Soil Arsenic Assessment Study
Kea‘au, Hawai‘i

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ASTM	American Society for Testing & Materials
CEC	Cation Exchange Capacity
COC	Chain of Custody
DI	Deionized Water
ESA	Environmental Site Assessment
GPS	Global Positioning System
HDOH	Hawaii Department of Health
HDPE	High-Density Polyethylene
HSP	Health and Safety Plan
ICP	Inductively Coupled Plasma
IDW	Investigation Derived Waste
LCS	Laboratory Control Sample
mg/kg	milligrams/kilogram
MS/MSD	Matrix Spike/Matrix Spike Duplicate
NCA	North Creek Analytical Laboratory
NIST	National Institute of Standards and Technology
pH	Potential of Hydrogen
PRDL	Project Required Detection Limit
QA/QC	Quality Assurance/Quality Control
SAP	Sampling and Analysis Plan
SAS	Soil Assessment Study
SOM	Soil Organic Matter
SRM	Standard Reference Material
TCLP	Toxicity Characteristic Leaching Procedure
UCL	Upper Confidence Level
UIC	Underground Injection Control Line
USCS	Unified Soil Classification System
USDA	United States Department of Agriculture
USEPA/EPA	United States Environmental Protection Agency

FORWARD

Field work detailed in this report was conducted in late 2004 and 2005 by the Hawaiʻi Department of Health (HDOH) Hazard Evaluation & Emergency Response Office (HEER Office) together with HDOH contractors from AMEC Earth and Environmental, Inc. (AMEC) under a non-emergency response contract (ASO Log No. 98-418). A draft report was developed by AMEC in 2005, and a community meeting was subsequently held by the HEER Office in Keaʻau to describe the findings of the soil arsenic testing. This report finalizes documentation of the work conducted in 2004 and 2005, and updates the report with information on produce testing (April and August 2005), additional evidence supporting the use of soil arsenic bioavailability in the Keaʻau area (2006 and 2007), and on HEER Office guidance relating to use and interpretation of soil arsenic bioaccessibility testing results (August 2006).

The HEER Office would like to acknowledge the cooperation of the State Department of Education, W.H. Shipman, Ltd., and other private landowners for providing access to their properties for soil testing in the Keaʻau area.

EXECUTIVE SUMMARY

This report summarizes an investigation carried out in 2004 and 2005 to examine soil arsenic levels in a number of areas around the town of Kea`au, Hawai`i (located near Hilo). The investigation focused on areas formerly used to cultivate sugarcane that are now used by residents on a regular basis. The investigation was undertaken by the Hawai`i Department of Health (HDOH), Hazard Evaluation and Emergency Response Office (HEER Office) with the assistance of an environmental consulting firm (AMEC Earth and Environmental, Inc.). The goals of the investigation included:

- Identify average total arsenic levels in surface soils of public areas where Kea`au residents may come in contact with soils on a regular basis, including schools, parks, and community gardens.

- Identify average total arsenic levels in surface soils of undeveloped land adjacent to residential subdivisions. This was used to estimate arsenic levels in surface soils that were present before individual residences were developed.

- Estimate the amount of *bioaccessible* arsenic in surface soils, and examine soil chemistry and physical properties that may influence arsenic bioaccessibility.

Soils were tested for both total and bioaccessible arsenic in order to better evaluate potential risks to human health. The investigation also included the use of multi-increment soil sample collection techniques to better estimate representative total and bioaccessible arsenic levels across the specific areas sampled, or "decision units".

A total of 18 decision units were evaluated, ranging is size from approximately 4,000 square feet to 1 acre in size. A multi-increment soil sample was collected from the 0-3 inch depth surface soil interval in each decision unit. Replicate samples were collected in selected decision units in order to evaluate the precision of the field sample collection, lab sub-sampling, and analytical work. The soil samples were air-dried and sieved to the <2mm particle size in the lab before sub-sampling and analysis for total arsenic. Soil chemistry and physical properties were also evaluated for the <2mm soil particle size fraction. Soil samples were further sieved to <250 μm particle size for bioaccessibility analyses.

Total arsenic concentrations in surface soils collected at the 0-3 inch depth in the 18 decision units ranged from 0.7 mg/kg to 366 mg/kg (dry weight). The community garden decision units contained the highest concentrations of total arsenic (mean 331 mg/kg, n=3), followed by undeveloped land adjacent to residential subdivisions (mean 278 mg/kg, n=6), parks (mean 121 mg/kg, n=3) and schools (mean 37.0, n=6).

Concentrations of total arsenic in the surface soils of 13 of the 18 decision units sampled exceeded the HDOH soil arsenic Environmental Action Level of 20 mg/kg (EAL, or initial soil screening level established by the HEER Office). Exceeding the 20 mg/kg total arsenic screening level does not necessarily indicate that the arsenic poses adverse health risks at a given site, only that further evaluation is warranted.

Most samples that exceeded the initial screening level of 20 mg/kg were subsequently tested for bioaccessible arsenic. "Bioaccessibility" (in-vitro) laboratory tests are used to estimate the proportion of arsenic that could be stripped from the soil in a person's digestive system and be available for uptake. The fine-grained portion of the soil samples is utilized in the bioaccessibility tests (<250μm particle size). This is believed to be the fraction of soil that humans may be most exposed to, and is most relevant for estimation of risks to human health. Bioaccessibility is then used to estimate "bioavailability," the actual fraction of arsenic in soil that may enter a person's bloodstream, if inadvertently ingested. The fraction of arsenic that is bioavailable is considered to pose potential risks to human health. The remainder is considered to be essentially nontoxic.

Bioaccessible arsenic tests were run on soil samples collected from 12 of the 18 decision units, including 10 decision units that did not pass the initial screening level of 20 mg/kg total arsenic. Enrichment of total arsenic in the fines fraction of the soil was evident in all but one of 12 samples. Arsenic bioaccessibility in the soils ranged from 1.5% to 20% (i.e., 80% to 98.5% of the arsenic in the soil is essentially "nontoxic"). Bioaccessibility was highest in the two community gardens, ranging between 18% and 20% bioaccessible. Arsenic bioaccessibility in the remaining, non-garden decision units ranged from 1.5% to 9.6%.

Actual concentrations of bioaccessible arsenic in decision units were estimated by multiplying the reported total arsenic in the fines soil particle fraction (<250 μm) times the reported bioaccessibility for the same fraction. The concentration of bioaccessible arsenic in soil was then compared to more detailed, risk-based HEER Office soil action levels for residential exposure, and areas investigated were placed into one of three categories.

"Category 1" (bioaccessible arsenic in soil ≤4.3 mg/kg) indicates minimal potential health risk. All but one of the school sites fell into Category 1 (six sites total). No further action is recommended for these areas.

The majority of the undeveloped areas adjacent to residential subdivisions as well as the Kea‘au Elementary School Courtyard fall into “Category 2” (bioaccessible arsenic >4.3 mg/kg but <23 mg/kg). The estimated risk to human health is within the USEPA’s acceptable range. Measures to reduce concentrations of bioaccessible arsenic in impacted soil and/or minimize exposure to the soils are still recommended to the extent practicable, however, based on site-specific conditions. This includes maintaining good hygiene and maintaining landscaping to avoid areas of bare soil.

“Category 3” sites could pose an increased risk of potentially chronic health risks over long periods of continuous exposure (bioaccessible arsenic >23 mg/kg). Both of the community gardens as well as the small garden at the Kea‘au Middle School fell into this category. The undeveloped property located adjacent to Nine Mile/Kea‘au Camp (KE005) marginally fell into this category. Measures to remediate soils, minimize exposures, and/or further evaluate potential for exposure to soils are recommended for Category 3 sites.

Produce from community gardens in the Kea‘au area was also tested. Levels of total arsenic were not significantly different from published data for produce sold in US markets. However, HDOH recommends that produce from gardens with elevated levels of arsenic be thoroughly washed prior to consumption to remove all soil particles. HDOH also recommends that the time spent in these garden areas by young children be minimized in order to reduce exposure to arsenic in soil.

Results of correlation analyses between various soil chemistry/physical parameters and arsenic bioaccessibility were limited by small sample sizes and other complicating factors, but indicated a negative correlation between aluminum (Al) and iron (Fe) and arsenic bioaccessibility, and a positive correlation with magnesium (Mg) and Calcium (Ca). This limited data suggests that strong binding of arsenic to soil particles may be associated with elevated aluminum and iron oxides in soils, and weak binding of arsenic to soil particles may be associated with elevated magnesium and calcium. Higher phosphorus levels were also noted in the two soil samples from community gardens that had the highest bioaccessibility measurements.

Based on the results of this study, further evaluation of soil arsenic in Category 2 and 3 areas is warranted. These evaluations should include a more site-specific review of daily and long-term exposure. Persons currently living or working at Category 2 or 3 sites should be informed of elevated arsenic levels in the soil and means to minimize exposure. In addition, residents or businesses located on Category 3 sites should consider removal of contaminated soil to an approved landfill if practicable or otherwise consider capping the area with clean soil and plants, pavement, new buildings or other means. Developments occurring on Category 2 sites should advise future residents or businesses of the elevated soil arsenic levels and inform them of means to minimize or avoid exposure to soil, as discussed above. Developments occurring on Category 3 sites should incorporate removal or capping of contaminated soil into development plans.

This report will be followed by the results of an HDOH-sponsored exposure study carried out with residents of the Keaʻau area. An expanded evaluation of arsenic exposure concerns will be provided in that report. Completion of the report is anticipated in the spring of 2008.

1 INTRODUCTION

This document presents the data, interpretations, and conclusions resulting from a soil assessment study of elevated arsenic concentrations in surface soil located on portions of former agricultural land, in the town of Kea‘au, on the island of Hawaii (hereafter referred to as the "Site").

1.1 Site Description

Kea‘au is located in the Puna district, on the southeastern side of the Island of Hawaii. Kea‘au is located approximately 9 miles southeast of Hilo, and 8 miles west of the shoreline (Figure 1.1). Kea‘au was the location of the former Ola`a Sugar Company sugar cane plantation. Cultivation of sugar cane in this area began about 1900 and continued until the early 1980's (the Puna Sugar Company took over the former Ola`a Sugar Company plantation in 1960). Arsenic-based herbicides, primarily arsenic trioxide mixed with sodium hydroxide and water, were used by the sugarcane plantation between about 1915 and 1945, and this is the presumed source of elevated soil arsenic levels (>20 mg/kg total arsenic) in the Kea‘au area. Although large-scale sugar cane cultivation is no longer practiced, several small residential communities formerly associated with the sugar mill and referred to as "camps", still exist and are adjacent to former sugar cane fields. These include: Eight and One Half Mile Camp, Nine Mile Camp/Kea‘au Camp, and Nine and One Half Mile Camp.

Other residential neighborhoods located in the Kea‘au vicinity include the Kea‘au Loop, Kea‘au-Kula, and Kea‘au Ag Lots subdivisions. A number of public schools serving a portion of the Puna District have been located in Kea‘au. These schools include the Kea‘au Elementary School, Kea‘au Middle School, Kea‘au High School, and Ke Kula O Nawahiokalaniopuu – a Hawaiian Language Immersion School (Figure 1.2). The population of the Kea‘au area, based on data from the United States Census Bureau, is estimated to be 2,010 (US Census 2004).

1.2 Previous Investigations

Public records indicate that three environmental investigations have been conducted in the Kea‘au area. One of these investigations was conducted under the Hawai‘i State Department of Health's Voluntary Response Program. All of the previous investigations were prepared for W.H Shipman Ltd. Results from these investigations have confirmed arsenic concentrations in the vicinity of Kea‘au above the USEPA Region IX Preliminary Remediation Goals for residential land use of 0.39 mg/kg and the HDOH action level of 20 milligram per kilogram (mg/kg) in soils (latter based on upper limit of background arsenic in soils in Hawai‘i).

In April 2003, M & E Pacific, Inc. conducted a Phase I Environmental Site Assessment (ESA) for W.H. Shipman, Ltd., on a 5-acre parcel proposed for a hotel development in Kea‘au. Six soil samples were collected from the 5-acre parcel and analyzed for arsenic. Arsenic was detected in all six soil samples with concentrations ranging from 50 to 170 mg/kg (M&E Pacific, Inc. 2003).

In November 2003, M & E Pacific, Inc. conducted a remedial investigation for the 5-acre property proposed for hotel development. This investigation was conducted with oversight by the HDOH, under the Voluntary Response Program. A total of 59 surface soil samples were collected at depth of approximately 4-6 inches and 12 subsurface samples at depth of approximately 18-24 inches, on a 60’ by 60’ sampling grid across the parcel. All soil sample data is reported on a dry-weight basis. Surface soil samples ranged from 2.5 mg/kg to 1,930 mg/kg of arsenic, and subsurface soil samples ranged from 19.6 mg/kg to 1,440 mg/kg. (M&E Pacific, Inc. 2004)

During March 2004, GeoEngineers, Inc. conducted a limited soil arsenic assessment study in the Kea‘au area. This investigation assessed arsenic concentrations in lands belonging to W.H. Shipman Ltd. in the vicinity of Kea‘au. The lands sampled in this investigation included the 5-acre parcel proposed for hotel development, various locations in Kea‘au, and potential sources of fill for the hotel site. A total of 21 discrete surface soil samples were obtained from various locations in Kea‘au on property belonging to W.H. Shipman Limited, and from potential fill sources. Each surface sample collected was pulverized and analyzed for arsenic using EPA method 7060A. Surface soil samples located out of the boundaries of the 5-acre parcel proposed for hotel development reported arsenic concentrations ranging from 0.5mg/kg to 407 mg/kg. The sampling locations in the 5-acre parcel for hotel development reported arsenic concentrations of 9.78 mg/kg to 893 mg/kg. Potential borrow sources of fill were sampled from five quarries located at various locations on the Big Island. Concentrations of arsenic from quarries located outside of the Kea‘au area reported arsenic concentrations of 1.29 to 28.2 mg/kg. Puna Rock quarry located in Kea‘au reported the highest concentration of arsenic for borrow material at 114 mg/kg (GeoEngineers 2004).

1.3 Physical Characteristics

1.3.1 Geology and Soils

A number of the sites may have imported soil associated with developments, so the USDA soil classification descriptions for the area may not strictly apply to each individual area sampled (See Figure 1-3).

According to the United States Department of Agriculture (USDA) *Soil Survey of the Island of Hawaii*, soil on the Site is predominantly classified as Ola‘a, extremely stony silty clay loam, with 0 to 20 percent slope (OlD). This soil type is undulating to rolling, and has a dominant slope of about 12 percent. A representative profile of OlD soil shows that the surface layer consists of very dark brown silty clay loam about 16 inches thick. The subsoil is a dark brown extremely stony silty clay loam about 9 inches thick, underlain with A‘a lava. The soil permeability is rapid, run-off is slow, and the erosion hazard is relatively minimal. OlD soil type is suited for sugar cane cultivation (USDA 1972).

In addition to OlD, the sites also included the USDA soil survey classifications OaC, rLW, rKFD, and HoC (Figure 1.3). Ola‘a silty clay loam, 0 to 10 percent slopes (OaC), is similar to OlD, except that the surface layer is nonstony, and the slope is generally less than 10 percent. Stones and cobbles occupy 10 to 20 percent of the soil by volume. This type of soil is used to cultivate sugarcane (USDA 1972).

Lava flows, pahoehoe (rLW), has been mapped as a miscellaneous land type. This lava has a billowy, glassy surface that is relatively smooth, however, in some areas the surface is rough and broken, and there are hummocks and pressure domes. Pahoehoe lava has no soil covering and is typically bare of vegetation except for mosses and lichens. In the areas of higher rainfall, however, scattered ‘ohia trees, ohelo berry, and aalii have gained a foothold in cracks and crevices. Soil type rLW can be found at an elevation from sea level to 13,000 feet.

Keaukaha extremely rocky muck, 6 to 20 percent slopes (rKFD) is found near the city of Hilo. It is undulating to rolling and follows the topography of the underlying pahoehoe lava. Included in mapping for this soil type are small areas of pahoehoe lava flows. Rocky outcrops occupy about 25 percent of the area. In a representative profile the surface layer is very dark brown muck about 8 inches thick. It is underlain by pahoehoe lava bedrock. This soil is strongly acid. The soil above the lava is rapidly permeable. The pahoehoe lava is very slowly permeable, but water moves rapidly through the cracks. Runoff is medium, and the erosion hazard is slight. In places roots are matted over the pahoehoe lava or extend a few feet into the cracks (USDA 1972).

Hilo silty clay loam, 0 to 10 percent slopes (HoC), is low on the windward side of Mauna Kea and is dissected by deep, narrow gulches. In a representative profile the surface layer is dark-brown silty clay loam about 12 inches thick. The subsoil is about 48 inches thick and consists of dark-brown, dark reddish-brown, and very dark grayish-brown silty clay loam. The surface layer is very strongly acid, and the subsoil is strongly acid to medium acid. This soils dehydrates irreversibly into fine gravel-size aggregates. Included in mapping are small areas of shallow soils over pahoehoe lava bedrock. Permeability is rapid, runoff is slow, and the erosion hazard is slight. This soil is used mostly for sugarcane (USDA 1972).

1.3.2 Surface Water Hydrology

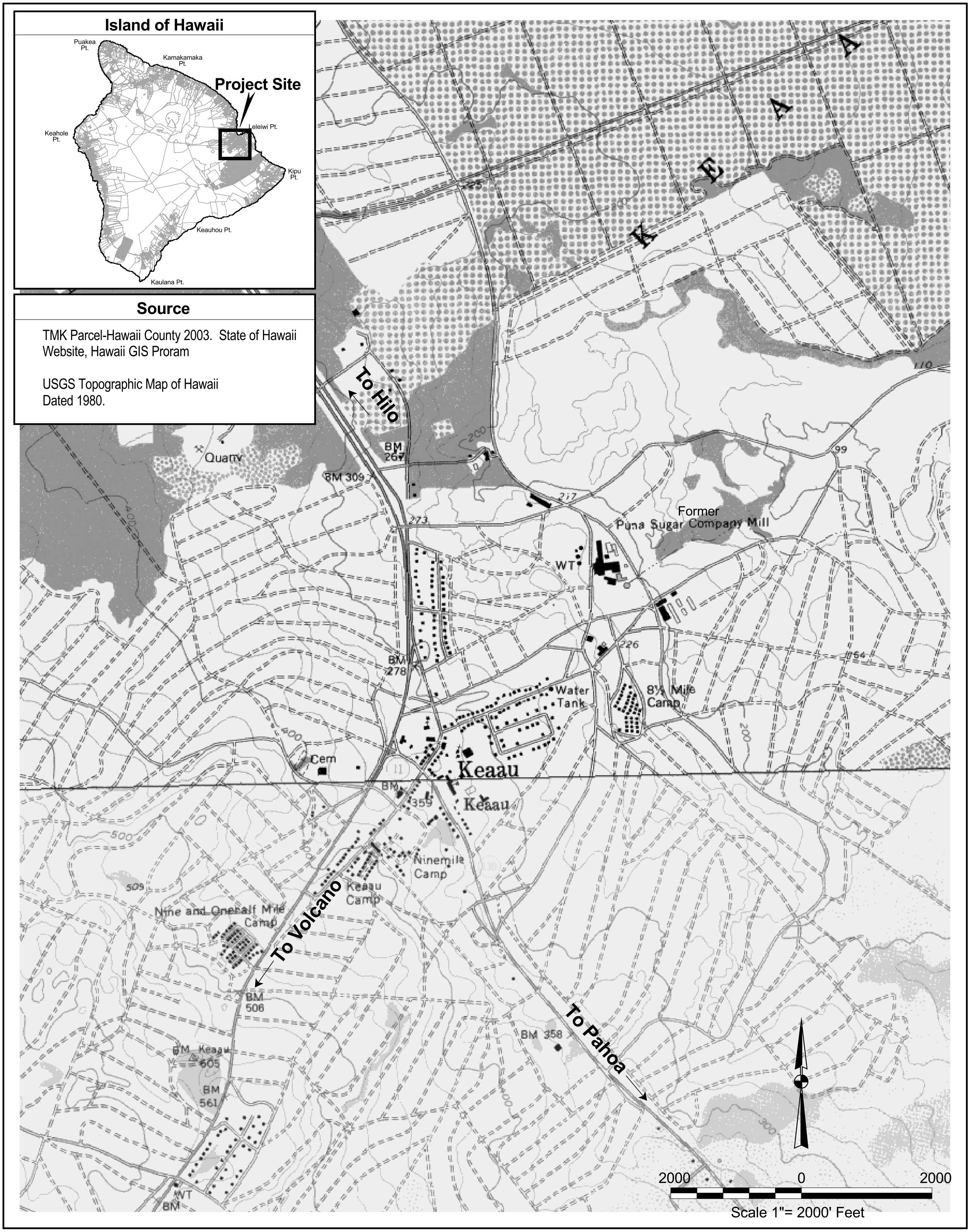
The average annual rainfall for the Site is about 138 inches. In general, on the Island of Hawaii, the average quantity of rainfall decreases at higher elevations, and increases toward the shoreline. Approximately 31% of the rainfall on the Island of Hawaii infiltrates the soil to recharge the groundwater aquifer. Approximately 44% of rainfall is lost to evapotranspiration and 25% is lost to surface run-off (Atlas of Hawaii 1983).

1.3.3 Groundwater Hydrology

The primary hydrogeologic feature within the island of Hawaii is a deep basal, fresh groundwater body floating on, displacing, and existing in dynamic equilibrium with salt water saturating the highly permeable basalt of the land base. This basal groundwater body originates primarily as rainwater percolating into the island from higher drainage basins. The tendency of percolated groundwater is to migrate seaward through zones of the highly permeable basalt rock until it meets the comparatively impermeable caprock that overlaps the seaward margins of basal rock.

The Island of Hawaii is divided into 9 Aquifer Sectors and 24 Aquifer Systems. The Site is located above the Kea‘au Aquifer System, which lies within the Northeast Mauna Loa Aquifer Sector. The Kea‘au Aquifer System is classified by Mink and Lau as unconfined, basal, and flank. The groundwater status is listed as an irreplaceable, currently used, fresh drinking water source that has a high vulnerability to contamination (Mink and Lau 1993).

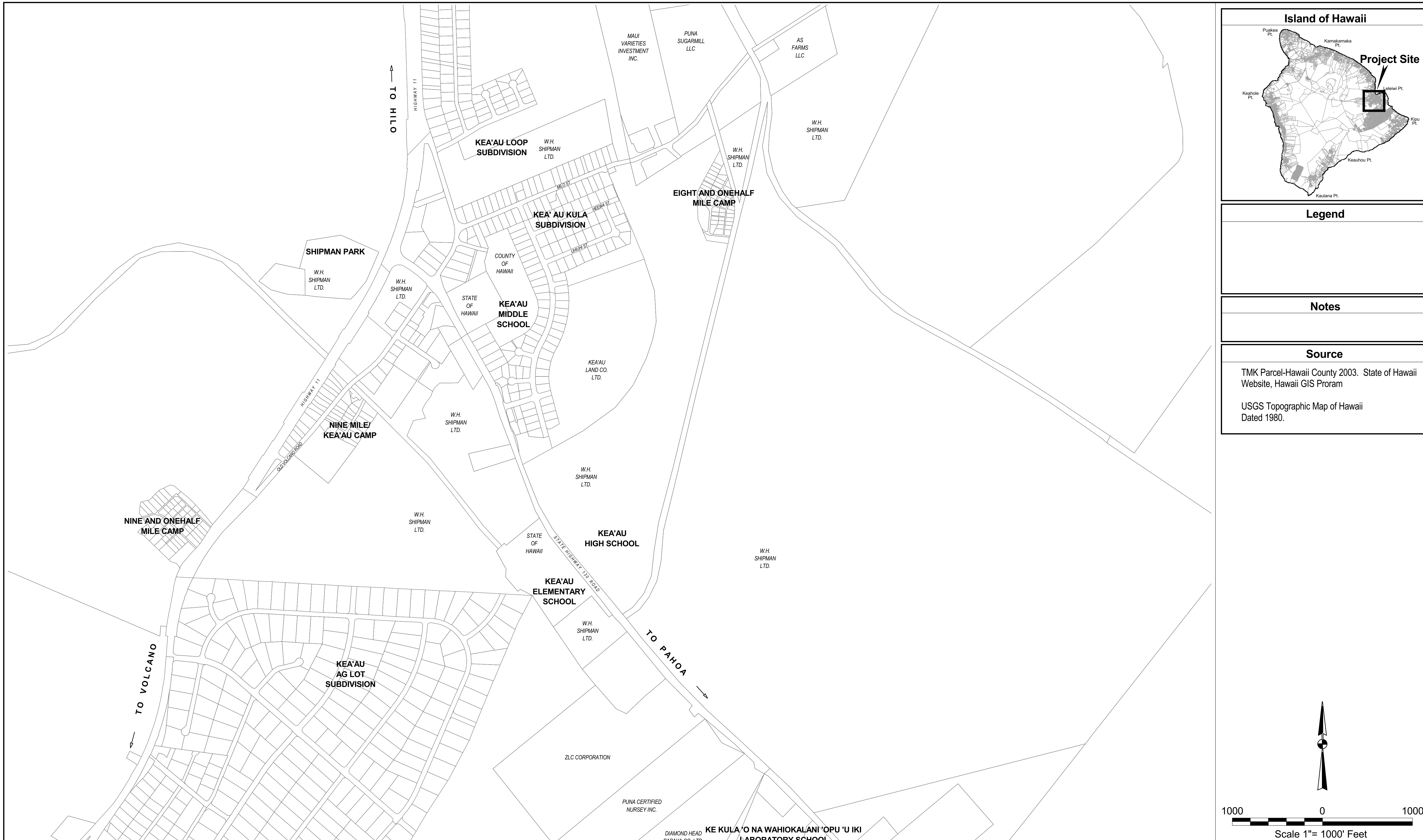
The Site is mauka, or up-gradient, of the Hawaii State Underground Injection Control Line (UIC). The UIC line typically segregates the potable groundwater from the nonpotable groundwater. Since the groundwater below the Site is a drinking water source, limited types of injection wells are allowed on the Site. Based on United States Geological Survey (USGS) data, depth to groundwater is approximately 200 feet below ground surface (USGS 2005).



FIGURE

1-1

Vicinity Map
Kea'au, Hawaii



FIGURE

1-2

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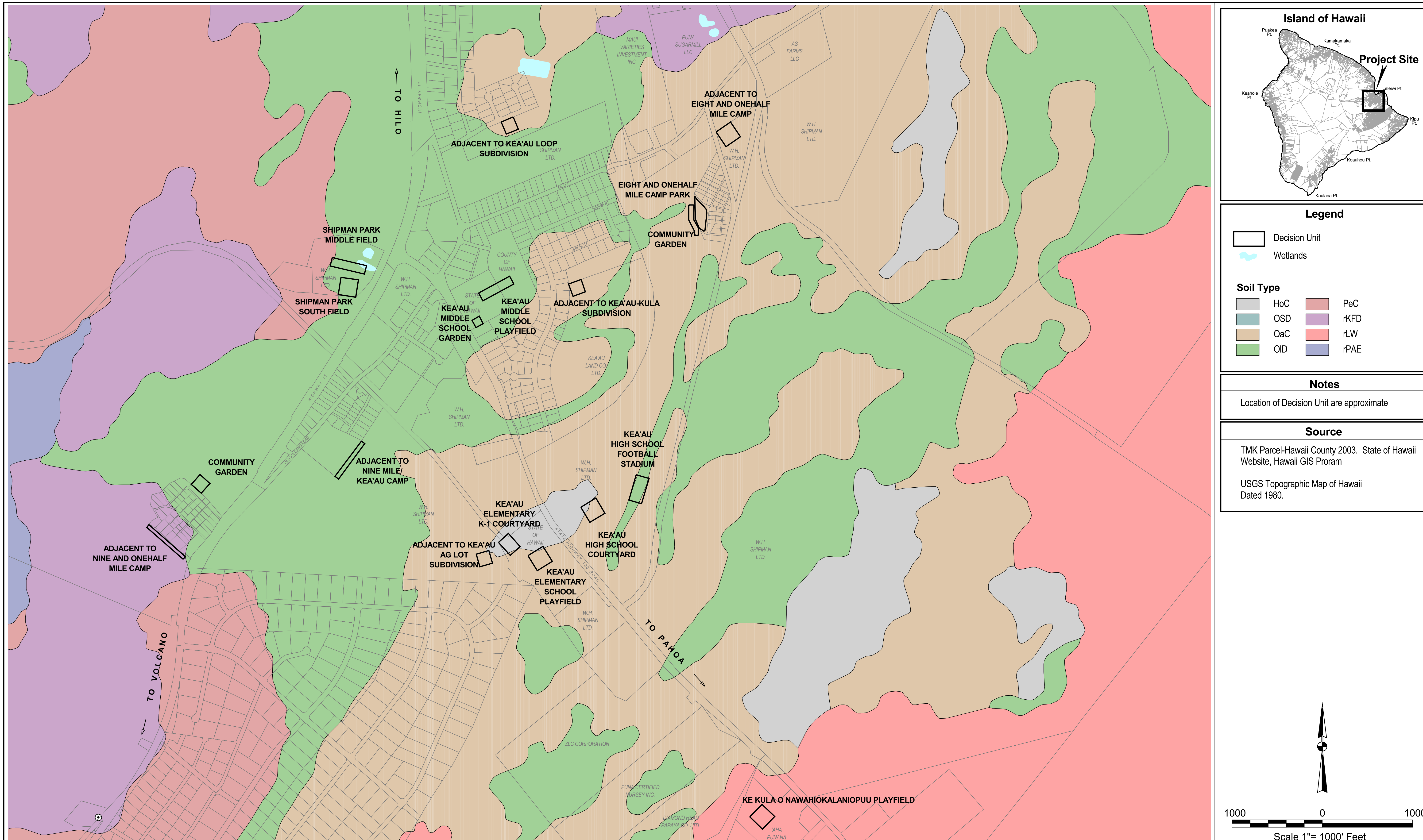
Site Location Map
Kea'au, Hawaii



FIGURE

1-3

Kea'au Soil Map
Kea'au, Hawaii

2 FIELD INVESTIGATION

Field activities were performed in accordance with the Kea‘au Sampling and Analysis Plan (SAP) (AMEC 2004), and the Site-specific health and safety requirements described in the HSP (AMEC 2004). Photographs documenting the field effort are located in Appendix A.

2.1 Investigation Objectives

As a result of the elevated arsenic concentrations in the Kea‘au area discovered in previous environmental investigations, the Hawaii Department of Health initiated a study with the following objectives:

- Determine average levels of arsenic in surface soils of decision units where exposure to surface soil is probable for residents; Also determine average arsenic concentrations in surface soil on undeveloped land adjacent to residential subdivisions;
    - Assess the mean concentration of arsenic in decision units using multi-increment soil sampling techniques; also specify use of multi-increment sampling techniques in the laboratory for sub-sampling soil before analysis. Conduct replicates of multi-increment field samples as well as laboratory sub-sampling to determine the range of error associated with these tasks. Compare total estimated field sampling error + laboratory sub-sampling error + analytical error to the data quality objective of ± 35% error established in the Kea‘au Sampling and Analysis Plan (SAP) (AMEC 2004);
    - If reported concentrations of total arsenic exceed anticipated background levels of arsenic in soil (e.g. if the arsenic levels exceed 20 mg/kg), estimate the percent of bioaccessible arsenic (amount of arsenic accessible for uptake by persons who may incidentally ingest soil) in a subset of samples;
    - Examine soil chemistry and physical parameters that may influence arsenic bioaccessibility in Kea‘au soils;
    - Evaluate the soil arsenic and soil arsenic bioaccessibility data by comparison to HDOH EALs; and

- Identify the need for further action at each of the decision units sampled in the Kea‘au area.

The study objectives identified were intended to help determine the magnitude of elevated levels of arsenic in surface soils, screen the arsenic concentrations against “action levels” indicating potential for long-term health concerns to residents of Kea‘au with regular soil exposure, as well as guide recommendations for avoiding soil arsenic exposures and for additional investigations.

2.2 Identification of Decision Units

On October 7, 2004, one AMEC representative and the HDOH Project Manager performed a site reconnaissance to identify and define decision units for the Site. For the purpose of this study, certain areas within the Kea‘au vicinity were selected as individual “Decision Units”. A decision unit is contiguous area of land within where sampling is focused and unit-specific decisions regarding risk to human health, etc., are made. Decision unit locations were selected based upon the following criteria:

- Locations within the community where public contact to surface soil is considered likely and exposure frequent (areas in schools, parks, and community gardens); and
- Undeveloped areas located adjacent to residential areas.

A total of 18 decision units were evaluated, all located within an approximate 2.5-square mile area in and around the town of Kea‘au. A summary of the decision units including location, size, and USDA soil type is provided in Table 2.1. The locations of the decision units are illustrated on Figure 2.1.

The decision units include areas frequented by residents in the Kea‘au community, such as schools, parks, and community gardens. Twelve decision units were chosen where public contact with surface soil is considered likely and exposure frequent. Six decision units were chosen on undeveloped land adjacent to existing residential areas. These were selected to provide an estimate of what the average arsenic concentrations in the surface soil of the adjacent residential areas may have been before they were developed. The size of the decision units ranged in size from approximately 4,000 sq. ft. to 1-acre, with the majority approximately ½ acre in size.

2.3 Surface Soil Sample Collection

In order to assess the mean concentration of arsenic in 0-3 inch surface soils on decision units, surface soils were collected using a multi-increment sampling approach, with a single multi-increment sample representative of each decision unit. A systematic random sampling design was used to select the increment locations for each decision unit. . Each multi-increment sample was made up of 40-50 equal volume increments at the 0-3 inch soil depth, and collected by using a stainless steel hand trier probe with a 7/8-inch inside diameter at the open end. In addition, on 5 of the 18 decision units a multi-increment field duplicate sample was collected. The multi-increment field duplicates also consisted of 40-50 equal volume increments, however the increments were collected at alternate systematic random locations across the decision units. The increments comprising each multi-increment sample were extracted from the trier probe directly into a large labeled ziplock bag. This ziplock bag was then placed into another ziplock bag, secured with custody seals, and placed into an iced cooler for direct shipment to the analytical laboratory.

Surface soil samples were collected between November 1 and November 5, 2004. Descriptive logs of visually observed surface soils for each decision unit were prepared by the Field Geologist, and described using the Unified Soil Classification System (Appendix B). Enough soil mass was collected for each decision unit (approximately 1 gallon of soil was collected per decision unit) to be analyzed for total arsenic, bioaccessibility, and chemistry/physical analyses of soils.

All samples were sent to the laboratory for analysis of total arsenic. Once the total arsenic data was reviewed, 12 of the 18 samples were selected and submitted for bioaccessibility analysis. The bioaccessibility analysis was performed to estimate how much of the total arsenic concentration found in soil is readily available for absorption by the human body. The <250µm soil fraction was analyzed for bioaccessibility. This is the size fraction most relevant to risk assessment. Total arsenic was determined in the <250µm soil fraction, so enrichment of arsenic in the fine fraction could be determined by comparing to the total arsenic concentrations determined in the <2mm soil samples.

Each sample submitted for bioaccessibility analysis was also submitted for soil chemistry/physical property analysis. Chemical/physical properties of soil analyzed included pH, particle size distribution of soil particles less than 2-mm, and cation exchange capacity. Total and Mehlich 3 analysis was conducted for boron, iron, manganese, copper, zinc, aluminum, calcium, phosphorus, and magnesium.

2.4 Survey of Decision Units

A Global Positioning System (GPS) file was created for each of the eighteen decision units within Kea‘au. GPS points were then taken at the four corners of each decision unit in order to delineate a boundary. A four-corner boundary was established at each decision unit, with the exception of three decision unit areas, as the physical area of the decision unit was too small rendering GPS accuracy ineffective, or the vegetation in the area prevented adequate satellite coverage. However, at least one GPS point was taken at each of these three decision units to identify the approximate location.

2.5 Field Quality Assurance/Quality Control (QA/QC) Procedures

To ensure the integrity of the sample analytical data, the following quality assurance/quality control (QA/QC) field procedures were followed:

- Collecting multi-increment field duplicate samples for 25% of the decision units (5 field duplicates collected for 18 decision units) and submitting these duplicate samples blindly to the laboratory. The multi-increment field duplicates consisted of the same number of increments as the original sample, however the increments were collected at alternate systematic random locations across the decision units;
- Decontaminating all non-disposable field equipment prior to each sample collection with a Liquinox™ solution and a triple- rinse with distilled water and isopropyl alcohol;
- Properly labeling, storing, and handling collected samples;
- Documenting observations and measurements in a bound log book; and
- Documenting sample information on a Chain of Custody (COC).

2.6 Investigation Derived Waste

No hazardous waste was removed from the site. During the investigation, two types of waste were generated: solid and liquid. The solid IDW, principally consisting of used personal protective equipment, was disposed of as municipal trash. Prior to disposal, loose soil was physically removed. Liquid IDW (decontamination rinsate water) was discharged to the ground surface at each Decision Unit, or place of origin. No more than two gallons of rinsate water was generated during equipment decontamination at each decision unit.

2.7 Produce Sample Collection

The uptake of arsenic in produce grown in impacted soils could lead to an increased risk of community exposure to arsenic (USEPA 1999). The correlation between levels of heavy metals in soils and plants is difficult to predict, however. Sampling and testing of homegrown produce for arsenic was therefore carried out to provide site-specific information for Kea‘au residents.

An initial discussion of homegrown produce was carried out with residents during community meetings held in April 2005 with residents of the Eight and a Half Mile Camp and Nine and a Half Mile Camp communities. Representative samples of fruits and vegetables being harvested from the gardens were collected by HDOH staff on two separate occasions (April and August 2005). Samples of produce were also collected in the Kea‘au Middle School garden, although this garden was primarily educational in nature and not depended on as a regular food source. A total of 41 samples of produce were collected, including nine types of fruits (defined as a vegetable that develops from a bloom), eleven types of leafy vegetables and four types of root vegetables. A summary of the types of produce collected is provided in Table 2-2.

The protocol for collection of the samples is included in Appendix C. Produce samples were thoroughly washed with brushes and soapy water, then trimmed and/or peeled in same manner as carried out for cooking and consumption by the residents (refer to Appendix C for preparation of specific types of produce). Prepared samples were placed in double zip-lock bags, frozen and shipped to the Food and Drug Administration laboratory in Lenexa, Kansas for total arsenic analysis.

Table 2.1 Summary of Selected Decision Units (refer also to Figure 2.1)

Description of Decision Units			
Category	**Decision Unit Location**	**Decision Unit Size (in acres)**	**USDA Soil Type**
Schools	Kea‘au High School Football Field Kea‘au High School Courtyard Ke Kula O Nawahiokalaniopuu playfield Kea‘au Elementary K-1 Courtyard Kea‘au Elementary Play Field Kea‘au Middle School Courtyard	1.0 0.5 1.0 0.1 0.5 0.92	OaC/OID* OaC/HoC* rLW* HoC* OaC/HoC* OID*
Parks	Shipman Park South Field Eight and One Half Mile Camp Park Shipman Park Middle Field	1.0 1.0 0.92	OID* OaC OID*
Community Gardens	Eight and One Half Mile Garden Nine and One Half Mile Garden Kea‘au Middle School Garden	0.52 0.52 0.15	OaC OID OID
Undeveloped Land Adjacent to Residential Subdivisions	Adjacent to Nine Mile/Kea‘au Camp Adjacent to Kea‘au Loop Subdivision Adjacent to Kea‘au –Kula Subdivision Adjacent to Nine and One Half Mile Camp Adjacent to Kea‘au Ag Lots Subdivision Adjacent to Eight and One Half Mile Camp	0.57 0.52 0.57 0.5 0.52 0.52	OID OaC OaC rKFD OaC OaC

* These decision units may have imported soils as part of site development, and consequently soil type is more uncertain.

