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## SECTION 4

# CHARACTERIZATION OF DECISION UNITS INTERIM FINAL – JULY 2021

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## 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<sup>1</sup> 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 shortcomings 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.

Multi Increment™ is a registered trademark of EnviroStat, Inc.

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## 4.1 SAMPLING THEORY AND VARIABILITY OF CONTAMINANT CONCENTRATIONS IN SOIL

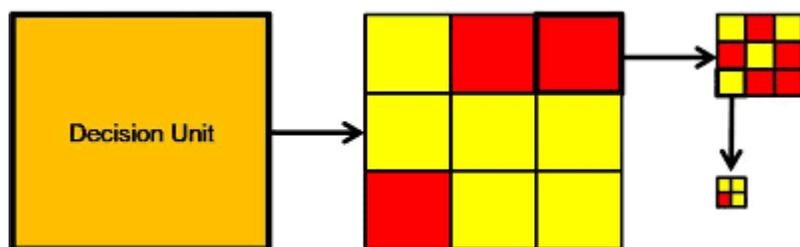
### 4.1.1 LARGE-SCALE AND SMALL-SCALE VARIABILITY

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.

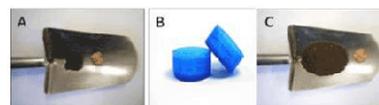
The concentration of a contaminant in soil will vary based on the mass of soil tested. A single value would be reported if the entire DU mass of soil within a targeted exposure area could be collected, extracted and analyzed as a single sample. The value reported represents the true *mean* concentration 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).

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**Figure 4-1. Variability of Mean Contaminant Concentration within Progressively Smaller Areas and Volumes of Soil within an Initially**



**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 bot-

**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 g) and tested by the laboratory (e.g., 1-30 g) clearly falls into this category ([Figure 4-2](#)).

tle 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 gram 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 ft<sup>2</sup> 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.

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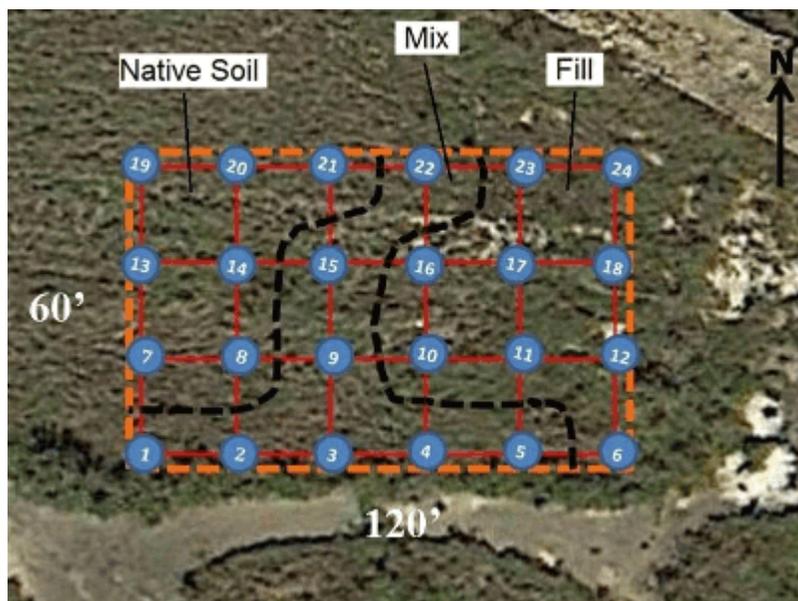


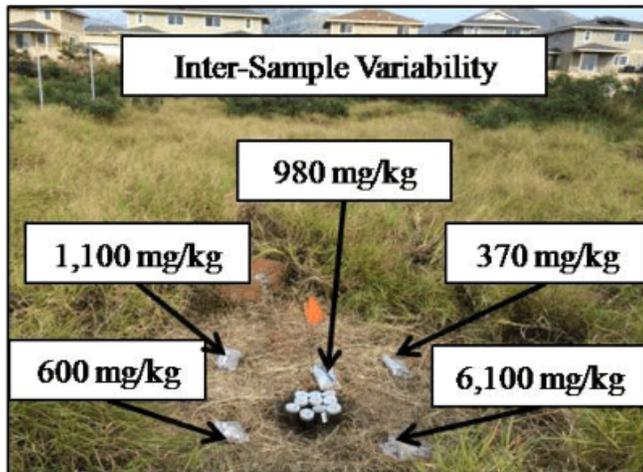
Figure 4-3. Study Site C in 2014

#### 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.

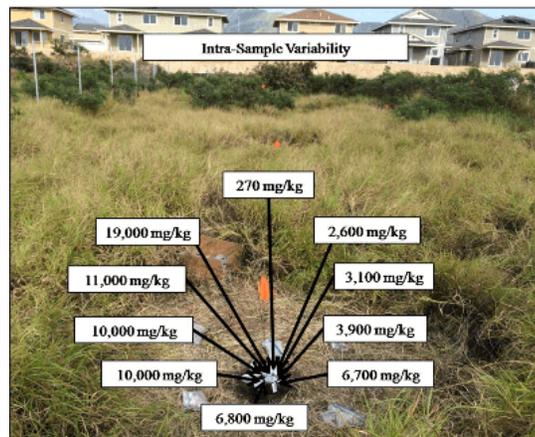
The site history, as well as discrete soil sample data collected as part of the study, suggests an overall higher concentration of PCBs in the eastern half of the study site where electrical equipment was formerly stored. This area is observable in the field by the presence of reddish fill material. 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](#)).

