingestion in the dose for a given receptor.

The ingested dose should be estimated using the following generic exposure equation. The equation can be modified, as necessary, based on the specific exposure pathways evaluated in the SLERA:

$$ED = \frac{[(C_f * I_f) + (C_s * I_s)] * SUF}{BW}$$

Where:

ED = exposure dose (mg/kg-day)
C_f = chemical concentration in food (mg/kg)
C_s = chemical concentration in sediment (mg/kg)
I_f = food ingestion rate (kg/day)
I_s = incidental sediment ingestion rate (kg/day)
SUF = site use factor (site/species home range – cannot exceed 1.0) (unitless)
BW = body weight (kg)

Chemical concentrations and ingestion rates (for sediment and food) should be reported in dry weight. If tissue concentrations are reported by the analytical laboratory in wet weight, dry weight concentrations can be estimated using either laboratory measures or standard default values for percent moisture.

For the SLERA, the estimated daily dose is intentionally biased high so that any error will be toward indicating greater risk than is present. In later phases of the ERA, biases are relaxed in favor of more realistic assumptions. For example, the estimated dose in the SLERA should be based on the

- Maximum chemical concentration in sediment and food;
- Maximum ingestion rates for sediment and food;
- Lowest body weight;
- Highest site use factor; and
- Most sensitive life stage present at the site.

The HEER Office provides species profiles for selected receptors at coastal marine sediment sites (Table 21-8). Species profiles are in Appendix 21-A. Values for exposure parameters required in the food chain model, such as body weight and home range, are included in the species profiles when available. The risk assessor should review the current published literature to obtain additional information where data are not provided.

Table 21-8. Selected Species Profiles

Receptor Group	Selected Species*
Marine Algae	Sea lettuce (*Ulva fasciata*)
Invertebrates	Samoan crab (*Scylla serrata*)
	Kona crab (*Ranina ranina*)
	White crab (*Portunus sanguinolentus*)
	Helmet urchin (*Colobocentrotus atratus*)
	Hawaiian limpet (*Cellana exarata*)
	Day octopus (*Octopus cyanea*)
	Polychaete (*Neanthes arenaceodentata*)
	Lobe coral (*Porites lobata*)
	Black sea cucumber (*Holothuria atra*)
Fish	Goatfish (*Mulloides vanicolensis*)
	Hawaiian flagtail (*Kuhlia sandvicensis*)
	Convict tang (*Acanthurus triostegus*)
	Pacific sergeant (*Abudefduf abdominalis*)
	Mozambique tilapia (*Oreochromis mossambicus*)
	Spectacled parrotfish (*Chlorurus perspicillatus*)
	Yellowbar parrotfish (*Calotomus zonarchus*)
	Moray eel (*Muraenidae*)
Birds	Wedge-tailed shearwater (*Puffinus pacificus*)
	Black-crowned night heron (*Nycticorax nycticorax hoactli*)
	Hawaiian coot (*Fulica alai*)

Sea Turtles	Green sea turtle (*Chelonia mydas*)
Marine Mammals	Monk seal (*Monachus schauinslandi*)

*** See Appendix 21-A for profiles of these species.**

Calculate Critical Body Residues

The HEER Office does not require that tissue concentrations be obtained during the SLERA. However, tissue samples collected to support a human consumption study or other phase of investigation at the site may be available for inclusion in the SLERA. The risk assessor should present the available tissue data in tabular form with details on the sample date, location, species, size of specimen, body part, analytical methods, and results (with data qualifiers). If the tissue samples are composites of more than one individual organism, the details above should be provided for all individuals in the composite. (When possible, tissue concentrations should be measured in single individuals rather than composites for comparison to CBRs.) The maximum detected tissue concentration is used as the exposure concentration in the SLERA. Non-detects are treated as zero values when detection limits are acceptable (see Step 2, Task 2).

21.3.4.4 STEP 2, TASK 4; CALCULATE SITE-SPECIFIC HAZARD QUOTIENTS

Risk calculations in the SLERA are simple and straightforward for chemicals that are not considered bioaccumulators. The maximum exposure concentration is divided by the no-effect screening level to calculate a hazard quotient (HQ). If the resulting HQ is greater than 1.0, that chemical is designated a chemical of potential ecological concern (COPEC) and should be evaluated further. If the HQ is less than 1.0 for that chemical, it is eliminated as a COPC and dropped from further consideration. Chemicals without screening levels are retained as COPECs at this point in the process. To compensate for the uncertainty inherent in single chemical SQGs, the initial step of the SLERA is purposefully biased toward including chemicals that may not pose a risk rather than eliminating COPECs that may pose a risk, by use of conservative exposure assumptions. This bias toward including COPECs is corrected during later phases of the ERA (i.e., Step 3a or the BERA) in which the COPEC list is refined using more realistic assumptions and site-specific exposure data. The HQs for receptors directly exposed to sediment should be calculated as follows:

HQsediment = maximum sediment concentration/no effect SQG

Risks from chemicals that bioaccumulate can be evaluated using the equation above to assess direct toxicity to organisms. If the resulting HQ is less than 1.0, no direct toxicity is indicated. However, a bioaccumulating chemical cannot be eliminated as a COPEC based on a simple sediment screen because it may be bioaccumulated even when its concentration in sediment is less than the SQG. Risk posed by food chain transfer of contaminants is evaluated using TRVs derived for higher trophic level receptors. The estimated daily dose of a chemical in a given receptor is compared with the no-effect TRV to calculate an HQ:

HQ-TRVlow = estimated daily dose/no-effect TRV

Bioaccumulating chemicals can also pose a direct risk to the receptor in the form of causing neurological, developmental, or other impairment. The concentration of a bioaccumulating chemical in the whole body (or specific tissue type) of a receptor can be compared to the concentration demonstrated to cause an adverse effect on that receptor (or a surrogate species). When tissue effect levels for comparable species and tissue types are available in the literature, risk is estimated by comparing site specific tissue concentrations to CBRs from the literature:

HQtissue = site-specific tissue concentration/CBR

21.3.4.5 STEP 2, TASK 5; DECISION CHECKPOINT

By this stage of the process, all available sediment, water, and tissue data have been screened against no-effect screening levels and HQs have been calculated. Chemicals for which all HQs are less than 1.0 can be eliminated from further evaluation. Chemicals for which at least one HQ is greater than 1.0 are retained as COPECs. The HEER Office recommends the SLERA include a summary table supporting the decision to eliminate or retain each chemical.

21.3.5 STEP 3A: REFINE SCREENING LEVEL DEFAULT ASSUMPTIONS

The COPECs retained at the end of Step 2 were shown to pose *potential* risk to receptors when conservative assumptions were used. Step 3A is focused on refining the list of COPECs to represent more realistic site-specific conditions. The objective of the COPEC refinement is to identify chemicals that significantly contribute to potentially unacceptable levels of ecological risk and

eliminate from further consideration those chemicals that are not likely causing a significant risk. This step consists of refining the conservative exposure assumptions/concentrations used to evaluate potential risks to ecological receptors and re-evaluating the analytical data using screening levels that are more appropriate for the assessment endpoints.

This refinement may result in eliminating chemicals as COPECs for some receptors but retaining them as COPECs for other receptors. For example, a chemical might be retained as a COPEC for benthic invertebrates but eliminated as a COPEC for shorebirds. This is important because if the site proceeds to a BERA, the studies in the BERA should focus only on the chemicals-receptor pairs for which risk is predicted. The following tasks will support a decision regarding the need for further evaluation.

21.3.5.1 STEP 3A, TASK 1; CONDUCT BACKGROUND SCREENING

The risk assessor should compare site-specific concentrations of COPECs with regionally-appropriate background, ambient, or reference concentrations to ensure that only site-related chemicals are carried through to the BERA. Inorganic chemicals pose unique difficulties for ERAs because of the role of site-specific geology in influencing exposure and effect concentrations. Background evaluations for sediment in Hawai‘i are complicated by spatial heterogeneity of volcanic and coralline sediment types.

In the absence of CBRs for selected receptors, the risk assessor may compare site-specific tissue concentrations with results from similar habitats or regions considered to be “unimpacted” by chemicals or to represent “background” tissue concentrations. The HEER Office is compiling tissue concentrations reported as “background” or “reference” in various published literature and reports. The values are not considered to represent “no effect” concentrations because the samples were not associated with toxicity testing. At best, the “reference” or “background” tissue concentrations indicate the range of concentrations existing in the area outside of known contaminated sediment sites. The risk assessor may compare site-specific tissue concentrations with the “reference tissue” results for the same species and habitat. Such comparisons are necessarily limited by uncertainty, yet they can provide a useful context for interpreting site-specific data. The relative magnitude of site-specific tissue concentrations compared with reference concentrations may indicate the need for further tissue sampling during the BERA or may strongly suggest that chemicals are not accumulating in tissues at the site to any measurable degree. The identification and interpretation of background, ambient, or reference concentrations should be discussed with the HEER Office before proceeding with the next task.

21.3.5.2 STEP 3A, TASK 2; EVALUATE MAGNITUDE OF SCREENING LEVEL EXCEEDANCE AND FREQUENCY OF DETECTION

Although the magnitude of risks may not relate directly to the magnitude of a criterion exceedance, the magnitude of the criterion exceedance may be used in a weight-of-evidence approach to determine the need for further site evaluation. The greater the criterion exceedance, the greater the probability and concern that an unacceptable risk exists.

Likewise, the frequency of chemical detection and spatial distribution of concentrations greater than the screening levels may indicate the need for additional investigation. A chemical detected at a low frequency typically is of less concern than a chemical detected at higher frequency if toxicity and concentrations and spatial areas represented by the data are similar. All else being equal, chemicals detected frequently are given greater consideration than those detected relatively infrequently. In addition, the spatial distribution of a chemical may be evaluated to determine the area that a sample represents. The risk assessor should discuss magnitude and frequency distributions with the HEER Office to resolve any issues before continuing with the SLERA.

21.3.5.3 STEP 3A, TASK 3; REFINE CONSERVATIVE EXPOSURE ASSUMPTIONS

Initial steps in the SLERA use assumptions of 100 percent bioavailability, high site use by sensitive receptors, representative contamination concentrations, and other factors to ensure that a chemical is not excluded from the SLERA if it poses an unacceptable risk. In Step 3a, more realistic site-specific exposure values replace the default values.

- Bioavailability: When selecting chemicals as COPECs in the SLERA, it is typically assumed that the chemicals are 100 percent bioavailable. However, in the COPEC refinement, the potential bioavailability of the chemicals can be evaluated by considering total organic carbon (TOC) and grain size data. Typically, this evaluation is more qualitative than quantitative in the SLERA. However, in a BERA, bioavailability can be measured directly through uptake in living organisms. Guidance on adjusting the assumption of 100 percent bioavailability is in Appendix 21-F.
- Site Use: The conservative default value of 100 percent site use assumes that an organism spends all of its time in contact with contaminants at the site. For some mobile species, this assumption is clearly unrealistic, and a more representative site use factor may be used.
- Contaminant Concentrations: The most conservative and reasonably representative contaminant concentration for a specific target chemical is used for initial comparison to applicable screening levels, and some potential COPECs may

be eliminated from the SLERA using this approach. However, smaller or additional DUs and/or more representative sampling techniques may be used during Step 3a to support further evaluation of the site.

21.3.5.4 STEP 3A, TASK 4; OBTAIN HEER OFFICE CONCURRENCE ON REFINEMENTS

Provide the HEER Office with tables, text, figures, or other defensible rationale for refining the exposure assumptions. After reviewing the submitted materials, the HEER Office may accept the refinements or request a meeting to discuss the rationale and assumptions so that consensus can be reached.

21.3.5.5 STEP 3A, TASK 5; RECALCULATE HQS USING REFINED EXPOSURE ASSUMPTIONS

Recalculate HQs using more realistic estimate of contaminant concentration and screen against background concentrations. Prepare a summary table of COPECs eliminated and retained and provide rationale for the decisions. If risk is below applicable screening levels (or approved alternative screening level) for all chemicals, the SLERA is complete and the site can move to closure. If COPECs are retained and risk is potentially unacceptable, the site will continue to the BERA (Subsection 21.6).

21.3.5.6 STEP 3A, TASK 6; DEVELOP SLERA RISK CHARACTERIZATION AND DECISION

Risk characterization in the SLERA focuses on the summary of HQs prepared in Step 3A, Task 5 and a discussion of uncertainty and data gaps to be addressed in the BERA.

21.3.6 UNCERTAINTY

During the risk characterization phase, the exposure and effects data are interpreted within the context of other site-specific information. Specifically, various sources of uncertainty are evaluated so that the risk assessor can provide a realistic description of risks posed by contaminants at the site. Uncertainty stems from many sources, including the extrapolation of exposure and effects data form one species to another. Efforts to customize the ERA to tropical marine conditions and native Hawaiian species will greatly reduce this source of uncertainty and strengthen the risk characterization. Conversely, modifying existing toxicity tests and adapting protocols to accommodate the environmental conditions that prevail in Hawai‘i may introduce additional uncertainty in the short term. Such trade-offs are explicitly recognized and addressed in the *Sediment Quality Assessment Handbook* (Simpson et al. 2005). The following paragraphs present some of the key uncertainties in SLERAs, and where applicable, how the uncertainties relate to sites in Hawai‘i.

Uncertainty in Ecotoxicity

The HEER Office recommended interim SQGs specifically acknowledge that uncertainty stems from gaps in the science of toxicology, particularly in tropical marine ecosystems. One fundamental source of uncertainty stems from the derivation of single-chemical trigger values from toxicity tests using field-collected sediments containing multiple contaminants. Attributing toxic effects to any one of the many chemicals in such sediments leads to uncertainty that must be addressed in controlled laboratory investigations using single contaminants (Batley and Simpson 2008). The ANZECC/ARMCANZ is actively working to develop bioassays using native Australian or New Zealand species that will better reflect the genetic and ambient environmental conditions in sediments there. Some opportunity exists to adapt the Australian bioassays by substituting native Hawaiian species of similar taxonomic and functional characteristics. Therefore, although toxicity testing is typically not conducted until the BERA, the use of native Hawaiian species as test organisms for toxicity tests is encouraged, when applicable, to reduce uncertainty.

Some ecological risk investigations have been conducted in tropical marine regions, but Australia has developed an organized national program to tailor EPA and ASTM International (ASTM) protocols to tropical marine ecosystems. Although the Australian program is still in a fledgling state, many of the foundational principles are congruent with Hawai‘i's goal to develop a state-specific ERA program. The Australian program recognizes the EPA framework and the large body of subsequent work on refining questions of metals bioavailability in whole sediments (Batley and Simpson 2008). The Australian group has focused on developing bioassays that reflect reasonable exposure and effects conditions for local habitats (see below). Finally, that group has implemented a regionalized program that incorporates land use, climate, and contaminant source data specific to a watershed so that background conditions can be properly evaluated (Australian Government 2006).

Uncertainty in Exposure

As indicated above, tissue samples can provide a direct measure of the bioavailability of chemicals. However, there is uncertainty in where and how they accumulated the chemicals (i.e., sediment, surface water, food, or a combination). Also, the

choice of organisms, portion analyzed (whole body, fillet, liver, etc.), environmental parameters (i.e., pH, TOC, grain size), along with other factors that influence bioaccumulation.

Particulate metal concentrations are nearly always higher in fine-grained sediments (<63 µm) because smaller sediment particles have a higher surface area and more binding sites available for metals (Angel et al. 2012). Although, HDOH does not recommend biasing sediment collection methods to only collect fine-grained sediments, sampling techniques must be appropriate to ensure that the finer-grained fractions are not lost during sample collection. For example, ponar samplers often allow silts to escape as the sampler is being lifted. A coring device may be more appropriate for ensuring that fine-grained sediments are represented in the sample to the extent they are present at the site (see TGM Section 5).

21.4 ANTICIPATING AND ADDRESSING DATA GAPS

The risk assessor should characterize and address data gaps during the scoping phase of the ERA, as part of the DQO process (see TGM Section 3). A data gap can be generally categorized as resulting from one of two sources: natural variability or incomplete knowledge. A direct evaluation of these types of data gaps can strengthen the DQO process and guide the risk assessor toward a more robust sampling design and a more defensible risk assessment.

The risk assessor should first distinguish between data gaps that result from incomplete knowledge and data gaps that result from inherent variability in the ecosystem. This categorization is based on general knowledge of environmental processes at the site, the CSM, the COPECs, and available data (Table 21-9).

Table 21-9. Data Gap Analysis

For data gaps that result from *natural variability* in the ecosystem, answer the questions below:

- Could this data gap be filled by additional study? (If you answer yes, make sure you have correctly identified the data gap as resulting from natural variability rather than lack of information).
- What is the source of variability for the parameter in question? Daily or seasonal fluctuations, genetic variations (including gender), age, size, and other features may introduce variability. Note that natural variability encompasses differences within the same individual over time (lifetime, seasonal, or daily); among individuals within a population (based on gender, size, or other factors); and among populations.
- Are existing data adequate to describe the variability statistically using probabilistic models and other quantitative techniques?
    - If yes, describe the methods used to develop probabilistic values and clearly explain any residual uncertainty associated with the values used in the ERA.
    - If no, choose one of the following:
        - Use the most conservative (i.e. most protective) value from the available range and provide rationale for why that value is or is not representative of conditions at the site.
        - Conduct additional study (sampling) to provide the necessary data covering the range of variability.

For data gaps that result from *incomplete knowledge* about a particular site, chemical, or receptor, answer the questions below:

- Could this data gap be filled by additional study?
- What is the range of possible values for the parameter in question?
- *Work through two hypothetical scenarios using the maximum value and the mean value for this parameter, respectively.*
- Consider the two results: Are the results of the two hypothetical scenarios different enough to substantially change remedial decisions at the site?
    - If no, then don't waste time or money refining this value. (*Use the maximum as a default value*.)
    - If yes, estimate the value (or order-of-magnitude) at which a different decision would be triggered and design a study to develop a realistic value. *The study could be desk-based, in which you search the existing literature and develop a rationale for extrapolating from another study, or for amassing a large set of relevant data to provide a reasonable context for your site. If the value is critical to a decision that will lead to a very expensive or controversial remediation, then you may find it is justifiable to conduct a site-specific study.*

21.5 SUMMARY OF DECISION LOGIC FOR ERAS

The HEER Office applies the decision logic indicated in Tables 21-10 and 21-11, and Figure 21-8 for sediment investigations (see below). It is important to note that the linear flow of the decision tree shown in Figure 21-8 should just be used as a starting point as it is not the only way to approach an ERA. The specific approach should be based on the process outlined in the DQOs and an iterative assessment of meaningful effects, dependent on the particular chemicals and receptors of concern at a site. Many of the items in Table 21-10 and Figure 21-8 are conducted as part of the BERA, such as toxicity testing and tissue sampling. Required, preferred, and optional data for sediment ERAs are summarized in Table 21-11.

Table 21-10. Questions Guiding Decision Logic for Contaminated Sediment Investigation

Question	Method	Step
Do any chemicals in sediment in the DU exceed HDOH interim No Effect SQGs?	Compare with HEER Interim No Effect SQGs	SLERA Step 2
Could chemicals in prey organisms at the site adversely affect other organisms that consume them?	Evaluate using food chain modeling	SLERA Step 2
Are the chemicals present at concentrations greater than what occur naturally in these sediments or typically in the local environment?	Compare with background/ambient/reference locations	SLERA Step 3A
Are the chemicals in a bioavailable form representing exposure to organisms?	Evaluate factors affecting bioavailability	SLERA Step 3A
Are organisms at the site directly affected by exposure to chemicals in sediment?	Conduct direct toxicity test or model using representative data	BERA
Are organisms at the site bioaccumulating chemicals from the sediment?	Measure field collected organisms or model bioaccumulation using representative data	BERA
If yes, could organisms at the site be adversely affected by the chemicals in their tissues?	Evaluate using appropriate tissue effect levels	BERA

Figure 21-8. Interim Decision Logic for Sediment Investigations in Hawai‘i

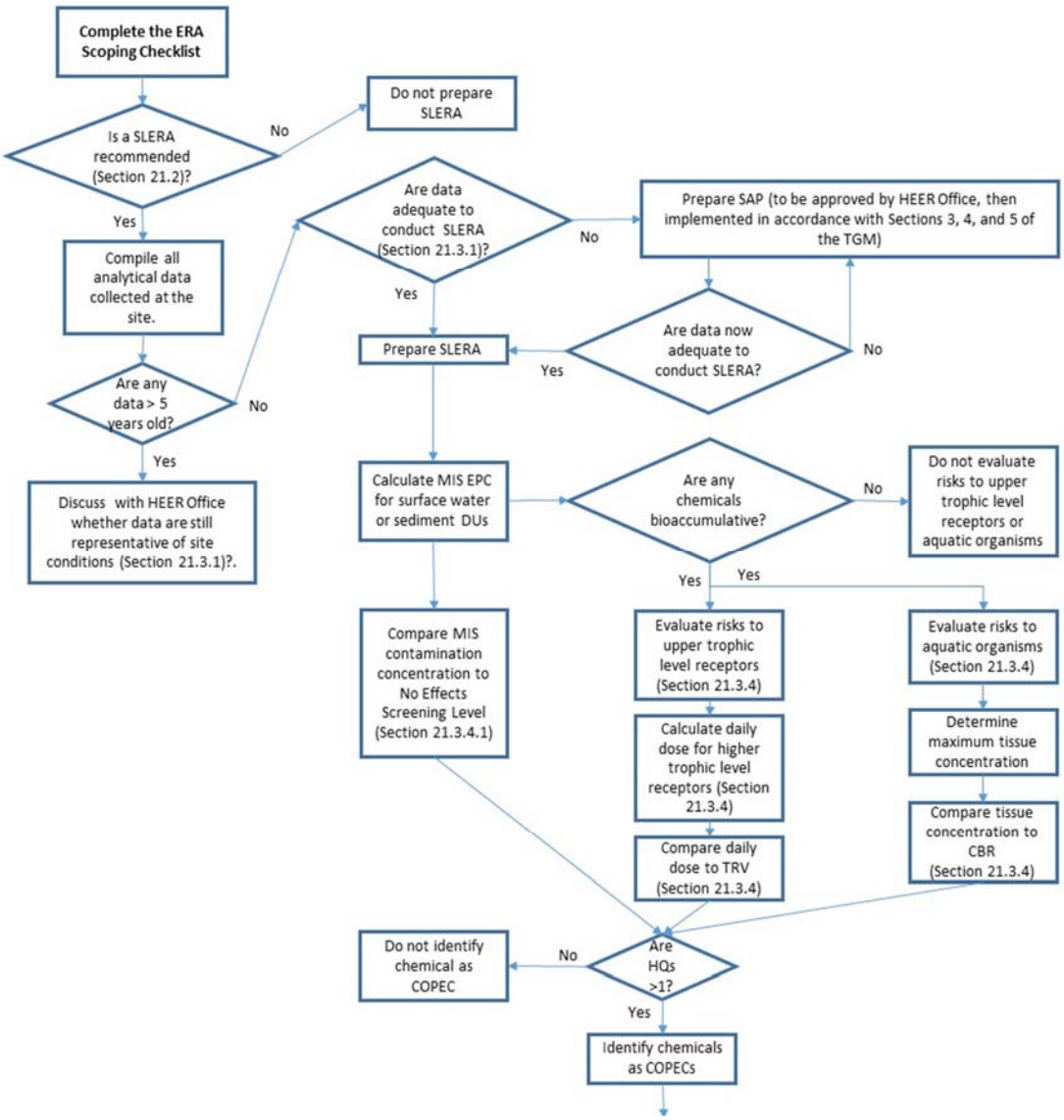


Figure 21-8 (continued). Interim Decision Logic for Sediment Investigations in Hawai‘i

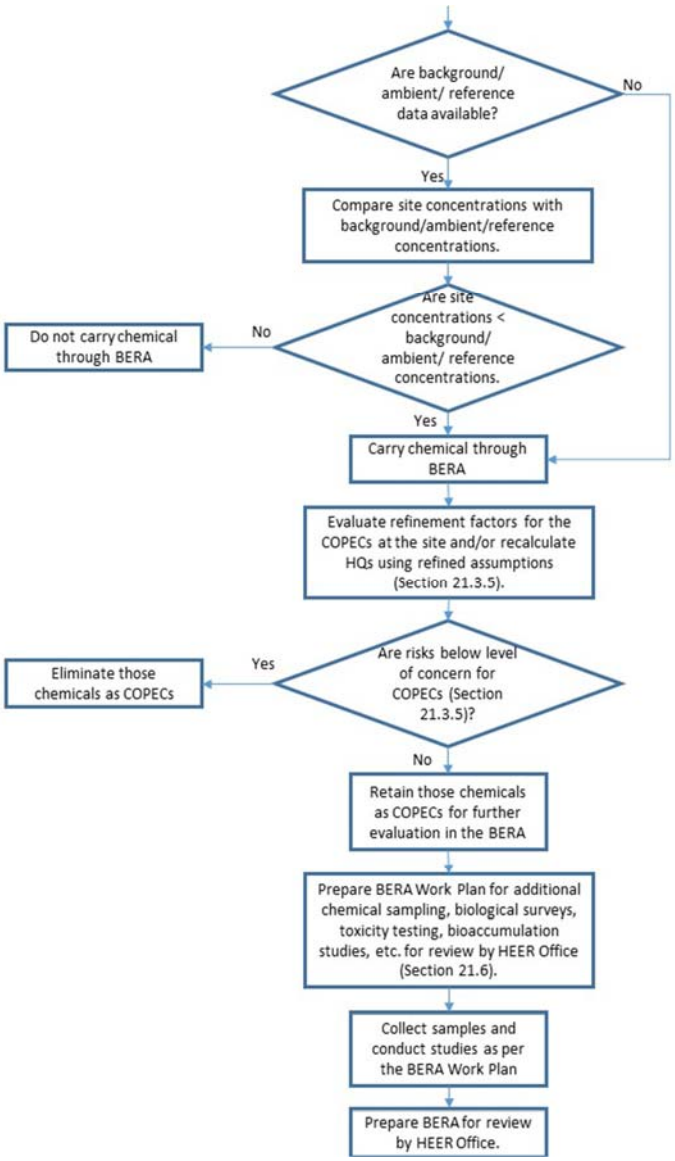


Table 21-11. Required, Preferred, and Optional Data for Sediment ERAs

Data Type	Required	Preferred	Optional
Sediment (for SLERA or BERA)			
Multi Increment Sediment (MIS) Samples in appropriate decision units (DU)	●		
Pre-approved Reference Location – all sample types	●		
Background metals analysis (literature)	●		
Total 0rganic carbon	●		
Grain size distribution	●		
Acid-volatile sulfide and simultaneously extracted metals (AVS/SEM)			●

Pore water		●	
Surface water		●	
Site-specific tissue (for bioaccumulating chemicals)		●	
Laboratory Tests (typically just for the BERA)			
Bioaccumulation Test (using native Hawaiian species[1])	(if known bioaccumulator is present or suspected)		
Lethal and sublethal toxicity tests using native Hawaiian species	(if one or more chemicals is greater than the Probable Effect SQG)	(if one or more chemicals is between the No Effect SQG and the Probable Effect SQG)	
Field-Collected Tissue *(typically just for the BERA)*			
Field-Collected Tissue (Benthic/epibenthic invertebrate such as crab or octopus; fish species with direct or indirect exposure to sediment)	(if known bioaccumulator is present or suspected)	(in general)	
Passive sampling device (for PCBs)			if PCBs exceed No Effect SQG

[1] If no standard test using a native species is available, provide rationale for a carefully-selected surrogate species

21.6 BASELINE ECOLOGICAL RISK ASSESSMENT

After completing the SLERA, including the Step 3a refinement, the risk assessor is ready to begin Step 4: the BERA. The first task of Step 4 is to prepare a BERA work plan (WP). If additional field data collection is required, the WP may include a field sampling and analysis plan (SAP). Typically, a combined WP/SAP is prepared to streamline the planning and approval process before BERA data collection begins.

The purpose of preparing a BERA WP is two-fold: (1) it compels the risk assessor to thoroughly evaluate existing data, describe site conditions, formulate DQOs, identify data gaps, and anticipate issues that may arise during later risk characterization and data interpretation phases; and (2) it provides a site-specific framework for discussions with the HEER Office during which information can be shared and common goals can be established. This subsection guides the risk assessor through the tasks typically included in the BERA, describes best practices, and reviews technical references to support the process. This subsection assumes that a combined WP/SAP is being prepared. The process of developing the BERA WP/SAP is described below.

1. Review the SLERA and ensure that you have access to all available data that contributed to the conclusions of the SLERA.
2. Compile any pertinent information collected since the SLERA was prepared. If any new information leads you to question the need for a BERA, present the information and your rationale to the HEER Office for discussion.
3. Once you are sure that a BERA is appropriate, prepare a BERA WP/SAP using the outline in Appendix 21-G. The rest of this subsection will provide templates and examples to help you develop the BERA WP.
4. Notify the HEER Office that you are preparing a BERA WP/SAP and request additional guidance as needed.
5. Submit the draft BERA WP/SAP to the HEER Office well before you expect to begin field work.

As described in previous subsections, the SLERA usually relies on literature-based toxicity and bioaccumulation factors and conservative default assumptions about exposure because site-specific data are not available. The purpose of the BERA is to replace literature or default values with site-specific data so that risk can be more accurately characterized. Site-specific data collection may include toxicity and bioaccumulation tests, collection of organisms, passive sampling of water or sediment, analysis of TOC and grain size, and other types of information. In addition to collection of new data, a more detailed analysis of data available during the SLERA may be warranted.

The components of the BERA mirror those of the SLERA. First, the problem formulation is refined to better describe the environmental setting, ecological receptors, and complete exposure pathways, resulting in a revised CSM (Subsection 2 of the BERA WP/SAP). Then, exposure and effects estimates are updated using site-specific information. The study design for collecting and analyzing new data is in Subsection 3 of the BERA WP/SAP (Study Design and DQOs). Elements of the BERA are presented in Subsections 21.6.1 through 21.6.4 below.

Although each BERA WP/SAP will represent site-specific conditions and address unique considerations, most or all can be prepared using the template in Appendix 21-G. The template provides general direction on which elements should be included in a site-specific BERA WP/SAP and includes useful tips. The HEER Office does not require that the risk assessor follow the template exactly, but it is important that all the necessary components of the BERA be included in the WP/SAP. The full set of topics to be included in the BERA will be determined by the location and geophysical features of the site, the site-specific COPECs, the selected assessment and measurement endpoints, and complete exposure pathways.