Table 2.2-Summary of Produce Types Collected from Kea‘au Community Gardens and Middle School Garden

Fruits (9)
avocado
banana
bitter melon fruit
eggplant
long squash
papaya
patani bean
pumpkin
string beans
Leafy Vegetables (11)
bamboo shoots
bitter melon leaves
fern shoots
kancun
onion stalk
marangi
mustard cabbage
squash shoots
sweet potato shoots
taro stems
taro leaves
Root Vegetables (4)
casava
onion bulb
sweet potatoes
taro root

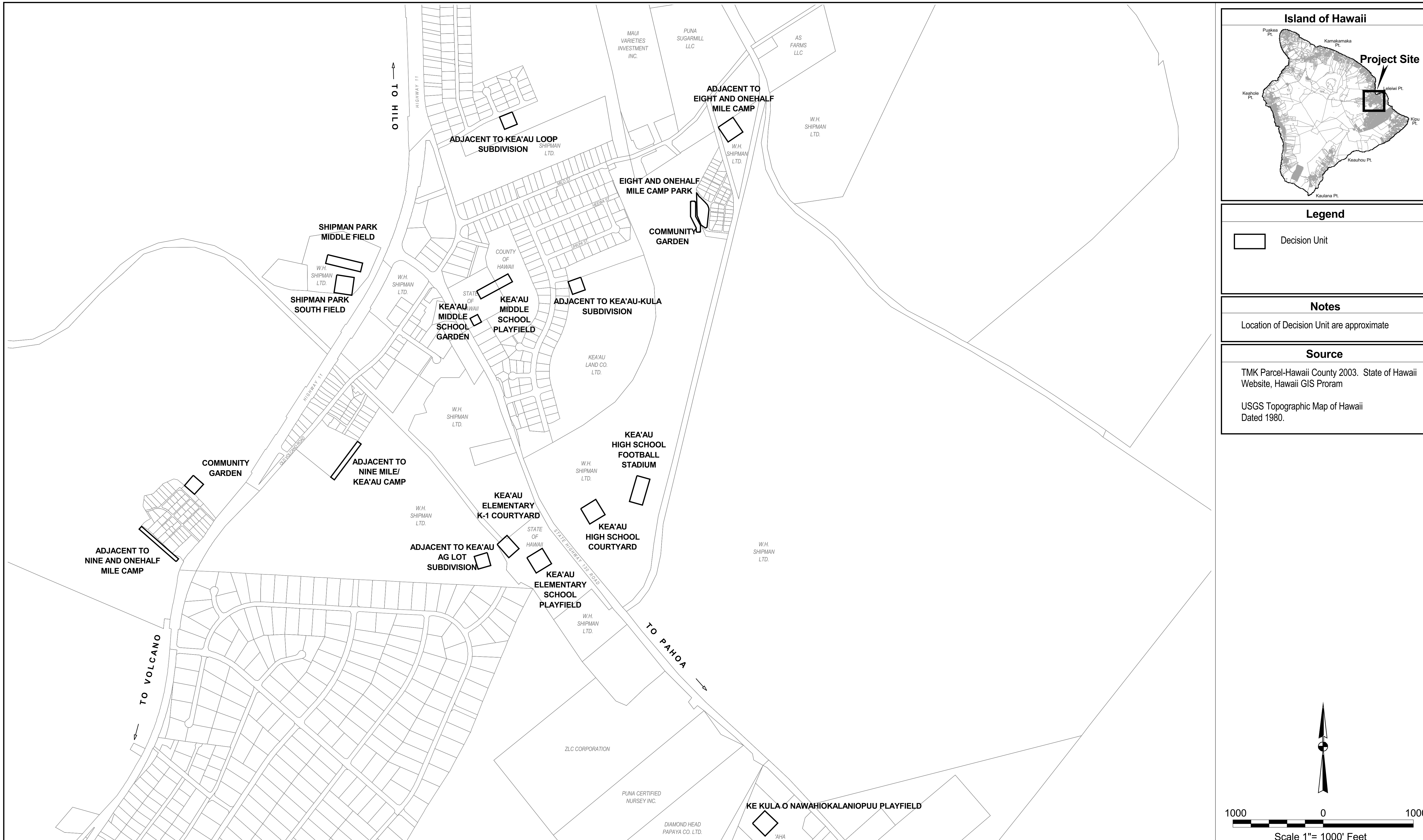


FIGURE **2 - 1**

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Decision Unit of Kea'au Soil Assement
Kea'au, Hawaii

3 ANALYTICAL PROGRAM

The following section outlines the protocols followed by the respective laboratories under the direction of HDOH.

3.1 North creek Analytical Laboratory – Total Inorganic Arsenic Analyses

North Creek Analytical Laboratory was contracted to conduct arsenic analyses of the multi-increment soil samples using a modified USEPA Method 3050B/6020. The modifications to the preparation and analytical methods were made to ensure adequate sample representativeness was obtained, minimize the overall sampling error, and to meet the specific DQO needs of the project. In general, sample analysis mass was increased to the extent practical and multi-increment lab sub-sampling was utilized to reduce the error introduced by inherent sample heterogeneity. The specific procedures used were as follows:

- Weigh entire sample
- Air-dry entire sample contents at 70-80 degrees F for up to 3 days.
- Weigh entire sample again (calculate moisture loss during air-drying).
- Screen entire sample through a 2-mm sieve. Use a clean-gloved hand or clean tool to break up any aggregates in the sieve. If soil is aggregated and resistant to breaking up by hand, put the portion that is resistant to passing through the sieve in a clean mortar/pestle and grind/mix to facilitate sieving process. All material greater than 2mm that does not pass through the sieve should be saved in a clean glass or plastic container for inspection. This container should be labeled with the same sample identification number as the original sample plus a note indicating the contents were larger than 2 mm.
- Spread out the entire sample passing through the 2mm sieve on a clean flat surface, by slowly pouring the sample out and then spreading it to a thin (about ¼ inch) even layer.
- Using a random pattern, incrementally sample the spread-out soil by collecting at least 20 small increments to make up a 5-gram sample for analysis (e.g., 20 increments of 0.25 grams). Collect another 5-gram multi-increment sample (from different random locations of the sample) for a duplicate analysis or digestion. Repeat the incremental sampling process for the sample(s) chosen for the lab duplicate samples or sample(s) for lab matrix spike.

- Using the same random, incremental sampling process, collect a 30-gram sub-sample of the soil (e.g., 30 one gram increments) and place in a clean glass or plastic jar to send to another lab for arsenic bioaccessibility testing. Label this sample with the same sample identification information as the original sample, with an added note "for bioaccessibility testing".

- Next, collect a 10-gram sub-sample of the soil to conduct a % moisture content analysis of the air-dried soil.

The remaining sample should be transferred to the original sample container (with original label) and archived at 4-6 degrees C.

- Digest the two 5-gram portions for each soil sample (and any lab duplicates and matrix spikes) utilizing EPA preparation method 3050B. Analyze each 5-gram sample separately (ten of the 23 samples submitted were sampled and analyzed in this manner). Alternately, combine the digestion extracts of the two 5-gram portions for a 10-gram sample analysis (thirteen of the 23 samples submitted were sampled and analyzed in this manner). In addition, conduct duplicate multi-increment sub-sampling and analyses for two of the 10-gram sample analyses.

- Note: The lab will also conduct and report on the results of an analysis of a 5-gram digest versus a 2.0 gram digest for a reference material with a known arsenic concentration.

- Analyze sample via EPA method 6020, ICP-MS utilizing octapole "collision cell" instrumentation to minimize potential interferences.

- Report arsenic sample results in mg/kg, dry weight.

- The laboratory reporting limit should be at least 1 mg/kg arsenic, dry weight.

- Lab staff person conducting the incremental soil sampling shall have prior experience at this task.

Report lab QA/QC data associated with the soil arsenic analyses in a data package to include:

- Details on instrument calibration, calibration checks, calibration verification criteria, and documentation that all samples analyses were "bracketed" in the linear range of the calibration standards.

- Results of method blank analyses (at least 2)

- Results of laboratory control sample analyses (at least 2)
- Results of matrix spike analyses (at least 2)
- Results of duplicate sample analyses (at least 2)

3.2 Brookside Laboratories – Soil Chemistry and Physical Properties

Brookside Laboratories Inc. was contracted to conduct soil chemistry and physical property analyses. Table 3.1 lists the different analyses used by Brookside.

QA/QC procedures utilized by Brookside included:

- Dedicated QC officers in the soils, agricultural, and environmental labs;
- Duplicate samples for physical analysis done under the A2LA certification;
- Routine check samples;
- SPEX standards; and
- Multiple blind QC samples done daily.

3.3 Exponent Laboratory – Bioaccessibility Testing

Exponent Laboratory was contracted to conduct bioaccessibility analyses and total arsenic analyses for the <250-µm soil fractions. The bioaccessibility analysis attempts to simulate gastrointestinal digestion by digesting soil samples in an acidic solution similar to stomach acid and the intestinal tract. The *in vitro* laboratory procedure determines an estimated bioaccessibility value for arsenic in soil (i.e., the fraction that would be soluble in the gastrointestinal tract and available for human absorption). Quality control elements of the bioaccessibility testing method included reagent and bottle blanks, blank spikes, duplicates, and a laboratory control sample. Appendix D contains a detailed description of the bioaccessibility procedures and QA/QC.

3.4 FDA Produce Testing

A total of 41 produce samples from the Eight and a Half Mile Camp and Nine and a Half Mile Camp community gardens and the Kea'au Middle School garden were shipped to the Federal Food and Drug Administration laboratory in Kansas for total arsenic analysis. A summary of the protocol used to test the produce is included in Appendix C.

Table 3-1. Soil Chemistry and Physical Property Analyses

Analysis	Method Number	Grams of Soil Utilized
Particle Size Distribution	ASTM D422	100 g
Total Organic Carbon	Walkley Black	1 g
Cation Exchange Capacity	EPA 9081	5 g
PH	EPA 9045	5 g
Metals (Mn, Mg, Ca, P, Fe, Al)	EPA 6010B	2-4 g*

* Both 0.5-1 gram as well as 2-4 gram sample sizes were analyzed. Based on the results, the 2-4 gram sample data was utilized.

4 RESULTS

Note: Tables and figures referenced are presented at the end of the chapter.

4.1 Total Arsenic (<2mm Soil Fraction)

North Creek Analytical (NCA) conducted the initial analyses with a 2mm particle size to determine total inorganic arsenic concentrations in all soil samples. Laboratory analytical reports can be found in Appendix E. Table 4.1 presents the results of these analyses by categorical land use. The four land use categories include community gardens, undeveloped land adjacent to residential subdivisions, parks, and schools. A total of 18 primary multi-increment samples and 5 field duplicate samples were collected to determine the average total arsenic concentrations in the decision units:

- 3 primary multi-increment samples and 1 multi-increment field duplicate were collected from community garden decision units;
- 6 primary multi-increment samples and 2 multi-increment field duplicates were collected from the decision units adjacent to residential subdivisions;
- 3 primary multi-increment samples and 1 multi-increment field duplicate were collected from park decision units; and
- 6 primary multi-increment samples and 1 multi-increment field duplicate were collected from decision units on school properties.

On average, the highest arsenic concentrations were found in the community gardens category, with all three samples displaying relatively similar concentrations (compared to the other categories). Concentrations were between 304 mg/kg and 366 mg/kg, with an average of 331 mg/kg, and a standard deviation of 31.6.

The category of decision units of undeveloped land adjacent to residential subdivisions had the second highest average arsenic concentrations in soil, with 278 mg/kg. Mean arsenic concentrations of the decision units ranged from 187 mg/kg to 361 mg/kg, with a standard deviation of 59.9.

The three park decision units displayed considerable variation in mean arsenic concentrations, with values ranging from 15.3 to 208 mg/kg, an average of 121 mg/kg, and a standard deviation of 97.4.

The school decision units had mean arsenic concentrations ranging from 0.7 to 131 mg/kg, an average of 37.0 mg/kg, and a standard deviation of 47.8. The low levels of arsenic found in surface soils of the school decision units is likely the result of site preparation and development history, and/or the use of imported soil and cinder for landscaping school property.

4.2 Total Arsenic (<250-µm Soil Fraction)

Total arsenic concentrations in the <250µm size soil fractions are presented in Table 4.2. Total arsenic analysis was conducted by Exponent for the <250-µm diameter soil size fraction. A soil fraction of <250µm was chosen because it is generally accepted in human health risk assessment to be the soil size fraction most relevant to human health. For example, it is presumed to be the size fraction more likely to adhere to hands and is therefore more likely to be ingested. Multi-increment samples from 12 of the 18 decision units were selected for additional arsenic analyses and bioaccessibility analyses of the fines fraction (<250µm). Two of these were split to provide quality assurance duplicates (KE010 duplicated by KE026 and KE017 duplicated by KE027). Analyses of total arsenic in the <250-µm size fractions were conducted by Columbia Analytical Services, Inc.

4.3 Arsenic Enrichment in Fine Soil Fraction

Table 4.3 presents total As data for the <2mm and <250µm size soil fractions and the percent arsenic enrichment in the fines. Comparison of As results conducted for the <2mm soil size fraction and the <250µm soil size fraction revealed an obvious and significant trend.

An analysis of the <250µm size fraction resulted in higher concentrations of arsenic per decision unit. It is suspected that this is due to the greater total surface area available for binding arsenic within smaller sized soil particles. All of the 12 samples analyzed at size fractions of <2mm and <250µm showed an increase in total arsenic concentration when comparing the smaller fraction size to the larger fraction analysis. On average the arsenic concentration increased by 82%, with increases ranging from 4% to 276%.

The mean As concentration for all samples in the <250µm size fraction was 299 mg/kg. Excluding samples from the garden category, the mean was 249 mg/kg. The mean +95% UCL for the <250µm size fraction was 428 mg/kg. Excluding samples from the garden category, the mean +95% UCL was 378 mg/kg.

The mean As concentration for all samples in the <2mm size fraction was 200 mg/kg. Excluding samples from the garden category, the mean was 170 mg/kg. The mean +95% UCL for the <2mm size fraction was 284 mg/kg. Excluding samples from the garden category, the mean +95% UCL was 260 mg/kg.

4.4 Bioaccessible Arsenic Analyses Results

Arsenic bioaccessibility data are presented in Table 4.4. Multi-increment samples from 12 of the 18 decision units (and two duplicate multi-increment samples) were selected for bioaccessibility analysis. Selection criteria included arsenic concentration, soil type and land use category.

The twelve soil samples were analyzed by Exponent to estimate the oral bioavailability of arsenic (i.e., the fraction that would be absorbed within the human body if these soils were ingested). This evaluation involved determining the amount of arsenic that becomes soluble in a simulated gastrointestinal extraction (the *in vitro* extraction test). The extraction procedure involved sequential stomach-phase and intestinal-phase extractions. The measured arsenic bioaccessibility was higher in the stomach-phase extraction than in the intestinal phase extraction for all samples, and assumed more appropriate for estimating bioaccessibility. Therefore, bioaccessibility results and discussion presented in tables and text throughout this report are based on the stomach-phase data. The complete Exponent report is provided in Appendix D.

Clear differences in bioaccessibility were identified between non-garden areas and garden areas. For non-garden areas, the 95% UCL mean bioaccessibility of arsenic in soil is estimated to be 5.4% (ten samples) with a range of 1.0% to 9.6%. Sample KE010 from the Eight and One Half Mile Garden and KE022 from the Kea‘au Middle School Garden displayed elevated levels of bioaccessibility in comparison to other samples, with values of 18% and 16% respectively. Sample KE009 from Eight and One Half Mile Camp Park had the third highest bioaccessibility result at 9.6%. Bioaccessibility in the remaining samples fell between 1% and 5.3%. The mean bioaccessibility for all samples was 5.7%. Excluding the highest two bioaccessibility samples in the community garden category, the mean was 3.5%. The mean +95% UCL bioaccessibility for all samples was 9.3%. Excluding the highest two bioaccessibility samples from the community garden category, the mean was 5.4%

A summary of total arsenic concentration for both the <2mm soil fraction and the <250µm soil fraction versus reported bioaccessibility is provided in Table 4.4. Concentrations of bioaccessible arsenic were estimated from total arsenic concentrations in the enriched soil fraction (<250 µm) and arsenic bioaccessibility percent for the twelve decision units where both types of data were available (Table 4.5). Enrichment and bioaccessibility data were not collected for the remaining six decision units. For these areas, the ranges of enrichment and bioaccessibility data reported for the previous twelve units were used to estimate a range of potential concentrations of bioaccessible arsenic (Table 4.6).

4.5 Soil Chemistry and Physical Properties

General soil chemistry and particle size data were determined for ten of the eighteen soil samples. A summary of the data is provided in Tables 4.7 and 4.8. In Section 5 these data are used to evaluate potential influencing or causal factors for bioaccessibility variation.

4.6 Quality Control Data

Quality Control (QC) data are used to evaluate field sampling error, lab sub-sampling error, and analytical error associated with estimates of the mean arsenic concentrations of the decision units. A summary of the data are provided in Table 4.9.

The average error estimated from the field duplicates was 14.1 % with a range between 3.6% and 21.7%. This falls within the desired data quality objective range for this project (+/- 35%). The average error estimated from the laboratory sub-sampling duplicates was 14.9 % with a range between 4.0% and 40%. The highest individual lab sub-sampling error falls just outside the upper limit of the desired QC range.

4.7 Arsenic in Community Garden Produce

A summary of total arsenic data for produce collected from two community gardens and one school garden in the Kea‘au area is presented in Tables 4.10 and 4.11 (see also Appendix C). Table 4.10 presents data for individual produce types. Table 4.11summarizes data for fruits, leafy vegetables and root vegetables in general. The last column of each table provides typical, total arsenic concentrations in produce published in the Food and Drug Administration (FDA) Market Basket Study (Total Diet Study, FDA 2004).

Table 4.1. Total Arsenic Concentration Results - < 2mm Size Soil Fraction.

Decision Unit	Location	Area of Decision Unit (acre)	Mean Total Arsenic Concentration (mg/kg dry wt)	Soil As Bioaccessibility Evaluated (yes/no)	USDA Soil Type
Community Gardens					
KE010	Eight and One Half Mile Garden	0.52	366	Yes	OaC
KE012/KE013*	Nine and One Half Mile Garden	0.52	304	No	OID
KE022	Kea‘au Middle School Garden	0.15	324	Yes	OID
			Average: 331		
Undeveloped Land Adjacent to Residential Subdivisions					
KE005	Adj. to Nine Mile/Kea‘au Camp	0.57	361	Yes	OID
KE006/KE007*	Adj. to Kea‘au Loop Subdivision	0.52	246	No	OaC
KE008	Adj. to Kea‘au-Kula Subdivision	0.57	311	Yes	OaC
KE011	Adj. to Nine and One Half Mile Camp	0.5	187	Yes	rKFD
KE018	Adj. to Kea‘au Ag Lots Subdivision	0.52	298	Yes	OaC
KE020/KE021*	Adj. to Eight and One Half Mile Camp	0.52	264	No	OaC
			Average: 278		
Parks					
KE001	Shipman Park South Field	1.0	15.3	Yes	OID**
KE009	Eight and One Half Mile Camp Park	1.0	139	Yes	OaC
KE014/KE015*	Shipman Park Middle Field	0.92	208	Yes	OID**
			Average: 121		
Schools					
KE002	Kea‘au High School Football Field	1.0	0.667	No	OaC/OID**
KE003	Kea‘au High School Courtyard	0.5	17.6	No	OaC/HoC**
KE004	Ke Kula O Nawahiokalaniopuu playfield	1.0	16	No	RLW**
KE016	Kea‘au Elementary K-1 Courtyard	0.1	131	Yes	Ho C**
KE017	Kea‘au Elementary Play Field	0.5	16.4	Yes	OaC/HoC**
KE023/KE024*	Kea‘au Middle School Courtyard	0.92	40.1	Yes	OID**
			Average: 37.0		

*** Average of Duplicate Results; ** These decision units may have imported soils and consequently soil type is more uncertain**.

Table 4.2. Total Arsenic Concentration Results <250µm Size Soil Fraction.

Decision Unit	Location	Area of Decision Unit (acre)	Total Arsenic Concentration (mg/kg dry wt)	USDA Soil Type
Community Gardens				
KE010B/KE026B*	Eight and One Half Mile Garden	0.52	467	OaC
KE022B	Kea‘au Middle School Garden	0.15	629	OlD
			Average: 548	
Undeveloped Land Adjacent to Residential Subdivisions				
KE005B	Adj. to Nine Mile/Kea‘au Camp	0.57	569	OlD
KE008B	Adj. to Kea‘au-Kula Subdivision	0.57	494	OaC
KE011B	Adj. to Nine and One Half Mile Camp	0.5	263	rKFD
KE018B	Adj. to Kea‘au Ag Lots Subdivision	0.52	375	OaC
			Average: 425	
Parks				
KE001B	Shipman Park South Field	1.0	57.6	OlD**
KE009B	Eight and One Half Mile Camp Park	1.0	202	OaC
KE014B	Shipman Park Middle Field	0.92	216	OlD**
			Average: 159	
Schools				
KE016B	Kea‘au Elementary K-1 Courtyard	0.1	193	OaC**
KE017B/KE027B*	Kea‘au Elementary Play Field	0.5	61.5	OaC/HoC**
KE023B	Kea‘au Middle School Courtyard	0.92	55.0	OlD**
			Average: 103	

Notes:

* Average of duplicate results.

** These decision units may have imported soils, and consequently soil type is more uncertain.

Table 4.3 Total Soil Arsenic Concentrations (<2mm and <250µm Fractions) and Percent Increase with Reduced Size Soil Fraction

Decision Unit	Location	Total arsenic concentration <2mm Fraction (mg/kg dry wt)	Total arsenic concentration <250µm Fraction (mg/kg dry wt)	Arsenic Concentration Increase with Reduction in Soil Size Fraction (%)
Community Gardens				
KE010*	Eight and One Half Mile Garden	366	467	28%
KE022	Kea'au Middle School Garden	324	629	94%
Undeveloped Land Adjacent to Residential Subdivisions				
KE005	Adj. to Nine Mile/Kea'au Camp	361	569	58%
KE008	Adj. to Kea'au-Kula Subdivision	311	494	59%
KE011	Adj. to Nine and One Half Mile Camp	187	263	41%
KE018	Adj. to Kea'au Ag Lots Subdivision	298	375	26%
Parks				
KE001	Shipman Park South Field	15.3	57.6	276%
KE009	Eight and One Half Mile Camp Park	139	202	45%
KE014	Shipman Park Middle Field	208	216	4%
Schools				
KE016	Kea'au Elementary K-1 Courtyard	131	193	47%
KE017*	Kea'au Elementary Play Field	16.4	61.5	275%
KE023	Kea'au Middle School Courtyard	40.1	55	37%

Notes:

* Average of duplicate results.

Table 4.4. Total Soil Arsenic Concentrations (<2mm and <250μm Size Fractions) and Arsenic Bioaccessibility (<250μm Size Fraction).

Decision Unit	Location	Total Arsenic Concentration <2mm Soil Fraction (mg/kg dry wt)	Total Arsenic Concentration <250μm Fraction (mg/kg dry wt)	Arsenic Bioaccessibility <250μm Fraction (%)
Community Gardens				
KE010*	Eight and One Half Mile Garden	366	467	18%
KE022	Kea‘au Middle School Garden	324	629	16%
Undeveloped Land Adjacent to Residential Subdivisions				
KE005	Adj. to Nine Mile/Kea‘au Camp	361	569	4.2%
KE008	Adj. to Kea‘au-Kula Subdivision	311	494	2.9%
KE011	Adj. to Nine and One Half Mile Camp	187	263	5.2%
KE018	Adj. to Kea‘au Ag Lots Subdivision	298	375	1.2%
Parks				
KE001	Shipman Park South Field	15.3	57.6	1.0%
KE009	Eight and One Half Mile Camp Park	139	216	9.6%
KE014	Shipman Park Middle Field	185	216	2.4%
Schools				
KE016	Kea‘au Elementary K-1 Courtyard	131	193	5.3%
KE017*	Kea‘au Elementary Play Field	16.4	61.5	1.5%
KE023	Kea‘au Middle School Courtyard	44.3	55	1.8%

Notes:

* Average of duplicate results.

Table 4.5. Estimated Bioaccessible Arsenic Concentrations in Decision Units with Both <250µm Size Fraction Soil Data and Bioaccessibility Data

Decision Unit	Location	Total Arsenic Concentration <250-µm Fraction (mg/kg dry wt)	Arsenic Bioaccessibility (%)	[1]Estimated Concentration of Bioaccessible Arsenic <250-µm Fraction (mg/kg)
Community Gardens				
KE010*	Eight and One Half Mile Garden	467	18%	81.7
KE022	Kea‘au Middle School Garden	629	16%	101
Undeveloped Land Adjacent to Residential Subdivisions				
KE005	Adj. to Nine Mile/Kea‘au Camp	569	4.2%	23.9
KE008	Adj. to Kea‘au-Kula Subdivision	494	2.9%	14.3
KE011	Adj. to Nine and One Half Mile Camp	263	5.2%	13.7
KE018	Adj. to Kea‘au Ag Lots Subdivision	375	1.2%	4.50
Parks				
KE001	Shipman Park South Field	57.6	1.0%	0.576
KE009	Eight and One Half Mile Camp Park	216	9.6%	20.7
KE014	Shipman Park Middle Field	216	2.4%	5.18
Schools				
KE016	Kea‘au Elementary K-1 Courtyard	193	5.3%	10.2
KE017*	Kea‘au Elementary Play Field	61.5	1.5%	0.892
KE023	Kea‘au Middle School Courtyard	55	1.8%	0.990

Notes:

* Average of duplicate results.

[1] Reported concentration of total arsenic multiplied by noted bioaccessibility factor.

Table 4.6. Estimated Range of Soil Bioaccessible Arsenic in Decision Units with <2mm Size Fraction Total Arsenic Data Only.

Decision Unit	Location	Reported Total Arsenic Concentration <2-mm Fraction (mg/kg dry wt)	[1]Estimated Range<250 µm Fraction Enrichment (%)	[2]Estimated Range Bioaccessibility (%)	[3]Estimated Range of Bioaccessible Arsenic <250-µm Fraction (mg/kg)
Community Gardens					
KE012/013*	Nine and One Half Mile Garden	*304	28-94%	16-18%	**62-106**
Undeveloped Land Adjacent to Residential Subdivisions					
KE006/KE007*	Adj. to Kea'au Loop Subdivision	*246	4-59%	1.0-9.6%	**2.6-37**
KE020/KE021*	Adj. to Eight and One Half Mile Camp	*264	4-59%	1.0-9.6%	**2.7-40**
Schools					
KE002	Kea'au High School Football Field	0.7	4-59%	1.0-9.6%	0.01-0.11
KE003	Kea'au High School Courtyard	17.6	4-59%	1.0-9.6%	0.2-2.7
KE004	Ke Kula O Nawahiokalaniopuu playfield	16.0	4-59%	1.0-9.6%	0.17-2.44

Notes:

* Average of duplicate results.

[1] Range of enrichment of total arsenic in <250µm size soil fraction reported in twelve decision units tested (see Table 4.3).

[2] Range of bioaccessibility of total arsenic in <250µm size soil fraction reported in similar decision units tested (see Table 4.4).

[3] Reported concentration of total arsenic times enrichment factor (1 + Assumed Enrichment/100%) divided by bioaccessibility factor (expressed as a fraction).

Bold: Estimated range of bioaccessible arsenic concentration exceeds USEPA Region IX PRGs for residential exposure of 39 mg/kg (10^{-4} excess cancer risk) and/or 22 mg/kg (noncancer concerns).

Table 4.7. Major Cation and Soil Property Data

Decision Unit	Location	Al (mg/kg)	Fe (mg/kg)	Mg (mg/kg)	Ca (mg/kg)	P (mg/kg)	Mn (mg/kg)	Cation Exchange Capacity	pH	Soil Organic Material
Community Gardens										
KE010*	Eight and One Half Mile Garden	28308	50855	42795	7781	3962	871	22.0	5.7	8.0%
KE022	Kea‘au Middle School Garden	43038	62180	43271	17484	4867	1012	20.5	6.8	8.8%
Undeveloped Land Adjacent to Residential Subdivisions										
KE005	Adj. to Nine Mile/Kea‘au Camp	42409	70001	43304	6269	2668	1098	31.5	5.9	10.3%
KE008	Adj. to Kea‘au-Kula Subdivision	49375	70282	42264	5382	2051	1144	31.6	5.5	7.6%
KE011	Adj. to Nine and One Half Mile Camp	37335	54583	44694	6433	2035	838	30.9	5.7	7.7%
KE018	Adj. to Kea‘au Ag Lots Subdivision	81074	96452	7689	2178	2965	1692	45.6	5.7	8.1%
Parks										
KE001	Shipman Park South Field	106617	137104	10575	3868	3564	980	17.8	6.5	9.1%
KE009	Eight and One Half Mile Camp Park	28174	50466	39891	6721	2668	887	27.8	5.8	7.5%
KE014	Shipman Park Middle Field	39295	55999	24814	4712	1977	924	30.4	5.8	8.5%
Schools										
KE016	Kea‘au Elementary K-1 Courtyard	30463	50972	48784	5877	1507	664	14.5	6.3	7.9%
KE017*	Kea‘au Elementary Play Field	86234	111901	17011	5433	2473	885	21.6	6.6	7.2%
KE023	Kea‘au Middle School Courtyard	74922	98428	17974	3544	2567	885	3.0	5.9	6.1%

Notes:

* Average of duplicate results.

Table 4.8. **Soil Particle Size Percentages for the <250µm Particle Size Group.

Decision Unit	Location	0.25 mm (%)	0.15 mm (%)	0.106 mm (%)	0.053 mm (%)	0.002 mm - 0.05 (%)	<0.002mm (%)
Community Gardens							
KE010*	Eight and One Half Mile Garden	22.5	10.7	7	7.7	45.8	6.3
KE022	Kea'au Middle School Garden	27.9	15.1	9.4	9.9	31.2	6.5
Undeveloped Land Adjacent to Residential Subdivisions							
KE005	Adj. to Nine Mile/Kea'au Camp	18.4	6.6	3.8	3.2	60.9	7.1
KE008	Adj. to Kea'au-Kula Subdivision	18.9	7.4	3.7	3.3	62.5	4.2
KE011	Adj. to Nine and One Half Mile Camp	27	10.7	4.8	4.8	45.3	7.4
KE018	Adj. to Kea'au Ag Lots Subdivision	10.6	3.9	2.1	2.5	74.5	6.4
Parks							
KE001	Shipman Park South Field	17	11.6	12.8	2.2	51.9	4.5
KE009	Eight and One Half Mile Camp Park	26.8	11.9	7	6.3	44.3	3.7
KE014	Shipman Park Middle Field	20.6	9.5	5.5	6	51.4	7
Schools							
KE016	Kea'au Elementary K-1 Courtyard	26.8	13.8	9	8.6	38.1	3.7
KE017*	Kea'au Elementary Play Field	23.4	15.3	9.7	12	36.2	3.4
KE023	Kea'au Middle School Courtyard	27.2	14	7.3	8	40	4

Notes:

* Average of duplicate results.

** Calculated by equating 100% of sample particles were <0.25mm in size

Table 4.9. Field and Laboratory Precision Data.

Decision Unit	Location	Analysis Mass	Total Arsenic Concentration (<2mm soil size fraction)	Estimated ** Range of Total Arsenic Concentration	Field Duplicates	Lab Sub-sampling Duplicates
		Grams	mg/kg dry wt	mg/kg dry wt	RPD***	RPD***
Community Gardens						
KE010	Eight and One Half Mile Garden	5	366	353-379		5.8% (376 & 355)
KE012/013	Nine and One Half Mile Garden	10	304*	293-315	3.6% (KE012-298 KE013-309)	24% (334 & 262) KE012
KE022	Kea‘au Middle School Garden	10	324	312-336		
			Average: 331			
Undeveloped Land Adjacent to Residential Subdivision						
KE005	Adj. to Nine Mile/Kea‘au Camp	10	361	316-406		
KE006/007	Adj. to Kea‘au Loop Subdivision	10	246*	215-277	13.4% (KE006- 229 KE007- 262)	6.1% (222 & 236) KE006
KE008	Adj. to Kea‘au-Kula Subdivision	10	311	272-350		
KE011	Adj. to Nine and One Half Mile Camp	10	187	164-210		
KE018	Adj. to Kea‘au Ag Lots Subdivision	5	298	261-335		21% (267 &329)
KE020/021	Adj. to Eight and One Half Mile Camp	5	264*	231-297	11.0% (KE020-249 KE021-278)	14%; 5.8% (266 & 232 – KE020) (270 & 286 – KE021)
			Average: 278			

Table 4.9. Field and Laboratory Precision Data (cont.).

Decision Unit	Location	Analysis Mass	Total Arsenic Concentration (<2mm soil size fraction)	Estimated ** Range of Total Arsenic Concentration	Field Duplicates	Lab Sub-sampling Duplicates
		Grams	mg/kg dry wt	mg/kg dry wt	RPD***	RPD***
Parks						
KE001	Shipman Park South Field	10	15.3	11.9-18.7		
KE009	Eight and One Half Mile Camp Park	10	139	108-170		
KE014/015	Shipman Park Middle Field	5	208*	162-254	21.7% (KE014-185 KE015-230)	40%; 19% (222 & 148 - KE014) (252 & 208 – KE015)
			Average: 121			
Schools						
KE002	Kea‘au High School Football Field	10	0.67	0.52-0.81		
KE003	Kea‘au High School Courtyard	5	17.6	13.7-21.5		12%; 5.4%; 4.0% (17.1 & 19.3 17.1 & 16.2 17.1 & 17.8)
KE004	Ke Kula O Nawahiokalaniopuu playfield	10	16	12.5-19.5		
KE016	Kea‘au Elementary K-1 Courtyard	5	131	102-160		6.1% (135 & 127)
KE017	Kea‘au Elementary Play Field	10	16.4	12.8-20.0		
KE023/024	Kea‘au Middle School Courtyard	5	40.1*	31.3-48.9	20.9% (KE023-44.3 KE024-35.9)	16.7%; 28.7% (48 & 40.6 – KE023) 30.7 & 41 – KE024)
			Average: 37.0		**14.1% avg.; N=5**	**14.9% avg.; N=14**
					3.6%-21.7% range	**4.0%-40% range**

Total arsenic concentrations based on <2mm soil fraction.

* Average of duplicate multi-increment field samples;

** Estimated range based on maximum total variability measured for field duplicates from location category noted (e.g. average 12.4% used for undeveloped lands),

*** Relative Percent Difference

Table 4.10. Summary of Total Arsenic in Produce Samples Collected from Kea‘au Community Gardens vs FDA Market Basket Studies.

Produce Type	KMS*	8 ½ Mile Camp		9 ½ Mile Camp		[2]USFDA Market Basket [1]Total Arsenic Mean (Maximum) (mg/kg)	FDA Study Basis
	April 2005 (mg/kg)	April 2005 (mg/kg)	August 2005 (mg/kg)	April 2005 (mg/kg)	August 2005 (mg/kg)		
Fruits							
avocado						<0.003 (0.037)	Avocado
banana		**0.018**				<0.001	Bananas
bitter melon fruit						<0.001 (0.043)	[3]Range fruits
eggplant				0.001		0.001 (0.013)	Eggplant
long squash				<0.001		<0.001 (0.011)	Deep yellow vegetables
papaya		0.005			0.003	<0.001 (0.043)	[3]Range fruits
Patani bean		0.001				0.001 (0.022)	Range beans
pumpkin	0.002			<0.001		<0.001 (0.043)	[3]Range fruits
string beans	0.003			0.003		0.001 (0.022)	Range beans
Leafy Vegetables							
bamboo shoots			0.041			<0.001 (0.043)	Range leafy vegetables
bitter melon leaves			0.032	0.018	**0.063**	<0.001 (0.043)	Range leafy vegetables
fern shoots				0.007		<0.001 (0.043)	Range leafy vegetables
kancun				0.024	0.021	<0.001 (0.043)	Range leafy vegetables
onion stalk				0.006		<0.001 (0.043)	Range leafy vegetables
marangi				<0.003		<0.001 (0.043)	Range leafy vegetables
mustard cabbage	**0.099**					<0.001 (0.043)	Range leafy vegetables
squash shoots			0.008			<0.001 (0.043)	Range leafy vegetables

Table 4.10 (cont.). Summary of Total Arsenic in Produce Samples Collected from Kea'au Community Gardens vs FDA Market Basket Studies.

	KMS*	8 ½ Mile Camp		9 ½ Mile Camp		[2]USFDA Market Basket	
Produce Type	**April 2005 (mg/kg)**	**April 2005 (mg/kg)**	**August 2005 (mg/kg)**	**April 2005 (mg/kg)**	**August 2005 (mg/kg)**	**[1]Total Arsenic Mean (Maximum) (mg/kg)**	**FDA Study Basis**
Leafy Vegetables (cont.)							
sweet potato shoots		**0.044**	**0.068**		0.003	<0.001 (0.043)	Range leafy vegetables
taro stems		0.020	0.011		0.005	<0.001 (0.043)	Range leafy vegetables
taro leaves		**0.061**	0.054		0.020	<0.001 (0.043)	Range leafy vegetables
Root Vegetables							
casava			0.009	0.001	0.002	<0.001 (0.043)	Range root vegetables
onion bulb				0.012		0.001 (0.015)	Onions
sweet potatoes	**0.065**					0.004 (0.026)	Sweet potatoes
taro root		**0.058**	**0.046**	0.008	0.004	<0.001 (0.043)	Range root vegetables

Bold: exceeds range of total arsenic in produce reported in [2]FDA Market Basket Survey.

* Kea'au Middle School Garden

1. All data in mg/kg fresh (wet) weight.
2. US Food and Drug Administration 2004, *Total Diet Study* (FY 3/4/05), Chapter 04 – Market Baskets 1991-1993 through 2002-2004, Pesticides and Chemical Contaminants, http://www.cfsan.fda.gov/~acrobat/tds1byel.pdf.
3. Fruits: Include all edible, non-leafy aboveground parts of plant.

Table 4.11. Summary of Total Arsenic Data Based on Produce Type vs FDA Market Basket Studies (mg/kg fresh (wet) weight).

Produce Type	Kea‘au Mean	Kea‘au Maximum	[1]FDA Mean	[1]FDA Maximum
[1]Fruits	0.025	0.058	0.003	0.037
Leafy Vegetables	0.030	0.068	<0.001	0.043
Root Vegetables	0.015	0.046	<0.001	0.043

1. Assumes 10% of consumed fruit by weight is bananas and papayas (average total As = 0.012 mg/kg) and 90% other fruits (assumed total As = 0.003 mg/kg).
2. US Food and Drug Administration 2004, *Total Diet Study* (FY 3/4/05), Chapter 04 – Market Baskets 1991-1993 through 2002-2004, Pesticides and Chemical Contaminants, http://www.cfsan.fda.gov/~acrobat/tds1byel.pdf.

5 SCREENING LEVEL ASSESSMENT OF ARSENIC DATA

5.1 Comparison of Total Arsenic Data to HDOH Action Levels

Arsenic data collected for the decision units were evaluated in accordance with the HDOH technical memorandum *Soil Action Levels and Categories for Bioaccessible Arsenic* (HDOH 2006a). Soil samples with total arsenic greater than 20 mg/kg (assumed upper limit of natural background) were analyzed for bioaccessible arsenic (refer to Sections 3.3 and 4.4). The bioaccessible arsenic data were then used to place the site in one of three health risk categories, as discussed below. Action levels used to define the categories are based on an assumption that residents will be exposed to the soil on a regular basis (350 days per year) for thirty years. Exposure is assumed to take place via incidental ingestion of soil, dermal absorption and inhalation of air-born dust. The presence of arsenic in soil above the action levels does not necessarily indicate that adverse effects on human health are occurring. This simply indicates that further assessment is warranted to better define potential concerns.

As noted in Table 4.1, total arsenic in surface soils from fourteen of the eighteen decision units exceeds the assumed background limit of 20 mg/kg. Additional evaluation of potential exposure concerns in these decision units was therefore warranted. This focused on an evaluation of the bioaccessibility of the arsenic in soils.

Note: Additional evidence supporting the use of bioaccessibility testing and arsenic bioavailability considerations in the evaluation of soil arsenic hazards in the Kea‘au area has been documented more recently. This additional evidence includes:

- *In vivo* studies that indicate low arsenic bioavailability in soil from a contaminated area in Kea‘au (Exponent 2005, Roberts et al., 2006);
- The correlation of *in vivo* study results with bioaccessible arsenic data collected at the same site (e.g., Cutler 2006);
- Correlation of decreasing arsenic bioavailability with increasing iron oxide concentration (Roberts et al., 2006);
- Average iron oxide concentration in soils used for agriculture in Hawai‘i of 10-30%, well above typical soils on the US mainland (NRCS 2007);

- A lack of arsenic in groundwater underlying current and former sugar cane areas, indicating strong binding to soil and minimal leaching potential (HDOH 2006b);
- Laboratory testing at UH Manoa that demonstrated tropical soils (Andisols and Oxisols) with high levels of oxide and hydroxide mineral species have a natural ability to sequester arsenic, even over a wide pH range, making the arsenic less available to the soil solution - and therefore also estimated to be less bioaccessible through human ingestion and digestion (Cutler et al., 2006);
- Soil uptake factors for vegetables and fruits grown in arsenic-contaminated soils in the Kea‘au area are >2 orders of magnitude less than uptake factors published in scientific literature, supporting a conclusion that the arsenic is much more tightly bound to the soils than might otherwise be expected (HDOH, internal data);
- Laboratory batch test data that indicate arsenic sorption coefficients in soil greater than 500 (HDOH, internal data)

The presumed source of soil arsenic contamination throughout the Kea‘au area (as well as for other former sugarcane lands in the islands) is the same – arsenic trioxide based herbicides used by the sugarcane industry for weed control, primarily between 1915 – 1945. This single primary source of soil arsenic contamination in former sugarcane lands reduces uncertainty that may exist if a number of different types of arsenic compounds or arsenic sources were being evaluated for bioaccessibility.

5.2 Evaluation of Bioaccessibile Arsenic Data

Reported concentrations of bioaccessible arsenic in soil around the Kea‘au area are well below concentrations that could pose potential acute health risks (effects within a matter of days following exposure). The ATSDR Minimal Risk Level for acute exposure is 0.005 mg/kg/day (ATSDR 2006, includes a ten-fold safety factor). This translates to an exposure of 350 ug/day for a 70kg adult and 75 ug/day for a 15kg child. The average exposure to arsenic in soil in the Kea‘au area is in contrast estimated to be less than 5 ug/day (assumes 14 mg/kg bioaccessible arsenic in soil and 200 mg/day ingestion rate for a child). The worst case exposure is estimated to be approximately 20 ug/day (assumed bioaccessible arsenic 100 mg/kg).

