Investigation of Arsenic in Sediment and Biota of Waiakea Pond, Hilo, Hawaii

(laboratory reports provided separately)

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Forward

This document presents sediment and biota data collected in association with arsenic contamination in Waiakea Pond in Hilo, Hawaii, by the Department of Health between 2013 and 2015. This document will be updated as additional assessment of the data is carried out in the future.

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1 Introduction

1.1 Project Scope

Waiakea Pond in Hilo, Hawaii, serves as an important estuary as well as recreation area for local residents and visitors. Multiple studies over last 30 years indicated high levels of arsenic in sediments resulting from the historic release of waste arsenic from past wood treatment and sugar mill operations between the 1910s and 1960s. Abrupt fish kills of unknown causes were reported for Waiakea Pond and Wailoa River until the late 1970s (HDOH 2005). Erosion and deposition of arsenic-contaminated soil from upland, former sugarcane land provides a continued input of arsenic into the pond. Concentrations of arsenic in upland soils are elevated (Cutler 2013) but lower on average than concentrations of arsenic in pond sediment tested during this study.

A Hawaii Department of Health (HDOH) fact sheet on contamination concerns associated with the pond is provided in Appendix A (HDOH 2019). Earlier fish consumption studies indicated fish were safe to eat but did not evaluate crab (HDOH 1978). An ecological risk assessment suggested potential arsenic hazards for water birds (HDOH 2005). Two newer studies identified arsenic-impacted soils in the park area surrounding the pond and in the Hilo area in general (Cutler 2013; HDOH 2013). Bioaccessibility and toxicity of the arsenic was determined to be relatively low, however, due to strong binding to iron in the soil.

A more detailed assessment of these potential risks required a more thorough investigation of the magnitude and extent of arsenic contamination in sediment associated with the pond. Such an investigation was carried out by HDOH in 2013 through 2014. This report summarizes the scope and findings of that investigation. It is hoped that the additional data collected can be used by other entities as part of a more detailed assessment of risk to human health and the environment associated with impacts to the pond.

1.1.1 Study Questions

Study questions developed to design the nature and scope of the investigation included:

- What is the magnitude and variability of arsenic contamination in sediments associated with different areas of Waiakea Pond?
- How does the form of arsenic affect toxicity?
- Does arsenic-contaminated sediment pose an unacceptable risk to human consumers of the recreational fishery and park users?
- Does arsenic-contaminated sediment pose an unacceptable risk to aquatic biota in the pond?
- What data would be needed to make recommendations about bird habitat restoration projects?

1.1.2 Research Approach

Data collection was carried out in order to address the following, specific research topics.

Gather adequate data to make fish advisory determinations. Early fish data did not indicate a risk from fish consumption, but the data used to make that decision are incomplete and not all documentation for past data are available for evaluation. Subsequent fish data showed an approximately 10-fold higher tissue arsenic concentration in the Pond site compared to a nearby reference area, and significantly higher concentrations in one of two, invasive Marquesan mullet as compared to the native, Hawaiian mullet (HDOH 2005). Data for edible portions of the fish will be collected to allow additional assessment of human health risk and determination of a consumption advisory.

Evaluate Samoan crab for advisory determination. Crustaceans are known to accumulate total arsenic. Samoan crabs are of particular interest both because of human consumption and their extent of contact with highly contaminated sediments. These crabs also actively re-suspend sediments in the pond due to their daily burrowing activities. Data for edible portions of the crustaceans will be collected to allow additional assessment of human health risk and determination of a consumption advisory.

Investigate association between sediment and tissue concentrations. Collect data for juvenile mullet and crab adequate to establish contribution to tissue burden from arsenic contamination in the pond sediment. Juveniles are resident within the pond/estuary, while adults might regularly move from the pond into Hilo Bay. Adult tissue concentrations could be confounded by other sources or depuration from feeding in other areas.

Investigate potential hazards to wildlife at the site. Generate data that will allow augmentation of the 2005 *Waiakea Pond Ecological Risk Assessment* (HDOH 2005) by comparison of tissue arsenic concentrations in whole organisms (adult and juvenile mullet and crab), concentrations in limu (seaweed) and sediment arsenic levels to the arsenic levels previously estimated (from literature) and modification of the ecological risk determination, as needed.

Assess limu for arsenic content. Evaluate common algae species eaten by mullet and collected for fishing for mullet by the public (Melosira spp). Confirm with local sources if limu kala is present at the site or downstream near the harbor. If present, consider collecting this species as well since it is closely related to another sargassum species, known to hyper accumulate arsenic.

Assess soil exposure risks for children at the park. Augment data from past studies as needed for exposed sediments along pond shorelines and soils in areas where children actively play to allow more detailed assessment of risk and determine measures necessary to reduce exposures, as needed.

Assess extent and magnitude of arsenic contamination in sediment. Use Multi Increment sampling techniques and analytical methods to collect arsenic data for sediment in the pond. Designate areas for investigation based on historical activities around the pond, ecological habitats and sediment deposition areas.

Assess forms of arsenic to establish toxicity. Data for total arsenic in sediment and biota have primarily been collected in past studies of the pond. Conduct speciation analyses to evaluate different arsenic fractions present. As part of data interpretation, consideration should be given to the role of different arsenic forms in both toxicity and bioaccumulation.

- Organic versus Inorganic Arsenic: Risk to humans dependent on inorganic fraction. Arsenic in fish and crab is largely in organic form (95% or more), however, given high sediment exposures, potential for unhealthy exposures to inorganic arsenic exist at this site. In addition, little is known about the toxicity of the primary arsenic breakdown product, dimethyl arsenate (DMA).
- Total versus Bioaccessible Arsenic: Arsenic in Hawaiian soils and sediment binds very tightly to the iron present. HDOH regulates based upon the “bioaccessible” fraction of arsenic that dissolves in gut acids. This is important to assess in soil and sediment that might be

inadvertently ingested by children during play activities. Implications for the risk posed to aquatic and terrestrial organisms are also important but have not been studied in detail. It is unknown how arsenic bioaccessibility is affected in oxic and anoxic sediment environments.

1.2 Geographic Setting

The Waiakea Pond study site is a 30-acre, brackish water body located in Hilo, on the north side of Hawaii Island (Big Island; Figure 1-1 and 1-2). The pond lies within the 132-acre, Wailoa River State Recreation Area and is situated just above sea level. The area receives an average of 140 inches of rain a year, with average daily temperatures between 70° and 75° Fahrenheit. Daily tidal fluctuation ranges from less than one foot to as much as three feet.

The pond can be roughly divided into two areas (Figure 1-3): 1) A three-pronged, mauka (southern) area approximately 500 meters long and up to 250 meters wide that encompasses roughly 60% of the total pond area and 2) A lower makai (northern), L-shaped area approximately 400 meters long and 50 to 100 meters wide. A lined, flood-control channel empties into the mauka area of the pond. The pond drains into Hilo Bay via the short (16-acre), Wailoa River at its makai terminus.

The mauka end of the pond receives stormwater runoff from the upland area. The pond is primarily fed, however, by discharges of groundwater from directly underlying springs, with an estimate 1.8 million cubic meters of freshwater entering the pond on a daily basis (Wiegner and Mead 2009).

The average depth of the pond is one to three meters with a maximum depth of four meters (Figure 1-4). Based on observations made during this study, the upper (southern) area of the pond is characterized by organic rich, clayey and silty sediments up to a meter or more thick and deposited in a low-energy environment. The sediment cover thins northward as the pond channel narrows and the depth of the pond decreases. The floor of the pond is covered by large cobbles with little sediment in the narrow, central point of the pond currently crossed by a foot bridge. The depth of water in this area is typically less than one meter. Water flow through this area is noticeably higher energy, particularly during periods when the tidal influx is receding.

The northern (makai) area of the pond is characterized by a thinner cover of organic-rich, clayey and silty sediment. The silt and sand content of the sediment increases in the narrow, higher energy channel of the Wailoa River that is strongly affected by rising and falling tides.

1.3 Ecological Habitats

The 2005 *Hilo Bay Watershed-Based Restoration Plan* (Silvius et al. 2005) presents an overview of conditions in the area that require attention in order to address impairment of water bodies in the area. Although not specific to Waiakea Pond, this report summarizes past studies of the Hilo watershed and discusses studies related to the pond itself. A recommendation was made in the report for a more detailed investigation of environmental contamination associated with the pond.

Waiakea Pond and the discharge point of the Wailoa River into Hilo Bay form the lower portion of the Wailoa watershed. The perennial, upper reaches of the Wailoa River discharge into the pond via a concrete-lined storm channel at the south end of the site (see Figure 1-3). Saltwater moves into the pond during high tide from Hilo Bay to the north. These actions, combined with voluminous and continuous discharges from springs underlying the pond results in an overall brackish but stratified, estuarine environment (Hallacher et al. 1985).

A summary of the Wailoa watershed features and biodiversity published in the Atlas of Hawaiian Watersheds and Their Aquatic Resources (HDLNR-BM 2008) is provided Appendix B. Fish found in the pond are primarily saltwater species, including mullet, aholehole and ulua. Striped mullet (Mugil cephalus), Marquesan mullet (Valamugil engeli), snapper (Lutjanus fulvus), goatfish (Mulloides vanicolensis), and Hawaiian flagtail (Kuhlia sandvicensis), white crab (Portunus sanguinolentus) and the Samoan crab (Scylla serrata) are all found in Waiakea Pond. At least 25 bird species, including the endangered Hawaiian coot (Fulica alai) and the Hawaiian duck (Anas wyvilliana) have been documented at the pond. Shoreline areas are characterized by freshwater plants while salt-tolerant, brown algae within the main body of the pond forms an important source of food for mullet that utilize the pond as a hatchery. The pond also serves as a habitat for other small fish species and salt tolerant mollusks. Waiakea Pond has also been identified as critical, primary waterfowl habitat (Henson 2002).

