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TO: Interested Parties

FROM: Keith E. Kawaoka, D. Env., Program Manager
Hazard Evaluation and Emergency Response Office

SUBJECT: **Soil Action Levels and Categories for Bioaccessible Arsenic**

Attached for your information is a technical report that represents guidance on the assessment of arsenic-contaminated soils in Hawai`i. This report serves as an addendum to the Hazard Evaluation and Emergency Response (HEER) Office document, *Screening for Environmental Concerns at Sites with Contaminated Soil and Groundwater (May 2005).*

If you have any questions regarding this report, please call Dr. Roger Brewer, HEER Office, at (808) 586-4249, or contact him by e-mail at *roger.brewer@doh.hawaii.gov.*

Attachment

Soil Action Levels and Categories for Bioaccessible Arsenic

Summary
This technical report presents action levels and corresponding soil categories for arsenic-contaminated soils in Hawai'i and serves as an addendum to the Hazard Evaluation and Emergency Response (HEER) office document *Screening For Environmental Concerns at Sites With Contaminated Soil and Groundwater* (HDOH 2005). The guidance is especially intended for use during the redevelopment of former agricultural areas, although it is applicable to any site where releases of arsenic may have occurred. The action levels should be used to help determine the magnitude of potential health risks at sites where arsenic-contaminated soil is discovered and help guide the scope of remedial actions needed. The action levels are intended to serve as guidelines only, however, and do not represent strict, regulatory cleanup requirements. Alternative action levels may be proposed for any site in a site-specific, environmental risk assessment.

The action levels presented are based on concentrations of *bioaccessible* arsenic in soil. *Total* arsenic data are considered appropriate for comparison to anticipated background levels of arsenic in soil but not for use in human health risk assessment or for setting risk-based action levels. An action level of 4.2 mg/kg bioaccessible arsenic is recommended for residential sites. For commercial/industrial sites, an action level of 19 mg/kg bioaccessible arsenic is recommended. Remediation of sites to permit future, unrestricted, residential land use is encouraged when technically and economically feasible. "Residential" use includes both single-family homes and high-density developments, where open spaces essentially serve as residential "backyards." Schools, parks, playgrounds, and other open public spaces that adult and child residents may visit on a regular basis should also be initially assessed under a residential use exposure scenario. Short- and long-term remedial actions in the latter areas may differ from actions recommended for high-density and single-family residential properties, however, due to greater control over digging and other activities that may expose contaminated soil.

Additional guidance and action levels are provided for sites where the preferred action levels noted above cannot be reasonably met and continued use or redevelopment of the site is still desired. Three categories of arsenic-contaminated soil are defined for both residential and commercial/industrial sites. Residential, Category 1 soils (R-1) are not considered to pose a significant risk to human health under any potential site conditions and can be reused onsite or offsite as desired. Commercial/Industrial, Category 1 soils (C-1) can be used as needed on commercial/industrial sites but should not be used as fill material offsite without prior consultation with HDOH. Category 2 Residential (R-2) and Commercial/Industrial (C-2) soils are not considered to pose a significant risk to human health under the specified land use provided that lawns and other landscaping are maintained to minimize exposure and control fugitive dust. Remediation of residential and commercial/industrial properties to action levels for Category 1 soils is recommended to the extent technically and economically feasible, however, and should be discussed with the HEER office on a site-by-site basis. Reuse of Category 2 Commercial/Industrial soil for daily cover at a regulated landfill may be acceptable but should be discussed with the landfill operator as well as the HDOH Solid and Hazardous Waste Branch. Category 3 Residential (R-3) and Commercial/Industrial (C-3) soils are considered to pose an unacceptable risk to human health and should be removed from the site or isolated onsite under permanent structures or properly designed caps, as described below.

This information provided in this technical report will be reviewed on a regular basis and updated as needed. Questions, comments and suggestions are welcome and should be sent to the attention of Roger Brewer at the above address or via email to roger.brewer@doh.hawaii.gov.

Background

Significantly elevated levels of arsenic have been identified in soils from former sugar cane fields and pesticide mixing areas in Hawai‘i, as well as in and around former plantation camps. High levels of arsenic have also been identified in soil samples from at least one former golf course. The presence of the arsenic is believed to be related the use of sodium arsenite and other arsenic-based pesticides in and around the cane fields in the 1920s through 1940s. During this period, up to 200,000 acres of land in Hawai‘i was being cultivated for sugar cane. The arsenic is generally restricted to the upper two feet of the soil column (approximate depth of plowing). Alternative action levels and approaches may be acceptable for contaminated soils situated greater than three feet below ground surface and should be discussed with HDOH on a site-by-site basis.

Current studies have focused on the Kea‘au area of the Big Island. Soils in the area have been described as stony, organic, iron-rich Andisols (Cutler et al., 2006). Concentrations of total arsenic in soils from undeveloped former sugar cane lands in this area have been reported to range from 100-400 mg/kg in the ≤2mm size fraction of the soil and >500 mg/kg in the <250µm size fraction (report pending). Concentrations greater than 1,000 mg/kg have been reported in one former plantation camp area. Background concentrations of arsenic in native soils range from 1.0 mg/kg up to 20 mg/kg. The presence of the arsenic initially posed concerns regarding potential groundwater impacts, uptake in homegrown produce and direct exposure of residents and workers to contaminated soil. Maximum-reported concentrations of bioaccessible arsenic in soil are far below levels that would cause immediate, acute health affects. Continued exposure to arsenic in heavily contaminated soils over many years or decades could pose long-term, chronic health concerns, however.