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**Figure 4-4. Example “Inter-Sample” Variability of PCB Concentrations in Soil**

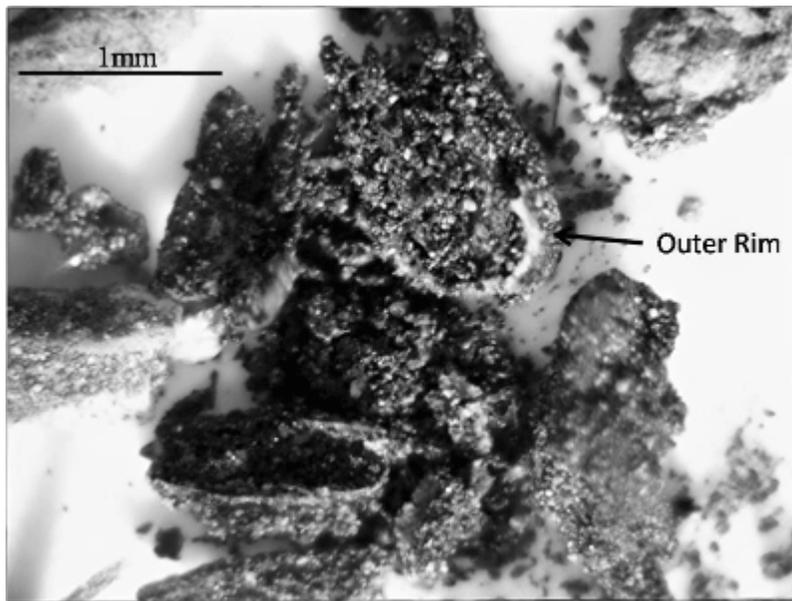
Data for processed, discrete samples collected within a 50 cm radius of a grid point ([HDOH, 2015](#)).



**Figure 4-5. Example “Intra-Sample” Variability of PCB Concentrations in Soil**  
Data for ten 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 reported 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.

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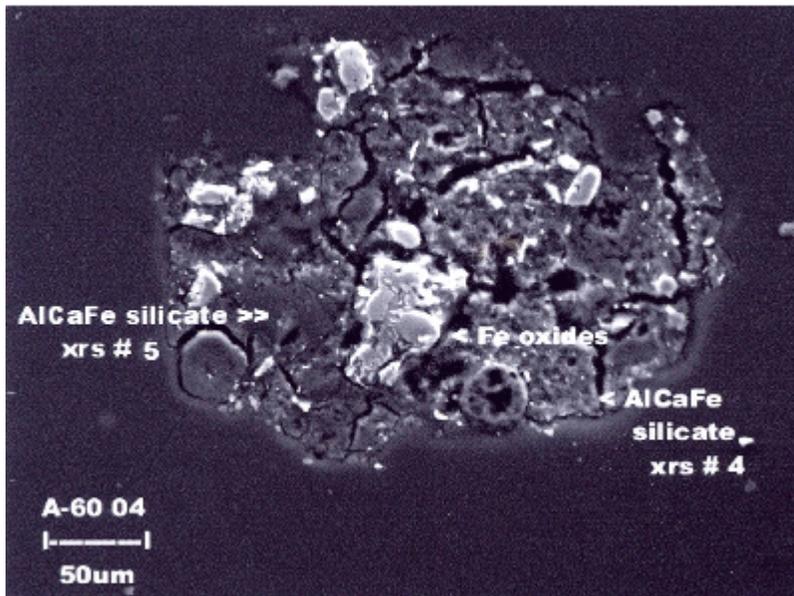
**Figure 4-6. Photomicrograph of Possible PCB-Infused Nugget of Silty Soil**

Interpreted to represent a remnant drop of waste transformer oil that sank into the soil ([HDOH, 2015](#)).

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 original 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](#)).

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**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).

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#### 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 ([USEPA, 1992b](#)):

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].

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 ([USEPA 1992](#)):

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.

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 (refer to [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 (refer to [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.

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#### 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 2 mm. 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.

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## 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 com-

pared to applicable HDOH Environmental Action Levels (EALs) or approved, alternative screening levels to make decisions regarding the need for any subsequent response actions.

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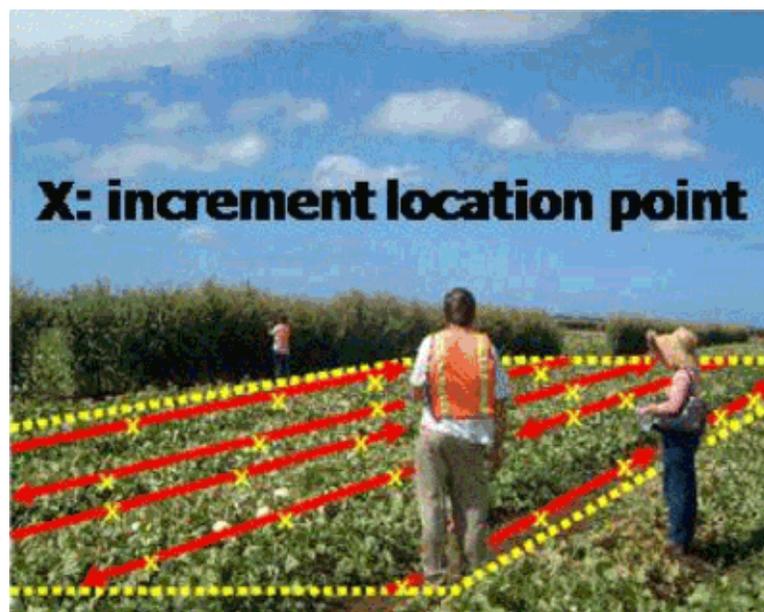
#### 4.2.1 MULTI INCREMENT SAMPLING METHODOLOGY

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.”

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**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.

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#### 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 (refer to [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 relative 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 er-

ror 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](#)).

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### 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 1.5kg bulk sample can be prepared by the collection and combination of 50, 30g increments. A minimum 10g 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 work station 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 g 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, five-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 followup 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.