Estimated arsenic bioaccessibility data were used to place the respective decision units into one of three health-risk categories, in accordance with guidance prepared by the Hawai‘i Department of Health (HDOH 2005, Appendix F):

Category 1: Bioaccessible arsenic $\leq$ 4.2 mg/kg;

Category 2: Bioaccessible arsenic 4.2 mg/kg to 23 mg/kg;

Category 3: Bioaccessible arsenic > 23 mg/kg;

The potential risk to human health increases from Category 1 to Category 3. The division between Category 1 and Category 2 soils is based on an excess cancer risk of 10^{-5}. Category 2 and Category 3 soils are separated based on a target noncancer Hazard Quotient of 1.0. Sites with concentrations of bioaccessible arsenic that exceed the action level based on an excess cancer risk of 10^{-4} (i.e., 42 mg/kg) would also fall into this category.

A summary of the site risk Categories based on bioaccessible arsenic levels is presented in Table 5.1. Each of the community garden sites fall into a Category 3 (elevated) health risk, indicating that estimated concentrations of bioaccessible arsenic exceed a target noncancer Hazard Quotient of 1.0. Estimated concentrations of bioaccessible arsenic at these three sites also exceed the action level based on a target excess cancer risk of 10^{-4}. The property located adjacent to Nine Mile/Kea‘au Camp (Decision Unit KE005) also marginally falls into Category 3. Estimated levels of bioaccessible arsenic in DU KE005 do not, however, exceed the action level based on an excess cancer risk of 10^{-4}.

The three remaining undeveloped sites adjacent to residential subdivisions where arsenic bioaccessibility was directly tested fall into Category 2 (refer to Table 5.1). Estimated levels of bioaccessible arsenic in Category 2 exceeded action levels based on a target excess cancer risk of 10^{-5} but did not exceed action levels based on a target noncancer Hazard Quotient of 1.0, or an excess cancer risk of 10^{-4}. The estimated range of bioaccessible arsenic in soil from the undeveloped properties adjacent to the Kea‘au Loop Subdivision and the Eight and One Half Mile camp was too broad to adequately place these properties in one of the three health risk categories. This emphasizes the need for site-specific data at all properties being evaluated for arsenic.

The Kea‘au Elementary K-1 Courtyard falls within the Category 2 health risk, although estimated levels of bioaccessible are well below the action level for noncancer concerns. Two of the three parks evaluated also fell within the Category 2 range (Eight and One Half Mile Camp Park and Shipman Park Middle Field). The remaining school and park sites fall into a Category 1 (minimal) health risk. This reflects both the relatively low total arsenic levels in soils from these areas as well as estimated low levels of bioaccessible arsenic. Note that bioaccessibility tests were not conducted on soil samples from the two Kea‘au High School decision units or the Ke Kula O Nawahiokalaniopuu Playfield. Reported levels of total arsenic in soil samples collected from these areas are well below potential levels of concern, however. By analogy with maximum enrichment and bioaccessibililty factors reported for the other non-garden areas, concentrations of bioaccessible arsenic in the Kea‘au High School decision units are likewise anticipated to be well below potential levels of concern.

Based on the bioaccessibility data obtained for the project, residents living in close proximity to the plantation camp community gardens are at most risk for exposure to arsenic in soils. Additional exposure studies of residents in the Eight and One Half and Nine and One Half Mile Camps are currently underway. Additional studies of the bioaccessibility as well as bioavailability of arsenic in soils around the Kea‘au area are also underway and will be reported at a later date. Recommendations for the areas investigated as part of this study are provided in Chapter 6.

5.3 Bioaccessibility Versus Soil Chemistry and Physical Properties

As discussed below, results of soil chemistry analyses indicate a potential correlation between As bioaccessibility and aluminum (Al), iron (Fe), magnesium (Mg) and Calcium (Ca) concentration when considering each analyte individually, and excluding the two highest arsenic bioaccessibility results from the community garden samples. The bioaccessibility levels in the community gardens were distinctly higher than other samples analyzed, but it is unclear why – perhaps due to higher levels of total arsenic and/or use of soil amendments commonly utilized in gardens. Aluminum and iron were found to be negatively correlated with bioaccessibility while Mg and Ca were found be somewhat positively correlated. Additional data are needed to draw definitive conclusions about these correlations, however. In addition to the limited numbers of samples analyzed, correlations among the samples were also complicated by the fact that a number of different soil types were involved in the comparisons (see Table 2.1). In addition, all correlation analyses were performed using a <250µm particle size fraction for bioaccessibility and a <2 mm particle size fraction for the chemistry and physical properties. Enrichment of elements in the smaller fraction size, as was demonstrated for arsenic (see section 4.3), may be expected to further complicate and reduce the correlation between various soil elements/physical properties and As bioaccessibility. An apparent correlation of elevated phosphorus and elevated arsenic bioaccessibility was identified in the gardens areas, although this issue again requires further investigation. Multi-variant analysis on the data may provide further insight into the combined effects of the analytes studied in terms of their influence on As bioaccessibility and should be considered for further investigation.

Aluminum (Al)

Aluminum was found to have the strongest correlation with arsenic bioaccessibility of any of the analytes studied. Jacobs et al. (1970), and Barringer et al. (1998), reported that As has a strong tendency to bond with Al oxides (and Fe oxides – reported below). Thus, soils high in Al have a strong As retention capacity, which in-turn translates into lower bioaccessibility. The negative correlation of Al in the samples with As bioaccessibility in this study, supports these findings. Utilizing a linear regression model on log transformed data for both variables, and excluding the two highest bioaccessibility samples (the community garden category samples), a strong negative correlation existed between Al concentration and As bioaccessibility, with a resultant R-Sq value of 89.0%. Results are presented in Figure 5.1.

Iron (Fe)

Similarly to Al, Fe showed a negative correlation to As bioaccessibility, but to a lesser degree than Al. This further supports the findings by Jacobs et al. (1970), and Barringer et al. (1998), that As has a strong tendency to bond with Fe oxides (and Al oxides – reported above) and thus soils high in Fe have a strong As retention capacity, which in-turn translates into lower bioaccessibility. Utilizing a linear regression model on log transformed data for both variables, and excluding the two highest bioaccessibility samples (the community garden category samples), a negative correlation existed between Fe concentration and As bioaccessibility, with a resultant R-Sq value of 79.8%. Results are presented in Figure 5.2.

Magnesium (Mg)

Datta et al. (2005) reported that As bound to Ca/Mg (Ca – reported below) has the potential to solublilize in the highly acidic environment of the human stomach, thus becoming bioaccessible. Utilizing a linear regression model on log transformed data for both variables, and excluding the two highest bioaccessibility samples (the community garden category samples), a positive correlation existed between Mg concentration and As bioaccessibility, with a resultant R-Sq value of 77.1%. Results are presented in Figure 5.3.

Calcium (Ca)

Datta et al. (2005) reported that As bound to Ca/Mg (Mg – reported above) has the potential to solublilize in the highly acidic environment of the human stomach, thus becoming bioaccessible. Utilizing a linear regression model on log transformed data for both variables, and excluding the two highest bioaccessibility samples (the community garden category samples), a positive correlation (though weak) existed between Ca concentration and As bioaccessibility, with a resultant R-Sq value of 58.7%. Results are presented in Figure 5.4.

Total Arsenic

A strong correlation between total arsenic concentration and bioaccessibility was not identified (Figures 5.5 and 5.6). Total arsenic concentration from the samples analyzed at both the <2mm (NCA) and <250µm fraction size does not appear to be a primary determinant of bioaccessibility. Utilizing a linear regression model on log transformed data for both variables, and excluding the two highest bioaccessibility samples (the community garden category samples), a poor correlation existed between total As concentration and As bioaccessibility, with a resultant R-Sq value of 21.9% for the <250µm size fraction, and 25.8% for the <2mm size fraction. A similar lack of correlation was observed in a study of various metals, including arsenic, in 22 soils (Hack et al. 2002).

Phosphorus (P)

Because both As and P occur as oxyanions in environmental systems and have similar chemical properties, high P concentrations could result in desorption of As, which in-turn translates into higher As bioaccessibility (Datta *et al.* 2005). Utilizing a linear regression model on log transformed data for both variables, and excluding the two highest bioaccessibility samples (the community garden category samples), a poor correlation existed between P concentration and As bioaccessibility, with a resultant R-Sq value of just 26.5% (Figure 5.7). Also, see discussion of phosphorus levels in community garden samples, section 5.5.

Manganese (Mn)

Manganese is not mentioned in any of the literature reviewed as a controlling factor in As bioaccessibility. However Mn was analyzed and evaluated in this investigation as a potential influencing factor in As bioaccessibility. Utilizing a linear regression model on log transformed data for both variables, and excluding the two highest bioaccessibility samples (the community garden category samples), a poor correlation existed between Mn concentration and As bioaccessibility, with a resultant R-Sq value of 22.0%. Results are presented in Figure 5.8.

Cation Exchange Capacity (CEC)

Brookside Laboratories used a 10-gram sample for the analysis of CEC. Any element with a positive charge is known as a cation. The amount of these positively charged cations a soil can hold is described as the cation exchange capacity, or CEC. The higher the CEC, the more cations the soil can hold. Higher CEC translates to higher amount of positive charge on the soil surface and thus a higher potential of As oxyanions to form electrostatic bonds with the positively charged surface sites (Datta et al. 2005). High CEC values thus should translate into lower bioavailability, as soil particles will have a stronger retention capacity. However, only a poor correlation existed between CEC and As bioaccessibility in this study (Figure 5.9). Utilizing a linear regression model on log transformed data for both variables, and excluding the two highest bioaccessibility samples (the garden category samples), a poor correlation existed between CEC and As bioaccessibility, with a resultant R-Sq value of 2.6%.

pH

Brookside Laboratories used a 7-gram sample for the analysis of pH. Sorption of As generally decreases with increasing pH (Adriano 2001). This influence is attributed to the negative surface charge on the adsorptive surface at higher pH as well as the negative charge of As oxyanions (Wasay et al. 2000). Yang et al. 2002, found pH to be the only statistically influencing factor affecting a decrease in bioaccessibility after aging of soil. Soils with pH < 6 generally sequestered As (V) more strongly over time, whereas pH >6 generally did not. Yang et al. 2002 also found that iron oxide content and pH had the greatest influence over steady-state bioaccessibility of As (V) in soil. However, only a poor correlation existed between pH and As bioaccessibility in this study (Figure 5.10) Utilizing a linear regression model on log transformed data for both variables, and excluding the two highest bioaccessibility samples (the garden category samples), a poor correlation existed between pH and As bioaccessibility, with a resultant R-Sq value of 10.7%.

Soil Organic Matter (SOM)

Brookside Laboratories used a 1-gram sample for the analysis of SOM. Some components of soil organic matter (SOM) (such as fulvic acid) tend to complex As, making it more soluble and thus more bioaccessible (Gough et al 1996). Other components (such as humic acids) can contribute more to the retention of As in acidic environments, thereby lowering bioaccessibility. Soil samples in this study were analyzed for their total SOM concentrations and not analyzed at the SOM component level. Only a poor correlation existed between total SOM and As bioaccessibility in this study (Figure 5.11). Utilizing a linear regression model on log transformed data for both variables, and excluding the two highest bioaccessibility samples (the garden category samples), a poor correlation existed between total SOM and As bioaccessibility, with a resultant R-Sq value of 0.1%.

5.4 Bioaccessibility Versus Soil Particle Distribution

Brookside Laboratories used a 100-gram sample for the analysis of soil particle size distribution. In an As bioaccessibility study covering 110 US soil samples, bioaccessibility in the range 10-60% were found with arsenic mineralogy and soil particle size as the major influencing factors of bioaccessibility (Ruby 1998). Soil particle size was evaluated for its influence on bioaccessibility as it was theorized that differing percentages of various particle size groupings may influence the biological mechanisms of arsenic bioaccessibility (Figures 5.5 and 5.6). A significant correlation was not identified in any of the soil particle groups analyzed for correlation with As bioaccessibility; resultant R-Sq values were less than 30%. Therefore in this study the particle size of samples and As bioaccessibility do not appear to be correlated.

5.5 Possible Factors of High Arsenic Bioaccessibility in Community Gardens

Elevated arsenic bioaccessibility in soils from the community gardens (16-18%, samples KE010 and KE022) could be attributed to various factors, including higher total arsenic concentrations as well as the application of fertilizer or other soil conditioning agents intended to make soil nutrients more accessible to plants. The gardens may therefore represent a statistically distinct population when compared to the non-garden categories.

Each analyte was qualitatively assessed to determine if samples KE010 and KE022 had some notable differences that may explain their divergent bioaccessibilities. Only Ca and P appeared qualitatively to have possible influencing potential on the two highest bioaccessibility results.

Phosphorus in particular could be influencing arsenic bioaccessibility, as the two samples with the highest bioaccessibility samples also have the highest P concentrations (refer to Tables 4.4 and 4.8). An increase in As bioaccessibility with an increase in P concentrations was noted by Chen et al. (1999), who lists P as a major controlling factor in As bioaccessibility. Datta et al. (2005) noted that high P content may result in desorption of As. However, as discussed in Section 5.3, a poor correlation exists between P and As bioaccessibility in the remaining samples analyzed, and a firm conclusion cannot be drawn. One possibility is that P concentration does not affect bioaccessibility until a threshold is reached. Additional investigation of this issue is currently underway by the University of Hawai‘i.

5.6 Evaluation of Total Arsenic in Produce

Levels of total arsenic in produce samples from the Kea‘au gardens are summarized in Tables 4-10 and 4-11. As indicated in the tables, arsenic data are within or only marginally above the range of total arsenic concentrations in typical market produce published by Food and Drug Administration. This is in agreement with bioaccessibility and other data presented in this report that indicates the arsenic is tightly bound to the soil and not significantly available for uptake.

5.7 Uncertainty Analysis

5.7.1 Sampling Approach

This investigation utilized a multi-increment sampling approach for surface soils. Rather than estimating a mean contaminant concentration by averaging relatively few discreet samples collected across a specific area, a single sample consisting of many increments collected across the specific area was used to estimate the average contaminant concentration. Increment soil samples were collected at 40-50 systematic random locations within the boundaries of a pre-selected decision unit. In addition, the precision of this sampling technique was evaluated at 25% of the sites by collecting field sample replicates – additional multi-increment samples collected from alternate (40-50) random locations across a decision unit. This approach helps to minimize the uncertainty associated with the analyses, results and interpretation of the investigation.

In an effort to limit laboratory variability and error, modified sample preparation methods were also requested prior to arsenic and soil chemistry analyses. Multi-increment sampling techniques (akin to the methods used to collect the field samples) were required for laboratory sub-sampling of the field samples. In addition, lab sub-sampling error was evaluated by requiring replicates of the lab sub-sampling for many of the samples. A larger sample analysis mass of 5-10 grams for arsenic analyses was required for a more representative sample (lab method originally called for 1 gram analysis mass). Increasing the mass of samples analyzed based on consideration of the maximum soil particle size being analyzed is an effective method of reducing lab error caused by the heterogeneity of soil and the associated soil contaminants (USEPA. 2003). These lab/method modifications are also believed to minimize the uncertainty associated with this investigation. Precision of the field and laboratory measurements was evaluated directly through the use of replicate sampling – see Table 4.9.

5.7.2 Arsenic Analysis

Quality control data for the field replicates (see Table 4.9) indicated the estimated mean total arsenic concentrations (<2mm size fraction) in the 18 decision units had a maximum precision error of ± 22%. This was less error than the sampling plan data quality objective of 35% total field sampling + lab sub-sampling + lab analytical error. The average lab sub-sampling error determined with lab sub-sampling replicates (see Table 4.9) was very similar to the total error (field replicates), indicating that improvements in data precision may be gained through use of a larger sample analysis mass (e.g. 25 gram samples vs 5-10 gram samples for analysis), or by grinding the soil samples to a small particle size before sub-sampling and analysis.

5.7.3 Bioaccessibility Analysis

Cleanup goals for sites contaminated with metals are often established on the basis of risk assessments. These risk assessments must utilize estimated toxicity values derived commonly from toxicity studies in which a soluble form of the metals was dissolved in water and ingested. These toxicity studies rarely account for the characteristics of a metal in soil or the limitations that these characteristics place on the gastrointestinal absorption within the human body. Therefore, in order to better assess risk, the bioavailability of the metal in soil must be accounted for. Historically, relative bioaccessibility estimates for metals in soils have been based on *in vivo* studies in laboratory animals. Given the excessive costs and time constraints with conducting such studies, *in vitro* surrogate tests have recently been developed. One such test was utilized to estimate the oral bioavailability of arsenic in Kea‘au soils. The *in vitro* test used in this study has previously been described (Ruby, 1998). The University of Colorado reported linear regression correlations between arsenic bioaccessibility and arsenic bioavailability testing (*in vitro* and *in vivo* tests) as showing an R^2 of 0.73 (University of Colorado, 2003). Although limited comparisons and correlation data introduce uncertainty into the interpretation of results, it is believed that the *in vitro* test is strong estimator of *in vivo* bioavailability.

The quality control data for the bioaccessibility analyses in this report was considered acceptable for the two “blind” duplicate soil samples sent to laboratory with other samples, as well as the two duplicate samples analyzed by the laboratory in their quality control procedures. Additional quality control data should be gathered in future bioaccessibility analyses to confirm the range of uncertainty for these analyses.

5.7.4 Bioaccessibility and Soil Chemistry Correlation Analyses

The bioaccessibility evaluation conducted by Exponent was performed on the less than 250µm soil size fraction. The <250µm fraction is generally accepted to represent the fraction of soil most likely to adhere to human hands and be ingested during hand-to-mouth activity. Soil chemistry parameters, on the other hand, as determined by Brookside Laboratories were estimated in soils <2mm in diameter. Consequently, all correlation analyses were performed using a <250µm size fraction for bioaccessibility and a <2 mm size fraction for each of the soil chemistry parameters. As Section 4.3 examines, in most samples significant arsenic concentration enrichment occurs when analyzed at the smaller fraction size, though the enrichment is non-uniform. It must therefore be noted that all correlation analyses were performed using two different size fractions, and this most likely would reduce the correlation between various soil chemistry parameters and arsenic bioaccessibility. This introduces uncertainty into the reported correlation analyses between soil chemistry and bioaccessibility.

Table 5.1. Categorization of sites with respect to potential residential health risks.

Decision Unit	Location	[1]Estimated Bioaccessible Arsenic (mg/kg)	[2]Comparison to Residential Action Levels		
			Category 1 (≤4.2 mg/kg)	**Category 2** (>4.2 mg/kg to 23 mg/kg)	**Category 3** (>23 mg/kg)
Community Gardens					
KE010	Eight and One Half Mile Garden	81.7			**X**
KE022	Kea‘au Middle School Garden	101			**X**
KE012/ KE013	Nine and One Half Mile Garden	62-106			**X**
Undeveloped Land Adjacent to Residential Subdivisions					
KE005	Adj. to Nine Mile/Kea‘au Camp	23.9		**X**	**X**
KE008	Adj. to Kea‘au-Kula Subdivision	14.3		**X**	
KE011	Adj. to Nine and One Half Mile Camp	13.7		**X**	
KE018	Adj. to Kea‘au Ag Lots Subdivision	4.5		**X**	
KE006/ KE007	Adj. to Kea‘au Loop Subdivision	2.6-37	**X** (possible)	**X** (possible)	**X** (possible)
KE020/ KE021	Adj. to Eight and One Half Mile Camp	2.7-40	**X** (possible)	**X** (possible)	**X** (possible)
Parks					
KE001	Shipman Park South Field	0.58	**X**		
KE009	Eight and One Half Mile Camp Park	20.7		**X**	
KE014	Shipman Park Middle Field	5.18		**X**	
Schools					
KE016	Kea‘au Elementary K-1 Courtyard	10.2		**X**	
KE017	Kea‘au Elementary Play Field	0.89	**X**		
KE023	Kea‘au Middle School Courtyard	0.99	**X**		
KE002	Kea‘au High School Football Field	0.01-0.11	**X**		
KE003	Kea‘au High School Courtyard	0.2-2.7	**X**		
KE004	Ke Kula O Nawahiokalaniopuu playfield	0.17-2.44	**X**		

Notes:

1. Refer to Tables 4.5 and 4.6.

2. Residential Action Levels: 4.2 mg/kg = target cancer risk of 10^{-5}; 23 mg/kg = target noncancer HQ of 1.0; 42 mg/kg = target cancer risk of 10^{-4}.

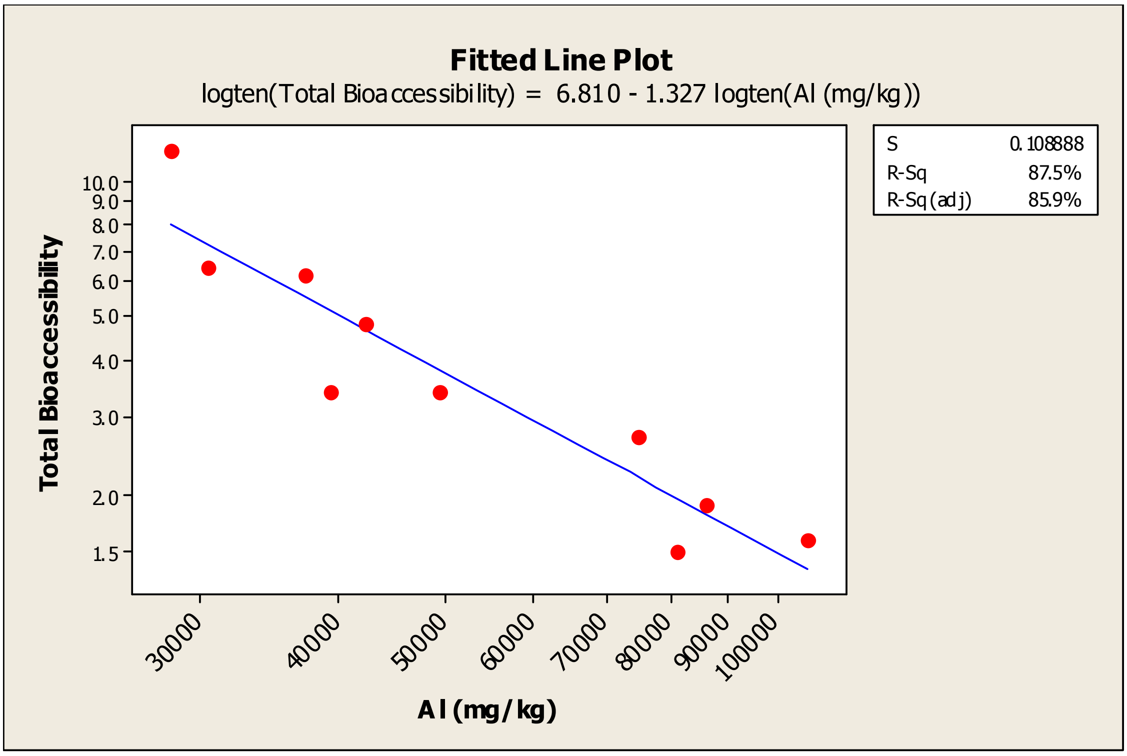

Figure 5.1 – Regression Analysis: Al Concentration vs. As Bioaccessibility in Soils

*** Correlation analysis excludes two community garden samples**

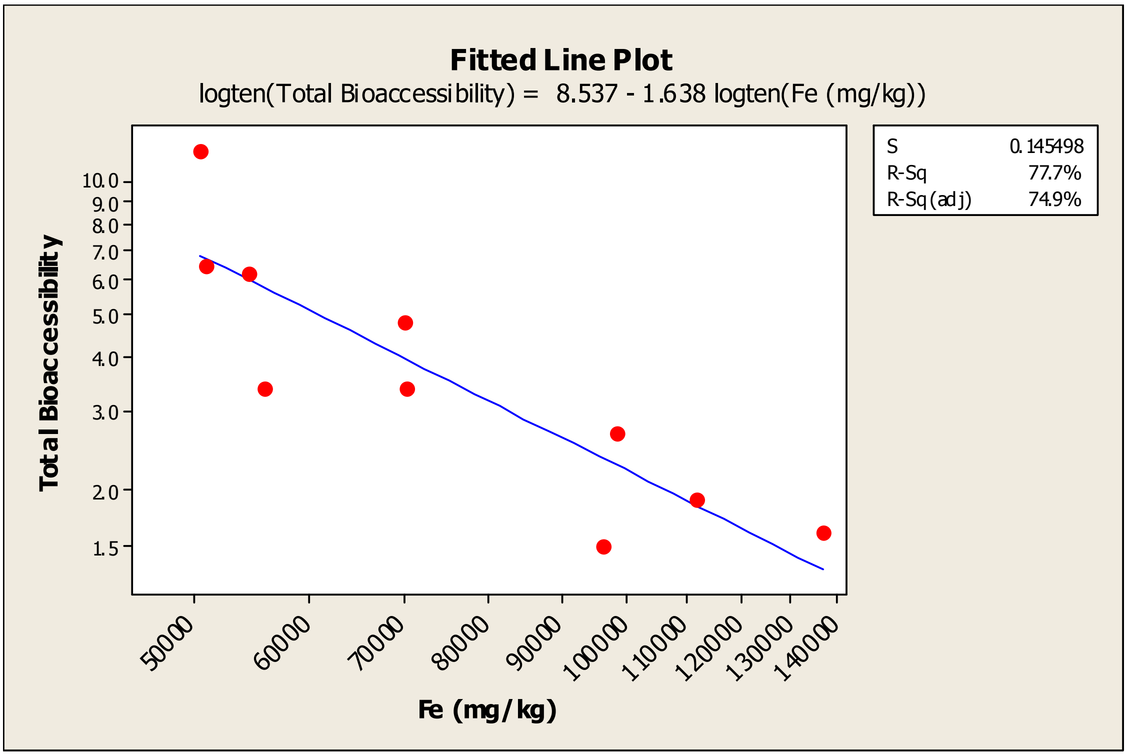

Figure 5.2 – Regression Analysis: Fe Concentration vs. As Bioaccessibility in Soils

*** Correlation analysis excludes two community garden samples**

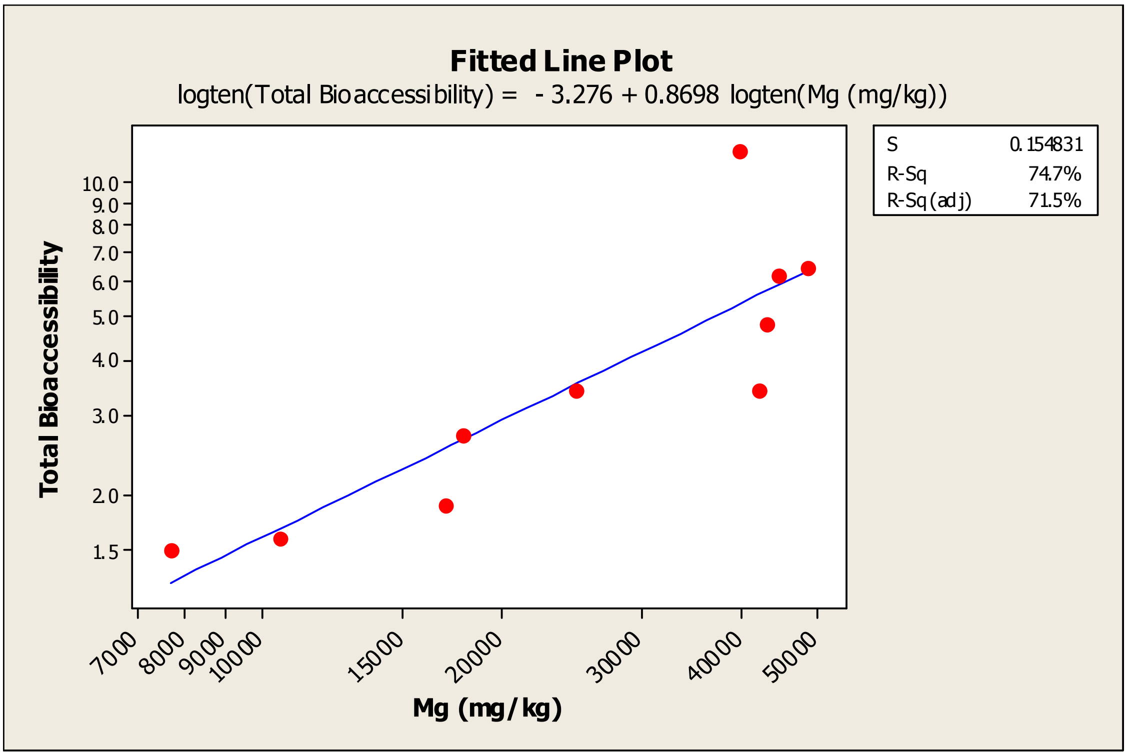

Figure 5.3 – Regression Analysis: Mg Concentration vs. As Bioaccessibility in Soils

*** Correlation analysis excludes two community garden samples**

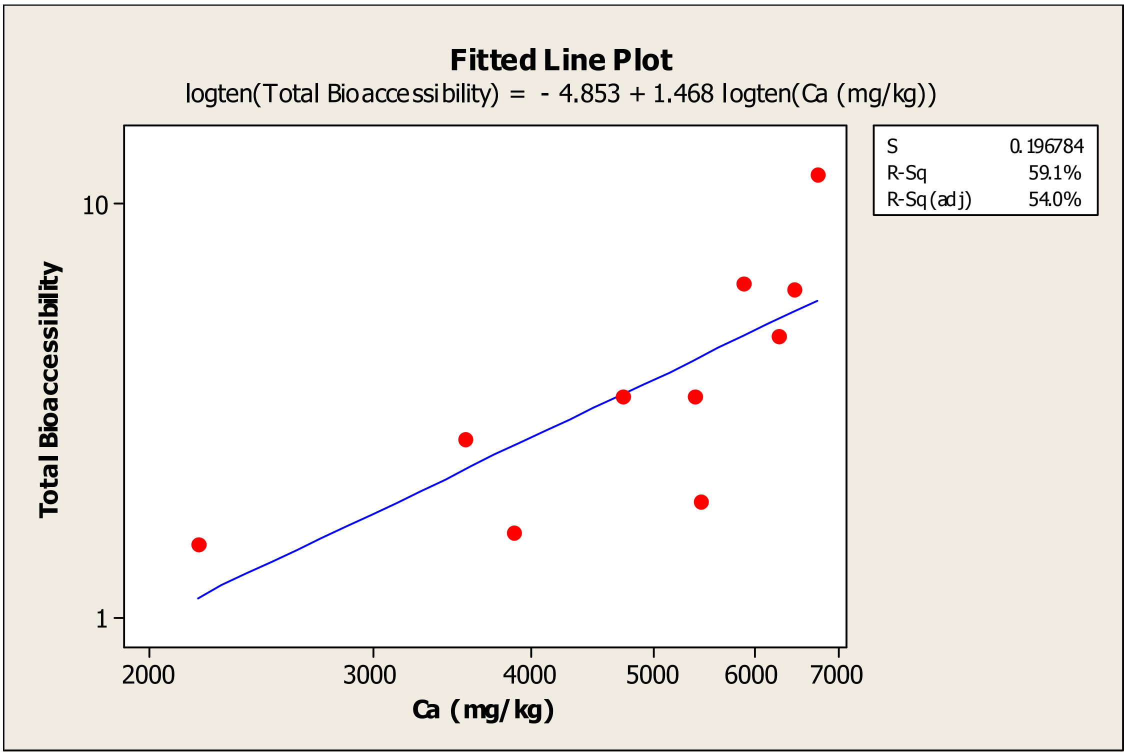

Figure 5.4 – Regression Analysis: Ca Concentration vs. As Bioaccessibility in Soils

*** Correlation analysis excludes two community garden samples**

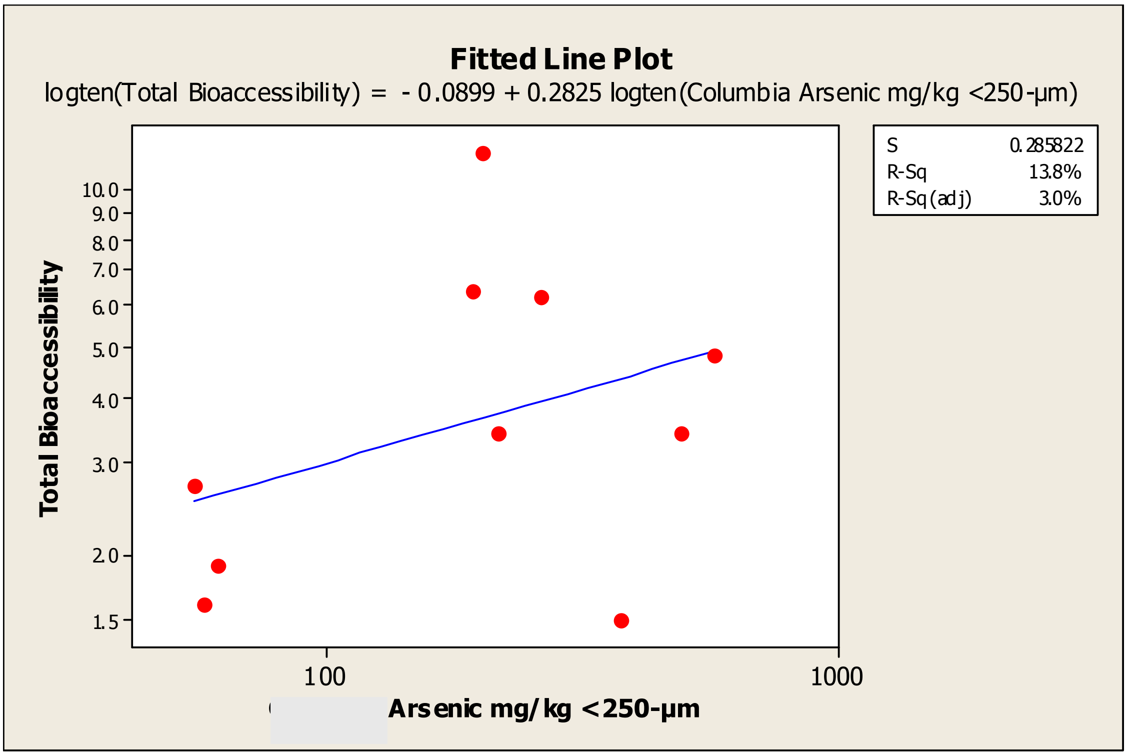

Figure 5.5 – Regression Analysis: Total As (<250-µm Size Fraction) vs. As Bioaccessibility in Soils

*** Correlation analysis excludes two community garden samples**

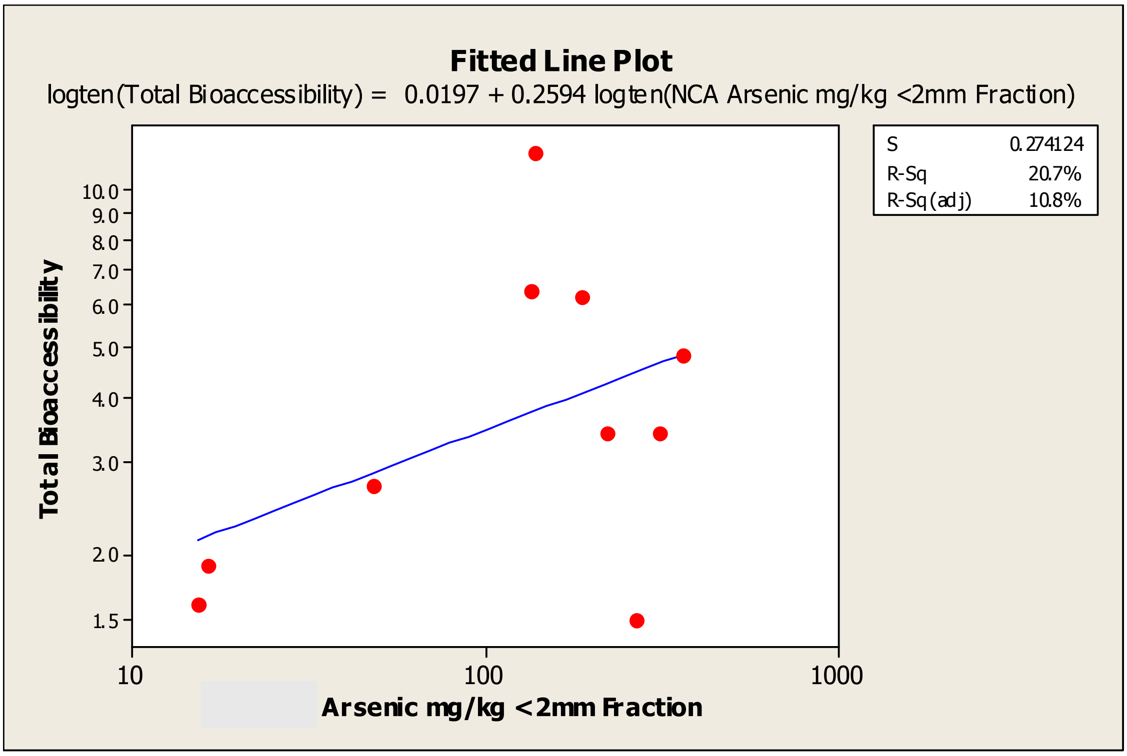

Figure 5.6 – Regression Analysis: Total As (<2 mm Size Fraction) vs. As Bioaccessibility in Soils

*** Correlation analysis excludes two community garden samples**

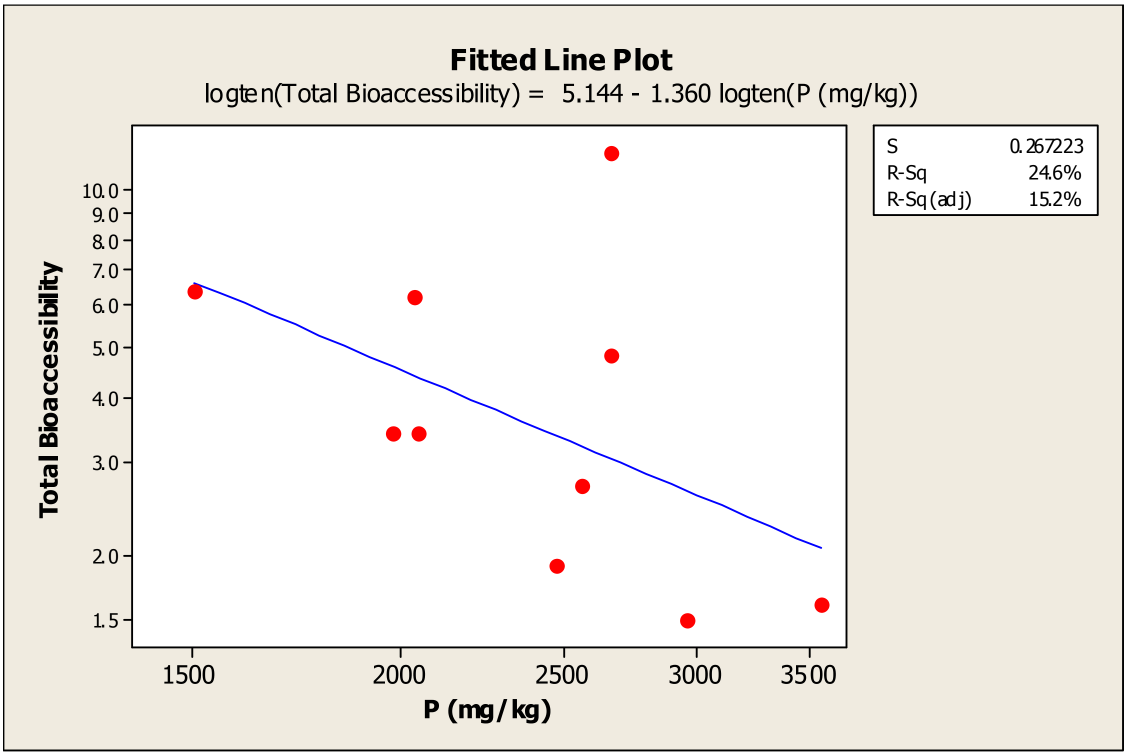

Figure 5.7 – Regression Analysis: P Concentration vs. As Bioaccessibility in Soils