Arsenic has not been detected in municipal groundwater wells in the area. Testing of produce from gardens in the Kea‘au area by the Department of Health in 2005 also did not identify levels of arsenic above U.S. norms, even though total arsenic in the garden soils approached or exceeded 300 mg/kg in the ≤2mm size fraction. Uptake of the arsenic in edible produce or other plants therefore does not appear to be a significant environmental health concern. These observations suggest that the arsenic is tightly bound to the soil and not significantly mobile. This is further supported by petrologic and leaching studies as well as “bioaccessibility” tests conducted on the soils (Cutler et al., 2006). Despite being relatively immobile, however, elevated levels of arsenic in some areas could still pose a potential chronic health risk to residents and workers who come into regular contact with the soil. The action levels and soil categories discussed below are intended to address this concern.

The evaluation of soil for arsenic has traditionally focused on the *total* amount of arsenic present and comparison to action levels based on a target excess cancer risk of one-in-a-million or 10^{-6}. This has always presented a dilemma in human health risk assessments. Natural, background concentrations of arsenic in soils are typically much higher than risk-based action levels for total arsenic. For example, the residential soil action level for arsenic presented in the HDOH document *Screening For Environmental Concerns at Sites With Contaminated Soil and Groundwater* is 0.42 mg/kg (HDOH 2005, Appendix 1, Table I-1), while background concentrations of arsenic in soil in Hawai‘i may range up to 20 mg/kg or higher. In addition, much of the arsenic in pesticide-contaminated

soil appears to be tightly bound to soil particles and not *available* for uptake in the human body. This portion of the arsenic is essentially nontoxic. These two factors led to a need for further guidance, particularly with respect to the use of *bioaccessible* arsenic data in human health risk assessments and in the development of risk-based, soil action levels.

Bioavailable and Bioaccessible Arsenic

Risk to human health posed by exposure to a contaminant in soil is evaluated in terms of the average daily dose or *intake* of the contaminant for an exposed person (e.g., in milligrams or micrograms per day; USEPA 1989, 2004). Intake can occur through incidental ingestion of soils, inhalation of dust of vapors, and to a lesser extent (for most contaminants) absorption through the skin. Assumptions are made about the fraction of the contaminant that is available for *uptake* in a persons blood stream via the stomach and small intestine. This is referred to as the *bioavailability* of the contaminant (NEPI 2000). The most widely accepted method to determine the bioavailability of a contaminant in soil is through *in vivo* studies where the soil is incorporated into a lab test animal's diet. In the case of arsenic, the amount that is excreted in the animal's urine is assumed to represent the fraction that entered the animal's blood stream and was available for uptake.

In vivo bioavailability tests are time consuming and expensive, however, and not practical for routine site evaluations. As an alternative, faster and more cost-effective laboratory tests have been developed to estimate arsenic bioavailability in soil. These methods, referred to as *in vitro* bioaccessibility tests, utilize an acidic solution intended to mimic a child's digestive tract (typically a glycine-buffered hydrochloric acid solution at pH 1.5; Ruby 1999; Gron and Andersen, 2003). Soil with a known concentration and mass of arsenic is placed in the solution and allowed to equilibrate for one hour. An extract of the solution is then collected and analyzed for arsenic. The concentration of arsenic in the solution is used to calculate the total mass of arsenic that was stripped from the soil particles. The ratio of the arsenic mass that went into solution to the original mass of arsenic in the soil is referred to as the *bioaccessible* fraction of arsenic.

The results of *in vitro* bioaccessibility tests for arsenic compare favorably with *in vivo* bioavailability studies (Ruby 1999; Gron and Andersen, 2003). This is supported by studies of arsenic-contaminated soils from the Kea'au area of the Big Island of Hawai'i. Samples of the soil were tested for bioavailable arsenic in an *in vivo* monkey study carried out by the University of Florida in 2005 and simultaneously tested for bioaccessible arsenic by *in vitro* methods (report pending publication). The concentration of total arsenic in the samples was approximately 700 mg/kg. The study concluded that the bioavailability of arsenic in the soil ranged from 3.2% to 8.9%. This correlated well with an *in vitro* test carried out on the same soil that yielded an arsenic bioaccessibility of 6.5%. The bioaccessibility of arsenic in soils from the same site was estimated to range from 16% to 20% in a separate study, suggesting that the *in vitro* test method may err on the conservative side in comparison to the more standard *in vivo* method (Cutler et al., 2006). This has been observed in other studies of bioavailability versus bioaccessibility. Bioaccessibility tests on soils from other areas around Kea'au yielded similar results and again indicated that 80% to >90% of the arsenic in the soil is so tightly bound to soil particles that it is essentially "nontoxic."

Bioaccessible arsenic was observed to increase with increasing total arsenic concentration (Cutler et al., 2006). This is probably because much of the arsenic in heavily contaminated soils is fixed to low-energy binding sites on soil particles and comparatively easy to remove. Continued stripping of remaining arsenic from progressively higher-energy binding sites requires greater effort (i.e., the arsenic becomes progressively less bioaccessible). Data from the study also indicate that arsenic

bioaccessibility (and therefore toxicity) may increase with increasing phosphorous concentration in soil related to the use of fertilizers in gardens. This is because phosphorus is able to out compete arsenic for high-energy binding sites on soil particles. The relationship has not been fully demonstrated, however, and is still under investigation.