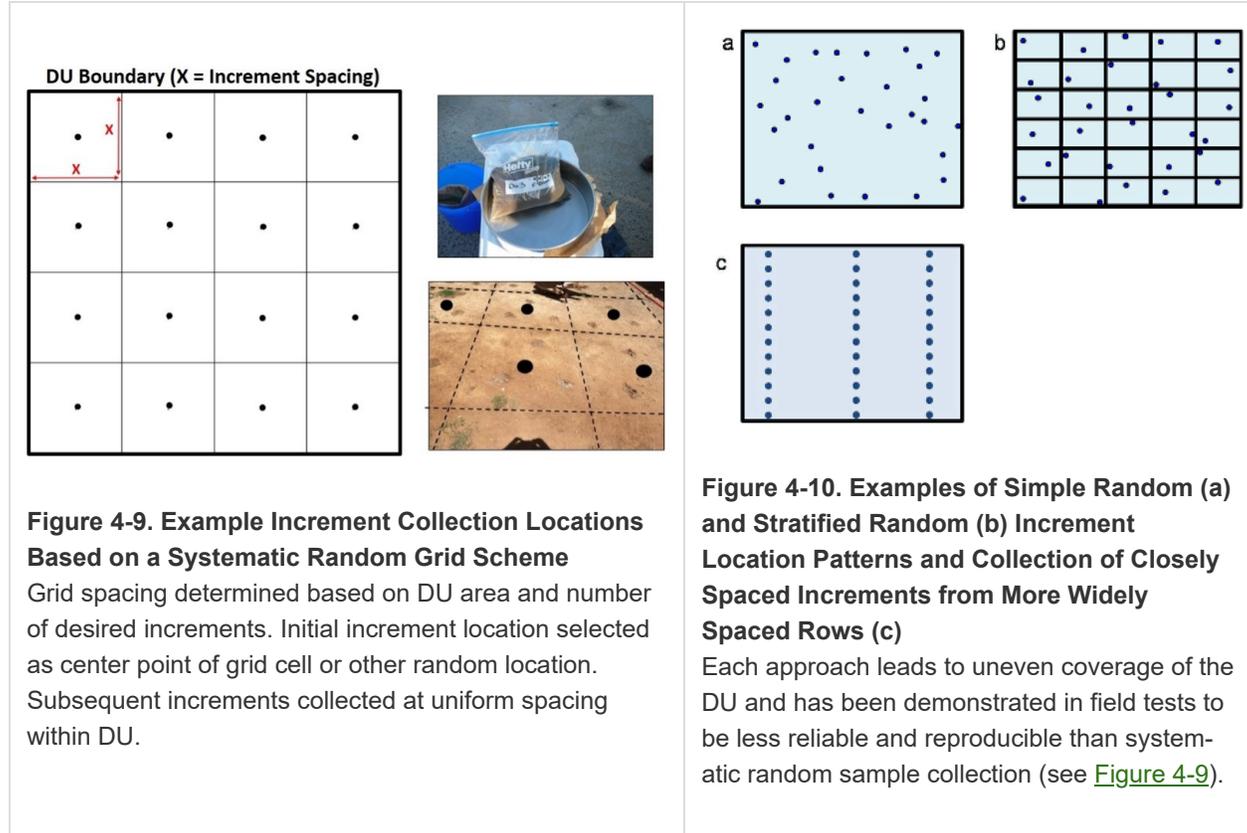
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#### 4.2.4 INCREMENT DISTRIBUTION

##### 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.

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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:

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$$\text{Increment Spacing} = \sqrt{\frac{\text{DU Area}}{\# \text{ Increments}}} \quad \text{Eq. 1.})$$

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 ft<sup>2</sup> 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 ft<sup>2</sup>. 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.

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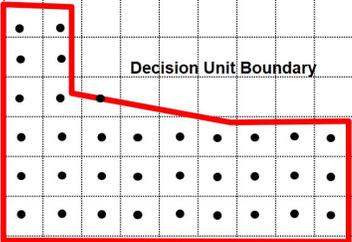
**Table 4-1. Approximate Increment Spacing (in feet) for Decision Unit Area (see Equation 1)**

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](#)).

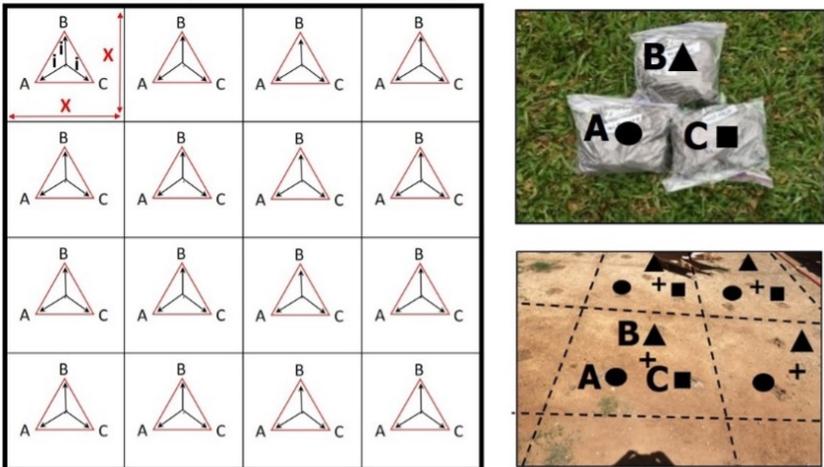
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**Figure 4-11. Systematic Increment Locations for Odd Shaped DUs (compare to [Figure 4-9](#))**

The number of increments collected within grid rows can vary in different areas of the DU.

**DU Boundary (X = Increment Spacing)**



**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 de-

picted 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.