21.6.1 BERA REFINED PROBLEM FORMULATION

The problem formulation subsection serves as the “backbone” of the ERA. The SLERA problem formulation (described in Subsection 21.3.3) included a description of the environmental setting, including ecological receptors, potential sources of contamination, and potential exposure pathways, which were used to develop the preliminary CSM. At the start of the BERA, the problem formulation is refined to reflect the conclusions from the SLERA.

The result of Step 3a is a list of COPECs that require further evaluation in the BERA and a list of chemicals eliminated from further evaluation because they were found not likely to cause significant risk. Ideally, the BERA will focus only on chemical-

receptor pairs posing potential risk. Careful completion of this step will prevent the risk assessor from wasting time and effort evaluating chemicals in the BERA that should have been screened out during Step 3A.

The refined problem formulation should also identify any data gaps necessary to characterize site-specific risk at the end of the BERA. In some case, information obtained since the SLERA was written may warrant inclusion of chemicals, receptors, or exposure pathways that were not evaluated in the SLERA. For example, the risk assessor may have learned of a historical spill at the site, or a unique habitat with receptors not considered during the SLERA may have been identified. Data gaps identified during review of the SLERA may also require additional lines of investigation. In general, the refined problem formulation should include the environmental setting, COPECs, and assessment and measurement endpoints. Each of these is discussed below.

This subsection of the BERA should describe the environmental setting, COPECs, and sources identified in Step 3a, and ecological receptors. Although much of the site characterization will remain as described in the SLERA, it should be updated with any new information, especially on habitats that will be the focus of the BERA.

21.6.1.1 SEDIMENT DYNAMICS

The SLERA may have relied on assumptions about sediment grain size based on regional geology, as described in the introduction to Section 21. For example, the area may have been described as depositional based on regional data, habitat, or conservative assumptions. For the BERA, it may be necessary to confirm substrate type and grain size at the site to determine whether the area is depositional to better predict chemical behavior and presence of receptors when refining the CSM. Grain size and wave energy must also be considered when selecting an appropriate reference location for the BERA.

Beaches are eroding more than accreting across Hawai‘i (Fletcher et al. 2012) and coastal erosion is expected to nearly double over the next few decades across the state (except Kailua Beach on O‘ahu). Nevertheless, sediment dynamics are spatially variable, and areas of erosion and accretion may be separated by only a few hundred meters. Each small embayment created by rocky headlands is influenced by local wave energy and terrestrial processes, creating a patchwork of erosion and accretion along the shore. The most recent data on coastal erosion and accretion of shorelines on Kaua‘i, O‘ahu, and Maui are available at (Fletcher et al. 2012). This USGS information should be consulted during the site characterization phase of the BERA.

21.6.1.2 CHEMICALS OF POTENTIAL ECOLOGICAL CONCERN

The list of COPECs developed at the end of Step 3A should include only those chemicals that exceed background or reference concentrations and ecotoxicological effect levels for receptors at the site. If new information suggests the presence of additional chemicals that were not analyzed during the SLERA, then new chemicals should be added to the BERA WP/SAP.

21.6.1.3 ECOLOGICAL RECEPTORS (ASSESSMENT AND MEASUREMENT ENDPOINTS)

Measurement Endpoints)

Based on the results of Step 3a, some receptors considered in the SLERA may be eliminated from further evaluation, and others may be added. The refined problem formulation should include only receptors that will be evaluated in the BERA, based on their known or expected presence at the site or their selection as surrogates for species of interest. The HEER Office has prepared species profiles for selected marine species in Hawai‘i (Appendix 21-A). The appropriate receptors from this list should be considered for evaluation in the BERA, noting that additional exposure information may be needed to quantify risks to some receptors. Note that the list of species in Appendix 21-A is not comprehensive; other species may be evaluated in the BERA if approved in advance by the HEER Office. In the BERA WP/SAP, explain any changes to the list of receptors in the SLERA.

Assessment and measurement endpoints that are commonly evaluated in marine sediment ERAs are summarized in Table 21-5 (see Subsection 21.3.3). This subsection of the BERA should provide rationale for the selected assessment endpoints and describe how each assessment endpoint will be evaluated using the selected measurement endpoints. A table similar to Table 21-5, including the following elements, should be developed for the BERA:

- ***Ecological Guild***: The functional niche of the receptor (such as benthic invertebrate)
- ***Assessment Endpoint***: The specific attributes of value for the ecological guild at the organism or population level.
- ***Species Evaluated***: Table 21-8 lists typical species included in each ecological guild. In the BERA, identify the species that were used to represent the ecological guild, along with the rationale for selecting the species. In some cases, species other than those listed in Table 21-8 may be used based on available data. Use of other species should be presented in the BERA WP/SAP and approved in advance by the HEER Office.

- ***Measurement Endpoint***: Table 21-5 lists common measurement endpoints for each of the assessment endpoints. In the BERA, present the specific measurement endpoints that were used to evaluate the assessment endpoints, along with the rationale for selecting those endpoints. The measurement endpoints may include some or all the endpoints listed in Table 21-5, and endpoints not listed in the table that are deemed appropriate for the site.

21.6.1.4 REFINED CONCEPTUAL SITE MODEL

The screening level CSM was developed as part of the SLERA based on what was known about the site at that time, without regard to potential ecological risks. As described in Step 1b, Task 5 (Subsection 21.3.3), the elements of the CSM include (1) ecological receptors present at the site; (2) sources of chemicals in the environment; (3) contaminant transport pathways; and, (4) exposure pathways to the ecological receptors. The same elements are included in the refined CSM, which represent the chemicals, receptors, and exposure pathways evaluated in the BERA.

Appendix 21-C describes the approach for defining the ecological DU. DUs set the boundaries for where the BERA investigations will be conducted. The refined conceptual site model should describe the DUs that were selected for each assessment endpoint evaluated in the BERA and the rationale for selecting them. Refer to the discussion of sediment types at the beginning of Section 21 before identifying DUs. Note also that the size of the DUs is determined in part by the receptors, as home range is an important variable in the evaluation of exposure and effects. The site may contain several DUs designated by sediment type, wave energy, preliminary contaminant concentrations, receptor distribution, and other factors.

21.6.2 BERA STUDY DESIGN AND DATA QUALITY OBJECTIVES

The BERA should describe the investigations conducted to evaluate each assessment endpoint, such as chemical analysis, toxicity testing, bioaccumulation studies, biological surveys, and tissue analyses. The DQO process that was followed during the SLERA (see TGM Sections 3, 4, and 5) should be revisited when preparing the BERA WP/SAP. The study design and DQOs should be presented in the BERA WP/SAP and cited in the BERA. Because the BERA WP/SAP will be included as an appendix to the BERA, it is not necessary to repeat the DQO subsection. A Quality Assurance Project Plan (QAPP) should also be prepared as part of the BERA planning effort (see TGM Section 10).

21.6.2.1 LABORATORY ANALYSES

Additional data collected for the BERA are likely to include field samples of sediment, sediment pore water, surface water, groundwater, or even soil (in case where terrestrial erosion is suspected as a transport pathway to the marine site). The BERA WP/SAP should identify analytical methods and detection limits to ensure that detection limits lower than selected screening levels can be achieved.

The HEER Office recommends evaluating chemicals with similar modes of toxicity as “total” concentrations, but analysis of individual constituents may also be necessary. Total concentrations are commonly calculated for HMW PAHs, LMW PAHs, total PAHs, total PCBs, DDT and its breakdown products (total DDTx), and dioxin toxic equivalency quotients (TEQs). Methods for calculating total PCBs and dioxin TEQs are discussed later in this subsection, but the risk assessor is encouraged to review the current literature and determine the most appropriate method for the site. No specific list of constituents or summation method is prescribed because methods are rapidly changing as new technical literature is published, methods are vetted, and best practices are disseminated within the risk assessment community. The BERA WP/SAP should describe the proposed methods of summing constituents and clearly identify the individual constituents to be included in the sum. Relevant literature should be cited to support the proposed methods.

In general, HDOH requires the following when calculating total values:

- Non-detected values should be assigned a value of zero provided the detection limits were acceptable, as described above.
- The mean of replicate samples (i.e. triplicates or duplicates) should be used for the calculation.
- The list of individual constituents included in the total calculations must be given (e.g. see notes at the bottom of Table 21-7 for a list of HMW and LWM PAH totals).

Risks from dioxins/furans should be evaluated by using Toxicity Equivalence Factors (TEFs) to calculate toxicity equivalence concentration (TEQ) as described in the *Framework for Application of the Toxicity Equivalence Methodology for Polychlorinated Dioxins, Furans, and Biphenyls in Ecological Risk Assessment* (USEPA 2008g). The detected concentration of each dioxin (or furan) in a sample is multiplied by its TEF. The resulting values for each sample are summed to calculate the TEQ

Dioxins/Furans for each sample. TEQs should be calculated for birds, mammals, and fish using chemical-specific TEFs for each group; no dioxin TEFs are available for plants and invertebrates.

PCB results historically have been reported as Aroclors (i.e., Aroclor-1254, Aroclor-1260) in BERAs because the early ecotoxicological studies were based on total PCBs expressed as the sum of Aroclors. Although some current studies continue to report effects of total PCBs, newer literature is increasingly focused on one or a small set of the 209 PCB congeners. Each Aroclor originally contained a specific combination of PCB congeners and could be identified by its distinctive chromatographic pattern when is analyzed by gas chromatography. However, as Aroclors age and weather, the chromatographic patterns may change and not be recognizable as standard patterns. Such degradation of Aroclors may cause the laboratory to underestimate the concentration of total PCBs in a sample. (See USEPA 2013c) for more detail on this issue.

Analysis of PCB congeners is considerably more expensive than Aroclors, so the decision of analytical method must be made with care. The HEER Office recommends that PCBs be analyzed as Aroclors during the SLERA. However, if total PCBs are detected at concentrations exceeding the screening level in the SLERA samples, a subset of samples (no less than 10 percent) should be analyzed for all 209 congeners. Note that twelve of the PCB congeners have been designated by the World Health Organization (WHO) as having “dioxin-like” toxicity (Van den Berg et al. 1998). The same process described above to calculate the TEQs for dioxins (USEPA 2008g) can be used to sum the dioxin-like PCBs when site conditions warrant. The BERA WP/SAP should describe the rationale for the selected analytical methods for PCBs (Aroclors, congeners, or a combination of the two) and discuss how the dioxin-like PCBs will be summed if samples are analyzed for PCB congeners.

21.6.2.2 SEDIMENT SAMPLING

The objectives of the study and availability of existing data play an important role in dictating the sampling design, methods, and equipment. For example, MI sampling should be conducted to determine representative average contaminant concentrations in sediment across a designated DU (see Sections 3, 4, and 5. Subsection 5.7 of the TGM (Sediment Sampling) discusses issues affecting sediment sampling in more detail.

A wide variety of sampling equipment is available for collecting sediment, but not all equipment is suitable for all sites. For example, grab samplers such as a ponar dredge or Van Veen grabs are capable of sampling only the top several inches of sediment, while sediment corers and vibracores can be used to collect deeper samples if historical chemical concentrations are needed. Other considerations include whether the sediment sample must be undisturbed (as it should be for analyzing volatile organic compounds). Water depth, currents, sediment volume, bottom firmness, and other parameters also influence the likelihood of success of each collection method. When acid volatile sulfides [AVS] are to be analyzed, exposure of the sample to oxygen must be limited. A thorough discussion of the various sediment sampling devices, including advantages and disadvantages of each and the best samplers to use for different types of sediment is presented in Chapter 3 in *Methods for Collection, Storage and Manipulation of Sediments for Chemical and Toxicological Analyses: Technical Manual* (USEPA 2001i). The BERA WP/SAP should include a complete description of equipment, techniques, and standard operating procedures (SOPs) for all sediment collection methods; references should be cited as needed to support the proposed methods.

The BERA WP/SAP should describe the procedures for any representative sub-sampling of sediment samples in the field. This is a critical component of sample processing and should be based on the objective of the investigation, the COPECs, and the sediment matrix. Typically, processing and representative sub-sampling of MI samples are conducted in the laboratory following an established SOP (see TGM Section 4).

Sediment samples must be collected from the appropriate depth to address the goals of the BERA (as identified in the DQO analysis). General guidance on selecting the appropriate depth for collecting sediment samples in the biologically active zone is in *Determination of the Biologically Relevant Sampling Depth for Terrestrial and Aquatic Ecological Risk Assessments* (USEPA 2015e). Table 21-12 summarizes the depths of the biotic zone associated with different sediment substrates and lists habitats in Hawai‘i that may contain that substrate.

Table 21-12. Typical Depths of Biotic Zone

Depth	Sediment Substrate	Example Habitat Type
5 cm	oligohaline/polyhaline mud	Mudflats
5 cm	oligohaline sand and marine coastal sand	Sandy Beach
10 cm	marine coastal mixed and marine offshore sand	Seagrass beds
10 to 15 cm	estuarine and tidal freshwater environments	Stream-fed Estuarine Wetlands

The HEER Office recommends taking the above-referenced guidance into consideration when determining appropriate sampling depths to capture the biotic zone. However, depending on the objective of the investigation, deeper samples (below the biotic zone) may also be needed to characterize vertical extent of contamination.

Special sediment sampling consideration may be warranted for target receptors that ingest sediment directly, as sediment effect levels may not account for the ingestion pathway. Ingestion is the basis for the food chain modeling used to evaluate risk to birds and mammals, but many benthic invertebrates and fish also consume sediment as part of a typical diet. Tissue concentrations of benthic invertebrates may reflect chemicals adsorbed to ingested sediment particles as well as chemicals absorbed directly from sediment and water (Lee et al. 2006; Belzunce-Segarra et al. 2015). To evaluate the sediment ingestion pathway, sample collection methods must ensure that the top layer of fine particles is retained for analysis.

When developing the BERA WP/SAP, sediment sample collection log sheets from the SLERA should be reviewed to determine whether they contain useful information to guide the BERA. For example, if sulfide odors were detected during sediment sampling, then AVS may be present in the sediment. Methods for evaluating bioavailability of metal mixtures in sediment containing AVS are discussed in *Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: Metal Mixtures (Cadmium, Copper, Lead, Nickel, Silver, and Zinc)* (USEPA 2005e).

At some sites, it may be appropriate to use a Dynamic Sampling Approach, in which field analytical methods such as x-ray fluorescence (XRF), immunoassays, or other mobile screening approaches help make quick decisions regarding the need to collect samples in a location. This approach is discussed briefly in Subsections 3.10 and 5.5.8 of the TGM. Basically, this approach allows samples to be collected and sites to be characterized more efficiently and quickly than traditional sampling. The costs and benefits of a dynamic sampling approach should be discussed in the BERA WP/SAP. See *A Guideline for Dynamic Workplans and Field Analytics: The Keys to Cost-Effective Site Characterization and Cleanup* (Robbatt 1997 and USEPA 1997i) for more information on field assessment techniques.

21.6.2.3 PORE WATER SAMPLING

In sediments where sediment pore water is relatively static, contaminants in the pore water are expected to be at thermodynamic equilibrium with the sediment (solid phase), making pore water useful for assessing contaminant levels and associated toxicity (USEPA 2001i). The utility of collecting sediment pore water at a site is influenced by a variety of factors, including the solubility of the chemicals, ongoing sources of chemicals in groundwater, grain size and organic content of sediment, and other factors. Sites where pore water analysis may be appropriate include fine-grained sediments in low energy depositional areas (such as bays and harbors) and nearshore sites where contaminated groundwater is known or suspected to discharge to sediment. The suitability of sediment pore water as an exposure pathway to ecological receptors should be evaluated as part of the DQO process and documented in the BERA WP/SAP.

Pore water collection methods should be tailored to the site and the contaminants of concern. No single method is clearly superior in all cases. For example, peepers are suitable for collecting small volumes of pore water for one or two analyses but are not practical for collecting large volumes required to analyze for numerous chemicals. Fine-grained sediments may be collected in buckets and taken to the laboratory for extraction of pore water by centrifugation. However, centrifugation may overestimate concentrations of freely dissolved contaminants (Cfree) in sediment porewater. Depending on the target receptors, the freely dissolved concentration may be a more appropriate exposure point concentration than the total concentration in pore water. Pore water samples also can be collected directly from the sediment using drive points and pushpoint samplers (Henry samplers). In coarser-grained sediments, especially where contaminants are being continuously discharged, in situ measures may be more practical because coarse grained sediment does not retain much water when collected. Traditional collection of sediment followed by centrifugation would require substantial effort because of the large volume of sediment needed to yield an adequate volume of pore water.

Passive in situ sampling methods may be suitable in cases where collecting large volumes of sediment for centrifugation is impractical. or when other limitations of centrifugation are of concern. For example, when chemicals of concern are volatile or unstable, concentrations in pore water may change as the sediment is transported to the lab and centrifuged.

Pore water in situ sampling methods for coarse-grained sediments are under development. The Laboratory, Field, and Analytical Procedures for Using Passive Sampling in the Evaluation of Contaminated Sediments: User's Manual (USEPA/SERDP/ESTCP. 2017) provides the most comprehensive review of methods for passive sampling of contaminated sediments. The manual provides guidance on selecting and implementing passive sampling technology to evaluate PCBs, PAHs, and selected metals (cadmium, copper, nickel, lead and zinc) in sediment. Earlier technical reviews of passive sampling are provided in (Ghosh et al. 2014), (Greenberg et al. 2014), (Lydy et al. 2014), (Mayer et al. 2014), and (Peijnenburg et al. 2014).

Passive sampling consists of inserting various materials such as polydimethylsiloxane (PDMS), low-density polyethylene (LDPE), or other similar materials into the sediment for a period of time (usually several weeks or months). The materials are typically mounted on frames and may be enclosed by screens or tubes for protection. The samplers are cleaned with an organic

solvent to remove oligomers, plasticizers, and contaminating organic chemicals prior to deployment in the field. In some cases, performance reference compounds (PRCs) are added to the sampler as a quality control for estimating the extent of equilibrium of the target contaminant. After the samplers are retrieved from the sediment, the sampling material is cleaned, the contaminants are extracted, the extract is analyzed for contaminants, and concentrations of cfree are calculated. The sampler can be sectioned prior to extraction, if desired, to investigate vertical concentration gradients.

The BERA WP/SAP should specify the methods of collecting and analyzing sediment pore water will be used and provide rationale for selecting the methods. It is essential that the same collection procedures be used and the pore water be collected at the same depth across the site so that appropriate comparisons can be made (USEPA 2001i). Likewise, the same methods must be used at the reference location. If the pore water concentrations will be compared with water quality criteria, the WP must specify how the cfree concentrations will be interpreted with respect to the dissolved criteria for protection of aquatic life. In some cases, side-by-side analysis of standard dissolved concentrations may be required to establish that the passive sampling methods are representative. Additional methods are discussed in several comprehensive technical references:

- USEPA 2001i: *Methods for Collection, Storage and Manipulation of Sediments for Chemical and Toxicological Analyses: Technical Manual* (Chapter 6).
- Carr et al. 2001: *SETAC Technical Workshop on Porewater Toxicity Testing: Biological, Chemical, and Ecological Considerations with a Review of Methods and Applications, and Recommendations for Future Areas of Research*
- Various authors 2014: *"Passive Sampling Methods for Contaminated Sediments,"* in the SETAC Technical Workshop "*Guidance on Passive Sampling Methods to Improve Management of Contaminated Sediments*" in *Integrated Environmental Assessment and Management* (Volume 10) reviews the use of passive samplers to quantify concentrations of chemicals in sediment pore water. (Ghosh et al. 2014, Greenberg et al. 2014, Lydy et al. 2014, Mayer et al. 2014, Parkerton et al. 2014, and Peijnenburg et al. 2014).

21.6.2.4 SURFACE WATER SAMPLING

The surface water pathway is evaluated by comparing chemical concentrations in surface water with water quality standards based on ecotoxicity. However, surface water should be evaluated only in places where the water has a relatively long residence time so that the exposure duration is meaningful. For example, surface water is not considered a measurable pathway at sites where high energy wave action mixes the water constantly. The HEER Office generally does not recommend collecting surface water samples from high energy environments or areas where considerable flushing occurs. In contrast, surface water could be an important pathway in a protected bay contaminated by a surface release, stream input, or groundwater flow. Surface water samples should be collected if chemicals in groundwater are known or suspected to discharge through sediment into protected surface water areas.

Surface water samples may be analyzed for total or dissolved chemicals, depending on the proposed use of the results. Samples that will be compared with the HEER Office EALs for aquatic life for metals should be analyzed for dissolved fractions, represented by samples passed through a 0.45 micrometer (µm) filter. The filtering step typically takes place in the lab, although field-filtering is an option under special circumstances. The USGS provides comprehensive guidance on proper methods for collecting water samples in the *National Field Manual for the Collection of Water-Quality Data: U.S. Geological Survey Techniques of Water-Resources Investigations*, Book 9, Chapters A1-A10 (USGS 2018).

Both freshwater and saltwater (marine) standards are available. Freshwater and saltwater standards apply to waters with a dissolved inorganic ion concentration less than and greater than 0.5 parts per thousand (ppt), respectively. Saltwater samples can be analyzed for dissolved constituents only. In freshwater habitats, however, total concentrations from unfiltered samples are better indicators of the concentrations ingested by animals as drinking water and are preferred as inputs to the food chain model (see Step 2, Task 3). Freshwater samples may be split and analyzed as both total and dissolved concentrations. The BERA WP/SAP should clearly indicate and provide rationale for which water quality standards will be applied and which water samples will be filtered.

Sample numbers and locations, sampling equipment, and proposed analyses should be presented in the BERA WP/SAP. Equipment should be selected based on the depth of water to be sampled, volume of water needed, strength of currents, and other logistical factors. For example, if the objective is to collect surface water samples at the surface water-sediment interface to determine whether groundwater discharge is transporting chemicals to surface water, a horizontal water bottle sampler may be appropriate. Alternatively, passive sampling devices can be deployed at the sediment-water interface to measure concentrations over time in a specific area. Passive sampling devices are newer and less standardized but may be acceptable for use at some sites. Regardless of the methods and equipment selected, it is important that site samples and reference area samples be collected in the same way.

The BERA WP/SAP should present a rationale for the selection of devices, equipment, and methods. The procedure should be designed so as to minimize incidental collection of suspended solids with the water sample, as solids can artificially inflate measured chemical concentrations. Such interference can be especially important when relatively hydrophobic chemicals such as PCBs and pesticides are being analyzed. In such cases, side-by-side analyses of filtered and unfiltered samples may be warranted.

21.6.2.5 BIOLOGICAL SURVEYS

Biological surveys may be conducted as part of a BERA for many reasons:

1. To document the presence and abundance of ecological receptors at the site, including protected or rare species;
2. To compare the distribution or abundance of species with reference areas or historical records;
3. To evaluate the health or integrity of the ecological community; and
4. To collect tissue samples for chemical analysis (described below) for use in food chain models or critical body residue analyses.

Field surveys may be designed for the reasons listed above, as well as simply to ground-truth the CSM. Unlike sediment and water sampling, which may be conducted by general field teams, biological surveys should be conducted by experienced biologists or ecologists who are prepared to document and interpret what they see in the field. Although a single species or type of organism may be targeted for collection, the presence and condition of other species may inform the BERA. Well-designed biological surveys focus on structured data collection, but a competent field biologist will also make opportunistic findings, such as the presence of unanticipated species; the relative scarcity of individuals where abundance was expected; evidence of degraded habitat such as algal overgrowth, stressed vegetation, or chemical sheens and odors; and other features that are not the direct target of the survey.

The BERA WP/SAP should describe the proposed survey as thoroughly as possible, including but not limited to the elements below:

- Objectives of the survey
- Qualifications of the field team
- Locations to be surveyed (with rationale), and process for adjusting the location when field conditions warrant
- Relation of survey locations to established DUs
- Intended dimensions of each survey location (length and width)
- Survey methods (areal grid, transect, etc.)
- Sample field forms
- Protocol for avoiding habitat degradation during survey
- Protocol for unintended encounters with protected species
- Temporal requirements of the survey: time of day, season, restrictions based on weather
- Health and safety issues (to be documented in a separate health and safety plan)
- Use of survey data (species richness, taxonomic diversity, percent dominant taxa, frequency and dominance of stressor tolerant taxa, etc.)

Surveys at the site should be repeated to the extent feasible at reference locations. The reference locations should be similar in size, substrate (grain size distribution), wave energy, surrounding habitat/land use (i.e. urban, rural, forested, etc.).

21.6.2.6 FIELD-COLLECTED TISSUE SAMPLING

Organisms may be collected from the site (and reference location) during a biological survey or as a separate activity. Field-collected organisms may contribute in several ways to the BERA:

1. Whole organisms or body parts may be analyzed for selected chemicals. When appropriate, chemical concentrations in the organisms can be compared with concentrations in sediment to evaluate bioavailability and uptake by the organism. Note that this approach requires that both the organisms and the sediment be relatively immobile.

2. Organisms may be collected as part of a biological inventory focused on characterizing the health of the community in a given area. Species distribution and abundance, species diversity, age or size class distribution, reproductive condition, and other parameters may be measured.
3. Organisms may be collected for evidence of disease, which may then be linked to chemical contaminants in the sediment or water. External tumors or lesions may indicate exposure to PAHs, for example. Internal examination may reveal parasites, liver damage, or other evidence of degraded health.

Note that a Special Activity Permit may be required for collecting marine organisms for the BERA, even if the organisms are returned to the water unharmed. The Hawai'i Division of Aquatic Resources should be contacted during the BERA planning stages to identify necessary permits (DLNR DAR 2018). Other permits may be required for collecting protected species or certain native species, or for collecting in parks or other specified areas. The risk assessor should coordinate with the Hawai'i Division of Forestry and Wildlife (DLNR DFW 2018) to obtain the required permits.

In addition to the elements listed above for biological surveys of any kind, the BERA WP/SAP should fully describe the proposed rationale and methods for collecting and analyzing organisms, including at a minimum the following details:

- Objective of the collection effort
- Target species to be collected and alternate species in the event that the target species cannot be collected
- Locations, relative to DU, and protocol for field adjustment of locations
- Number of individuals of each species to be collected (by sex and size, if relevant), per location, including reference location
- Number of organisms to be composited in each sample (single species only)
- Body part(s) to be tested (whole body, liver, eggs, blood, etc.)
- Other parameters to be measured (lesions, parasites, fin rot, etc.)

Selection of Appropriate Species for Field Collection

Selecting the appropriate species for field collection is critical to the defensibility of the BERA. Not all species are suitable for answering all questions. The three principal reasons for collecting organisms from the site are (1) chemical analysis; (2) community metrics; and (3) evidence of disease.

All three of these lines of evidence require species with the following characteristics:

- ***Exposure:*** The species is exposed to the site (and the reference area) for a substantial period of time relative to its lifespan, so that observed effects can be linked to the site. Year-round residency is desired but not required.
- ***Ecological Relevance:*** Organisms should be ecologically relevant to the evaluation. For example, if risk to the wedge-tailed shearwater from fish consumption is being evaluated, individual fish of the appropriate species and size should be collected. Seasonality should also be considered (see below).
- ***Abundance:*** Field-collected species should be abundant enough at the site and reference area to support collection of specimens for the intended use. See Table 21-13 for tissue volumes generally required for chemical analyses.

Table 21-13. Typical Tissue Volumes Required for Selected Chemical Analysis

Chemical Group	Tissue Volume Required (grams wet weight)	
	Low Level Detection	Standard Level Detection
Metals	2	2
Pesticides	15	1.5
PCBs	15	1.5
Dioxins/Furans	10	10
SVOCs	30	2

Percent Lipids and Moisture	10	3

Species collected specifically for chemical analysis must meet the following additional criteria:

- **Ability to accumulate the chemical:** Many metals are accumulated by both plants and animals, but most organic chemicals are not likely to be accumulated in plants. Metals that are essential nutrients may be actively regulated by the organism and thus not suitable for use as indicators of bioavailability. Verify that the COPECs being evaluated are known or expected to accumulate in the organism targeted for collection.
- **Limited ability to metabolize the chemical:** Some organisms metabolize certain organic chemicals, which makes the compounds less likely to accumulate in tissues. For example, PAHs induce mixed function oxidase enzymes (and thus their own biotransformation) in fish and other vertebrates, but not in mollusks or crustaceans (USEPA 2000i). Although fish may show signs of PAH exposure, such as lesions or tumors, tissues may not contain elevated concentrations of PAHs relative to sediments.
- **Sex and Seasonal Variability:** Chemical concentrations in a species may vary by sex, often influenced by reproductive processes. For example, a female fish or invertebrate may transfer some organic chemicals to her eggs, thus reducing her body burden. Chemical analysis of composite samples made up of several individuals may vary from one another simply because the sex ratios in the samples differed. This situation would confound the analysis of site-related bioavailability and compromise the findings of the BERA. Whenever possible, the sex and reproductive condition (pre- or post-spawning) of individuals in a composite (and across the site and reference area) should be matched. Likewise, chemical concentrations in organisms may vary by season. A study of tissue concentrations at Ordnance Reef reported that metals were higher in goatfish samples in the fall, but higher in octopus samples in the spring. The BERA WP/SAP should include a review of published findings on factors affecting seasonal variability to support the proposed sampling approach.

Collection and analysis of organisms can be time consuming and costly, as well as potentially affecting the habitats and communities at the site and reference area. The rationale for tissue collection should be clearly explained in the BERA WP/SAP so that the most appropriate organisms are collected to address the study objectives. Appendix 21-A presents profiles of 22 common Hawaiian species, including information on previous tissue analysis. The HEER Office recommends that these 22 species be used whenever possible so that a more robust statewide dataset can be developed.

Tissue Sample Handling and Processing

The BERA WP/SAP should describe methods for handling and processing field-collected organisms, including preservation (freezing or refrigerating), dissection (body parts to be analyzed), homogenization techniques, and other procedures. No single approach is appropriate for all tissue samples. If the tissue concentrations will be used in a food chain model, then the whole body should generally be analyzed. If a COPEC is known to differentially accumulate in a single organ, such as the liver, then an organ-specific analysis may be more appropriate. In some cases, only a part of an organism (blood, eggs, feathers) is collected.

The approach to preparing laboratory analysis replicates of tissue samples should be described in the QAPP. In most cases, replicate samples for tissue samples (i.e. triplicates or duplicates) will be prepared by the laboratory after the sample is homogenized and replicates need to be collected in separate random locations across the homogenized tissue, not co-located. Separate samples collected in the field, even from a single location, are considered different samples for analysis, not replicates.