Based on a review of published literature and studies conducted to date in Hawai‘i, HDOH considers arsenic bioaccessibility tests to be sufficiently conservative and an important tool in the assessment of arsenic-contaminated properties. Bioaccessible arsenic analyses should always be conducted on the ≤250µm size fraction of the soil since this is the fraction that is most likely to be incidentally ingested. Most soils only contain a small percentage of particles 250µm in size or less. This typically requires the collection of very large samples (several kilograms) to obtain the mass needed for bioaccessibility tests. Appropriate sample handling, processing, and sub-sampling by the lab conducting bioaccessibility testing is essential. Guidance on suggested procedures and quality control for bioaccessibility lab tests will be forthcoming from HDOH. For more information on this subject contact John Peard of the HDOH HEER office (john.peard@doh.hawaii.gov).

Basis of Soil Action Levels

Arsenic action levels and correlative soil categories for residential and commercial/industrial properties are presented in Tables 1 and 2 and summarized in Figure 1. An action level of 20 mg/kg total arsenic in the ≤2mm size soil fraction is recommended to screen out sites where naturally occurring ("background") concentrations of arsenic are not significantly exceeded (HDOH 2005). Background total arsenic may approach 50 mg/kg in some areas but this is considered rare. Analysis of soil samples for bioaccessible arsenic is recommended at sites where total arsenic exceeds anticipated background concentrations.

Action levels for bioaccessible arsenic are presented in Table 1 (residential land use) and Table 2 (commercial/industrial land use). The action levels are based on direct-exposure models used by USEPA Region IX to develop soil "Preliminary Remediation Goals (PRGs)" (USEPA 2004). The USEPA PRGs for arsenic for residential and commercial/industrial land use are 0.39 mg/kg and 1.6 mg/kg, respectively, based on a target excess cancer risk of $1x10^{-6}$ (one-in-a-million). Risk-based action levels for arsenic of 0.42 mg/kg and 1.9 mg/kg are presented in the HDOH document *Screening For Environmental Concerns at Sites With Contaminated Soil and Groundwater*, based on a similar target risk but assuming a slightly lower, dermal absorption factor (HDOH 2005). Both the USEPA PRGs and the HDOH Tier 1 action levels assume that 100% of the soil arsenic is bioavailable.

The USEPA PRGs and HDOH Tier 1 action levels for total arsenic are far below typical background concentrations of arsenic in soils from Hawai‘i as well as most of the mainland US. To address this issue, action levels for Category 1 soils in Tables 1 and 2 are based on a target excess cancer risk of $1x10^{-5}$ (one-in-one-hundred-thousand) rather than $1x10^{-6}$. This generates residential and commercial/industrial action levels for bioaccessible arsenic of 4.2 mg/kg and 19 mg/kg, respectively. These action levels serve as useful starting points to help identify arsenic-contaminated sites that warrant further evaluation.

A second set of action levels is used to define soils that are most likely impacted above natural background levels but still may be acceptable for use in residential or commercial/industrial areas if adequate lawns and landscaping are maintained (Category 2 soils). An action level of 23 mg/kg bioaccessible arsenic was selected as an upper limit for soils in residential areas (Table 1). This

reflects a noncancer Hazard Quotient of 1.0 and correlates to an excess cancer risk of approximately $5x10^{-5}$. Commercial/industrial action levels based on a similar excess cancer risk of $5x10^{-5}$ and a noncancer Hazard Quotient of 1.0 are 95 mg/kg and 310 mg/kg, respectively. Since the correlative action level for excess cancer risk is less than the action level for noncancer risk, the former (95 mg/kg) was chosen as an upper limit for soils in commercial/industrial areas (Table 2). These action levels are used to define the lower boundary of Category 3 soils.

At concentrations greater than 180 mg/kg, bioaccessible arsenic in soil begins to pose a potentially significant health risk to construction workers and utility workers (HDOH 2005, refer to Table I-3 in Appendix 1, based on an excess cancer risk of $1x10^{-5}$). As discussed below, this is used as a "ceiling level" for soil that can be isolated under clean soil caps, buildings or paved areas.

The action levels for bioaccessible arsenic were used to group soils into three categories (see Tables 1 and 2). A discussion of potential remedial actions at each sites that fall into these soil categories is provided in the following sections. The ultimate action taken at an individual site will be dependent on numerous site-specific factors, including current and planned land use, available options for onsite isolation or offsite disposal, and technical and economic constraints.

Soil Categories and Action Levels for use at Residential Sites

Category 1 Soils (R-1): Bioaccessible Arsenic $\leq$4.2 mg/kg, No Further Action

Long-term exposure to Category 1 (R-1) residential soils is not considered to pose a significant risk to residents. No further action is necessary at sites where the reported concentration of bioaccessible arsenic in soil is equal to or below 4.2 mg/kg.

Category 2 Soils (R-2): Bioaccessible Arsenic >4.2 mg/kg and $\leq$23 mg/kg, Consider Removal or Isolation

Long-term exposure to Category 2 (R-2) residential soils is not considered to pose a significant risk to residents provided that lawns and landscaping are maintained to minimize exposure and control fugitive dust. Remediation of residential properties to action levels approaching those for R-1 soils is strongly recommended when technically and economically feasible, however, and should be discussed with the HEER office on a site-by-site basis. When selecting remedial options, long-term effectiveness should be given increasing weight as concentrations of bioaccessible arsenic approach the upper boundary for R-2 soils.