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#### 4.2.5 SAMPLE COLLECTION

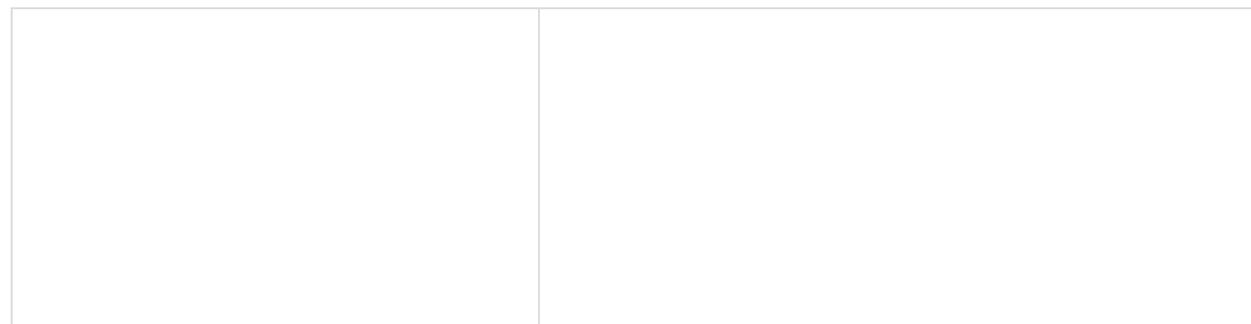
A detailed, logistical discussion of the collection of increments and Multi Increment samples in the field is provided in [Section 5](#). An overview of the basic design of Multi Increment sample collection is provided below.

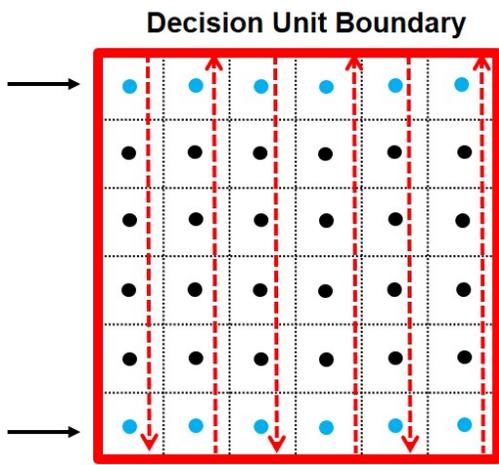
##### 4.2.5.1 LOCATING INCREMENT COLLECTION POINTS

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.

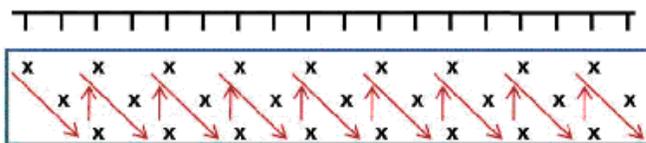
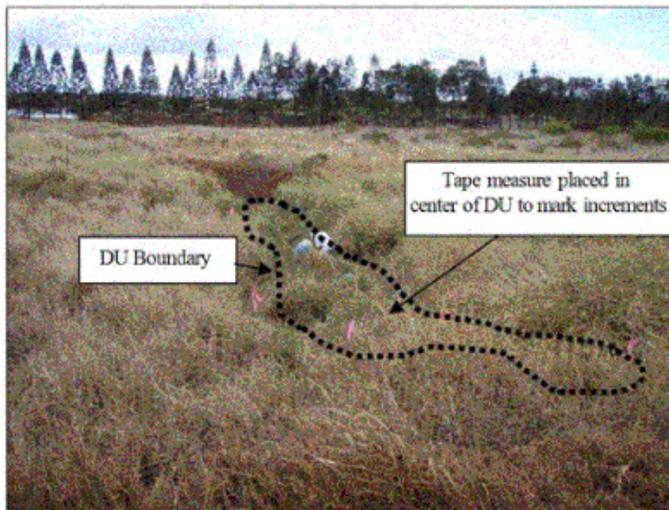
Approximate increment spacing should be estimated using Equation 1 given in [Subsection 4.2.4.1](#). A tape measure (or careful pacing) can be used to identify increment locations within the DU. Documenting or flagging the location of every individual increment collected within a DU is not necessary, 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.

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**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).

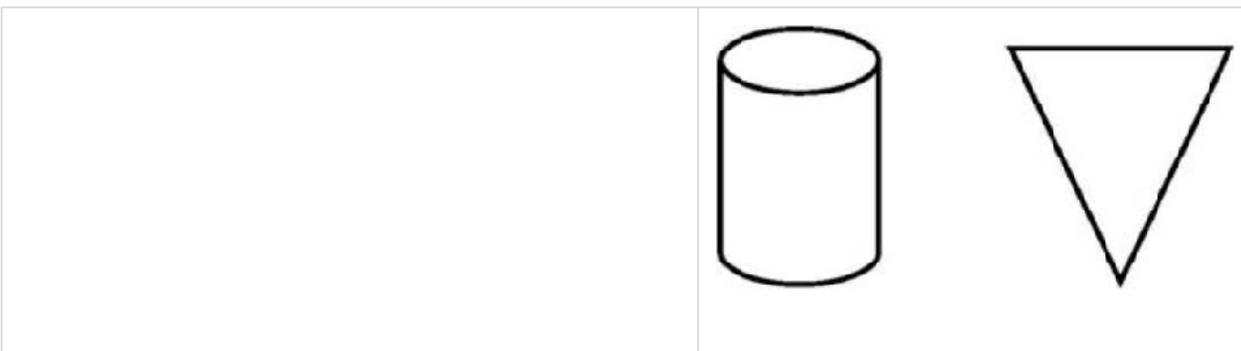
Use of a GPS in the absence of flags can expedite the location and collection of increments for very large DUs, where error in increment location within a few meters is acceptable and where pacing might not be accurate or practical due to vegetation, topography, or other access issue (e.g., tens or hundreds 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.

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4.2.5.2 INCREMENT AND BULK SAMPLE COLLECTION

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**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.

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**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 (refer to [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.

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., four groupings of ten 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 (refer to [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.

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#### 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 ten grams for the <2 mm 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 <250µm 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., TPHd 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.