*** Correlation analysis excludes two community garden samples**

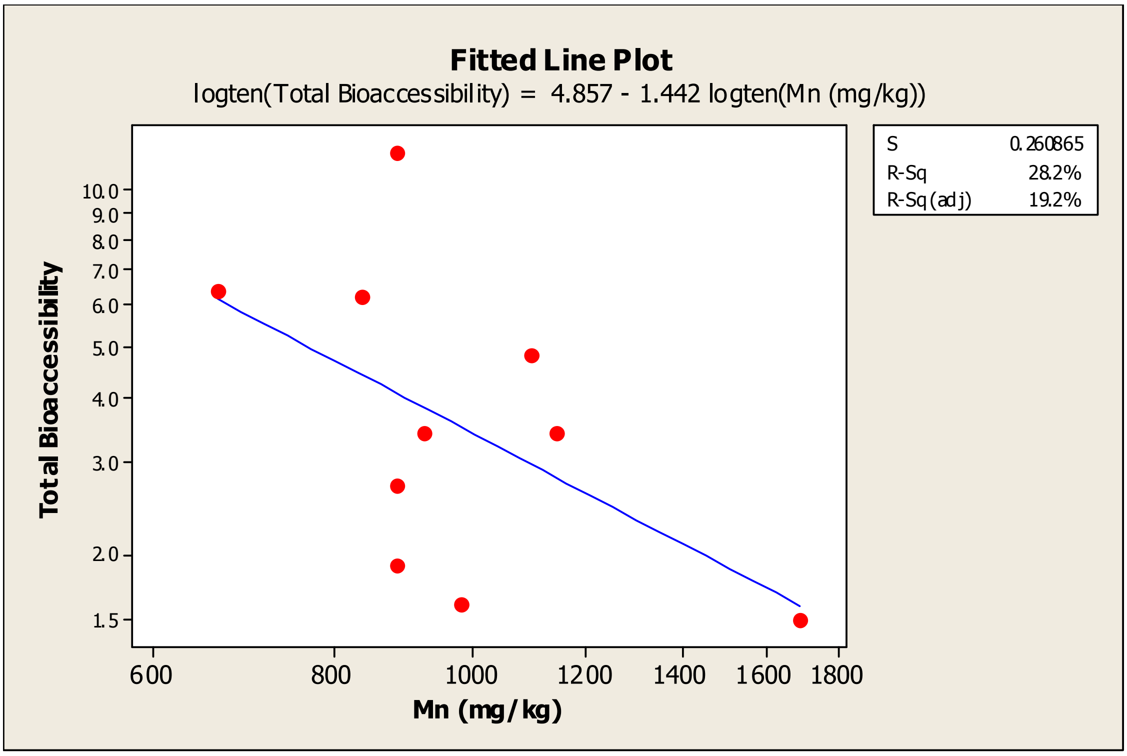

Figure 5.8 – Regression Analysis: Mn Concentration vs. As Bioaccessibility in Soils

*** Correlation analysis excludes two community garden samples**

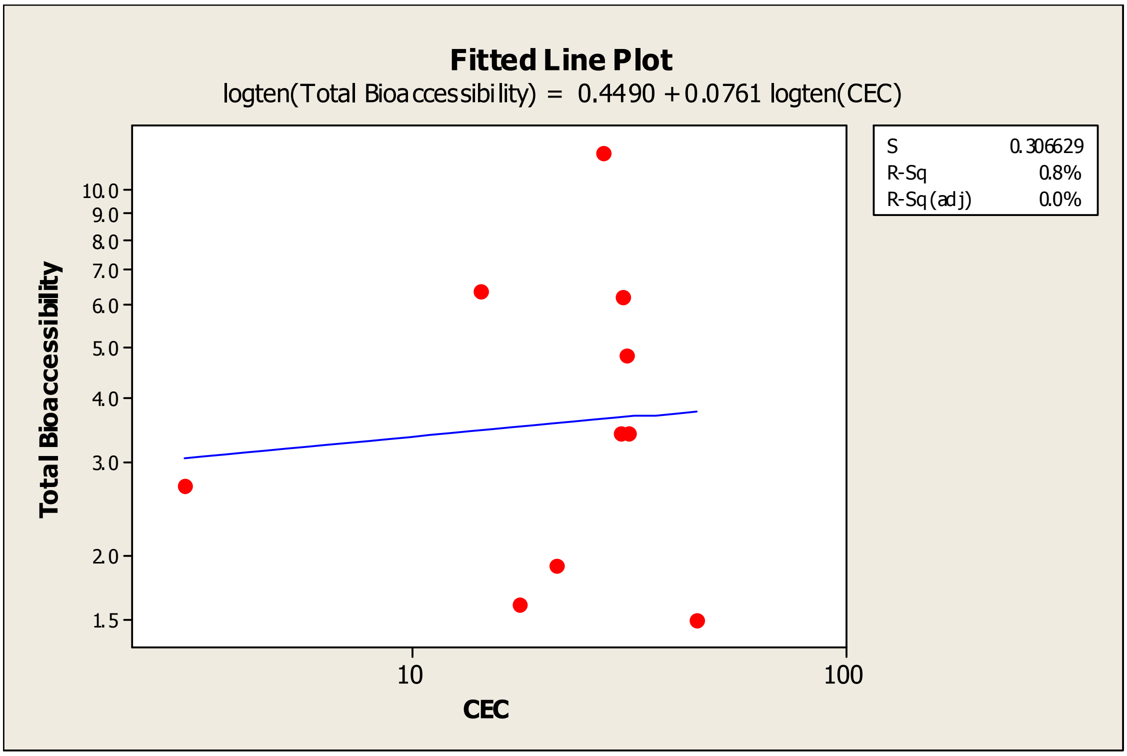

Figure 5.90 – Regression Analysis: Cation Exchange Capacity vs. As Bioaccessibility in Soils

*** Correlation analysis excludes two community garden samples**

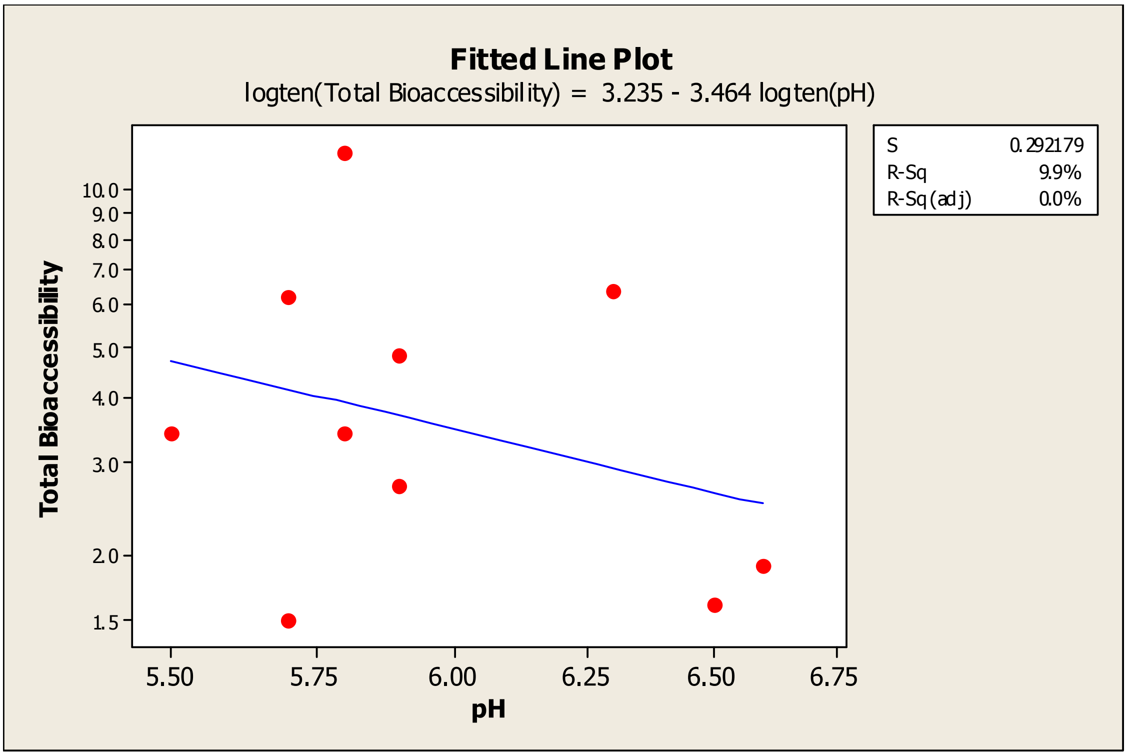

Figure 5.10 – Regression Analysis: pH vs. As Bioaccessibility in Soils

*** Correlation analysis excludes two community garden samples**

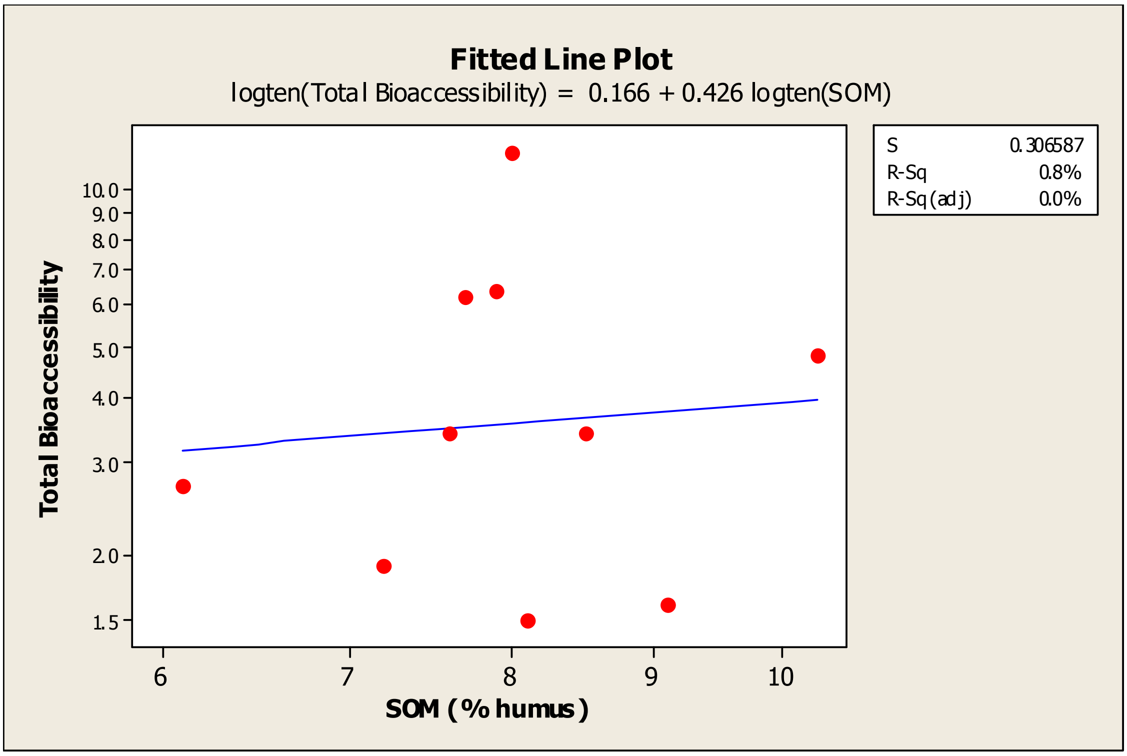

Figure 5.11 – Regression Analysis: Soil Organic Matter vs. As Bioaccessibility in Soils

*** Correlation analysis excludes two community garden samples**

6 SUMMARY AND RECOMMENDATIONS

6.1 Summary

Concentrations of total arsenic in soil exceeded background levels (>20 mg/kg total arsenic) in 15 of the 18 areas (“Decision Units”) tested in the Kea‘au area (refer to Tables 4.1 and 4.2). Total arsenic concentrations in the <2mm size fraction of surface soils (0-3 inch depth) ranged from 0.7 mg/kg (dry wt.) to 366 mg/kg. Total arsenic concentrations measured in fine soil fractions (“enriched fraction,” <250µm size fraction) ranged from 55 mg/kg to 629 mg/kg. Arsenic bioaccessibility ranged from 1.0% to 9.6% in soils tested from undeveloped lands, parks and schools. Arsenic bioaccessibility in the two community gardens tested ranged from 16% to 18%.

Direct estimates of bioaccessible arsenic levels in soil were made for the twelve sites where both enriched-fraction total arsenic data and bioaccessibility data were available. Estimated bioaccessible arsenic levels ranged from 0.58 mg/kg at the Shipman Park South Field site to 101 mg/kg at the Kea‘au Middle School Garden (refer to Table 4.5). Ranges of bioaccessible arsenic in soils at the remaining six sites were estimated by analogy to land use, enriched data and bioaccessibility data from the other 12 sites. Estimated ranges of bioaccessible arsenic levels varied from a low of 0.01 to 0.11 mg/kg at the Kea‘au High School Football Field to a high of 62 to 106 mg/kg at the Nine and One Half Community Garden site (refer to Table 4.6).

Based on the directly or indirectly estimated levels of bioaccessible arsenic in soils, each of the 18 decision unit areas was placed into one of three categories for potential risk to human health following guidance prepared by the Hawai‘i DOH (HDOH 2006a, refer to Table 5.1). The categories conservatively assume current or future residential use of the properties. “Category 1” indicates minimal potential health risks and reflects estimated levels of bioaccessible arsenic below action levels based on a target excess cancer risk of 10^{-5} (one-in-one-hundred-thousand excess cancer risk). All but one of the school sites fell into this category. Further actions are not considered to be necessary for surface soils on sites that fall into this category.

The majority of the undeveloped land sites and the Kea‘au Elementary K-1 Courtyard fell under a “Category 2” health risk. Estimated levels of bioaccessible arsenic were between action levels based on a target excess cancer risk of 10^{-5} and a noncancer hazard quotient of 1.0. Category 2 sites still fall within the USEPA 10^{-4} to 10^{-6} potentially acceptable cancer risk range and below action limits of concern for non-cancer effects of arsenic. However, these sites warrant a closer look at site-specific factors affecting risk as well as uncertainties with the estimated exposures.

Measures to reduce concentrations of bioaccessible arsenic in impacted soil and/or minimize exposure to the soils should be evaluated and implemented, as appropriate, based the additional site-specific assessments.

“Category 3” indicates a potential chronic health risk due to concentrations of bioaccessible arsenic in soil that exceed action levels based on a non-cancer hazard quotient of 1.0 and/or a target cancer risk of 10^{-4}. Each of the community garden areas clearly fell into this category. The undeveloped property located adjacent to Nine Mile/Kea‘au Camp (KE005) marginally fell into this category. At these sites, testing of people exposed to soils on a regular basis is warranted to determine the degree of exposure to arsenic. Remediation of impacted soil and/or controls to significantly reduce potential exposure is generally recommended.

Estimates of bioaccessible arsenic levels in soils from the property located adjacent to the Kea‘au Loop Subdivision (KE006/KE007) and the open lot near Eight and One Half Mile Camp (KE020/KE021) were too variable to confidently place the sites into one of the three health risk categories described above (refer to Table 5.1). Enriched-fraction data and bioaccessibility data were not available for these areas. Although generalizations regarding soil type and bioaccessible arsenic levels can be made, this emphasizes the need for site-specific data.

Results of a correlation analysis between various soil constituents and arsenic bioaccessibility indicates a negative correlation with aluminum (Al) and iron (Fe), and a positive correlation with magnesium (Mg) and Calcium (Ca), though this data is limited and the correlations are complicated by a number of factors (refer to section 5.3). The limited data suggest that strong binding of arsenic to soil particles may be associated with elevated aluminum and iron oxides in soils, and weak binding of arsenic to soil particles may be associated with elevated magnesium and calcium. Increasing phosphorus levels in soil may also be related to elevated arsenic bioaccessibility in gardens areas, although this issue warrants further investigation.

6.2 Recommendations

Preliminary actions were developed for each of the 18 decision unit areas in the Kea‘au area based on current land use, estimated levels of bioaccessible arsenic in soils and assumed health-risk category. The recommendations are applicable to surface soils that were tested and reported on in this study. Subsurface soils on these decision units were not evaluated. Recommended actions are summarized in Table 6-1.

<u>Category 3 Sites (Bioaccessible Arsenic >23 mg/kg):</u>

The following four sites were placed into a Category 3 health risk due to significantly elevated levels of bioaccessible arsenic in soil:

- Eight and One Half Mile Camp Garden;
- Nine and One Half Mile Camp Garden;
- Kea‘au Middle School Garden;
- Property adjacent To Nine Mile/Kea‘au Camp.

Based on the results of this preliminary risk assessment, estimated levels of bioaccessible arsenic in soils from these sites could pose health concerns to individuals continually exposed to the soils over long periods of time (e.g., over several decades). It is important to note, however, that reported levels of arsenic do not pose short-term, acute health risks to individuals that come in contact with the soil.

Additional assessment of resident exposure to arsenic in soils from the 8.5 Mile Camp Garden and 9.5 Mile Camp Garden is warranted. A voluntary, urinary arsenic exposure evaluation of potentially affected residents in the camps was recommended (note –results of a urine arsenic study carried out in 2006/2007 pending as of the date of this report).

Residents using the gardens were informed of potential health concerns and ways to reduce potential exposure to soil from the gardens. A copy of a fact sheet provided to residents during community meetings is provided in Appendix G (fact sheets were provided in English and Ilicano, the language used by the large majority of local Filipino residents). Residents should minimize exposure to garden soils by washing their hands and face well before eating. Vegetables grown in the gardens should be thoroughly washed before consumption. This applies especially to root vegetables and leafy vegetables that may be covered in a significant amount of soil or dust and are difficult to wash. Residents should also avoid bringing soil into their homes on clothes, shoes or tools and should keep open areas vegetated in order to reduce contact with soil and dust. Time spent in the garden areas by young children should be minimized.

Use of the Kea‘au Middle School garden was discontinued and should remain off-limits to school children until such time that the impacted soil is removed, the soil treated to further reduce bioavailability or exposure potential, or at a minimum covered with several feet of clean soil. In contrast to the camp gardens, staff and students at the school did not rely on the school garden as a regular source of food, but used the garden infrequently, primarily as a learning exercise.

Estimated concentrations of bioaccessible arsenic in soil samples collected at the property adjacent To Nine Mile/Kea‘au Camp (23.9 mg/kg, KE005) fall at the boundary of Category 2 and Category 3 health risks. Potential health risks posed by exposure to soils in this area are not as significant as the previous three areas noted. Potential exposure to arsenic in these soils should be minimized in a similar manner as noted above, however. Use of this area for future residential homes should be carefully evaluated, based on considerations for Category 2 sites discussed below.

<u>Category 2 Sites (>4.2mg/kg to <23mg/kg Bioaccessible Arsenic):</u>

The following six sites were placed into a Category 2 health risk due to moderately elevated levels of bioaccessible arsenic in soil:

- Property Adjacent To Kea‘au-Kula Subdivision;
- Property Adjacent To Nine and One Half Mile Camp;
- Property Adjacent To Kea‘au Ag Lots Subdivision;
- Eight and One Half Mile Camp Park;
- Shipman Park Middle Field;
- Kea‘au Elementary K-1 Courtyard.

These sites should be reviewed in more depth to determine site-specific factors affecting risk, and to evaluate uses/potential uses and associated risk in light of uncertainties with estimated exposures for bioaccessible arsenic. For new developments, opportunities to reduce potential exposures through planning, soil management practices, and landscaping should be examined and implemented, as practicable. Residents living on Category 2 sites should also be informed of the elevated soil arsenic levels and ways to minimize potential direct soil exposures by washing their hands and face well before eating, thoroughly washing vegetables grown in gardens, avoiding bringing soil into their homes on clothes, shoes or tools, keeping open areas vegetated to reduce contact with soil and dust, and other protective measures.

<u>Category 1 Sites:</u>

The following six sites were placed into a Category 1 health risk due to low reported concentrations of bioaccessible arsenic in surface soil:

- Shipman Park South Field

- Kea‘au Elementary Play Field
- Kea‘au Middle School Courtyard
- Kea‘au High School Football Field
- Kea‘au High School Courtyard
- Ke Kula O Nawahiokalaniopuu playfield

The potential health risk posed to individuals by exposure to arsenic in surface soil at these sites is estimated to be below levels of concern and no further investigation is recommended. Although reported concentrations of total arsenic in soils from several of these areas is above anticipated, natural background levels, bioaccessibility studies conducted on the soils suggest that arsenic available for human uptake is below levels of potential concern. Based on the results of this assessment, exposure to surface soils in these areas does not pose significant human health concern and no restrictions are needed on future use of the properties with respect to surface soils. If subsurface soils at these sites will be accessed or brought to the surface via disturbance or development activities, analysis for soil arsenic concentrations is recommended to verify that levels are low, as in the surface soil.

Other Sites:

Bioaccessibility and soil enrichment data were inadequate to place the following sites into a health risk category:

- Property Adjacent to Kea‘au Loop Subdivision;
- Property Adjacent to Eight and One Half Mile Camp.

Soil samples collected in undeveloped land adjacent to the Kea‘au Loop Subdivision, and the agricultural field adjacent to the 8.5 Mile Camp decision units were not tested for enrichment of total arsenic in the fine-size soil fraction or for arsenic bioaccessibility. Estimation of potential bioaccessible arsenic levels at these sites based on comparison to data from similar areas was not adequate to place the sites in one of the three health risk categories (refer to Table 5.1). Bioaccessibility data for soils in these areas should be collected and evaluated to determine the need for further action. In the interim, residents frequenting these areas should minimize potential exposure to arsenic in soils in the same manner as described above for Category 2 and 3 sites.

Arsenic in Produce:

Residents of the camps grow and rely on a significant amount of vegetables and fruits from their community gardens. Plants are known to naturally uptake and accumulate metals such as arsenic in their cell structure. This could lead to additional exposure to arsenic via consumption of homegrown produce, although the amount may vary significantly depending on plant type and soil chemistry.

Based on analyses of produce from community gardens in the Kea‘au area (refer to Tables 4.10 and 4.11), levels of total arsenic measured in the produce do not pose a significant added threat to human health in comparison to potential exposure to arsenic in the soil. As discussed during community meetings, however, HDOH recommends that produce from the gardens be thoroughly washed prior to consumption to remove all soil particles and that the time spent in the garden areas by young children be minimized in order to reduce exposure to arsenic in soil.

Table 6-1. Actions Recommended for Individual Decision Units.

Decision Unit	Location	[1]Health Risk Category	Recommendations
Community Gardens			
KE010	Eight and One Half Mile Garden	Category 3	Minimize exposure to garden soils, particularly by young children. Inform residents of potential health concerns and means to reduce direct exposure to soils. Carry out urinary exposure evaluation of potentially exposed residents. Remediation and/or controls to minimize exposure recommended if considered for residential homes in future.
KE012/KE013	Nine and One Half Mile Garden	Category 3	
KE022	Kea‘au Middle School Garden	Category 3	Prohibit use of garden area by students until arsenic-impacted soil is removed, treated, or covered.
Undeveloped Land Adjacent to Residential Subdivisions			
KE005	Adj. To Nine Mile/Kea‘au Camp	Category 3	Minimize Exposure. Remediation and/or controls to minimize exposure recommended if considered for residential homes in future.
KE008	Adj. To Kea‘au-Kula Subdivision	Category 2	Minimize Exposure. Further evaluate need for remediation and/or other controls to minimize exposure
KE011	Adj. To Nine and One Half Mile Camp	Category 2	Minimize Exposure. Further evaluate need for remediation and/or other controls to minimize exposure.
KE018	Adj. To Kea‘au Ag Lots Subdivision	Category 2	Minimize Exposure. Further evaluate need for remediation and/or other controls to minimize exposure.

Table 6-1 (cont.). Actions Recommended for Individual Decision Units.

Decision Unit	Location	[1]Health Risk Category	Recommendations
Undeveloped Land Adjacent to Residential Subdivisions (cont.)			
KE006/KE007	Adj. To Keaʻau Loop Subdivision	Undetermined	Evaluate site-specific bioaccessible arsenic. Minimize exposure to soil pending results.
KE020/KE021	Adj. To Open Lot near Eight and One Half Mile Camp	Undetermined	Evaluate site-specific bioaccessible arsenic. Minimize exposure to soil pending results.
Parks			
KE001	Shipman Park South Field	Category 1	No additional investigation necessary for surface soils.
KE009	Eight and One Half Mile Camp Park	Category 2	Minimize Exposure. Further evaluate need for remediation and/or other controls to minimize exposure.
KE014/KE015	Shipman Park Middle Field	Category 2	Minimize Exposure. Further evaluate need for remediation and/or other controls to minimize exposure.
Schools			
KE016	Keaʻau Elementary K-1 Courtyard	Category 2	Minimize Exposure. Further evaluate need for remediation and/or other controls to minimize exposure
KE017	Keaʻau Elementary Play Field	Category 1	No additional investigation necessary for surface soils.
KE023/KE02	Keaʻau Middle School Courtyard	Category 1	No additional investigation necessary for surface soils.
KE002	Keaʻau High School Football Field	Category 1	No additional investigation necessary for surface soils.
KE003	Keaʻau High School Courtyard	Category 1	No additional investigation necessary for surface soils.
KE004	Ke Kula O Nawahiokalaniopuu playfield	Category 1	No additional investigation necessary for surface soils.

Notes:

[1] Refer to Section 5.2 for discussion of health risk categories.

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APPENDIX A

Field Photographs

Photograph 1: Sample Collection at Shipman Park Middle Field.

Photograph 2: Sample Collection at Kea'au Elementary School.

November 2004 Site Photographs

FIGURE

A-1

Photograph 3: Soil Sample Collection.

Photograph 4: Exposed Soil in Garden Plots (9.5 Mile Camp)

FIGURE

November 2004 Site Photographs

A-2

APPENDIX B

Field Soil Logs

Surface and Shallow Soil Sample Log

Project Number: 3-251-90015	Project Name: Keaau	Date: 11/1/04	Time: 11:00
Sample Identification Number and Time: KE001 @ 11:00		Checked by:	
Sampled by: CI, BU		Recorded by:	
Method of Collection: Slotted Soil Sampling Probe			
Surface Description: Lawn Grass			
Notes: Multi-increments sample (50)			

Soil Sample Data

Location: Shipman Park South Field (Soccer Field)	
Coordinates:	Elevation:

Lithology	Depth (ft.)	Soil Description	Est.% of G	Est.% of S	Est.% of F	Comments
ML	0-3"	Silt: 5YR 3/2. Moist/Wet. Soft (Hard near goal posts). Low plasticity. Trace clay.	5	20	75	No exposed soil.

Surface and Shallow Soil Sample Log

Project Number: 3-251-90015	Project Name: Keaau	Date: 11/1/04	Time: 14:00
Sample Identification Number and Time: KE002 @ 14:00		Checked by:	
Sampled by: CI, BU		Recorded by: C Inouye	
Method of Collection: Slotted Soil Sampling Probe			
Surface Description: Lawn Grass			
Notes: Multi-increments sample (50)			

Soil Sample Data

Location: Kea'au High School Football Field	
Coordinates:	Elevation:

Lithology	Depth (ft.)	Soil Description	Est.% of G	Est.% of S	Est.% of F	Comments
ML	0-3"	Silt with Gravel: 10YR 2.5/2. Dusky Red. Moist. Loose.	35	15	50	Patches of exposed soil. Imported soil.

Surface and Shallow Soil Sample Log

Project Number: 3-251-90015	Project Name: Keaau	Date: 11/1/04	Time: 15:00
Sample Identification Number and Time: KE003 @ 15:00		Checked by:	
Sampled by: CI, BU		Recorded by: C Inouye	
Method of Collection: Slotted Soil Sampling Probe			
Surface Description: Lawn Grass			
Notes: Multi-increments sample (50)			

Soil Sample Data

Location: Kea'au High School Courtyard (behind administration building)	
Coordinates:	Elevation:

Lithology	Depth (ft.)	Soil Description	Est.% of G	Est.% of S	Est.% of F	Comments
ML	0-3"	Silt with Gravel: 5YR 3/3. Dark Reddish Brown. Moist. Soft. Low Plasticity. Trace clay.	5	15	80	No exposed soil. Suspected offsite fill soil.

Surface and Shallow Soil Sample Log

Project Number: 3-251-90015	Project Name: Keaau	Date: 11/1/04	Time: 17:00
Sample Identification Number and Time: KE004 @ 17:00		Checked by:	
Sampled by: CI, BU	Recorded by: C Inouye		
Method of Collection: Slotted Soil Sampling Probe			
Surface Description: Lawn Grass			
Notes: Multi-increments sample (50)			

Soil Sample Data

Location: Punana Leo School	
Coordinates:	Elevation:

Lithology	Depth (ft.)	Soil Description	Est.% of			Comments
			G	S	F	
ML	0-3"	Silt with Gravel: 5YR 3/2. Dark Reddish Brown. Moist. Soft. Low Plasticity. Trace clay.	<5	10	85	No exposed soil in sampling area, however exposed soil was observed in adjacent animal pens. Sampling area is larger than football field. Based on conversations with Shipman representatives, area is also non Shipman land.

Surface and Shallow Soil Sample Log

Project Number: 3-251-90015	Project Name: Keaau	Date: 11/2/04	Time: 09:00

Sample Identification Number and Time: KE005 @ 09:00	Checked by:
Sampled by: CI, BU	Recorded by: C Inouye

Method of Collection: Slotted Soil Sampling Probe

Surface Description: Heavily vegetated

Notes: Multi-increments sample (50)

Soil Sample Data

Location: Kea'au/9 Mile Camp (behind Puna Congregational Camp)

Coordinates:	Elevation:

Lithology	Depth (ft.)	Soil Description	Est.% of			Comments
			G	S	F	
CL	0-3"	Lean Clay: 5YR 3/2. Dark Reddish Brown. Moist. Very soft. Low plasticity. Trace sand.	<5	10	85	Large boulders on Shipman property along western border.

Surface and Shallow Soil Sample Log

Project Number: 3-251-90015	Project Name: Keaau	Date: 11/2/04	Time: 11:00
Sample Identification Number and Time: KE006 @ 11:00 / KE007 @ 12:00 (Field Dup)		Checked by:	
Sampled by: CI, BU		Recorded by: C Inouye	
Method of Collection: Slotted Soil Sampling Probe			
Surface Description: Heavily vegetated			
Notes: Multi-increments sample (50)			

Soil Sample Data

Location: Kea'au Loop Subdivision – ATV trails south of neighborhood	
Coordinates:	Elevation:

Lithology	Depth (ft.)	Soil Description	Est.% of G	S	F	Comments
ML	0-3"	Sandy Silt: 10 YR/2. Very Dusky Red. Moist. Soft. Medium to low Plasticity. With clay.	<5	20	75	Exposed soil along former ATV trails.

Surface and Shallow Soil Sample Log

Project Number: 3-251-90015	Project Name: Keaau	Date: 11/2/04	Time: 13:30
Sample Identification Number and Time: KE008 @ 13:30		Checked by:	
Sampled by: CI, BU		Recorded by: C Inouye	
Method of Collection: Slotted Soil Sampling Probe			
Surface Description: Heavily vegetated			
Notes: Multi-increments sample (50)			

Soil Sample Data

Location: Kea'au / Kula Subdivision – Hame Street (undeveloped area east of neighborhood)	
Coordinates:	Elevation:

Lithology	Depth (ft.)	Soil Description	Est.% of G	S	F	Comments
CL	0-3"	Silty Clay: N 2.5 YR. Reddish black. Moist. Soft. Medium plasticity.	<5	10	85	Sugar cane present.

Surface and Shallow Soil Sample Log

Project Number: 3-251-90015	Project Name: Keaau	Date: 11/2/04	Time: 15:00
Sample Identification Number and Time: KE009 @ 15:00		Checked by:	
Sampled by: CI, BU		Recorded by: C Inouye	
Method of Collection: Slotted Soil Sampling Probe			
Surface Description: Lawn grass			
Notes: Multi-increments sample (50)			

Soil Sample Data

Location: 8.5 Mile Community Park	
Coordinates:	Elevation:

Lithology	Depth (ft.)	Soil Description	Est.% of			Comments
			G	S	F	
ML	0-3"	Silt: 5YR 2.5/1. Black. Moist. Very soft. Low plasticity.	<5	10	85	Kids observed playing on grass. Exposed soil under mango tree in northern area of park.

Surface and Shallow Soil Sample Log

Project Number: 3-251-90015	Project Name: Keaau	Date: 11/2/04	Time: 16:30

Sample Identification Number and Time: KE010 @ 16:30

Checked by:

Sampled by: CI, BU

Recorded by: C Inouye

Method of Collection: Slotted Soil Sampling Probe

Surface Description: Vegetable garden plots

Notes: Multi-increments sample (50)

Soil Sample Data

Location: 8.5 Mile Community Garden

Coordinates:

Elevation:

Lithology	Depth (ft.)	Soil Description	Est.% of G	Est.% of S	Est.% of F	Comments
ML	0-3”	Silt: 5YR 2.5/1. Black. Moist. Very soft. Low plasticity. Trace clay	5	10	85	Exposed soil. Easy to sample.

Surface and Shallow Soil Sample Log

Project Number: 3-251-90015	Project Name: Keaau	Date: 11/3/04	Time: 8:30
Sample Identification Number and Time: KE011 @ 8:30		Checked by:	
Sampled by: CI, BU		Recorded by: C Inouye	
Method of Collection: Slotted Soil Sampling Probe			
Surface Description: Grass pastureland			
Notes: Multi-increments sample (50)			

Soil Sample Data

Location: Costa's pasture – south of 9.5 Mile Camp	
Coordinates:	Elevation:

Lithology	Depth (ft.)	Soil Description	Est.% of G	Est.% of S	Est.% of F	Comments
ML	0-3"	Silt: 5YR 2.5/1. Black. Moist. Very soft. Low plasticity. Trace clay	10	5	85	No exposed soil. Soil is shallow. Basalt outcrops observed in area.

Surface and Shallow Soil Sample Log

Project Number: 3-251-90015	Project Name: Keaau	Date: 11/3/04	Time: 10:30
Sample Identification Number and Time: KE012 @ 10:30 / KE013 @11:00		Checked by:	
Sampled by: CI, BU		Recorded by: C Inouye	
Method of Collection: Slotted Soil Sampling Probe			
Surface Description: Vegetable garden plots			
Notes: Multi-increments sample (50)			

Soil Sample Data

Location: 9.5 Mile Camp Community Garden	
Coordinates:	Elevation:

Lithology	Depth (ft.)	Soil Description	Est.% of G	Est.% of S	Est.% of F	Comments
ML	0-3”	Silt: 5YR N2.5/1. Reddish black. Moist. Soft. Low plasticity. Trace clay.	5	15	80	Exposed soil throughout. Basalt outcrops observed in area.

Surface and Shallow Soil Sample Log

Project Number: 3-251-90015	Project Name: Keaau	Date: 11/3/04	Time: 13:00

Sample Identification Number and Time: KE014 @ 13:30 / KE015 @ 14:00	Checked by:
Sampled by: CI, BU	Recorded by: C Inouye

Method of Collection: Slotted Soil Sampling Probe

Surface Description: Lawn grass

Notes: Multi-increments sample (50)

Soil Sample Data

Location: Shipman Park Middle Field – Soccer field and baseball outfield

Coordinates:	Elevation:

Lithology	Depth (ft.)	Soil Description	Est.% of			Comments
			G	S	F	
CL	0-3"	Clay: 2.5YR N2.5/1. Reddish black. Moist. Loose (Hard near goal posts). With cinder gravel.	10	5	85	Soil exposed near goal posts and in baseball field.

Surface and Shallow Soil Sample Log

Project Number: 3-251-90015	Project Name: Keaau	Date: 11/3/04	Time: 15:30
Sample Identification Number and Time: KE016 @ 15:30		Checked by:	
Sampled by: CI, BU		Recorded by: C Inouye	
Method of Collection: Slotted Soil Sampling Probe			
Surface Description: Lawn grass			
Notes: Multi-increments sample (50)			

Soil Sample Data

Location: Kea'au Elementary (K-1 courtyard)	
Coordinates:	Elevation:

Lithology	Depth (ft.)	Soil Description	Est.% of			Comments
			G	S	F	
ML	0-3"	Silt: 2.5YR N2.5/1. Reddish black. Moist. Loose. With red cinder and black basalt gravel.	10	15	75	No exposed soil except in garden area where children are not allowed to play in. Suspected fill soil.

Surface and Shallow Soil Sample Log

Project Number: 3-251-90015	Project Name: Keaau	Date: 11/3/04	Time: 16:30
Sample Identification Number and Time: KE017 @ 16:30		Checked by:	
Sampled by: CI, BU	Recorded by: C Inouye		
Method of Collection: Slotted Soil Sampling Probe			
Surface Description: Lawn grass			
Notes: Multi-increments sample (50)			

Soil Sample Data

Location: Kea'au Elementary School – Grass area between Administration building and Cafeteria (play area for A-Plus program)	
Coordinates:	Elevation:

Lithology	Depth (ft.)	Soil Description	Est.% of			Comments
			G	S	F	
ML	0-3"	Silt: 10YR 3/2. Dusky Red. Loose – Medium hard. Low plasticity. Trace clay.	<5	10	85	Exposed soil in areas near administration building and tetherball area. Suspected fill soil.

Surface and Shallow Soil Sample Log

Project Number: 3-251-90015	Project Name: Keaau	Date: 11/4/04	Time: 9:30
Sample Identification Number and Time: KE018 @ 9:30		Checked by:	
Sampled by: CI, BU		Recorded by: C Inouye	
Method of Collection: Slotted Soil Sampling Probe			
Surface Description: Heavily vegetated except for “bulldozed” clearings			
Notes: Multi-increments sample (50)			

Soil Sample Data

Location: Kea’au Agriculture Lots Subdivision	
Coordinates:	Elevation:

Lithology	Depth (ft.)	Soil Description	Est.% of G	Est.% of S	Est.% of F	Comments
CL	0-3”	Clay: 2.5YR 2.5/2. Very Dusky Red. Moist. Soft. Medium plasticity.	0	5	95	Exposed soil in bulldozed areas/roadway.

Surface and Shallow Soil Sample Log

Project Number: 3-251-90015	Project Name: Keaau	Date: 11/4/04	Time: 11:30
Sample Identification Number and Time: KE020 @ 11:30 / KE021 @ 12:00		Checked by:	
Sampled by: CI, BU		Recorded by: C Inouye	
Method of Collection: Slotted Soil Sampling Probe			
Surface Description: Some vegetation with exposed soil			
Notes: Multi-increments sample (50)			

Soil Sample Data

Location: Open Lot north of 8.5 Mile Camp	
Coordinates:	Elevation:

Lithology	Depth (ft.)	Soil Description	Est.% of G	Est.% of S	Est.% of F	Comments
ML	0-3"	Silt: 2.5YR N2.5/1. Reddish Black. Moist. Loose. Trace clay.	20	10	70	Boulders/Gravel strewn about. Site was cleared and grubbed ~ three weeks prior to sample collection. Surface soil disturbed during clearing process. Resident from 8.5 Mile Camp stated that this area previously contained vegetable plots during the 1980's.

Surface and Shallow Soil Sample Log

Project Number: 3-251-90015	Project Name: Keaau	Date: 11/4/04	Time: 14:45
Sample Identification Number and Time: KE022 @ 14:45		Checked by:	
Sampled by: CI, BU	Recorded by: C Inouye		
Method of Collection: Slotted Soil Sampling Probe			
Surface Description: Vegetable garden plots			
Notes: Multi-increments sample (50)			

Soil Sample Data

Location: Open Lot north of 8.5 Mile Camp	
Coordinates:	Elevation:

Lithology	Depth (ft.)	Soil Description	Est.% of G	Est.% of S	Est.% of F	Comments
ML	0-3”	Silt: 2.5YR N2.5/1. Reddish Black. Moist. Soft. With black basalt gravel.	20	10	70	Exposed soil throughout. Suspected import soil from offsite.

APPENDIX C

Produce Sampling Protocols and Laboratory Reports

Exposure Investigation Protocol

Kea'au Area Gardens

Kea'au, Hawai'i

April 3, 2005
(Amended April 7, 2005)

Prepared by

Roger Brewer and John Peard

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

I. Purpose of Exposure Investigation

This investigation will assess exposure to arsenic among residents who grow fruits and vegetables ("produce") in former sugar cane fields in the area of Kea'au, Hawai'i. A draft Soil Assessment Study report identified elevated levels of arsenic in soils of this area (HIDOH 2005). Potential health hazards posed by exposure to arsenic in soil and dust are currently underway. Uptake of arsenic in locally grown and consumed garden produce is also an exposure route of potential concern.

This investigation proposes to further evaluate the potential exposure of residents to arsenic in the Kea'au area by measuring and evaluating arsenic concentrations in locally grown produce. Results of this investigation will help local agencies identify if public health actions are needed to reduce exposure and will assist in determining a focus for future studies. The results of this investigation will also be useful in the evaluation of former sugar cane fields in other areas of Hawai'i. Results of this exposure investigation cannot, however, be used to predict the future occurrence of disease.

II. Background

Kea'au was the location of a former sugar cane plantation. Cultivation of sugar cane in this area began about 1900 and continued until the early 1980's. Although large-scale sugar cane cultivation is no longer practiced, several small residential communities formerly associated with the sugar mill (referred to as "camps") still exist and are adjacent to former sugar cane fields. These include: Eight-and-One-Half Mile Camp, Nine-Mile Camp/Kea'au Camp and Nine-and-One-Half-Mile Camp. In addition, there are three other residential neighborhoods located in the Kea'au vicinity – the Kea'au Loop, Kea'au-Kula, and Kea'au Ag Lots subdivisions. A number of public schools serving a portion of the Puna District have been located in Kea'au. These schools include the Kea'au Elementary School, Kea'au Middle School, Kea'au High School, and Ke Kula O Nawahiokalaniopuu – a Hawaiian Language Immersion School

Public records indicate that three environmental investigations have been conducted in the Kea'au area. One of these investigations was conducted under the Hawai'i State

Department of Health's Voluntary Response Program. Results from these investigations have confirmed elevated concentrations of arsenic in soils of the Kea'au area.

A study conducted earlier this year (Draft March 2005) included the use of multi-increment soil collection and lab sub-sampling techniques to evaluate arsenic concentrations in the soils of community gardens at the Eight-and-One-Half Mile Camp, Nine-and-One-Half-Mile Camp and the Kea'au Middle School. Soil samples collected for total arsenic concentrations as well as soil chemistry and physical properties were screened to < 2 mm particle size. Average total arsenic concentrations in surface soils collected at 0-10 cm depth in the community gardens were:

- Eight and One-half Mile Camp Garden: 366 mg/kg dry weight;
- Nine and One-half Mile Camp Garden: 304 mg/kg dry weight;
- Kea`au Middle School Garden: 324 mg/kg dry weight.