1.4 Historic Industrial Activities

Industrial activities along the margins of the pond include a former sugar mill and a factory that produced arsenic-infused lumber for construction purposes (see Figure 1-3). The lumber, referred to as "canec," was prepared by compressing waste sugarcane "bagasse" generated by the sugar mill (HDOH 2019). A 1932 photo of the plant is shown in Figure 1-5.

The plant is estimated to have released 3.5 million gallons of arsenic-contaminated wastewater into the pond per day until it's closure in 1963 (Bernard et al. 1983; USEPA 1989). Although not documented, it is reasonable to assume that arsenic containing wastewater was initially discharged directly into the pond at the plant location. A pipeline was later added that allowed wastewater to be discharged closer to the northern, discharge point of the pond into the Wailoa River and Hilo Bay (see Figure 1-3). The plant was demolished in 1970 and the site was redeveloped as a resort (Woodward-Clyde 1989a,b). The resort is now used as residential apartments.

The Waiakea Sugarmill operated on the southern edge of Waiakea Pond from approximately 1879 until 1947 and served the sugarcane fields in the area (see Figure 1-4; Cutler 2013). Freshly cut sugarcane was brought to the mill, where the cane was washed and then crushed to extract the sugar. Wastewater from cane washing, including soil from the fields impacted by past use of arsenic-based herbicides, was discharged directly into the pond.

Sodium arsenate is known to have been used for weed control in sugarcane fields that drain into Waiakea Pond. Large-scale studies of former sugarcane lands in the Hilo area have identified widespread arsenic at an average concentration of almost 300 mg/kg (refer Cutler 2013). This compares to an assumed, upperbound background level of 24 mg/kg referenced in the HDOH Environmental Action Level guidance (HDOH 2012, 2017). The arsenic is tightly bound to iron hydroxide and other particles in the soil and not significantly bioavailable or "toxic" to humans or terrestrial flora and fauna (refer to Cutler 2013). The bioavailability of the arsenic in sediments and potential toxicity to aquatic flora and fauna within Waiakea Pond has not, however, been investigated in detail.

2 Past Studies

2.1 Overview

Several water and sediment quality studies carried out in the Hilo area in the 1960s to 1980s included testing in Waiakea Pond. A summary prepared by the National Oceanic and Atmospheric Administration (NOAA) of past sediment studies is provided in Appendix C (NOAA 1990). A summary of past data for algae, crab and fish is provided in an ecological risk assessment carried out for Waiakea Pond in 2005 (HDOH 2005). This report is also included in Appendix C.

Past studies reported levels of arsenic in pond sediment well above anticipated, natural background. A summary of the data is provided below. Data for algae, crab and fish are less conclusive (HDOH 2005). Some studies suggested an elevated concentration of arsenic in mullet within the pond while other studies suggest levels typical of background. The 2005 risk assessment suggested that arsenic contamination in the pond posed a potential risk to aquatic birds. A more detailed review of potential effects on aquatic biota using past data as well as data collected as part of the study discussed in this report is required.

2.2 University of Hawaii (1985)

The University of Hawaii – Hilo, carried out a limited study of arsenic in sediment and biota in Waiakea Pond in the early 1980s (Hallacher et al. 1985). Cores up to 110 cm deep were collected from 7 locations within the pond and Wailoa River (Figure 2-1). Two-centimeter sections near the top and bottom of the cores were removed for testing. Sediment in between these points was not tested.

A summary of the data is provided in Table 2-1. The reported concentration of total arsenic in the samples collected near the top of four cores collected ranged from 2.0 to 251 mg/kg. The concentration of arsenic in samples collected from the bottom part of the cores ranged from non-detect (presumably < 2.0 mg/kg) to 550 mg/kg. Total arsenic ranged from 43 mg/kg to 151 mg/kg in the tops of three cores collected from the Wailoa River and 17 mg/kg to 715 mg/kg in the bottom of the cores.

While highlighting the presence of significant contamination in the pond sediments, the data were too limited to draw conclusions regarding the lateral and vertical distribution of arsenic in the pond and river area as a whole or temporal changes over time. Sediment data were based on the collection of small numbers of discrete samples. Variability in discrete sample data collected in similar locations within the pond and in Hilo Bay over time was interpreted to reflect a potential decrease in arsenic concentrations in shallow sediment over time. Based on current understandings of discrete sample data reliability, however, it is more reasonable to conclude that the observed differences are due to inherent, small-scale, random variability of arsenic concentrations in sediment at the scale of a discrete sample (Brewer et al. 2017a,b). The collection of Multi Increment sample data, as carried out in the study presented in this report, is required to reliably assess long-term changes in contaminant concentrations in shallow sediment over time.

2.3 Hawaii Department of Health (2013)

A 2013 study of the Wailoa park area that immediately surrounds Waiakea pond identified levels of arsenic impacts well above anticipated, natural background (HDOH 2013). A total of 14 Decision Units (DU) were designated for investigation along the pond perimeter (Figure 2-2). A single, Multi Increment

(MI) sample was collected from the upper two to six inches of soil in each DU. Replicate samples were not collected as part of the investigation.

Samples were processed in accordance with MI sampling protocols discussed in the HEER Office Technical Guidance Manual (HDOH 2016) and tested for total arsenic. A summary of the resulting data is provided in Table 2-2. Total arsenic above anticipated, natural background was reported for 12 of the 14 DUs tested. Total arsenic in excess of 100 mg/kg was reported for DU-1, DU-3 and DU-4, along the eastern edge of the pond. The <250 µm fraction of these samples was further tested for total and bioaccessible arsenic.

The estimated concentration of bioaccessible arsenic in DU-3 (33 mg/kg) and DU-4 (30 mg/kg) marginally exceeded the HDOH screening level for unrestricted land use of 23 mg/kg (HDOH 2017). The bioaccessibility of arsenic in the samples was relatively low, ranging from <3% to a high of 9%. This is typical of arsenic in soil throughout the Hilo area (Cutler 2012).

The source of excess arsenic in the soil is uncertain and likely varies. It is suspected that sediments from the pond were transferred to surfaces soils of the park from dredging of the pond for maintenance, and/or were disrupted by the tsunamis that impacted the area in April 1946 and May 1960 (HDOH 2013). Sugarcane is not known to have been grown immediately adjacent to the pond. The use of arsenic-based herbicides for weed control around the pond is possible, given the widespread use of these chemicals in the area. Still other areas might have been impacted by direct discharges of arsenic containing wastewater from the former Canec and sugar mill operations.

3 Investigation Objectives and Methods

Sediment and biota samples were collected from Waiakea Pond and control sites from other parts of the islands. The investigation described in this report was designed to provide improved data for arsenic in sediment and biota in Waiakea pond. Such data are necessary for planning of future actions to reduce potential adverse impacts to park users the flora and fauna that comprise the pond ecosystem. A brief discussion of potential risks to human health and the environment is provided.

3.1 Decision Unit Designation

Five Decision Units were designated for the collection of sediment samples from Waiakea Pond (Figure 3-1). The pond area was divided into DUs based distinct ecological habitats (DU-1), proximity to known, historical industrial operations that utilized arsenic (DU-2), central areas not in immediate proximity to suspect source areas (DU-3 and DU-4) and the area of the canec wastewater discharge point (DU-5). A triangular area between DUs 1, 2 and 3 was inadvertently not sampled during initial field work and could not be sampled prior to completion of the project due to a lack of funding and equipment.

The upper 12 inches of sediment was targeted for sample collection and subdivided into three DU Layers: 1) DU Layer A (0-4”), 2) DU Layer B (4-8”) and 3) DU Layer C (8-12”). The exact thickness of sediment in different areas of the pond was unknown. It was anticipated, however, that sediment thickness would be adequate to collect increments and prepare samples for all three DU layers in most areas of the designated DUs. The sedimentation rate in the pond is unknown but believed to be relatively low, due to a continuous movement of water and suspended sediment out of the pond in association with discharges from the underlying springs and tidal action. It was hypothesized that the concentration of arsenic might decrease upwards, due to cessation of activities at the sugarmill in the 1940s and at the canec plant in the 1960s.

3.2 Sediment Sample Collection and Processing

3.2.1 Sample Collection

Thirty points were designated for in a systematic random (grid) fashion for increment collection within each of the five, designated DU areas. Increment point spacing was estimated based on the approximate area of the DU and the number of increments to be collected (increment spacing equal to the square root of the DU area divided by the number of increments). Example increment collection point maps for DUs 1 and 2 are shown n Figure 3-2.

Field activities were carried out over a four-day period in August 2013. Sediment increments were collected using a core sampler (Figure 3-3). A clear, pre-cleaned, two-foot, plastic tube was attached to the end of an extendable pushrod. A small boat and GPS were used to maneuver to pre-established, increment collection locations within each DU. The coring device was manually forced into the sediment to a minimum of 12 inches and retrieved. A valve at the top of the sampling tube helped to hold in the sediment as the tube was extracted from the increment location. The base of the sampling tube was capped as the core was pulled up from the water in order to minimize sediment loss. The sampling tube was then removed from the pushrod, capped on the other end and stored, with the “up” and “down” directions of the core marked. Triplicate sets of increments were collected from separate, increment grid points in DU-2 and used to prepare triplicate Multi Increment samples to test the total precision of the resulting data.

A total of 210 cores were collected from the five DU areas over the four-day period. Cores were collected in groups of 10 to 15 and then returned to a processing area set up at the Department of Land and Natural Resources station on the north edge of the pond. A total of 21 Multi Increment (MI) samples were prepared from the cores, one sample per each of the three, targeted, depth layers in each of the five DUs and six additional, replicate samples collected from DU-2.