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#### 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 coarse 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

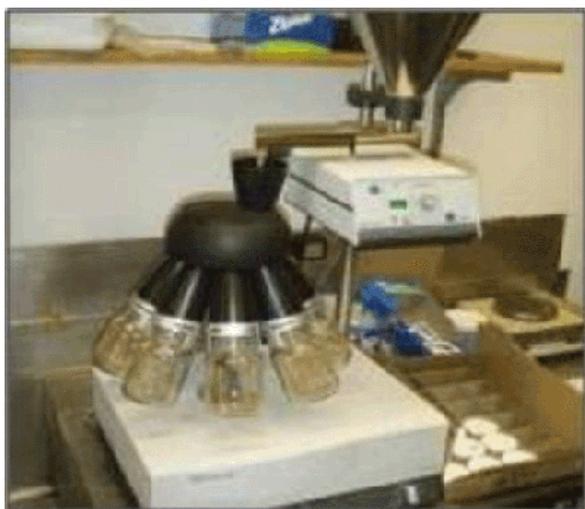
and sieving to address fundamental error concerns, although some degree of drying and sieving may be desirable by the laboratory for testing purposes. Exceeding recommended holding times for non-volatile chemicals in order to permit drying, sieving, and more definitive subsampling and data is generally acceptable but should be minimized to the extent practicable (see [Section 11](#); see also [USEPA, 2003c](#)).

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#### 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.

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**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 < 2 mm 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 < 2 mm 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 one gram to be tested. With the possible exception of mercury, extraction and testing of 10 g 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 five 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 volatilize (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., < 250 µm), 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).

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#### 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 speci-

fied 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 < 2 mm or smaller particle fraction of the soil ([USEPA, 2011d](#)). Milling of the < 2 mm 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., > 2 mm) 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., ≤ 10g; refer to [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.

Refer to the ITRC Incremental Sampling Methodology document for a detailed review of milling options ([ITRC, 2012](#)). Milling of a minimum 300g of soil is recommended (minimum mass necessary to address Fundamental Error; see [Subsection 4.2.3](#)). Milling of larger masses (e.g., 1kg) is preferable. Milling of a minimum 20g 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.

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 grind 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.

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**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

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#### 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-A2a](#)). 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 25°C or if the Henry's Law Constant exceeds 0.00001 atm-m<sup>3</sup>/mol ([USEPA 2015](#)). Chemicals listed in the HDOH EAL guidance that fall into this category include TPHd, 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-A2a](#) provides information on specific SVOCs (including TPHd, 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). Refer to [Section 9](#) and [Appendix 9-B](#) for a list of chemicals with low persistence that are known to 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 > 2 mm particles prior to subsampling (see [ITRC, 2012](#)). An effort should otherwise be made to collect < 2 mm 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; refer to [Section 9](#)). Note also that naphthalene can be reported under most VOC analyses if the laboratory is notified ahead of time.

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#### 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 < 2 mm 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 < 2 mm particle size fraction.

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#### 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 < 250 µm 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 < 2 mm particle size fraction (generally < 24 mg/kg, default HEER Office EAL background level).

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#### 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.

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#### 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 ten percent of DUs characterized as part of a site investigation. A minimum of one set of replicate samples should be collected, if less than ten

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.

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## Decision Unit Boundary

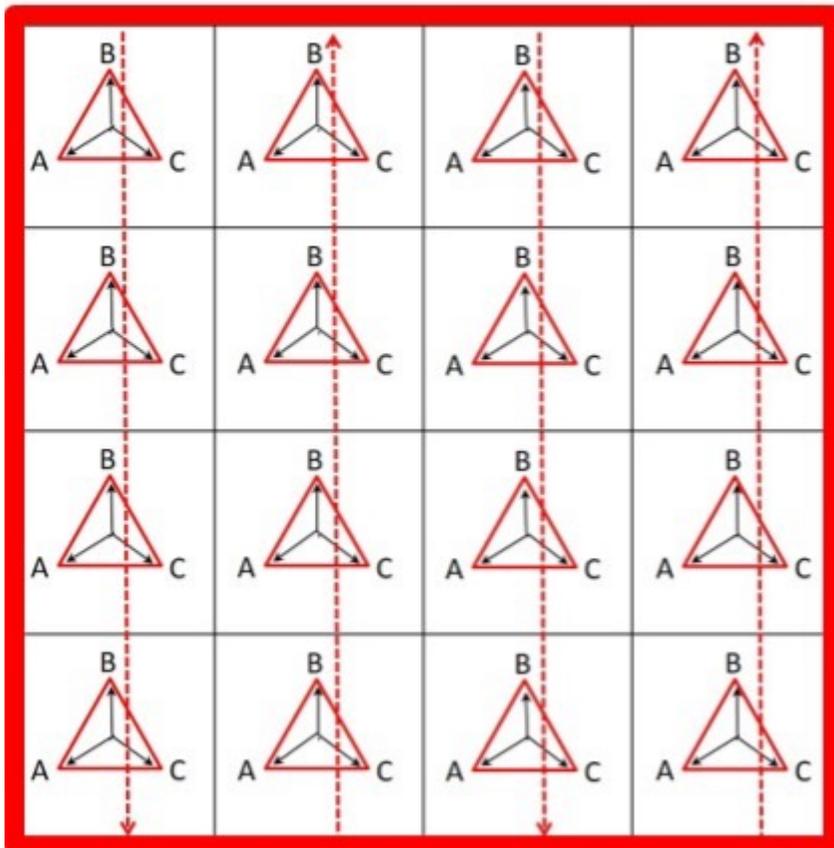


Figure 4-22. Example Pattern of Increment Collection for Triplicate Multi Increment Samples

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 pattern around the center point of grid cells (see [Figure 4-12](#)). This helps to simplify sample collection in the field.

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.

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#### 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 ten to twenty percent 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.

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#### 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 combining 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 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.