In most cases, the HEER Office recommends that the laboratory report the results in dry weight and also measure and report percent moisture. Various uses of the results may require wet weight or dry weight concentrations. For example, if the results will be used as inputs into a food chain model, and the predator's ingestion rate is on a dry-weight basis, then the results should be in dry-weight. However, if the tissue results will be compared to critical body residues that are presented in wet-weight, then the results should be presented in wet-weight. In either case, if percent moisture in the tissue samples is reported, concentrations can be converted between wet-weight and dry-weight by the risk assessor as needed. Percent lipids should also be measured in any tissue analyzed for organic chemicals.

Spatial Correlation with Sediment Samples

As mentioned above, tissue concentrations can provide a strong line of evidence for bioavailability and potential toxicity of chemicals in sediment. However, the strength of this line of evidence is dependent on the degree to which the organisms are linked to the area of known sediment concentrations. It is essential that tissue samples be co-located in space and time with sediment samples, and that both are relevant to the DUs previously established.

Collection of Reference Samples

Because most sites are affected by general human activity apart from any site-related chemical release, the use of reference locations is essential to a strong ERA. Reference samples are used as a basis of comparison so that site-related chemical concentrations can be interpreted in the context of ambient or background chemical concentrations. The designation of reference areas was discussed previously (Step 3A, Task 1 in Subsection 21.3.4 and Appendix 21-E, Step 3). The HEER Office is compiling a database of tissue concentrations collected across the state for numerous purposes. During the BERA WP/SAP review process, the HEER Office may make these data available to the risk assessor to support a more robust analysis of ambient tissue concentrations.

The HEER Office must approve the reference area prior to sample collection. A minimum of three tissue samples should be collected at the reference site, using the following guidelines:

- Reference samples should be of the same species, size (±20%), and sex as the site samples.
- Site samples should be collected first, followed immediately by reference samples. This ensures that the reference species can be matched to the site samples.
- Reference areas should reflect general regional conditions (air deposition, general land use) but not be affected by site contaminants or other known sources of contamination. Physical habitat must be comparable to the site (wave energy, grain size, salinity, etc.)

21.6.2.7 TOXICITY TESTING

Chemicals detected in sediment, surface water, or pore water are not necessarily in a form that can cause adverse effects on receptors. To directly measure the bioavailability and potential toxicity of a sample, a test organism is exposed to the sample under controlled conditions. Laboratory bioassays are used to test the reactions of living organisms to water or sediment collected from a potentially contaminated site. Because interpretation of *in situ* field bioassays using native organisms can be confounded by multiple factors, standardized laboratory bioassay tests with a small number of well-studied species are typically used instead. Whether the suite of bioassay organisms and the particular test protocols that have become the norm in the mainland U.S. are reasonable tools for tropical marine assessments has been the topic of discussion during the past 20 years (Peters et al. 1997; Batley and Simpson 2008; Simpson et al. 2007).

Need for specific protocols to address ecological risk in tropical marine ecosystems was identified during the early stages of the USEPA ERA framework process because differences in the geochemistry and physical nature of sediment, climatic conditions, and other features of tropical ecosystems suggest that the exposure pathways may not be adequately represented by protocols developed for temperate ecosystems. Tropical marine ecosystems are not well represented by standard USEPA bioassays or exposure models.

Since that initial review paper (Peters et al. 1997), which thoroughly described the steps necessary to develop a tropical marine program, progress has been slow. Despite substantial advances in assessing ecological risk in general, the focus is still on temperate ecosystems (Batley and Simpson 2008).

Tropical marine species can be substituted for temperate species in some cases. Examples of new bioassay protocols developed to address tropical regions of Australia include the following (based on Adams and Stauber 2008):

- Tests using native benthic unicellular microalgae measure enzyme activity rather than growth; the test can be used in a wide range of grain sizes.
- A native polychaete (*Scoloplos* sp.) was substituted in an ASTM method; the native polychaete is an infaunal tunneler that lives in sediment of a wide range of grain sizes.

- No tropical amphipod test has been developed, but these authors suggest that amphipods exposed to typical coarse-grained sediments of coralline habitats may have to be fed during the test. (Tests with the freshwater Australian amphipod *Melita plumulosa* were not compromised by feeding.)
- The tropical hermit crab (*Diogenes* sp.) can be used for whole sediment bioassays. (Although this genus may not occur in Hawai‘i, other members of the Family Diogenidae may be equally useful as test organisms.)
- A standard bivalve bioassay can be modified to use the widespread tropical *Donax cuneata*.

The *Sediment Evaluation Framework for the Pacific Northwest* (Northwest Regional Sediment Evaluation Team (RSET 2016) provides a useful overview of toxicity testing and approaches for evaluating the results. The HEER Office continues to work with researchers to identify appropriate test organisms for contaminated marine sediment sites in Hawai‘i. The BERA WP/SAP should provide rationale for the proposed toxicity tests, including and modifications to standard protocols that would make the tests more representative of site conditions (water temperature, day length, etc.). The HEER Office will discuss other options with the risk assessor as needed.

In addition to the test species, the BERA WP/SAP Work Plan should describe the overall approach to the toxicity tests, including the duration of exposure; feeding regime; endpoints evaluated (growth, survival, reproduction, other); number of replicates; parameters measured during the test and frequency of measurements (pH, ammonia, other); and other specific test procedures. The criteria for sample selection should also be described. Issues that must be considered in the design of toxicity test samples include, but are not limited to, those below:

- What is the purpose of the toxicity test? What is the null hypothesis?
- Will toxicity testing run concurrent with or after chemical analysis?
- If chemical results are known, will samples for toxicity tests be selected randomly or purposefully to represent a range of concentrations?
- If purposefully selected, how will concentration bins be determined? What if more than one chemical is detected at the site (the most typical situation)?
- What types of correlation or regression analyses are planned? How many samples are required for robust analysis?
- How will variability among endpoints be interpreted? (For example, the test may show no effect on growth but a significant decrease in reproductive output, or vice versa.)
- How will samples form the reference area be selected?
- How will toxicity in site samples be evaluated with respect to the reference area?

The questions above, and any other relevant issues, should be thoroughly discussed in the BERA WP/SAP. Well-designed toxicity tests can provide a strong line of evidence to the BERA, but poorly designed tests waste time and money while only adding to the uncertainty in the BERA.

21.6.2.8 LABORATORY BIOACCUMULATION TESTING

Several limitations with field collected organisms can be addressed by conducting laboratory bioaccumulation tests. For example, while field collected organisms can answer questions about exposure to chemicals in the wild, it is never possible to identify with certainty when or how the chemicals were taken into the organism's tissues. In other cases, organisms may be too scarce or difficult to collect from the site. Laboratory bioaccumulation tests also have disadvantages, such as using test organisms that are not native to the site, misrepresenting conditions in overlying water at the site, and interrupting normal feeding habits of the test organisms. Even when the same species is tested in the field and in the laboratory, results may vary. For example, tests comparing bioaccumulation in an estuarine bivalve (*Tellina deltoidalis*) under lab and field conditions reported that important parameters differed between lab and field over the 31-day exposure period. Percent fines at the surface of the test sediment increased in the field but not in the lab. AVS increased in lab but not in the field (Belzunce-Segarra et al. 2015). This and other studies serve as a caution against extrapolating or over-interpreting both lab and field results. Despite these caveats, laboratory bioaccumulation tests can provide an independent line of evidence to the ERA. The *Sediment Evaluation Framework for the Pacific Northwest* (Northwest Regional Sediment Evaluation Team (RSET 2016) provides a useful overview of bioaccumulation testing.

The proposed laboratory bioaccumulation test should be thoroughly described in the BERA WP/SAP, referencing protocols when available. Include information on the exposure duration, test organisms, depuration, parameters measured during the test, frequency of measurements, endpoints, replacement of overlying water, feeding, and any other variable that could affect the usefulness of the test. The BERA WP/SAP should describe how samples will be selected for bioaccumulation testing, in keeping with the discussion above for toxicity tests.

Prior to initiating the test, at least one representative tissue sample of test organisms must be collected and either immediately analyzed or frozen for analysis with the test samples after the test is completed. This sample will serve as the baseline concentration for comparison of test samples.

Depending on the study objective, organisms may or may not be depurated to eliminate sediment from the gut prior to chemical analysis. When the goal of the test is to derive a BSAF, or to compare bioaccumulation among several samples, then the organisms are typically depurated. If the goal of the bioaccumulation test is to provide concentrations in prey organisms for use in the food chain model, then the test organisms should not be depurated. The rationale for depurating (or not) should be given in the BERA WP/SAP.

After the exposure period, test organisms are processed and analyzed for chemical constituents. The BERA WP/SAP should provide details on which samples (if not all) will be analyzed, how they will be homogenized, whether they will be frozen or otherwise preserved, and which analyses will be performed.

As mentioned above, tissue analytical results should be reported as dry weights. Percent moisture and percent lipids should be measured whenever organic compounds are analyzed. The BERA WP/SAP should specify how tissue results will be interpreted with respect to laboratory controls and reference area samples. For example, what does it mean when tissue concentrations at the site are 10 times concentrations at the reference area?

21.6.3 DATA ANALYSIS AND INTERPRETATION

The results of the chemical sampling, biological surveys, toxicity testing, bioaccumulation studies, and any other data collected are evaluated in the data analysis subsection of the BERA. The HEER Office expects that the risk assessor will follow current practice and adhere to professional standards in analyzing and interpreting the data. If the risk assessor is not familiar with the general process of preparing an ERA or would like a review, numerous publications available to the public offer guidance and assistance on specific topics. Current USEPA ERA guidance can be accessed online (USEPA 2018b). Older ERA guidance documents have been made easily accessible by Oak Ridge National Laboratory (ORNL 2018).

In general, all field-generated data and records (such as the field data sheets) should be reviewed for completeness and accuracy by the risk assessment technical lead. All field-generated data, including photographs and videos, should be maintained in the project file and included (as appropriate) in the final BERA. Notes on selected topics important to the HEER Office are presented below. The risk assessor should contact the HEER Office to request additional support if needed.

21.6.3.1 FIELD NOTES

Descriptions of the sediment, surface water, and habitat such as odors, colors, sheens, debris, presence of organisms, sediment substrate (i.e., sand, silt, gravel), signs of scouring, water depth, outfalls, and other features can be helpful when interpreting results of site-specific studies. Therefore, all observations should be documented in a field log book and photographs should be taken of the sediment and sample locations. Any field variances of the SAP should be clearly documented in the field log book. These observations should be presented in a summary table to aid the reviewer of the BERA (Table 21-14).

Table 21-14. Example of Qualitative Field Notes

Station	Redox Discontinuity (cm)	Sediment Description	Biota Present	Other Comments/Notes	Photos
SD01	< 1	black color, silt/clay with some sand	worm burrows, iron secretions	Collected samples in the mudflat located on the peninsula on the side facing the bridge.	2
SD02	no redox	red-brownish color sand with some silt	none observed		1

SD03	3	medium brown sand with medium grey silt below	worm burrows	Moved 14 feet toward water because riprap was present at proposed sample location.	1
SD04	< 1	black silt	one mussel shell (open)	Collected sample 30 feet south of 2nd wooden pier.	1
SD05	1 to 4	brown sand at surface, brown/dark grey to black silt below	limu, eelgrass, some live gastropods		3

Redox Discontinuity - Depth at which the color changes from brown to gray/black

21.6.3.2 ANALYTICAL RESULTS

Data that will be used in a risk assessment should undergo a Stage 4 data validation in accordance with the USEPA National Functional Guidelines to ensure that the data are of good quality and are legally defensible. Methods for validating the data should be given briefly in the BERA WP/SAP and explained fully in the QAPP, along with the criteria for determining the acceptability of the data. Guidance on data validation is available from USEPA through the Contract Laboratory Program National Functional Guidelines for Data Review (USEPA 2018).

Data packages should also be reviewed to determine whether any data should be rejected and whether any data qualifiers assigned during the validation process affect the usability of the data as defined in the QAPP. The validated analytical data packages should contain a summary of all data qualifier flags and their explanations.

Analytical results for all media should be presented in summary statistics tables including the following information: chemical name and CAS number, number of samples analyzed, maximum and minimum detected concentrations, data qualifiers, range of detection limits, and frequency of detection. When samples sizes are large enough (n>10), estimates of the mean such as the 95 percent upper confidence limit on the mean concentration (UCL_{95}) may be used to represent the exposure point concentration in the DU. See TGM Section 4 for more information on calculating UCL_{95}. When appropriate, separate tables that show results only for chemicals detected in at least one sample may be presented to focus the BERA. However, whenever a result is listed as “not detected,” the sample-specific detection limit must be given in the table.

The sample-specific detection limits reported by the laboratory should be reviewed prior to using the data in the BERA. If the laboratory was not able to meet the detection limits presented in the WP/SAP, the data may not be useable for the BERA. Regardless of the format of tables chosen by the risk assessor, all data for all analyzed parameters, including parameters not detected in any sample, must be included as appendices to the BERA.

Pay close attention to concentration units (e.g., µg/kg, mg/kg) in all tables and throughout the text. Laboratory results, regulatory criteria, and published literature may use different units. It is the risk assessor's responsibility to convert all units to a uniform standard so that meaningful comparisons can be made. Many components of the BERA incorporate ratios (such as hazard quotients and bioaccumulation factors) that are rendered meaningless when units are not consistent. Likewise, double-check that the dry-weight or wet-weight concentrations are properly represented. In peer-reviewed publications, this detail may appear only in a table or figure legend rather than stated explicitly in the text. When in doubt, contact the HEER Office for assistance.

21.6.3.3 TOXICITY AND BIOACCUMULATION TESTS

The BERA should refer to the description of toxicity and bioaccumulation tests proposed in the WP/SAP and explain any variances to the proposed procedures. When results of the laboratory toxicity tests are presented, the reasons for variances and potential effects of results should be explained. For example, the laboratory technician may have decided to aerate the samples because the dissolved oxygen level decreased below a certain threshold.

The full laboratory toxicity test report should be included as an appendix to the BERA and the results summarized in the BERA. The format of results may vary with the type of test; Table 21-15 is provided as an example only. Any potentially confounding factors, such as high ammonia or low dissolved oxygen, should be discussed in the text. The laboratory control sample results should be evaluated to determine whether the test met acceptability criteria.

Table 21-15. Summary of *Leptocheirus plumulosus* Toxicity Test Results

Sample Number	Mean Survival (%)	Mean Dry Weight (mg/organism)	Mean Overall Juvenile Production (juveniles/ amphipod)	Mean Juvenile Production per Surviving Female (juveniles/female amphipod)
Lab Control Sample	85	1.47	6	13
Reference Samples				
RF-SD01	83	1.40	7	13
RF-SD02	84	1.48	6	14
RF-SD03	80	1.52	6	12
Site Samples				
SD101	63	0.99	6	12
SD102	77	1.57	5	17
SD103	81	1.27	5	9
SD104	53	1.30	7	13
SD105	71	1.55	9	17

Several methods can be used to evaluate toxicity test results. The three most common endpoints for sediment toxicity testing include (1) mortality as measured by survival of the amphipods; (2) growth as measured by weight and biomass; and (3) reproduction as measured by overall juvenile production and juvenile production per surviving female. The BERA WP/SAP should provide details on how results will be interpreted for any endpoints other than these.

Site samples are identified as toxic relative to the reference samples using a statistical test. The laboratory control samples are included simply to determine whether the test organisms were healthy; laboratory controls are not used to evaluate site-specific toxicity. Methods to interpret toxicity test results should have been specified in the BERA WP/SAP and discussed with the HEER Office. (Guidance on statistical tests appropriate for analyzing toxicity test results is under development and will be added to this TGM when available.)

Laboratory bioaccumulation studies should be treated in the same way as toxicity studies, with the added component of final tissue concentrations. As discussed previously, tissue concentrations should be provided in dry weight, along with percent moisture and percent lipid results. Tissue results from laboratory bioaccumulation tests should be presented in the same way as field-collected tissues, with the additional component of calculated BSAFs, if warranted.

Risks to Receptors from Food Chain Exposure

Tissue concentrations are used in food chain models to estimate daily doses to consumers, as described in Subsection 21.3.3. While the SLERA intentionally biased the estimated daily dose high using conservative exposure parameters, the average dose is used in the BERA to represent a more realistic exposure scenario. The focus of the BERA is risk to populations of receptors, not to individual organisms. Therefore, average exposure assumptions are used. For example, the estimated daily dose in the BERA should incorporate the components below:

- Mean chemical concentrations in sediment and food;
- Mean ingestion rates for sediment and food;
- Mean body weight;
- Appropriate site use factor; and
- Most sensitive life stage present at the site.

In the SLERA, concentrations in food are estimated from concentrations in sediment using BSAFs as described in Appendix 21-E. However, if site-specific tissue samples were analyzed in the BERA, those concentrations should be substituted in the dose equation. Alternatively, if site-specific BSAFs are determined in the BERA, they should be used instead of BSAFs from the literature to estimate tissue concentrations at the site.

21.6.4 RISK CHARACTERIZATION

The risk characterization subsection of the BERA is where all available data are evaluated holistically to determine whether the site poses unacceptable risk to any of the assessment endpoints. The risk characterization should present both quantitative and qualitative characterizations of risk, to the extent supported by available data. As described in Step 3a (Task 6), the risk characterization focused on interpreting exposure and effects data within the context of other site-specific information. Risk characterization in the BERA is similar, in that it synthesizes all available data and various sources of uncertainty, while acknowledging data gaps that may limit conclusions.

When multiple measures of effect are available for a single assessment endpoint, then a weight-of-evidence approach should be used to interpret the implications of different datasets. For example, as discussed in Subsection 21.6.2.5, biological surveys are often collected as part of a sediment triad approach where three lines of evidence (sediment chemistry, sediment toxicity test data, and benthic community data) are evaluated to as part of an overall investigation of the benthic community. This can be done by assigning each line of evidence a score and associated weighting factors.

The risk assessment results can be presented graphically to highlight locations where chemical concentrations exceed toxicity screening levels that were identified in the BERA WP/SAP. Maps and graphs may be used to illustrate spatial distribution of risk using various measures. The HEER Office can offer examples of effective data presentation methods, as needed.

SECTION 21 REFERENCES

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APPENDIX 21-A
Species Profiles and Exposure/Effects Summary

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1.0 **Sea Lettuce (*Ulva fasciata*)**

2.0 **Samoan crab (*Scylla serrata*)**

3.0 **Kona crab (*Ranina ranina*)**

4.0 **White crab (*Portunus sanguinolentus*)**

5.0 **Helmet urchin (*Colobocentrotus atratus*)**

6.0 **Hawaiian limpet (*Cellana exarata*)**

7.0 **Day octopus (*Octopus cyanea*) and Night Octopus (*O. ornatus*)**

8.0 **Polychaete (*Neanthes arenaceodentata*)**

9.0 **Lobe coral (*Porites lobata*)**

10.0 **Black sea cucumber (*Holothuria atra*)**

11.0 **Goatfish (*Mulloides*)**

12.0 **Hawaiian flagtail (*Kuhlia sandvicensis*)**

13.0 **Convict tang (*Acanthurus triostegus*)**

14.0 **Pacific Sergeant (*Abudefduf abdominalis*)**

15.0 **Mozambique tilapia (*Oreochromis mossambicus*)**

16.0 **Spectacled parrotfish (*Chlorurus perspicillatus*) and Yellowbar parrotfish (*Calotomus zonarchus*)**

17.0 **Moray eel (*Muraenidae*)**

18.0 **Wedge-tailed shearwater (*Puffinus pacificus*)**

19.0 Black-crowned night heron (*Nycticorax nycticorax hoactli*)

20.0 Hawaiian coot (*Fulica alai*)

21.0 Green sea turtle (*Chelonia mydas*)

22.0 Monk seal (*Monachus schauinslandi*)

1 - Sea Lettuce (*Ulva fasciata*)



Limu palahalaha (Sea lettuce)
(*Ulva fasciata*)



Limu kohu
(*Asparagopsis taxiformis*)

Native Hawaiian Species: Numerous native species of seaweed, or limu, occur around the main Hawaiian Islands and the Northwest Hawaiian Islands.

Habitat: Sea lettuce and other limu generally occur in the intertidal zone on rock or coral; a few species grow in sandy locations (Waikīkī Aquarium 2014). Heavy growth may indicate high nutrients and freshwater input from storm water runoff or mouths of streams. Limu is most abundant where wave action is low (University of Hawai'i 2001).

Locations: Limu occurs throughout the Hawaiian Islands.

Seasonality (year-round resident or migrant): Year-round resident.

Cultural Use (historical and current): Various species of limu are added to stews and salads; prepared as flavorful condiments; and eaten as a source of vitamins (A, C, B12, and riboflavin) (Preskitt 2002). Some species were used to make traditional hula attire (Waikīkī Aquarium 2014).

Recreational Harvest: Yes, popular for consumption (University of Hawai'i 2014, Preskitt 2002).

Commercial Harvest: Yes.

Home Range: Not applicable.

Size/Body Weight: Some species, such as Limu palahalaha, may grow up to 1 meter in length (University of Hawai'i 2001). Tissues of limu may contain up to 86 percent water (McDermid et al. 2007).

Diet/Ingestion Rates: Photosynthetic organisms.

Predators: Consumed by humans, the green sea turtle (McDermid et al. 2007), herbivorous fishes, and sea urchins. Some Hawaiian herbivores appear to prefer to feed on invasive algal species rather than native limu (Vermeij et al. 2009).

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation factors:

- Sea lettuce is high in energy, soluble carbohydrate, protein, vitamin A content, and some minerals (McDermid, et al. 2007). In a study of several species of seaweed evaluating their use as bioindicators, sea lettuce had the lowest concentration of metals (El-Din et al. 2014). This study also determined bioconcentration factors for metals in several algal species.
- A total of 19 seaweed samples (species not given) were collected in 2009 from locations on the Wai'anae Coast of O'ahu (fall and spring samples), including five samples from a reference location. Samples were analyzed for energetic

compounds, metals, phthalate esters, and pyrene (U.S. Army Corps of Engineers [ACOE] 2012). Detected constituents at the reference location (Table 9 in ACOE 2012) included the following:

  - *Inorganic Constituents:* Arsenic, Barium, Chromium, Cobalt, Copper, Lead, Nickel, Strontium, Vanadium, and Zinc
  - *Organic Constituents:* None

- Four seaweed composites samples were collected from the nearshore waters at Mākua (See Figure 2-1 in Tetra Tech 2009). The samples were composites of *Acanthophora spicifera, Sargassum muticum*, and *Sargassum polyphyllum*. Samples were analyzed for dioxins/furans, VOCs SVOCs, organochlorine pesticides, explosives, and metals (See Tables 2-2 and 3-1 in Tetra Tech 2009). The sample had 75.4 to 88.4 percent moisture. Detected constituents included the following:
  - *Inorganic Constituents:* Aluminum, Antimony, Arsenic, Barium, Beryllium, Cadmium, Chromium, Cobalt, Copper, Iron, Lead, Manganese, Mercury, Selenium, Silver, Thallium, Vanadium, and Zinc
  - *Organic Constituents:* Dioxins/Furans, m+p-Xylenes, Bis(2-ethylhexyl)phthalate, di-n-Butylphthalate, Aldrin, beta-BHC, Heptachlor, Heptachlor epoxide, Perchlorate, and RDX

Conservation Status: Not threatened.

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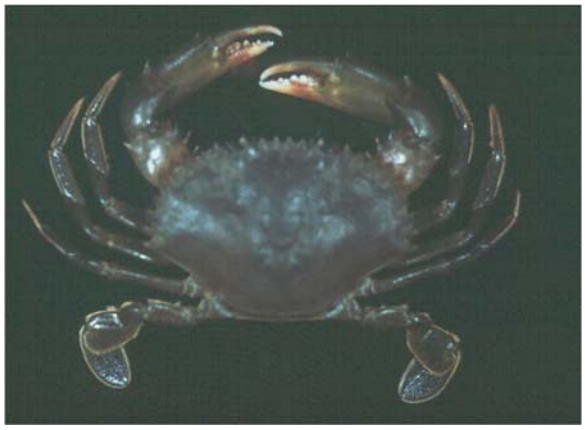
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Photo Credit: Preskitt, L. 2002. Edible Limu: Gifts from the Sea. Poster. http://www.Hawaii.edu/reefalgae/publications/ediblelimu/index.htm

2 - Samoan crab (*Scylla serrata*)



Samoan crab
(*Scylla serrata*)

Native Hawaiian Species: No. Crabs from Sāmoa were released on Oʻahu, Molokaʻi, and Hawaiʻi to establish a commercial crab fishery (Eldredge and Smith 2001).

Habitat: This crab inhabits muddy bottoms in brackish water along the shoreline, mangrove areas, and river mouths (Eldredge and Smith 2001). During the day, it may live intertidally in burrows but mostly buries in the mud at subtidal levels (Rowling and Ives 2010).

Locations: All main islands (Eldredge and Smith 2001).

Cultural Use (historical and current): None found.

Recreational Harvest: Yes, but no harvest numbers available.

Commercial Harvest: Prized, sought-after commercial species (Eldredge and Smith 2001).

Home Range: In Australia, apart from spawning migrations, the mud crab appears to move little within its habitat; most individuals remain on site in distinct populations (Shelley and Lovatelli 2011). However, longer-term tagging has shown that individuals can move several kilometers from their home range over time; nightly movements of *S. serrata* fitted with transmitters averaged 461 meters (Shelley and Lovatelli 2011).

Size/Body Weight: It is the largest portunid in Hawaiʻi, exceeding 18 cm in width of carapace (Eldredge and Smith 2001). It can reach 28 cm in carapace width and 3 kg in weight but is more commonly 15 to 20 cm in width and 0.5 to 1.0 kg (Rowling and Ives 2010).

Diet/Ingestion Rates: It is primarily a carnivore, eating mollusks, crustaceans, and polychaetes, as well as small amounts of plants and debris (Eldredge and Smith 2001). Feeding rates are linked to body weight. On a wet weight basis, feeding rates were reported as 5 to 10 percent of body weight (Baliao, De Los Santos & Franco 1999; Quinitio 2004 [as cited in (Rowling and Ives 2010)]). No food or sediment ingestion rates were found.

Predators: No predators other than humans were reported.

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation Factors: One sample of Samoan crab from the Mākua north muliwai was analyzed for dioxins/furans, VOCs SVOCs, organochlorine pesticides, explosives, and metals (See Figure 2-1 and Tables 2-2 and 3-1 in Tetra Tech 2009). The sample had 0.7 percent lipids and 71.3 percent moisture. Detected constituents included the following:

- Inorganic Constituents: Aluminum, Arsenic, Barium, Chromium, Cobalt, Copper, Iron, Manganese, Mercury, Selenium, Vanadium, and Zinc
- Organic Constituents: Dioxins/furans

Conservation Status: No special status, but taking females is prohibited (Hawai‘i DLNR Fishing Regulations).

Other Notes:

The Samoan crab was first introduced into Kāne‘ohe Bay to start a fishery in 1926 (Eldredge and Smith 2001). Between 1926 and 1935, 98 crabs were released on O‘ahu, Hawai‘i, and Moloka‘i, all from Sāmoa (Brock 1960, as cited in Eldredge and Smith 2001). By 1940 it had “already become thoroughly established about the shores, entering estuaries of streams and ascending far up some of the larger rivers” (Edmondson and Wilson 1940, as cited in Eldredge and Smith 2001).

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Photo Credit: Eldredge and Smith. 2001

3 - Kona crab (*Ranina ranina*)



Kona crab
(*Ranina ranina*)

Native Hawaiian Species: Yes

Habitat: The Kona crab is found in offshore coastal environmental at depths between 6 and 200 meters. It prefers sandy ocean bottoms where it burrows in the sand (Fielding and Haley 1976). It spends 95% of its time buried in sand and emerges from the sand less than two hours a day, on average (Skinner and Hill 1986).

Locations: Found throughout the Indo-Pacific region and in the Hawaiian Islands (Fielding and Haley 1976).

Seasonality (year-round resident or migrant): Year-round resident.

Cultural Use (historical and current): None identified.

Recreational Harvest: Yes. Spearing these crabs is not permitted (Hawai‘i Administrative Rules, 1989).

Commercial Harvest: Yes, this species is harvested commercially in Hawai‘i (Fielding and Haley 1976). Per Hawaiian fishing regulations, the minimum size to harvest is 4 inches (carapace length) (Hawai‘i Administrative Rules, 1989). Females cannot be collected, per a 2006 ruling.

Home Range: Not reported.

Size/Body Weight: Mature female Kona crabs have a minimum carapace length of 86 ± 8 mm (Fielding and Haley 1976). The estimated time for a Kona crab to reach 100 mm in length ranged from approximately 6 years for females to 4 years for males (Kirkwood et al. 2005). The estimated mean maximum lengths of the Kona crab is 122 mm for females and 156 mm for males, based on commercial catch data (Kirkwood et al. 2005).

Diet/Ingestion Rates: This crab is likely a scavenger, given the composition of items found in its gut (Baylon and Tito 2012, Skinner and Hill 1986). Kona crabs in the Philippines feed on fish (*Sardinella*), other crabs, shrimp, bivalves, rays, hydroids, copepods, and squid (Baylon and Tito 2012). Silt and sand accounted for 12 to 20 percent of gut contents (Baylon and Tito 2012). In Australia, echinoderms were the most common item in the gut of Kona crabs, followed by polychaetes and fish (Skinner and Hill 1986).

Predators: Humans, sharks, rays, jacks, turtles, and marine mammals (Thomas, undated).

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation Factors:

- 28 crabs (species inferred to be Kona crab) collected in 2009 from three locations on the Wai‘anae Coast of O‘ahu (fall and spring samples) were analyzed for energetic compounds, metals, phthalate esters, and pyrene (U.S. Army Corps of Engineers [ACOE] 2012). Detected constituents (as shown in Table 8 in ACOE 2012) included the following:

    - *Inorganic Constituents:* Arsenic, Barium, Cadmium, Chromium, Cobalt, Copper, Lead, Mercury, Selenium, Strontium, and Zinc
    - *Organic Constituents:* 1,3,5-Trinitrobenzene.
- One Kona crab sample was collected from nearshore waters at Mākua and analyzed for dioxins/furans, VOCs, SVOCs, organochlorine pesticides, explosives, and metals (See Figure 2-1 and Tables 2-2 and 3-1 in Tetra Tech 2009). The sample had 21 percent lipids and 61.5 percent moisture. Detected constituents included the following:
    - *Inorganic Constituents:* Aluminum, Arsenic, Barium, Cadmium, Chromium, Cobalt, Copper, Iron, Lead, Manganese, Selenium, Vanadium, and Zinc
    - *Organic Constituents:* None

Conservation Status: Not threatened.