Upon collection of all core increments for a DU (30), sediment was extracted from each sampling tube and a Multi Increment sample prepared for each of the targeted, DU layers (Figure 3-4). This was accomplished by removing the base cap from the bottom of a sampling tube and placing the tube on a plunger. The upper cap was then removed and the tube forced downwards, progressively exposing increments for each targeted, DU layer. Increments for each layer were cut from the exposed core using a putty knife and placed in one of three, five-gallon plastic buckets dedicated to each DU layer sample. Increments were combined in the respective buckets to form a bulk, Multi Increment sample for each layer (total three sample per each set of 30 DU cores).

3.2.2 Field Processing

Bulk Multi Increment samples consisted of approximately 10 kilograms (kg) of sediment (approximately three gallons) and were too large to submit to the laboratory for processing. Subsampling of the bulk samples was therefore carried out at the field station in order to reduce the sediment mass and volume to a manageable, 3-4 kg size. Excess water that accumulated in the sample bucket was drained through a coffee filter with trapped material placed back in the sample. Each sample was then placed on clean, plastic sheeting and spread out to a thickness of approximately ½ inch (Figure 3-5). A flat edge spatula was used to collect subsamples from the sample in a systematic, random fashion. A minimum of 30 subsamples was collected from each bulk sample.

Final samples were placed in a heavy-duty, two-gallon, zip-lock plastic bag and double bagged. The reduced-volume samples were submitted to Test America Laboratories for further processing and testing in accordance with incremental sampling methods. Excess sediment for each sample was placed in a separate bag for additional testing in the future, as needed. The sediment is being stored in a freezer at the HEER Office in Pearl City at the time that this report was prepared. (In 2018, subsamples from each the stored, sediment samples were provided to Jared Goodwin in Hilo as part of a high school science project to assess spreading of arsenic-contaminated soil and sediment during the tsunami of 1960).

3.2.3 Laboratory Processing and Analysis

Sediment samples (total 21) were delivered to Test America laboratory in Honolulu for final processing and analysis. All processing and subsampling of the samples was carried out at this laboratory. The samples were air dried and then passed through a 2mm (#10) sieve to remove large material. Each bulk sample was then flattened into a pancake layer no more than one-centimeter thick. A minimum, 30-increment subsample consisting of 10 grams of soil was then collected and extracted for analysis.

The subsamples were submitted to another Test America laboratory in the mainland US for testing of total arsenic, total iron and total organic carbon. Replicate subsamples (“splits”) were collected and submitted to Brooks Rand laboratory for comparison analysis in order to assess subsampling precision.

Each bulk sample was then sieved to <250 µm fraction. One-gram subsamples of this size fraction were collected and submitted to a Test America laboratory in the mainland US for testing of total arsenic, total iron and bioaccessible arsenic.

Ten-gram subsamples of the <2mm fraction of split, bulk samples submitted to Brooks Rand Laboratory for processing were tested for total arsenic, inorganic arsenic, dimethyl arsenic (DMA), monomethyl arsenic (MMA), total iron and percent total solids.

Sediment samples were tested using the laboratory methods noted in below table.

Analysis	**Test America Laboratory**	**Brooks Rand Laboratory**
Arsenic (total)	[1]EPA 6010B	[2]EPA 1638 DRC
Arsenic (bioaccessible)	[3]PBET	-
Arsenic (inorganic)	-	EPA 1632
Arsenic (monomethyl)	-	EPA 1632
Arsenic (dimethyl)	-	EPA 1632
Iron (total)	[1]EPA 6010B	[2]EPA 1638 DRC
Total Organic Carbon	EPA Method 9060	-
Total Solids	-	SM 2540G
Particle Size Analysis	ASTM D422	-

Notes:
1. EPA Method 6010B (partial extraction)
2.EPA Method 1638 DRC (total extraction)
3. Physiological Based Extraction

Sediment samples were analyzed for Total Arsenic and Total Iron by Test America Laboratory using Method 6010B (partial digestion). Splits of the samples were tested by Brooks Rand Laboratory using Method 1638 DRC (total digestion). This was done to compare the efficiency of the respective extraction methods as well as for comparison with bioaccessible arsenic data for the same samples.

3.3 Biota Sample Collection and Processing

3.3.1 Targeted Biota

Samples of brown algae (M. tropicalis), Samoan Crab, Striped mullet and Marquesan mullet were targeted for sample collection (Figure 3-4). The algae serves as an important food source for mullet and grows in direct contact with the pond sediment. Crab and mullet that live in the pond are sometimes caught and used for food by residents. In total, 64 fish samples, 36 crab samples, and 12 algae samples were to be collected, processed and shipped to Brooks-Rand laboratory for testing. Final sample collection was incomplete due to access and time constraints.

3.3.2 Sample Collection

Biota samples were collected from Waiakea Pond during and subsequent to the collection of sediment samples. Five samples of brown algae were collected from the pond. Six juveniles and six adult Samoan crab specimens were collected. Twelve samples of Striped mullet were collected. Twelve samples of Marquesan mullet were also collected. All samples will be stored in resealable plastic bags.

3.3.3 Field Processing

Six Samoan crab specimens were tested whole without processing. Meat with no shell or gills was collected from six additional specimens and tested independently. The hepatopancreas of the specimens was also removed and tested separately, as was the gastrointestinal tract of one specimen.

Both whole fish and scaled and gutted fish with gills removed were submitted to the laboratory for testing. Scales, internal organs and gills from the latter group of fish were respectively combined for separate testing.

No field processing of algae samples was required. Final samples were stored on ice and shipped to the laboratory for testing.

3.3.4 Laboratory Processing and Analysis

Biota samples were submitted to Brooks Rand Laboratory for analysis of total arsenic, inorganic arsenic monomethyl arsenic and dimethyl arsenic as well as percent total solids. Individual biota samples were homogenized in a blender. Subsamples were collected and tested in accordance with the laboratory methods noted in below table.

Analysis	**Brooks Rand Laboratory**
Arsenic, Iron (total)	EPA 1638 DRC
Arsenic (inorganic)	EPA 1632
Arsenic (monomethyl)	EPA 1632
Arsenic (dimethyl)	EPA 1632
Total Solids	SM 2540G

Some samples were received at the laboratory at 18°C, above the -4°C threshold, due to a shipping error. Data for the sample are qualified with an “H” in the laboratory report and in the summary tables.

There was no indication that the samples had become significantly putrid at the time they were received at the laboratory. Discussions with laboratory chemists suggested that a one-time thawing of the samples and short-term exposure to what was still a relatively cool temperature was unlikely to have significantly affected the resulting quality and representativeness of the data, including alteration of originally organic or inorganic forms of arsenic.

4 Control Area Sample Collection and Analysis

4.1 Control Site Settings

Additional sediment and/or biota control samples were collected from Lokowaka Pond (Figure 4-1), Lili’uokalani Pond (Figure 4-2) and Pelekane Bay (Figure 4-3) on Hawaii Island, and He’eia Pond (Figure 4-4) on O’ahu. Each area allowed for the collection of sediment and biota samples similar to those collected in Waiakea Pond. None of the control areas were known to have been directly impacted by agriculture-related or otherwise anthropogenic-related arsenic in the past.

Both Lokowaka Pond and Lili’uokalani Pond are formed by a large, freshwater spring and similar in nature but smaller than Waiakea Pond. Pelekane Bay is a small, shallow, one- to two-meter deep, 100 meter-wide bay on the southwest side of Hawaii Island. The bay receives runoff from the Kohala mountains to the north and is floored by a layer of silty and clayey sediment. He’eia Pond is a similarly shallow but much larger, 900-meter by 450-meter fish pond constructed by the original, Hawaiian inhabitants of O’ahu and still maintained for that purpose. The pond receives runoff from the Ko’olau mountains to the south. Sediment in the pond is very fine-grained and consists of silty, organic rich clays.

4.2 Sediment Sample Collection, Processing and Analysis

Sediment samples were collected from each of the Pelekane Bay and He’eia Pond control areas. Each area was subdivided into two DUs of approximately equal size. Thirty-increment samples were collected from two DUs at Pelekane Bay to a depth of approximately four inches (see Figure 4-2). A single, replicate sample was also collected from each DU. Thirty-increment samples were also collected from two DUs at He’eia Pond to a depth of approximately six inches (see Figure 4-4). Replicate samples were not collected due to time limitations. Samples were collected with a thin-walled, push tube. No subsampling was necessary to reduce the sample masses

Samples were submitted to Brooks Rand Laboratory for processing and testing in the same manner as described above for sediment samples collected from Waiakea Pond. Ten-gram subsamples of the <2mm fraction were tested for total arsenic, inorganic arsenic, dimethyl arsenic (DMA), monomethyl arsenic (MMA), total iron and percent total solids. Field -prepared subsamples of control site sediment samples were submitted to Test America Laboratory for total organic carbon and grain-size distribution analyses. The <250 µm fraction was not tested separately.

4.3 Biota Sample Collection and Processing

Biota samples were collected from each of the three control sites. A single sample of brown algae (M. tropicalis) was collected from Lokowaka Pond. Two juvenile, Samoan crab specimens were collected from Lili’uokalani Pond. Five juvenile and 6 adult Samoan crab specimens were collected from He’eia Pond. Eight striped mullet specimens were collected from Lokowaka Pond. Eight Marquesan mullet and 4 Australian mullet specimens were collected from Pelekane Bay.

Biota samples were submitted to Brooks Rand Laboratory for processing and testing in the same manner as described for the samples collected from Waiakea Pond.