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**Table 4-2. Sample data quality and usability checklist.**

Acceptable?	
	<b>Conceptual Site Model and Decision Unit Designation (Section 3)</b>
<input type="checkbox"/>	<ul style="list-style-type: none"> <li>• Site history and potential sources and type of contamination well understood?</li> </ul>
<input type="checkbox"/>	<ul style="list-style-type: none"> <li>• Site investigation questions used to designate DU for testing clearly stated and based on risk and/or optimization of anticipated remediation?</li> </ul>
<input type="checkbox"/>	<ul style="list-style-type: none"> <li>• Questions and decision statements developed for individual DU presented?</li> </ul>
<input type="checkbox"/>	<ul style="list-style-type: none"> <li>• Area and total volume of soil associated with each DU noted and acceptable for intended purposes?</li> </ul>
<input type="checkbox"/>	<ul style="list-style-type: none"> <li>• To-scale map depicting location and size of DU provided?</li> </ul>
	<b>Field Sample Collection (Section 4.2.5)</b>
<input type="checkbox"/>	<ul style="list-style-type: none"> <li>• Summary of sample collection methods provided, including approximate final mass of each sample?</li> </ul>
<input type="checkbox"/>	<ul style="list-style-type: none"> <li>• Multi Increment samples prepared by collecting and combining a minimum of</li> </ul>

	increments appropriate to chemical present and nature of contamination?
<input type="checkbox"/>	<ul style="list-style-type: none"> <li>• Increments appropriately spaced and collected?</li> </ul>
<input type="checkbox"/>	<ul style="list-style-type: none"> <li>• Complete, unobstructed access to all portions of the DU soil available for sample collection?</li> </ul>
<input type="checkbox"/>	<ul style="list-style-type: none"> <li>• Core-shaped increments collected?</li> </ul>
<input type="checkbox"/>	<ul style="list-style-type: none"> <li>• Samples to be tested for volatile chemicals preserved in methanol in the field or met requirements for alternative preservation and testing methods?</li> </ul>
<input type="checkbox"/>	<ul style="list-style-type: none"> <li>• Minimum sample mass of 1-2 kilograms met (minimum 300 grams for samples to be tested for volatile contaminants)?</li> </ul>
<input type="checkbox"/>	<ul style="list-style-type: none"> <li>• Triplicate Multi Increment Samples collected in at least 10% of DUs (minimum 1 set) to test total data precision?</li> </ul>
	<b>Laboratory Processing and Testing (Section 4.2.6)</b>
<input type="checkbox"/>	<ul style="list-style-type: none"> <li>• Samples to be tested for non-volatile chemicals air-dried and sieved to target particle size for each specific DU?</li> </ul>
<input type="checkbox"/>	<ul style="list-style-type: none"> <li>• Analytical subsample collected using a sectoral splitter or manually collected from at least 30 points?</li> </ul>
<input type="checkbox"/>	<ul style="list-style-type: none"> <li>• Minimum 10-gram analytical subsample mass extracted for &lt;2mm particles (increase to 30 grams when possible)?</li> </ul>
<input type="checkbox"/>	<ul style="list-style-type: none"> <li>• Minimum 1-gram analytical subsample mass extracted for &lt;250µm particles (increase to 10 grams for unground samples when possible)?</li> </ul>
<input type="checkbox"/>	<ul style="list-style-type: none"> <li>• Triplicate analytical subsamples collected from at least 10% of samples submitted (minimum 1 set)?</li> </ul>
<input type="checkbox"/>	<ul style="list-style-type: none"> <li>• Holding times met?</li> </ul>
<input type="checkbox"/>	<ul style="list-style-type: none"> <li>• Analytical quality control and quality assessment criteria met (e.g., spikes, blanks, etc.; refer also to USEPA 2002)?</li> </ul>
	<b>Data Precision (Section 4.2.7 and Table 4-3)</b>
<input type="checkbox"/>	<ul style="list-style-type: none"> <li>• Replicate field sample and laboratory subsample data meet data precision requirements?</li> </ul>

<input type="checkbox"/>	<ul style="list-style-type: none"> <li>• Source of error for replicate data that exceed an RSD of 35% determined?</li> </ul>
<input type="checkbox"/>	<ul style="list-style-type: none"> <li>• Laboratory subsampling error identified and subsamples recollected after grinding of primary sample or larger subsample mass collected?</li> </ul>
<input type="checkbox"/>	<ul style="list-style-type: none"> <li>• Data adjusted or new samples collected for DUs with replicate data that exceed an RSD of 50%?</li> </ul>

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#### 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:

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$$RSD (\%) = \frac{\text{Replicate Standard Deviation}}{\text{Replicate Mean}} \times 100\% \quad \text{Eq. 2)}$$

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  $\leq 35\%$  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. Retest affected DUs using samples with a greater number of increments and increased bulk sample mass. As an alternative, and at the discretion of the HEER Office project manager, refer to the mean concentration for decision making for DUs where replicate samples were collected. For DUs where replicate samples were not collected, increase the data by the RSD calculated for the correlative DU with replicate samples (use the mean RSD if multiple sets of replicate samples collected). While somewhat subjective, this approach allows for consideration of factors such as the ability (or inability) to improve the sample collection method and the safety margin built into the action level for decision making. An RSD >100% indicates very poor data precision and the likely need to resample the affected DUs, with the possible exceptions discussed in Table 4.3.

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 mean concentration of the contaminant reported for replicate samples and the unadjusted concentration of the contaminant for DUs 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	Use of MI Sample Data for Decision Making
-----------	-------------------------------------------

Sample Data Precision	
Good (RSD ≤35%)	<ul style="list-style-type: none"> <li>• <b>Data acceptable for final decision making;</b></li> <li>• Compare data to target action levels or use to calculate risk (use the arithmetic mean of replicate sample data);</li> <li>• Collection of followup, confirmation samples for DUs where remedial action is necessary not required if data for laterally and vertically adjacent DUs meet target action levels.;</li> </ul>
Moderate (35% <RSD≤50%)	<ul style="list-style-type: none"> <li>• <b>Data acceptable for final decision making, with the noted exception for remedial confirmation samples;</b></li> <li>• 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.);</li> <li>• Compare data to target action levels or use to calculate risk (use the arithmetic mean of replicate sample data);</li> <li>• Collection of followup, 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.);</li> </ul>
Poor (50% <RSD≤100%)	<ul style="list-style-type: none"> <li>◦ <b>Data not acceptable for final decision making in absence of adjustment to improve margin of safety;</b></li> <li>◦ Review and discuss sampling methods and laboratory processing and analysis methods and summarize potential sources of error and suggestions for future improvements in report;</li> <li>◦ 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;</li> <li>◦ If replicate sample data precision is still poor, consider retesting affected DUs using samples with a greater number of increments and total, bulk mass;</li> </ul> <p>OR, if determined acceptable by a risk assessor trained in Multi Increment sampling methods:</p> <ul style="list-style-type: none"> <li>• For DUs with replicate sample data, compare the mean concentration of the contaminant to the action or cleanup level;</li> <li>• 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. × RSD);</li> <li>• 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</li> </ul>