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Photo Credit: "*Ranina ranina* " by Kzhr - Kzhr's file. Licensed under Creative Commons Attribution-Share Alike 2.5 via Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Ranina_ranina.jpg#mediaviewer/File:Ranina_ranina.jpg

4 - White crab (*Portunus sanguinolentus*)



White crab
(*Portunus sanguinolentus*)

Native Hawaiian Species: Yes. The white crab is also known as the three spot swimming crab (Atlas of Living Australia 2014).

Habitat: The white crab is found on sandy ocean floors at depths around 30 meters (Sumpton et al. 1989, Carpenter et al. 1997 [as cited in Rasheed and Mustaquim 2010]). It is also reported to inhabit sandy and muddy substrates in shallow coastal waters from 10-30 meters but can occur at depths outside coastal waters reaching 80 m (Atlas of Living Australia 2014).

Locations: This crab is found throughout the Indo-Pacific region and in the Hawaiian Islands (Apel and Spiridonov 1998 [as cited in Rasheed and Mustaquim 2010]).

Seasonality (year-round resident or migrant): Year-round resident.

Cultural Use (historical and current): None identified.

Recreational Harvest: Yes

Commercial Harvest: Yes

Home Range: A related species of crab (*Portunus pelagicus*) in the coastal water of the South China Sea was reported to travel mean distances of 7.36 km ± 1.78 (males) and 9.15 km ± 1.87 (females) (Ikhwanuddin et al. 2012). The movement of the crabs was attributed to migration associated with reproduction as the male crabs moved to deeper off-shore areas and the female crabs moved both to deeper off-shore and shallow near-shore areas. Generally, crabs were recaptured within a 2-km radius of the sampling site (Ikhwanuddin et al. 2012). A study of *Portunus pelagicus* in Australia reported similar movements, with 79% caught within 2 km of the release point and 4% caught more than 10 km from the release point (Potter et al. 1991 [as cited in Ikhwanuddin et al. 2012]).

Size/Body Weight: The maximum sizes of white crabs captured in one study were 125 mm short carapace width (SCW) for males (n = 233) and 130 mm SCW for females (n = 224) (Rasheed and Mustaquim 2010). Juvenile and adult crabs were captured. The study determined that the crabs were mature at 64–69 mm SCW or 83–89mm long carapace width (LCW) for males and 63–71mm SCW or 81–93 mm LCW for females (Rasheed and Mustaquim 2010). An investigation of the white crab in Australia determined mature males were 83 mm long carapace width (LCW) and mature females were 74 mm LCW (Sumpton et al. 1989 [as cited in Rasheed and Mustaquim 2010]).

Diet/Ingestion Rates: The white crab eats mostly crustaceans (47%) followed by fish (29%) and mollusks (6%); sand; it also consumes sand/mud/debris (5%) (Sukumaran and Neelakantan 1997). It is reported to scavenge dead fish discarded by fishing vessels (Paul 1981, and Wasseflberg and Hill 1982 [as cited in Sukumaran and Neelakantan 1997]). It also feeds on detritus (Atlas of Living Australia 2014).

Predators: Predators include turtles, sharks, rays and large fish.

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation Factors:

Conservation Status: Not threatened.

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Photo Credit: Portunus sanguinolentus by Self, Licensed under GNU Free Documentation License via http://commons.wikimedia.org/wiki/File:Portunus_sanguinolentus.jpg

5 - Helmet urchin (*Colobocentrotus atratus*)



Helmet urchin
(*Colobocentrotus atratus*)

Native Hawaiian Species: Yes. Also known as the shingle urchin or haukeuke kaupali (Parrish et al. 1990).

Habitat: The helmet urchin is abundant in the intertidal zone, often on vertical substrates and in shallow basalt pavement habitats (Parrish, et al., 1990). The helmet urchin inhabits areas of high wave energy (>Waikīkī Aquarium 2014).

Locations: Indo-Pacific region and throughout the Hawaiian Islands (Waikīkī Aquarium 2014).

Seasonality (year-round resident or migrant): Year-round resident.

Cultural Use (historical and current): Historically, other sea urchins (*Echinothrix calamaris* and *Echinothrix diadema*) were preferred for food over the helmet urchin (Parrish et al. 1990).

Recreational Harvest: The helmet urchin is harvested for food, particularly the eggs (Parrish et al. 1990).

Commercial Harvest: Yes.

Home Range: Not identified.

Size/Body Weight: The helmet urchin may reach 3 inches in diameter (Waikīkī Aquarium 2014).

Diet/Ingestion Rates: Feeds on algae (Parrish et al. 1990). The helmet urchin grazes predominately on red coralline algae (Waikīkī Aquarium 2014).

Predators: Predators of sea urchins in general include humans and large fish (such as Balistidae, Labridae, Lethrinidae, Gaterinidae and Lutjanidae (McClanahan 1998).

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation Factors:

- The helmet urchin (*Colobocentrotus atratus*) was collected from tidal pools at ʻĪlio Point, Molokaʻi in 2010 from locations near a debris pile site and a reference location 150 meters northeast of the debris pile site (See Figure 9 in ESI 2012). Individuals weighed 41 to 87 grams and were 3.8 to 7.5 cm in length (See Table 2-12 in ESI 2012). Tissue samples were analyzed for metals and PCBs (See Tables 2-18 and 2-19 in ESI 2012). No significant difference was noted between site and reference samples.
- Two composite samples were collected from nearshore waters at Mākua and three composite samples from a background location at Sandy Beach (See Figure 2-1 and Subsection 5.4.1 in Tetra Tech 2009). A single sample required collecting more than 100 sea urchins (See Subsection 3.1 in Tetra Tech 2009). Samples were analyzed for dioxins/furans, VOCs, SVOCs, organochlorine pesticides, explosives, and metals (See Tables 2-2 and 3-1 in Tetra

Tech 2009). Samples ranged from 0.77 to 2.7 percent lipids and 37.7 to 48.1 percent moisture. Detected constituents included the following:

  - *Inorganic Constituents:* Aluminum, Arsenic, Barium, Beryllium, Chromium, Cobalt, Copper, Iron, Lead, Manganese, Selenium, Vanadium, and Zinc
  - *Organic Constituents:* Dioxins/Furans, Toluene, Aldrin, and Perchlorate

- Sediment pore water from Hanalei Bay on the north coast of Kauaʻi and a reference location at Keʻe Beach, Kauaʻi were tested for effects on fertilization and embryonic development of the purple-spined sea urchin (*Arbacia punctulata*), which is generally used as a surrogate echinoderm for toxicity testing of sediment pore water (Carr et al. 2006). Toxicity was reported at two stations; however, no synoptic chemical analyses were conducted to identify the cause of the toxicity.
- Sea urchin fertilization tests and larval development tests were used to evaluate toxicity of sediment pore water in Australia (McCready et al. 2006).

Conservation Status: Not threatened.

Other Notes: Sea urchins may have a beneficial effect on coastal ecosystems through foraging on invasive seaweeds. Native Hawaiian collector urchins (*Tripneustes gratilla*) were released in Kāneʻohe Bay to control fast growing seaweed on coral reefs (Department of Land and Natural Resources 2014).

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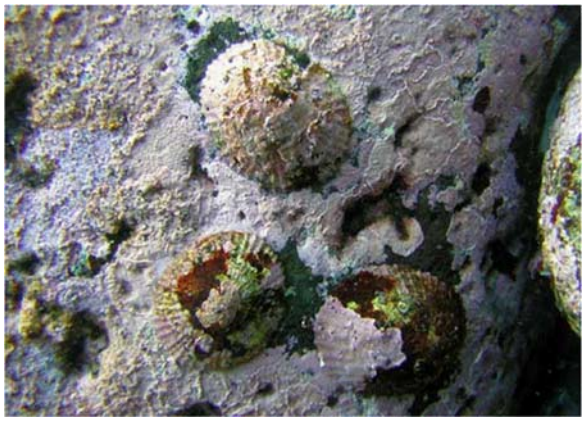
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Photo Credit: “Colobocentrotus atratus. ha'uke'uke kaupali. helmet urchin” Photo taken by Bryan Harry, National Park Service. http://www.botany.Hawaii.edu/basch/uhnpscesu/htms/kahoinvr/fish_pops/echinomet/wana05.htm

6 - Hawaiian limpet (*Cellana exarata*)



Hawaiian limpet
(*Cellana exarata*)
opihi

Native Hawaiian Species: Yes. Known locally as opihi. Three species are endemic to the Hawaiian Islands: blackfoot (*Cellana exarata*), yellowfoot (*Cellana sandwicensis*), and giant opihi (*Cellana talcosa*) (Bird et al. 2007).

Habitat: The three endemic Hawaiian limpets inhabit different positions on wave-exposed rocky shores. *C. exarata* inhabits the high intertidal zone, followed by *C. sandwicensis* at the low intertidal zone, and *C. talcosa* in the shallow subtidal zone (Kay and Magruder 1977, C.E.B. unpublished data [as cited in Bird et al. 2007]). *C. talcosa* is submerged at high tide but occurs no deeper than 3 to 4 meters (Bird 2011).

Locations: Throughout the MHI and NWHI (Bird et al. 2007).

Seasonality (year-round resident or migrant): Year-round resident.

Cultural Use (historical and current): Hawaiian limpets are a component of culinary culture (Bird et al. 2007).

Recreational Harvest: Yes. All species of *Cellana* must be 31.8 mm shell length to harvest (Hawai‘i Administrative Rules 1981).

Commercial Harvest: Yes.

Home Range: Not identified; but assumed small.

Size/Body Weight: Mature *C. sandwicensis* have a shell length of 20 mm and mature *C. talcosa* have a shell length of 35 to 40 mm (Kay et al. 2006).

Diet/Ingestion Rates: Algae.

Predators: Humans, intertidal thaid gastropods, and crabs. *C. talcosa* is also exposed to predatory fish (Bird 2011).

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation Factors: The Hawaiian limpet (*Cellana exarata*) was collected from tide pools at ‘Īlio Point, Moloka‘i in 2010 from locations near a debris pile site and a reference location 150 meters northeast of the debris pile site (See Figure 9 in ESI 2012). Individuals weighed 10 to 40 grams and were 3.1 to 5.5 cm in length (See Table 2-12 in ESI 2012). Samples were analyzed for metals and PCBs (See Tables 2-18 and 2-19 in ESI 2012). No significant difference was noted between results for site and reference samples.

Conservation Status: Not threatened.

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Photo Credit: “Cellana sandwicensis. 'opihi 'alinalina. yellow-foot opihi” Photo taken by Larry Basch, National Park Service. http://www.botany.Hawaii.edu/basch/uhnpscesu/htms/kahoinvr/fish_pops/patell/shell02.htm

7 - Day octopus (*Octopus cyanea*) and Night Octopus (*O. ornatus*)



Day octopus and Night Octopus
(*Octopus cyanea*) and (*Octopus ornatus*)
he‘e; he‘e-mākoko

Native Hawaiian Species: Yes. The day octopus (*Octopus cyanea*) and the night octopus (*Octopus ornatus*) are common in Hawai‘i (*Waikīkī Aquarium 2014*).

Habitat: The day octopus is a common Pacific coral reef resident. It may excavate holes or occupy existing crevices in rocky areas from the intertidal zone to depths of about 45 meters on reef flats and reef slopes (Van Heukelem 1976; Sims 1998). The day octopus in Kāne‘ohe Bay most often dens in areas of loose rocks and broken coral on a sandy bottom (Sims 1998). An octopus den is not permanent but may be occupied for several days (Forsythe and Halon 1997). Once inside the den, the octopus may pull loose rocks or rubble over the opening, camouflaging the den and its entrance (Forsythe and Halon 1997).

Locations: Throughout the Hawaiian Islands (Waikīkī Aquarium 2014)

Seasonality (year-round resident or migrant): Year-round resident

Cultural Use (historical and current): None identified

Recreational Harvest: Yes. The day octopus is often collected with a three-pronged spear in shallow depths or by handline (Monterey Bay Aquarium Seafood Watch 2014).

Commercial Harvest: Yes.

In terms of biomass caught, he'e ranked 28th of the 87 species/categories commercially fished in Hawai‘i in 2011 at 35,347 pounds and had the highest catch of any invertebrate fishery. Combined with catch from the recreational fishery, the overall he'e catch is likely to be at least twice as large. *O. cyanea* comprised approximately 45% and 26,000 pounds of the estimated total annual harvest (1991) of fishes and invertebrate species in Kāne‘ohe Bay (Everson 1994 [as cited in Sims, 1998]).

Home Range: Distances traveled during hunting trips for prey ranged from 3 to 91 meters in six individual octopus studied within constructed ponds. The maximum distances ranged from 21 to 91 meters (Yarnall 1969). The estimated total forage distance observed in two octopuses on a coral atoll in French Polynesia was 15 to 120 meters with average distances for each octopus of 52 ± 9.3 meters and 65 ± 12.7 meters (Forsythe and Hanlon 1997). The octopus foraged both morning and afternoon, travelling more than 100 meters a day for food (Forsythe and Hanlon 1997).

Size/Body Weight: The day octopus has been reported to reach 6 kilograms (Van Heukelem 1983; Roper and Hochberg 1988 [as cited in Forsythe and Hanlon 1997]), although typical specimens of both species do not exceed 4.5 kilograms (Waikīkī Aquarium 2014).

Diet/Ingestion Rates: The diet of the day octopus in Kāneʻohe Bay, Oʻahu, is dominated by five genera of crabs, including *Thalamita* and *Leptodius* (Mather et al. 2012). Bivalve and gastropod mollusks are also eaten (Forsythe and Hanlon 1997).

Predators: Humans, Hawaiian monk seal, eels, large fish

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation Factors:

- Pearl Harbor Ecological Risk Assessment: Octopus tissues were analyzed for 16 metals and 19 energetic compounds at four marine areas in spring and fall: (1) discarded military munitions (ordnance) locations; (2) the Waiʻanae wastewater treatment plant outfall area; (3) the coastal non-point source discharge area; and (4) a control area with habitat similar to the ordnance area but assumed not to contain discarded munitions. Metals concentrations in octopus tissue were generally higher in samples collected in spring than in fall (Navy 2007b).
- A total of 36 whole-body samples of octopus were collected in 2009 from locations on the Waiʻanae Coast of Oʻahu (fall and spring samples) including eight samples from a reference location. Samples were analyzed for energetic compounds, metals, phthalate esters, and pyrene (U.S. Army Corps of Engineers [ACOE] 2012). Metals concentrations in octopus tissue were higher in the spring than the fall (this is opposite of the pattern observed in goatfish also sampled in this investigation). Detected constituents at the reference location as shown in Table 7 (ACOE 2012) included the following:
    - *Inorganic Constituents:* Arsenic, Barium, Cadmium, Chromium, Cobalt, Copper, Lead, Mercury, Selenium, Strontium, and Zinc
    - *Organic Constituents:* None

Conservation Status: Not threatened.

Other Notes:

The day octopus lives about 12 to 15 months (Van Heukelem 1976 [as cited in Sims 1998). It mates once, then dies soon after (Sims 1998). Upon reaching sexual maturity, an unmated female lays a clutch of unfertilized eggs, then dies (Sims 1998).

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Photo Credit: "*Octopus ornatus*" Dr. Dwayne Meadows, NOAA/NMFS/OPR http://www.photolib.noaa.gov/index.html

8 - Polychaete (*Neanthes arenaceodentata*)



Polychaete
(*Neanthes arenaceodentata*)

Native Hawaiian Species: not determined.

Habitat: This polychaete occurs in sandy sediments near ocean outfalls (Bailey-Brock et al. 2002). *Neanthes arenaceodentata* co-occurs with *Neanthes succinea* in a variety of marine and estuarine intertidal to subtidal habitats, including sand and mud bottoms, seagrass meadows, rocky benthic areas, mussel and oyster beds, and dock pilings (Orth 1973, Craig et al. 2003 [as cited in Masterson 2008]). This worm generally occurs from 10 to 15 cm beneath the sediment surface (Hines and Comtois 1985 [as cited in Masterson 2008]).

Locations: Throughout the Hawaiian Islands.

Seasonality (year-round resident or migrant): Year-round.

Cultural Use (historical and current): None identified.

Recreational Harvest: None.

Commercial Harvest: None.

Home Range: Not reported but assumed small based on observed behavior.

Size/Body Weight: Approximately 5 to 12 mm in length (Bailey-Brock et al. 2002).

Diet/Ingestion Rates: Omnivorous, feeding on particles and debris of various sizes (Bailey-Brock et al. 2002).

Predators: Numerous birds and fish feed extensively on benthic invertebrates, including polychaetes.

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation Factors: *Neanthes arenaceodentata* is commonly used in laboratory tests. Standardized laboratory toxicity tests have focused predominantly on bioaccumulation in *N. arenaceodentata*, which is known to for its high sediment ingestion rates and rapid bioaccumulation of organic compounds such as PCBs (Janssen et al. 2011). A new 96-hour feeding test using *N. arenaceodentata* is being developed to evaluate sublethal effects following exposure to toxic water or sediment (Burton et al. 2011).

Conservation Status: Not threatened.

Other notes: *Neanthes arenaceodentata* is recognized internationally as a bioindicator for contaminated sediments.

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Photo Credit: "Alitta succinea" by Hans Hillewaert Licensed under Public domain via Wikimedia Commons http://commons.wikimedia.org/wiki/Alitta_succinea#mediaviewer/File:Alitta_succinea_2.jpg

9 - Lobe coral (*Porites lobata*)



Lobe coral
(*Porites lobata*)



Lobe coral
(*Porites lobata*)

Native Hawaiian Species: This is one of several species of stony coral native to Hawai‘i.

Habitat: This reef building coral is dominant all habitats, including forereef, backreef, and lagoons (Kenyon et al. 2006). *Porites* occurs at depths up to 30 meters (Sheppard et al. 2014).

Locations: *Porites lobata* is the most abundant coral species throughout the Hawaiian Islands.

Seasonality (year-round resident or migrant): Year-round resident.

Cultural Use (historical and current): Historically, coral reef ecosystems have provided food and medicine (Hawai‘i Coral Reef Initiative 2002).

Recreational Harvest: None.

Commercial Harvest: None. Commercial harvesting of live coral is illegal within Hawaiian waters (Friedlander et al. 2008a,b).

Home Range: Not applicable.

Size: This species of coral develops massive and encrusting growth forms. In forereef locations, high-energy sea conditions limit its size to generally less than 20 cm in diameter (Kenyon et al. 2006).

Diet/Ingestion Rates: Corals feed on small plankton and the sugars produced by symbiotic algae.

Predators: Several species of reef fish specialize on coral, including *Porites lobata* (Cole et al. 2008). Typical corallivorous fishes in Hawai‘i include the spotted puffer (*Arothron meleagris*) and the barred filefish (*Cantherhines dumerilii*) (Jayewardene et al. 2009).

Tissue Data/Bioaccumulation Factors/Toxicity Data:

- Irgarol 1051®, a marine herbicide (anti-fouling compound) was shown to be toxic to coral larvae at concentrations measured in small boat marinas in O‘ahu. Laboratory exposures of 100 ng/L Irgarol caused a reduction in settlement of larvae of *Porites Hawai‘iensis*, a Hawaiian coral typical of shady marinas (Knutson et al. 2012).
- Bioaccumulation of trace metals from sediment and seawater were reported in *Porites lobata* in Malaysia (Mokhtar et al. 2012).
- Coral (*Porites astreoides*) collected in Puerto Rico were analyzed for PAHs, PCBs, organochlorine pesticides, and metals (Pait et al. 2009). Coral tissues accumulated PAHs, PCBs and trace elements, such as copper and zinc. Generally, corals contained higher levels of alkylated PAHs than the sediments.

- PCBs and metals (arsenic, cadmium, lead, and selenium) were analyzed in coral (*Porites lobata*) collected from Tern Island in the NWHI (Miao et al. 2000a). Results indicated that coral preferentially accumulated less chlorinated PCBs. Metal concentrations in coral were generally equal to or less than those in sediment. Another coral species (*Porites evermanni*) collected from Tern Island and Disappearing Island in the French Frigate Shoals was analyzed for PCBs (Miao et al. 2000b).
- Metals (arsenic, cadmium, chromium, copper, lead, and selenium) were analyzed in coral (*Porites evermanni*) collected from O'ahu and French Frigate Shoals (Miao et al. 2001). Lead concentrations were greater in samples from French Frigate Shoals than from O'ahu. Lead may be from activities associated with Navy and USCG occupation of the atoll.
- Scleractinian coral (*Stylophora pistillata*) obtained from culture tanks in Taiwan were exposed to Aroclor-1254 (Chen et al. 2012) to evaluate short and long term toxicity. No mortality or bleaching was observed during the 96-hour exposure period and delayed effects were not observed in the 50-day recovery period.
- Three species of scleractinian corals were exposed to copper (Bielmyer et al. 2010). Sensitivity to copper varied among the three species.

Conservation Status: Not threatened.

Other notes: Many stony corals are threatened by overgrowth of introduced marine algae (Hawai'i Coral Reef Initiative 2002). Other threats include disease, fishing pressures, and nutrient and sediment runoff (Hawai'i Coral Reef Initiative 2002). *Porites lobata* has demonstrated low susceptibility to bleaching (Kenyon et al. 2006).

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Photo Credit: Dr. James P. McVey, NOAA Sea Grant Program and National Oceanic and Atmospheric Administration/Department of Commerce http://www.photolib.noaa.gov/index.html

10 - Black sea cucumber (*Holothuria atra*)



Black sea cucumber
(*Holothuria atra*)
loli okuhi kuhi

Native Hawaiian Species: Yes

Habitat: Fourteen species of sea cucumbers are known to occur in Hawai'i. They are found in tide pools, on reefs, in bays and lagoons, and in deeper waters (Waikīkī Aquarium 2014d). The black sea cucumber is a common species of tide pools (Waikīkī Aquarium 2014d). The black sea cucumber occurs in sandy habitats in Indonesia and Guam and among coral rubble in Western Australia (Roberts and Bryce 1982).

Locations: The black sea cucumber is the most common holothurian on Hawaiian coral reefs and is found throughout the Indo-Pacific region (Skillings et al. 2014).

Seasonality (year-round resident or migrant): Year-round resident.

Cultural Use (historical and current): None known

Recreational Harvest: Yes, certain species are consumed (Waikīkī Aquarium 2014d).

Commercial Harvest: In the Pacific, *H. atra* is harvested, although it is a low value species (Skillings et al. 2014). Other species of sea cucumbers such as *H. whitmaei* are preferred as a food source. There is no regulated sea cucumber fishery in Hawai'i (Skillings et al. 2014).

Home Range: The movement of another species of sea cucumber, *H. sanctori*, found that they traveled between 1.86 and 21.47 meters each day with a mean distance of 11.12 ± 4.24 meters (Navarro, et al., 2013). These distances are greater than those observed in other sea cucumber species, such as *A. mauritiana* (3.02 meters, Graham and Battaglene 2004 [as cited in Navarro et al. 2013]) and *P. californicus* (3.93 meters, Da Silva et al. 1986 [as cited in Navarro et al. 2013]). In areas with numerous potential refuges, the sea cucumbers do not return to the same shelters (Navarro et al. 2013). Sea cucumbers may also move accidents as they can become dislodged from the ocean floor by waves (Roberts and Bryce 1982).

Size/Body Weight: The black sea cucumber may reach up to 12 inches in length (Waikīkī Aquarium 2014e).

Diet/Ingestion Rates: Sea cucumbers feed on organic matter in water and sediment (Waikīkī Aquarium 2014e).

Predators: Humans and marine invertebrates such as crabs and gastropods (Kropp 1982). The black sea cucumber releases a red substance to defense itself against predators (Waikīkī Aquarium 2014e); the substance is toxic to marine fish but is not effective against crustaceans (Yamanouchi 1955, Bakus 1968 [as cited in Kropp 1982]).

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation Factors: None identified.

Conservation Status: Not threatened.

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Photo Credit: "*Holothura atra*. loli okuhi kuhi. black sea cucumber" Photo taken by Scott Godwin, National Park Service. http://www.botany.Hawaii.edu/basch/uhnpscesu/htms/kahoinvr/fish_pops/holothur/wana02.htm

11 - Goatfish (*Mulloides*)



Yellowfin Goatfish
(*Mulloides vanicolensis*)
Wele‘ula

Native Hawaiian Species: Yes

Taxonomy: Family Mullidae

Habitat: Goatfish comprise a major component of Hawaiian reefs. They are named for the chemosensory barbels on their chins that they use to detect benthic invertebrate prey (Szabó et al. 2014). All goatfish are expected to be exposed to sediment. The yellowtail goatfish is most abundant near primary reefs. This species tends to remain low in the water column; most individuals observed off O‘ahu were less than 2 meters above the substrate. Other species of goatfish occur in slightly different habitats: the manybar goatfish ventures farther from the primary reef, but also stays low in the water column. The white goatfish lives in large schools higher in the water column (Schumacher and Parrish, 2004). The white-saddle goatfish and white goatfish forage at night on sandflats (Meyer et al. 2000, Holland et al. 1993).

Locations: Goatfish occur throughout the Hawaiian Islands and Indo-Pacific region.

Seasonality: Year-round resident.

Cultural Use (historical and current): Some species of goatfish, such as the kūmū, were historically used in religious ceremonies as offerings (Titcomb 1972 [as cited in Meyer et al. 2000], Waikīkī Aquarium 2014).

Recreational Harvest: Yes. Goatfishes may be harvested by spear fishing (Meyer 2010). They are a popular food in Hawai‘i (Waikīkī Aquarium 2014). Recreational catch of weke‘ā (yellowstripe goatfish) constitutes the second largest landings within the state, with over 1.0 million kg in reported landings between 2005 and 2009, and 1.2 million kg reported for all species of Mullidae during that period (WPRFMC 2011). The arrival of large numbers of juvenile goatfish, o‘ama, is a popular

Other commonly observed native goatfishes include the following;



White-saddle Goatfish
(*Parupeneus porphyreus*)
Kūmū



Banded or Manybar Goatfish
(*Parupeneus multifasciatus*)
Moano

event for recreational fishermen, who can be seen all around the islands in late summer standing in the shallow waters, catching the small fish for live bait or to eat.

Commercial Harvest: The mean archipelago-wide commercial catch of goatfish between 2005 and 2009 was 5,395 kg, which is down 80 percent from the long-term (1966-2009) average (WPRFMC 2011). (Hawai'i DLNR 2011) reported on commercial landings of almost 50,000 pounds of goatfishes (all species combined), including 9400 pounds of kumu and 5400 pounds of moano.

Home Range: Movement patterns indicate that goatfishes are mobile and have a less well-defined home range compared to surgeonfish and parrotfish (Meyer et al. 2010). In an investigation of several reef fishes (parrotfishes, surgeonfishes, and goatfishes) most fish ranged along 0.2 to 1.6 km of coastline (Meyer et al. 2010). The white-saddle goatfish range across 9,070 to 35,163 square meters in 3 to 14 days (Meyer et al. 2000). The white goatfish ranged across 8,267 square meters at night and 2,533 square meters during the day (Holland et al. 1993).



Yellowstripe Goatfish
(*Mulloides flavolineatus*)
Weke'ā

(Schumacher and Parrish 2004)

Size/Body Weight: Adult goatfishes range from 23 to 40 cm in length (Waikīkī Aquarium, 2014).

Diet/Ingestion Rates: Goatfishes feed on benthic organisms in sand and mud around reefs. Their diet includes bottom-dwelling invertebrates such as worms, crustaceans, small mollusks, brittle stars and heart urchins (Waikīkī Aquarium, 2014). Some goatfish species will also feed on small fishes (Waikīkī Aquarium, 2014).

Predators: Humans, marine mammals, other goatfishes, and the greater amberjack (*Seriola dumerili*) (Schumacher and Parrish 2004).

Available Tissue Data/Bioaccumulation Factors:

- Constituents in 21 samples of goatfish fillets from reference locations on the Wai'anae Coast of O'ahu (fall and spring samples) (U.S. Army Corps of Engineers [ACOE] 2012):
- *Inorganic Constituents:* Antimony, Arsenic, Barium, Cadmium, Chromium, Cobalt, Copper, Lead, Mercury, Nickel, Selenium, Strontium, Thallium, Uranium, Vanadium, and Zinc
- *Organic Constituents:* PCBs, several energetic compounds.
- Composite samples of manybar goatfish (*Parupeneus multifasciatus*) were collected from nearshore waters at Mākua (2 samples) and the background location Sandy beach (1 sample) (See Figure 2-1 and Table 2-2 in Tetra Tech 2009). Samples were analyzed for dioxins/furans, VOCs SVOCs, organochlorine pesticides, explosives, and metals (Table 3-1 in Tetra Tech 2009). The samples had 3.9 to 9.6 mg/kg total lipids and 65.8 to 70 percent moisture. Detected constituents included the following:
    - *Inorganic Constituents:* Aluminum, Arsenic, Barium, Cadmium, Chromium, Cobalt, Copper, Iron, Lead, Manganese, Mercury, Methyl Mercury, Selenium, Silver, Vanadium, and Zinc
    - *Organic Constituents:* Dioxins/furans, Acetone, m+p-Xylenes, bis(2-ethylhexyl)phthalate, di-n-Butylphthalate, Aldrin, alpha-BHC, 4,4'-DDT, Heptachlor, Heptachlor epoxide, Nitroglycerin, Perchlorate, and RDX
- 7 whole-body samples of the bandtail goatfish (*Upeneus taeniopterus*) were collected from Pearl Harbor and analyzed in 1996 for metals, butyltins, polycyclic aromatic hydrocarbons, semi-volatile organic compounds, organochlorine pesticides, PCBs, dioxins/furans, herbicides, triazine pesticides, 2,4,6-trinitrotoluene , and other ordnance chemicals (See Subsection 4.3 and Table 4-3 in Navy 2007b.) These data along with data from tilapia were used to estimate bioaccumulation in bottom fish (See Subsection 6.1.3 in Navy 2007).
- 60 whole fish samples (composites or single specimens) of the bandtail goatfish (*Upeneus taeniopterus*) were collected from Pearl Harbor in 2009 and analyzed for metals, PCBs, pesticides, and dioxins/furans. Fish were 6.5 to 12.5 inches total length. Concentrations of these constituents in goatfish were reported to have decreased since previous sampling in 1996 (See Subsection 3.2.3 in Navy 2010).
- Whole body samples and whole body composite samples were collected from the Kure Lagoon (length 7 to 12 inches and weight 5.75 to 14.5 grams) in 2008 and analyzed for PCBs, metals (arsenic, cadmium, chromium, lead, and mercury), and percent lipids (See Figure 3-3 and Tables 3-5 and B-10 to B-12 in Element Environmental 2009). Lead

and PCBs analyzed for in whole body goatfish samples from Tern Island and Midway Atoll, which were used as reference locations (Element Environmental 2009).