5 Results

Summaries of sediment and biota data are provided below. Laboratory reports for sediment are provided in Appendix E. Reports for biota are provided in Appendix F. Chain of Custody forms are provided in Appendix G. Sediment subsample replicate data tested by Brooks Rand is summarized in Appendix H.

5.1 Sediment

5.1.1 Waiakea Pond

5.1.1.1 Primary Sample Data

Laboratory test data for primary sediment samples collected from Waiakea Pond and the control sites are summarized in Table 5-1a (Test America Data) and Table 5-1b (Brooks Rand data). Replicate sample data collected from DU-2 are presented in Table 5-1c (Test America Data) and Table 5-1d (Brooks Rand data). Summary maps of sediment data reported by Test America Laboratory and Brooks Rand Laboratory are presented in Tables 5-1a and 5-1b, respectively.

The concentration of total arsenic in the <2mm fraction of the sediment samples analyzed by Test America Laboratory (Table 5-1a) ranges from a low of 50 mg/kg in the 0-4" layer of DU-5 (single sample) to a high of 870 mg/kg in the 0-4" layer of DU-2 (average of triplicate sample data). The overall average of total arsenic for all of the sediment samples collected from the pond combined is 218 mg/kg (see Table 5-1a).

Brooks Rand reported significantly higher concentrations of total arsenic in splits of the samples (Table 5-1b), with a range of 145 mg/kg (0-4" layer of DU-5; single sample) to 1,086 mg/kg (0-4" layer of DU-2; average of triplicate sample data) and an overall average of 387 mg/kg. The average concentration of inorganic arsenic in the samples tested by Brooks Rand was 175 mg/kg.

Brooks Rand data for separate, inorganic arsenic, dimethyl arsenic (DMA) and monomethyl arsenic (MMA) in the <2mm fraction are summarized in Table 5-1b. Reported concentrations of inorganic arsenic range from 47 mg/kg to 736 mg/kg, with an average of 223 mg/kg. Concentrations of MMA and DMA in the sample were very low, ranging from 0.14 mg/kg to 1.4 mg/kg for DMA (average 0.70 mg/kg) and 0.10 mg/kg to 1.0 mg/kg for MMA (average 0.52 mg/kg).

Arsenic is overwhelmingly and consistently dominated by inorganic species (average of >99%; Table 5-1b). Note that the percent of inorganic versus organic arsenic presented in the Table 5-1b is calculated based on the sum of inorganic arsenic, MMA and DMA based on EPA Method 1632, rather than the reported concentration of total arsenic for the sample based on EPA Method 1638 DRC. The reported concentration of total arsenic in the samples based on the latter method is consistently well above the sum of inorganic arsenic and MMA and DNA organic arsenic based on Method 1632. This is interpreted to be due to use of a weaker extraction method for the latter. Reported concentrations of inorganic arsenic based on EPA Method 1632 are similar to the data reported by Test America based on EPA Method 6010B.

Total iron reported by Test America for the <2mm fraction of the sediment samples ranged from 32,667 mg/kg (0-4" layer of DU-2, average of triplicate samples) to 51,000 mg/kg (8-12" layer of DU-4, single sample), with an overall average of 41,844 mg/kg. The concentration of total iron based on samples tested by Brooks Rand ranged from 36,833 mg/kg (4-8” layer of DU-1, single sample) to 74,167 mg/kg (0-4” layer of DU-5, single sample) with an overall average of 60,408 mg/kg.

The concentration of total arsenic in the <250µm fraction of the sediment samples analyzed by Test America Laboratory ranged from 110 mg/kg to 1,400 mg/kg, with an average of 271 mg/kg (see Table 5-1a). The concentration of bioaccessible arsenic ranged from 6.5 mg/kg to 38 mg/kg (2.7% to 8.7% of reported total arsenic), with an average of 14 mg/kg (average 6.2% of total arsenic). The concentration of total iron in the <250µm fraction ranged from 35,000 mg/kg to 64,000 mg/kg, with an average of 49,524 mg/kg.

A summary of total organic carbon, percent solids and moisture, and grain-size distribution for the <2mm fraction of sediment samples from Waiakea Pond is presented in Table 5-2a. The reported concentration of total organic carbon ranged from 9,800 mg/kg (1.0%) to 53,000 mg/kg (5.3%), with an average of 29,076 mg/kg (2.9%). The sediment samples were on average dominated by sand (63%) and silt (27%) with less amounts of clay (9%) and gravel (1.1%). In terms of textural classification (Chotiros 2017), the sediment is on average a muddy sand and ranges from a gravely, muddy sand in the narrow channel where the pond discharges into the Wailoa River (DU-5) to a muddy sand or sandy mud in the upper area of the pond (DU 1 and DU-2).

5.1.1.2 Replicate Sample Data

Replicate data for Waiakea Pond sediment samples are summarized in Table 5-1c (Test America Data) and 5-1d (Brooks Rand data). The overall data precision and data quality is noted in the tables.

The Relative Standard Deviation (RSD) for reported concentrations of total arsenic in the 0-4” layer of DU-2 exceeds 50% for both the Test America and Brooks Rand data, indicating poor precision. The RSD for organic arsenic data is well below 35%, indicating good precision.

The high concentration of arsenic in the primary sample collected from DU-2 in comparison to the two replicate samples is most likely due to the chance inclusion of disintegrated fragments of arsenic-infused canec in that sample. Replicate data for the 4-8” and 8-12” DU layers was, by contrast, well below 35% in both sets of data and the overall quality of the data is considered to be very good.

Data for replicate laboratory subsamples tested by Brooks Rand are provide in Appendix H. The RSD for subsample replicates was below 35% in all cases and below 10% in most cases, indicating good overall data precision. This supports a conclusion that variability in the replicate data is related to field sampling error, rather than subsampling and analytical error in the laboratory.

5.1.2 Control Sites

Sediment data for samples collected at the control sites is presented in Table 5-1e (arsenic, iron) and Table 5-2b (total organic carbon, grain size). Concentrations of 16 mg/kg total arsenic and 13 mg/kg inorganic arsenic were reported for the two sediment samples collected from He’eia Pond (see Table 5-1e). The average concentration of DMA and MMA in the samples was reported to be 0.11 mg/kg and 0.09 mg/kg, respectively, indicating an overwhelming dominance of arsenic in the sediment by inorganic species, as observed for the Waiakea Pond study site. The average concentration of total iron in the samples was 175,500 mg/kg.

The concentration of inorganic and organic arsenic in replicates of sediment samples collected from the two DUs tested in Pelekane Bay was essentially identical, with an average of 7.7 mg/kg and 5.1 mg/kg, respectively. Concentrations of DMA and MMA in the samples were again minimal, at 0.041 mg/kg and 0.032 mg/kg. The average total iron in the samples was 87,350 mg/kg. Duplicate sediment sample data collected from each of the control sites showed reasonably good precision.

Average total organic carbon in the samples collected from He’eia Pond and Pelekane Bay was 19,500 mg/kg and 47,500 mg/kg, respectively (Table 5-2b). Texturally the sediment samples from He’eia Pond are sandy muds with a trace of gravel. Sediment samples from Pelekane Bay are muddy sands, again with a trace of gravel.

5.2 Biota

5.2.1 Algae (M. tropicalis)

5.2.1.1 Waiakea Pond

Laboratory test data for algae samples collected from Waiakea Pond and the control sites are summarized in Table 5-3. Concentrations of total arsenic in the five samples of brown algae collected from Waiakea pond ranged from 2.9 mg/kg to 11 mg/kg, with an average of 4.9 mg/kg (Table 5-3). Concentrations of inorganic arsenic ranged from 1.4 mg/kg to 6.9 mg/kg, with an average of 3.5 mg/kg. In Sample WP-DU-5-Algae, the reported concentration of inorganic arsenic exceeded the concentration of total arsenic. The reason for this discrepancy is not clear. Dimethyl arsenic was reported at 0.11 mg/kg to 0.38 mg/kg and an average of 0.20 mg/kg. Monomethyl arsenic was reported in two samples above the method detection level but below the method reporting level.

5.2.1.2 Control Sites

A concentration of 0.43 mg/kg total arsenic was reported for the single sample of brown algae collected from Lokowaka Pond (see Table 5-3). Inorganic arsenic was not identified in the sample above the method detection limit. Dimethyl arsenic was detected at a concentration of 0.13 mg/kg. Monomethyl arsenic was again not identified in the sample above the method detection limit.

5.2.2 Samoan Crab

5.2.2.1 Waiakea Pond

Data for Samoan crab specimens collected from Waiakea Pond are presented in Table 5-4a. Due to a shipping error, some samples were received above the -4°C threshold. These sample results are qualified with an “H” in the laboratory report and in the summary tables.

Concentrations of total arsenic in whole, juvenile crabs ranged from 1.0 mg/kg to 6.0 mg/kg, with an average of 2.5 mg/kg. The average concentration of inorganic arsenic in the samples ranged from 0.11 mg/kg to 0.35 mg/kg, with an average of 0.21 mg/kg. Dimethyl arsenic was reported at concentrations ranging from 0.31 mg/kg to 0.99 mg/kg, with an average of 0.61 mg/kg. Monomethyl arsenic was not identified above method detection limits.

Concentrations of total arsenic in the meat (excluding shell and gills) of adult crabs ranged from 0.68 mg/kg to 1.2 mg/kg, with an average of 1.1 mg/kg. The average concentration of inorganic arsenic in the samples ranged from 0.01 mg/kg to 0.12 mg/kg, with an average of 0.05 mg/kg. Dimethyl arsenic was reported at concentrations ranging from 0.12 mg/kg to 0.80 mg/kg, with an average of 0.31 mg/kg. Monomethyl arsenic was not identified above method detection limits.