The bioaccessible fraction of arsenic in the fines portion of soil (<250-µm) in the community gardens was reported to be in range from 18% and 20%. Natural background levels of arsenic in soils of the area are typically less than 20 mg/kg.

The results of the draft report suggest potential concerns regarding the uptake of arsenic in produce and subsequent exposure to residents who use the garden produce on a regular basis as part of their diet. The proposed investigation is intended to initially address this concern. The investigation consists of three objectives:

1) Measure arsenic in produce from the targeted community gardens;

2) Prepare an initial evaluation of potential health risk posed by consumption of the produce; and

3) Based on the results of this initial evaluation, determine the need for additional testing in the area to more conclusively evaluate health risks.

Information from the investigation will also be used to help develop a urinary arsenic testing study currently being planned for the targeted area as a public health service to the community.

III. Agency Roles

This Exposure Investigation will be a cooperative effort between the HIDOH and ATSDR. The roles and responsibilities of each agency are outlined below.

HIDOH:

- Conduct a public meeting with affected communities to discuss the nature and scope of the planned study.
- Contact local representatives to organize collection of produce samples from community gardens.
- Collect, clean and prepare produce samples and arrange for sample shipment and analysis.

ATSDR:

- Provide technical support for community meetings as well as the collection, analysis and interpretation of produce samples.

Data from the investigation will be shared with ATSDR for further evaluation.

IV. Target Population

This exposure investigation targets three community gardens in the Kea'au area: 1) Eight-and-One-Half Mile Camp, 2) Nine-and-One-Half-Mile Camp and 3) the Kea'au Middle School. The tropical climate of the area allows produce to be grown in the gardens year round, although growing times for specific types of produce vary. The proposed sampling will occur in April. A representative cross section of produce being harvested at that time will be collected (estimated 20 to 25 sample; Addendum: See summary of produce collected in Attachment 2).

During the week of April 4, 2005, staff from HIDOH and other local health agencies will hold a public meeting with the residents to inform them of the exposure investigation and the desire to collect produce samples from their gardens. Where permitted, produce samples will be collected from accessible gardens and with the assistance of local representatives. Information on the general use and reliance on produce from the gardens will be collected. HIDOH staff will collect the produce samples, follow proper chain of custody procedures and freeze the produce samples for shipment to the laboratory. Produce samples will be thoroughly washed and subsequently trimmed and/or peeled in same manner as would be carried out for consumption by the residents.

V. Confidentiality

Confidentiality will be protected to the fullest extent possible by law. The test results may be released only to other federal, state and local public health and environmental agencies involved in the project. These agencies must also protect all confidential information. Confidential information will be kept in locked cabinets at HIDOH or on password-protected computers.

VI. Methods

The sugar cane fields of the Kea'au area were active for approximately 80 years, although the use of arsenic-based pesticides in the fields is believed to have been restricted to period between 1915 and 1945. The uptake of arsenic in produce grown in impacted soils could lead to an increased risk of community exposure to arsenic (USEPA 1999). Long-term exposure to low levels of arsenic can lead to various health concerns, including some types of skin cancer (ATSDR 2000). The correlation between levels of heavy metals in soils and plants is difficult to predict, however. Therefore, sampling of homegrown produce for arsenic will provide valuable site-specific information for Kea'au residents.

An initial discussion of homegrown produce use will be held with residents during community meetings scheduled for April 6, 2005 (see Attachment 1). As available, a representative sample of fruits and vegetables currently being harvested from the gardens will be collected. HIDOH staff will document samples on chain-of-custody forms and maintain chain of custody until sample shipment. Samples will be placed in doubled Ziploc bags; frozen for storage and shipped on ice overnight to Food & Drug Administration (11510 W. 80th St., Lenexa, KS 66214). Samples will be analyzed for total arsenic using ICP-MS lab methodology. Method detection limits are anticipated to be approximately 6 µg/kg (0.006 ppm) for arsenic. The minimum amount of sample needed to meet these detection limits is 100 grams**.** The laboratory will follow method-specific QA/QC procedures.

Test results will be reported as weight of metal per whole weight (not dry weight) of food (e.g. mg/kg).

[Addendum (April 7, 2005,): Summary of samples collected provided in Attachment 2.]

VIII. Data management, analysis and interpretation

Analytical results will be electronically transmitted from the Food and Drug Administration (FDA) to HIDOH in spreadsheet format. No personal identifiers will be included in the spreadsheet. Data quality assurance and quality control will be performed by the lab.

Reported concentrations of arsenic in produce will be compared to data provided in the FDA Total Market Basket Survey (*Total Diet Study*, USFDA 2004) for initial screening purposes and other published data as available. If arsenic concentrations significantly exceed comparable levels presented in the FDA survey, then additional exposure calculations will be conducted to estimate if the levels pose a potential health concern to residents and the need for additional testing will be evaluated.

IX. Reporting of results

Individual test results with a written explanation of their meaning will be provided to the participants. Following dissemination of individual results, HIDOH staff contact will be available to discuss individual questions by phone. Recommendations for follow-up actions will be made, as warranted. Results of the produce testing will be used in part to develop a planned urinary testing study among residents in the Kea'au area in cooperation with ATSDR (mid-2005). At the conclusion of the investigation, HIDOH will prepare a report summarizing the findings of the investigation and present the data at a community meeting.

X. Limitations of Exposure Investigation

Testing of arsenic in homegrown produce is a useful screening method to evaluate the potential exposure of residents who consume the produce on a regular basis. The results of the testing cannot be used to predict past exposure, however, or directly estimate the likelihood of developing health effects from exposure to arsenic in homegrown produce.

XI. Risks and benefits of EI to participants

There are no expected risks to individuals who participate by donating produce samples from their gardens.

The benefits of testing homegrown produce include knowing if the produce are safe to consume and determining if additional preventive measures are needed to reduce exposure. An investigation of arsenic levels in produce from other gardens in the Kea'au area or produce imported from other areas has not been carried out. The need to expand the testing of produce to other areas will be evaluated based in part on the results of the proposed investigation.

XII: References

ATSDR, 2000, Toxicological Profile for Arsenic (September 2000). Agency for Toxic Substances and Disease Registry, U.S. Department of Health and Human Services, Public Health Services.

HIDOH, 2005, Kea'au Soil Assessment Study (Draft March 2005): Hawai'i Department of Health, prepared by AMEC Earth and Environmental, Inc.

USEPA, 1999, Estimating Risk from Contaminants Contained in Agricultural Fertilizers: U.S., Environmental Protection Agency (Draft August 1999), Office of Solid Waste.

USFDA, 2004, Total Diet Study Statistics on Element Results (July 2004): U.S. Food and Drug Administration, Revision 2, Market Baskets 1991-3 through 2002-4.

Attachment 1
Garden Produce Questionnaire

GARDEN PRODUCE QUESTIONNAIRE

Name:___________________________ Phone: ________________________

Address: ____

____

1. What vegetables do you grow in your garden? __________________________

____

____

2. How often do you or your family eat the vegetables grown in your garden? (List each vegetable and how often you eat it.)

____

____

____

____

____

____

____

3. What type of fertilizer do you use in your vegetable garden? (Please give brand name.)

____

____

4. Do you add lime to the soil in your vegetable garden? Y N

5. Is the soil in your vegetable garden acidic (pH less than 6.5)?

Yes No Don't Know

6. Did you grow these vegetables in a raised garden? Y N

7. Did you add soil in your garden? Y N

If yes, from where did you buy it and what kind of soil?

____

____

Attachment 2
Addendum: Summary of Samples Collected
(April 7, 2005)

Samples of produce currently being grown and used in the 8 ½ Mile Camp, 9 ½ Mile Camp and Kea'au Middle School gardens were collected on April 7, 2005. Samples were collected, prepared and submitted to the lab for analysis in accordance with the April 4, 2005, protocol prepared for the study. The following samples were collected:

Location	Sample ID Number	Produce Type	Sample Preparation
8 ½ Mile Camp	K8.5MC-1	Patani bean	Washed; outer husk removed
8 ½ Mile Camp	K8.5MC-2A	taro root	Washed, ends trimmed
8 ½ Mile Camp	K8.5MC-2B	taro stems	Washed
8 ½ Mile Camp	K8.5MC-2C	taro leaves	Washed
8 ½ Mile Camp	K8.5MC-3	papaya	Washed, peeled, halved, seeds removed
8 ½ Mile Camp	K8.5MC-4	banana	Washed, peeled
8 ½ Mile Camp	K8.5MC-5	sweet potato shoots	Washed
9 ½ Mile Camp	K9.5MC-1A	onion stalk	Washed
9 ½ Mile Camp	K9.5MC-1B	onion bulb	Washed, outer peel removed
9 ½ Mile Camp	K9.5MC-2	string beans	Washed
9 ½ Mile Camp	K9.5MC-3	casava	Washed, outer skin removed
9 ½ Mile Camp	K9.5MC-4	fern shoots	Washed
9 ½ Mile Camp	K9.5MC-5	taro root	Washed, ends trimmed
9 ½ Mile Camp	K9.5MC-7	eggplant	Washed, stem end trimmed
9 ½ Mile Camp	K9.5MC-8	pumpkin	Washed, stem end trimmed
9 ½ Mile Camp	K9.5MC-9	Kancun leaves	Washed
9 ½ Mile Camp	K9.5MC-10	bitter melon leaves	Washed
9 ½ Mile Camp	K9.5MC-11	long squash	Washed, stem end trimmed
9 ½ Mile Camp	K9.5MC-12	Marangi leaves	Washed
Kea'au Middle School	KMS-1	string beans	Washed
Kea'au Middle School	KMS-2	mustard cabbage	Washed
Kea'au Middle School	KMS-3	pumpkin	Washed, stem end trimmed
Kea'au Middle School	KMS-4	sweet potatoes	Washed, ends trimmed

Produce samples were thoroughly washed and then trimmed and/or peeled in same manner as carried out for cooking and consumption by the residents (summarized above). Prepared samples were placed in double zip-lock bags, frozen and shipped to the Food and Drug Administration laboratory in Lenexa, Kansas for total arsenic analysis.

LINDA LINGLE
GOVERNOR OF HAWAII

CHIYOME L. FUKINO, M.D.
DIRECTOR OF HEALTH

STATE OF HAWAII
DEPARTMENT OF HEALTH
P.O. Box 3378
HONOLULU, HAWAII 96801-3378

In reply, please refer to:
File: EHA/HEER Office

April 18, 2005
913-752-2157

Food & Drug Administration
ATTN: Duane Hughes
11510 W. 80th Street
Lenexa, KS 66214

Duane,
Enclosed are the produce samples from Kea'au, Hawai'i to be tested for total arsenic (ICP-MS). As noted on the chain of custody form, a total of 23 samples were collected. Also enclosed is the investigation protocol used for the study.

Please send the sample data report to my office e-mail at rbrewer@eha.health.state.hi.us. If needed, my mailing address is:

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

Please contact me at 1-808-586-4328 or via e-mail at if you have any questions. Thanks again for your assistance in this study.

Sincerely,

Roger C. B

Roger C. Brewer

STATE OF HAWAII
DEPARTMENT OF HEALTH
ENVIRONMENTAL HEALTH ADMINISTRATION
OFFICE OF HAZARD EVALUATION AND EMERGENCY RESPONSE

CHAIN OF CUSTODY RECORD

Project: Kea'au, Hawai'i

Date Shipped: 4/19/05

Carrier: FedEx
Airbill Number:

Sampler: Roger Brewer, HI Dept. of Health
Telephone: 1-808-[redacted] 586-4328

Sampler Signature: Roger B

Ship To:
Food & Drug Administration
ATTN: Duane Hughes
11510 W. 80th St.
Lenexa, KS 66214 tel: 1-913-752-2157

Sample Number	Date	Time	Number Of Containers	Preservative	Description of Samples	Analysis
K9.5MC-1A	4/7/05	0800	1	Frozen	Produce (onion stalk)	Total Arsenic (ICP-MS)
K9.5MC-1B	4/7/05	0800	1	Frozen	Produce (onion bulb)	Total Arsenic (ICP-MS)
K9.5MC-2	4/7/05	0800	1	Frozen	Produce (string beans)	Total Arsenic (ICP-MS)
K9.5MC-3	4/7/05	0800	1	Frozen	Produce (casava)	Total Arsenic (ICP-MS)
K9.5MC-4	4/7/05	0800	1	Frozen	Produce (fern shoots)	Total Arsenic (ICP-MS)
K9.5MC-5	4/7/05	0800	1	Frozen	Produce (taro root)	Total Arsenic (ICP-MS)
K9.5MC-7	4/7/05	0800	1	Frozen	Produce (eggplant)	Total Arsenic (ICP-MS)
K9.5MC-8	4/7/05	0800	1	Frozen	Produce (pumpkin)	Total Arsenic (ICP-MS)
K9.5MC-9	4/7/05	0800	1	Frozen	Produce (kancun)	Total Arsenic (ICP-MS)
K9.5MC-10	4/7/05	0800	1	Frozen	Produce (bitter melon leaves)	Total Arsenic (ICP-MS)
K9.5MC-11	4/7/05	0800	1	Frozen	Produce (long squash)	Total Arsenic (ICP-MS)
K9.5MC-12	4/7/05	0800	1	Frozen	Produce (marangi)	Total Arsenic (ICP-MS)
KMS-1	4/7/05	1000	1	Frozen	Produce (string beans)	Total Arsenic (ICP-MS)
KMS-2	4/7/05	1000	1	Frozen	Produce (mustard cabbage)	Total Arsenic (ICP-MS)
KMS-3	4/7/05	1000	1	Frozen	Produce (pumpkin)	Total Arsenic (ICP-MS)
KMS-4	4/7/05	1000	1	Frozen	Produce (sweet potatoes)	Total Arsenic (ICP-MS)
K8.5MC-1	4/7/05	1600	1	Frozen	Produce (Patani bean)	Total Arsenic (ICP-MS)
K8.5MC-2A	4/7/05	1600	1	Frozen	Produce (taro root)	Total Arsenic (ICP-MS)
K8.5MC-2B	4/7/05	1600	1	Frozen	Produce (taro stems)	Total Arsenic (ICP-MS)
K8.5MC-2C	4/7/05	1600	1	Frozen	Produce (taro leaves)	Total Arsenic (ICP-MS)
K8.5MC-3	4/7/05	1600	1	Frozen	Produce (papaya)	Total Arsenic (ICP-MS)
K8.5MC-4	4/7/05	1600	1	Frozen	Produce (banana)	Total Arsenic (ICP-MS)
K8.5MC-5	4/7/05	1600	1	Frozen	Produce (sweet potato shoots)	Total Arsenic (ICP-MS)

Chain of Custody Record

Relinquished By:	Received By:	Time	Date
Roger B			
Relinquished By:	Received By:	Time	Date

Kea'au Area Gardens Exposure Investigation
April/May 2005

Twenty-three samples were received, contained within a cooler, each enclosed in two "Zip-Loc" type bags. Each sample was weighed, while still contained within the bags, and the weight recorded to within 0.1 gram. The two plastic bags collectively weigh approximately 17 grams, this value was not subtracted from the "Total smple wt + bag(s)" value.

Each sample was chopped and mixed using either a Waring Commercial Blender or the Robot Coupe 6N, depending upon size of sample.

Approximately five grams from each mixed sample was weighed out, in duplicate, the weight recorded, and placed within a microwave digestion vessel. Eight mls of concentrated HNO3 and two mls of 30% H2O2 were added to each vessel. One to two mls of H2O were also added. These vessels were then capped, allowed to stand overnight and then placed in the microwave oven the following day. The "Digest" program was used for heating. Five reagent blanks were also prepared, five reference material samples were prepared, and two field samples were spiked in duplicate with 3.00 mls of 100 ug/L arsenic solution. After heating, the samples were allowed to cool and then diluted to 50 mls with DI H2O.

As the microwave oven holds a total of 12 vessels, each digestion set consists of one reagent blank, one reference material sample and ten field samples. A total of five digestion sets were prepared.

The digested samples were then analyzed for arsenic using the Agilent 7500c ICP-MS using Ge^{72} as an internal standard.

A detection limit of 6 ug/kg (as indicated in the "Exposure Investigation Protocol of April 3, 2005") was achieved and would be the suggested lower limit for reporting. No samples required dilution. All quality control parameters for arsenic were within control. [Matrix spikes 100 ± 20%, Reference Material Recovery (NBS Spinach 1570) 100 ± 20%, Initial Calibration Verification (ICV) 100 ± 10% and all (seven) Continuing Calibration Verification standards (CCV) 100 ± 10%.]

Lead and cadmium were also analyzed, although not requested, as they were part of this analytical scheme. Should we wish to report these as well they are included. If not, they can easily be deleted. All quality control parameters for lead and cadmium were also met, *except* for one high recovery of lead from one reference material sample. I would *suggest* a lower limit of 5 ug/kg for cadmium and 10 ug/kg for lead be used, should we wish to report these elements as well. These values are indicated on the spreadsheet through the use of color coding.

Sean

Kea'au Hawaii Total Arsenic
Hawaii Department of Health

Sample No.	QC Type	Total sample wt + bags (g)	vessel #	Digest Set	Sample wt.	Vol (ml)	ug/L As	mg/kg As	ug/L Cd	mg/kg Cd			ug/L Pb	mg/kg Pb		
K9.5MC-1A	Original	92.9	2	A	5.0548	50	0.6171	0.006	1.9100	0.019			0.3799	0.004		
K9.5MC-1A	Duplicate		4	A	5.3609	50	0.6098	0.006	1.6570	0.015			0.3341	0.003		
K9.5MC-1B	Original	68.0	5	A	5.1206	50	1.2590	0.012	0.7408	0.007			0.6680	0.007		
K9.5MC-1B	Duplicate		6	A	5.1203	50	1.1380	0.011	0.7647	0.007			0.3764	0.004		
K9.5MC-2	Original	86.0	7	A	5.2141	50	0.3020	0.003	0.0960	0.001			0.4058	0.004		
K9.5MC-2	Duplicate		8	A	5.1624	50	0.3150	0.003	0.0822	0.001			0.2515	0.002		
K9.5MC-3	Original	552.0	10	A	5.1072	50	0.0827	0.001	9.1360	0.089			0.6258	0.006		
K9.5MC-3	Duplicate		11	A	5.0125	50	0.1255	0.001	9.4460	0.094			0.8209	0.008		
K9.5MC-4	Original	133.5	12	A	5.6927	50	0.7890	0.007	1.1550	0.010			0.3846	0.003		
K9.5MC-4	Duplicate		13	A	5.1075	50	0.6594	0.006	1.0260	0.010			0.3293	0.003		
K9.5MC-5	Original	260.3	19	B	5.0481	50	0.6579	0.007	10.5200	0.104			2.4530	0.024		
K9.5MC-5	Duplicate		22	B	4.9972	50	0.7814	0.008	11.5200	0.115			2.2710	0.023		
K9.5MC-7	Original	254.2	23	B	5.0397	50	0.0788	0.001	3.9030	0.039			0.3016	0.003		
K9.5MC-7	Duplicate		24	B	5.2510	50	0.0927	0.001	3.9470	0.038			0.2502	0.002		
K9.5MC-8	Original	1017.9	26	B	5.1621	50	0.0254	0.000	0.0000	0.000			0.1112	0.001		
K9.5MC-8	Duplicate		27	B	5.0680	50	0.0088	0.000	0.0000	0.000			0.1386	0.001		
K9.5MC-9	Original	143.1	28	B	4.9937	50	2.2740	0.023	6.1820	0.062			1.7140	0.017		
K9.5MC-9	Duplicate		35	B	5.0155	50	2.3590	0.024	6.6060	0.066			1.6910	0.017		
K9.5MC-10	Original	237.6	37	B	5.3553	50	1.9050	0.018	0.1681	0.002			1.0340	0.010		
K9.5MC-10	Duplicate		38	B	5.4113	50	1.8110	0.017	0.1353	0.001			0.8834	0.008		
K9.5MC-11	Original	393.4	41	C	5.6046	50	0.0000	0.000	0.2523	0.002			0.1876	0.002		
K9.5MC-11	Duplicate		43	C	5.1909	50	0.0000	0.000	0.2248	0.002			0.1673	0.002		
K9.5MC-12	Original	79.2	45	C	5.0039	50	0.3112	0.003	0.1129	0.001			0.6686	0.007		
K9.5MC-12	Duplicate		46	C	5.0846	50	0.2880	0.003	0.1018	0.001			0.5913	0.006		
KMS-1	Original	494.1	47	C	5.0395	50	0.3222	0.003	0.0000	0.000			0.1011	0.001		
KMS-1	Duplicate		48	C	5.2336	50	0.3298	0.003	0.0000	0.000			0.1324	0.001		
KMS-2	Original	236.1	49	C	5.0085	50	9.8280	0.098	1.7220	0.017			0.6892	0.007		
KMS-2	Duplicate		53	C	5.0200	50	9.9390	0.099	1.7900	0.018			0.7379	0.007		
KMS-3	Original	610.8	54	C	5.1160	50	0.2097	0.002	0.0000	0.000			0.0645	0.001		
KMS-3	Duplicate		56	C	5.0916	50	0.2169	0.002	0.0000	0.000			0.0565	0.001		
KMS-4	Original	218.1	3	D	5.1240	50	6.6290	0.065	0.6901	0.007			0.5079	0.005		
KMS-4	Duplicate		36	D	5.0035	50	5.8510	0.058	0.5820	0.006			0.4367	0.004		
K8.5MC-1	Original	135.3	39	D	5.0399	50	0.0808	0.001	0.0000	0.000			0.0463	0.000		
K8.5MC-1	Duplicate		57	D	5.0081	50	0.0737	0.001	0.0000	0.000			0.0264	0.000		
K8.5MC-2A	Original	281.5	62	D	5.3117	50	5.2140	0.049	15.3800	0.145			6.5080	0.061		
K8.5MC-2A	Duplicate		63	D	5.5419	50	6.4100	0.058	18.3200	0.165			7.8240	0.071		
K8.5MC-2B	Original	54.4	64	E	5.9997	50	2.2220	0.019	31.1100	0.259			1.5580	0.013		
K8.5MC-2B	Duplicate		66	E	4.7279	50	1.8610	0.020	24.2000	0.256			1.2280	0.013		
K8.5MC-2C	Original	72.6	72	D	5.2523	50	6.4340	0.061	23.6700	0.225			0.7709	0.007		
K8.5MC-2C	Duplicate		67	D	5.0011	50	5.8120	0.058	22.8800	0.229			0.7343	0.007		
K8.5MC-2C	Spike		73	D	5.0294	50	12.4300	0.124	29.6300	0.295			7.0570	0.070		
K8.5MC-2C	Spike Dup		77	D	5.0449	50	12.3100	0.122	28.1300	0.279			6.9270	0.069		
K8.5MC-3	Original	472.3	83	E	5.2048	50	0.4356	0.004	0.0000	0.000			0.0769	0.001		
K8.5MC-3	Duplicate		87	E	5.2388	50	0.4873	0.005	0.0000	0.000			0.0920	0.001		
K8.5MC-3	Spike		91	E	5.1375	50	6.0190	0.059	5.6210	0.055			6.2070	0.060		
K8.5MC-3	Spike Dup		93	E	5.0373	50	6.1030	0.061	5.6370	0.056			6.1340	0.061		
K8.5MC-4	Original	151.5	101	E	5.0487	50	1.7360	0.017	0.0432	0.000			0.0687	0.001		
K8.5MC-4	Duplicate		105	E	5.0320	50	1.8020	0.018	0.0657	0.001			0.0882	0.001		
K8.5MC-5	Original	130.1	111	E	5.0762	50	4.4050	0.043	0.4683	0.005			1.3080	0.013		
K8.5MC-5	Duplicate		118	E	5.1602	50	4.5240	0.044	0.4631	0.004			1.2780	0.012		
Blank-1	Mthd Blk		15	A	5.0000	50	-0.0314	0.000	-0.1428	-0.001			0.0699	0.001		
Blank-2	Mthd Blk		51	B	5.0000	50	-0.0549	-0.001	-0.0994	-0.001			0.5563	0.006		
Blank-3	Mthd Blk		9	C	5.0000	50	-0.0810	-0.001	-0.1438	-0.001			0.5823	0.006		
Blank-4	Mthd Blk		16	D	5.0000	50	-0.1013	-0.001	-0.1478	-0.001			-0.0027	0.000		
Blank-5	Mthd Blk		21	E	5.0000	50	-0.0596	-0.001	-0.1410	-0.001			-0.0382	0.000		
RM1570-1	Ref Materl	RM 1570	1	A	0.8080	50	2.2990	0.140	21.4200	1.304			17.2900	1.053		
RM1570-2	Ref Materl	corrected	17	B	0.5779	50	1.6570	0.141	15.2700	1.300			12.4200	1.057		
RM1570-3	Ref Materl	for	14	C	0.5567	50	1.4820	0.131	14.0600	1.243			12.1000	1.069		
RM1570-4	Ref Materl	1.60% moisture	125	D	0.5889	50	1.5900	0.133	15.3900	1.286			18.0600	1.509		
RM1570-5	Ref Materl		131	E	0.5677	50	1.5490	0.134	14.1900	1.230			15.3300	1.329		

April/May 2005 by SMR

Kea'au Hawaii Total Arsenic
Hawaii Department of Health

	As									**Cd**				**Pb**		
Sample	**ug/l**								**Sample**	**ug/l**			**Sample**	**ug/l**		
Blank-1	-0.0314								Blank-1	-0.1428			Blank-1	0.0699		
Blank-2	-0.0549								Blank-2	-0.0994			Blank-2	0.5563		
Blank-3	-0.0810								Blank-3	-0.1438			Blank-3	0.5823		
Blank-4	-0.1013								Blank-4	-0.1478			Blank-4	-0.0027		
Blank-5	-0.0596								Blank-5	-0.1410			Blank-5	-0.0382		
Mean	-0.0656		**mg/kg**		<-- (based on method blk noise) -->				Mean	-0.1350		**mg/kg**	Mean	0.2335		**mg/kg**
std. dev	0.0266	**LOD:**	0.001						std. dev	0.0200	**LOD:**	0.001	std. dev	0.3091	**LOD:**	0.009
3 X std. dev	0.0798	**LOQ:**	0.003						3 X std. dev	0.0601	**LOQ:**	0.002	3 X std. dev	0.9274	**LOQ:**	0.031
Sample	**mg/kg**	**% Recovery**							**Sample**	**mg/kg**	**% Recovery**		**Sample**	**mg/kg**	**% Recovery**	
RM1570-1	0.140	93.3							RM1570-1	1.304	87.0		RM1570-1	1.053	87.7	
RM1570-2	0.141	94.0							RM1570-2	1.300	86.7		RM1570-2	1.057	88.1	
RM1570-3	0.131	87.3							RM1570-3	1.243	82.8		RM1570-3	1.069	89.1	
RM1570-4	0.133	88.6							RM1570-4	1.286	85.7		RM1570-4	1.509	125.7	
RM1570-5	0.134	89.5							RM1570-5	1.230	82.0		RM1570-5	1.329	110.7	
Spike % Rec	**mg/kg**	**% Recovery**							**Spike % Rec**	**mg/kg**	**% Recovery**		**Spike % Rec**	**mg/kg**	**% Recovery**	
K8.5MC2CSP	0.124	107.1							K8.5MC2CSP	0.295	113.2		K8.5MC2CSP	0.070	105.3	
K8.5MC2CSPD	0.122	104.8							K8.5MC2CSPD	0.279	87.0		K8.5MC2CSPD	0.069	103.1	
K8.5MC3SP	0.059	92.8							K8.5MC3SP	0.055	93.7		K8.5MC3SP	0.060	102.1	
K8.5MC3SPDu	0.061	94.3							K8.5MC3SPDu	0.056	94.0		K8.5MC3SPDu	0.061	100.9	
		As	**Cd**	**Pb**												
Initial Cal Ver.	(ug/L)	29.29	5.382	9.744												
(ICV)	True Value:	27.00	5.000	9.000												
	% Recvry	108.5	107.6	108.3												
Cont. Cal Ver.	(ug/L)	**As**	**Cd**	**Pb**					Cont. Cal Blank	(ug/L)	**As**	**Cd**	**Pb**			
(CCV)	True Value:	50.00	50.00	50.00					CCB	True Value:	0.00	0.00	0.00			
CCV-1		51.40	50.05	50.08					CCB-1		0.0001	-0.0670	-0.0192			
CCV-2		50.68	49.23	49.68					CCB-2		-0.0747	-0.1482	-0.0793			
CCV-3		51.11	48.51	49.20					CCB-3		-0.0185	-0.0860	-0.0124			
CCV-4		50.72	49.16	49.52					CCB-4		0.0290	-0.0384	0.0269			
CCV-5		51.77	49.10	49.33					CCB-5		-0.0249	-0.1113	-0.0467			
CCV-6		52.19	49.53	50.04					CCB-6		-0.0756	-0.1479	-0.0870			
CCV-7		46.62	47.44	48.47					CCB-7		-0.1294	-0.1459	-0.0886			
Cal Stds:	(ug/L)	0, 1.0, 5.0, 10, 20, 50 & 100														
Corr coef:		1.0000	1.0000	1.0000												
slope:		0.1364	0.0665	1.1450												
y-int:		0.0285	0.0104	0.1207												
Analyte isotope:		75	111	206+207 +208												
Int. Std Used:		Ge^{72}	Rh^{103}	Bi^{209}												
Balance used:		Mettler AT201														
Black:	mg/kg	As <0.006, Cd <0.005, Pb <0.010														
Red:	mg/kg	As ≥0.006, Cd ≥ 0.005, Pb ≥0.010														
Green:	mg/kg	Matrix Spike Results.														

April/May 2005 by SMR

Exposure Investigation Protocol

Kea'au Area Gardens

Kea'au, Hawai'i

August 31, 2005

Prepared by

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State of Hawai'i
Department of Health
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I. Purpose of Exposure Investigation

This investigation will assess exposure to arsenic among residents who grow fruits and vegetables ("produce") in former sugar cane fields in the area of Kea'au, Hawai'i. A draft Soil Assessment Study report identified elevated levels of arsenic in soils of this area (HIDOH 2005). Potential health hazards posed by exposure to arsenic in soil and dust are currently underway. Uptake of arsenic in locally grown and consumed garden produce is also an exposure route of potential concern.

This investigation proposes to further evaluate the potential exposure of residents to arsenic in the Kea'au area by measuring and evaluating arsenic concentrations in locally grown produce. Results of this investigation will help local agencies identify if public health actions are needed to reduce exposure and will assist in determining a focus for future studies. The results of this investigation will also be useful in the evaluation of former sugar cane fields in other areas of Hawai'i. Results of this exposure investigation cannot, however, be used to predict the future occurrence of disease.

II. Background

Kea'au was the location of a former sugar cane plantation. Cultivation of sugar cane in this area began about 1900 and continued until the early 1980's. Although large-scale sugar cane cultivation is no longer practiced, several small residential communities formerly associated with the sugar mill (referred to as "camps") still exist and are adjacent to former sugar cane fields. These include: Eight-and-One-Half Mile Camp, Nine-Mile Camp/Kea'au Camp and Nine-and-One-Half-Mile Camp. In addition, there are three other residential neighborhoods located in the Kea'au vicinity – the Kea'au Loop, Kea'au-Kula, and Kea'au Ag Lots subdivisions. A number of public schools serving a portion of the Puna District have been located in Kea'au. These schools include the Kea'au Elementary School, Kea'au Middle School, Kea'au High School, and Ke Kula O Nawahiokalaniopuu – a Hawaiian Language Immersion School

Public records indicate that three environmental investigations have been conducted in the Kea'au area. One of these investigations was conducted under the Hawai'i State

Department of Health's Voluntary Response Program. Results from these investigations have confirmed elevated concentrations of arsenic in soils of the Kea'au area.

A study conducted earlier this year (Draft August 2005) included the use of multi-increment soil collection and lab sub-sampling techniques to evaluate arsenic concentrations in the soils of community gardens at the Eight-and-One-Half Mile Camp, Nine-and-One-Half-Mile Camp and the Kea'au Middle School. Soil samples collected for total arsenic concentrations as well as soil chemistry and physical properties were screened to < 2 mm particle size. Average total arsenic concentrations in surface soils collected at 0-10 cm depth in the community gardens were:

- Eight and One-half Mile Camp Garden: 366 mg/kg dry weight;
- Nine and One-half Mile Camp Garden: 304 mg/kg dry weight;
- Kea`au Middle School Garden: 324 mg/kg dry weight.

The bioaccessible fraction of arsenic in the fines portion of soil (<250-μm) in the community gardens was reported to be in range from 18% and 20%. Natural background levels of arsenic in soils of the area are typically less than 20 mg/kg.

The results of the draft report suggest potential concerns regarding the uptake of arsenic in produce and subsequent exposure to residents who use the garden produce on a regular basis as part of their diet. The proposed investigation is intended to initially address this concern. The investigation consists of three objectives:

1) Measure arsenic in produce from the targeted community gardens;

2) Prepare an initial evaluation of potential health risk posed by consumption of the produce; and

3) Based on the results of this initial evaluation, determine the need for additional testing in the area to more conclusively evaluate health risks.

Initial produce samples were collected in April 2005. The current study represents a followup action to collect types of produce not available earlier in the year and to obtain additional data on targeted root and leaf vegetables.

III. Agency Roles

This Exposure Investigation will be a cooperative effort between the HIDOH and ATSDR. The roles and responsibilities of each agency are outlined below.

HIDOH:

- Conduct a public meeting with affected communities to discuss the nature and scope of the planned study.
- Contact local representatives to organize collection of produce samples from community gardens.
- Collect, clean and prepare produce samples and arrange for sample shipment and analysis.

ATSDR:

- Provide technical support for community meetings as well as the collection, analysis and interpretation of produce samples.

Data from the investigation will be shared with ATSDR for further evaluation.

IV. Target Population

This exposure investigation targets two community gardens in the Kea'au area: 1) Eight-and-One-Half Mile Camp and 2) Nine-and-One-Half-Mile Camp. The tropical climate of the area allows produce to be grown in the gardens year round, although growing times for specific types of produce vary. The proposed sampling will occur in August and September 2005. A representative cross section of produce being harvested at that time will be collected (estimated 15-20 samples).

During the week of August 22, 2005, staff from HIDOH and other local health agencies will hold a public meeting with the residents to inform them of the exposure investigation and the desire to collect produce samples from their gardens. Where permitted, produce samples will be collected from accessible gardens and with the assistance of local representatives. Information on the general use and reliance on produce from the gardens will be collected. HIDOH staff will collect the produce samples, follow proper chain of custody procedures and freeze the produce samples for shipment to the laboratory. Produce samples will be thoroughly washed and subsequently trimmed and/or peeled in same manner as would be carried out for consumption by the residents.

V. Confidentiality

Confidentiality will be protected to the fullest extent possible by law. The test results may be released only to other federal, state and local public health and environmental agencies involved in the project. These agencies must also protect all confidential information. Confidential information will be kept in locked cabinets at HIDOH or on password-protected computers.

VI. Methods

The sugar cane fields of the Kea'au area were active for approximately 80 years, although the use of arsenic-based pesticides in the fields is believed to have been restricted to period between 1915 and 1945. The uptake of arsenic in produce grown in impacted soils could lead to an increased risk of community exposure to arsenic (USEPA 1999). Long-term exposure to low levels of arsenic can lead to various health concerns, including some types of skin cancer (ATSDR 2000). The correlation between levels of heavy metals in soils and plants is difficult to predict, however. Therefore, sampling of homegrown produce for arsenic will provide valuable site-specific information for Kea'au residents.

As available, a representative sample of fruits and vegetables currently being harvested from the gardens will be collected. HIDOH staff will document samples on chain-of-custody forms and maintain chain of custody until sample shipment. Samples will be placed in doubled Ziploc bags; frozen for storage and shipped on ice overnight to Food & Drug Administration (11510 W. 80th St., Lenexa, KS 66214). Samples will be analyzed for total arsenic using ICP-MS lab methodology. Method detection limits are anticipated to be approximately 6 µg/kg (0.006 ppm) for arsenic. The minimum amount of sample needed to meet these detection limits is 100 grams**.** The laboratory will follow method-specific QA/QC procedures.

Test results will be reported as weight of metal per whole weight (not dry weight) of food (e.g. mg/kg).

[Addendum (April 7, 2005,): Summary of samples collected provided in Attachment 1.]

VIII. Data management, analysis and interpretation

Analytical results will be electronically transmitted from the Food and Drug Administration (FDA) to HIDOH in spreadsheet format. No personal identifiers will be included in the spreadsheet. Data quality assurance and quality control will be performed by the lab.

Reported concentrations of arsenic in produce will be compared to data provided in the FDA Total Market Basket Survey (*Total Diet Study*, USFDA 2004) for initial screening purposes and other published data as available. If arsenic concentrations significantly exceed comparable levels presented in the FDA survey, then additional exposure calculations will be conducted to estimate if the levels pose a potential health concern to residents and the need for additional testing will be evaluated.

IX. Reporting of results

Individual test results with a written explanation of their meaning will be provided to the participants. Following dissemination of individual results, HIDOH staff contact will be available to discuss individual questions by phone. Recommendations for follow-up actions will be made, as warranted. Results of the produce testing will be used in part to develop a planned urinary testing study among residents in the Kea'au area in cooperation with ATSDR (mid-2005). At the conclusion of the investigation, HIDOH will prepare a report summarizing the findings of the investigation and present the data at a community meeting.

X. Limitations of Exposure Investigation

Testing of arsenic in homegrown produce is a useful screening method to evaluate the potential exposure of residents who consume the produce on a regular basis. The results of the testing cannot be used to predict past exposure, however, or directly estimate the likelihood of developing health effects from exposure to arsenic in homegrown produce.

XI. Risks and benefits of EI to participants

There are no expected risks to individuals who participate by donating produce samples from their gardens.

The benefits of testing homegrown produce include knowing if the produce are safe to consume and determining if additional preventive measures are needed to reduce exposure. An investigation of arsenic levels in produce from other gardens in the Kea'au area or produce imported from other areas has not been carried out. The need to expand the testing of produce to other areas will be evaluated based in part on the results of the proposed investigation.

XII: References

ATSDR, 2000, Toxicological Profile for Arsenic (September 2000). Agency for Toxic Substances and Disease Registry, U.S. Department of Health and Human Services, Public Health Services.

HIDOH, 2005, Kea'au Soil Assessment Study (Draft March 2005): Hawai'i Department of Health, prepared by AMEC Earth and Environmental, Inc.

USEPA, 1999, Estimating Risk from Contaminants Contained in Agricultural Fertilizers: U.S., Environmental Protection Agency (Draft August 1999), Office of Solid Waste.

USFDA, 2004, Total Diet Study Statistics on Element Results (July 2004): U.S. Food and Drug Administration, Revision 2, Market Baskets 1991-3 through 2002-4.

Attachment 1
Addendum: Summary of Samples Collected
(September 1, 2005)

Samples of produce currently being grown and used in the 8 ½ Mile Camp and 9 ½ Mile Camp were collected on August 31 and September 1, 2005. Samples were collected, prepared and submitted to the lab for analysis in accordance with the August 31, 2005, protocol prepared for the study. The following samples were collected:

Location	Sample ID Number	Produce Type	Sample Preparation
8 ½ Mile Camp	K8.5MC-6	avocado	Washed, outer skin removed, seed removed, halved
8 ½ Mile Camp	K8.5MC-7	chayote squash shoots	Washed
8 ½ Mile Camp	K8.5MC-8	bitter melon shoots	Washed
8 ½ Mile Camp	K8.5MC-9	sweet potato shoots	Washed
8 ½ Mile Camp	K8.5MC-10A	taro root	Washed, outer skin removed, ends trimmed
8 ½ Mile Camp	K8.5MC-10B	taro stems	Washed, peeled
8 ½ Mile Camp	K8.5MC-10C	taro leaves	Washed
8 ½ Mile Camp	K8.5MC-11	bitter melon fruit	Washed
8 ½ Mile Camp	K8.5MC-12	bamboo shoots	Washed, outer skin removed
8 ½ Mile Camp	K8.5MC-13	cassava root	Washed, outer skin removed, ends trimmed
9 ½ Mile Camp	K9.5MC-13	cassava root	Washed, outer skin removed, ends trimmed
9 ½ Mile Camp	K9.5MC-14A	taro root	Washed, outer skin removed, ends trimmed
9 ½ Mile Camp	K9.5MC-14B	taro stems	Washed, peeled
9 ½ Mile Camp	K9.5MC-14C	taro leaves	Washed
9 ½ Mile Camp	K9.5MC-15	bitter melon shoots	Washed
9 ½ Mile Camp	K9.5MC-16	Kancun leaves	Washed
9 ½ Mile Camp	K9.5MC-17	sweet potato shoots	Washed
9 ½ Mile Camp	K9.5MC-18	papaya	Washed, outer skin removed, seeds removed, halved

Produce samples were thoroughly washed and then trimmed and/or peeled in same manner as carried out for cooking and consumption by the residents (summarized above). Prepared samples were placed in double zip-lock bags, frozen and shipped to the Food and Drug Administration laboratory in Lenexa, Kansas for total arsenic analysis.