For new developments, isolation of R-2 soils under buildings, private roadways and other areas with a permanent cap that workers are unlikely to disturb in the future is recommended when feasible. Isolation of R-2 soils under public roadways should be done in coordination with the local transportation authority. Offsite reuse of some or all of the soil as daily cover material in a regulated landfill may also be possible. This should be discussed with the landfill in question as well as with the HDOH Solid and Hazardous Waste Branch. Offsite reuse of R-2 soils for fill or other purposes may also be acceptable but should likewise be discussed with the HEER office and the HDOH Solid and Hazardous Waste Branch. Utility corridors should be backfilled with clean fill material (e.g., R-1 soils) in order to prevent excavation of contaminated soil and inappropriate reuse in other areas in the future.

At sites where R-2 soils are discovered in the vicinity of existing homes, residents should be encouraged to minimize exposure to the soil by taking the following precautions:

- Reduce areas of bare soil by planting and maintaining grass or other vegetative cover, or cover barren areas with gravel or pavement.
- Keep children from playing in bare dirt.
- Keep toys, pacifiers, and other items that go into childrens' mouths clean.
- Wash hands and face thoroughly after working or playing in the soil, especially before meals and snacks.
- Wash fruits and vegetables from home gardens before bringing them in the house. Wash again with a brush before eating or cooking to remove any remaining soil particles. Pare root and tuber vegetables before eating or cooking.
- Bring in clean sand for sandboxes and bring in clean soil for garden areas or raised beds.
- Avoid tracking soil into the house and keep the floors of the house clean. Remove work and play shoes before entering the house.

Testing of produce from gardens in the Kea'au area by the Department of Health in 2005 did not identify levels of arsenic above U.S. norms. Uptake of the arsenic in edible produce or other plants therefore does not appear to be a significant environmental health concern. Produce should be thoroughly cleaned before cooking or eating, however, in order to avoid accidental ingestion of small amounts of soil.

Category 3 Soils (R-3): Bioaccessible Arsenic >23 mg/kg, Removal or Isolation Recommended
Long-term exposure of residents to Category 3 (R-3) residential soils is considered to pose potentially significant health risks. As discussed above, maximum-reported concentrations of bioaccessible arsenic in soil from former agricultural areas are far below levels that would cause immediate, acute health affects. Continued exposure to arsenic in R-3 soils over many years or decades could pose long-term, chronic health concerns, however.

Offsite disposal of R-3 soils in a permitted landfill facility is recommended when technically and economically feasible. Reuse of some or all of the soil as daily cover at a landfill may also be possible. This should be discussed with the landfill in question as well as with the HDOH Solid and Hazardous Waste Branch. Offsite disposal of soil with bioaccessible arsenic in excess of 180 mg/kg is especially recommended (action level for construction/trench work exposure).

Soils that fall into this category but cannot be disposed offsite due to technical and/or cost constraints should be placed in *soil isolation areas*. Optimally, a soil isolation area would be created under public buildings, private roadways, parking lots and other facilities/structures that constitute a permanent physical barrier that residents are unlikely to disturb in the future. Isolation of R-3 soils under public roadways should be done in coordination with the local transportation authority. Isolation of R-3 soils under permanent structures is preferable to isolation in open areas, due to the increased potential for open areas to be inadvertently disturbed during future gardening, landscaping or subsurface utility work. Soil that cannot be placed under a permanent structure or disposed of offsite should be isolated in well-controlled common areas, rather than on individual residential lots. Contaminated soil should be consolidated in as few isolation areas as possible. Areas where R-3 soils are placed and capped for permanent onsite management must be clearly identified on surveyed, post-redevelopment map(s) of the property. These maps should be included a risk management plan that is provided to HDOH for inclusion in the public file for the site (see "Identification of Soil Isolation Areas" below). Utility corridors should be backfilled with clean fill

material (e.g., R-1 soils) when initially installed or following maintenance work in order to prevent excavation and inappropriate reuse of contaminated soil in the future.

Depending on site-specific conditions, permanent covers or caps for soil isolation areas may be constructed of paving materials such as asphalt and concrete ("hard cap") or earthen fill material ("soil cap") that meets R-1 (preferred) or R-2 action levels. A soil cap thickness of 24 inches is recommended for areas where landscaping activities may involve digging deeper than one foot or where gardens may be planted in the future (based on USEPA guidance for lead-contaminated soils, USEPA 2003). A cap of twelve inches may be acceptable in high-density residential redevelopments where gardens will not be allowed and use of the area will be strictly controlled. A clearly identifiable, marker barrier that cannot be easily penetrated with shovels or other handheld digging tools (e.g., orange construction fencing or geotextile webbing) should be placed between the contaminated soil and the overlying clean fill material. A similar marker barrier should be placed below or above gravel, concrete or other hard material placed on top of contaminated soil in order to avoid confusion with former building foundations or road beds.

Permeable marker barriers may be necessary in areas of high rainfall in order to prevent ponding of water during wet seasons. Leaching tests should be carried out on R-3 soils in order to evaluate potential impacts to groundwater (see discussion below).

When R-3 soils are identified at existing homes, removal or permanent capping of the soils should be strongly considered. In the interim, residents should follow the measures outlined for residential R-2 soils to minimize their daily exposure. Children should avoid areas of bare soil and regular work in garden areas.