- Metal concentrations in goatfish from Honolua Bay compared to other geographical areas (See Table 2 and 4 in Hedouin et al. 2011).
- Yellowfin goatfish (*Mulloidichthys vanicolensis*) collected from Disappearing Island in French Frigate Shoals were analyzed for PCBs and metals (arsenic, cadmium, chromium, copper, lead, selenium, and zinc) (Miao et al. 2000; Miao et al. 2001).

Conservation Status: Not threatened.

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Names of fishes in this species profile are taken from *Fishes of Kaloko-Honokohau National Historical Park* (http://www.botany.Hawaii.edu/basch/uhnpscesu/htms/kahofish/NSAlista_g.htm), which cites *Reef and Shore Fishes of the Hawaiian Islands* (Randall 2007).

Photo Credit: Bryan Harry (yellowfin and manybar goatfishes); Peg Bethany (yellowstripe goatfish) http://www.botany.Hawaii.edu/basch/uhnpscesu/htms/kahofish/plates/pictz05.htm

12 - Hawaiian flagtail (*Kuhlia sandvicensis*)



Hawaiian flagtail
(*Kuhlia sandvicensis*)
Aholehole

Native Hawaiian Species: yes (McRae et al. 2011)

Habitat: Marine and freshwater habitats (Benson and Fitzsimons 2002). Two recognized forms of *Kuhlia* occur in Hawai'i (*K. sandvicensis and K. xenura*); both live in schools on or near coral reefs as adults, and spawn in marine or estuarine waters (see other notes below). *K. sandvicensis* occurs predominately in marine habitats, but juvenile *K. xenura* are known from freshwater streams, estuaries, on reef flats, along rocky shorelines, and in tide-pool habitats. Along rocky shorelines and in tidepools, *K. sandvicensis* uses microhabitats characteristic of high-energy surge zones-deep areas close to the open ocean that have high salinities. *K. xenura* occurs along shallower rocky shorelines, typically in lower salinities; it may range farther inland, including protected tide pools with low salinities (McRae et al. 2011).

Locations: All islands (Hawai'i DLNR 2005)

Cultural Use (historical and current): These species were culturally important to the ancient Hawaiian people and were often used in religious ceremonies (Titcomb 1972 [as cited in McRae 2011]).

Recreational Harvest: Important food fish in the Hawaiian Islands (Gosline and Brock 1965 [as cited in McRae, 2011]).

Commercial Harvest: Commercial landings for both *Kuhlia* species in the Main Hawaiian Islands averaged about 1,350 kilograms (3,000 pounds) a year in recent years; landings dropped to 900 kilograms (2,000 pounds) in 2003, the most recent year for which data are available (Hawai'i DLNR 2005).

Home Range: No data found.

Size/Body Weight: The aholehole can grow to about 30 cm total length (Gosline and Brock 1965, as cited in McRae, 2011). No body weight data were found.

Diet/Ingestion Rates: The aholehole consumes a variety of small items, consisting of algae, invertebrates, and, insects (Tester and Trefz 1954). No food or sediment ingestion rates were found.

Predators: Humans. No other specific predators were reported.

Tissue Data: One composite sample of Hawaiian flagtail (*Kuhlia sandvicensis*) collected from the Mākua north muliwai was analyzed for dioxins/furans, VOCs, SVOCs, organochlorine pesticides, explosives, and metals (See Figure 2-1 and Tables 2-2 and 3-1 in Tetra Tech 2009). The sample had 6.4 percent total lipids and 72.3 percent moisture. Detected constituents included the following:

- *Inorganic Constituents:* Aluminum, Antimony, Arsenic, Barium, Cadmium, Chromium, Cobalt, Copper, Iron, Lead, Manganese, Mercury, Methyl Mercury, Selenium, Silver, Vanadium, and Zinc
- *Organic Constituents:* Dioxins/furans, di-n-Butylphthalate, Aldrin, 4,4'-DDT, Heptachlor epoxide

Conservation Status: None, but regulations set minimum catch size at five inches (Hawai‘i DLNR 2005).

Other Notes:

Two morphotypes (based primarily on eye size) had long been noted by local fishermen and biologists, before 2001, but only one species, *K. sandvicensis* (Steindachner 1876) was recognized in the scientific literature until recently (McRae, 2011). Randall and Randall (2001 [as cited in McRae 2011]) published a revision of the genus that, effectively “split” *K. sandvicensis* into two species. The “big-eyed” (colloquial) morphotype was assigned the name *K. xenura* (Jordan & Gilbert 1882); this species is believed to be endemic to the Hawaiian Islands. Meanwhile, the “small-eyed” morphotype, even though less frequently observed in what were formerly known as the Sandwich Islands, retained the name *K. sandvicensis*.

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Photo Credit: "Kuhlia sandvicensis" by National Park Service photo - Bryan Harry – http://www.nps.gov/archive/kaho/KAHOckLs/KAHOreef/flagtail2.htm. Licensed under Public domain via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:Kuhlia_sandvicensis.jpg#mediaviewer/File:Kuhlia_sandvicensis.jpg

13 - Convict tang (*Acanthurus triostegus*)



Convict tang
(*Acanthurus triostegus*)
Manini

Native Hawaiian Species: Yes

Habitat: The convict tang is common on coral reefs, but also occurs in tide pools and other nearshore habitats. This species occurs across the Indo-Pacific in temperatures from 24 to 26 ºC and depths of 0 to 45 m (Waikīkī Aquarium 2014; Gamoke 2012 and references within).

Locations: The convict tang occurs on all Hawaiian islands. It was reported among the top 10 most common species within most of the Marine Life Conservation Districts (MLCD) in the state (Friedlander et al. 2006).

Cultural Use (historical and current): Used as food by early Hawaiians; various life stages of this fish are known by separate Hawaiian names (Waikīkī Aquarium 2014).

Recreational Harvest: Convict tangs are popular recreational fish in Hawai‘i (McIlwain 2012, Longenecker et al. 2008). An average of 84,000 pounds were harvested annually between 2004 and 2011 throughout the state; in some years, the recreational catch occasionally exceeds 100,000 pounds (Williams and Ma 2013).

Commercial Harvest: Hawai‘i DLNR reported that about 18,000 pounds of manini were landed by commercial fisheries in 2011, the last year for which records are available (DLNR 2011).

Home Range: No published information on the home range or territory size of the convict tang is available (Gamoke, 2012). An early tagging study indicated that juveniles remain in the same tidepool to which they originally recruit, then move onto a nearby reef to live out their adult lives. Migration was not observed, although some logistical problems with the tagging study limited the interpretation of the data (Randall 1961). However, data for other surgeonfish with similar life histories indicate that individuals generally move between foraging locations and spawning locations every two or three days. Some convict tangs were reported to migrate up to 2 km to reach spawning sites on the seaward side of reefs in Hawai‘i (Domeier and Colin, 1997, as cited in Gamoke, 2012)

Size/Body Weight: The convict tang averages about 17 cm total length; a typical adult has a total length of 20 cm and weighs 200 grams (Longenecker et al. 2008). Life expectancy is estimated to be at least 4 years (Longenecker et al. 2008).

Diet/Ingestion Rates: The adult convict tang is herbivorous, grazing on fine, filamentous algae growing on rocks and corals. It will not take animal food even when deprived of other food under laboratory conditions (Randall 1961). It is often observed feeding on algae-covered rocks where freshwater enters nearshore waters (McIlwain 2012). Sediment ingestion by the manini is virtually zero. Unlike other surgeonfishes that ingest coarse sediment to aid digestion in their thick-walled stomachs, the thin-walled stomachs of manini were completely devoid of sediment (Randall 1961).

Predators: Juvenile manini are consumed by many larger fishes, but adults are thought to be relatively free from predation except by humans (Randall 1961). Eagle rays are also known to feed on manini gametes, which are released unguarded into the water column (Gamoke 2012 and references within).

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation factors:

- Whole body samples were collected at Kure Atoll at the site of a former Coast Guard LORAN Station (Length 5 to 8 inches and Weight 3.25 to 7 grams) in 2008 and were analyzed for PCBs, metals (arsenic, cadmium, chromium, lead, and mercury), and percent lipids (See Figure 3-3 and Tables 3-5 and B-10 to B-12 in Element Environmental 2009). Reference tissue concentrations in manini were reported from other NWHI locations.
- Whole body samples were collected from locations within Cocos Lagoon, Guam (sample coordinates provided in Table 3-4 in Element Environmental 2010). This fish is typically eaten whole. Samples (45 to 96 grams) were analyzed for PCBs with a mean concentration of 13.74 µg/kg (See Table 6-1 in Element Environmental 2010).
- Convict tang (*Acanthurus triostegus*) were collected from the near shore area at ʻĪlio Point, Molokaʻi in 2010 from locations near a debris pile site (See Figure 9 in ESI 2012). Species weighted 25 to 173 grams and were 10.4 to 19.2 cm in length (See Table 2-12 in ESI 2012). Samples were analyzed for metals and PCBs (See Tables 2-18 and 2-19 in ESI 2012).
- Convict tang (*Acanthurus triostegus*) collected from Disappearing Island in French Frigate Shoals were analyzed for PCBs and metals (arsenic, cadmium, chromium, copper, lead, selenium, and zinc) (Miao et al. 2000; Miao et al. 2001).

Conservation Status: No special status (Gamoke 2012; McIlwain 2012).

Other Notes: The convict tang is considered by some to be a subspecies endemic to Hawaiʻi, *Acanthurus triostegus sandvicensis* (Longenecker et al. 2008; Randall 1961).

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Photo Credit: "Convict Surgeonfish, Acanthurus triostegus" by brian.gratwicke - Convict Surgeonfish, *Acanthurus triostegus*. Licensed under Creative Commons Attribution 2.0 via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:Convict_Surgeonfish,_Acanthurus_triostegus.jpg#mediaviewer/File:Convict_Surgeonfish,_Acanthurus_triostegus.jpg

14 - Pacific Sergeant (*Abudefduf abdominalis*)



Pacific Sergeant
(*Abudefduf abdominalis*)
Mamo

Native Hawaiian Species: Yes, endemic to Hawai‘i (Waikīkī Aquarium 2014).

Habitat: Common marine reef fish; non-migratory; depth range 1 to 50 m (Lieske and Myers 1994 [as cited in Froese and Pauly 2011]). Large aggregations occur in quiet waters over rocky bottoms on inshore and offshore reefs; juveniles frequent surge and tide pools (Waikīkī Aquarium 2014, Breder and Rosen 1966). Aggregations of Hawaiian sergeants swarm high off the bottom during the day to feed on plankton, then settle to the bottom during the night. Spawning occurs almost year round, but is most common from January to June (Hoover 2003).

Locations: Endemic to Hawai‘i; widespread within MHI and NWHI (Waikīkī Aquarium 2014).

Cultural Use (historical and current): None known.

Recreational Harvest: Taken as food by Hawaiians (Titcomb 1972 [as cited in Froese and Pauly 2011]).

Commercial Harvest: None

Home Range: Aggregations of adults generally feed in water column above spawning substrate. Males are territorial around nest sites. Juveniles occur in tide pools prior to joining adult population (Hoover 2003, Waikīkī Aquarium 2014).

Size/Body Weight: 30.0 cm total length (Lieske and Myers 1994 [as cited in Froese and Pauly 2011]). Up to 25 cm, but usually smaller (Hoover 2003, Waikīkī Aquarium 2014).

Diet/Ingestion Rates: Feed in the water column on a variety of algae and zooplankton (Froese and Pauly 2011, Hoover 2003). No food or sediment ingestion rates were found.

Predators: Hawaiian sergeant eggs provide a significant food source for other fish (including milletseed butterflyfish, raccoon butterflyfish, and black triggerfish) (Hoover 2003).

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation factors:

- Composite samples of blackspot sergeant (*Abudefduf sordidus*) were collected from the nearshore waters at Mākua (1 sample) and the background location at Sandy Beach (1 sample) (See Figure 2-1 and Table 2-2 in Tetra Tech 2009). Samples were analyzed for dioxins/furans, VOCs, SVOCs, organochlorine pesticides, explosives, and metals (See Table 3-1 in Tetra Tech 2009). The samples had 2.6 to 9.09 percent lipids and 69.3 to 71.2 percent moisture. Detected constituents included the following:

- *Inorganic Constituents:* Aluminum, Antimony, Arsenic, Barium, Cadmium, Chromium, Cobalt, Copper, Iron, Lead, Manganese, Mercury, Methyl Mercury, Selenium, Silver, Thallium, Vanadium, and Zinc
- *Organic Constituents:* Acetone, m+p-Xylenes, di-n-Butylphthalate, delta-BHC, 4,4'-DDT, Heptachlor epoxide, and Perchlorate

- Whole body samples of sergeant major (*Abudufduf abdominalis*) were collected from locations within Cocos Lagoon, Guam (sample coordinates provided in Table 3-4 in Element Environmental 2010). This fish is typically eaten whole. Samples (60 to 120 grams) were analyzed for PCBs with a mean concentration of 123.76 µg/kg (See Table 6-1 in Element Environmental 2010).

Conservation Status: No special status

Other Notes: *Abudefduf vaigiensis*, the Indo-Pacific damselfish, has appeared in Hawaiian waters in the past two decades, and has been shown to hybridize with the Hawaiian sergeant (Maruka and Peyton 2007, Maruka et al. 2007). Based on life history characteristics and field observations, hybridization is expected to continue and to possibly lead to replacement of the endemic Hawaiian sergeant over time (Maruka and Peyton 2007, Maruka et al. 2007).

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Photo Credit: National Park Service, Brian Harry
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15 - Mozambique tilapia (*Oreochromis mossambicus*)



Mozambique tilapia
(*Oreochromis mossambicus*)

Native Hawaiian Species: No. *Oreochromis mossambicus* was introduced in 1951 around O‘ahu (Coles et al. 1999, Randall 1987). The blackchin tilapia (*Sarotherodon melanotheron*) has also become established in Hawaiian waters (Randall 1987).

Habitat: These tilapia occur in diverse habitats throughout Hawai‘i including harbors, streams, estuaries, low wetlands, and reservoirs or ponds of Hawai‘i (Coles 1999, USGS 2013). Tilapia can tolerate a range of salinities, temperatures, and dissolved oxygen levels (MacKenzie and Bruland 2012). *O. mossambicus* occurs in high salinities of atoll lagoons, where it nests in the calm sandy areas (Jubb 1967 [as cited in Russell et al. 2012], Lobel 1980 [as cited in ISSG 2014]).

Locations: Established throughout the Hawaiian Islands (Randall 1987).

Seasonality (year-round resident or migrant): Year-round resident.

Cultural Use (historical and current): None identified.

Recreational Harvest: Limited.

Commercial Harvest: Yes. Tilapia were introduced as potential aquaculture species (Yamamoto and Tagawa 2000 [as cited in MacKenzie and Bruland 2012]). About 3,000 pounds of tilapia (undefined species) were landed by commercial fisheries in 2011 (Hawai‘i DLNR 2011).

Home Range: Not identified.

Size/Body Weight: Approximately 40 cm total length (Skelton 1993 [as cited in USGS 2013]). Adult tilapia collected from a stream and canal in O‘ahu weighed approximately 200 grams (Yang et al. 2008).

Diet/Ingestion Rates: Tilapia are opportunistic omnivores, consuming vegetation, algae, plankton, invertebrates, and fish (Arthington and Bluhdorn 1994, Bruton and Boltt 1975, De Moor et al. 1986, De Silva et al. 1984, Fuselier 2001, Jameson 1991, Komarkova and Tavera 2003, Mathavan et al. 1976, Wager and Rowe-Rowe 1972 [as cited in Russell et al. 2012]). A laboratory investigation estimated a maximum ingestion rate of 3.89×10^9 μm^3 g^{-1} h^{-1} for another tilapia species consuming blue-green algae (Northcott et al. 1991).

Predators: Humans and predatory fishes such as barracuda (Randall 1987).

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation Factors:

- PCBs in tilapia in streams on O‘ahu were in the middle range of levels found worldwide in freshwater and marine waters (Yang 2008).

- 8 whole-body samples of *Oreochromis mossambicus* were collected from Pearl Harbor and analyzed in 1996 for metals, butyltins, polycyclic aromatic hydrocarbons, semi-volatile organic compounds, organochlorine pesticides, PCBs, dioxins/furans, herbicides, triazine pesticides, 2,4,6-trinitrotoluene, and other ordnance chemicals (See Subsection 4.3 and Table 4-3 in Navy 2007b). These data along with data from goatfish were used to estimate bioaccumulation of by bottom fish (See Subsection 6.1.3 in Navy 2007b).
- Composite samples of tilapia (*Talapia zillii*, *T. rendalii*, *Oreochromis macrochir*, *O. mossambicus*, *Sarotherdon melanotheron, Melanotheron*) were collected from Mākua North Muliwai (3 samples), Mākua South Muliwai (3 samples) and the background location Nanakuli Muliwai (3 samples) (See Figure 2-1 and Table 2-2 in Tetra Tech 2009). Samples were analyzed for dioxins/furans, VOCs, SVOCs, organochlorine pesticides, explosives, and metals (See Table 3-1 in Tetra Tech 2009). Lipid content of tilapia samples ranged from 3.3 to 5.1 mg/kg total lipids and 13.9 to 21.3 percent lipid. Total moisture in tilapia samples ranged from 71.3 to 74.3 percent. Detected constituents included the following:
    - *Inorganic Constituents:* Aluminum, Antimony, Arsenic, Barium, Cadmium, Chromium, Cobalt, Copper, Iron, Lead, Manganese, Mercury, Methyl Mercury, Selenium, Silver, Thallium, Vanadium, and Zinc
    - *Organic Constituents:* Dioxins/furans, Acetone, m+p-Xylenes, Bis(2-ethylhexyl)phthalate, di-n-Butylphthalate, beta-BHC, delta-BHC, gamma-BHC, 4,4'-DDT, Heptachlor epoxide, and Perchlorate

Conservation Status: Invasive nonindigenous species.

Other Notes: Tilapia are considered threats to native species such as the mullet (*Mugil cephalus*) based on competition for food (Randall 1987).

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Photo Credit: Blue tilapia (*Oreochromis aureus*) by Leonard Lovshin, US Army Corps of EngineersLicensed under Public domain via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:Blue_tilapia_identification_ASACE.jpg

16 - Spectacled parrotfish (*Chlorurus perspicillatus*) and Yellowbar parrotfish (*Calotomus zonarchus*)



Spectacled parrotfish
(*Chlorurus perspicillatus*)
Uhu Uliuli, Uhu 'ahu'ula



Yellowbar parrotfish
(*Calotomus zonarchus*)
ponuhunuhu

Native Hawaiian Species: Both species are native to the Hawaiian Islands. The spectacled parrotfish also occurs at Johnston Atoll; otherwise, both species are endemic to Hawai‘i (Bishop Museum 1997, Hawai‘i DLNR 2005).

Habitat: Like all parrotfishes, these species are associated with coral reefs. Spectacled parrotfish occur in surface waters and range to more than 60 meters (200 feet) deep. The yellowbar parrotfish is not known from shallow surface waters, but occur in waters at least 10 meters (35 feet) deep (Hawai‘i DLNR 2005).

Locations: The spectacled parrotfish is widely distributed across Hawai‘i. The yellowbar parrotfish occurs from O‘ahu through the Northwestern Hawaiian Islands (Hawai‘i DLNR 2005).

Cultural Use (historical and current): None reported.

Recreational Harvest: Both species are fished recreationally and are especially vulnerable to nighttime spearfishing (Hawai‘i DLNR 2005).

Commercial Harvest: Parrotfishes are harvested commercially, although landings are not tracked by species. (DLNR 2011) reported that 72,000 pounds of uhu were landed in Hawai‘i in that year.

Home Range: The mean home range for the redlip parrotfish (*Scarus rubroviolaceus*) ranges from 382 to 834 m^2 at 5 m depth and 1,043 to 2,279 m^2 at 15 m depth, depending on the phase of the fish.

Size/Body Weight: These parrotfishes typically grow to about 30 centimeters (1 foot) in total length in the MHI (Hawai‘i DLNR 2005). Larger individuals have been reported from the NWHI. The size at which individuals become terminal phase males varies among islands, possibly in response to differential predation from sharks and other large piscivorous fishes such as trevallies (Family Carangidae). Terminal phase males on Midway were longer than 50 cm (about 22 inches) (DeMartini et al. 2005). No body weight data were found.

Diet/Ingestion Rates: Parrotfishes are herbivorous and graze algae from rock and coral surfaces (Hawai‘i DLNR 2005). No food or sediment ingestion rates were found.

Predators: In the NWHI, apex predators such giant trevally (*Caranx ignobilis*) and bluefin trevally (*C. melampygus*), feed heavily on parrotfishes (DeMartini et al. 2005). In the MHI, where stocks of apex predators have been reduced by harvest, humans are the predominant predator on parrotfishes (Friedlander and DeMartini 2002).

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation factors: No tissue data or bioaccumulation factors were found.

Conservation Status: No special status (Russel et al. 2012)

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Photo Credit: Spectacled parrotfish, "Reef0620 - Flickr - NOAA Photo Library" by Dr. Dwayne Meadows, NOAA/NMFS/OPR. - NOAA Photo Library: reef0620. Licensed under Public domain via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:Reef0620_-_Flickr_-_NOAA_Photo_Library.jpg#mediaviewer/File:Reef0620_-_Flickr_-_NOAA_Photo_Library.jpg

17 - Moray eel (*Muraenidae*)



Moray eel
(*Muraenidae*)

Native Hawaiian Species: Several species are native to Hawai'i. Forty-two species of moray eel have been found in the Hawaiian Islands (Böhlke and Randall, 2000). Common species include the yellow margin moray (*G. flavimarginatus*) and undulated moray (*G. undulates*). Some species of moray eel are endemic to the Hawaiian Islands, including the Atoll moray (*Gymnothorax atolli*), Nutting's moray (*G. nuttingi*), brown speckled eel (*G. steindachneri*), and possibly the manyvertebrate moray (G. polyspondylus) (Böhlke and Randall, 2000).

Habitat: Moray eels occur in shallow to moderately deep tropical and subtropical seas. They are frequently observed in coral reefs or lagoons. They tend to hide in reefs or rocky bottoms (Böhlke and Randall 2000).

Locations: Throughout the Hawaiian Islands.

Seasonality (year-round resident or migrant): Year-round resident.

Cultural Use (historical and current): None identified.

Recreational Harvest: Moray eels are harvested and consumed throughout the Indo-Pacific region, including the Hawaiian Islands. However ciguatera poisoning may result from eating large piscivorous reef fishes, such as large morays (greater than 4 kg), particularly the yellow margin moray, undulated moray, giant moray (*G. javanicus*), and white mouth moray (*G . meleagris*) (Böhlke and Randall, 2000).

Commercial Harvest: Some species may be harvested.

Home Range: The yellow margin moray and undulated moray occupy reefs and rocky substrates from depths of 1 to 150 meters (Reece et al. 2011). Other morays have a more restricted range. For example, the snowflake moray (*Echidna nebulosa*) and zebra moray (*Gymnomuraena zebra*) occur between 0 and 15 meters but are most common at less than 2 meters (Hiatt & Strasburg 1960, Yukihira et al. 1994 [as cited in Reece et al. 2011]). The average depths where eels were captured for a study across the Indian Ocean and Pacific Ocean were 22 meters for the yellow margin moray, 24 meters for the undulated moray, 1.9 meters for the zebra moray, and 1.8 meters for the snowflake moray (Reece et al. 2011).

Size/Body Weight: The yellow margin moray and undulated moray are large fish. The undulated moray ranged from 312 to 628 mm (females) and 282 to 756 mm (males) (Böhlke and Randall 2000). The yellow margin moray ranged from 230 to 1175 mm. The zebra moray ranged from 427 to 920 mm (females) and 425 to 734 mm (males). All three of these species may reach 1500 mm. The snowflake moray ranged from 273 to 570 mm (females) and 302 to 703 (males), with a maximum length of 750 mm (Böhlke and Randall 2000).

Diet/Ingestion Rates: Moray eels in Hawai'i are generally separated into two groups based on their diet. The species with fang-like teeth, including the yellow margin moray and undulated moray, feed on fishes and soft-bodied invertebrates (e.g., octopus).

The species with pebble-like teeth, such as the snowflake moray and zebra moray, feed on crustaceans (e.g., crabs and molluscs) (Waikīkī Aquarium 2014).

Predators: Humans and large fish species (e.g., grouper)

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation Factors: The conger eel (*Conger cinereus*), undulated moray eel (*Gymnothorax undulates*), whitemouth moray eel (*Gymnothorax meleagris*), and yellowmargin moray eel (*Gymnothorax flavimarginatus*) collected from French Frigate Shoals were analyzed for PCBs and metals (arsenic, cadmium, chromium, copper, lead, mercury, selenium, and zinc) (Miao et al. 2000, Miao et al. 2001). The results indicated that the undulated moray eel bioaccumulated high levels of arsenic compared with the other eel species (Miao et al. 2001). The other metal concentrations varied little among species.

Conservation Status: Not threatened.

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Photo Credit: Jon Hanson Licensed under Public domain via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:Yellow_Margined_Moray_Eel.jpg

18 - Wedge-tailed shearwater (*Puffinus pacificus*)



Wedge-tailed shearwater
(*Puffinus pacificus*)

Native Hawaiian Species: Yes

Habitat: Occurs over the open ocean most of the year. Nests in burrows, which may be concealed or in the open. Shearwater burrows at Mālaekahana ranged from concealment under thickets of naupaka, at the base of ironwood and heliotrope trees, to bare sand under clumps of ʻakiʻaki grass (Smith et al. 2002).

Locations: This bird occurs throughout most of the tropical and subtropical Pacific and Indian Oceans, including the Hawaiian Islands (Harrison 1983, Harrison 1990, Whittow 1997 [as cited in Smith et al. 2002). It is a common breeder on almost every island in Hawaiʻi and on many small offshore islets (Pyle and Pyle 2009).

Seasonality (year-round resident or migrant): Migrant. The wedge-tailed shrearwater spends much of the year on the open ocean but returns to coastal areas to breed (Smith et al. 2002). It returns to nesting areas on Oʻahu in April (Smith et al. 2002). In November, the fledglings fly out to sea (Smith et al. 2002).

Cultural Use (historical and current): None identified.

Recreational Harvest: None.

Commercial Harvest: None. Seabirds in Hawaiʻi are protected by the federal Migratory Bird Treaty Act (50 CFR 10) and by State law under Title 13, Part 2, Chapter 125 of the Hawaiʻi Administrative Rules, which prohibit the hunting, capturing, killing, possession, shipping, etc., of migratory birds, unless authorized by a permit (Smith et al. 2002).

Home Range: Not identified. It remains close to its burrow during nesting.

Size/Body Weight: The wedge-tailed shearwater was reported to weigh from 0.30 to 0.57 kg (sample size = 576 birds) (Bull, 2006).

Diet/Ingestion Rates: An adult shearwater consumes an average 35.01 ± 1.34 grams per day, based on a study in Australia (Peck and Congdon 2005 [as cited in McDuie et al. 2013]). A study in the NWHI reported that fish comprised 67.0% and cephalopods 28.6% by volume of stomach contents. By number of items, fish comprised 73.3% and cephalopods 23.1%. The remaining small portions consisted of crustaceans, insects, and coelenterates. Typical prey size was approximately 5.7 cm in length. Common fish prey include Mullidae and Carangidae, especially shortfin scad (*Decapterus macrosoma*); cephalopods were mostly Ommastrephidae (Marchant and Higgins 1990 [as cited in Australian Department of the Environment 2014]).

Predators: Humans and introduced mammals, such as dogs, cats, mongooses, and rats (Olson and James 1982, Steadman 1995 [as cited in Smith et al. 2002]). Predation by feral cats was reported to reduce reproductive success to near zero at Mālaekahana, and pedestrian traffic can collapse nesting burrows (Smith, et al., 2002). Invasive ants were observed to injure nesting shearwaters on windward Oʻahu (Plentovich et al. 2009).

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation Factors:

- Feathers from wedge-tailed shearwaters from Midway Atoll were analyzed for metals (arsenic, cadmium, chromium, manganese, mercury, lead, selenium, and tin) (Burger and Gochfeld 2000). Chromium was high in the wedge-tailed shearwaters compared to other sea birds.
- Feathers from flesh-footed shearwaters (*Puffinus carneipes*) from New Zealand, Lord Howe Island, and Australia were analyzed for metals (Bond and Lavers 2011). Mercury, and potentially arsenic and cadmium were noted as toxicological concerns for the species.

Conservation Status: Not threatened. Another species, Newell Shearwater (*Puffinus newelli*) is threatened.

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Photo Credit: Duncan Wright, USFWS Licensed under Public domain via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:W-tail_with_chick.jpg

19 - Black-crowned night heron (*Nycticorax nycticorax hoactli*)



Black-crowned night heron
(*Nycticorax nycticorax hoactli*)

Native Hawaiian Species: yes

Habitat: The night heron is frequently found in permanent freshwater wetlands, lowland streams, and man-made wetlands. It is also known to occur in lagoons, reefs, and lava benches exposed during low tide (Engilis and Pratt 1993).

Locations: It occurs on every continent except Australia and Antarctica (U.S. Army Center for Health Promotion and Preventive Medicine 2004). Within the Hawaiian Islands, it is observed commonly on Kaua‘i, O‘ahu, Moloka‘i, Maui, and Hawai‘i and reported less often on Ni‘ihau, Lana‘i, and Kaho‘olawe (Pyle and Pyle 2009).

Seasonality (year-round resident or migrant): Year-round resident.

Cultural Use (historical and current): None identified.

Recreational Harvest: None.

Commercial Harvest: None.

Home Range: Most colonies of the black-crowned night heron are in the vicinity of large wetlands. During nesting, both the male and female defend a territory around a large nest (approximately 8 ft wide and 4 ft high. Adults often return to previously used nests (Davis 1993 [as cited in U.S. Army Center for Health Promotion and Preventive Medicine 2004]; Custer et al. 1980 [as cited in USGS 2010]). Individuals disperse widely after nesting is completed.