LINDA LINGLE
GOVERNOR OF HAWAII

CHIYOME L. FUKINO, M.D.
DIRECTOR OF HEALTH

STATE OF HAWAII
DEPARTMENT OF HEALTH
P.O. Box 3378
HONOLULU, HAWAII 96801-3378

In reply, please refer to:
File: EHA/HEER Office

September 19, 2005

Food & Drug Administration
ATTN: Duane Hughes
11510 W. 80th Street
Lenexa, KS 66214

Duane,

Enclosed are the second round of produce samples from Kea'au, Hawai'i to be tested for total arsenic (ICP-MS). As noted on the chain of custody form, a total of 18 samples were collected. Also enclosed is the investigation protocol used for the study.

Please send the sample data report to my office e-mail at rbrewer@eha.health.state.hi.us. If needed, my mailing address is:

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

Please contact me at 1-808-586-4328 or via e-mail at if you have any questions.. Thanks again for your assistance in this study.

Sincerely,

Roger C. Brewer

STATE OF HAWAII
DEPARTMENT OF HEALTH
ENVIRONMENTAL HEALTH ADMINISTRATION
OFFICE OF HAZARD EVALUATION AND EMERGENCY RESPONSE

CHAIN OF CUSTODY RECORD

Project: Kea'au, Hawai'i
Date Shipped: Sept. 19, 2005
Carrier:
Airbill Number:

Sampler: Roger Brewer, HI Dept. of Health
Telephone: 1-808--586-4324

Sampler Signature: Roger B

Ship To:
Food & Drug Administration
ATTN: Duane Hughes
11510 W. 80th St.
Lenexa, KS 66214 **tel: 1-913-752-2157**

Sample Number	Date	Time	Number Of Containers	Preservative	Description of Samples	Analysis
K8.5MC-6	8/31/05	1700	1	Frozen	Produce (avocado)	Total Arsenic (ICP-MS)
K8.5MC-7	8/31/05	1700	1	Frozen	Produce (squash shoots)	Total Arsenic (ICP-MS)
K8.5MC-8	8/31/05	1700	1	Frozen	Produce (bitter melon shoots)	Total Arsenic (ICP-MS)
K8.5MC-9	8/31/05	1700	1	Frozen	Produce (sweet potato shoots)	Total Arsenic (ICP-MS)
K8.5MC-10A	8/31/05	1700	1	Frozen	Produce (taro root)	Total Arsenic (ICP-MS)
K8.5MC-10B	8/31/05	1700	1	Frozen	Produce (taro stems)	Total Arsenic (ICP-MS)
K8.5MC-10C	8/31/05	1700	1	Frozen	Produce (taro leaves)	Total Arsenic (ICP-MS)
K8.5MC-11	8/31/05	1700	1	Frozen	Produce (bitter melon fruit)	Total Arsenic (ICP-MS)
K8.5MC-12	8/31/05	1700	1	Frozen	Produce (bamboo shoots)	Total Arsenic (ICP-MS)
K8.5MC-13	8/31/05	1700	1	Frozen	Produce (cassava root)	Total Arsenic (ICP-MS)
K9.5MC-13	9/1/05	1730	1	Frozen	Produce (cassava root)	Total Arsenic (ICP-MS)
K9.5MC-14A	9/1/05	1730	1	Frozen	Produce (taro root)	Total Arsenic (ICP-MS)
K9.5MC-14B	9/1/05	1730	1	Frozen	Produce (taro stems)	Total Arsenic (ICP-MS)
K9.5MC-14C	9/1/05	1730	1	Frozen	Produce (taro leaves)	Total Arsenic (ICP-MS)
K9.5MC-15	9/1/05	1730	1	Frozen	Produce (bitter melon shoots)	Total Arsenic (ICP-MS)
K9.5MC-16	9/1/05	1730	1	Frozen	Produce (kancun leaves)	Total Arsenic (ICP-MS)
K9.5MC-17	9/1/05	1730	1	Frozen	Produce (sweet potato shoots)	Total Arsenic (ICP-MS)
K9.5MC-18	9/1/05	1730	1	Frozen	Produce (papaya)	Total Arsenic (ICP-MS)

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Chain of Custody Record

Relinquished By: Roger B	**Received By:**	**Time**	**Date**
Relinquished By:	**Received By:**	**Time**	**Date**

Kea'au Hawaii Total Arsenic
Hawaii Department of Health

Sample No.	QC Type	Total smple wt. + bags (g)	Vessel No.	Digest Set	Sample wt. (g)	Vol (ml)	ug/L As	mg/kg As	ug/L Cd	mg/kg Cd			ug/L Pb	mg/kg Pb		
K8.5MC-6	Original	213.7	10	A	5.3190	50	5.6730	0.053	1.9250	0.018			0.2769	0.003		
K8.5MC-6	Duplicate		42	A	5.5380	50	6.4390	0.058	1.9400	0.018			0.4416	0.004		
K8.5MC-7	Original	205.0	11	A	5.5480	50	0.9286	0.008	0.3075	0.003			0.4173	0.004		
K8.5MC-7	Duplicate		13	A	5.5758	50	0.8867	0.008	0.2156	0.002			0.2740	0.002		
K8.5MC-8	Original	111.9	16	A	5.1135	50	3.2730	0.032	0.3828	0.004			2.6530	0.026		
K8.5MC-8	Duplicate		17	A	5.2127	50	2.8790	0.028	0.3883	0.004			2.3460	0.023		
K8.5MC-9	Original	112.4	19	A	5.0624	50	6.9230	0.068	0.2211	0.002			0.4449	0.004		
K8.5MC-9	Duplicate		22	A	5.5051	50	6.8520	0.062	0.2223	0.002			0.3928	0.004		
K8.5MC-10A	Original	48.0	23	A	5.0365	50	4.6090	0.046	1.4450	0.014			0.3546	0.004		
K8.5MC-10A	Duplicate		26	A	4.8936	50	3.4970	0.036	1.5780	0.016			0.8284	0.008		
K8.5MC-10B	Original	134.2	35	B	5.0327	50	1.0570	0.011	0.8617	0.009			0.1759	0.002		
K8.5MC-10B	Duplicate		37	B	5.1121	50	0.9789	0.010	2.7130	0.027			0.1931	0.002		
K8.5MC-10C	Original	83.6	38	B	5.0467	50	5.2680	0.052	0.4743	0.005			0.3274	0.003		
K8.5MC-10C	Duplicate		39	B	5.6590	50	6.1070	0.054	0.5555	0.005			0.3253	0.003		
K8.5MC-11	Original	62.2	41	B	5.0751	50	1.4110	0.014	0.1168	0.001			0.3486	0.003		
K8.5MC-11	Duplicate		43	B	5.0693	50	1.4960	0.015	0.1298	0.001			0.4326	0.004		
K8.5MC-12	Original	99.1	45	B	5.5269	50	4.5780	0.041	0.5978	0.005			0.1646	0.001		
K8.5MC-12	Duplicate		46	B	5.1070	50	3.7480	0.037	0.5025	0.005			0.1377	0.001		
K8.5MC-13	Original	185.3	47	B	5.2985	50	0.9293	0.009	1.9020	0.018			2.5090	0.024		
K8.5MC-13	Duplicate		51	B	5.0860	50	0.9379	0.009	1.8140	0.018			2.6680	0.026		
K9.5MC-13	Original	142.8	14	C	5.1563	50	0.2365	0.002	3.4190	0.033			1.9500	0.019		
K9.5MC-13	Duplicate		49	C	5.2781	50	0.1942	0.002	3.6070	0.034			1.7840	0.017		
K9.5MC-14A	Original	108.7	53	C	5.0688	50	0.3486	0.003	8.8950	0.088			1.5260	0.015		
K9.5MC-14A	Duplicate		54	C	5.3056	50	0.4247	0.004	9.7700	0.092			1.6880	0.016		
K9.5MC-14B	Original	100.8	56	C	5.5539	50	0.5142	0.005	12.2400	0.110			0.1553	0.001		
K9.5MC-14B	Duplicate		57	C	5.4444	50	0.5019	0.005	11.7100	0.108			0.1425	0.001		
K9.5MC-14C	Original	62.0	62	C	5.2784	50	2.1300	0.020	7.1230	0.067			0.2853	0.003		
K9.5MC-14C	Duplicate		66	C	5.1802	50	2.0780	0.020	7.3240	0.071			0.3262	0.003		
K9.5MC-15	Original	107.8	67	C	5.5403	50	6.9520	0.063	0.7321	0.007			1.0960	0.010		
K9.5MC-15	Duplicate		77	C	5.1372	50	6.0650	0.059	0.6312	0.006			0.9962	0.010		
K9.5MC-16	Original	200.2	24	D	5.1054	50	2.1940	0.021	1.2930	0.013			0.6242	0.006		
K9.5MC-16	Duplicate		28	D	5.9267	50	1.9460	0.016	1.3340	0.011			0.5777	0.005		
K9.5MC-17	Original	105.6	31	D	5.3542	50	0.3473	0.003	0.7148	0.007			0.2556	0.002		
K9.5MC-17	Duplicate		32	D	4.9778	50	0.2968	0.003	0.5522	0.006			0.2313	0.002		
K9.5MC-18	Original	96.8	34	D	5.0100	50	0.2789	0.003	-0.0546	-0.001			0.0157	0.000		
K9.5MC-18	Duplicate		36	D	5.0649	50	0.2942	0.003	-0.0575	-0.001			0.0162	0.000		
K9.5MC-18	Spike		44	D	5.0815	50	6.2290	0.061	6.4900	0.064			7.6830	0.076		
K9.5MC-18	Spike Dup		93	D	5.0027	50	6.5010	0.065	6.8800	0.069			8.0970	0.081		
Blank-1	Mthd Blk		2	A	5.0000	50	0.0107	0.000	-0.0535	-0.001			0.0701	0.001		
Blank-2	Mthd Blk		4	B	5.0000	50	0.0106	0.000	-0.0522	-0.001			0.1044	0.001		
Blank-3	Mthd Blk		8	C	5.0000	50	0.0048	0.000	-0.0554	-0.001			0.1107	0.001		
Blank-4	Mthd Blk		7	D	5.0000	50	0.0050	0.000	-0.0576	-0.001			0.0061	0.000		
RM1570-1	Ref Materl	mg/kg corrected for	131	A	1.4226	50	3.7740	0.131	34.4600	1.192			29.0300	1.004		
RM1570-2	Ref Materl	moisture of 1.60 %	125	B	1.0439	50	2.5790	0.122	24.8000	1.169			22.1000	1.042		
RM1570-3	Ref Materl		11	C	1.1934	50	3.6630	0.151	31.5200	1.299			24.6000	1.014		
RM1570-4	Ref Materl		111	D	1.0666	50	2.7960	0.129	26.0100	1.200			21.0400	0.971		
	As									**Cd**				**Pb**		
Sample	**ug/l**								**Sample**	**ug/l**			**Sample**	**ug/l**		
Blank-1	0.0107								Blank-1	-0.0535			Blank-1	0.0701		
Blank-2	0.0106								Blank-2	-0.0522			Blank-2	0.1044		
Blank-3	0.0048								Blank-3	-0.0554			Blank-3	0.1107		
Blank-4	0.0050								Blank-4	-0.0576			Blank-4	0.0061		
		(Based upon									(Based upon				(Based upon	
Mean	0.0078	method blank noise)	**mg/kg**						Mean	-0.0547	method blank noise)	**mg/kg**	Mean	0.0728	method blank noise)	**mg/kg**
std. dev	0.0033	**LOD:**	0.0001						std. dev	0.0023	**LOD:**	0.0001	std. dev	0.0479	**LOD:**	0.0014
3 X std. dev	0.0099	**LOQ:**	0.0003						3 X std. dev	0.0070	**LOQ:**	0.0002	3 X std. dev	0.1438	**LOQ:**	0.0048

Kea'au Hawaii Total Arsenic
Hawaii Department of Health

Sample	**mg/kg**	**% Recovery**							**Sample**	**mg/kg**	**% Recovery**		**Sample**	**mg/kg**	**% Recovery**	
RM1570-1	0.131	87.0	Cert. at 0.15 ug/kg As, 1.50 ug/kg Cd, 1.20 ug/kg Pb						RM1570-1	1.192	79.5		RM1570-1	1.004	83.7	
RM1570-2	0.122	81.0							RM1570-2	1.169	77.9		RM1570-2	1.042	86.8	
RM1570-3	0.151	100.7							RM1570-3	1.299	86.6		RM1570-3	1.014	84.5	
RM1570-4	0.129	86.0							RM1570-4	1.200	80.0		RM1570-4	0.971	80.9	
Spike % Rec	**mg/kg**	**% Recovery**							**Spike % Rec**	**mg/kg**	**% Recovery**		**Spike % Rec**	**mg/kg**	**% Recovery**	
K8.5MC-18SP	**0.061**	74.2							K8.5MC-18SP	**0.064**	81.8		K8.5MC-18SP	**0.076**	95.8	
K8.5MC-18SPD	**0.065**	77.7							K8.5MC-18SPDu	**0.069**	86.7		K8.5MC-18SPDu	**0.081**	101.0	
		As	**Cd**	**Pb**												
Initial Cal Ver.	(ug/L)	24.11	5.252	9.906												
(ICV)	True Value:	27.00	5.000	9.000												
	% Recvry	89.3	105.0	110.1												
Cont. Cal Ver.	(ug/L)	**As**	**Cd**	**Pb**					Cont. Cal Blank	(ug/L)	**As**	**Cd**	**Pb**			
(CCV)	True Value:	20.00	20.00	20.00					CCB	True Value:	0.0000	0.0000	0.0000			
CCV-1		20.33	20.44	20.29					CCB-1		0.0536	-0.0578	-0.0159			
CCV-2		18.95	20.43	20.15					CCB-2		0.0512	-0.0590	-0.0183			
CCV-3		18.55	20.07	20.08					CCB-3		0.0548	-0.0582	-0.0177			
CCV-4		18.45	20.00	19.92					CCB-4		0.0454	-0.0570	-0.0171			
CCV-5		18.63	20.05	20.26					CCB-5		0.0476	-0.0585	-0.0164			
CCV-6		18.55	19.98	20.04					CCB-6		0.0748	-0.0537	-0.0054			
Cal Stds:	(ug/L)	0, 1.0, 2.0, 5.0, 10, 20, 50														
Corr coef:		1.0000	0.9999	1.0000												
slope:		0.1463	0.0676	1.1760												
y-int:		0.0039	0.0043	0.0558												
Analyte isotope:		75	111	206+207+208												
Int. Std Used:		Ge^{72}	Rh^{103}	Bi^{209}												
Balance used:		Mettler AT201														
Black:	mg/kg	<0.006, Cd <0.005, Pb <0.010														
Red:	mg/kg	0.006, Cd ≥ 0.005, Pb ≥0.010														
Green:	mg/kg	Matrix Spike Results.														

April/May 2005 by SMR

APPENDIX D

Exponent Report: Bioaccessibility of Arsenic from 14 Hawaii Soils

Exponent®

Bioaccessibility of Arsenic from 14 Hawaii Soils

Prepared for

AMEC Earth & Environmental, Inc.
Honolulu, Hawaii

Exponent

Bioaccessibility of Arsenic from 14 Hawaii Soils

Prepared for

AMEC Earth & Environmental, Inc.
Honolulu, Hawaii

Prepared by

Exponent
4940 Pearl East Circle, Suite 300
Boulder, Colorado 80301

February 2005

BO02833.001 0101 0205 CC14

Contents

Bioaccessibility—Background and Objectives

It is generally known that metals exhibit reduced bioavailability from soil matrices relative to the metals' soluble forms (Allen and Huang 1994; Dreesen and Williams 1982; Ruby et al. 1999).[1] Thus, a particular data need for assessing human health risk from exposure to metals in soil is the bioavailability of the specific metals or metalloids in soil, as compared to the more soluble forms that generally serve as the basis of the toxicity reference values and cancer slope factors. However, the amount of an element in soil that is available for absorption in the human digestive system can vary (e.g., for arsenic, from 8% to 50% relative to soluble forms [U.S. EPA 1997a]), making the estimation of bioavailability for a particular site difficult without directly testing site-specific environmental media.

Simple *in vitro* extraction tests have been used for several years to assess the degree of metal dissolution in a simulated gastrointestinal-tract environment (Ruby et al. 1993, 1996; Rodriquez et al. 1999). Such tests mimic the temperature, pH, and fluid conditions of the digestive system to yield estimates of the amount of a metal in soil that is bioaccessible (i.e., the fraction that will be soluble and available for absorption). For example, the European Standard for Safety of Toys (CEN 1994) provides for an extraction test (2-hour extraction in pH-1.5 [HCl] fluid) to evaluate the bioaccessibility of eight metals (antimony, arsenic, barium, cadmium, chromium, lead, mercury, and selenium) from children's toys. This method has been used since 1994 by the 18 member countries of the Comite European de Normalization (CEN) to regulate the safety of toys.

A considerable amount of work has been performed to develop simple, reproducible extraction tests that can predict the oral bioavailability of arsenic and lead in animal models (Ruby et al. 1993, 1996; Medlin 1997; Rodriguez et al. 1999). Although formal validation of *in vitro* bioaccessibility results against data from animals studies has been completed only for lead (Henningson et al. 1999), these testing procedures can be used to evaluate the fraction of other metals that would be soluble and available for absorption.

This report provides the results of *in vitro* extraction testing of arsenic from 14 soil samples provided to Exponent by AMEC Earth & Environmental, Inc. Included is information regarding preparation of the soil substrates for analyses, the extraction and analytical methods used to assess the bioaccessibility of arsenic, and the results and implications of the bioaccessibility testing. The results and any interpretation communicated in this document are applicable only to the samples tested.

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[1] Oral bioavailability is defined herein as the fraction of ingested metal that is absorbed into systemic circulation. Bioaccessibility, on the other hand, refers to the fraction of a metal that is soluble in a simulated gastrointestinal environment, and would therefore be available for absorption. Bioaccessibility is therefore a precursor to, and provides an estimate of, bioavailability.

Methods

Sample preparation and bioaccessibility extractions were performed in Exponent's laboratory in Boulder, Colorado. Analyses for total arsenic concentrations in the sample substrates and extraction fluids were conducted by Columbia Analytical Services, Inc. (CAS) in Kelso, Washington.

Sample Preparation and Analysis

Fourteen soil samples were received at Exponent's Boulder laboratory on January 6, 2005. Samples were oven-dried at 40 °C and then sieved to <250 μm.

The <250-μm soil size fraction was used for bioaccessibility testing, because it is believed to represent the fraction of soil that is most likely to adhere to human hands and be ingested during hand-to-mouth activity (Maddaloni et al. 1998). A one-gram aliquot of each substrate was collected and subjected to the *in vitro* extraction procedure (described below). Additionally, a split of each <250-μm soil sample was used for analysis of total arsenic concentrations.

Bioaccessibility Testing

The sieved soil samples (<250-μm size fraction) were subjected to bioaccessibility testing according to the Standard Operating Procedure (SOP) developed by the Solubility/ Bioavailability Research Consortium (SBRC). This protocol is provided as Attachment 1. The testing included extraction and analysis of two duplicates (samples KE011 and KE022).

Deviations from the SBRC method with regard to sample preparation and analysis included the following:

- The bioaccessibility test was modified to include a simulation of the small-intestinal environment (i.e., a second phase, at neutral pH, was added to the extraction procedure). This was done to evaluate whether an extraction procedure that simulates the environment of the small intestine would influence the bioaccessibility of arsenic from the sample substrates (e.g., by affecting either the arsenic solubility or the integrity of the soil matrix that contains the arsenic). This was accomplished by adding the following steps at the end of the standard SBRC extraction procedure:
    - At the end of the 1-hour extraction, a 5-mL sample of the extraction fluid was collected and stored at 4 ºC for analysis.
    - The extraction fluid in each bottle was then titrated to pH 7.0 ±0.2 with NaOH (50% w/w) (this required approximately 20–30 drops of NaOH solution).

- Once the extraction fluid had been neutralized, 175 mg of bile salts and 50 mg of porcine pancreatin were added to each extraction bottle, and the bottles were returned to the extractor for an additional 4 hours of extraction time.
- At the end of the small-intestinal-phase extraction, a 10- to 20-mL sample of the extraction fluid was collected from each bottle, filtered through a 0.45-μm cellulose acetate membrane filter, preserved with 20 μL of trace-metal-grade, concentrated nitric acid, and stored at 4 ºC for analysis.

All of the extracts produced from the bioaccessibility testing were shipped to CAS under chain of custody for analysis of total concentrations of arsenic.

Analytical Methods

Extraction fluids (from both the stomach-phase and intestinal-phase extractions) were analyzed for arsenic by inductively coupled plasma/mass spectrometry (ICP/MS) (EPA Method 200.8), and solids were analyzed for arsenic by ICP (EPA Method 6010B). All solid and aqueous/fluid samples were shipped at 4 ºC to CAS under chain of custody.

Results

Arsenic Concentrations in Soil Samples

Total arsenic concentrations in the sieved soil samples (<250-μm size fraction) are indicated in Table 1.

The concentrations of arsenic in the soil samples ranged from 55 to 629 mg/kg. Duplicate analyses were conducted for sample substrates KE011 and KE022, and the results demonstrated good reproducibility (relative percent deviation values ranged from 0% to 5.7%; Table 2).

Bioaccessibility of Arsenic from Soil Samples

Table 1 presents data from the *in vitro* extractions and chemical analyses, as well as the calculation of the sample-specific bioaccessibility values. The data regarding bioaccessibility in the stomach-phase and intestinal-phase extractions are also presented graphically in Figures 1 and 2. Figure 1 provides a summary of the calculated bioaccessibility values by soil sample ID, and allows for a quick comparison of the bioaccessibility in each phase of the extraction process. Figure 2 provides a comparison of bioaccessibility versus the soil arsenic concentration.

The measured arsenic bioaccessibility was higher in the stomach-phase extraction than in the intestinal-phase extraction for all samples (Table 1, Figures 1 and 2). The lower percent recovery in the intestinal phase is likely due to precipitation reactions and/or arsenic species interactions with the soil substrate at the higher pH value. In general, it would be appropriate to assume that the bioaccessibility is best approximated by whichever extraction phase (stomach or intestinal) yields the higher value. Therefore, the stomach-phase data are more reliable for assessing bioaccessibility of arsenic in these 14 soil samples, and serve as the basis for further discussions in this report.

Measured bioaccessibility values across all samples tested ranged from 1.0% to 18% (Table 1, Figures 1 and 2). Ten of the fourteen samples had bioaccessibility values less than 6%, and eleven of the fourteen samples had bioaccessibility values of less than 10%.

Another observation is that the soil arsenic concentration in the samples does not appear to be a primary determinant of bioaccessibility. Samples with low (or high) soil arsenic concentrations were associated with calculated bioaccessibility values at the low and high ends of the bioaccessibility range (Figure 2). Differences in bioaccessibility are likely due to differences in the nature of the soil substrate and/or arsenic mineralogy.

Table 2 presents the results from the quality assurance data generated during this study. Two sample substrates were subjected to the extraction procedure in duplicate (samples KE011 and KE022). Both samples demonstrated consistent bioaccessibility across the two extractions, with relative percent deviations ranging from 2.0% to 3.6% for the stomach phase and from 1.3% to

1.9% for the intestinal phase. Similarly, the results from the duplicate analyses of the corresponding solid substrates are in good agreement, with relative percent deviations ranging from 0% to 5.7%.

Additional quality control (QC) samples included a reagent blank for the stomach phase, a method blank, a matrix spike, and a standard reference material (SRM) sample. The reagent and method blank samples for the stomach phase were all non-detect for arsenic at the method detection limit of 2 µg/L. Arsenic was detected in the method blank for the intestinal phase at an estimated concentration of 4 µg/L, which is below the method reporting limit of 5 µg/L, but above the method detection limit of 2 µg/L. This estimated concentration is below the blank control limit of 10 µg/L and has no impact on the data. The matrix spike for the stomach phase had an acceptable percent recovery of 112%. The matrix spike recovery for the intestinal phase was slightly higher, 119%, but the control limits are only relevant for the stomach phase. The SRMs (NIST 2711) produced an arsenic concentration of 0.613 mg/L and 0.518 mg/L for the stomach- and intestinal-phase extracts, respectively, which are both within the method control limits. No data were qualified due to the bioaccessibility method quality control sample results.

Data Quality Assurance Review

This quality assurance review discusses the results from the analyses for total concentrations of arsenic in soil samples and *in vitro* extracts by CAS. The samples submitted for analysis consisted of 16 soil samples (including 2 duplicates), 20 stomach-fluid extracts (including 2 duplicates, 1 SRM, 1 method blank, 1 matrix spike, and 1 reagent blank), and 19 intestinal-fluid extracts (including 2 duplicates, 1 SRM, 1 method blank, and 1 matrix spike).

A quality assurance review was conducted to determine the quality of the analytical results and to determine whether the data are of acceptable quality for their intended use. The laboratory data packages were reviewed, and the associated quality control results were assessed to determine the quality of the reported data. All data were assessed as acceptable for use.

Four intestinal-phase extract arsenic concentrations were qualified as estimated during the quality assurance review, because the concentrations fell between the method detection limit of 2 μg/L and the method reporting limit of 5 μg/L. These four concentrations are qualified as estimated, as indicated by the "B" qualifier in Table 1.

Conclusions

Fourteen soil samples provided by AMEC Earth & Environmental, Inc. were evaluated for the bioaccessibility of arsenic. These analyses were conducted to estimate the oral bioavailability of arsenic (i.e., the fraction that would be absorbed within the human body if these soils were ingested). This evaluation involved determining the amount of arsenic that becomes soluble in a simulated gastrointestinal extraction (the *in vitro* extraction test). The extraction procedure involved sequential stomach-phase and intestinal-phase extractions. Results from this testing are presented in Table 1 and Figures 1 and 2.

The results of this study indicate that:

- All samples demonstrated higher bioaccessibility in the stomach-phase extraction than in the intestinal-phase extraction. Therefore, data from the stomach-phase extractions should serve as the basis for any interpretation of the bioaccessibility results.

- Arsenic bioaccessibility from the stomach-phase extraction ranged from 1.0% to 18% across all samples tested.

- Ten of the fourteen samples had bioaccessibility values less than 6%, and eleven of the fourteen samples had bioaccessibility values less than 10%.

- Soil arsenic concentration does not appear to be a primary determinant of bioaccessibility, because low (or high) soil arsenic concentrations were associated with calculated bioaccessibility values at the low and high ends of the bioaccessibility range.

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Figures and Tables

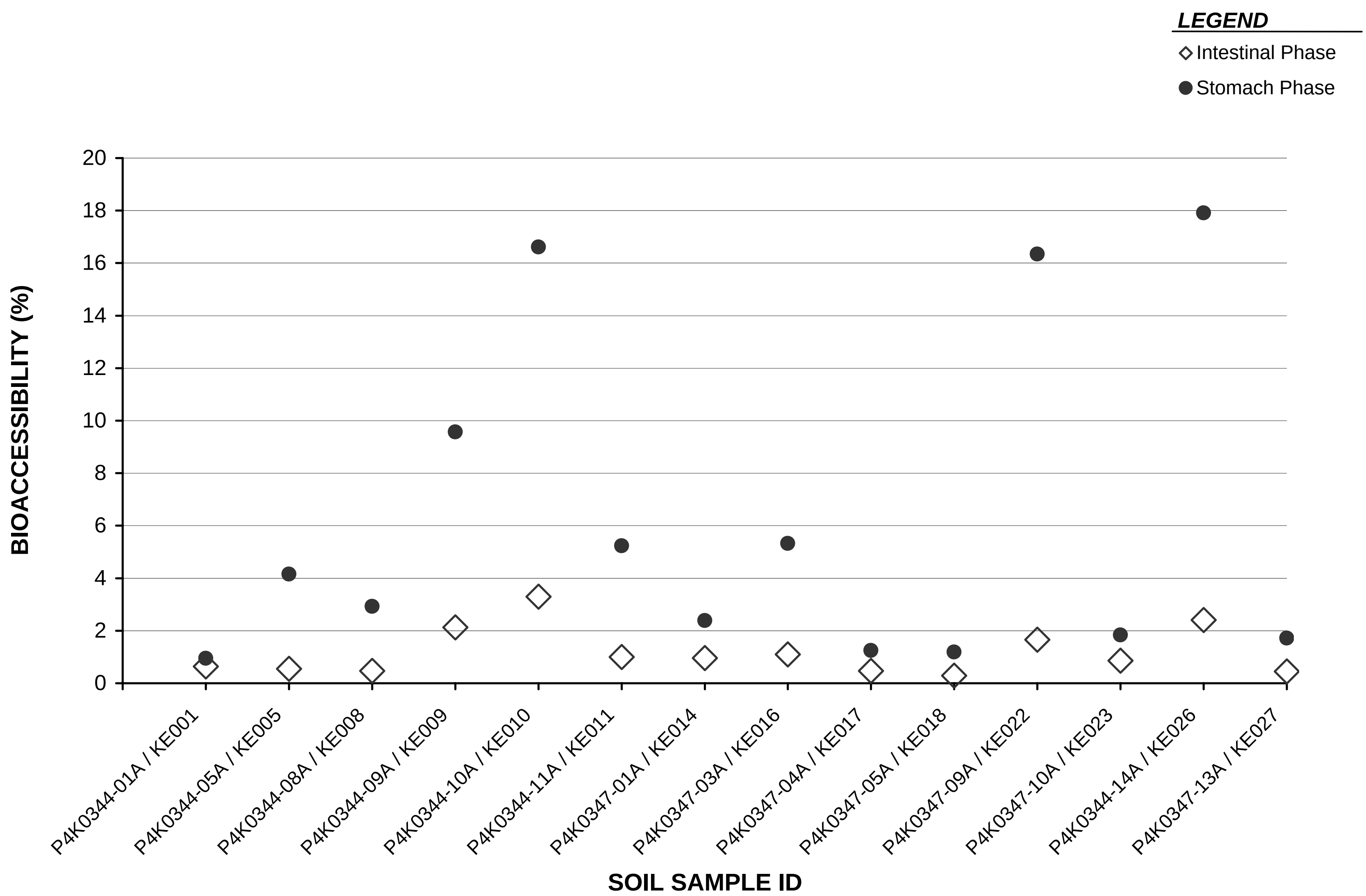

Figure 1. Arsenic bioaccessibility for each soil sample

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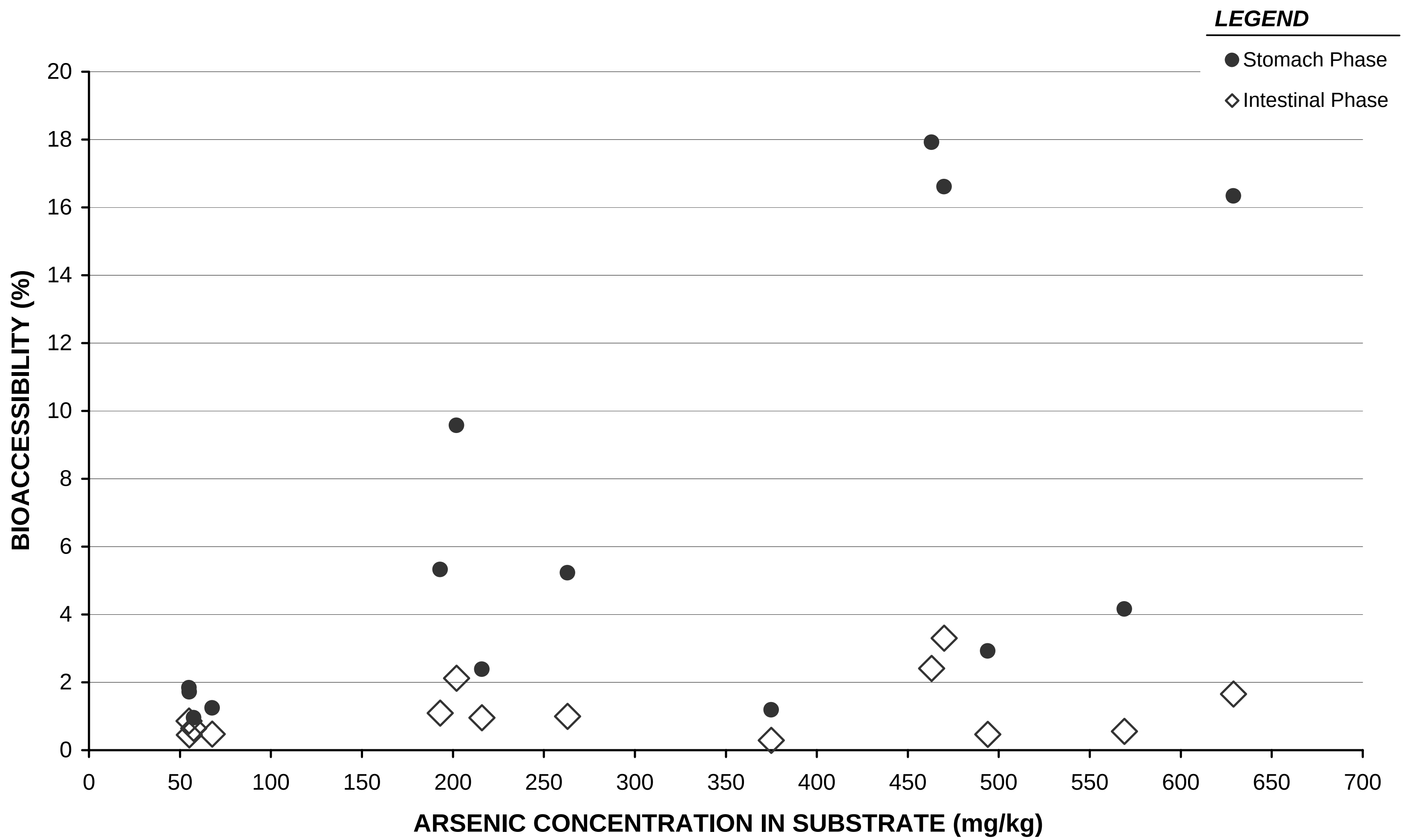

Figure 2. Effect of substrate arsenic concentration on bioaccessibility in soils

Table 1. Results from *in vitro* bioaccessibility testing of arsenic in soil samples

NCAS Sample ID	Exponent Soil Sample ID	Arsenic Conc. in Substrate (mg/kg)	Mass of Soil Tested (g)	Mass of Arsenic in Soil Extracted (mg)	Extraction Date	Phase	Final pH (s.u.)	Arsenic Conc. in Extract (mg/L)	Volume of Extract (L)	Mass of Arsenic in Extract (mg)	Arsenic Bioaccessibility (%)
P4K0344-01A	KE001	57.6	1.0014	0.0577	1/12/2005	stomach	1.64	0.0055	0.100	0.00055	1.0
						intestinal	6.85	0.0039 *B*	0.095	0.00037	0.6
P4K0344-05A	KE005	569	1.0017	0.5700	1/12/2005	stomach	1.61	0.237	0.100	0.0237	4.2
						intestinal	6.89	0.0331	0.095	0.00314	0.6
P4K0344-08A	KE008	494	1.0026	0.4953	1/12/2005	stomach	1.59	0.145	0.100	0.0145	2.9
						intestinal	6.87	0.0243	0.095	0.00231	0.5
P4K0344-09A	KE009	202	1.0031	0.2026	1/12/2005	stomach	1.55	0.194	0.100	0.0194	9.6
						intestinal	6.96	0.0453	0.095	0.00430	2.1
P4K0344-10A	KE010	470	1.0042	0.4720	1/12/2005	stomach	1.56	0.784	0.100	0.0784	17
						intestinal	6.95	0.164	0.095	0.0156	3.3
P4K0344-11A	KE011	263 [a]	1.0030 [a]	0.2638	1/12/2005	stomach	1.60 [a]	0.138 [a]	0.100	0.0138	5.2
						intestinal	6.89 [a]	0.0277 [a]	0.095	0.00263	1.0
P4K0347-01A	KE014	216	1.0037	0.2168	1/13/2005	stomach	1.61	0.0517	0.100	0.00517	2.4
						intestinal	6.91	0.0219	0.095	0.00208	1.0
P4K0347-03A	KE016	193	1.0028	0.1935	1/13/2005	stomach	1.60	0.103	0.100	0.0103	5.3
						intestinal	7.01	0.0223	0.095	0.00212	1.1
P4K0347-04A	KE017	67.8	1.0067	0.0683	1/13/2005	stomach	1.58	0.0085	0.100	0.00085	1.2
						intestinal	7.03	0.0034 *B*	0.095	0.00032	0.5
P4K0347-05A	KE018	375	1.0013	0.3755	1/13/2005	stomach	1.61	0.0446	0.100	0.00446	1.2
						intestinal	6.94	0.0114	0.095	0.00108	0.3
P4K0347-09A	KE022	629 [a]	1.0022 [a]	0.6304	1/13/2005	stomach	1.66 [a]	1.03 [a]	0.100	0.1030	16
						intestinal	6.92 [a]	0.110 [a]	0.095	0.0105	1.7
P4K0347-10A	KE023	55.0	1.0081	0.0554	1/13/2005	stomach	1.59	0.0102	0.100	0.00102	1.8
						intestinal	6.88	0.0050 *B*	0.095	0.00048	0.9
P4K0344-14A	KE026	463	1.0042	0.4649	1/13/2005	stomach	1.59	0.833	0.100	0.0833	18
						intestinal	6.86	0.118	0.095	0.0112	2.4
P4K0347-13A	KE027	55.1	1.0012	0.0552	1/13/2005	stomach	1.58	0.0095	0.100	0.00095	1.7
						intestinal	6.92	0.0026 *B*	0.095	0.00025	0.4

Note: *U* - not detected; value represents detection limit
B - result is an estimated concentration that is less than the method reporting limit, but greater than or equal to the method detection limit
[a] Average of duplicate results.

Table 2. QA sample results for *in vitro* bioaccessibility testing of arsenic in soils

Sample ID	Final pH Stomach Phase (s.u.)	Final pH Intestinal Phase (s.u.)	Arsenic Conc. in Substrate (mg/kg)	Relative Percent Deviation (%)	Arsenic Spike Conc. (mg/L)	Arsenic Concentration in Extract Stomach Phase (mg/L)	Arsenic Concentration in Extract Intestinal Phase (mg/L)	Percent Recovery Stomach Phase (%)	Percent Recovery Intestinal Phase (%)	Relative Standard Deviation Stomach Phase (%)	Relative Standard Deviation Intestinal Phase (%)	Control Limits
Soil Duplicates												
P4K0344-11A / KE011	--	--	270	--	--	--	--	--	--	--	--	
P4K0344-11A / KE011(A)	--	--	255	5.7	--	--	--	--	--	--	--	0–20%
P4K0347-09A / KE022	--	--	629	--	--	--	--	--	--	--	--	
P4K0347-09A / KE022(A)	--	--	629	0.0	--	--	--	--	--	--	--	0–20%
Duplicate Extractions												
P4K0344-11A / KE011	1.61	6.90	--	--	--	0.141	0.0279	--	--	--	--	
P4K0344-11A / KE011(A)	1.59	6.88	--	--	--	0.134	0.0274	--	--	3.6	1.3	0–20%
P4K0347-09A / KE022	1.65	6.93	--	--	--	1.02	0.108	--	--	--	--	
P4K0347-09A / KE022(A)	1.66	6.90	--	--	--	1.05 [a]	0.111 [a]	--	--	2.0	1.9	0–20%
QC Samples												
Reagent Blank	--	--	--	--	--	0.002 *U*	--	--	--	--	--	<0.005 mg/L
Method Blank	1.49	7.28	--	--	--	0.002 *U*	0.0040 *B*	--	--	--	--	<0.01 mg/L
Matrix Spike	1.50	7.38	--	--	1.00	1.12	1.19	112	119	--	--	85–115%[b]
SRM NIST 2711	1.56	7.20	--	--	--	0.613	0.518	--	--	--	--	0.5–0.68 mg/L[b]

Notes: -- - not available/not applicable

U - not detected; value represents detection limit

B - result is an estimated concentration that is less than the method reporting limit, but greater than or equal to the method detection limit

[a] Average of analytical laboratory replicate results.

[b] Control limit relevant for recovery in the stomach phase only.

Attachment 1

In Vitro Extraction Procedure

Solubility/Bioavailability Research Consortium

Standard Operating Procedure:

***In Vitro* Method for Determination of Lead and Arsenic Bioaccessibility**

Doc. No.: 8601102.001 0601 1099 RN01

Contents

1. Introduction

1.1 Synopsis

This SOP describes an *in vitro* laboratory procedure to determine a bioaccessibility value for lead or arsenic (i.e., the fraction that would be soluble in the gastrointestinal tract) for soils and solid waste materials. A recommended quality assurance program to be followed when performing this extraction procedure is also provided.

1.2 Purpose

An increasingly important property of materials/soils found at contaminated sites is the bioavailability of individual contaminants. Bioavailability is the fraction of a contaminant in a particular environmental matrix that is absorbed by an organism via a specific exposure route. Many animal studies have been conducted to experimentally determine the oral bioavailability of individual metals, particularly lead and arsenic. During the period 1989–1997, a juvenile swine model developed by EPA Region VIII was used to predict the relative bioavailability of lead and arsenic in approximately 20 soils/solid materials (Weis and LaVelle 1991; Weis et al. 1994; Casteel et al. 1997a,b). The bioavailability determined was relative to that of a soluble salt (i.e., lead acetate trihydrate or sodium arsenate). The tested materials had a wide range of mineralogy, and produced a range of lead and arsenic bioavailability values. In addition to the swine studies, other animal models (e.g., rats and monkeys) have been used to measure the bioavailability of lead and arsenic from soil.