Soil Categories and Action Levels for use at Commercial/Industrial Sites

Category 1 Soils (C-1): Bioaccessible Arsenic >4.2 mg/kg and ≤19 mg/kg, No Further Action

Long-term exposure to Category 1 (C-1) soils is not considered to pose a significant health risk to workers at commercial or industrial sites. Remediation of soil that exceeds action levels for residential, R-1 (preferred) or R-2 action levels, however, will minimize restrictions on future land use and should be considered when feasible. Note that this may require a more detailed sampling strategy than is typically needed for commercial/industrial properties (e.g., decision units 5,000 ft^2 in size or less). Long-term institutional controls to restrict use of property to commercial/industrial purposes may be required if the site will not be investigated to the level of detail required for future, unrestricted land use to ensure that action levels for Category 2 Residential soils are not exceeded

Category 2 Soils (C-2): Bioaccessible Arsenic >19 mg/kg and ≤95 mg/kg, Consider Removal or Isolation

Long-term exposure to Category 2 (C-2) soils is not considered to pose a significant risk to workers provided that lawns and landscaping are maintained to minimize exposure and control fugitive dust or if the soils. Remediation of commercial/industrial properties to action levels approaching those for C-1 soils or lower is recommended when technically and economically feasible, however, and should be discussed with the HEER office on a site-by-site basis. When selecting remedial options, long-term effectiveness should be given increasing weight as concentrations of bioaccessible arsenic approach the upper boundary for C-2 soils.

For new developments, isolation of C-2 soils under buildings, private roadways and other areas with a permanent cap that workers are unlikely to disturb in the future is recommended when feasible.

Isolation of C-2 soils under public roadways should be done in coordination with the local transportation authority. Offsite reuse of C-2 soil as fill material should be avoided. Reuse of some or all of the soil as daily cover in a regulated landfill may be feasible, however. This should be discussed with the landfill in question as well as with the HDOH Solid and Hazardous Waste Branch. Areas of the property where capped or uncapped C-2 soil is located must be clearly identified on surveyed, post-redevelopment map(s) of the property and included in a risk management plan that is documented in the HDOH public file for the site (see "Identification of Soil Isolation Areas" below). Care must be taken to ensure that soil from these areas is not excavated and inadvertently reused in offsite areas where residents could be exposed on a regular basis. Utility corridors should be backfilled with clean fill material (e.g., R-1 soils) when initially installed or following maintenance work in order to prevent excavation and inappropriate reuse of contaminated soil in the future.

At existing facilities, areas of bare C-2 soils should be minimized by maintaining grass or other vegetative cover or by covering bare areas with gravel or pavement. Workers should be encouraged to maintain clean work areas and thoroughly wash hands before breaks and meals.

Category 3 Soils (C-3): Bioaccessible Arsenic >95 mg/kg, Removal or Isolation Recommended
Long-term exposure to Category 3 (C-3) soils is considered to pose potentially significant health risks to workers at commercial or industrial sites. Offsite disposal of C-3 soils is recommended when technically and economically feasible. Offsite disposal of soil with bioaccessible arsenic in excess of 180 mg/kg is especially recommended (action level for construction/trench work exposure). Soil that cannot be removed from the site should be placed in designated isolation areas under public buildings, private roadways, parking lots and other facilities/structures that constitute a permanent physical barrier that residents are unlikely to disturb in the future. Contaminated soil should be consolidated in as few isolation areas as possible. Areas of the property where C-3 soil is located must be clearly identified on surveyed, post-redevelopment map(s) of the property and included in a risk management plan that is documented in the HDOH public file for the site (see"Identification of Soil Isolation Areas" below). Care must be taken to ensure that soil from these areas is not excavated and inadvertently reused in offsite areas where residents could be exposed on a regular basis. Utility corridors should be backfilled with clean fill material (e.g., R-1 soils) in order to prevent inadvertent excavation and reuse of contaminated soil in other areas in the future.

As discussed for residential sites, isolation of contaminated soil under buildings or other permanent structures is preferred over isolation in open areas. If placement of the soil in an open area is necessary, use of areas that are unlikely to be disturbed in the future is preferred. A minimum cap thickness of twelve inches is generally acceptable for commercial/industrial sites where use of the area will be strictly controlled (USEPA 2003). A clearly identifiable marker barrier should be placed between the contaminated soil and the overlying clean fill material (e.g., orange construction fencing or geotextile webbing). Fencing, geotextile fabric or similar, easily identifiable markers should likewise be placed above any gravel, concrete or other hard material placed on top of contaminated soil in order to avoid confusion with former building foundations or road beds.

Use of Total Arsenic Data
Based on data collected to date, it is possible that a significant portion of former sugar cane land situated in areas of high rainfall (e.g., >100 inches per year) will fall into the R-2 or C-2 soil categories as described above and summarized in Tables 1 and 2. Some of these areas have already

been redeveloped for residential houses. Determination of bioaccessible arsenic levels on individual lots with existing homes may not be economically feasible for some residents (current analytical costs $500 to $1000). If site-specific, bioaccessible arsenic data is not affordable for a private homeowner, HDOH recommends that the soil be tested for total arsenic (generally less than $100). The resulting data should then be adjusted using a default *bioavailability* value to estimate bioavailable arsenic concentrations. Based on data collected to date in the Kea'au area, a 10% bioavailability factor (BF) is recommended for total arsenic values at or below 250 mg/kg. Measured concentrations of total arsenic should be multiplied by 0.1 and the adjusted concentration compared to the action levels in Table 1 or Table 2. For total arsenic above 250 mg/kg, a more conservative bioavailability factor of 20% (0.2) is recommended.