Size/Body Weight: Adult black-crowned night herons are approximately 58 to 65 cm in length, with an average mass of 883 grams (Dunning 1993 [as cited in USGS 2010]). Body mass in four males ranged from 785 to 1014 grams with an average mass of 913 grams; four females ranged from 727 to 862 grams with an average mass of 827 grams (Gross 1923 [as cited in U.S. Army Center for Health Promotion and Preventive Medicine 2004])

Diet/Ingestion Rates: While fish are the primary food source, the black-crowned night heron is an opportunistic feeder (Davis 1993 [as cited in U.S. Army Center for Health Promotion and Preventive Medicine, 2004]). Its diet varies by habitat and regional, but is typically about 50 percent fish, 40 percent insects and crustaceans, and 10 percent amphibians and reptiles (Palmer 1962 [as cited in Madenjian and Gabrey 1995]). The black-crowned night heron may prey upon Hawaiian coot chicks (Brisbin et al. 2002 [as cited in USFWS 2011]). This heron may consume fish at a rate of 0.15 kg/day (Alberta Agriculture and Rural Development 1999). A food consumption rate of 0.061 kg/kg body weight/day was estimated using a mean body weight of 0.87 kg and assuming a diet of 59 percent fish, 37 percent invertebrates, 7 percent amphibians, and 1.7 percent mammals with respective water contents of 75, 76, 85, and 68 percent. Using the same body weight, a water ingestion rate of 0.062 L/kg BW/day was calculated (U.S. Army Center for Health Promotion and Preventive Medicine 2004). The heron may ingest soil or sediment when feeding on burrowing crustaceans. U.S. Army Center for (Health Promotion and Preventive Medicine 2004) estimated that a soil/sediment ingestion rate of 2 percent, as reported in (Beyer et al. 1994), was appropriate.

Predators: Not identified.

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation Factors:

- See Pearl Harbor BERA for use of black-crowned night heron as assessment endpoint (Navy 2007b).

Conservation Status: Not threatened.

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Photo Credit: "Black-crowned night heron. 'Auku'u. Nycticorax nycticorax hoactii" Photo taken by Tom Fake, National Park Service.

20 - Hawaiian coot (*Fulica alai*)



Hawaiian coot
(*Fulica alai*)
'Alae Ke'oke'o

Native Hawaiian Species: Yes

Habitat: Low elevations in wetland habitats with both emergent plant growth and open water (USFWS 2011). The coot prefers freshwater wetlands but will use brackish wetlands.

Locations: Currently on all of the main Hawaiian Islands except Kahoʻolawe, which lacks suitable wetland habitat (USFWS 2011). It is present on Lānaʻi in artificial wetland areas near water treatment sites (USFWS 2011).

Seasonality (year-round resident or migrant): Year-round resident (USFWS 2011).

Cultural Use (historical and current): None identified.

Recreational Harvest: Hunted in early twentieth century, but now protected (Reed et al. 2011).

Commercial Harvest: None.

Home Range: The coot typically feeds and nests in the same area but will travel long distances when food is not locally available (Shallenberger 1977 [as cited in USFWS 2011]).

Size/Body Weight: Adult Hawaiian coots weigh approximately 0.53 ± .08 kilograms (n = 231) (Desrochers et al. 2010). The Pearl Harbor BERA used an adult body weight of 0.56 kg (Navy 2007b).

Diet/Ingestion Rates: The coot forages near the surface of the water or deeper; it will dive for food and forage in submerged mud or sand. It also grazes on upland grassy sites, such as golf courses adjacent to wetland (USFWS 2011). Food items include aquatic plants, particularly seeds and leaves; invertebrates such as snails, crustaceans, and insects; and small fish (Schwartz and Schwartz 1949 [as cited in USFWS 2011]).

No food or sediment ingestion rates were found. A large-scale study of the American coot, a closely related species (formerly considered another subspecies) common on the U.S. mainland, reported that the stomach held up to 30 percent sand or sediment (Jones 1940). The Pearl Harbor BERA calculated a normalized food ingestion rate of 0.071 kg food/kg body weight-day) using methods in (EPA 1993) and an incidental sediment ingestion rate of 3 percent for the coot (Navy 2007b).

Predators: Non-native cats, rats, mongooses, dogs, and to a lesser extent wild pigs, barn owls, cattle egrets, predatory fish, and bullfrogs prey on eggs, young, or adult birds (Underwood et al. 2013). The native black-crowned night heron may prey upon Hawaiian coot chicks (Brisbin et al. 2002 [as cited in USFWS 2011]).

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation factors: See Pearl Harbor BERA for use of Hawaiian coot as assessment endpoint (Navy 2007b).

Waiākea Pond (Hilo) ERA provides life history parameters for food chain modeling and toxicity reference values for arsenic.

Conservation Status: Endangered. The main cause of decline of the Hawaiian coot is loss of wetland habitat (USFWS 2011).

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Photo Credit: “Hawaiian coot. 'Alae ke'oke'o. Fulica alai” Photo taken by Bryan Harry, National Park Service. http://www.botany.Hawaii.edu/basch/uhnpscesu/htms/kahobird/fish_pops/Rallidae/rail01.htm

21 - Green sea turtle (*Chelonia mydas*)



Green sea turtle
(*Chelonia mydas*)
Honu

Native Hawaiian Species: yes

Habitat: The green sea turtle forages in seagrass beds, shallow patch reefs, and coral-covered areas; it rests on deep mud bottom channels and in small caves and crevices in the sides of reefs (Brill et al. 1995). Immature green turtles stay in the open ocean, moving inshore as adults (Parker et al. 2011).

Locations: The green sea turtle occurs in tropical waters worldwide and is the most common sea turtle in Hawai‘i, occurring throughout the islands. Most nesting is at French Frigate Shoals (Balazs 1980).

Seasonality (year-round resident or migrant): Year-round resident

Cultural Use (historical and current): Historically, the green sea turtle was used as a food source and harvest was often restricted to special occasions. Certain parts of the green turtle, such as the fat, were also used for medicinal purposes. In addition, parts of the turtle were used as containers, tools, and ornaments (NOAA 1998).

Recreational Harvest: Sea turtles and their eggs are harvested for food (NOAA, 1998).

Commercial Harvest: Incidental harvest by commercial fisheries (NOAA, 1998).

Home Range: Telemetry tracing the journeys of male and female turtles between breeding and foraging areas found some individuals traveled 1050 to 1200 km (Balazs and Ellis, undated). Adults feed in areas less than 10 meters deep, typically only 3 meters deep (Balazs 1980).

Size/Body Weight: The straight carapace length of the green sea turtle turtles is $\leq$65 cm for juveniles; 65-81 cm for sub-adults, and >81 cm for adults. The mean body weight of adult females is 110 kg (range 68-148 kg) based on a sample size of 69 turtles (Balazs 1980).

Diet/Ingestion Rates: Algae is the dominant food, supplemented by jellyfish, salps, mollusks, sponges, and tubeworms (NOAA 2018). An adult green sea turtle consumes the equivalent of only 0.24 to 0.33 % of its body weight each day (dry weight to wet weight ratio) (Bjorndal 1980). Juvenile turtles in the pelagic phase (which lasts from 5 to 10 years) are carnivorous or omnivorous, consuming zooplankton, pelagic crustaceans, and mollusks (Parker et al. 2011).

Predators: Sea turtle eggs are eaten by feral dogs and cats, rats, mongooses, and ghost crabs. Hatchlings may be taken by large crabs and fishes. Humans and tiger sharks prey on juvenile and adult turtles (Balazs 1980, NOAA 2018).

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation Factors:

- Arsenic concentrations were measured in green turtle tissues (liver, kidney, muscle, and stomach contents) collected in Japan (Agusa et al. 2008). Concentrations of arsenic in the stomach versus tissues were reported to indicate bioaccumulation of arsenic.
- Toxicity reference values were derived for sea turtles on Tern Island using terrestrial bird laboratory toxicological studies (USCG 2000).

Conservation Status: Threatened; Hawaiian population is under review for delisting (Federal Register, 2012).

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Photo Credit: Andy Bruckner, NOAA (http://www.nmfs.noaa.gov/pr/species/turtles/photos.htm)

22 - Monk seal (*Monachus schauinslandi*)



Monk seal
(*Monachus schauinslandi*)
ilio-holo-i-ka-uaua or na mea hulu

Native Hawaiian Species: Yes. Endemic to Hawai'i (NOAA 2018)

Habitat: The Hawaiian monk seal uses shallow water reef habitat for pupping, weaning and foraging, sandy beach areas for resting, and deeper reef areas for foraging (Kittinger et al. 2011). It forages in various habitats such as coral reefs, sandy bottom, rubble flats, and sub-photic slopes (Sprague et al. 2013). Most foraging dives are 200 meters or less (Sprague et al. 2013).

Locations: The largest population of Hawaiian monk seal occurs in the NWHI (approximately 1,400); a second population of about 200 seals occurs on the MHI (Sprague et al. 2013). The NWHI population is declining, while the number of seals in the MHI is increasing (Lopez et al. 2012, Johanos et al. 2014).

Seasonality (year-round resident or migrant): Year-round resident; some movement between the two populations occurs.

Cultural Use (historical and current): The Hawaiian monk seal is seen by some native Hawaiians as an interloper from the NWHI that competes with local subsistence fishing communities. Other people report strong positive cultural associations and a feeling of stewardship toward the seal (Kittinger et al. 2011).

Recreational Harvest: Monk seals may have been harvested historically for meat and fur but harvest is illegal now under the Endangered Species Act (Kittinger et al. 2011).

Commercial Harvest: The monk seal was hunted historically but is now protected from harvest.

Home Range: The species ranges over 2500 km throughout the Hawaiian Islands (Baker et al. 2004, 2012). Although individual monk seals may move between the NWHI and the MHI, most do not. Pups tend to stay on their natal island, but adults may visit adjacent islands throughout the year (Johanos et al. 2014). Foraging trips may extend to 322 km from the island of origin (Stewart 2004, Stewart et al. 2006 [as cited in Johanos et al. 2014]).

Size/Body Weight: The average body mass for monk seals is 170 kg for an adult (>5 years), 140 kg for a subadult (3-5 years), and 66 kg for a juvenile (weaning to 3 years) (Sprague et al. 2013).

Diet/Ingestion Rates: The Hawaiian monk seal consumes more than 22 families of fish and marine invertebrates. Principal prey items include triggerfish, moray and white eels, large crustaceans, and surgeonfishes (Sprague et al. 2013). Generally, the monk seal does not eat apex predators such as tuna or mahi, preferring the slower reef fishes that are easier to catch (Baker et al. 2012).

Life Stage	Daily food ingestion (kg/day)[1]	Food Ingestion Rate (% body mass/day)[1]	Sediment Ingestion (grams/day)[2]
Adult	5.89	3.5	3 to 10
Subadult	7.61	5.5	No data
Juvenile	5.01	7.6	No data
Nursing Pup	No data	No data	10 (for 5 weeks)

Source:
[1] Sprague et al. 2013
[2] Woodward-Clyde Consultants 1994.

Predators: Monk seal pups may be taken by sharks or injured by adult male seals (Baker et al. 2012).

Tissue Data/Bioaccumulation Factors:

Mean concentrations of persistent organic pollutants (POP) in monk seal blubber were similar in seals in the Main Hawaiian Islands and the Northwestern Hawaiian Islands; however, some individuals from the main Hawaiian Islands had high contaminant levels (Lopez et al. 2012). Adult males generally have higher blubber and serum concentrations of POPs than do adult females or juveniles (Ylitalo et al. 2008; Lopez et al. 2012). POPs in monk seals from NWHI were generally equal to or lower than those reported for other pinniped species in the North Pacific Ocean (Ylitalo et al. 2008). Monk seals from French Frigate Shoals were analyzed for PCBs, DDT and DDT metabolites (Willcox et al 2004). Correlations were noted between concentrations of DDE and PCBs in blubber or blood and body mass, age, or condition (Willcox et al 2004).

Blood and Blubber Concentrations: Organochlorine Compounds (DDTs and dioxin-like PCBs): Health effect levels and reference levels in North Pacific Ocean; safe upper PCB concentration of 8700 ng/g, lw for marine mammal blood; 17,000 ng/g, lw for PCBs in blubber

Sediment Preliminary Remediation Goals (PRG) protective of monk seal:

Lead: 270 to 890 mg/kg lead at Kure Atoll (NWHI) (Woodward-Clyde Consultants 1994)

PCBs: 250 to 849 mg/kg in sand on the island at Kure Atoll (NWHI) (Woodward-Clyde Consultants 1994)

PCBs: 3 mg/kg PCB soil cleanup level, based on target action level of 0.165 mg/kg in sediment. Tern Island, French Frigate Shoals (NWHI) (USCG 2000).

Toxicity Reference Value (no effect daily dose) for monk seal:

Lead = 0.02 mg/kg-body weight/day at Kure Atoll (NWHI) (Woodward-Clyde Consultants 1994)

PCBs = 0.0190 mg/kg-body weight/day at Kure Atoll (NWHI) (Woodward-Clyde Consultants 1994)

Conservation Status: Federally Endangered

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Photo Credit: " *Monachus schauinslandi*. Hawaiian monk seal" Photo taken by Tom Fake, National Park Service.
http://www.botany.Hawaii.edu/basch/uhnpscesu/htms/kahomamm/fish_pops/phocidae/seal02.htm

APPENDIX 21-B
Ecological Risk Assessment Scoping Checklist

ECOLOGICAL RISK ASSESSMENT SCOPING CHECKLIST

The purpose of this *Ecological Risk Assessment (ERA) Scoping Checklist* is to determine whether the target site requires an ERA based on known or suspected release of chemicals in sensitive coastal/marine habitat. The *Checklist* is intended to guide the preparer to assemble available data on conditions at the site and identify complete and potentially significant ecological exposure pathways. It is important that the *Checklist* be completed early in the investigation process to ensure coordination with the HEER Office on the need for additional data collection to support an ERA. This *Checklist* cross-references the HEER Office Technical Guidance Manual (TGM) for specific information on sampling design and other general topics, as needed.

Instructions for Completing the *ERA Scoping Checklist*:

When completing the *ERA Scoping Checklist*, all available relevant information/analytical data on known or suspected chemical releases to soil, groundwater, surface water, or sediment should be considered. Refer to the HEER Office TGM, particularly Section 21.0 (ERA Guidance), for information on sediment quality guidelines (SQG) and other screening levels, bioaccumulative chemicals, conceptual site models (CSM), typical habitats, and other components of this *Checklist*. Submit the completed *ERA Scoping Checklist* to the HEER Office for review. Note that the preparer is responsible for providing complete information to support the Checklist, including associated data tables, and must advise the HEER Office of any new data or information that becomes available during the review process that could alter the findings or conclusions of the *ERA Scoping Checklist*.

Ecological Risk Assessment Scoping Checklist
(Coastal and Marine Sites)

1. **Site Name:**

_____

2. **Location (County, City or Lat/Long):**

_____

3. **Describe site history: List past uses, any known or suspected releases, visible signs of contamination, or other evidence that the site may be contaminated. Include any onshore area considered a source to the coastal/ marine site.**

_____

_____

_____

_____

_____

_____

Note: *Attach applicable site maps and photographs; a topographical map; a diagram of any adjacent on-shore facilities (if applicable) showing site boundaries and structures. Include a CSM identifying potential ecological receptors, release mechanisms, and exposure pathways. (See TGM Subsection 21.3.3.5 [Step 1B, Task 5] for example CSMs.)*

4. **List previous studies/investigations conducted at the site and summarize their findings (add rows as needed):**

Study/Investigation (Date)	Findings

5. **Indicate the approximate size of the potentially affected area:**

Acres:

_____

Linear feet of shoreline:

_____

Distance seaward from the shoreline:

_____

6. **Indicate whether the potentially affected area is in an erosional or depositional zone. Provide literature or site-specific data to support the designation.** Data on coastal erosion and accretion (of shorelines) is available at http://pubs.usgs.gov/of/2011/1051/ (Fletcher et al. 2012)

7. **Indicate analytical data available at site:**

Sediment: (No) (Yes) (Number of samples: _____)

Surface water: (No) (Yes) (Number of samples: _____)

Soil (source area): (No) (Yes) (Number of samples: _____)

Groundwater: (No) (Yes) (Number of samples: _____)

Sediment Pore Water: (No) (Yes) (Number of samples: _____)
Organisms/Tissue: (No) (Yes) (Number of samples: _____)

Briefly describe the available data for any "Yes" answer above. For example, include description of whether any sediment sample data represent MIS or discrete samples. Complete Table 21-B-1 (attached; add rows as needed) and attach figures showing sample locations.

_____

_____

_____

_____

_____

8. **Complete Table 21B-2 (attached). In the notes section below the table, indicate the relative abundance of various habitat types, if known. Describe any potential offsite migration pathways.**

9. **Have the following site media been impacted or potentially impacted by site-related contamination?**

Sediment:	No	Yes	If Yes, complete **Table 21B-3**.
Surface water:	No	Yes	If Yes, complete **Table 21B-4**.
Groundwater:	No	Yes	If Yes, complete **Table 21B-4**.
Sediment Pore Water:	No	Yes	If Yes, complete **Table 21B-4**.
Soil (source area):	No	Yes	Explain in notes below.
Tissue/Organisms:	No	Yes	Explain in notes below.

Provide notes below to identify any soil or tissue contamination:

10. **Is any threatened, endangered or special status species known or suspected to occur at the site?** (No) (Yes) (If yes, list below):

Scientific Name	Common Name	Hawaiian Name	Federal/State Status	Habitat

11. **Check all of the statements below that are true at the site:**

1. A known release of chemicals occurred at the site.
2. Signs of adverse effects are obvious at the site (diseased, deformed, dying, or dead organisms).
3. Bioaccumulating chemicals are present at the site.
4. Chemical concentrations at the site exceed screening levels and/or background concentrations.
5. Sensitive habitat (e.g. threatened or endangered species, spawning or nursery areas) occurs within or immediately adjacent to the site.

If any one of #1 through #4 are true, AND #5 is true, then the site is recommended for the ERA Program.

12. **Recommendation**

Is an ERA recommended for the site? No Yes

Please list any additional factors supporting this recommendation:

13. **Preparer**

Name:

Organization / Position or Role:

Address:

Email:

Phone:

Table 21B-1 - Potentially Site-Related Contaminants

Chemical Name	CAS No.	Bioaccumulative[1]		Potentially Affected Offshore Media		
		Yes	No	Sediment	Surface Water	Organisms

[1] See Table 21-7 and Appendix 21-E

TABLE 21B-2 - Potential Contaminants in Marine Habitats

Habitat	Habitat Present at Site		Presence of Site-Related Contamination				Source of Potential Contamination			
	No	Yes	Documented	Suspected	Not Expected	Unknown	Direct Release	Migration from Soil	Migration from Groundwater	Other
Young Volcanic Substrate; Little Sediment										

Deep Channels										
Mixed Sediment Bays and Harbors										
Soft Sediment Bays										
Sandy Beach										
Anchialine Pools										
Stream-fed Estuarine Wetlands										
Coastal Fishponds										
Lagoon/Coastal Wetland										
Seagrass Beds										
Mangroves (Introduced)										
Mudflats										
Rocky Intertidal / Tidepools										
Subtidal Hardbottom										
Coral Reef										
Other:										
Other:										

Notes:

Table 21B-3 - Initial Sediment Screening

Chemical	Frequency of Detection	Minimum Detected Concentration	Maximum Detected Concentration	Location of Maximum Detection[1]	Mean Concentration	Sediment Quality Guideline[1]		Maximum Hazard Quotient[2]	Is Chemical Bioaccumulative[4]
						Value	Source		Yes/No/ Basis[4]

[1] Sediment Quality Guidelines (SQG) for selected chemicals are in Table 21-7. For chemicals not listed in Table 21-7, the preparer may recommend SQG from the literature and provide a source document.

[2] Hazard Quotient (HQ) = Maximum detected concentration / SQG

[3] List of common bioaccumulative chemicals are in Table 21-7.

[4] Cite Table 21-7 or other basis (e.g. log K_{ow}, tissue concentrations, other)

Table 21B-4 - Initial Surface Water, Groundwater, or Pore Water Screening

Chemical	Frequency of Detection	Minimum Detected Concentration	Maximum Detected Concentration	Location of Maximum Detection[1]	Mean Concentration	Water Quality Criterion[2]		Maximum Hazard Quotient[3]	Is Chemical Bioaccumulative[4]
						Value	Source		Yes/No/ Basis[5]

[1] For groundwater results, provide depth of well, if known.

[2] USEPA Water Quality Criteria (WQC) are available on-line at http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm#altable

[3] Hazard Quotient (HQ) = Maximum detected concentration / WQC

[4] List of common bioaccumulative chemicals are in Table 21-6.

[5] Cite Table 21-7 or other basis (e.g. log K_{ow}, tissue concentrations, other)

APPENDIX 21-C
Defining Ecologically-based Decision Units

An important step in the DQO process is to define the study boundaries, which includes defining decision units (DUs). A general discussion of DUs is presented in Subsection 3.4 of the Hawai'i HEER TGM. As discussed above, The HEER Office has adopted the use of Multi Increment sampling (MIS) sampling for specific applications and suggests that the size and shape of a DU is primarily controlled by the environmental concerns posed by the contaminants present at the site. (HDOH 2018, ITRC, 2012) Ecological DUs should be based on: (1) the phase of ecological risk assessment being planned (SLERA or BERA); (2) the assessment endpoints and receptors of interest; and (3) the available habitat and its contiguity with site.

Ecological DUs must be defined both laterally and vertically. The approach to defining the lateral extent of a DU should consider the following factors:

- **The ERA process, particularly problem formulation, conceptual site model (CSM) development, and the resulting assessment endpoints** The assessment endpoints selected for the site, and the receptors selected to represent them, are the critical first step in defining the lateral extent of a DU.
- **Population versus individual exposures.** With the exception of special status species (those listed as rare, threatened, or endangered) or migratory birds, risk management decisions for vertebrates should be based upon protecting local receptor populations. Lower trophic level receptors, such as benthic invertebrates, are typically assessed at the community level. However, ERAs for upper trophic level wildlife species (e.g., birds and mammals) are typically based on effects to individuals. Individual-level responses are then used to estimate population-level responses for management purposes (Sample et al. 1996). It can be assumed that there is a distinct (local) population of the receptor of interest on the site so that the exposure of the population is represented by the exposure of all of the individuals, which are assumed to experience equivalent exposure. This assumption is appropriate for organisms with relatively small home ranges.

  It is thus critical to define the population and address questions of scale. The size of a typical sediment site is generally too small to support viable populations of most upper trophic level receptors. However, many sites can support populations and communities of lower trophic level species such as sediment invertebrates, coral, and aquatic plants. Confined aquatic habitats (Anchialine Pools, tidepools, etc.) may support distinct populations and communities of benthic invertebrates and fish. For tidal creeks, bays, harbors, etc., portions of the water body may be capable of supporting populations or communities of receptors, but they are not isolated and may "exchange" organisms with off-site areas. This may confound attempts to determine if there are impacts, since immigration from surrounding, uncontaminated areas may mask the effects of site-associated contaminants.

  Fish and other aquatic communities in streams and rivers should be generally be defined by reach, which is the appropriate scale at which to address effects (Suter 2007). The size of the reaches (which could correspond to DUs) may be defined based upon changes in physical attributes (such as habitat shifts represented by sediment grain size distribution, marine influence, and wave energy) and habitat attributes.

  For mobile vertebrates, such as birds and mammals, the population is generally defined as a function of individual spatial use patterns (home range). Sites sufficiently large to contain multiple home ranges for a given species can be said to support a "local population" of that species provided that the habitat is suitable. Home ranges can be defined in a number of ways, depending upon receptor. During the breeding season, some species defend territories that contain all life requisite needs (food, breeding sites, etc.). Others may defend small breeding sites but forage (nonexclusively) over larger areas. Because ingestion of food is the greatest exposure pathway for these receptors, the foraging range strongly influences site-related exposure. For species with home ranges smaller than the area of suitable habitat present on a site, it is typically assumed that exposures (on a spatially averaged basis) of individuals can be extrapolated to the population level. For species whose home range size exceeds the area of suitable habitat at a site, a site use factor (SUF), calculated as the area of suitable habitat on the site divided by the home range, is typically used to adjust the exposure.

- **Seasonal considerations**. Some species are migratory and only spend a portion of the year in an area. Upper trophic level receptors are typically selected and exposures calculated based upon the breeding season. This is because reproduction is often emphasized as the toxicological endpoint in ERAs, and reproductive effects are generally most relevant to population-level effects (especially when extrapolated from individual-level responses).
- **Bioaccumulation and bioavailability considerations.** Bioaccumulation and bioavailability may vary across the site based upon variability in factors that influence these functions, such as pH, total organic carbon (TOC), grain size, and acid-volatile sulfide/simultaneously extracted metals (AVE/SEM). The influence may be direct (through binding or otherwise limiting bioavailability) or indirect (by influencing the form of the chemical to a species that is less toxic). Although most receptors are not expected to perceive or respond directly to differences in bioavailability of chemicals, they will respond to physical or chemical features of the habitat known to influence bioavailability. For example, a given receptor may prefer a certain range of pH, TOC, or grain size, and so may indirectly increase or decrease exposure to chemicals in microhabitats.
- Depositional or Accretional Areas. The processes of erosion and deposition of sediment creates a patchwork of unconsolidated substrates throughout coastal Hawai‘i. Physical characteristics of the sediment particles, such as grain size and associated organic carbon, play a substantial role in the fate and transport, bioavailability, and toxicity of contaminants in the marine environment. Many chemicals that cause ecological effects (such as metals, pesticides, PCBs) are known to be associated most strongly with finer-grained sediment, especially silts and clays (also called “muds”) (Morrison et al. 2011). Fine-grained sediments generally accumulate in coastal bays and other sites where wave energy is low or absent. Contaminant concentrations are expected to be highest in such depositional areas where particles smaller than 62.5 µm accumulate (NRC 1989, Grabe and Barron 2004). In contrast, sites with predominantly sand or gravel are less likely to contain toxic levels of contaminants (Morrison et al. 2011). The U.S. Geological Survey (USGS) has conducted numerous studies of natural processes that affect erosion and deposition in Hawai‘i. Geophysical processes affect not only where sediments accumulate, but also how receptors are exposed to contaminated sediments. See (Fletcher et al. 2012) for a summary of discussion of depositional and erosional areas in Hawai‘i.

The vertical extent of a DU is defined by the depth to which ecological receptors are typically exposed (HDOH 2018). For sediment, the depth of samples to evaluate ecological exposures should generally be from the sediment surface down to the redox boundary, which generally defines the biologically active zone. This is generally no deeper than 5 to 15 cm in marine systems.

[Additional guidance on defining DUs for ERAs in Hawai‘i is under development.]