Concentrations of total arsenic in the hepatopancreas (butter) of five adult specimens ranged from 1.4 mg/kg to 4.0 mg/kg, with an average of 2.7 mg/kg. The average concentration of inorganic arsenic in the samples ranged from 0.05 mg/kg to 2.4 mg/kg, with an average of 0.56 mg/kg. Dimethyl arsenic was reported at concentrations ranging from 0.42 mg/kg to 1.0 mg/kg, with an average of 0.62 mg/kg. Monomethyl arsenic was not identified above method detection limits.

A concentration of 2.7 mg/kg total arsenic was reported for the hepatopancreas (butter) of a sixth specimen (Sample SS-HP-S-A-2). A concentration of 0.24 mg/kg inorganic arsenic was reported. Dimethyl arsenic was detected at a concentration of 0.63 mg/kg. Monomethyl arsenic was not identified above method detection limits.

A concentration of 4.0 mg/kg total arsenic was reported for the gastrointestinal tract of the same specimen (Sample SS-GI-S-A-2). A concentration of 2.4 mg/kg inorganic arsenic was also reported. Dimethyl arsenic was detected at a concentration of 0.32 mg/kg. Monomethyl arsenic was not identified above method detection limits.

5.2.2.2 Control Sites

Data for Samoan crab specimens collected from the control sites are presented in Table 5-4b. Concentrations of 4.7 mg/kg to 4.9 mg/kg total arsenic were reported for two whole, juvenile crabs collected from the Lili'uokalani Pond control site. Concentration of inorganic arsenic in the samples were 0.09 mg/kg and 0.11 mg/kg. Dimethyl arsenic was reported at concentrations of 1.1 mg/kg and 1.2 mg/kg. Monomethyl arsenic was not identified above method detection limits.

Concentrations of total arsenic in whole, juvenile crabs collected from the He'eia Pond control site ranged from 0.62 mg/kg to 2.3 mg/kg, with an average of 1.6 mg/kg. The concentration of inorganic arsenic in the samples ranged from 0.034 mg/kg to 0.081 mg/kg, with an average of 0.055 mg/kg. Dimethyl arsenic was reported at concentrations ranging from 0.030 mg/kg to 0.099 mg/kg, with an average of 0.063 mg/kg. Monomethyl arsenic was not identified above method detection limits.

Concentrations of total arsenic in the edible meat of adult crabs from He'eia Pond of ranged from 3.7 mg/kg to 9.8 mg/kg, with an average of 7.2 mg/kg. The average concentration of inorganic arsenic in the edible meat samples was below method detection limits or above detection limits but below reporting levels. Dimethyl arsenic was reported at concentrations ranging from 0.023 mg/kg to 0.172 mg/kg, with an average of 0.76 mg/kg. Monomethyl arsenic was not identified above method detection limits.

Concentrations of total arsenic in the internal organs of adult crabs from He'eia Pond of ranged from 2.9 mg/kg to 4.7 mg/kg, with an average of 3.5 mg/kg. The average concentration of inorganic arsenic in the samples ranged from 0.011 mg/kg to 0.023 mg/kg in three of the six samples tested and was below method reporting levels in the remaining samples. Dimethyl arsenic was reported at concentrations ranging from 0.017 mg/kg to 0.083 mg/kg, with an average of 0.046 mg/kg. Monomethyl arsenic was not identified above method detection limits.

5.2.3 Striped Mullet

5.2.3.1 Waiakea Pond

Data for Striped Mullet specimens collected from Waiakea Pond are presented in Table 5-5a. Concentrations of total arsenic in whole, juvenile mullet ranged from 1.7 mg/kg to 4.2 mg/kg, with an average of 2.8 mg/kg. The average concentration of inorganic arsenic in the samples ranged from 0.051 mg/kg to 1.46 mg/kg, with an average of 0.634 mg/kg. Dimethyl arsenic was reported at concentrations ranging from 0.043 mg/kg to 0.195 mg/kg, with an average of 0.095 mg/kg. Monomethyl arsenic was not identified above method detection limits.

Concentrations of total arsenic in whole, adult mullet samples ranged from 1.4 mg/kg to 2.2 mg/kg, with an average of 1.8 mg/kg. Inorganic arsenic was detected in only two of the four sample tested, at concentrations of 0.009 mg/kg and 0.024 mg/kg. Dimethyl arsenic was reported at concentrations ranging from 0.031 mg/kg to 0.272 mg/kg, with an average of 0.172 mg/kg. Monomethyl arsenic was not identified above method detection limits.

Concentrations of total arsenic in adult mullet samples with the scales, gills and internal organs removed ranged from 1.7 mg/kg to 2.3 mg/kg, with an average of 2.0 mg/kg. Inorganic arsenic was detected in only one of the four sample tested, at a concentration of 0.010 mg/kg. Dimethyl arsenic was reported at concentrations ranging from 0.035 mg/kg to 0.087 mg/kg, with an average of 0.057 mg/kg. Monomethyl arsenic was not identified above method detection limits.

Concentrations of total arsenic in composites of scales, gills and internal organs of the above samples of adult mullet samples were 0.19 mg/kg, 2.0 mg/kg and 3.8 mg/kg, respectively. Inorganic arsenic in the composited scales, gills and organs was reported at 0.130 mg/kg, 0.025 mg/kg and 0.176 mg/kg, respectively. Dimethyl arsenic was detected below reporting for composited scales and at 0.130 mg/kg and 0.122 mg/kg for composited gills and internal organs, respectively. Monomethyl arsenic was not identified above method detection limits.

5.2.3.2 Control Sites

Data for Striped Mullet specimens collected from Lokowaka Pond are presented in Table 5-5b. Concentrations of total arsenic in whole, adult mullet ranged from 0.67 mg/kg to 1.1 mg/kg, with an average of 0.90 mg/kg. Inorganic arsenic was not detected in the samples. Dimethyl arsenic was reported at concentrations ranging from 0.005 mg/kg to 0.013 mg/kg, with an average of 0.009 mg/kg. Monomethyl arsenic was not identified above method detection limits.

Concentrations of total arsenic in adult mullet samples from Lokowaka Pond with the scales, gills and internal organs removed ranged from 0.13 mg/kg to 1.1 mg/kg, with an average of 0.77 mg/kg. Inorganic arsenic was not detected in the samples. Dimethyl arsenic was detected in two of the four samples at concentrations of 0.012 mg/kg and 0.023 mg/kg. Monomethyl arsenic was not identified above method detection limits.

Concentrations of total arsenic in composites of scales, gills and internal organs of the above samples of adult mullet samples from Lokowaka Pond were 0.13 mg/kg, 0.98 mg/kg and 2.0 mg/kg, respectively. Inorganic arsenic was not detected in the samples. Dimethyl arsenic was not detected in the composited scales but detected in the composited gills and internal organs at concentrations of 0.031 mg/kg and 0.048 mg/kg, respectively. Monomethyl arsenic was not identified above method detection limits.

5.2.4 Marquesan Mullet

5.2.4.1 Waiakea Pond

Data for Marquesan Mullet specimens collected from Waiakea Pond are presented in Table 5-6a. Due to a shipping error, some samples were received above the -4°C threshold. These sample results are qualified with an “H” in the laboratory report and in the summary tables.

Concentrations of total arsenic in whole, juvenile mullet ranged from 1.5 mg/kg to 2.5 mg/kg, with an average of 2.0 mg/kg. The average concentration of inorganic arsenic in the samples ranged from 0.036 mg/kg to 0.097 mg/kg, with an average of 0.068 mg/kg. Dimethyl arsenic was reported at concentrations ranging from 0.137 mg/kg to 0.216 mg/kg, with an average of 0.190 mg/kg. Monomethyl arsenic was not identified above method detection limits.

Concentrations of total arsenic in whole, adult mullet samples ranged from 1.4 mg/kg to 4.5 mg/kg, with an average of 2.3 mg/kg. Inorganic arsenic was reported at a concentration of 4.6 mg/kg in Sample VE-W-S-A-1, significantly higher than the other three samples. The source of the elevated concentration of inorganic arsenic reported for the sample is unknown but could be related to sediment in the fish's gastrointestinal tract. Inorganic arsenic in the three, remaining samples ranged from 0.019 mg/kg to 0.069 mg/kg, with an average of 0.041 mg/kg. Dimethyl arsenic was reported at concentrations ranging from 0.092 mg/kg to 0.170 mg/kg, with an average of 0.134 mg/kg. Monomethyl arsenic was not identified above method detection limits.

Concentrations of total arsenic in adult mullet samples with the scales, gills and internal organs removed ranged from 0.82 mg/kg to 2.4 mg/kg, with an average of 1.6 mg/kg. Inorganic arsenic was detected in only two of the four sample tested, at concentration of 0.017 mg/kg and 0.060 mg/kg. Dimethyl arsenic was reported at concentrations ranging from 0.033 mg/kg to 0.071 mg/kg, with an average of 0.054 mg/kg. Monomethyl arsenic was not identified above method detection limits.

Concentrations of total arsenic in composites of scales, gills and internal organs of the above samples of adult mullet samples were 0.27 mg/kg, 1.4 mg/kg and 8.9 mg/kg, respectively. Inorganic arsenic in the composited scales, gills and organs was reported at 0.161 mg/kg, 0.199 mg/kg and 4.49 mg/kg, respectively. Dimethyl arsenic was detected below reporting for composited scales and at 0.126 mg/kg and 0.121 mg/kg for composited gills and internal organs, respectively. Monomethyl arsenic was not identified above method detection limits.