	<p>analyzing samples, closeness of data to action levels and safety margins built into the action levels, and other information as available and pertinent.</p> <ul style="list-style-type: none"> <li>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.</li> </ul>
Very Poor (RSD>100%)	<ul style="list-style-type: none"> <li><b>Data not acceptable for final decision making except in noted cases and with approval of overseeing regulatory agency;</b></li> <li>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;</li> <li>Review and discuss field sampling methods and laboratory processing and analysis methods and summarize potential sources of error in reports for future reference;</li> <li>Retesting is not required for DUs where the need for remediation is already clear from the data and other field evidence.</li> <li>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;</li> <li>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).</li> <li>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.</li> <li>Collect replicate confirmation samples in all DUs requiring remediation.</li> </ul>

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#### 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 al-

lowed 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.

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#### 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.

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#### 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 (25°C) or the Henry's Law Constant is greater than 0.00001 atm-m<sup>3</sup>/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 (refer to [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., five 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 (refer to [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. Refer to 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.

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#### 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 than 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 g – 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 5-10 g plugs at two to four inch intervals is recommended (similar to the method used for VOCs), or as otherwise necessary to generate a 1-2 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.

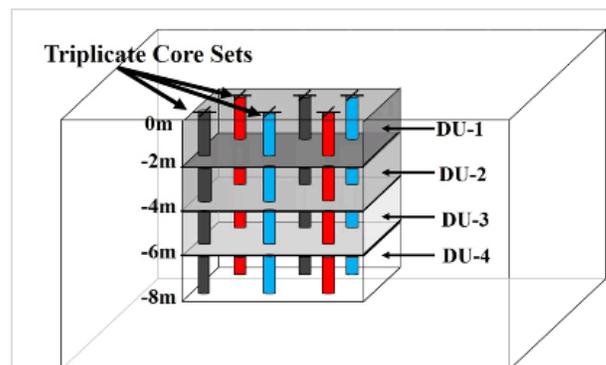
In some cases collection of the recommended minimum number of increments from subsurface DU layers may not be feasible due to access or cost constraints. Reducing the number of increments collected for the Multi Increment may be necessary. If this is the case, it is important to recognize that the quality 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.

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**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, two to four-inch (5-10 cm) spacing for removal of 5-10 g 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 g 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](#)).

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#### 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.

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### 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](#); refer to [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 (refer to [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 1-2kg of soil (recommended MI sample mass, minimum 300g; [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 10g 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.

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**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 (refer to [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.

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#### 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.

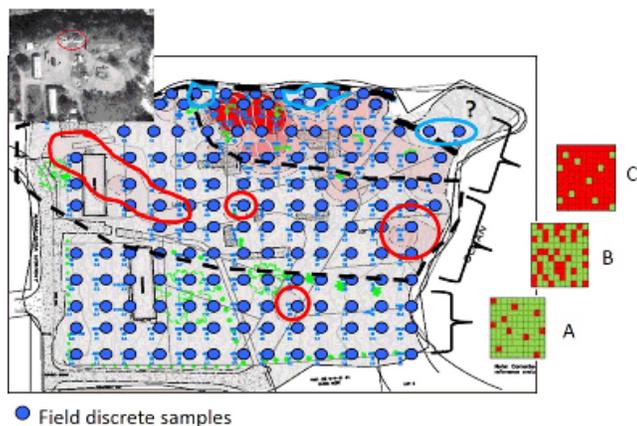
**Isocontour maps should be adjusted to reflect site knowledge and professional judgment not reflected in computer-generated maps.** Such adjustments are not possible in existing computer programs to the knowledge of HDOH and must be done by hand. Boundaries between apparent large-scale patterns should 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, 2015,b](#)).

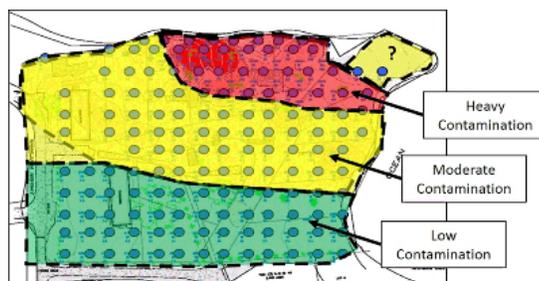
Three distinct areas of arsenic contamination are apparent in the figure (see [Figure 4-26](#)). The concentration of arsenic in the majority of discrete samples collected from Area A is below a screening level 20 mg/kg, with occasional “outliers” that exceed this value. Arsenic is randomly above 20 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.

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**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.

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.

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.

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#### 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 (refer to [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).

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**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.

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 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. Refer to [Subsection 3.4](#) for additional information on DU designation for investigation and remedial purposes.