For residential sites, this approach corresponds to an upper limit of 42 mg/kg total arsenic for R-1 soils and 230 mg/kg total arsenic for R-2 soils (10% BF used). For commercial/industrial sites, this corresponds to an upper limit of 190 mg/kg total arsenic for C-1 soils (10% BF used) and 475 mg/kg total arsenic for C-2 soils (20% BF used). Soils that potentially fall into Category 3 for residential or commercial/industrial sites should be tested for bioaccessible arsenic if at all possible. In the absence of bioaccessibility data, it is recommended that children avoid playing or working in gardens or other areas where total arsenic action levels indicate the potential presence of R-3 soils. The default bioaccessibility factors presented were developed based on data from the Kea'au region and are subject to revision as more data becomes available.

The total arsenic action levels proposed above should not be used for general screening purposes at sites where a formal environmental investigation is being carried out. As previously discussed and as noted in the summary tables, bioaccessible arsenic data should be collected at all sites where total arsenic concentrations exceed an assumed background concentration of 20 mg/kg unless otherwise approved by HDOH.

Identification of Soil Isolation Areas

Isolation areas where arsenic-contaminated soils has been capped for permanent onsite management must be clearly identified on surveyed, post-redevelopment map(s) of the property. Areas of soil at commercial/industrial sites that exceed action levels for residential R-1, R-2 and R-3 soils should also be clearly surveyed and mapped. The maps identifying arsenic-impacted soils should be incorporated into a Risk Management Plan that describes proper management, reuse and disposal of contaminated soil if disturbed during later redevelopment activities. A copy of the plan should be submitted to both HDOH and to the agency(s) that grants permits for construction, trenching, grading or any other activities that could involve future disturbance or excavation of the soil. The need to incorporate the risk management plan and specific land use restrictions in a formal covenant to the property deed should be discussed with HDOH on a site-by-site basis.

Soil Sampling Methods

The use of multi-increment field soil sampling and lab sub-sampling techniques is recommended over the use of discrete or traditional composite sampling techniques. This sampling approach allows for the determination of a statistically "representative" mean arsenic level across a specific area of investigation, such as an individual yard, a park, a garden or any other well-defined "decision unit." It is important that the laboratory used to analyze the soil samples is set up to handle the increased sample mass and carry out the additional sub-sampling required by the method. Formal guidance on multi-increment sampling techniques is currently being prepared by HDOH

and will be made available to the general public when completed. In the interim, contact John Peard of the HEER office for additional information (john.peard@doh.hawaii.gov).

Other Potential Environmental Concerns

The action levels presented in this technical report do not address potential leaching of arsenic from soil and subsequent impacts to underlying groundwater or potential toxicity to terrestrial flora and fauna. These issues should be evaluated on a site-specific basis as directed by HDOH. Based on data collected to date, leaching of arsenic from former sugar cane fields is not anticipated to pose a significant concern in Hawai‘i due to the apparent, relative immobility of the arsenic. Additional field data are needed to support this assumption, however, particularly for soils that exceed the upper action level for R-2 residential soils (i.e., >23 mg/kg bioaccessible arsenic). HDOH recommends that potential leaching of arsenic from soils that exceed 23 mg/kg bioaccessible arsenic be evaluated using the USEPA Synthetic Precipitation Leaching Procedure (SPLP) test or a comparable method. Total arsenic in soil must also be analyzed. SPLP data cannot be directly compared to target groundwater action levels. Instead, the data should be used to calculate a soil-specific sorption coefficient (kd) for arsenic (USEPA 1999). The measured kd value and total arsenic concentration can then be input put into a simple, soil leaching model (e.g., HDOH QUICKSOIL spreadsheet). The results of the model can then be compared to target groundwater action levels. HDOH is currently preparing guidance to assist in carrying out SPLP soil leaching evaluations. Contact Roger Brewer of the HEER office for additional information (roger.brewer@doh.hawaii.gov).

Assessment of additional pesticides and pesticide-related contaminants in agricultural areas should be carried out as needed based on the past use of the property. Pesticides and related contaminants commonly identified in former ag land soils and/or underlying groundwater in Hawai‘i include atrazine, dalapon, DBCP, 2,4-D, dieldrin, dioxins, EDB, hexazinone, isophorone, pentachlorophenol, simazine, 2,4,5-P and TCP (refer also to HDOH 2006). Action levels for several contaminants not included in the May 2005 EAL document are currently being prepared by HDOH. In the interim, guidance provided in that document should be followed to prepare site-specific action levels for all potential environmental concerns potentially related to the contaminants of interest (e.g., direct exposure, leaching from soil and impacts to groundwater, drinking water concerns, aquatic toxicity concerns, etc.).

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Table 1. Soil categories and recommended actions for Residential Sites.