5.2.4.2 Control Sites

Data for Marquesan Mullet specimens collected from the control sites are presented in Table 5-6b. Samples were also received at the laboratory above the -4°C threshold. These sample results are again qualified with an "H" in the laboratory report and in the summary tables.

Concentrations of total arsenic in whole, juvenile mullet ranged from 1.1 mg/kg to 2.2 mg/kg, with an average of 1.8 mg/kg. Inorganic arsenic was reported at concentrations ranging from 0.384 mg/kg to 0.582 mg/kg, with an average of 0.462 mg/kg. Dimethyl arsenic was reported at concentrations ranging from 0.042 mg/kg to 0.120 mg/kg, with an average of 0.071 mg/kg. Monomethyl arsenic was not identified above method detection limits.

Concentrations of total arsenic in whole, adult mullet ranged from 1.4 mg/kg to 1.8 mg/kg, with an average of 1.7 mg/kg. Inorganic arsenic was reported at concentrations ranging from 0.216 mg/kg to 0.501 mg/kg, with an average of 0.374 mg/kg. Dimethyl arsenic was reported at concentrations ranging from 0.026 mg/kg to 0.115 mg/kg, with an average of 0.064 mg/kg. Monomethyl arsenic was not identified above method detection limits.

Concentrations of total arsenic in adult mullet samples with the scales, gills and internal organs removed ranged from 0.48 mg/kg to 0.76 mg/kg, with an average of 0.67 mg/kg. Concentrations of inorganic arsenic ranged from 0.013 mg/kg to 0.041 mg/kg, with an average of 0.026 mg/kg. Dimethyl arsenic ranged from 0.035 mg/kg to 0.074 mg/kg, with an average of 0.055 mg/kg. Monomethyl arsenic was not identified above method detection limits.

Concentrations of total arsenic in composites of scales, gills and internal organs of the above samples of adult mullet samples were 0.58 mg/kg, 0.98 mg/kg and 2.4 mg/kg, respectively. Concentrations of inorganic arsenic were 0.419 mg/kg, 0.119 mg/kg and 0.487 mg/kg, respectively. Dimethyl arsenic was not detected in the composited scales but detected in the composited gills and internal organs at concentrations of 0.050 mg/kg and 0.047 mg/kg, respectively. Monomethyl arsenic was not identified above method detection limits.

6 Conclusions

The objective of this study was to acquire a detailed suite of data for arsenic in sediment and biota data of Waiakea Pond. The data confirm contamination of at least the first foot of sediment with arsenic. Impacts extend across the entire pond but are noticeably higher in the vicinity of the former canec plant. Biota data indicate increased levels of arsenic in brown algae in comparison to algae from control sites. Data for mullet and crabs are less clear.

Bioaccessibility data for the sediment indicate that the arsenic is tightly bound to iron in the sediment and would not be significantly released in the stomach or intestines if the soil was accidentally ingested. Arsenic in the sediment therefore does not pose a significant health risk to children and adults who regularly use the park.

Data for tissue from striped and Marquesan mullet species as well as crabs collected from Waiakea Pond and estuary did not indicate elevated levels of inorganic arsenic concentrations compared to natural, reference site locations. Arsenic was slightly elevated in samples of brown algae from the pond in comparison to algae from other ponds. The algae is not known to be regularly used for human consumption. A detailed review of arsenic data for the specific species of algae present has not been carried out. Reported concentrations are, however, within the range of arsenic typically reported for algae (limu) in marine environments consumed by humans (UKFSA 2004, Llorente-Mirandes 2010). Occasional consumption of the algae by park users is therefore not considered to pose a significant health risk.

A detailed review of the biota data has not yet been carried out but is anticipated in the future. Researchers are encouraged to contact the HEER Office for additional information on this study and potential collaboration on further interpretation of the data and assessment of potential risk posed to people using the pond for recreational fishing as well as risks to the pond flora and fauna.

7 References

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Tables

Table 2-1. Total arsenic in discrete, sediment samples collected from Waiakea Pond by the University of Hawaii-Hilo (Hallacher et al. 1985; see Figure 2-1).

Sediment Sample ID	[1]Upper Sample (mg/kg)	[2]Lower Sample (mg/kg)
I-MP	2.0 (8-10 cm)	ND (16-18cm)
2-MP	251 4-6 cm)	550 (56-58 cm)
3-MP	27 (6-8 cm)	3.0 (108-110 cm)
4-MP	115 (10-12 cm)	ND (52-54 cm)
5-WR	151 (4-6 cm)	715 (57-59 cm)
6-WR	34 (3-5 cm)	60 (61-63 cm)
7-WR	43 (3-5 cm)	17 (103-105 cm)
8-HB	34 (3-5 cm)	63 (66-68 cm)
9-HB	56 (3-5 cm)	19 (50-52 cm)
10-BW	ND (surface)	-
11-BW	40 (surface)	-

1. Depth interval of core removed as a discrete sample indicated.

Table 2-2. Total and bioaccessible arsenic in Multi Increment soil sample samples collected as part of a 2013 Hawaii Department of Health investigation of arsenic in soil around the perimeter of Waiakea Pond (HIDOH 2013; see Figure 2-2).

Shoreline Area DUs	Approximate Length (ft)	[1]Approximate DU Area (ft^2)	[2]Total Arsenic < 2mm Fraction (mg/kg)	[3]Total Arsenic < 250µm Fraction (mg/kg)	[3]Bioaccessible Arsenic (mg/kg)	Percent Bioaccessibility
1	700	20,000	120	140	12	8%
2	700	20,000	72	97	ND (< 1.0)	<3%
3	800	25,000	330	410	33	8%
4	600	20,000	260	320	30	9%
5	600	30,000	56	71	ND (< 1.0)	<4%
6	600	30,000	54	69	ND (< 1.0)	<4%
7	600	30,000	24	37	ND (< 1.0)	<8%
8	300	45,000	12	-	-	-
9	600	30,000	35	42	ND (< 1.0)	<7%
10	600	30,000	42	49	ND (< 1.0)	<6%
11	600	30,000	53	65	ND (< 1.0)	<5%
12	600	30,000	65	87	6.4	7%
13	600	30,000	58	82	6.3	-
14	800	40,000	22	-	-	-

Notes:

1. DU width 30ft DU from shoreline for DUs 1-7 and 9-14; DU 8 width 150 ft.
2. Total arsenic based on testing of the <2mm soil fraction.
3. Bioaccessible arsenic based on testing of the <250 µm soil fraction for samples with >24 mg/kg total arsenic in the <2mm soil fraction.

Table 5-1a. Waiakea Pond sediment data for iron, arsenic and bioaccessible arsenic (Test America Laboratory).

Sample ID	Total Arsenic (<2mm) mg/kg	Total Iron (<2mm) mg/kg	Total Arsenic (<0.25mm) mg/kg	Total Iron (<0.25mm) mg/kg	Bioaccessible Arsenic (<0.25mm) mg/kg	Bioaccessible Arsenic %
WP-DU-1 (0-4 in)	240	35,000	300	40,000	21	6.9%
WP-DU-1 (4-8 in)	290	39,000				
WP-DU-1 (8-12 in)	210	37,000				
WP-DU-2 (0-4 in)	870	32,000	1,400	37,000	38	2.7%
WP-DU-2 (4-8 in)	380	38,000				
WP-DU-2 (8-12 in)	350	43,000				
***WP-DU-6 (0-4 in)**	250	32,000	440	35,000	13	2.9%
***WP-DU-6 (4-8 in)**	320	34,000				
***WP-DU-6 (8-12 in)**	310	36,000				
***WP-DU-7 (0-4 in)**	270	34,000	440	35,000	15	3.4%
***WP-DU-7 (4-8 in)**	300	35,000				
***WP-DU-7 (8-12 in)**	320	36,000				
WP-DU-2 (0-4 in) Average	463	32,667	760	35,667	22	3.0%
WP-DU-2 (4-8 in) Average	333	35,667				
WP-DU-2 (8-12 in) Average	327	38,333				
WP-DU-3 (0-4 in)	160	43,000	180	44,000	8.1	4.5%
WP-DU-3 (4-8 in)	160	42,000				
WP-DU-3 (8-12 in)	180	49,000	240	51,000	21	8.7%
WP-DU-4 (0-4 in)	100	48,000	140	54,000	8.0	5.7%
WP-DU-4 (4-8 in)	150	49,000				
WP-DU-4 (8-12 in)	140	51,000	170	58,000	14	8.4%
WP-DU-5 (0-4 in)	50	44,000	110	64,000	6.5	5.9%
WP-DU-5 (4-8 in)	170	43,000				
WP-DU-5 (8-12 in)	300	41,000				
Minimum:	**50**	**32,000**	**110**	**35,000**	**6.5**	**2.7%**
Maximum:	**870**	**51,000**	**1,400**	**64,000**	**38**	**8.7%**
Average:	**218**	**41,844**	**271**	**49,524**	**14**	**6.2%**

Notes:
All analyses reported on a dry weight basis
<2mm = <2mm particle size analysis
<.25mm = <0.25mm particle size analysis
* DU-6 and DU-7 are replicate data for DU-2. Average of triplicate samples used in calculation of averages for pond as a whole.

Table 5-1b. Waiakea Pond sediment data, including laboratory replicate data (Brooks Rand Laboratory).