APPENDIX 21-D
Habitat Profiles

Key Habitats and Species in Hawai‘i
Mudflats/Coastal Wetlands/Lagoons



Freshwater and Brackish

Representative Location	Kāne‘ohe Bay (represented above); other principal mudflats occur in Mamala Bay and Pearl Harbor		
Sediment Characteristics	Well-sorted, fine-grained		
Wave Energy	Low		
Typical Species	Common Name	Hawaiian Name	Scientific Name
Birds	Black-crowned night-heron	‘Auku‘u	*Nycticorax nycticorax hoactli*
Fish	Scalloped hammerhead shark (nursery)	Manō kihikihi	*Sphyrna lewini*

	Broad stingray (nursery) 	lupe	*Dasyatis lata*
	Gobies	not known	Gobiidae
Benthic Invertebrates	Alpheid shrimps	not known	*Alpheus malabaricus*
	Portunid crabs	not known	*Podophthalmus vigil, Libystes villosus*
	Stomatopods	not known	*Oratosquilla oratoria, Gonodactylaceus falcatus, Pseudosquilla ciliata*
	Polychaetes	not known	*Neanthes* spp.
Plants	Bulrushes	not known	*Schoenoplectus spp.*
	Panic grass (invasive)	not known	*Panicum purpurascens*
	Pickleweed (invasive)	not known	*Batis maritima*
	Green algae	limu	*Ulva, Enteromorpha*
	Seagrasses	not known	*Halophila Hawaiiana and H. decipiens*
Threatened or Endangered Species			
Sea Turtles	Green turtle	Honu	*Chelonia mydas*
Birds	Hawaiian stilt	Ae'o	*Himantopus mexicanus knudseni*
	Hawaiian coot	'Alae Ke'oke'o	*Fulica alai*
	Hawaiian duck	Koloa maoli	*Anas wyvilliana*
	Hawaiian common moorhen	'Alae 'Ula	*Gallinula chloropus sandvicensis*

Photo Credits:
Kāneʻohe Mudflat: http://lovelyHawaiʻi.blogspot.com/2009/05/kaneohe-bay-low-tide-sunrise.html
Dasyatis lata: http://en.wikipedia.org/wiki/Broad_stingray

Key Habitats and Species in Hawaiʻi

Rocky Intertidal and Tide Pools



High Wave Energy



Low Wave Energy

Representative Location	Shorelines of all islands where constant wave action, currents, steep submarine slopes, and a lack of offshore sand reservoirs limit the accumulation of sand. ʻĪlio Point on Hawaiʻi is a typical high-energy tide pool habitat.		
Sediment Characteristics	Little sediment where wave energy is high; accumulation of fine sediment may occur where wave energy is low		
Wave Energy	Various		
Typical Species	Common Name	Hawaiian Name	Scientific Name
Birds	Black-crowned night-heron	ʻAukuʻu	*Nycticorax nycticorax hoactli*
Fish	Hawaiian Flagtail	Aholehole	*Kuhlia sandvicensis*
	Convict Tang	Manini	*Acanthurus triostegus*
	Zebra rockskipper	Pao ʻo	*Istiblennius zebra*
	Gobies	Not known	Gobiidae
Benthic Invertebrates	Hawaiian Limpet	opihi	*Cellana exarata*
	Helmet Urchin	haukeuke kaupali	*Colobocentrotus atratus*
	Gastropods	Not known	*Littoraria pintado, Siphonaria normalis, Nerita picea, and Morula granulata*
	Samoan crab	Not known	*Scylla serrata*
	Day Octopus	Not known	*Octopus cyanea*
	Polychaetes	Not known	*Neanthes* spp.
Plants	Sea lettuce	Not known	*Ulva fasciata; Ulva reticulata*
	Green Algae	Not known	*Halimeda, Neomeris, Caulerpa*
	Red algae	Not known	*Hydrolithon, Melanamansia, Pterocladiella, Jania*
	Brown algae	Not known	*Padina, Turbinaria, Dictyota*
Threatened or Endangered Species			
Sea Turtles	Green turtle	Honu	*Chelonia mydas*
Birds	Hawaiian stilt	Ae'o	*Himantopus mexicanus knudseni*

Photo Credits:
Low Wave Energy: Tidepools at Maui, Puhilele Pt Haleakala National Park by Forest & Kim Starr. Licensed under Public

domain via Wikimedia Commons. https://commons.wikimedia.org/wiki/File:Starr_040423-0115_Scaevola_taccada.jpg
High Wave Energy: Exposed wave-cut platform in bedrock.
ftp://ftp.nodc.noaa.gov/pub/data.nodc/coris/data/NOAA/nos/EnvironmentalSensitivityIndices/Hawaii/ESI_DATA/INTRO.PDF

Key Habitats and Species in Hawai‘i

Coastal Fishponds



He‘eia Fish pond



Moli‘i Fish Pond

Representative Location	Mamala Bay, Pearl Harbor, several around Kāne‘ohe Bay (above), and three on the southwestern coast of Kaua‘i		
Sediment Characteristics	Surface layer of fine-grained sediment and underlying coarse grains.		
Wave Energy	Low		
Typical Species	Common Name	Hawaiian Name	Scientific Name
Birds	Black-crowned night-heron	‘Auku‘u	*Nycticorax nycticorax hoactli*
	Northern Shovelers	Koloa Moha	*Anas clypeata*
Fish	Striped Mullet	Ama ama	*Mugil cephalus*
	Milkfish	Awa	*Chanos chanos*
	Hawaiian Flagtail	Aholehole	*Kuhlia sandvicensis*
Benthic Invertebrates	Hawaiian Oysters	not known	*Dendrostrea sandvicensis*
	Anchialine shrimp	Opae ‘ula	*Halocaridina rubra*
	Samoan Crab		*Scylla serrata*
Plants	Seaweed	Limu	Numerous species
	Rock-dwelling algae		
	Pickleweed (invasive)	not known	*Batis maritima*
	Red Mangrove (invasive threatens habitat conversion)	not known	*Rhizophora mangle*
	Seagrasses	not known	*Halophila Hawaiiana and H. decipiens*
	Red Algae (invasive)	not known	*Acanthophora spicifera*
Threatened or Endangered Species			
Sea Turtles	Green turtle	Honu	*Chelonia mydas*

Birds	Hawaiian stilt	Ae'o	*Himantopus mexicanus knudseni*
	Hawaiian coot	'Alae Ke'oke'o	*Fulica alai*
	Hawaiian duck	Koloa maoli	*Anas wyvilliana*
	Hawaiian common moorhen	'Alae 'Ula	*Gallinula chloropus sandvicensis*

Photo Credits:
Moli'i Fishpond by Joel Bradshaw. Licensed under Public domain via Wikimedia Commons.
https://commons.wikimedia.org/wiki/Category:Molii_Fishpond#/media/File:Oahu-Moliifishpond-rockwall.JPG
He'eia Fishpond: https://fishpondfever.wordpress.com/about/

Key Habitats and Species in Hawai'i

Seagrass Beds





Representative Location	Inner reef flats of south Moloka'i; 'Anini (Kaua'i); near Mamala Bay and Kāne'ohe Bay		
Sediment Characteristics	Seagrass can inhabit various sediment types including silt, mud, sand, gravel, rock		
Wave Energy	Various		
Typical Species	Common Name	Hawaiian Name	Scientific Name
Birds	Black-crowned night-heron	'Auku'u	*Nycticorax nycticorax hoactli*
Fish	Striped Mullet	Ama ama	*Mugil cephalus*
	Hawaiian Flagtail	Aholehole	*Kuhlia sandvicensis*
Benthic Invertebrates	Sea cucumbers	loli okuhi kuhi	*Holothuria atra*
	Hawaiian gastropod	not known	*Smaragdia bryanae*
	Polychaetes	not known	*Neanthes* spp.
Plants	Seagrasses	not known	*Halophila Hawaiiana and H. decipiens*
	Green Algae/Mudweed (invasive)	not known	*Avrainvillea amadelpha*
	Sea lettuce	not known	*Ulva reticulata*
	Green Algae	not known	*Halimeda discoidea*
	Red algae	not known	*Spyridia filamentosa*

Threatened or Endangered Species			
Sea Turtles	Green turtle	Honu	*Chelonia mydas*
Birds	Hawaiian coot	'Alae Ke'oke'o	*Fulica alai*
	Hawaiian common moorhen	'Alae 'Ula	*Gallinula chloropus sandvicensis*

Photo Credits:
Left: Seagrass. Halophila Hawaiiana. LIMU Species List 2005. University of Hawai'i's Marine Option Program Summer Course Quantitative Underwater Ecological Surveying Techniques (QUEST). LIMU Species List 2005. http://www.kmec.uhh.Hawaii.edu/QUESTInfo/limujs/Limulist/LIMU%20Species%20List%202005JS.htm
Right: http://coconutislandnews.blogspot.com/2012/03/Hawaiian-seagrass-not-your-average.html

Key Habitats and Species in Hawai'i
Mixed Sediment Bays and Harbors



Representative Location	Pearl Harbor		
Sediment Characteristics	Soft sediment overlaid on limestone platform of fossil reef origin; soft sediments often composed of carbonate grains derived from coralline algae, coral, mollusk fragments, foraminiferans, and tests of bryozoans and echinoderms		
Wave Energy	low		
Typical Species	Common Name	Hawaiian Name	Scientific Name
Birds	Black-crowned night-heron	'Auku'u	*Nycticorax nycticorax hoactli*
	Bristle-thighed curlew	Kioea	*Numenius tahitiensis*
	Pacific golden plover	*klea*	*Pluvialis dominica fulva*
	Brown booby	Not known	*Sula leucogaster plotus*
	Black noddy	noio, 'eki'eki	*Anous minutus melanogenys*
Fish	Hawaiian Flagtail	Aholehole	*Kuhlia sandvicensis*
	yellowfin goatfish	Weke, weke'ula	*Mulloidicthyes vanicolensis*
	Mozambique Tilapia (invasive)	Not known	*Oreochromis mossambicus*
	Gobies	Not known	*Gobiidae*

	Hawaiian anchovy	Nehu	*Enchasicholina purpurea*
	Striped Mullet	Ama ama	*Mugil cephalus*
Benthic Invertebrates	White crab	Kuahonu	*Portunus sanguinolentus*
	Samoan crab	Not known	*Scylla serrata*
	Hooded oyster *(invasive)*	Not known	*Saccostrea cucullata*
	Hawaiian rock oyster	Not known	*Ostrea sandvichensis*
	Soft bodied sea cucumber	Not known	*Ophiodesoma spectabilis*
	Day Octopus	he‘e	*Octopus cyanea*
	Polychaetes	not known	*Neanthes* spp.
Plants	Pickleweed (invasive)	not known	*Batis maritima*
	Red Mangrove (invasive)	not known	*Rhizophora mangle*
	Sea lettuce	not known	*Ulva reticulata*
Threatened or Endangered Species			
Sea Turtles	Green turtle	Honu	*Chelonia mydas*
Birds	Hawaiian stilt	Ae'o	*Himantopus mexicanus knudseni*
	Hawaiian coot	'Alae Ke'oke'o	*Fulica alai*
	Hawaiian duck	Koloa maoli	*Anas wyvilliana*
	Hawaiian common moorhen	'Alae 'Ula	*Gallinula chloropus sandvicensis*
	white tern	Manu-o-Kū	*Gygis alba rothschildi*

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Aerial view of Pearl Harbor. https://en.wikipedia.org/wiki/Pearl_Harbor

APPENDIX 21-E
Evaluating Bioaccumulative Chemicals

Evaluation of Risks of Bioaccumulative Chemicals

A bioaccumulative chemical is one that is taken up and retained for some duration by a living organism; the chemical may or may not have a measurable adverse effect on the organism in which it is measured. Once an organism incorporates a chemical into its tissues, the organism becomes a secondary source of contamination to other organisms that feed on it.

The terms bioconcentration, bioaccumulation, and biomagnification are sometimes used interchangeably in the literature; however, each describes a specific process, as described below (based on USEPA 2000i).

- ***Bioconcentration*** - the process by which there is a net accumulation of a chemical directly from water into aquatic organisms resulting from simultaneous uptake (e.g., by gill or epithelial tissue) and elimination.
- ***Bioaccumulation*** - the accumulation of a chemical in the tissue of organisms through any route, including respiration, ingestion, or direct contact with contaminated water, sediment, or sediment pore water.
- ***Biomagnification*** - the net result of the process of bioconcentration and bioaccumulation by which tissue concentrations of bioaccumulated chemicals increase as the chemical passes up through two or more trophic levels. The term implies an efficient transfer of chemicals from food to consumer, so that residue concentrations increase systematically from one trophic level to the next. (The movement of contaminants from prey to predator is called trophic transfer.)

Chemicals known to bioaccumulate may also cause direct toxicity to organisms exposed through simple ingestion or direct contact with sediment or water. For example, some invertebrates are adversely affected by direct exposure to copper in water and sediment. Organisms that are less susceptible to direct effects may survive and grow, incorporating the copper into their tissues. At some tissue concentration, which may be well above the sediment concentration the organism was initially exposed to, the accumulated copper may begin to exert a toxic effect on the organism. Additionally, the organism (and its tissue burden of copper) has become a concentrated source of copper to its predator. Thus, copper must be evaluated for both its direct effects and as a bioaccumulating chemical. The relative importance of direct effects versus effects resulting from bioaccumulation varies by species and chemical, as some species are capable of regulating, transforming, or eliminating some chemicals.

Most sources agree on the basic list of bioaccumulative chemicals derived from decades of empirical evidence (see Table 21-7). Several metals (arsenic, copper, lead, mercury, and zinc); most if not all organochlorine pesticides (DDT, chlordane, endrin, dieldrin); PCBs; dioxins/furan; and some PAHs are considered bioaccumulative under most circumstances and are included as such in this guidance.

These bioaccumulative chemicals share several traits: (1) hydrophobicity (excluding metals); (2) log K_{ow} > 3.5; (3) documented tissue concentrations under many environmental conditions; and (4) empirical evidence of toxicological effects of tissue concentrations (ODEQ 2017; ACOE et al. 2016). Note that it is possible, although unlikely, to measure elevated concentrations of a bioaccumulative chemical in tissues without detecting the chemical in collocated sediment or water samples. This could occur under conditions of high bioavailability of the chemical in the sediment or water, coupled with high laboratory detection limits. Alternatively, the organism could have accumulated the chemical from a different location. The HEER Office ERA Guidance is designed to identify areas where risk is likely, and so focuses on sediment sites with measurable concentrations of target contaminants.

Predicting the bioaccumulative potential of a chemical not listed in any of the references cited below is less straightforward and subject to nuances of chemistry and physiology. The risk assessor is responsible for designating the bioaccumulation potential of each chemical detected at the site and providing rationale for the designation. Generally, all chemicals on Table 21-7 are considered bioaccumulators, and any other chemical with a log K_{ow} greater than 3.5 must be discussed with the HEER Office (note that log K_{ow} is not a reliable predictor of bioaccumulation for organotins). Suggested references for developing a list of

bioaccumulative chemicals include Beyer et al., 2011; Hoffman 2007; ODEQ 2017; Northwest Regional Sediment Evaluation Team (RSET 2016); USEPA 2000i.

Steps for Evaluating Risks of Bioaccumulative Chemicals

The SLERA (described in Section 21) evaluated direct effects of bioaccumulating chemicals. If the direct effects are nonlethal and the organism incorporates the chemical into its tissues, indirect effects may occur. This subsection describes the process of evaluating risk of bioaccumulating chemicals within the tissues of living organisms, both to the organism itself and to its predators. The evaluation of such indirect effects of bioaccumulating chemicals is more complex because the physiology of the target organisms must be taken into account.

The HEER Office encourages the risk assessor to use existing information to the extent possible, and to conduct a focused field investigation when necessary to fill gaps in essential data. Close coordination with the HEER Office will ensure that data collection efforts are appropriate to support an ERA. The eight steps below describe essential components of the ERA for bioaccumulating chemicals. However, each ERA is necessarily tailored to an individual site.

- Step 1 – Identify Potential Bioaccumulative Chemicals
- Step 2 - Determine Likely Exposure Pathways
- Step 3 – Compare Site-Specific Concentrations with Background/Reference/Ambient Concentrations
- Step 4 – Compile Screening Level Data for Bioaccumulating Chemicals
- Step 5 – Compile Toxicity Reference Values (TRV)
- Step 6 – Identify Chemicals of Potential Ecological Concern (COPEC)
- Step 7 - Determine the Need for Additional Information
- Step 8 – Conduct a Site-Specific Bioaccumulation Investigation

Step 1 – Identify Potential Bioaccumulative Chemicals

The *ERA Scoping Checklist* requests information on chemicals detected or suspected at the site, and asks whether any of the chemicals are bioaccumulative. If any chemicals listed in Tables 21-B-1 or 21B-3 are known to bioaccumulate (based on Table 21-7 or other source), then it is necessary to complete this evaluation.

If the bioaccumulative status of any chemical at the site is unknown, the risk assessor should use the published literature to determine the potential bioaccumulative properties of the chemical. For example, the *Technical Support Document for Revision of the Dredged Material Management Program Bioaccumulative Chemicals of Concern List* (Hoffman 2007) provides four groups of chemicals with shared bioaccumulative properties:

- List 1 – Primary Bioaccumulative Chemicals of Concern (Table 9 in [Hoffman 2007])
- List 2 – Candidate Bioaccumulative Contaminants (Table 10 in [Hoffman 2007])
- List 3 – Potentially Bioaccumulative Contaminants (Table 11 in [Hoffman 2007])
- List 4 – Not Currently Considered Bioaccumulative Contaminants (Table 12 in [Hoffman 2007])

Although some of the discussion of chemicals in Hoffman (2007) pertains to regional ambient concentrations, most of the logic for identifying bioaccumulating chemicals is relevant to marine sediments sites in Hawai‘i.

The Northwest Regional Sediment Evaluation Team, (RSET 2016) modified the lists in Hoffman (2007) to remove some of the metals that are not known to occur in organic forms. The chemicals on Lists 1, 2, and 3 in Appendix C of Northwest Regional Sediment Evaluation Team, (RSET 2016) provide a reasonable starting point for evaluating chemicals not on Table 21-7 of the HEER Office guidance. New chemicals should be considered bioaccumulative based on the following considerations:

- A site-related chemical not included on any of the lists discussed above should be considered bioaccumulative if
    - its Log K_{ow} is greater than 3.5; or
    - it has been demonstrated to bioaccumulate in living organisms.

Step 2 - Determine Likely Exposure Pathways

The exposure pathways should have been described in the conceptual site model (CSM) during a previous phase of the ERA. The exposure pathways for bioaccumulating chemicals may be refined at this time to focus on the likely routes of uptake by

target receptors. Note that some information on diet and sediment ingestion is included in the species profiles in Appendix 21A. The risk assessor should supplement the information using the published literature as needed.

Step 3 – Compare Site-Specific Concentrations with Background/Reference/Ambient Concentrations

The uncertainty associated with evaluating bioaccumulating chemicals stems in part from the complexity of trophic transfer, which includes processes that are difficult to measure or observe, including uptake, biotransformation, sequestration, depuration, and excretion. In most cases, measuring in-situ trophic transfer is beyond the scope of an ERA. Modeling necessarily relies on conservative assumptions, which drives the protective screening level toward zero. It is not uncommon for a calculated screening level to be lower than background/ambient/reference concentrations, calling into question the legitimacy of the ERA. Rather than allow conservative exposure assumptions of BCFs, BSAFs, and toxicity thresholds to drive the ERA, the HEER Office recommends first refining the list of bioaccumulative chemicals by comparing site concentrations with background/ambient/reference concentrations.

The HEER Office is currently compiling background/ambient/reference concentrations of sediment and tissue from published reports across Hawai‘i. Ideally, the risk assessor will be able to search the database by habitat, chemical, species, and other variable to locate sediment and tissue concentrations considered representative of background/ambient/reference concentrations. Until that database is available, the risk assessor should discuss the need for collecting background/ambient/reference samples as part of the ERA.

In general, a minimum of three background/ambient/reference samples should be collected during the site-specific investigation. The samples should be collected from an area with similar sediment and wave energy that is believed not to be impacted by the chemicals under investigation at the site or any direct chemical release. The proposed reference locations should be discussed with the HEER Office early in the process to ensure that the samples are acceptable and representative.

Step 4 – Compile Screening Level Data for Bioaccumulating Chemicals

Evaluation of bioaccumulating chemicals may include comparing site-specific concentrations in tissue, sediment, and water with regional reference areas and/or toxicity-based screening levels, as described below. The risk assessor should compile information relevant to the site based on habitat, species, and chemicals. Include bioaccumulation factors, laboratory bioaccumulation tests, and other available information to provide regional context for the site.

Tissue Screening Level: Critical Body Residues

A critical body residue is a chemical concentration in a tissue (or whole body) that is considered protective of the receptor that accumulates the chemicals through exposure to sediment, water, and/or prey. As described below for sediment screening levels for bioaccumulating chemicals, CBRs taken from the published literature may or may not be appropriate for use at coastal marine sites in Hawai‘i. The use of CBRs in ERAs is relatively undeveloped and heavily reliant on temperate North American species and locations. The process of deriving CBRs described in Appendix E of Northwest Regional Sediment Evaluation Team, (RSET 2016) is technically sound, but the resulting values are not necessarily appropriate for sites in Hawai‘i. Moreover, in many cases back-calculating protective sediment concentrations from CBRs yields sediment screening levels that are lower than ambient concentrations. The HEER Office does not support any method that results in suggesting remediation of sediments that are already within background concentrations.

In lieu of adopting CBRs from temperate sites, the HEER Office recommends that site-specific tissue concentrations be compared with concentrations from either a pre-approved local reference location or from published studies in Hawai‘i. The species profiles presented in Appendix 21A provide some data on tissue concentrations reported in other studies. The HEER Office continues to collect and compile relevant data from across the state to support this element of the ERA Program.

Sediment Screening Levels for Bioaccumulating Chemicals

The sediment screening level for a bioaccumulating chemical is a concentration in sediment considered to pose little to no risk to ecological receptors exposed to the sediment. At concentrations less than the screening level, bioaccumulation is expected to be low enough to allow the receptor to live in the sediment without experiencing adverse effects caused by bioaccumulation of the chemical In principle, the screening level concentrations in sediment should ensure that the receptor would not bioaccumulate the chemical to concentrations greater than the CBR of any target receptor.

Development of a sediment screening level for a bioaccumulating chemical requires that a biota-sediment accumulation factor (BSAF) be used to model the accumulation of the chemical in an organism based on the sediment concentration. Although theoretically possible, development of BSAFs is a complicated process that is influenced by numerous factors such as the developmental stage, age, sex, reproductive state, and condition of the receptor; physico-chemical features of the sediment such as organic carbon content, pH, salinity, redox, and temperature); and the form of the chemical present in the sediment. BSAFs reported in the literature can vary widely and are not reliably transferred from one site to another, especially from

temperate fluvial habitats to tropical marine habitats. Few BSAFs are available for species and habitats in Hawai‘i. For these reasons, the HEER Office does not recommend the use of literature-based BSAFs to estimate tissue concentrations unless the BSAF was derived from a regionally-appropriate study. Therefore, the HEER Office is not providing sediment screening levels for bioaccumulating chemicals at this time. The risk assessor may conduct studies as needed to develop site-specific BSAFs or measure tissue concentrations directly at the site.

Surface Water Screening Levels

Surface water screening levels for bioaccumulating chemicals are similar to the sediment screening levels described above. Development of a surface water screening levels for a bioaccumulating chemical requires that a bioconcentration factor (BCF) be used to model the accumulation of the chemical in an organism based on the concentration in surrounding water. However, species and site-specific water quality conditions (pH, temperature, conductivity, and other water quality parameters) influence the value of the BCF. Moreover, most bioaccumulative chemicals are hydrophobic (not water soluble) and are not often detected in surface water. The dynamic movement of water, especially in coastal Hawai‘i, further complicates the link between water concentrations and tissue concentrations. Finally, chemical concentrations in surface water are spatially and temporally more variable than in sediment, as water is influenced by rainfall, suspended and dissolved solids, and other factors. The HEER Office does not provide surface water screening levels for bioaccumulating chemicals. The risk assessor may provide literature supporting the use of existing BCFs at the site or propose site-specific studies in support of BCF derivation.

Step 5 – Compile Toxicity Reference Values

A TRV is a chemical dose, given in mg of chemical per kg body weight per day; it is used to evaluate risk to a receptor ingesting bioaccumulative chemicals in sediment, water, and prey. Most TRVs are derived from laboratory studies of a few standard test species measuring effects on growth, reproduction, and mortality. Although the ideal TRV is specific to a chemical-receptor pair that occurs at the site, data limitations generally require the risk assessor to apply a general TRV to an entire class of receptors, such as birds or mammals. The HEER Office has compiled TRVs for some receptors and chemicals (see Appendix 21-A). The risk assessor is responsible for reviewing the available information and supplementing it as needed with current toxicological data from the published literature. The risk assessor should prepare a list of proposed TRVs, with rationale, for review by the HEER Office.

Step 6 – Identify Chemicals of Potential Ecological Concern (COPEC)

The decision process below should be applied to each chemical separately to identify which bioaccumulating chemicals will be retained as chemicals of potential ecological concern (COPEC) for further evaluation in the ERA.

- Are site sediment concentrations greater than background/ambient/reference concentrations?
    - If no, the chemical is not retained as a COPEC.
    - If yes, the chemical is retained as a COPEC.
    - If no background/ambient/reference concentrations are available, the chemical is retained as a COPEC and additional investigation may be required. Consult with the HEER Office.
- Are site tissue concentrations greater than background/ambient/reference concentrations?
    - If no, the chemical is not retained as a COPEC.
    - If yes, the chemical is retained as a COPEC.
    - If no background/ambient/reference concentrations are available, the chemical is retained as a COPEC and additional investigation may be required. Consult with the HEER Office.
- Are site tissue concentrations greater than all CBRs?
    - If no, the chemical is not retained as a COPEC.
    - If yes, the chemical is retained as a COPEC.
    - If no CBRs are available, the chemical is retained as a COPEC and additional investigation may be required. Consult with the HEER Office.

Note that this decision process will be modified if and when screening levels for bioaccumulating chemicals in sediment and surface water become available.

Step 7 - Determine the Need for Additional Information

To proceed with the ERA for bioaccumulating chemicals, the following information is required:

- List of COPECs (specific to each receptor or group of receptors)

- Exposure point concentration for each COPEC in each medium (sediment, prey items)
- CBRs for target receptors
- TRVs for target species-chemical pairs (for example marine mammal – PCBs)
- Values for key exposure parameters for target receptors, such as body weight, ingestion rates for food and sediment, diet, site use factors, and others (see Subsection 21.3.4.3)

If any of the information above is unavailable and cannot be estimated using literature values relevant to Hawai‘i, additional site-specific work may be required before the ERA can be completed.

Step 8 – Conduct a Site-Specific Bioaccumulation Investigation

When a bioaccumulating chemical is present at a site at concentrations greater than regional background/ambient/reference concentrations, the most efficient way to evaluate risk of the chemical is to measure its bioaccumulation in target receptors at the site that have small home ranges (if the receptors are not legally protected). If site-specific tissue cannot be obtained, tissue concentrations may be estimated using concentrations in sediment and BSAFs, when available. Alternatively, laboratory bioaccumulation tests of site sediment samples can provide tissue concentrations and BSAFs for benthic invertebrates. A detailed sampling and analysis plan should be submitted to the HEER Office for review to ensure that any field sampling effort addresses the necessary requirements for an ERA. At a minimum, the following components of field sampling should be addressed in the sampling and analysis plan:

Sediment Sampling

- Depth of samples (should reflect exposure of target receptors)
- Number of sediment samples (minimum = 5)
- Multi Increment sampling (MIS) and decision unit (DU) design (see Appendix 21-C and TGM Sections 3, 4, and 5).

Biota Sampling

- Target receptors (should be relevant to CSM and linked to existing reference data, if possible)
- Rationale for selection of species (e.g. small home range, known to accumulate the chemical, availability of background/ambient/reference tissue concentrations, etc.)
- Number of samples (minimum = 5 site; 3 reference)
- Sample composition: composite vs individuals; age; sex; size/length; reproductive condition
- Sample processing methods (e.g. whole body, specific organs, muscle only, etc.)
- Seasonal considerations
- MIS and DU considerations
- Chemical/physical analyses; percent moisture; percent lipid

Laboratory Bioaccumulation Study

- Number of samples (minimum = 7 site)
- Method for selecting samples (ensure a concentration gradient)
- Test species relevant to Hawai‘i (e.g. *Neanthes arenaceodentata* polychaete)
- Method for calculating the BSAF
- Duration of test
- Sample processing methods (depuration)
- MIS and DU considerations
- Chemical/physical analyses of sediment and tissue; percent moisture and percent lipid in tissue

APPENDIX 21-F
Background/Ambient/Reference Concentrations Evaluating Bioavailability

Background/Ambient/Reference Concentrations

See Subsection 21.3.5.1. Additional information on background concentrations is being compiled by the HEER Office, and this information will be made available in the future.

Evaluating Bioavailability

In the initial steps of the SLERA, it is assumed that chemicals are 100 percent bioavailable. Refinement of this conservative assumption requires site-specific information. Total organic carbon (TOC) and grain size distribution data should be collected during the site investigation, so the potential bioavailability of the chemicals can be evaluated in the refinement step (Step 3a). These parameters should also be evaluated during the background comparison to determine whether the background sediment has similar physical characteristics as the site sediment because TOC and grain size can influence the amount of chemicals accumulating in sediment, as discussed below.

Very little debate remains over the role of grain size in influencing bioavailability. In general, finer-grained sediments have a proportionately higher number of binding sites (based strictly on increased surface area) than coarser-grained sediments. When fine-grained particles are ingested by an organism, a relatively higher dose of the chemical is also ingested.

The other hand, there are conflicting views on whether toxicity to sediment invertebrates is correlated with TOC. The tendency of PCBs, PAHs, and other organic chemicals (including mercury) to sorb to the organic carbon fraction is well documented and is used in equilibrium partitioning models to predict bioavailable fractions. However, the relationship between TOC and concentration of organic compounds is not as straightforward as the EqP models assume. For example, some studies have concluded that TOC normalization had little if any influence on the outcome of the screening process using the low sediment quality guidelines (McCready et al. 2006). Not all organic carbon is equally capable of binding organic chemicals; the type of organic carbon (humic matter particles, humic matter sorbed on mineral surfaces, animal and plant matter, combustion by-products) may also determine the strength of the association with organic compounds (Ghosh et al. 2003). Remediation engineers take advantage of the tendency of organic carbon to bind PCBs and apply specific types of activated organic carbon to sediments contaminated with PCBs, PCDD/Fs, and mercury as a means of reducing the bioavailability of chemicals to organisms (Millward Et al. 2005; Patmont et al. 2015; Gilmour et al. 2013).

It is recommended that TOC and grain size be analyzed in sediment ERAs so that the relationship can be independently tested in Hawai'i. If similar results are confirmed over time, this requirement may be modified or eliminated. Additional discussion of methods for measuring and interpreting results of grain size and TOC analyses is available in (Opel et al. 2011);

Under some conditions, chemical analysis of field-collected organisms can provide site-specific evidence of bioavailability of chemicals in sediment. Organisms should be resident at the site, relatively sessile, and exposed to sediment either through direct contact or ingestion of sediment (or both). Note that tissue concentrations will reflect exposure to chemicals in overlying water as well as sediment, potentially confounding data interpretation.

If tissue data are not available, chemical concentrations in food items can be calculated using sediment-to-fish and sediment-to-invertebrate BSAFs, as follows:

$$C_f \text{ (for metals)} = C_{sd} * BSAF$$

Where:

C_f = Contaminant concentration in food (mg/kg)
C_{sd} = Contaminant concentration in sediment (mg/kg)

BSAF = Biota-sediment bioaccumulation factor (unitless)

$$C_f \text{ (for organics)} = C_{sd} * \left(BSAF * \frac{\%L}{\%TOC} \right)$$

Where:

C_f = Contaminant concentration in food (mg/kg)
C_{sd} = Contaminant concentration in sediment (mg/kg)
BSAF = Biota-sediment bioaccumulation factor (for organics) (unitless)
%L = Percent lipids [species-specific value (dry weight)
%TOC = Percent total organic carbon (site-specific value)

For the SLERA, conservative exposure assumptions should be used for food chain models, such as:

- Maximum sediment concentrations
- Conservative receptor body weight and ingestion rates
- Assume that receptors obtain all of their food from the site (home range factor of 1.0)

Table 21F-1. Biota-Sediment Accumulation Factors for Fish and Invertebrates

Analyte	Sediment Invertebrate Bioaccumulation Factors			Fish Bioaccumulation Factors		
	Conservative	Average	Source	Conservative	Average	Source
Metals						
Arsenic	0.69	0.143	(ORNL 1998)	-		-
Copper	5.25	1.556	(ORNL 1998)	-		-
Lead	0.607	0.071	(ORNL 1998)	-		-
Mercury	2.868	1.136	(ORNL 1998)	-		-
Zinc	7.527	1.936	(ORNL 1998)	-		-
Pesticides/PCBs/Dioxins						
4,4'-DDD	-		-	0.28		(USEPA 2004)
4,4'-DDE	-		-	7.7		(USEPA 2004)
Total DDTs	-		-	7.7		(USEPA 2004)
Total Chlordanes	-		-	4.77		(USEPA 2004)
Dieldrin	-		-	1.8		(USEPA 2004)
Endrin	-		-	1.8		(USEPA 2004)
Total PCBs	6.41E+01	3.62E+01	(ORNL 1998)	(USEPA 2004)		(USEPA 2004)
2,3,7,8-TCDD	-		-	0.025		(USEPA 2004)
Semivolatile Organic Compounds						
Acenaphthene	-		-	0.29		(USEPA 2004)
Acenaphthylene	-		-	0.29		(USEPA 2004)
Anthracene	-		-	0.29		(USEPA 2004)
Benzo(a)anthracene	-		-	0.29		(USEPA 2004)
Benzo(a)pyrene	-		-	0.29		(USEPA 2004)
Chrysene	-		-	0.29		(USEPA 2004)

Dibenzo(a,h)anthracene	-	-	0.29	(USEPA 2004)
Fluoranthene	-	-	0.29	(USEPA 2004)
Fluorene	-	-	0.29	(USEPA 2004)
Naphthalene	-	-	0.29	(USEPA 2004)
Phenanthrene	-	-	0.29	(USEPA 2004)
Pyrene	-	-	0.29	(USEPA 2004)
Sum HMW PAHs	-	-	0.29	(USEPA 2004)
Sum LMW PAHs	-	-	0.29	(USEPA 2004)
Total PAHs	-	-	0.29	(USEPA 2004)

- no data
(ORNL 1998).
(USEPA 2004g).