Total Arsenic (≤ 2 mm size fraction)	**Action**
≤20 mg/kg	Within range of natural background. No further action required and no restrictions on land use.
>20 mg/kg	Exceeds typical background. Re-evaluate local background data as available. Test soil for bioaccessible arsenic if background is potentially exceeded.
Bioaccessible Arsenic (≤250μm size fraction)	**Action**
R-1 Soils (≤4.2 mg/kg)	No further action required and no restrictions on land use.
R-2 Soils (>4.2 but ≤23 mg/kg)	Remedial actions vary depending on site-specific factors, including current and planned use, available options for onsite isolation or offsite disposal, and technical and economical constraints (see text). Potential actions include: Consider removal and offsite disposal of small, easily identifiable "hot spots" when possible in order to reduce the average concentration of bioaccessible arsenic on the property. Use of soil as daily cover at a regulated landfill may also be possible. For existing homes, consider capping the soil with one-foot clean fill material (two feet in potential garden areas). If capping of soil is not feasible, consider measures to reduce daily exposure to soil (e.g., maintain lawn cover, ensure good hygiene, thoroughly wash homegrown produce, etc.). For new developments, consider use of soil under house foundations, buildings, private roads or other permanent structures as structural fill when technically and economically feasible. Backfill utility corridors with clean fill material (e.g., R-1 soils) to avoid excavation and inappropriate reuse of the soil in the future. Recommend notice to current and future homeowners of elevated levels of arsenic on the property (e.g., include in information provided to potential buyers during property transactions).
R-3 Soils (>23 mg/kg)	For existing homes, removal or onsite isolation of exposed soil is strongly recommended. Consider a minimum one-foot cover of clean fill material (two feet in potential garden areas) if soil cannot be removed. An easily identifiable marker barrier should be placed between the contaminated soil and the overlying fill (e.g., orange construction fencing or geotextile/geonet material). In the interim, take measures to reduce daily exposure to soil (e.g., maintain lawn cover, ensure good hygiene, thoroughly wash homegrown produce, etc.). Children should avoid areas of bare soil and regular work in gardens areas. For new residential developments, removal and offsite disposal of soil should be strongly considered. At a minimum, consider removal and offsite disposal of soil with concentrations of bioaccessible arsenic that approach or exceed 180 mg/kg (direct exposure action level for construction and trench workers). Use of soil as daily cover at a regulated landfill may be possible if concentrations of bioaccessible arsenic meets

Table 1. Soil categories and recommended actions for Residential Sites (cont.).

R-3 Soils (cont.) (>23 mg/kg)	C-2 commercial/industrial soil criteria. If offsite disposal is not feasible but redevelopment of the property is still desired, consider use of soil as structural fill under public buildings, parking lots, private roads, or other paved and well-controlled structures. If capping in open areas is unavoidable, consider a one-foot minimum cap thickness with an easily definable marker barrier placed between the soil and the overlying clean fill (e.g., orange construction fencing or geotextile fabric). Capping of R-3 soils on newly developed, private lots is not recommended due to difficulties in ensuring long-term management of the soil. Backfill utility corridors with clean fill material (e.g., R-1 soils) to avoid excavation and inappropriate reuse of the soil in the future. Require formal, long-term institutional controls to ensure appropriate management of soil in the future (e.g., Covenants, Conditions and Restrictions (CC&Rs), deed covenants, risk management plans, etc.). All areas of capped soil should be delineated on a surveyed map of the property to be subsequently included in the risk management plan.

The soil categories and arsenic action levels noted above are intended to be used as guidelines only and do not represent strict, regulatory cleanup requirements.

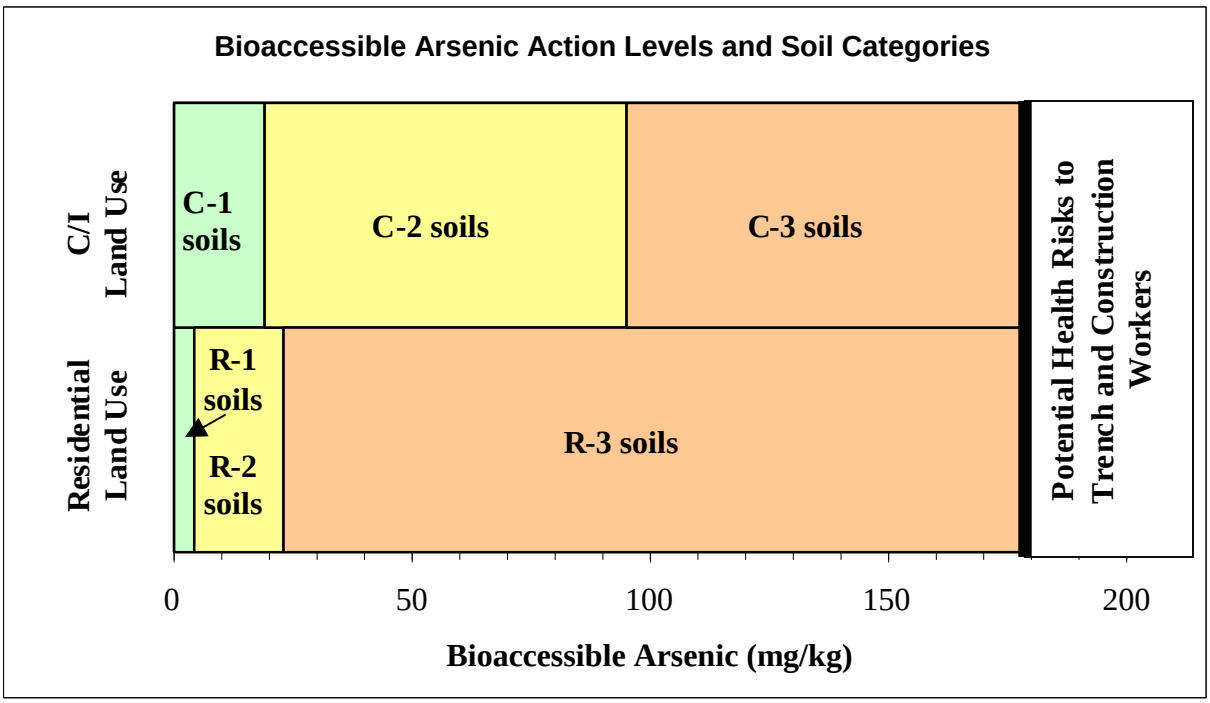
Table 2. Soil categories and recommended actions for Commercial/Industrial Sites.