Sample ID	Total Arsenic mg/kg	Inorganic Arsenic (mg/kg)	[3]Inorganic Arsenic %	Dimethyl Arsenic (mg/kg)	Monomethyl Arsenic (mg/kg)	Total Iron mg/kg	Total Solids %
WP-DU-1 (0-4 in)	351	191	99.0%	1.2	0.77	57,267	39%
WP-DU-1 (4-8 in)	407	193	98.8%	1.3	1.1	36,833	40%
WP-DU-1 (8-12 in)	313	138	98.4%	1.3	0.93	59,667	40%
[1]WP-DU-2 (0-4 in)	2,317	736	99.7%	1.4	0.90	49,967	37%
[1]WP-DU-2 (4-8 in)	709	275	99.3%	1.2	0.78	60,400	42%
[1]WP-DU-2 (8-12 in)	581	321	99.4%	1.2	0.79	56,367	40%
[1]WP-DU-6 (0-4 in)	486	250	99.3%	1.0	0.80	50,667	36%
[1]WP-DU-6 (4-8 in)	582	285	99.3%	1.1	0.86	54,767	34%
[1]WP-DU-6 (8-12 in)	546	297	99.4%	0.96	0.77	59,200	36%
[1]WP-DU-7 (0-4 in)	457	249	99.2%	1.1	0.88	48,500	37%
[1]WP-DU-7 (4-8 in)	576	331	99.4%	1.1	0.89	51,467	38%
[1]WP-DU-7 (8-12 in)	620	339	99.4%	1.1	0.90	57,533	37%
WP-DU-2 (0-4 in) Average	1,086	412	99.5%	1.2	0.86	49,711	37%
WP-DU-2 (4-8 in) Average	623	297	99.3%	1.1	0.84	55,544	38%
WP-DU-2 (8-12 in) Average	582	319	99.4%	1.1	0.82	57,700	38%
WP-DU-3 (0-4 in	191	96	99.3%	0.37	0.29	57,533	51%
WP-DU-3 (4-8 in)	227	115	99.2%	0.54	0.43	60,933	50%
WP-DU-3 (8-12 in)	252	156	99.5%	0.42	0.34	62,800	45%
WP-DU-4 (0-4 in)	145	82	99.1%	0.40	0.32	67,633	55%
WP-DU-4 (4-8 in)	186	94	99.4%	0.34	0.27	65,733	58%
WP-DU-4 (8-12 in)	157	100	99.4%	0.34	0.27	71,400	58%
[2]WP-DU-5 (0-4 in)	209	42	99.4%	0.14	0.10	74,167	75%
[2]WP-DU-5 (4-8 in)	393	73	99.2%	0.33	0.22	63,567	75%
WP-DU-5 (8-12 in)	691	322	99.8%	0.48	0.32	65,633	69%
Minimum:	**145**	**42**	**98.4%**	**0.14**	**0.10**	**36,833**	**34%**
Maximum:	**2,317**	**736**	**99.8%**	**1.4**	**1.1**	**74,167**	**75%**
Average:	**387**	**175**	**99.3%**	**0.70**	**0.52**	**60,408**	**51%**

Table 5-1b (cont.)

Notes: All analyses reported on a dry weight basis; mean concentration of laboratory triplicate data for each sample noted. Original lab report and summary of replicate data provided in Appendix E and Appendix H, respectively.

1. DU-6 and DU-7 are replicate data for DU-2. Average of triplicate samples used in calculation of averages for pond as a whole.
2. Reported inorganic arsenic as proportion of total arsenic unexpectedly low. No error identified in laboratory data.
3. Percent inorganic arsenic based on sum of reported inorganic arsenic, DMA and MMA.

Table 5.1c. Waiakea Pond replicate data (Test America Laboratory).

Sample ID	Total Arsenic (<2mm) mg/kg	Total Iron (<2mm) mg/kg	Total Arsenic (<0.25mm) mg/kg	Total Iron (<0.25mm) mg/kg	Bioaccessible Arsenic (<0.25mm) mg/kg	Bioaccessible Arsenic %
WP-DU-2 (0-4 in)	870	32,000	1,400	37,000	38	2.7%
WP-DU-6 (0-4 in)	250	32,000	440	35,000	13	2.9%
WP-DU-7 (0-4 in)	270	34,000	440	35,000	15	3.4%
Mean	463	32,667	760	35,667	22	3.0%
SD	**352**	**1,155**	**554**	**1,155**	**14**	**0**
RSD	**76%**	**4%**	**73%**	**3%**	**62%**	**13%**
WP-DU-2 (4-8 in)	380	38,000				
WP-DU-6 (4-8 in)	320	34,000				
WP-DU-7 (4-8 in)	300	35,000				
Mean	333	35,667				
SD	**42**	**2,082**				
RSD	**12%**	**6%**				
WP-DU-2 (8-12 in)	350	43,000				
WP-DU-6 (8-12 in)	310	36,000				
WP-DU-7 (8-12 in)	320	36,000				
Mean	327	38,333				
SD	**21**	**4,041**				
RSD	**6%**	**11%**				

Table 5-1d. Waiakea Pond replicate data (Brooks Rand Laboratory).

Sample ID	Total Arsenic mg/kg	Inorganic Arsenic (mg/kg)	[1]Inorganic Arsenic %	Dimethyl Arsenic (mg/kg)	Monomethyl Arsenic (mg/kg)	Total Iron mg/kg	Total Solids %
WP-DU-2 (0-4 in)	2,317	736	99.7%	1.4	0.90	49,967	37%
WP-DU-6 (0-4 in)	486	250	99.3%	1.0	0.80	50,667	36%
WP-DU-7 (0-4 in)	457	249	99.2%	1.1	0.88	48,500	37%
Mean	**1086**	**412**	**99.4%**	**1.2**	**0.86**	**49711**	**37%**
SD	**1,066**	**281**	**0.3%**	**0.2**	**0.05**	**1,106**	**1%**
RSD	**98%**	**68%**	**0.3%**	**16%**	**6%**	**2%**	**2%**
WP-DU-2 (4-8 in)	709	275	99.3%	1.2	0.78	60,400	42%
WP-DU-6 (4-8 in)	582	285	99.3%	1.1	0.86	54,767	34%
WP-DU-7 (4-8 in)	576	331	99.4%	1.1	0.89	51,467	38%
Mean	**623**	**297**	**99.3%**	**1.1**	**0.84**	**55544**	**38%**
SD	**75**	**30**	**0.1%**	**0.1**	**0.05**	**4,517**	**4%**
RSD	**12%**	**10%**	**0.1%**	**5%**	**6%**	**8%**	**10%**
WP-DU-2 (8-12 in)	581	321	99.4%	1.2	0.79	56,367	40%
WP-DU-6 (8-12 in)	546	297	99.4%	0.96	0.77	59,200	36%
WP-DU-7 (8-12 in)	620	339	99.4%	1.1	0.90	57,533	37%
Mean	**582**	**319**	**99.4%**	**1.1**	**0.82**	**57700**	**38%**
SD	**37**	**21**	**0.0%**	**0.12**	**0.07**	**1,424**	**2%**
RSD	**6%**	**7%**	**0.0%**	**11%**	**8%**	**2%**	**5%**

1. Percent inorganic arsenic based on sum of reported inorganic arsenic, DMA and MMA.

Table 5-1e. Control sites sediment data, including laboratory replicate data (Brooks Rand Laboratory).

Sediment Sample ID	Total Arsenic mg/kg	Inorganic Arsenic (mg/kg)	Inorganic Arsenic %	Dimethyl Arsenic (mg/kg)	Monomethyl Arsenic (mg/kg)	Total Iron mg/kg	Total Solids %
HP-DU-1-A (0-6 in)	12	11	90%	0.10	0.08	170,000	56%
HP-DU-2-A (0-6 in)	20	14	70%	0.12	0.09	181,000	55%
Average	**16**	**13**	**80%**	**0.11**	**0.09**	**175,500**	**56%**
RPD %	**48%**	**25%**		**18%**	**12%**	**6.3%**	
PB-DU-A-1 (0-4 in), rep. 1	7.6	6.5	85	0.049	0.039	95,900	67%
PB-**DU-A-1 (0-4 in), rep. 2**	7.8	4.4	57	0.035	0.028	94,100	66%
PB-DU-B-1 (0-4 in), rep. 1	7.6	4.7	62	0.039	0.031	69,900	66%
PB-DU-B-1 (0-4 in), rep. 2	7.8	4.6	58	0.039	0.031	89,500	66%
Average	**7.7**	**5.1**	**65**	**0.041**	**0.032**	**87,350**	**66%**
Standard Deviation	0.14	0.97		0.006	0.005	11,941	
Relative Std Dev %	**1.8%**	**19%**		**15%**	**15%**	**14%**	

Notes:

All analyses reported on a dry weight basis.

HP = He'eia Pond, Oahu - replicates collected, 0-6 in vertical increments, 60 and 64 increments collected for each MIS.

PB = Pelekane Bay, Hawaii - replicates collected, 0-4 inch vertical increments, 40 increments collected for each MIS.

Table 5.2a. Waiakea Pond sediment data for total organic carbon and grain-size distribution (Test America Laboratory).