Calculating Biota-Sediment Accumulation Factors

A BSAF for organic chemicals is a unitless ratio of the lipid-normalized wet weight concentration in tissue to the organic carbon-normalized concentration in surface sediment. For inorganic chemicals, the BSAF is a simple unadjusted ratio. BSAFs are transfer coefficients that relate chemical concentrations in biota to chemical concentrations in sediment (USEPA 2004g). In the BERA, site-specific tissue data (either from field-collected organisms or tissue samples from laboratory bioaccumulation tests) can be used to develop site-specific BSAFs. BSAFs are the ratio of chemical concentrations in tissue and chemical concentration in collocated sediment, as follows:

$$BSAF(metals) = \frac{\text{tissue concentration}}{\text{sediment concentration}}$$

Where:
BSAF(metals) = Biota-sediment accumulation factor for metals (unitless)
Tissue Concentration = Chemical concentration in tissue (mg/kg or µg/kg)
Sediment Concentration = Chemical concentration in sediment (mg/kg or µg/kg)

$$BSAF(organics) = \frac{\text{tissue concentration} / \%\text{lipids}}{\text{sediment concentration} / \%\text{TOC}}$$

Where:
BSAF(organics) = Biota-sediment accumulation factor for organics (unitless)
Tissue Concentration = Chemical concentration in tissue (mg/kg or µg/kg)
Percent Lipids = Percent lipids in tissue sample (%)
Sediment Concentration = Chemical concentration in sediment (mg/kg or µg/kg)
Percent TOC = Percent total organic carbon of the sediment (%)

Normalizing the tissue and sediment concentrations for the organic chemicals to percent lipids and TOC, respectively, is done because organic chemicals have a tendency to bind to lipids and organic carbon.

When field-collected invertebrate tissue concentrations are not available, BSAFs can be calculated using site-specific sediment concentrations and tissue concentrations measured in laboratory bioaccumulation tests. The BSAFs can then be used to estimate the concentrations of chemicals that could occur in invertebrates exposed to average concentrations in sediment in each DU. BSAFs incorporate the percent lipid in tissue and total organic carbon (TOC) in sediment to predict the total concentration in the prey tissue. Although separate site-specific BSAFS for each species of interest would be ideal, application of BSAFs derived for one laboratory invertebrate test species to other invertebrates within the study area is considered appropriate because BSAFs for benthic invertebrates have been shown to be relatively insensitive to interspecific variability (Tracey and Hansen 1996; Burkhard et al. 2010).

Differences in BSAFs in site samples and other sites reported in the literature may be explained by numerous physical, chemical, and biological factors. Bioaccumulation of PCBs and other compounds with high log K_{ow} may differ from what is predicted by equilibrium partitioning because sediment ingestion by the organism may enhance bioavailability in ways not accounted for by log K_{ow} and similar physico-chemical models (Sormunen et al. 2008). Empirical BSAFs derived from site-

specific samples are considered a reliable indicator of bioavailability of chemicals in sediment and a direct measure of bioaccumulation under laboratory conditions. The differences between estimated and field-derived BSAFs are lowest between the same species at different locations within a site, or different species at a single site. The extrapolation of BSAFs within or among species at distant unrelated sites decreases the reliability of the estimated BSAF (Burkhard et al. 2010).

Evidence for chemical uptake from sediment includes BSAFs greater than 1.0.

Numerous sources of uncertainty are associated with the derivation, application, and interpretation of benthic invertebrate BSAFs. (Judd et al. 2014) concluded a review of more than 200 BSAFs with words of caution against the over-reliance on BSAFs. In particular, BSAFs should not be extrapolated beyond the chemical concentration on which they were based because the relationship may not be linear. Likewise, the BSAF curve intercept may not be zero. Lastly, one of two outlier concentrations can skew the BSAFs. While an understanding of the influence of lipid concentration on BSAFs may improve the interpretation of bioavailability for some lipophilic compounds, in wild populations lipid concentrations can vary dramatically with season, diet, and reproductive stage (Beckvar and Lotufo 2011). Lipid-adjusted tissue concentrations are not reliably more predictive than standard wet weights for interpreting bioaccumulation *processes* or toxicity in wild organisms (Wenning et al. 2011). Nevertheless, investigators *require* some approach to measuring bioaccumulation, and BSAFs can be useful within the limits of these known liabilities (Judd et al. 2014).

A review of publications on bioconcentration factors and bioaccumulation factors for hundreds of organic compounds and test species concluded that field-derived BAFs may be higher than laboratory-derived BAFs (Arnot and Gobas 2006). Conversely, a more directly relevant side-by-side laboratory and in-situ comparison of BSAFs and BAFs using *Lumbriculus* reported that the two measures were comparable for PCBs (Beckingham and Ghosh 2010).

BSAFs based on field collected data will typically be less accurate that BSAFs derived from laboratory studies because the exposure point concentration for field collected organisms is less certain than it is for laboratory studies. For example, even though non-mobile organisms like mollusks live in the sediment, they are filter feeders and get their exposure from chemicals in the overlying water. While some of the contaminants in the overlying water may be from the adjacent sediment, in aquatic systems, water and sediment are transient so exposure will change over time. Therefore, sediment that is co-located with organisms collected in the field may not accurately represent exposure of the organisms. This is a much greater source of uncertainty with mobile organisms such as crabs and fish.

HDOH recommends that BSAFs should generally only be calculated for detected and non-rejected data. Non-detected data can be used to calculate average sediment concentrations over an exposure area (an MIS approach to sediment sampling reduces the likelihood of obtaining non-detect data), however, non-detected data should not be used to calculate BSAFs if either the tissue or sediment concentrations were non-detect.

APPENDIX 21-G
Sample Contents of A BERA Work Plan/Sampling and Analysis Plan and BERA Report

Contents of a BERA Work Plan/Sampling and Analysis Plan

(see Subsection 21.6.3 and Subsection 21.6.4 for guidance on preparing the BERA Report)

1.0 INTRODUCTION

2.0 REFINED PROBLEM FORMULATION

2.1 Environmental Setting, COPCs, and Receptors of Concern

2.2 Assessment and Measurement Endpoints

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2.4 Identification of Decision Units

3.0 STUDY DESIGN AND DATA QUALITY OBJECTIVE PROCESS

3.1 Data Quality Objectives
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MASTER REFERENCE LIST

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TGM for the Implementation of the Hawai'i State Contingency Plan
MASTER ACRONYM AND ABBREVIATION LIST

MASTER ACRONYM AND ABBREVIATION LIST

%	Percent
°C	Degree Celsius
°F	Degrees Fahrenheit
µg	Micrograms
µg/g	Micrograms per Gram
µg/kg	Micrograms per kilogram
µg/L	Microgram per Liter
µg/m^3	Micrograms per cubic meter
µm	Micrometers (micron)
≤	Less than or equal to
2,4,5-T	2,4,5-trichlorophenoxyacetic acid
2,4,5-TP	2,4,5-trichlorophenoxypropionic acid
2,4-D	Dichlorophenoxyacetic Acid
A	Hold time after extraction until analysis
ANZECC	Australian/New Zealand Environment and Conservation Council
APHA	American Public Health Association
API	American Petroleum Institute
ARAR	Applicable or relevant and appropriate requirements
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
ASTM	American Society for Testing and Materials
atm-m^3/Mol	Moles per cubic meter for air to moles per cubic meter for water
ATSDR	Agency for Toxic Substances and Disease Registry
AVS/SEM	Acid-volatile Sulfide and Simultaneously Extracted Metals
BERA	Baseline Ecological Risk Assessment
BGS	Below ground surface
BSAF	Biota-to-Sediment Accumulation Factor
BTEX	Benzene, toluene, ethylbenzene, and total xylenes
CAB	Clean Air Branch
CAD	Computer-Aided Design
CalEPA	California Environmental Protection Agency
CAO	Compliance Assistance Office
CAS	Chemical Abstract Service
CBR	Critical Body Residue
CCME	Canadian Council of Ministers of the Environment
CD	Compact-disc
CERCLA	Comprehensive Environmental Response, Compensation & Liability Act (also known as the Federal Superfund Law)
CFR	Code of Federal Regulations
cm	Centimeters
cm^3/g	cubic centimeters per gram
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COC	Chain-of-custody

COC	Contaminant of concern
COPC	Chemicals (or Contaminants) of Potential Concern
COPEC	Contaminant of Potential Environmental Concern
CPT	Cone Penetrometer Technologies
CSM	Conceptual Site Model
CSV	Comma separated values
CWA	Clean Water Act
CWB	Clean Water Branch
D	Discrete
D-D	A mixture of 1,2-dichloropropane; 1,3-dichloropropene; and 2,3-dichloropropene
DBCP	1,2-dibromo-3-chloropropane
DCE	Dichloroethene
DDT	dichloro-diphenyl-trichloroethane
Dioxins	Polychlorinated dibenzodioxins
DNAPL	Dense Non-Aqueous Phase Liquid
DoD	United States Department of Defense
DOT	U.S. Department of Transportation
DPE	Dual-phase extraction
DPT	Direct Push Technologies
DQA	Data Quality Assessment
DQO	Data Quality Objective
Draft RAM	Draft Response Action Memorandum
DSITMS	Direct Sampling Ion Trap Mass Spectrometry
DSMOA	DoD State Memorandum of Agreement
DTSC	Department of Toxic Substances Control
DU	Decision Unit
DVD	Digital video disk
E	Hold time to extraction
EAL	Environmental Action Level
EDB	1,2-dibromoethane
EHE	Environmental Hazard Evaluation
EHMP	Environmental Hazard Management Plan
EHSD	Environmental Health Services Division
EM	Electromagnetics
EMD	Environmental Management Division
EP&R	HEER Office Emergency Preparedness and Response Section
EPCRA	Emergency Planning and Community Right-to-know Act
EPDM	Ethylene propylene diene monomer
EPO	Environmental Planning Office
ER-L	Effects Range-Low
ER-M	Effects Range-Median
ERA	Ecological Risk Assessment
ERO	Environmental Resources Office
ESA	Endangered Species Act
ESA	Environmental Site Assessment
eV	Electron Volt
FFDs	Fuel Fluorescence Detectors
FID	Flame Ionization Detector
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act

Final RAM	Final Response Action Memorandum
FRTR	Federal Remediation Technologies Roundtable
ft	Feet
ft^2	Square feet
FTC	Fast Track Cleanup
FTP	File Transfer Protocol
Furans	Polychlorinated dibenzofurans
FWS	Fish and Wildlife Service
g	Gram(s)
GAC	Granulated activated carbon
GC	Gas Chromatograph
GC/MS	Gas Chromatography-Mass Spectrometry
GIS	Geographical Information System
GPR	Ground Penetrating Radar
GPS	Global Positioning Satellite
HAR	Hawai'i Administrative Rules
HASP	Health and Safety Plan
Hawai'i SCP	Hawai'i State Contingency Plan (HAR, Title 11, Chapter 451)
HAZWOPER	Hazardous Waste Operations and Emergency Response
HCIF	Hawai'i Chemical Inventory Form
HCl	Hydrochloric acid
HDLNR	Hawai'i Department of Land and Natural Resources
HDOA	Hawai'i Department of Agriculture
HDOH	Hawai'i Department of Health
HDPE	High density polyethylene
HDX	Octahydro-1,3,5,7-Tetranitro-1,3,5,7-Tetrazocine
HEER Office	Hazard Evaluation and Emergency Response Office
HEPCRA	Hawai'i Emergency Planning and Community Right-to-Know Act (HRS, Chapter 128E)
HERL	Hawai'i Environmental Response Law (HRS, Chapter 128D)
HHRA	Human Health Risk Assessment
HIOSH	Hawai'i Occupational Safety and Health
HMW	High Molecular Weight
HMX	Octogen (nitroamine explosive)
HNO_3	Nitric acid
HOCC	Hawai'i One Call Center
HQ	Hazard Quotient
HRS	Hawai'i Revised Statutes
HSA	Hollow-Stem Auger
HSERC	Hawai'i State Emergency Response Commission
HTTD	High-temperature thermal desorption
HVAC	Heating, Ventilating and Air Conditioning
HVOCs	Halogenated Volatile Organic Compounds
ID	Identity
IDW	Investigation-Derived Waste
IEQ	Indoor Environmental Quality
IEUBK	Integrated Exposure Uptake Biokinetic Model for Lead in Children
in Hg	Inches of Mercury
IRIS	Integrated Risk Information System
ISQG	Interim Sediment Quality Guideline

ITRC	Interstate Technology and Regulatory Council
K	Kelvins (the Kelvin scale is a thermodynamic temperature scale)
kg	kilogram
km	kilometer
Koc	organic carbon sorption coefficient
L	Liter
lb	Pound(s)
LCS	Laboratory control sample
LCSD	Laboratory control sample duplicate
LEL	Lower Explosive Limit
LEPC	Local Emergency Planning Committees
LIF	Laser-Induced Fluorescence
LIMS	Laboratory Information Management System
LMW	Low Molecular Weight
LNAPL	Light Non Aqueous Phase Liquid
LOAEL	Lowest Observed Adverse Effect Level
LOC	Letter of Completion
LTTD	Low-temperature thermal desorption
LUCIP	Land Use Controls Implementation Plan
LUCs	Land Use Controls
LVP	Large Volume Purge
m^3/mol	cubic meters per mole
MADEP	Massachusetts Department of Environmental Protection
MC	Munitions Contaminants
MCS	Modified California Sampler
MDL	Method Detection Limit
MDNR	Missouri Department of Natural Resources
mg/kg	Milligrams per kilogram
mg/L	Miligrams per liter
mg/m^3	Milligrams per cubic meter
MGP	Manufactured gas plants
MHI	Main Hawaiian Islands
MI	Multi Increment
MIBK	Methyl isobutyl ketone
MIP	Membrane Interface Probe
MIS	Multi Increment sample(s)
mL	Milliliter
MLE	Maximum Likelihood Estimation
mm	Millimeter
mm Hg	Millimeters of mercury
MOU	Memorandum of Understanding
MPE	Multi-phase extraction
MRBCA	Missouri Risk-Based Corrective Action
MS	Mass Spectrometer
MSD	Matrix spike duplicate
MSMA	monosodium methane arsenate
MTBE	Methyl tertiary butyl ether
MW	Molecular Weight
Na_2SO_4	Sodium bisulfate

NAD83	North American Datum 1983
NaOH	Sodium hydroxide
NAPL	Non Aqueous Phase Liquid
NaS_2O_3	Sodium thiosulfate
NAVFAC	Naval Facilities Engineering Command
NCEA	USEPA National Center for Environmental Assessment
NCP	National Contingency Plan
NEIWPCC	New England Interstate Water Pollution Control Commission
NELAC	National Environmental Laboratory Accreditation Conference
NFA	No Further Action
NIOSH	National Institute for Occupational Safety and Health
NJDEP	New Jersey Department of Environmental Protection
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOAEL	No Observed Adverse Effect Level
NPL	National Priorities List
NRC	National Response Center
NRDA	Natural resource damage assessment
NTP	National Toxicology Program
NTU	Nephelometric turbidity units
NWHI	Northwest Hawaiian Islands
NYDOH	New York Department of Health
O&M	Operation and maintenance
OC	Organic Carbon
OEQC	HDOH Office of Environmental Quality Control
OEQC	Office of Environmental Quality Control
OEQC	HDOH Office of Environmental Quality Control
One atmosphere	760 millimeters of mercury
OPA	Oil Pollution Act of 1990
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response
PAH	Polynuclear Aromatic Hydrocarbon
PARCC	Precision, accuracy, representativeness, completeness, and comparability
PCB	Polychlorinated Biphenyl
PCDDs/PCDFs	Polychlorinated Dibenzodioxins and Polychlorinated Dibenzofurans
PCE	Tetrachloroethylene
PCP	Pentachlorophenol
PDBE	Polybrominated Diphenyl Ether
PDF	Portable Document Format
PID	Photo Ionization Detector
POC	Purgeable organic compounds
POX	Purgeable organic halogens
ppb	Parts per billion
ppbv	Parts per billion by volume
PPE	Personal Protective Equipment
ppm	Parts per million
ppmv	Parts per Million by Volume
PQL	Practical Quantitation Limit

PRGs	Preliminary Remedial Goals
PRP	Potentially Responsible Party
PRP	Potentially Responsible Party
PTFE	Polytetrafluoroethylene
PUC	Public Utilities Commission
PVC	Polyvinyl chloride
QA	Quality Assurance
QA/QC	Quality Assurance and Quality Control
QAPP	Quality Assurance Project Plan
QAPP	Quality Assurance Project Plan
QC	Quality Control
RAA	Remedial alternatives analysis
RAM	Response Action Memorandum
RAR	Removal Action Report
RCRA	Resource Conservation and Recovery Act
RDX	Hexahydro-1,2,5-Trinitro-1,3,5-Triazine
redox	Reduction/oxidation
RFH	Radio frequency heating
RFI	RCRA (Resource Conservation and Recovery Act) Facility Investigation
RI	Remedial Investigation
RL	Reporting Limit
RME	Reasonable maximum exposure
ROST™	Rapid Optical Screen Tool
RPD	Relative percent difference
RPM	Remedial Project Manager
RSD	Relative standard deviation
RSL	Regional Screening Level
RWQCB	Regional Water Quality Control Board
SAP	Sampling and Analysis Plan
SBRC	Solubility Bioaccessibility Research Consortium
SCP	Hawai'i State Contingency Plan
SD	Standard deviation
SDAR	HEER Office Site Discovery, Assessment and Remediation Section
SDWA	Safe Drinking Water Act
SDWB	Safe Drinking Water Branch
SHWB	HDOH Solid and Hazardous Waste Branch
SIM	Selected ion mode
SLERA	Screening Level Ecological Risk Assessment
SOP	Standard Operating Procedure
SOSC	State On-Scene Coordinator
SPLP	Synthetic Precipitation Leaching Procedure
SPSH	Six-phase soil heating
SPT	Standard Penetrometer Test
SQG	Sediment Quality Guideline
SSCS	Site Specific Calibration Standard(s)
SSD	Subslab depressurization
SUF	Site Use Factor
SVE	Soil vapor extraction
SVOC	Semi-volatile organic compound

SW-846	USEPA publication entitled Test Methods for Evaluating Solid Waste, Physical/Chemical Methods
TBC	To-Be-Considered
TBT	Tributyltin
TCA	Trichlorethane
TCDD	Tetrachlorodibenzo-p-dioxin
TCE	Trichloroethylene
TCLP	Toxicity characteristic leaching procedure
TCP	1,2,3-trichloropropane
TEF	Toxicity Equivalence Factor
Telone	1,3-dichloropropene
TEQ	Toxic Equivalency
TGM	Technical Guidance Manual
THMs	Trihalomethanes
TMK	Tax Map Key
TNT	2,4,6-Trinitrotoluene
TOC	Total Organic Carbon
TOX	Total Organic Halogens
TPH	Total Petroleum Hydrocarbons
TPH-D	Total Petroleum Hydrocarbons-diesel range
TPH-G	Total Petroleum Hydrocarbons-gasoline range
TPH-O	Total Petroleum Hydrocarbons-oil range
TRV	Toxicity Reference Value
TSA	Transportation Security Administration
TSCA	Toxic Substances Control Act
TSD	Treatment, storage, and disposal
TVH	Total Volatile Hydrocarbons
TVH	Total Volatile Hydrocarbons
TWG	Technical Working Group
U.S.	United States
UCL	Upper Confidence Level
UCL_{95}	95 percent upper confidence limit on the mean concentration
UECA	Uniform Environmental Covenants Act (HRS, Chapter 508C)
UIPA	Uniform Information Practices Act
US Army	United States Department of the Army
US Navy	United States Department of the Navy
USACE	United States Army Corps of Engineers
USAFCEE	U.S. Air Force Center for Environmental Excellence
USCS	Unified Soil Classification System
USDA	United States Department of Agriculture
USDA-NRCS	United States Department of Agriculture, Natural Resources Conservation Service
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
USNFESC	U.S. Naval Facilities Engineering Service Center
UST	Underground Storage Tank
UTM	Universal Transverse Mercator
UV	Ultra Violet
VOA	Volatile organic analysis
VOC	Volatile Organic Compound
VRP	HEER Office Voluntary Response Program

VSP	Visual Sample Plan
WHO	World Health Organization
WWB	Wastewater Branch
XRF	X-Ray Fluorescence
yd^3	Cubic Yard

TGM for the Implementation of the Hawai'i State Contingency Plan
LOG OF TGM UPDATES

Technical Guidance Manual

LOG OF TGM UPDATES

This page updated: January 29, 2018

Section	Section Name	Issue Date	Comments	Status
1	Hazard Evaluation and Emergency Response Office Authorities, Responsibilities, and Organization	Nov 12, 2008		Interim Final, In Effect
2	Emergency Response and the Site Discovery, Investigation, and Cleanup Process under Hawai`i Administrative Rules Chapter 11-451, the State Contingency Plan	Nov 12, 2008		Interim Final, In Effect
	Appendix 2-A, Hazardous Substance Release Notification And Inventory Guideline	May 28, 2013		Interim Final, In Effect
3	Site Investigation Design and Implementation	Aug 2016		Interim Final, In Effect
	Appendix 3-A, Guidance for Soil Stockpile Characterization and Evaluation of Imported and Exported Fill Material	Oct 2017		Interim Final, In Effect
4	Decision Unit Characterization	Aug 2016		Interim Final, In Effect
5	Field Collection of Soil and Sediment Samples	Aug 2016		Interim Final, In Effect
6	Groundwater and Surface Water Sampling Guidance	Dec 31, 2008		Interim Final, In Effect
7	Soil Vapor and Indoor Air Sampling Guidance	Dec 2017		Interim Final, In Effect
8	Field Screening Methods	Jul 2017		Interim Final, In Effect
9	Supplemental Guidance for Select Contaminants of Concern	Apr 2014		Interim Final, In Effect
10	Data Quality Assurance and Quality Control (QA/QC)	Dec 31, 2008		Interim Final, In Effect
11	Handling and Analysis of Samples	Jul 2017		Interim Final, In Effect
12	Supplemental Analytical Guidance for Select Procedures			Pending
13	Environmental Hazard Evaluation	Sep 19, 2017		Interim Final, In Effect

14	Removal Actions	Jun 21, 2009		Interim Final, In Effect
15	Fast Track Cleanup	Feb 20, 2009		Interim Final, In Effect
16	Remedial Actions	Jun 21, 2009		Interim Final, In Effect
17	Site Cleanup Planning and Cleanup Options			Pending
18	Report Formats	Jun 21, 2009		Interim Final, In Effect
19	Site Closures	Apr 2014		Interim Final, In Effect
20	Additional Detail on Select HEER Office Programs			Pending
21	Related Environmental Program Regulations			Pending
	References		References included with (and updated with) individual TGM Sections	Link to the Master List of References

LOG OF UPDATES TO ADDITIONAL GUIDANCE DOCUMENTS

	Name	Issue Date	Comments	Status
	Guidance for Soil Stockpile Characterization and Evaluation of Imported and Exported Fill Material. Reference: HDOH 2017d	Oct 8, 2017	Listed in additional guidance documents.	Link *will open a new window.*
	Additional Notes on HDOH report Field Investigation of the Chemistry and Toxicity of TPH in Petroleum Vapors. Reference: HDOH 2012c	Oct 2012	Listed in additional guidance documents	Link *will open a new window.*
	Summary of Pesticide and Dioxin Contamination Associated with Former Sugarcane Operations. Reference: HDOH 2011d	Jun 2012	Listed in additional guidance documents.	Link *will open a new window.*
	Use of Decision Unit and Multi-increment Soil Sample Investigation Approaches to Characterize a Subsurface Solvent Plume. Reference: HDOH 2011i Additional Notes From the Author (Link)	Mar 2011	Listed in additional guidance documents.	Link *will open a new window.*
	Technical Guidance Manual Notes: Decision Unit and Multi-increment Sample Investigations.	Mar 25, 2011	Listed in additional	Link *will open a new window.*

	Reference: HDOH 2011b		guidance documents.	
	Screening for Environmental Hazards at Sites with Contaminated Soil and Groundwater. Reference: HDOH 2011f External Link:	Fall 2011, (rev April 2013)	Listed in additional guidance documents.	Link *will open a new window.*
	Long-term Management of Petroleum-Contaminated Soil and Groundwater. Reference: HDOH 2007c	Jun 27, 2007	Listed in additional guidance documents.	Link *will open a new window.*
	Use of Laboratory Batch Tests to Evaluate Potential Leaching of Contaminants from Soil. Reference: HDOH 2007	Apr 12, 2007	Listed in additional guidance documents.	Link *will open a new window.*

LOG OF MISCELLANEOUS UPDATES

	Name	Issue Date	Comments	Status
	Update TGM PDF file.	Apr 11, 2018	Created PDF file better suited for offline viewing	In Effect
	Update layout of TGM Homepage and TGM print function	Jun 11, 2010	To improve ease of use. Does not resullt in any substantive changes in the technical guidance .	In Effect
	Minor typographical errors corrected in some TGM sections	Jun 11, 2010	These corrections do not result in any substantive changes in the technical guidance.	In Effect
	HEER Office TGM Update Announcement Letter from Keith Kawaoka	Nov 14, 2008	Historical Document for Reference	Link *will open a new window.*

TGM for the Implementation of the Hawai'i State Contingency Plan
ADDITIONAL GUIDANCE DOCUMENTS

Technical Guidance Manual
ADDITIONAL GUIDANCE DOCUMENTS

Effective Date	Description	Link
October 2017	**Guidance for Soil Stockpile Characterization and Evaluation of Imported and Exported Fill Material:** Provides guidance related to import and export of fill material for contaminant removal or remediation sites. This includes: • The HEER Office definition of "acceptable fill material" • Overview of the fill material determination process • Some sources of fill considered suspect for contamination • Fill material sampling strategies and methods (including stockpiles), and • Other fill material management considerations Reference: HDOH 2017d	PDF Link *will open a new window.*
October 2012	**Additional Notes on HDOH report Field Investigation of the Chemistry and Toxicity of TPH in Petroleum Vapors** • This Q&A provides responses to common questions regarding the August 2012 HDOH TPH vapor report. Reference: HDOH 2012c	PDF Link *will open a new window.*
June 2012	**Summary of Pesticide and Dioxin Contamination Associated with Former Sugarcane Operations** • Provides an overview of chemical contaminants found at former Sugarcane Operations, compiled from case files at HDOH. • Includes target pesticide groups for different former sugarcane operations, and individual site data summaries. • Supplemental data to Section 9 of the Hawai'i HEER TGM addressing pesticide contamination at former agricultural facilities and sites. Reference: HDOH 2011d	PDF Link *will open a new window.*
October 2011	**Batch Test Leaching Model Spreadsheet:** An update to the October 2008 spreadsheet to calculate Kd desorption coefficient and estimate contaminant concentration in source area leachate and in groundwater.	XLS Link *will open a new window.*

	• Refer to April 12, 2007 guidance on "*Use of Laboratory Batch Tests to Evaluate Potential Leaching of Contaminants from Soil*" for background and use of this spreadsheet	
March 2011	**Use of Decision Unit and Multi-increment Soil Sample Investigation Approaches to Characterize a Subsurface Solvent Plume.** • TCE-contaminated soil located from 6 ft below ground surface down to 15-25 feet below ground surface at a site on Hickam Air Force Base, O'ahu was investigated using Decision Unit (DU) and Multi-increment Sampling (MIS) techniques. • 29 borings were installed within an area of approximately 100,000 square feet (the DU), and DU soils were further subdivided into seven vertical layers. The boreholes and layers were investigated separately, but combined to make decisions about the DU as a whole. • A total of 164 "core increments" (a section of a borehole corresponding to a specific DU layer) were subsampled and collected from targeted DU layers, and replicates were also collected from a number of boreholes. • Data was utilized to determine average concentrations of VOCs in each borehole and for targeted DU layers. The data were also used to identify the lateral and vertical location and mass of the subsurface contamination. • Note: The data tables included in the PDF copy of this report (see "PDF Link") are provided <HERE> in EXCEL Tables to enable users to run discrete vs multi-increment sample scenarios, or other analyses of this data. • Author notes and calculations are provided <HERE> Reference: HDOH 2011i	PDF Link *will open a new window.*
March 25, 2011	**Technical Guidance Manual Notes: Decision Unit and Multi-increment Sample Investigations.** • A compilation of notes and recommendations for Decision Unit (DU) and Multi-increment Sampling (MIS) site investigations. • Addendum to TGM guidance, based on experience since publication of the revised TGM in 2008 and 2009. • This information will be incorporated in future updates to the TGM. Reference: HDOH 2011b	PDF Link *will open a new window.*
Initially posted February 2005 then periodically updated – see link for latest update	**Screening for Environmental Hazards at Sites with Contaminated Soil and Groundwater** (or "EHE Guidance"). The HEER Office EHE Guidance and HEER Office TGM are the two major HEER Office technical guidance documents. Topics covered in the EHE Guidance include: • Environmental Action Levels for Soil, Soil Gas, and Groundwater	Link *will open a new window.*

	• Environmental Action Levels Surfer (electronic lookup tables) • Guidance on the site-specific evaluation of environmental hazards, including direct exposure, vapor intrusion, leaching and contamination of groundwater, impacts to drinking water resources, impacts to aquatic and terrestrial ecological habitats, gross contamination, etc. • Additional guidance on the preparation of Environmental Hazard Evaluations (EHEs) • Additional spreadsheet models for use in more site-specific EHEs Reference: HDOH 2011f	
June 27, 2007	**Long-term Management of Petroleum-Contaminated Soil and Groundwater.** • Technical memorandum outlines procedures for long-term management of residual petroleum contamination in soil and groundwater at sites where full cleanup is not practicable. Reference: HDOH 2007c	PDF Link *will open a new window.*
April 12, 2007	**Use of Laboratory Batch Tests to Evaluate Potential Leaching of Contaminants from Soil.** Guidance for assessing the potential impact to groundwater posed by leaching of contaminants from vadose-zone soils. This model uses site-specific soil data to evaluate contaminant mobility and estimate contaminant concentrations in soil leachate and future impacts to groundwater based on leachate dilution assumptions. • See October 2008 *Batch Test Leaching Model Spreadsheet* to facilitate use of this model. Reference: HDOH 2007	PDF Link *will open a new window.*