Total Arsenic (≤ 2 mm size fraction)	**Action**
≤20 mg/kg	Within range of natural background. No further action required and no restrictions on land use.
>20 mg/kg	Exceeds typical background. Re-evaluate local background data as available. Test soil for bioaccessible arsenic if background is potentially exceeded.
Bioaccessible Arsenic (≤250µm size fraction)	**Action**
C-1 Soils (>4.2 mg/kg but ≤19 mg/kg)	No remedial action required. However, consider remediation of commercial/industrial properties to meet Residential R-1 (preferred) or R-2 action levels when feasible in order to minimize restrictions on future land use. Note that this may require a more detailed sampling strategy than typically needed for commercial/industrial properties (e.g., smaller decision units). Require formal, long-term institutional controls to restrict use of property to commercial/industrial purposes if the site will not be investigated to the level of detail required for future, unrestricted land use (i.e., inform potential buyers, deed covenants, risk management plans, etc.).
C-2 Soils (>19 but ≤95 mg/kg)	Remedial actions vary depending on site-specific factors, including current and planned use, available options for onsite isolation or offsite disposal, and technical and economical constraints (see text). Potential actions include: Consider removal and offsite disposal of small, easily identifiable "hot spots" when possible in order to reduce the average concentration of bioaccessible arsenic on the property. Use of C-2 soils as daily cover at a regulated landfill may also be possible. For sites that have already been developed, consider a minimum one-foot cover of clean fill material if the soil cannot be removed. If capping of soil is not feasible, consider measures to reduce daily exposure to soil (e.g., maintain lawn cover, ensure good hygiene, etc.). For new developments, consider isolation of soil under buildings, private roads or other permanent structures if technically and economically feasible. If isolation under permanent structures is not feasible, consider a minimum one-foot cover of clean fill material. Maintain landscaping and lawns in open areas where soil will not be capped. Backfill utility corridors with clean fill material (e.g., R-1 soils) to avoid excavation and inappropriate reuse of contaminated soil in the future. Require formal, long-term institutional controls to restrict use of site to commercial/industrial purposes only and ensure appropriate management of soil if exposed in the future (e.g., inform potential buyers, deed covenants, risk management plans, etc.). All areas of capped soil should be delineated on a surveyed map of the property to be subsequently included in the risk management plan.

Table 2. Soil categories and recommended actions for Commercial/Industrial Sites (cont.).

C-3 Soils (>95 mg/kg)	Removal of soil at existing commercial/industrial sites strongly recommended. At a minimum, consider removal and offsite disposal of soil with concentrations of bioaccessible arsenic that approach or exceed 180 mg/kg (direct exposure action level for construction and trench workers). If C-3 soils cannot be removed for technical or economic reasons, consider a minimum one-foot cover of clean fill material (two feet in potential deep landscaping areas) and placement of an easily identifiable marker barrier between the clean fill and the underlying soil (e.g., orange construction fencing or geotextile/geonet material). For new developments, removal and offsite disposal of soil should be strongly considered. At a minimum, consider removal and offsite disposal of soil with concentrations of bioaccessible arsenic that approach or exceed 180 mg/kg (direct exposure action level for construction and trench workers). If offsite disposal is not feasible but redevelopment of the property is still desired, consider use of soil as structural fill under public buildings, private roads, or other paved and well-controlled structures. If capping in open areas is unavoidable, consider a one-foot minimum cap thickness with an easily definable marker barrier placed between the soil and the overlying clean fill (e.g., orange construction fencing or geotextile/geonet material). Backfill utility corridors with clean fill material (e.g., R-1 soils) to avoid excavation and inappropriate reuse of contaminated soil in the future. Require formal, long-term institutional controls to ensure appropriate management of soil in the future (e.g., inform potential buyers, deed covenants, risk management plans, etc.). All areas of capped soil should be delineated on a surveyed map of the property to be subsequently included in the risk management plan.

The soil categories and arsenic action levels noted above are intended to be used as guidelines only and do not represent strict, regulatory cleanup requirements.



Residential Land Use Soil Categories		Commercial/Industrial Land Use Soil Categories	
R-1	≤4.2 mg/kg	C-1	≤19 mg/kg
R-2	>4.2 mg/kg to ≤23 mg/kg	C-2	>19 mg/kg to ≤95 mg/kg
R-3	>23 mg/kg	C-3	>95 mg/kg
>180 mg/kg: Potential risk to trench & construction workers			

Figure 1. Summary of bioaccessible arsenic action levels and correlative soil categories for residential and commercial/industrial (C/I) land-use scenarios.