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#### 4.3.3 ESTIMATION OF MEAN CONTAMINANT CONCENTRATIONS IN RISK ASSESSMENTS

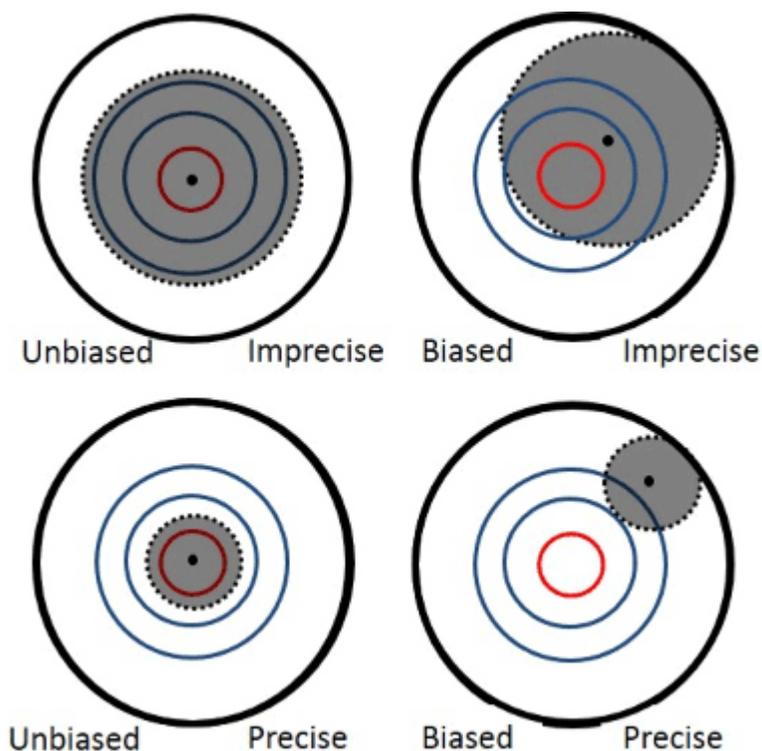
Discrete soil sample data have traditionally been used to estimate the mean contaminant concentration for targeted exposure areas in environmental site assessments and remedial actions (e.g., [USEPA 1987](#), [2013b](#)). The reliability of this approach was called into question by the HEER Office in 2006, due to the inability to verify the field representativeness of a single data 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 (refer to [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](#).

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**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

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.

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 ([USEPA, 1992b](#)):

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 percent UCL).

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 (refer to [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.

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## 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 ft<sup>2</sup>; 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 (refer to [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 ft<sup>2</sup> 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 4.2.8](#)), 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.

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#### 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.

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#### 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 (refer to [Subsection 4.1](#)). Recall that the number of increments collected and the representative sample methodology used is independent of the size of the DU (refer to [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 (refer to [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 30-50 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.

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#### 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.

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#### 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 gravelly 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.

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#### 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.

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#### 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 (refer to [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.

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#### 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 <2 mm particle size ([Subsection 4.2.6](#)). When possible, a larger subsample mass (e.g., 30+ g) 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 one 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.

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#### 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.

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#### 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 ft<sup>2</sup> or even <10 ft<sup>2</sup> 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.

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#### 4.4.11 DU-MIS INVESTIGATIONS UNDER TSCA

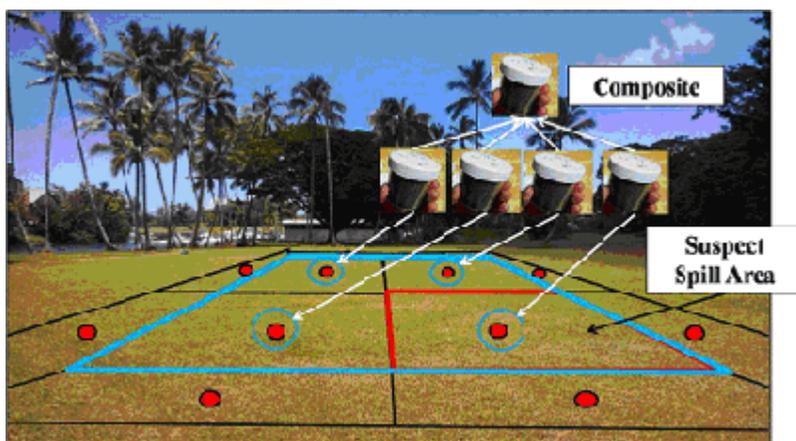
The investigation, cleanup, verification and disposal of soil contaminated with polychlorinated biphenyls (PCBs) is regulated under [40 CFR § 761.61](#) (PCB remediation waste) of the Toxic Substances Control Act (TSCA; [USEPA 1998h](#)). The Hawai'i State Contingency Plan also authorizes HDOH to require the investigation and remediation of PCB-contaminated properties (refer to [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:

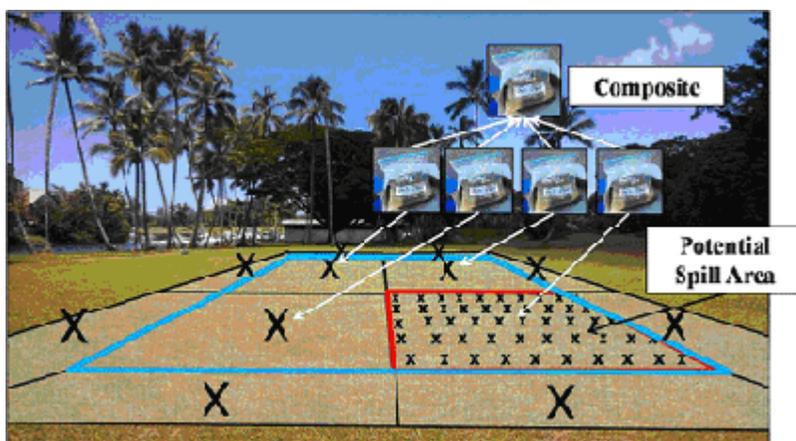
Any person wishing to sample, cleanup, or *dispose* of PCB remediation waste in a manner other than prescribed in paragraphs (a) or (b) of this section ... must apply in writing to the EPA Regional Administrator in the Region.

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.

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**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.** Refer to [Section 3](#) of HDOH Technical Guidance Manual for information on designation of Decision Units at contaminated properties.

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 US. 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 percent chance of missing a 100ft-by-100ft (10,000ft<sup>2</sup>) contaminated zone is acceptable but only a 5 percent chance of missing a 200ft-by-200ft (40,000ft<sup>2</sup>) 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 in the composite, however, in order to ensure that no single “sampling area” exceeded the target cleanup level. A maximum of ten 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 compari-

son 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 (refer to [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 ft<sup>2</sup>; 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.