Several researchers have developed *in vitro* tests to measure the fraction of a chemical solubilized from a soil sample under simulated gastrointestinal conditions. This measurement is referred to as "bioaccessibility" (Ruby et al. 1993). Bioaccessibility is thought to be an important determinant of bioavailability, and several groups have sought to compare bioaccessibility determined in the laboratory to bioavailability determined in animal studies (Imber 1993; Ruby et al. 1996; Medlin 1997; Rodriguez et al. 1999). The *in vitro* tests consist of an aqueous fluid, into which soils containing lead and arsenic are introduced. The solution then solubilizes the soil under simulated gastric conditions. Once this procedure is complete, the solution is analyzed for lead and/or arsenic concentration. The mass of lead and/or arsenic found in the aqueous phase, as defined by filtration at the 0.45-μm pore size, is compared to the mass introduced into the test. The fraction liberated into the aqueous phase is defined as the bioaccessible fraction of lead or arsenic in that soil. To date, for lead-bearing soils tested in the EPA swine studies, this *in vitro* method has correlated well with relative bioavailability values.

2. Procedure

2.1 Sample Preparation

All soil/material samples should be prepared for testing by oven drying (<40 °C) and sieving to <250 μm. The <250-μm size fraction is used because this particle size is representative of that which adheres to children's hands. Subsamples for testing in this procedure should be obtained using a sample splitter.

2.2 Apparatus and Materials

2.2.1 Equipment

The main piece of equipment required for this procedure consists of a Toxicity Characteristic Leaching Procedure (TCLP) extractor motor that has been modified to drive a flywheel. This flywheel in turn drives a Plexiglass block situated inside a temperature-controlled water bath. The Plexiglass block contains ten 5-cm holes with stainless steel screw clamps, each of which is designed to hold a 125-mL wide-mouth high-density polyethylene (HDPE) bottle (see Figure 1). The water bath must be filled such that the extraction bottles are immersed. Temperature in the water bath is maintained at 37±2 °C using an immersion circulator heater (for example, Fisher Scientific Model 730). Additional equipment for this method includes typical laboratory supplies and reagents, as described in the following sections.

The 125-mL HDPE bottles must have an air-tight screw-cap seal (for example, Fisher Scientific 125-mL wide-mouth HDPE Cat. No. 02-893-5C), and care must be taken to ensure that the bottles do not leak during the extraction procedure.

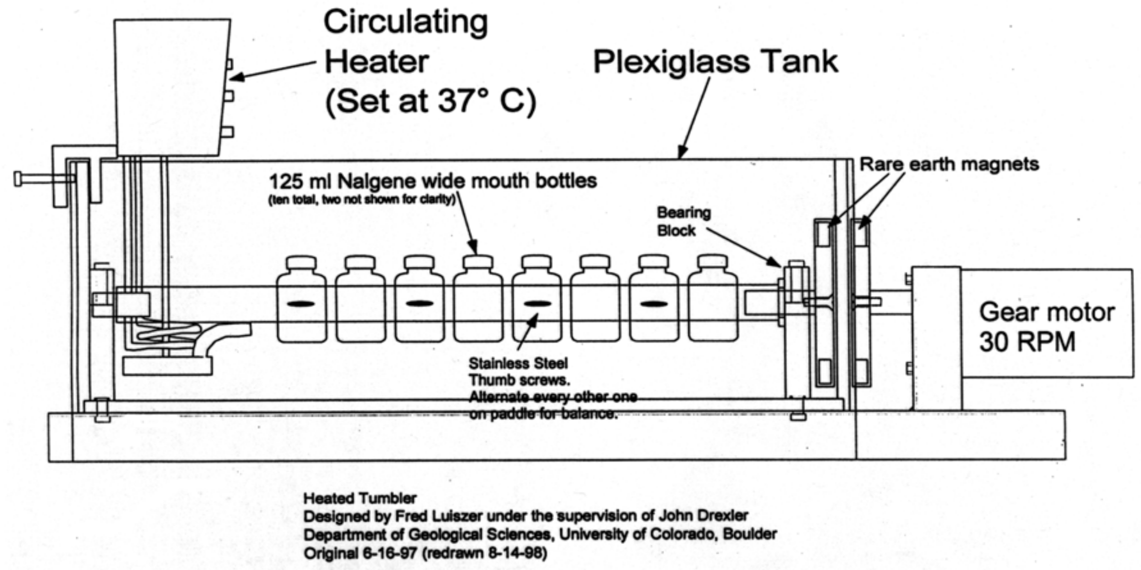

Figure 1. Extraction device for performing the SBRC *in vitro* extraction

2.2.2 Standards and Reagents

The leaching procedure for this method uses a buffered extraction fluid at a pH of 1.5. The extraction fluid is prepared as described below.

The extraction fluid should be prepared using ASTM Type II deionized (DI) water. To 1.9 L of DI water, add 60.06 g glycine (free base, Sigma Ultra or equivalent). Place the mixture in a water bath at 37 °C until the extraction fluid reaches 37 °C. Standardize the pH meter using temperature compensation at 37 °C or buffers maintained at 37 °C in the water bath. Add concentrated hydrochloric acid (12.1 N, Trace Metal grade) until the solution pH reaches a value of 1.50 ±0.05 (approximately 120 mL). Bring the solution to a final volume of 2 L (0.4 M glycine).

Cleanliness of all reagents and equipment used to prepare and/or store the extraction fluid is essential. All glassware and equipment used to prepare standards and reagents must be properly cleaned, acid washed, and finally, rinsed with DI water prior to use. All reagents must be free of lead and arsenic, and the final fluid should be tested to confirm that lead and arsenic concentrations are less than 25 and 5 μg/L, respectively.

2.3 Leaching Procedure

Measure 100 ±0.5 mL of the extraction fluid, using a graduated cylinder, and transfer to a 125-mL wide-mouth HDPE bottle. Add 1.00 ±0.05 g of test substrate (<250 μm) to the bottle, ensuring that static electricity does not cause soil particles to adhere to the lip or outside threads of the bottle. If necessary, use an antistatic brush to eliminate static electricity prior to adding the soil. Record the volume of solution and mass of soil added to the bottle on the extraction test checklist (see Attachment A for example checklists). Hand-tighten each bottle top, and shake/invert to ensure that no leakage occurs, and that no soil is caked on the bottom of the bottle.

Place the bottle into the modified TCLP extractor, making sure each bottle is secure and the lid(s) are tightly fastened. Fill the extractor with 125-mL bottles containing test materials or Quality Control samples.

The temperature of the water bath must be 37±2 °C. Record the temperature of the water bath at the beginning and end of each extraction batch on the appropriate extraction test checklist sheet (see Attachment A).

Rotate the extractor end over end at 30±2 rpm for 1 hour. Record start time of rotation.

When extraction (rotation) is complete, immediately remove bottles, wipe them dry, and place them upright on the bench top.

Draw extract directly from reaction vessel into a disposable 20-cc syringe with a Luer-Lok attachment. Attach a 0.45-μm cellulose acetate disk filter (25 mm diameter) to the syringe, and filter the extract into a clean 15-mL polypropylene centrifuge tube or other appropriate sample vial for analysis. Store filtered sample(s) in a refrigerator at 4 °C until they are analyzed.

Record the time that the extract is filtered (i.e., extraction is stopped). If the total elapsed time is greater than 1 hour 30 minutes, the test must be repeated.

Measure and record the pH of fluid remaining in the extraction bottle. If the fluid pH is not within ±0.5 pH units of the starting pH, the test must be discarded and the sample reanalyzed as follows.

If the pH has dropped by 0.5 or more pH units, the test will be re-run in an identical fashion. If the second test also results in a decrease in pH of greater than 0.5 s.u., the pH will be recorded, and the extract filtered for analysis. If the pH has increased by 0.5 or more units, the test must be repeated, but the extractor must be stopped at specific intervals and the pH manually adjusted down to pH 1.5 with dropwise addition of HCl (adjustments at 5, 10, 15, and 30 minutes into the extraction, and upon final removal from the water bath [60 minutes]). Samples with rising pH values must be run in a separate extraction, and must not be combined with samples being extracted by the standard method (continuous extraction).

Extracts are to be analyzed for lead and arsenic concentration using analytical procedures taken from the U.S. EPA publication, *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods. SW-846*. (current revisions). Inductively coupled plasma (ICP) analysis, method 6010B (December 1996 revision) will be the method of choice. This method should be adequate for determination of lead concentrations in sample extracts, at a project-required detection limit (PRDL) of 100 μg/L. The PRDL of 20 μg/L for arsenic may be too low for ICP analysis for some samples. For extracts that have arsenic concentrations less than five times the PRDL (e.g., <100 μg/L arsenic), analysis by ICP-hydride generation (method 7061A, July 1992 revision) or ICP-MS (method 6020, September 1994 revision) will be required.

2.4 Calculation of the Bioaccessibility Value

A split of each solid material (<250 μm) that has been subjected to this extraction procedure should be analyzed for total lead and/or arsenic concentration using analytical procedures taken from the U.S. EPA publication, *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods. SW-846*. (current revisions). The solid material should be acid digested according to method 3050A (July 1992 revision) or method 3051 (microwave-assisted digestion, September 1994 revision), and the digestate analyzed for lead and/or arsenic concentration by ICP analysis (method 6010B). For samples that have arsenic concentrations below ICP detection limits, analysis by ICP-hydride generation (method 7061A, July 1992 revision) or ICP-MS (method 6020, September 1994 revision) will be required.

The bioaccessibility of lead or arsenic is calculated in the following manner:

$$\textit{Bioaccessibility value} = \frac{\textit{(concentration in in vitro extract, mg/L)}\ (0.1L)}{\textit{(concentration in solid, mg/kg)}\ (\,0.001\ \textit{kg})} \times 100$$

2.5 Chain-of-Custody/Good Laboratory Practices

All laboratories that use this SOP should receive test materials with chain-of-custody documentation. When materials are received, each laboratory will maintain and record custody of samples at all times. All laboratories that perform this procedure should follow good laboratory practices as defined in 40 CFR Part 792 to the extent practical and possible.

2.6 Data Handling and Verification

All sample and fluid preparation calculations and operations should be recorded in bound and numbered laboratory notebooks, and on extraction test checklist sheets. Each page must be dated and initialed by the person who performs any operations. Extraction and filtration times must be recorded, along with pH measurements, adjustments, and buffer preparation. Copies of the extraction test checklist sheets should accompany the data package.

3. Quality Control Procedures

3.1 Elements of Quality Assurance and Quality Control (QA/QC)

A standard method for the *in vitro* extraction of soils/solid materials, and the calculation of an associated bioaccessibility value, are specified above. Associated QC procedures to ensure production of high-quality data are as follows (see Table 1 for summary of QC procedures, frequency, and control limits):

- Reagent blank—Extraction fluid analyzed once per batch.
- Bottle blank—Extraction fluid only run through the complete extraction procedure at a frequency of no less than 1 per 20 samples or one per extraction batch, whichever is more frequent.
- Blank spikes—Extraction fluid spiked at 10 mg/L lead and/or 1 mg/L arsenic and run through the extraction procedure at a frequency of no less than every 20 samples or one per extraction batch, whichever is more frequent. Blank spikes should be prepared using traceable 1,000-mg/L lead and arsenic standards in 2 percent nitric acid.
- Duplicate—duplicate extractions are required at a frequency of 1 for every 10 samples. At least one duplicate must be performed on each day that extractions are conducted.
- Standard Reference Material (SRM)—National Institute of Standards and Technology (NIST) material 2711 (Montana Soil) should be used as a laboratory control sample (LCS).

Control limits for these QC samples are delineated in Table 1, and in the following discussion.

Table 1. Summary of QC samples, frequency of analysis, and control limits

QC Sample	Minimum Frequency of Analysis	Control Limits
Reagent Blank	Once per batch (min. 5%)	<25 μg/L lead <5 μg/L arsenic
Bottle Blank	Once per batch (min. 5%)	<50 μg/L lead <10 μg/L arsenic
Blank Spike	Once per batch (min. 5%)	85–115% recovery
Duplicate	10%	±20% RPD
SRM (NIST 2711)	2%	9.22 ±1.50 mg/L Pb 0.59 ±0.09 mg/L As

3.2 QA/QC Procedures

Specific laboratory procedures and QC steps are described in the analytical methods cited in Section 2.3, and should be followed when using this SOP.

3.2.1 Laboratory Control Sample (LCS)

The NIST SRM 2711 should be used as a laboratory control sample for the *in vitro* extraction procedure. Analysis of 18 blind splits of NIST SRM 2711 (105 mg/kg arsenic and 1,162 mg/kg lead) in four independent laboratories resulted in arithmetic means ± standard deviations of 9.22 ±1.50 mg/L lead and 0.59 ±0.09 mg/L arsenic. This SRM is available from the National Institute of Standards and Technology, Standard Reference Materials Program, Room 204, Building 202, Gaithersburg, Maryland 20899 (301/975-6776).

3.2.2 Reagent Blanks/Bottle Blanks/Blank Spikes

Reagent blanks must not contain more than 5 μg/L arsenic or 25 μg/L lead. Bottle blanks must not contain arsenic and/or lead concentrations greater than 10 and 50 μg/L, respectively. If either the reagent blank or a bottle blank exceeds these values, contamination of reagents, water, or equipment should be suspected. In this case, the laboratory must investigate possible sources of contamination and mitigate the problem before continuing with sample analysis. Blank spikes should be within 15% of their true value. If recovery of any blank spike is outside this range, possible errors in preparation, contamination, or instrument problems should be suspected. In the case of a blank spike outside specified limits, the problems must be investigated and corrected before continuing sample analysis.

4. References

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Attachment A:

Extraction Test Checklist Sheets

Extraction Fluid Preparation

Date of Extraction Fluid Preparation:____________ Prepared by:_____________

Extraction Fluid Lot #:________________________

Component	Lot Number	Fluid Preparation 1L	2L	Acceptance Range	Actual Quantity	Comments
Deionized Water		0.95 L (approx.)	1.9 L (approx.)	---		
Glycine		30.03±0.05 g	60.06±0.05g	---		
HCl [a]		60 mL (approx.)	120 mL (approx.)	---		
Final Volume	---	1 L (Class A, vol.)	2 L (Class A, vol.)	---		
Extraction Fluid pH value (@ 37°C)	---	1.50±0.05	1.50±0.05	1.45–1.55		

[a] Concentrated hydrochloric acid (12.1 N)

INVITRO PROCEDURE REQUIRED PARAMETERS:

Volume of extraction fluid (V) = 100 ±0.5 mL
Mass of test substrate (M) = 1.00 ±0.05 g
Temperature of water bath = 37 ±2 °C
Extraction time = 60 ±5 min

Extractor rotation speed = 30 ±2 rpm
Maximum elapsed time from extraction to filtration = 90 minutes
Maximum pH difference from start to finish (ΔpH)= 0.5 pH units
Spike solution concentrations: As = 1 mg/L; Pb = 10 mg/L

Date of Extraction:__________________________
Extraction Fluid Lot #:________________________
Extracted by:_______________________________

As Spike Solution Lot #:_________________________________
Pb Spike Solution Lot #:_________________________________

EXTRACTION LOG (Page 1 of 2)
[Complete 1 log for every batch of 20 samples]

	Sample Preparation		Extraction								Filtration	
Sample ID	V (mL)	M (g)	Start Time[a]	End Time[a]	Elapsed Time (min)	Start pH	End pH	ΔpH	Start Temp (°C)	End Temp (°C)	Time[a]	Time Elasped from extraction (min)
Acceptance Range	(95.5–100.5)	(0.95–1.05)	---	---	(55–65 min)	---	---	(≤ 0.5)	(35–39)	(35–39)		(Max = 90 min)

EXTRACTION LOG (Page 2 of 2)
[Complete 1 log for every batch of 20 samples]

	Sample Preparation		Extraction								Filtration	
Sample ID	V (mL)	M (g)	Start Time[a]	End Time[a]	Elapsed Time (min)	Start pH	End pH	ΔpH	Start Temp (°C)	End Temp (°C)	Time[a]	Time Elasped from extraction (min)
Acceptance Range	(95.5–100.5)	(0.95–1.05)	---	---	(55–65 min)	---	---	(≤ 0.5)	(35–39)	(35–39)		(Max = 90 min)

[a] 24-hour time scale

NOTES:

Analytical Procedures

QC Requirements:

QC Sample	Minimum Analysis Frequency	Control Limits	Corrective Action[a]
Reagent blank	once per batch (min. 5%)	< 25 µg/L Pb <5 µg/L As	Investigate possible sources of target analytes. Mitigate contamination problem before continuing analysis.
Bottle blank	once per batch (min. 5%)	< 50 µg/L Pb <10 µg/L As	Investigate possible sources of target analytes. Mitigate contamination problem before continuing analysis.
Blank spike	once per batch (min. 5%)	85–115%	Re-extract and reanalyze sample batch
Duplicate	10% (min. once/day)	±20% RPD	Re-homongenize, re-extract and reanalyze

RPD – Relative percent difference
a – Action required if control limits are not met

APPENDIX E

Soil Laboratory Reports

Seattle 11720 North Creek Pkwy N, Suite 400, Bothell, WA 98011-8244
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907.563.9200 fax 907.563.9210

December 09, 2004

Russel Okoji
AMEC- Hawaii
3375 Koapaka St. Suite F 251
Honalulu, HI 96814

RE: Keaau

Enclosed are the results of analyses for samples received by the laboratory on 11/06/04 09:00.
The following list is a summary of the NCA Work Orders contained in this report.
If you have any questions concerning this report, please feel free to contact me.

Work	Project	ProjectNumber
P4K0347	Keaau	3-251-90015

Thank You,

Lisa Domenighini, Project Manager

The results in this report apply to the samples analyzed in accordance with the chain of custody document. This analytical report must be reproduced in its entirety.

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Environmental Laboratory Network

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AMEC- Hawaii	Project Name: **Keaau**	
3375 Koapaka St. Suite F 251	Project Number: 3-251-90015	Report Created:
Honalulu, HI 96814	Project Manager: Russel Okoji	12/09/04 12:33

ANALYTICAL REPORT FOR SAMPLES

Sample ID	Laboratory ID	Matrix	Date Sampled	Date Received
KE017	P4K0347-04	Soil	11/03/04 16:30	11/06/04 09:00
KE022	P4K0347-09	Soil	11/04/04 14:45	11/06/04 09:00

North Creek Analytical - Portland

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Lisa Domenighini, Project Manager

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AMEC- Hawaii
3375 Koapaka St. Suite F 251
Honalulu, HI 96814

Project Name: **Keaau**
Project Number: 3-251-90015
Project Manager: Russel Okoji

Report Created:
12/09/04 12:33

Total Metals per EPA 6000/7000 Series Methods

North Creek Analytical - Portland

Analyte	Method	Result	MDL*	MRL	Units	Dil	Batch	Prepared	Analyzed	Notes
P4K0347-04 Soil KE017	**Sampled: 11/03/04 16:30**									
Arsenic	EPA 6020	**16.4**	-----	0.0988	mg/kg dry	20x	4111095	11/24/04	12/01/04 22:03	
P4K0347-09 Soil KE022	**Sampled: 11/04/04 14:45**									
Arsenic	EPA 6020	**324**	-----	0.335	mg/kg dry	69.5x	4111095	11/24/04	12/01/04 22:53	

North Creek Analytical - Portland

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Lisa Domenighini, Project Manager

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AMEC- Hawaii	Project Name: **Keaau**	
3375 Koapaka St. Suite F 251	Project Number: 3-251-90015	Report Created:
Honalulu, HI 96814	Project Manager: Russel Okoji	12/09/04 12:33

Percent Dry Weight (Solids) per Standard Methods

North Creek Analytical - Portland

Analyte	Method	Result	MDL*	MRL	Units	Dil	Batch	Prepared	Analyzed	Notes
P4K0347-04 Soil KE017	**Sampled: 11/03/04 16:30**									
% Solids	NCA SOP	**84.9**	-----	1.00	% by Weight	1x	4111100	11/24/04	11/29/04 10:43	
P4K0347-09 Soil KE022	**Sampled: 11/04/04 14:45**									
% Solids	NCA SOP	**86.5**	-----	1.00	% by Weight	1x	4111100	11/24/04	11/29/04 10:43	

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AMEC- Hawaii
3375 Koapaka St. Suite F 251
Honalulu, HI 96814

Project Name: **Keaau**
Project Number: 3-251-90015
Project Manager: Russel Okoji

Report Created:
12/09/04 12:33

Total Metals per EPA 6000/7000 Series Methods - Laboratory Quality Control Results
North Creek Analytical - Portland

QC Batch: 4111095 Soil Preparation Method: EPA 3050

Analyte	Method	Result	MDL*	MRL	Units	Dil	Source Result	Spike Amt	% REC	(Limits)	% RPD	(Limits)	Analyzed	Notes
Blank (4111095-BLK1)								**Extracted: 11/24/04 10:53**						
Arsenic	EPA 6020	ND	---	0.100	mg/kg	20x	--	--	--	--	--	--	12/01/04 15:39	
LCS (4111095-BS1)								**Extracted: 11/24/04 10:53**						
Arsenic	EPA 6020	1.92	---	0.100	mg/kg	20x	--	2.00	96.0%	(80-120)	--	--	12/01/04 15:49	
LCS Dup (4111095-BSD1)								**Extracted: 11/24/04 10:53**						
Arsenic	EPA 6020	1.99	---	0.100	mg/kg	20x	--	2.00	99.5%	(80-120)	3.58%	(20)	12/01/04 15:59	
Duplicate (4111095-DUP1)				**QC Source: P4K0344-06**				**Extracted: 11/24/04 10:53**						
Arsenic	EPA 6020	236	---	0.356	mg/kg dry	75.4x	222	--	--	--	6.11%	(40)	12/01/04 18:11	
Duplicate (4111095-DUP2)				**QC Source: P4K0344-12**				**Extracted: 11/24/04 10:53**						
Arsenic	EPA 6020	262	---	0.348	mg/kg dry	71.5x	334	--	--	--	24.2%	(40)	12/01/04 21:13	
Matrix Spike (4111095-MS1)				**QC Source: P4K0344-06**				**Extracted: 11/24/04 10:53**						
Arsenic	EPA 6020	214	---	0.339	mg/kg dry	71.3x	222	2.40	NR	(75-125)	--	--	12/01/04 18:51	Q-03
Matrix Spike (4111095-MS2)				**QC Source: P4K0344-12**				**Extracted: 11/24/04 10:53**						
Arsenic	EPA 6020	262	---	0.357	mg/kg dry	72.2x	334	2.41	NR	(75-125)	--	--	12/01/04 21:33	Q-03

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AMEC- Hawaii
3375 Koapaka St. Suite F 251
Honalulu, HI 96814

Project Name: **Keaau**
Project Number: 3-251-90015
Project Manager: Russel Okoji

Report Created:
12/09/04 12:33

Percent Dry Weight (Solids) per Standard Methods - Laboratory Quality Control Results

North Creek Analytical - Portland

QC Batch: 4111100 **Soil Preparation Method: Dry Weight**

Analyte	Method	Result	MDL*	MRL	Units	Dil	Source Result	Spike Amt	% REC	(Limits)	% RPD	(Limits)	Analyzed	Notes
Duplicate (4111100-DUP1)					**QC Source: P4K0796-03**			**Extracted: 11/24/04 11:23**						
% Solids	NCA SOP	88.2	---	1.00	% by Weight	1x	87.8	--	--	--	0.455%	(20)	11/29/04 10:43	
Duplicate (4111100-DUP2)					**QC Source: P4K0823-02**			**Extracted: 11/24/04 11:23**						
% Solids	NCA SOP	85.6	---	1.00	% by Weight	1x	85.6	--	--	--	0.00%	(20)	11/29/04 10:43	
Duplicate (4111100-DUP3)					**QC Source: P4K0823-07**			**Extracted: 11/24/04 11:23**						
% Solids	NCA SOP	84.3	---	1.00	% by Weight	1x	84.7	--	--	--	0.473%	(20)	11/29/04 10:43	
Duplicate (4111100-DUP4)					**QC Source: P4K0823-21**			**Extracted: 11/24/04 11:23**						
% Solids	NCA SOP	88.7	---	1.00	% by Weight	1x	88.8	--	--	--	0.113%	(20)	11/29/04 10:43	

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AMEC- Hawaii	Project Name:	**Keaau**	
3375 Koapaka St. Suite F 251	Project Number:	3-251-90015	Report Created:
Honalulu, HI 96814	Project Manager:	Russel Okoji	12/09/04 12:33

Notes and Definitions

Report Specific Notes:

Q-03 - The matrix spike recovery, and/or RPD, for this QC sample cannot be accurately calculated due to the high concentration of analyte already present in the source sample.

Laboratory Reporting Conventions:

DET - Analyte DETECTED at or above the Reporting Limit. Qualitative Analyses only.

ND - Analyte NOT DETECTED at or above the reporting limit (MDL or MRL, as appropriate).

NR / NA - Not Reported / Not Available

dry - Sample results reported on a dry weight basis. Reporting Limits are corrected for %Solids when %Solids are <50%.

wet - Sample results and reporting limits reported on a wet weight basis (as received).

RPD - Relative Percent Difference. (RPDs calculated using Results, not Percent Recoveries).

MRL - METHOD REPORTING LIMIT. Reporting Level at, or above, the lowest level standard of the Calibration Table.

MDL* - METHOD DETECTION LIMIT. Reporting Level at, or above, the statistically derived limit based on 40CFR, Part 136, Appendix B. *MDLs are listed on the report only if the data has been evaluated below the MRL. Results between the MDL and MRL are reported as Estimated results.

Dil - Dilutions are calculated based on deviations from the standard dilution performed for an analysis, and may not represent the dilution found on the analytical raw data.

Reporting limits - Reporting limits (MDLs and MRLs) are adjusted based on variations in sample preparation amounts, analytical dilutions and percent solids, where applicable.

North Creek Analytical - Portland

Lisa Domenighini, Project Manager

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December 09, 2004

Russel Okoji
AMEC- Hawaii
3375 Koapaka St. Suite F 251
Honalulu, HI 96814

RE: Keaau

Enclosed are the results of analyses for samples received by the laboratory on 11/06/04 09:00.
The following list is a summary of the NCA Work Orders contained in this report.
If you have any questions concerning this report, please feel free to contact me.

Work	Project	ProjectNumber
P4K0344	Keaau	3-251-90015

Thank You,

Lisa Domenighini, Project Manager

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AMEC- Hawaii	Project Name: **Keaau**	
3375 Koapaka St. Suite F 251	Project Number: 3-251-90015	Report Created:
Honalulu, HI 96814	Project Manager: Russel Okoji	12/09/04 12:30

ANALYTICAL REPORT FOR SAMPLES

Sample ID	Laboratory ID	Matrix	Date Sampled	Date Received
KE001	P4K0344-01	Soil	11/01/04 11:00	11/06/04 09:00
KE002	P4K0344-02	Soil	11/01/04 14:00	11/06/04 09:00
KE003	P4K0344-03	Soil	11/01/04 15:00	11/06/04 09:00
KE004	P4K0344-04	Soil	11/01/04 17:00	11/06/04 09:00
KE005	P4K0344-05	Soil	11/02/04 09:00	11/06/04 09:00
KE007	P4K0344-07	Soil	11/02/04 12:00	11/06/04 09:00
KE008	P4K0344-08	Soil	11/02/04 13:30	11/06/04 09:00
KE009	P4K0344-09	Soil	11/02/04 15:00	11/06/04 09:00
KE010	P4K0344-10	Soil	11/02/04 16:30	11/06/04 09:00
KE011	P4K0344-11	Soil	11/03/04 08:30	11/06/04 09:00
KE013	P4K0344-13	Soil	11/03/04 13:00	11/06/04 09:00

North Creek Analytical - Portland

Lisa Domenighini, Project Manager

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Total Metals per EPA 6000/7000 Series Methods

North Creek Analytical - Portland

Analyte			Method	Result	MDL*	MRL	Units	Dil	Batch	Prepared	Analyzed	Notes
P4K0344-01	**Soil**	**KE001**	**Sampled: 11/01/04 11:00**									
Arsenic			EPA 6020	**15.3**	-----	0.0994	mg/kg dry	20x	4111095	11/24/04	12/01/04 16:10	
P4K0344-02	**Soil**	**KE002**	**Sampled: 11/01/04 14:00**									
Arsenic			EPA 6020	**0.667**	-----	0.0956	mg/kg dry	20x	4111095	11/24/04	12/01/04 16:50	
P4K0344-03	**Soil**	**KE003**	**Sampled: 11/01/04 15:00**									
Arsenic			EPA 6020	**17.1**	-----	0.0476	mg/kg dry	10x	4110700	11/15/04	11/17/04 05:01	**A-01**
P4K0344-04	**Soil**	**KE004**	**Sampled: 11/01/04 17:00**									
Arsenic			EPA 6020	**16.0**	-----	0.0978	mg/kg dry	20x	4111095	11/24/04	12/01/04 17:00	
P4K0344-05	**Soil**	**KE005**	**Sampled: 11/02/04 09:00**									
Arsenic			EPA 6020	**361**	-----	0.343	mg/kg dry	73.1x	4111095	11/24/04	12/01/04 17:30	
P4K0344-07	**Soil**	**KE007**	**Sampled: 11/02/04 12:00**									
Arsenic			EPA 6020	**262**	-----	0.349	mg/kg dry	70.9x	4111095	11/24/04	12/01/04 19:11	
P4K0344-08	**Soil**	**KE008**	**Sampled: 11/02/04 13:30**									
Arsenic			EPA 6020	**311**	-----	0.342	mg/kg dry	71x	4111095	11/24/04	12/01/04 19:31	

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AMEC- Hawaii
3375 Koapaka St. Suite F 251
Honalulu, HI 96814

Project Name: **Keaau**
Project Number: 3-251-90015
Project Manager: Russel Okoji

Report Created:
12/09/04 12:30

Total Metals per EPA 6000/7000 Series Methods

North Creek Analytical - Portland

Analyte		Method	Result	MDL*	MRL	Units	Dil	Batch	Prepared	Analyzed	Notes
P4K0344-09	**Soil**	**KE009**	**Sampled: 11/02/04 15:00**								
Arsenic		EPA 6020	**139**	-----	0.356	mg/kg dry	72.1x	4111095	11/24/04	12/01/04 19:52	
P4K0344-10	**Soil**	**KE010**	**Sampled: 11/02/04 16:30**								
Arsenic		EPA 6020	**376**	-----	0.990	mg/kg dry	200x	4110700	11/15/04	11/19/04 15:02	**A-01**
P4K0344-11	**Soil**	**KE011**	**Sampled: 11/03/04 08:30**								
Arsenic		EPA 6020	**187**	-----	0.363	mg/kg dry	72.8x	4111095	11/24/04	12/01/04 20:12	
P4K0344-13	**Soil**	**KE013**	**Sampled: 11/03/04 13:00**								
Arsenic		EPA 6020	**309**	-----	0.358	mg/kg dry	72.9x	4111095	11/24/04	12/01/04 21:53	

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Percent Dry Weight (Solids) per Standard Methods

North Creek Analytical - Portland

Analyte	Method	Result	MDL*	MRL	Units	Dil	Batch	Prepared	Analyzed	Notes
P4K0344-01 Soil KE001	**Sampled: 11/01/04 11:00**									
% Solids	NCA SOP	**87.5**	-----	1.00	% by Weight	1x	4111100	11/24/04	11/29/04 10:43	
P4K0344-02 Soil KE002	**Sampled: 11/01/04 14:00**									
% Solids	NCA SOP	**87.4**	-----	1.00	% by Weight	1x	4111100	11/24/04	11/29/04 10:43	
P4K0344-03 Soil KE003	**Sampled: 11/01/04 15:00**									
% Solids	NCA SOP	**81.0**	-----	1.00	% by Weight	1x	4110698	11/15/04	11/16/04 11:39	
P4K0344-04 Soil KE004	**Sampled: 11/01/04 17:00**									
% Solids	NCA SOP	**79.5**	-----	1.00	% by Weight	1x	4111100	11/24/04	11/29/04 10:43	
P4K0344-05 Soil KE005	**Sampled: 11/02/04 09:00**									
% Solids	NCA SOP	**71.1**	-----	1.00	% by Weight	1x	4111100	11/24/04	11/29/04 10:43	
P4K0344-07 Soil KE007	**Sampled: 11/02/04 12:00**									
% Solids	NCA SOP	**81.4**	-----	1.00	% by Weight	1x	4111100	11/24/04	11/29/04 10:43	
P4K0344-08 Soil KE008	**Sampled: 11/02/04 13:30**									
% Solids	NCA SOP	**67.6**	-----	1.00	% by Weight	1x	4111100	11/24/04	11/29/04 10:43	

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AMEC- Hawaii	Project Name:	**Keaau**	
3375 Koapaka St. Suite F 251	Project Number:	3-251-90015	Report Created:
Honalulu, HI 96814	Project Manager:	Russel Okoji	12/09/04 12:30

Percent Dry Weight (Solids) per Standard Methods

North Creek Analytical - Portland

Analyte	Method	Result	MDL*	MRL	Units	Dil	Batch	Prepared	Analyzed	Notes
P4K0344-09 Soil KE009		**Sampled: 11/02/04 15:00**								
% Solids	NCA SOP	**77.7**	-----	1.00	% by Weight	1x	4111100	11/24/04	11/29/04 10:43	
P4K0344-10 Soil KE010		**Sampled: 11/02/04 16:30**								
% Solids	NCA SOP	**90.1**	-----	1.00	% by Weight	1x	4110698	11/15/04	11/16/04 11:39	
P4K0344-11 Soil KE011		**Sampled: 11/03/04 08:30**								
% Solids	NCA SOP	**78.3**	-----	1.00	% by Weight	1x	4111100	11/24/04	11/29/04 10:43	
P4K0344-13 Soil KE013		**Sampled: 11/03/04 13:00**								
% Solids	NCA SOP	**87.1**	-----	1.00	% by Weight	1x	4111100	11/24/04	11/29/04 10:43	

North Creek Analytical - Portland

Lisa Domenighini, Project Manager

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AMEC- Hawaii	Project Name:	Keaau	
3375 Koapaka St. Suite F 251	Project Number:	3-251-90015	Report Created:
Honalulu, HI 96814	Project Manager:	Russel Okoji	12/09/04 12:30

Total Metals per EPA 6000/7000 Series Methods - Laboratory Quality Control Results

North Creek Analytical - Portland

QC Batch: 4110700 Soil Preparation Method: EPA 3050

Analyte	Method	Result	MDL*	MRL	Units	Dil	Source Result	Spike Amt	% REC	(Limits)	% RPD	(Limits)	Analyzed	Notes
Blank (4110700-BLK1)								**Extracted: 11/15/04 11:45**						
Arsenic	EPA 6020	ND	---	0.250	mg/kg	10x	--	--	--	--	--	--	11/17/04 04:10	
LCS (4110700-BS1)								**Extracted: 11/15/04 11:45**						
Arsenic	EPA 6020	9.32	---	0.250	mg/kg	10x	--	9.52	97.9%	(80-120)	--	--	11/17/04 04:20	
LCS Dup (4110700-BSD1)								**Extracted: 11/15/04 11:45**						
Arsenic	EPA 6020	9.18	---	0.250	mg/kg	10x	--	9.43	97.3%	(80-120)	1.51%	(20)	11/17/04 04:30	
Duplicate (4110700-DUP1)				**QC Source: P4K0344-03**				**Extracted: 11/15/04 11:45**						
Arsenic	EPA 6020	19.3	---	0.0468	mg/kg dry	10x	17.1	--	--	--	12.1%	(40)	11/17/04 05:21	A-01
Duplicate (4110700-DUP2)				**QC Source: P4K0344-10**				**Extracted: 11/15/04 11:45**						
Arsenic	EPA 6020	355	---	0.984	mg/kg dry	200x	376	--	--	--	5.75%	(40)	11/19/04 15:28	A-01
Duplicate (4110700-DUP3)				**QC Source: P4K0347-01**				**Extracted: 11/15/04 11:45**						
Arsenic	EPA 6020	148	---	0.211	mg/kg dry	42.9x	222	--	--	--	40.0%	(40)	11/17/04 13:01	A-01
Duplicate (4110700-DUP4)				**QC Source: P4K0347-02**				**Extracted: 11/15/04 11:45**						
Arsenic	EPA 6020	208	---	0.207	mg/kg dry	42.2x	252	--	--	--	19.1%	(40)	11/17/04 13:42	A-01
Duplicate (4110700-DUP5)				**QC Source: P4K0347-03**				**Extracted: 11/15/04 11:45**						
Arsenic	EPA 6020	127	---	0.187	mg/kg dry	39.1x	135	--	--	--	6.11%	(40)	11/17/04 14:02	A-01
Duplicate (4110700-DUP6)				**QC Source: P4K0347-05**				**Extracted: 11/15/04 11:45**						
Arsenic	EPA 6020	329	---	0.201	mg/kg dry	40.2x	267	--	--	--	20.8%	(40)	11/17/04 14:22	A-01
Duplicate (4110700-DUP7)				**QC Source: P4K0347-07**				**Extracted: 11/15/04 11:45**						
Arsenic	EPA 6020	232	---	0.486	mg/kg dry	100x	266	--	--	--	13.7%	(40)	12/08/04 19:15	A-01
Duplicate (4110700-DUP8)				**QC Source: P4K0347-08**				**Extracted: 11/15/04 11:45**						
Arsenic	EPA 6020	286	---	0.971	mg/kg dry	200x	270	--	--	--	5.76%	(40)	11/19/04 15:36	A-01
Duplicate (4110700-DUP9)				**QC Source: P4K0347-10**				**Extracted: 11/15/04 11:45**						
Arsenic	EPA 6020	40.6	---	0.0469	mg/kg dry	10x	48.0	--	--	--	16.7%	(40)	11/17/04 15:13	A-01
Duplicate (4110700-DUPA)				**QC Source: P4K0347-11**				**Extracted: 11/15/04 11:45**						
Arsenic	EPA 6020	41.0	---	0.0498	mg/kg dry	10x	30.7	--	--	--	28.7%	(40)	11/17/04 15:53	A-01
Duplicate (4110700-DUPB)				**QC Source: P4K0344-03**				**Extracted: 11/15/04 11:45**						
Arsenic	EPA 6020	16.2	---	0.0488	mg/kg dry	10x	17.1	--	--	--	5.41%	(40)	11/17/04 05:21	A-01
Duplicate (4110700-DUPC)				**QC Source: P4K0344-03**				**Extracted: 11/15/04 11:45**						

North Creek Analytical - Portland

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AMEC- Hawaii
3375 Koapaka St. Suite F 251
Honalulu, HI 96814

Project Name: **Keaau**
Project Number: 3-251-90015
Project Manager: Russel Okoji

Report Created:
12/09/04 12:30

Total Metals per EPA 6000/7000 Series Methods - Laboratory Quality Control Results

North Creek Analytical - Portland

QC Batch: 4110700 Soil Preparation Method: EPA 3050

Analyte	Method	Result	MDL*	MRL	Units	Dil	Source Result	Spike Amt	% REC	(Limits)	% RPD	(Limits)	Analyzed	Notes
Duplicate (4110700-DUPC)				QC Source: P4K0344-03				Extracted: 11/15/04 11:45						
Arsenic	EPA 6020	17.8	---	0.0491	mg/kg dry	10x	17.1	--	--	--	4.01%	(40)	11/17/04 11:41	A-01
Matrix Spike (4110700-MS1)				QC Source: P4K0344-03				Extracted: 11/15/04 11:45						
Arsenic	EPA 6020	7.57	---	0.0493	mg/kg dry	10x	17.1	2.44	NR	(75-125)	--	--	11/17/04 05:40	A-01, Q-02
Matrix Spike (4110700-MS2)				QC Source: P4K0344-03				Extracted: 11/15/04 11:45						A-01, Q-02
Arsenic	EPA 6020	7.77	---	0.0483	mg/kg dry	10x	17.1	2.38	NR	(75-125)	--	--	11/17/04 12:01	

QC Batch: 4111095 Soil Preparation Method: EPA 3050

Analyte	Method	Result	MDL*	MRL	Units	Dil	Source Result	Spike Amt	% REC	(Limits)	% RPD	(Limits)	Analyzed	Notes
Blank (4111095-BLK1)								Extracted: 11/24/04 10:53						
Arsenic	EPA 6020	ND	---	0.100	mg/kg	20x	--	--	--	--	--	--	12/01/04 15:39	
LCS (4111095-BS1)								Extracted: 11/24/04 10:53						
Arsenic	EPA 6020	1.92	---	0.100	mg/kg	20x	--	2.00	96.0%	(80-120)	--	--	12/01/04 15:49	
LCS Dup (4111095-BSD1)								Extracted: 11/24/04 10:53						
Arsenic	EPA 6020	1.99	---	0.100	mg/kg	20x	--	2.00	99.5%	(80-120)	3.58%	(20)	12/01/04 15:59	
Duplicate (4111095-DUP1)				QC Source: P4K0344-06				Extracted: 11/24/04 10:53						
Arsenic	EPA 6020	236	---	0.356	mg/kg dry	75.4x	222	--	--	--	6.11%	(40)	12/01/04 18:11	
Duplicate (4111095-DUP2)				QC Source: P4K0344-12				Extracted: 11/24/04 10:53						
Arsenic	EPA 6020	262	---	0.348	mg/kg dry	71.5x	334	--	--	--	24.2%	(40)	12/01/04 21:13	
Matrix Spike (4111095-MS1)				QC Source: P4K0344-06				Extracted: 11/24/04 10:53						
Arsenic	EPA 6020	214	---	0.339	mg/kg dry	71.3x	222	2.40	NR	(75-125)	--	--	12/01/04 18:51	Q-03
Matrix Spike (4111095-MS2)				QC Source: P4K0344-12				Extracted: 11/24/04 10:53						
Arsenic	EPA 6020	262	---	0.357	mg/kg dry	72.2x	334	2.41	NR	(75-125)	--	--	12/01/04 21:33	Q-03

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AMEC- Hawaii
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Honalulu, HI 96814

Project Name: **Keaau**
Project Number: 3-251-90015
Project Manager: Russel Okoji

Report Created:
12/09/04 12:30

Percent Dry Weight (Solids) per Standard Methods - Laboratory Quality Control Results

North Creek Analytical - Portland

QC Batch: 4110698 Soil Preparation Method: Dry Weight

Analyte	Method	Result	MDL*	MRL	Units	Dil	Source Result	Spike Amt	% REC	(Limits)	% RPD	(Limits)	Analyzed	Notes
Duplicate (4110698-DUP1)				**QC Source: P4K0506-01**				**Extracted: 11/15/04 11:36**						
% Solids	NCA SOP	73.4	---	1.00	% by Weight	1x	72.9	--	--	--	0.684%	(20)	11/16/04 11:39	
Duplicate (4110698-DUP2)				**QC Source: P4K0506-02**				**Extracted: 11/15/04 11:36**						
% Solids	NCA SOP	73.1	---	1.00	% by Weight	1x	72.6	--	--	--	0.686%	(20)	11/16/04 11:39	
Duplicate (4110698-DUP3)				**QC Source: P4K0534-04**				**Extracted: 11/15/04 11:36**						
% Solids	NCA SOP	68.5	---	1.00	% by Weight	1x	68.5	--	--	--	0.00%	(20)	11/16/04 11:39	
Duplicate (4110698-DUP4)				**QC Source: P4K0566-02**				**Extracted: 11/15/04 11:36**						
% Solids	NCA SOP	80.1	---	1.00	% by Weight	1x	80.5	--	--	--	0.498%	(20)	11/16/04 11:39	

QC Batch: 4111100 Soil Preparation Method: Dry Weight

Analyte	Method	Result	MDL*	MRL	Units	Dil	Source Result	Spike Amt	% REC	(Limits)	% RPD	(Limits)	Analyzed	Notes
Duplicate (4111100-DUP1)				**QC Source: P4K0796-03**				**Extracted: 11/24/04 11:23**						
% Solids	NCA SOP	88.2	---	1.00	% by Weight	1x	87.8	--	--	--	0.455%	(20)	11/29/04 10:43	
Duplicate (4111100-DUP2)				**QC Source: P4K0823-02**				**Extracted: 11/24/04 11:23**						
% Solids	NCA SOP	85.6	---	1.00	% by Weight	1x	85.6	--	--	--	0.00%	(20)	11/29/04 10:43	
Duplicate (4111100-DUP3)				**QC Source: P4K0823-07**				**Extracted: 11/24/04 11:23**						
% Solids	NCA SOP	84.3	---	1.00	% by Weight	1x	84.7	--	--	--	0.473%	(20)	11/29/04 10:43	
Duplicate (4111100-DUP4)				**QC Source: P4K0823-21**				**Extracted: 11/24/04 11:23**						
% Solids	NCA SOP	88.7	---	1.00	% by Weight	1x	88.8	--	--	--	0.113%	(20)	11/29/04 10:43	

AMEC- Hawaii	Project Name:	**Keaau**	
3375 Koapaka St. Suite F 251	Project Number:	3-251-90015	Report Created:
Honalulu, HI 96814	Project Manager:	Russel Okoji	12/09/04 12:30

Notes and Definitions

Report Specific Notes:

A-01 - Percent solids determined on sample that was dried for three days and then sieved.

Q-02 - The matrix spike recovery, and/or RPD, for this QC sample is outside of established control limits due to sample matrix interference.

Q-03 - The matrix spike recovery, and/or RPD, for this QC sample cannot be accurately calculated due to the high concentration of analyte already present in the source sample.

Laboratory Reporting Conventions:

DET - Analyte DETECTED at or above the Reporting Limit. Qualitative Analyses only.

ND - Analyte NOT DETECTED at or above the reporting limit (MDL or MRL, as appropriate).

NR / NA - Not Reported / Not Available

dry - Sample results reported on a dry weight basis. Reporting Limits are corrected for %Solids when %Solids are <50%.

wet - Sample results and reporting limits reported on a wet weight basis (as received).

RPD - Relative Percent Difference. (RPDs calculated using Results, not Percent Recoveries).

MRL - METHOD REPORTING LIMIT. Reporting Level at, or above, the lowest level standard of the Calibration Table.

MDL* - METHOD DETECTION LIMIT. Reporting Level at, or above, the statistically derived limit based on 40CFR, Part 136, Appendix B. *MDLs are listed on the report only if the data has been evaluated below the MRL. Results between the MDL and MRL are reported as Estimated results.

Dil - Dilutions are calculated based on deviations from the standard dilution performed for an analysis, and may not represent the dilution found on the analytical raw data.

Reporting limits - Reporting limits (MDLs and MRLs) are adjusted based on variations in sample preparation amounts, analytical dilutions and percent solids, where applicable.

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December 09, 2004

Russel Okoji
AMEC- Hawaii
3375 Koapaka St. Suite F 251
Honalulu, HI 96814

RE: Keaau

Enclosed are the results of analyses for samples received by the laboratory on 11/06/04 09:00.
The following list is a summary of the NCA Work Orders contained in this report.
If you have any questions concerning this report, please feel free to contact me.

Work	Project	ProjectNumber
P4K0344	Keaau	3-251-90015

Thank You,

Lisa Domenighini, Project Manager

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AMEC- Hawaii	Project Name:	Keaau	
3375 Koapaka St. Suite F 251	Project Number:	3-251-90015	Report Created:
Honalulu, HI 96814	Project Manager:	Russel Okoji	12/09/04 12:31

ANALYTICAL REPORT FOR SAMPLES

Sample ID	Laboratory ID	Matrix	Date Sampled	Date Received
KE006	P4K0344-06	Soil	11/02/04 11:00	11/06/04 09:00
KE012	P4K0344-12	Soil	11/03/04 10:30	11/06/04 09:00

North Creek Analytical - Portland

Lisa Domenighini, Project Manager

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AMEC- Hawaii	Project Name: **Keaau**	
3375 Koapaka St. Suite F 251	Project Number: 3-251-90015	Report Created:
Honalulu, HI 96814	Project Manager: Russel Okoji	12/09/04 12:31

Total Metals per EPA 6000/7000 Series Methods

North Creek Analytical - Portland

Analyte		Method	Result	MDL*	MRL	Units	Dil	Batch	Prepared	Analyzed	Notes
P4K0344-06	**Soil**	**KE006**	**Sampled: 11/02/04 11:00**								
Arsenic		EPA 6020	**222**	-----	0.357	mg/kg dry	73.7x	4111095	11/24/04	12/01/04 17:50	
P4K0344-12	**Soil**	**KE012**	**Sampled: 11/03/04 10:30**								
Arsenic		EPA 6020	**334**	-----	0.340	mg/kg dry	68.8x	4111095	11/24/04	12/01/04 20:52	

North Creek Analytical - Portland

Lisa Domenighini, Project Manager

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AMEC- Hawaii	Project Name:	**Keaau**	
3375 Koapaka St. Suite F 251	Project Number:	3-251-90015	Report Created:
Honalulu, HI 96814	Project Manager:	Russel Okoji	12/09/04 12:31

Percent Dry Weight (Solids) per Standard Methods

North Creek Analytical - Portland

Analyte	Method	Result	MDL*	MRL	Units	Dil	Batch	Prepared	Analyzed	Notes
P4K0344-06 Soil KE006	**Sampled: 11/02/04 11:00**									
% Solids	NCA SOP	**79.2**	-----	1.00	% by Weight	1x	4111100	11/24/04	11/29/04 10:43	
P4K0344-12 Soil KE012	**Sampled: 11/03/04 10:30**									
% Solids	NCA SOP	**82.1**	-----	1.00	% by Weight	1x	4111100	11/24/04	11/29/04 10:43	

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AMEC- Hawaii	Project Name: **Keaau**	
3375 Koapaka St. Suite F 251	Project Number: 3-251-90015	Report Created:
Honalulu, HI 96814	Project Manager: Russel Okoji	12/09/04 12:31

Total Metals per EPA 6000/7000 Series Methods - Laboratory Quality Control Results

North Creek Analytical - Portland

QC Batch: 4111095 Soil Preparation Method: EPA 3050

Analyte	Method	Result	MDL*	MRL	Units	Dil	Source Result	Spike Amt	% REC	(Limits)	% RPD	(Limits)	Analyzed	Notes
Blank (4111095-BLK1)								**Extracted: 11/24/04 10:53**						
Arsenic	EPA 6020	ND	---	0.100	mg/kg	20x	--	--	--	--	--	--	12/01/04 15:39	
LCS (4111095-BS1)								**Extracted: 11/24/04 10:53**						
Arsenic	EPA 6020	1.92	---	0.100	mg/kg	20x	--	2.00	96.0%	(80-120)	--	--	12/01/04 15:49	
LCS Dup (4111095-BSD1)								**Extracted: 11/24/04 10:53**						
Arsenic	EPA 6020	1.99	---	0.100	mg/kg	20x	--	2.00	99.5%	(80-120)	3.58%	(20)	12/01/04 15:59	
Duplicate (4111095-DUP1)				**QC Source: P4K0344-06**				**Extracted: 11/24/04 10:53**						
Arsenic	EPA 6020	236	---	0.356	mg/kg dry	75.4x	222	--	--	--	6.11%	(40)	12/01/04 18:11	
Duplicate (4111095-DUP2)				**QC Source: P4K0344-12**				**Extracted: 11/24/04 10:53**						
Arsenic	EPA 6020	262	---	0.348	mg/kg dry	71.5x	334	--	--	--	24.2%	(40)	12/01/04 21:13	
Matrix Spike (4111095-MS1)				**QC Source: P4K0344-06**				**Extracted: 11/24/04 10:53**						
Arsenic	EPA 6020	214	---	0.339	mg/kg dry	71.3x	222	2.40	NR	(75-125)	--	--	12/01/04 18:51	Q-03
Matrix Spike (4111095-MS2)				**QC Source: P4K0344-12**				**Extracted: 11/24/04 10:53**						
Arsenic	EPA 6020	262	---	0.357	mg/kg dry	72.2x	334	2.41	NR	(75-125)	--	--	12/01/04 21:33	Q-03

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Lisa Domenighini, Project Manager

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AMEC- Hawaii
3375 Koapaka St. Suite F 251
Honalulu, HI 96814

Project Name: **Keaau**
Project Number: 3-251-90015
Project Manager: Russel Okoji

Report Created:
12/09/04 12:31

Percent Dry Weight (Solids) per Standard Methods - Laboratory Quality Control Results

North Creek Analytical - Portland

QC Batch: 4111100 Soil Preparation Method: Dry Weight

Analyte	Method	Result	MDL*	MRL	Units	Dil	Source Result	Spike Amt	% REC	(Limits)	% RPD	(Limits)	Analyzed	Notes
Duplicate (4111100-DUP1)				**QC Source: P4K0796-03**				**Extracted: 11/24/04 11:23**						
% Solids	NCA SOP	88.2	---	1.00	% by Weight	1x	87.8	--	--	--	0.455%	(20)	11/29/04 10:43	
Duplicate (4111100-DUP2)				**QC Source: P4K0823-02**				**Extracted: 11/24/04 11:23**						
% Solids	NCA SOP	85.6	---	1.00	% by Weight	1x	85.6	--	--	--	0.00%	(20)	11/29/04 10:43	
Duplicate (4111100-DUP3)				**QC Source: P4K0823-07**				**Extracted: 11/24/04 11:23**						
% Solids	NCA SOP	84.3	---	1.00	% by Weight	1x	84.7	--	--	--	0.473%	(20)	11/29/04 10:43	
Duplicate (4111100-DUP4)				**QC Source: P4K0823-21**				**Extracted: 11/24/04 11:23**						
% Solids	NCA SOP	88.7	---	1.00	% by Weight	1x	88.8	--	--	--	0.113%	(20)	11/29/04 10:43	

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AMEC- Hawaii	Project Name:	**Keaau**	
3375 Koapaka St. Suite F 251	Project Number:	3-251-90015	Report Created:
Honalulu, HI 96814	Project Manager:	Russel Okoji	12/09/04 12:31

Notes and Definitions

Report Specific Notes:

Q-03 - The matrix spike recovery, and/or RPD, for this QC sample cannot be accurately calculated due to the high concentration of analyte already present in the source sample.

Laboratory Reporting Conventions:

DET - Analyte DETECTED at or above the Reporting Limit. Qualitative Analyses only.

ND - Analyte NOT DETECTED at or above the reporting limit (MDL or MRL, as appropriate).

NR / NA - Not Reported / Not Available

dry - Sample results reported on a dry weight basis. Reporting Limits are corrected for %Solids when %Solids are <50%.

wet - Sample results and reporting limits reported on a wet weight basis (as received).

RPD - Relative Percent Difference. (RPDs calculated using Results, not Percent Recoveries).

MRL - METHOD REPORTING LIMIT. Reporting Level at, or above, the lowest level standard of the Calibration Table.

MDL* - METHOD DETECTION LIMIT. Reporting Level at, or above, the statistically derived limit based on 40CFR, Part 136, Appendix B. *MDLs are listed on the report only if the data has been evaluated below the MRL. Results between the MDL and MRL are reported as Estimated results.

Dil - Dilutions are calculated based on deviations from the standard dilution performed for an analysis, and may not represent the dilution found on the analytical raw data.

Reporting limits - Reporting limits (MDLs and MRLs) are adjusted based on variations in sample preparation amounts, analytical dilutions and percent solids, where applicable.

North Creek Analytical - Portland

Lisa Domenighini, Project Manager

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December 09, 2004

Russel Okoji
AMEC- Hawaii
3375 Koapaka St. Suite F 251
Honalulu, HI 96814

RE: Keaau

Enclosed are the results of analyses for samples received by the laboratory on 11/06/04 09:00.
The following list is a summary of the NCA Work Orders contained in this report.
If you have any questions concerning this report, please feel free to contact me.

Work	Project	ProjectNumber
P4K0347	Keaau	3-251-90015

Thank You,

Lisa Domenighini, Project Manager

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AMEC- Hawaii
3375 Koapaka St. Suite F 251
Honalulu, HI 96814

Project Name: **Keaau**
Project Number: 3-251-90015
Project Manager: Russel Okoji

Report Created:
12/09/04 12:32

ANALYTICAL REPORT FOR SAMPLES

Sample ID	Laboratory ID	Matrix	Date Sampled	Date Received
KE014	P4K0347-01	Soil	11/03/04 13:30	11/06/04 09:00
KE015	P4K0347-02	Soil	11/03/04 14:00	11/06/04 09:00
KE016	P4K0347-03	Soil	11/03/04 14:30	11/06/04 09:00
KE018	P4K0347-05	Soil	11/04/04 09:30	11/06/04 09:00
KE019	P4K0347-06	Water	11/04/04 10:00	11/06/04 09:00
KE020	P4K0347-07	Soil	11/04/04 11:30	11/06/04 09:00
KE021	P4K0347-08	Soil	11/04/04 12:00	11/06/04 09:00
KE023	P4K0347-10	Soil	11/04/04 16:00	11/06/04 09:00
KE024	P4K0347-11	Soil	11/04/04 17:00	11/06/04 09:00
KE025	P4K0347-12	Water	11/04/04 17:30	11/06/04 09:00

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AMEC- Hawaii	Project Name: **Keaau**	
3375 Koapaka St. Suite F 251	Project Number: 3-251-90015	Report Created:
Honalulu, HI 96814	Project Manager: Russel Okoji	12/09/04 12:32

Total Metals per EPA 6000/7000 Series Methods

North Creek Analytical - Portland

Analyte	Method	Result	MDL*	MRL	Units	Dil	Batch	Prepared	Analyzed	Notes
P4K0347-01 Soil KE014		**Sampled: 11/03/04 13:30**								
Arsenic	EPA 6020	**222**	-----	0.208	mg/kg dry	42.3x	4110700	11/15/04	11/17/04 07:21	**A-01**
P4K0347-02 Soil KE015		**Sampled: 11/03/04 14:00**								
Arsenic	EPA 6020	**252**	-----	0.196	mg/kg dry	41x	4110700	11/15/04	11/17/04 07:41	**A-01**
P4K0347-03 Soil KE016		**Sampled: 11/03/04 14:30**								
Arsenic	EPA 6020	**135**	-----	0.191	mg/kg dry	40.2x	4110700	11/15/04	11/17/04 08:00	**A-01**
P4K0347-05 Soil KE018		**Sampled: 11/04/04 09:30**								
Arsenic	EPA 6020	**267**	-----	0.199	mg/kg dry	40.1x	4110700	11/15/04	11/17/04 08:20	**A-01**
P4K0347-06 Water KE019		**Sampled: 11/04/04 10:00**								
Arsenic	EPA 6020	ND	-----	0.000500	mg/l	1x	4110757	11/16/04	11/17/04 01:48	
P4K0347-07 Soil KE020		**Sampled: 11/04/04 11:30**								
Arsenic	EPA 6020	**266**	-----	0.975	mg/kg dry	200x	4110700	11/15/04	11/19/04 15:11	**A-01**
P4K0347-08 Soil KE021		**Sampled: 11/04/04 12:00**								
Arsenic	EPA 6020	**270**	-----	0.996	mg/kg dry	200x	4110700	11/15/04	11/19/04 15:19	**A-01**

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AMEC- Hawaii	Project Name: **Keaau**	
3375 Koapaka St. Suite F 251	Project Number: 3-251-90015	Report Created:
Honalulu, HI 96814	Project Manager: Russel Okoji	12/09/04 12:32

Total Metals per EPA 6000/7000 Series Methods

North Creek Analytical - Portland

Analyte	Method	Result	MDL*	MRL	Units	Dil	Batch	Prepared	Analyzed	Notes
P4K0347-10 Soil KE023	**Sampled: 11/04/04 16:00**									
Arsenic	EPA 6020	**48.0**	-----	0.0485	mg/kg dry	10x	4110700	11/15/04	11/17/04 09:51	**A-01**
P4K0347-11 Soil KE024	**Sampled: 11/04/04 17:00**									
Arsenic	EPA 6020	**30.7**	-----	0.0497	mg/kg dry	10x	4110700	11/15/04	11/17/04 10:11	**A-01**
P4K0347-12 Water KE025	**Sampled: 11/04/04 17:30**									
Arsenic	EPA 6020	ND	-----	0.000500	mg/l	1x	4110757	11/16/04	11/17/04 01:58	

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AMEC- Hawaii	Project Name: **Keaau**	
3375 Koapaka St. Suite F 251	Project Number: 3-251-90015	Report Created:
Honalulu, HI 96814	Project Manager: Russel Okoji	12/09/04 12:32

Percent Dry Weight (Solids) per Standard Methods

North Creek Analytical - Portland

Analyte			Method	Result	MDL*	MRL	Units	Dil	Batch	Prepared	Analyzed	Notes
P4K0347-01	**Soil**	**KE014**	**Sampled: 11/03/04 13:30**									
% Solids			NCA SOP	**69.6**	-----	1.00	% by Weight	1x	4110698	11/15/04	11/16/04 11:39	
P4K0347-02	**Soil**	**KE015**	**Sampled: 11/03/04 14:00**									
% Solids			NCA SOP	**67.7**	-----	1.00	% by Weight	1x	4110698	11/15/04	11/16/04 11:39	
P4K0347-03	**Soil**	**KE016**	**Sampled: 11/03/04 14:30**									
% Solids			NCA SOP	**86.1**	-----	1.00	% by Weight	1x	4110698	11/15/04	11/16/04 11:39	
P4K0347-05	**Soil**	**KE018**	**Sampled: 11/04/04 09:30**									
% Solids			NCA SOP	**53.5**	-----	1.00	% by Weight	1x	4110698	11/15/04	11/16/04 11:39	
P4K0347-07	**Soil**	**KE020**	**Sampled: 11/04/04 11:30**									
% Solids			NCA SOP	**88.3**	-----	1.00	% by Weight	1x	4110698	11/15/04	11/16/04 11:39	
P4K0347-08	**Soil**	**KE021**	**Sampled: 11/04/04 12:00**									
% Solids			NCA SOP	**93.2**	-----	1.00	% by Weight	1x	4110698	11/15/04	11/16/04 11:39	
P4K0347-10	**Soil**	**KE023**	**Sampled: 11/04/04 16:00**									
% Solids			NCA SOP	**81.0**	-----	1.00	% by Weight	1x	4110698	11/15/04	11/16/04 11:39	

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AMEC- Hawaii	Project Name: **Keaau**	
3375 Koapaka St. Suite F 251	Project Number: 3-251-90015	Report Created:
Honalulu, HI 96814	Project Manager: Russel Okoji	12/09/04 12:32

Percent Dry Weight (Solids) per Standard Methods

North Creek Analytical - Portland

Analyte	Method	Result	MDL*	MRL	Units	Dil	Batch	Prepared	Analyzed	Notes
P4K0347-11 Soil KE024		**Sampled: 11/04/04 17:00**								
% Solids	NCA SOP	**82.3**	-----	1.00	% by Weight	1x	4110698	11/15/04	11/16/04 11:39	

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AMEC- Hawaii	Project Name:	**Keaau**	
3375 Koapaka St. Suite F 251	Project Number:	3-251-90015	Report Created:
Honalulu, HI 96814	Project Manager:	Russel Okoji	12/09/04 12:32

Total Metals per EPA 200 Series Methods - Laboratory Quality Control Results

North Creek Analytical - Portland

QC Batch: 4110757 **Water Preparation Method: EPA 200/3005**

Analyte	Method	Result	MDL*	MRL	Units	Dil	Source Result	Spike Amt	% REC	(Limits)	% RPD	(Limits)	Analyzed	Notes
Blank (4110757-BLK1)								**Extracted: 11/16/04 12:53**						
Arsenic	EPA 200.8	ND	---	0.000500	mg/l	1x	--	--	--	--	--	--	11/17/04 01:17	
LCS (4110757-BS1)								**Extracted: 11/16/04 12:53**						
Arsenic	EPA 200.8	0.108	---	0.000500	mg/l	1x	--	0.100	108%	(85-115)	--	--	11/17/04 01:27	
LCS Dup (4110757-BSD1)								**Extracted: 11/16/04 12:53**						
Arsenic	EPA 200.8	0.110	---	0.000500	mg/l	1x	--	0.100	110%	(85-115)	1.83%	(20)	11/17/04 01:37	
Duplicate (4110757-DUP1)				**QC Source: P4K0630-01**				**Extracted: 11/16/04 12:53**						
Arsenic	EPA 200.8	0.00535	---	0.000500	mg/l	1x	0.00636	--	--	--	17.3%	(20)	11/17/04 02:59	
Matrix Spike (4110757-MS1)				**QC Source: P4K0630-01**				**Extracted: 11/16/04 12:53**						
Arsenic	EPA 200.8	0.108	---	0.000500	mg/l	1x	0.00636	0.100	102%	(70-130)	--	--	11/17/04 03:09	

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AMEC- Hawaii
3375 Koapaka St. Suite F 251
Honalulu, HI 96814

Project Name: **Keaau**
Project Number: 3-251-90015
Project Manager: Russel Okoji

Report Created:
12/09/04 12:32

Total Metals per EPA 6000/7000 Series Methods - Laboratory Quality Control Results

North Creek Analytical - Portland

QC Batch: 4110700 Soil Preparation Method: EPA 3050

Analyte	Method	Result	MDL*	MRL	Units	Dil	Source Result	Spike Amt	% REC	(Limits)	% RPD	(Limits)	Analyzed	Notes
Blank (4110700-BLK1)								**Extracted: 11/15/04 11:45**						
Arsenic	EPA 6020	ND	---	0.250	mg/kg	10x	--	--	--	--	--	--	11/17/04 04:10	
LCS (4110700-BS1)								**Extracted: 11/15/04 11:45**						
Arsenic	EPA 6020	9.32	---	0.250	mg/kg	10x	--	9.52	97.9%	(80-120)	--	--	11/17/04 04:20	
LCS Dup (4110700-BSD1)								**Extracted: 11/15/04 11:45**						
Arsenic	EPA 6020	9.18	---	0.250	mg/kg	10x	--	9.43	97.3%	(80-120)	1.51%	(20)	11/17/04 04:30	
Duplicate (4110700-DUP1)				**QC Source: P4K0344-03**				**Extracted: 11/15/04 11:45**						
Arsenic	EPA 6020	19.3	---	0.0468	mg/kg dry	10x	17.1	--	--	--	12.1%	(40)	11/17/04 05:21	A-01
Duplicate (4110700-DUP2)				**QC Source: P4K0344-10**				**Extracted: 11/15/04 11:45**						
Arsenic	EPA 6020	355	---	0.984	mg/kg dry	200x	376	--	--	--	5.75%	(40)	11/19/04 15:28	A-01
Duplicate (4110700-DUP3)				**QC Source: P4K0347-01**				**Extracted: 11/15/04 11:45**						
Arsenic	EPA 6020	148	---	0.211	mg/kg dry	42.9x	222	--	--	--	40.0%	(40)	11/17/04 13:01	A-01
Duplicate (4110700-DUP4)				**QC Source: P4K0347-02**				**Extracted: 11/15/04 11:45**						
Arsenic	EPA 6020	208	---	0.207	mg/kg dry	42.2x	252	--	--	--	19.1%	(40)	11/17/04 13:42	A-01
Duplicate (4110700-DUP5)				**QC Source: P4K0347-03**				**Extracted: 11/15/04 11:45**						
Arsenic	EPA 6020	127	---	0.187	mg/kg dry	39.1x	135	--	--	--	6.11%	(40)	11/17/04 14:02	A-01
Duplicate (4110700-DUP6)				**QC Source: P4K0347-05**				**Extracted: 11/15/04 11:45**						
Arsenic	EPA 6020	329	---	0.201	mg/kg dry	40.2x	267	--	--	--	20.8%	(40)	11/17/04 14:22	A-01
Duplicate (4110700-DUP7)				**QC Source: P4K0347-07**				**Extracted: 11/15/04 11:45**						
Arsenic	EPA 6020	232	---	0.486	mg/kg dry	100x	266	--	--	--	13.7%	(40)	12/08/04 19:15	A-01
Duplicate (4110700-DUP8)				**QC Source: P4K0347-08**				**Extracted: 11/15/04 11:45**						
Arsenic	EPA 6020	286	---	0.971	mg/kg dry	200x	270	--	--	--	5.76%	(40)	11/19/04 15:36	A-01
Duplicate (4110700-DUP9)				**QC Source: P4K0347-10**				**Extracted: 11/15/04 11:45**						
Arsenic	EPA 6020	40.6	---	0.0469	mg/kg dry	10x	48.0	--	--	--	16.7%	(40)	11/17/04 15:13	A-01
Duplicate (4110700-DUPA)				**QC Source: P4K0347-11**				**Extracted: 11/15/04 11:45**						
Arsenic	EPA 6020	41.0	---	0.0498	mg/kg dry	10x	30.7	--	--	--	28.7%	(40)	11/17/04 15:53	A-01
Duplicate (4110700-DUPB)				**QC Source: P4K0344-03**				**Extracted: 11/15/04 11:45**						
Arsenic	EPA 6020	16.2	---	0.0488	mg/kg dry	10x	17.1	--	--	--	5.41%	(40)	11/17/04 05:21	A-01
Duplicate (4110700-DUPC)				**QC Source: P4K0344-03**				**Extracted: 11/15/04 11:45**						

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Project Name: **Keaau**
Project Number: 3-251-90015
Project Manager: Russel Okoji

Report Created:
12/09/04 12:32

Total Metals per EPA 6000/7000 Series Methods - Laboratory Quality Control Results

North Creek Analytical - Portland

QC Batch: 4110700 Soil Preparation Method: EPA 3050

Analyte	Method	Result	MDL*	MRL	Units	Dil	Source Result	Spike Amt	% REC	(Limits)	% RPD	(Limits)	Analyzed	Notes
Duplicate (4110700-DUPC)				QC Source: P4K0344-03				Extracted: 11/15/04 11:45						
Arsenic	EPA 6020	17.8	---	0.0491	mg/kg dry	10x	17.1	--	--	--	4.01%	(40)	11/17/04 11:41	A-01
Matrix Spike (4110700-MS1)				QC Source: P4K0344-03				Extracted: 11/15/04 11:45						
Arsenic	EPA 6020	7.57	---	0.0493	mg/kg dry	10x	17.1	2.44	NR	(75-125)	--	--	11/17/04 05:40	A-01, Q-02
Matrix Spike (4110700-MS2)				QC Source: P4K0344-03				Extracted: 11/15/04 11:45						A-01, Q-02
Arsenic	EPA 6020	7.77	---	0.0483	mg/kg dry	10x	17.1	2.38	NR	(75-125)	--	--	11/17/04 12:01	

QC Batch: 4110757 Water Preparation Method: EPA 200/3005

Analyte	Method	Result	MDL*	MRL	Units	Dil	Source Result	Spike Amt	% REC	(Limits)	% RPD	(Limits)	Analyzed	Notes
Blank (4110757-BLK1)								Extracted: 11/16/04 12:53						
Arsenic	EPA 6020	ND	---	0.000500	mg/l	1x	--	--	--	--	--	--	11/17/04 01:17	
LCS (4110757-BS1)								Extracted: 11/16/04 12:53						
Arsenic	EPA 6020	0.108	---	0.000500	mg/l	1x	--	0.100	108%	(80-120)	--	--	11/17/04 01:27	
LCS Dup (4110757-BSD1)								Extracted: 11/16/04 12:53						
Arsenic	EPA 6020	0.110	---	0.000500	mg/l	1x	--	0.100	110%	(80-120)	1.83%	(20)	11/17/04 01:37	
Duplicate (4110757-DUP1)				QC Source: P4K0630-01				Extracted: 11/16/04 12:53						
Arsenic	EPA 6020	0.00535	---	0.000500	mg/l	1x	0.00636	--	--	--	17.3%	(20)	11/17/04 02:59	
Matrix Spike (4110757-MS1)				QC Source: P4K0630-01				Extracted: 11/16/04 12:53						
Arsenic	EPA 6020	0.108	---	0.000500	mg/l	1x	0.00636	0.100	102%	(75-125)	--	--	11/17/04 03:09	

Percent Dry Weight (Solids) per Standard Methods - Laboratory Quality Control Results

North Creek Analytical - Portland

QC Batch: 4110698 Soil Preparation Method: Dry Weight

Analyte	Method	Result	MDL*	MRL	Units	Dil	Source Result	Spike Amt	% REC	(Limits)	% RPD	(Limits)	Analyzed	Notes
Duplicate (4110698-DUP1)				**QC Source: P4K0506-01**				**Extracted: 11/15/04 11:36**						
% Solids	NCA SOP	73.4	---	1.00	% by Weight	1x	72.9	--	--	--	0.684%	(20)	11/16/04 11:39	
Duplicate (4110698-DUP2)				**QC Source: P4K0506-02**				**Extracted: 11/15/04 11:36**						
% Solids	NCA SOP	73.1	---	1.00	% by Weight	1x	72.6	--	--	--	0.686%	(20)	11/16/04 11:39	
Duplicate (4110698-DUP3)				**QC Source: P4K0534-04**				**Extracted: 11/15/04 11:36**						
% Solids	NCA SOP	68.5	---	1.00	% by Weight	1x	68.5	--	--	--	0.00%	(20)	11/16/04 11:39	
Duplicate (4110698-DUP4)				**QC Source: P4K0566-02**				**Extracted: 11/15/04 11:36**						
% Solids	NCA SOP	80.1	---	1.00	% by Weight	1x	80.5	--	--	--	0.498%	(20)	11/16/04 11:39	

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Notes and Definitions

Report Specific Notes:

A-01 - Percent solids determined on sample that was dried for three days and then sieved.

Q-02 - The matrix spike recovery, and/or RPD, for this QC sample is outside of established control limits due to sample matrix interference.

Laboratory Reporting Conventions:

DET - Analyte DETECTED at or above the Reporting Limit. Qualitative Analyses only.

ND - Analyte NOT DETECTED at or above the reporting limit (MDL or MRL, as appropriate).

NR / NA - Not Reported / Not Available

dry - Sample results reported on a dry weight basis. Reporting Limits are corrected for %Solids when %Solids are <50%.

wet - Sample results and reporting limits reported on a wet weight basis (as received).

RPD - Relative Percent Difference. (RPDs calculated using Results, not Percent Recoveries).

MRL - METHOD REPORTING LIMIT. Reporting Level at, or above, the lowest level standard of the Calibration Table.

MDL* - METHOD DETECTION LIMIT. Reporting Level at, or above, the statistically derived limit based on 40CFR, Part 136, Appendix B. *MDLs are listed on the report only if the data has been evaluated below the MRL. Results between the MDL and MRL are reported as Estimated results.

Dil - Dilutions are calculated based on deviations from the standard dilution performed for an analysis, and may not represent the dilution found on the analytical raw data.

Reporting limits - Reporting limits (MDLs and MRLs) are adjusted based on variations in sample preparation amounts, analytical dilutions and percent solids, where applicable.

APPENDIX F

Soil Action Levels and Categories for Bioaccessible Arsenic

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In reply, please refer to:
File: EHA/HEER Office

06-283 RB

August 7, 2006

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 Hawaiʻi, 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 Hawaiʻi 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 Keaʻau 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 Keaʻau 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 Hawaiʻi 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 ≤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 ≤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.

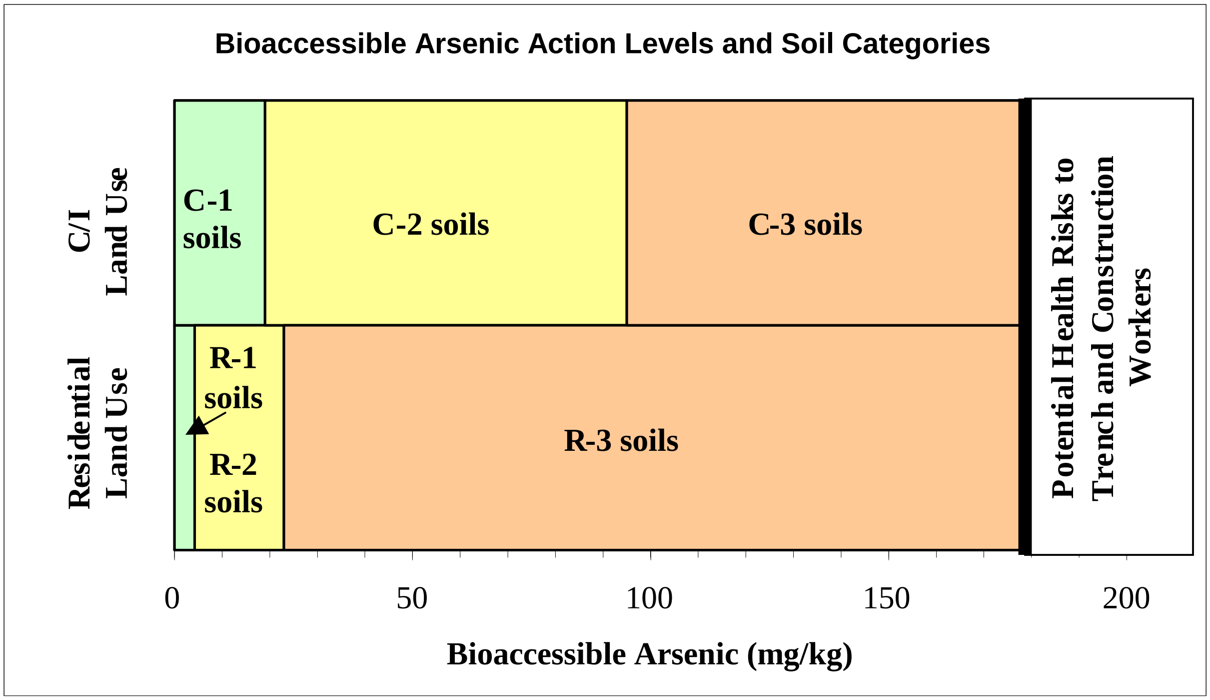
Table 2. Soil categories and recommended actions for Commercial/Industrial Sites.

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.

APPENDIX G

Arsenic Fact Sheet

Hawaiʻi State Department of Health

Arsenic and Arsenic Soil Contamination Facts

What is arsenic?

Arsenic is a naturally occurring element found in trace amounts in rocks, soil, water, plants, and animals. Arsenic can be toxic and may present a health risk to humans who are exposed to very high amounts for a short time or who are exposed to high amounts over long periods of time (i.e. many years).

Arsenic compounds in the environment have no distinct smell, taste or visible appearance, and you need to have samples tested by a laboratory to determine if levels exceed those expected in nature.

Arsenic is found naturally in soils throughout Hawaiʻi at varying concentrations, but generally reported to be in the range of 5 to 20 milligrams of arsenic per kilogram of dry soil (5-20 mg/kg). The units "mg/kg" are also informally called "parts per million".

What are sources of arsenic contamination in soil?

Herbicides containing arsenic were used for weed control in sugarcane production from about 1915 into the 1950s in the Hawaiian Islands. Other potential sources of arsenic contamination include the past use of arsenic as an insecticide in "canec" wallboard, which was used widely for home and building construction in Hawaiʻi during the 1930s through the 1950s, and also the past use of arsenic as a common ingredient used in wood preservatives (e.g. "CCA" pressure-treated lumber). Certain types of fertilizers containing arsenic may be another source of contamination.

Is arsenic in the water?

The Hawaiʻi Department of Health Safe Drinking Water Branch has a water quality-testing program for all public water systems in the state, and they have been testing for arsenic, as well as many other chemicals, for years. They have not found arsenic in any of the state's public drinking water sources (above their lab's lower detection limit of 2 parts per billion).

How are people exposed to arsenic in soil?

If arsenic is in the soil, ingesting the soil is the primary route of exposure. The main concern is that some people will unintentionally swallow contaminated soil - especially young children who are unaware of the hazards and may be exposed to contaminated soil through normal play activities. Most children put their hands, toys, or other objects in their mouths, and these often have small amounts of soil and dust on them that the child swallows. Residual dirt on improperly washed vegetables and poor hand washing may also contribute to arsenic exposure through accidental ingestion of soil particles.

How can arsenic affect my health?

People who have been exposed to high levels of arsenic over long periods of time have had health symptoms that include changes in skin pigmentation (dark spots), thickening or warts on the skin of the palms of the hands and soles of the feet, damage to heart and blood vessels, and inflammation of the liver. In addition, long-term exposure to high levels of arsenic has been associated with an increased risk of cancer.

These types of health effects have been identified in some countries where drinking water is contaminated with high amounts of arsenic. However, health effects have not been documented in people exposed to arsenic-contaminated soil, and have not been identified in Hawai'i. Arsenic does not have a tendency to accumulate in the body (bioaccumulate). Stopping exposure will reduce arsenic levels in the body.

How bad is the soil contamination in the Keaʻau area?

Reported levels of arsenic in soils of former sugarcane lands around the Keaʻau area (near Hilo) are significantly higher than normal. However, testing of the soils over the past several years indicates that most of the arsenic is no longer toxic. This is partly due to the high levels of iron and aluminum compounds in the soil. The iron and aluminum strongly bind the arsenic to the soil and prevent it from being taken up in the body.

Reported levels of arsenic in parks, schools and most undeveloped areas tested do not pose a significant health risk to residents. However, good hygiene and maintenance of landscaping to avoid areas of bare soil is still recommended. Reported levels of arsenic in the 8 ½ Mile Camp and 9 Mile Camp community gardens were higher. Exposure to soil in these areas could pose a slight increase in health risk to young children if visited on a regular basis. The time spent in these gardens by young children should be minimized or avoided all together. Further study of arsenic levels in soil in the Kea'au area and other areas of Hawai'i is underway.

How do I determine whether my soil has high levels of arsenic?

Since arsenic cannot be seen or smelled, a laboratory test is required to determine the levels in soil. The Department of Health has prepared a *Homeowner's Guide to Soil Testing for Arsenic* that explains how soil samples are collected and sent for laboratory testing.

What can I do to prevent exposure to contaminated soil?

Exposure to arsenic contaminated soil can be minimized through a variety of means to significantly reduce the potential for health effects. If your property is determined to contain high levels of arsenic, some options for limiting exposure to contaminated soil include:

- Keep grass, other vegetative cover, or some kind of surface material over soil on your property. This acts as a barrier to prevent soil exposure.
- Keep children from playing in contaminated dirt.
- Keep toys, pacifiers, and other items that go into kid's mouths clean.
- Wash hands and face thoroughly after working or playing in the soil, especially before meals and snacks.
- Wash fruits and vegetables from the garden with water before bringing them in the house, then wash again inside with a brush to remove any remaining soil particles. Pare root and tuber vegetables before eating.
- Bring in clean sand for sandboxes and add soil known to be free of contamination to food garden areas. You could also make raised garden beds with clean soils.
- Avoid tracking soil into the home and clean up right away if soil is tracked in. Remove work and play shoes before entering the house. Keep pets from tracking contaminated soil into your home.