Sample ID	TOC mg/kg	TOC	Solids	Moisture	Gravel	Sand	Course Sand	Medium Sand	Fine Sand	Silt	Clay
WP-DU-1 (0-4 in)	39,000	3.9%	39%	61%	0.0%	59%	1.0%	6.9%	51%	33%	7.8%
WP-DU-1 (4-8 in)	43,000	4.3%	49%	51%	0.0%	50%	0.6%	3.5%	46%	41%	8.3%
WP-DU-1 (8-12 in)	42,000	4.2%	44%	56%	0.9%	51%	0.6%	1.9%	49%	34%	13%
***WP-DU-2 (0-4 in)**	40,000	4.0%	39%	61%	1.1%	50%	0.9%	3.9%	45%	40%	8.9%
***WP-DU-2 (4-8 in)**	48,000	4.8%	42%	58%	6.6%	45%	1.6%	5.4%	38%	36%	13%
***WP-DU-2 (8-12 in)**	51,000	5.1%	42%	58%	1.1%	51%	2.5%	7.1%	41%	37%	11%
***WP-DU-6 (0-4 in)**	52,000	5.2%	40%	60%	0.0%	38%	0.3%	2.7%	35%	46%	16%
***WP-DU-6 (4-8 in)**	43,000	4.3%	38%	62%	0.2%	48%	0.6%	4.7%	43%	38%	13%
***WP-DU-6 (8-12 in)**	51,000	5.1%	42%	58%	2.3%	48%	1.5%	6.0%	41%	36%	14%
***WP-DU-7 (0-4 in)**	40,000	4.0%	39%	61%	0.0%	43%	0.2%	2.5%	41%	44%	13%
***WP-DU-7 (4-8 in)**	53,000	5.3%	40%	60%	0.3%	48%	0.6%	3.9%	43%	40%	12%
***WP-DU-7 (8-12 in)**	46,000	4.6%	40%	60%	0.4%	49%	0.5%	4.2%	44%	36%	15%
WP-DU-2 (0-4 in) Average	44,000	4.4%	39%	61%	0.4%	44%	0.5%	3.0%	40%	43%	13%
WP-DU-2 (4-8 in) Average	48,000	4.8%	40%	60%	2.4%	47%	0.9%	4.7%	42%	38%	13%
WP-DU-2 (8-12 in) Average	49,333	4.9%	41%	59%	1.3%	49%	1.5%	5.8%	42%	36%	13%
WP-DU-3 (0-4 in)	22,000	2.2%	50%	50%	0.3%	66%	0.9%	5.3%	60%	26%	7.5%
WP-DU-3 (4-8 in)	22,000	2.2%	55%	45%	1.1%	66%	0.8%	6.0%	59%	26%	7.5%
WP-DU-3 (8-12 in)	37,000	3.7%	49%	51%	0.1%	57%	0.4%	5.3%	51%	33%	10%
WP-DU-4 (0-4 in)	21,000	2.1%	58%	42%	0.1%	62%	1.0%	4.3%	57%	29%	9.0%
WP-DU-4 (4-8 in)	18,000	1.8%	61%	39%	0.2%	67%	0.8%	4.5%	61%	25%	8.0%
WP-DU-4 (8-12 in)	17,000	1.7%	58%	42%	0.6%	72%	0.5%	4.6%	67%	18%	10%
WP-DU-5 (0-4 in)	12,000	1.2%	71%	29%	3.0%	80%	5.3%	27%	48%	11%	6.0%
WP-DU-5 (4-8 in)	12,000	1.2%	72%	28%	6.2%	82%	6.7%	30%	46%	6.8%	4.9%
WP-DU-5 (8-12 in)	9,800	1.0%	71%	29%	0.3%	85%	1.1%	13%	71%	9.2%	5.5%
Minimum:	**9,800**	**1.0%**	**38%**	**28%**	**0.0%**	**38%**	**0.2%**	**1.9%**	**35%**	**6.8%**	**4.9%**
Maximum:	**53,000**	**5.3%**	**72%**	**62%**	**6.6%**	**85%**	**6.7%**	**30%**	**71%**	**46%**	**16%**
Average:	**29,076**	**2.9%**	**53%**	**47%**	**1.1%**	**63%**	**1.5%**	**8%**	**53%**	**27%**	**9%**

Table 5-2a (cont.)

Notes: TOC (Total Organic Carbon) by Method 9060, and % Solids, % Moisture, and Particle Size Analyses by ASTM D422.
*DU-6 and DU-7 are replicate data for DU-2. Average of triplicate samples used in calculation of averages for pond as a whole.

Table 5.2b. Control site sediment data for total organic carbon and grain-size distribution (Test America Laboratory).

					Grain Size Distribution						
Sample ID	**TOC mg/kg**	**TOC**	**Solids**	**Moisture**	**Gravel**	**Sand**	**Course Sand**	**Medium Sand**	**Fine Sand**	**Silt**	**Clay**
HP-DU-1-A (0-6 in)	19,000	1.9%	59%	41%	1.5%	39%	4.3%	16%	20%	41%	18%
HP-DU-2-A (0-6 in)	20,000	2.0%	57%	43%	1.1%	45%	2.9%	19%	23%	39%	16%
Average	**19,500**	**2.0%**	**58%**	**42%**	**1.3%**	**42%**	**3.6%**	**17%**	**21%**	**40%**	**17%**
RPD %	5.1%	5.1%	3.4%	4.8%	31%	13%	39%	20%	16%	6.8%	12%
PB-DU-A-1 (0-4 in)	48,000	4.8%	68%	32%	1.5%	68%	5.6%	20%	43%	25%	5.7%
PB-DU-B-1 (0-4 in)	47,000	4.7%	65%	35%	2.9%	65%	5.2%	20%	40%	25%	7.4%
Average	**47,500**	**4.8%**	**67%**	**34%**	**2.2%**	**67%**	**5.4%**	**20%**	**42%**	**25%**	**6.6%**
RPD %	2.1%	2.1%	4.5%	9.0%	64%	3.8%	7.4%	1.5%	5.8%	2.0%	26%

Notes:

TOC (Total Organic Carbon) by Method 9060, and % Solids, % Moisture, and Particle Size Analyses by ASTM D422.

HP = He’eia Pond, Oahu - replicates collected, 0-6 in vertical increments, 60 and 64 increments collected for each MIS sample; see map for DU).

PB = Pelekane Bay, Hawaii - replicates collected, 0-4 inch vertical increments, 40 increments collected for each MIS sample; see map for DU).

Table 5-3. Brown algae data.

Waiakea Pond Biota Species	Sample ID	Total Arsenic (mg/kg)	Inorganic Arsenic (mg/kg)	Dimethyl Arsenic (mg/kg)	Monomethyl Arsenic (mg/kg)	Total Solids	Inorganic Arsenic
Algae (M. tropicalis)	WP-DU-1-Algae	2.9 N	2.2	0.18	0.017 B	12%	77%
Algae (M. tropicalis)	WP-DU-2-Algae	11	6.9	0.11	0.014 U	11%	61%
Algae (M. tropicalis)	WP-DU-3-Algae	1.9	1.4	0.16	0.009 B	13%	72%
Algae (M. tropicalis)	WP-DU-4-Algae	3.4	2.5	0.19	0.006 U	13%	75%
Algae (M. tropicalis)	WP-DU-5-Algae	2.9	4.3	0.38	0.016 U	18%	148%
	Average:	**4.9**	**3.5**	**0.20**	**-**	**14%**	**87%**
Lokowaka Pond (Control site) Biota Species	**Sample ID**	**Total Arsenic (mg/kg)**	**Inorganic Arsenic (mg/kg)**	**Dimethyl Arsenic (mg/kg)**	**Monomethyl Arsenic (mg/kg)**	**Total Solids %**	**% Inorganic Arsenic**
Algae (M. tropicalis)	LW-DU-C-Algae	0.43	0.004 U	0.13	0.004 U	10%	0.9%

Notes: All data on wet weight basis; U= <MDL; B=>MDL but <MRL; N= Spike recovery off, estimate.

Table 5-4a. Samoan crab data (Waiakea Pond).

Biota Species	Sample ID	Length (mm)	Whole Weight (g)	Sample Weight (g)	Age - sex	Sample Type	Total Arsenic (mg/kg)	Inorganic Arsenic (mg/kg)	Dimethyl Arsenic (mg/kg)	Monomethyl Arsenic (mg/kg)	Total Solids	Inorganic Arsenic
Samoan crab	SS-W-S-J-4	75	82	82	Juv, male	whole	1.0 H	0.11* H	0.38 H	0.008 H,U	16.3%	10.9%
Samoan crab	SS-W-S-J-5	52	38	38	Juv, male	whole	1.4 H	0.18 H	0.31 H	0.007 H,B	37.3%	13.2%
Samoan crab	SS-W-S-J-7	70	79	79	Juv, male	whole	6.0 H	0.25 H	0.99 H	0.007 H,U	30.0%	4.1%
Samoan crab	SS-W-S-J-8	59	41	41	Juv size - but gravid female	whole	3.0 H	0.21 H	0.99 H	0.007 H,U	36.8%	7.2%
Samoan crab	SS-W-S-J-9	70	70	70	Juv, male	whole	1.2 H	0.14 H	0.36 H	0.014 H,U	34.7%	11.5%
Samoan crab	SS-W-S-J-10	62	60	60	Juv, male	whole	2.5 H	0.35 H	0.64 H	0.013 H,U	31.0%	14.2%
	Average:	**65**	**62**	**62**			**2.5**	**0.21**	**0.61**			**10.2%**
Samoan crab	SS-E-S-A-1	150	497	114	Adult, male	Meat (no shell or gills)	0.89 H	0.05* H	0.28 H	0.016 H,U	10.9%	5.8%
Samoan crab	SS-E-S-A-2	143	466	80	Adult, male	Meat (no shell or gills)	0.87 H	0.12 H	0.19 H	0.014 H,U	14.1%	13.7%
Samoan crab	SS-E-S-A-3	132	367	40	Adult, female	Meat (no shell or gills)	1.2 H	0.01 H	0.26 H	0.016 H,U	19.1%	1.0%
Samoan crab	SS-E-S-A-4	179	716	75	Adult, male	Meat (no shell or gills)	0.70 H	0.05 H	0.22 H	0.013 H,U	10.3%	7.2%
Samoan crab	SS-E-S-A-5	110	173	46	Adult,male	Meat (no shell or gills)	2.1 H	0.01 H	0.80 H	0.015 H,U	19.4%	0.5%
Samoan crab	SS-E-S-A-6	120	275	67	Adult, male	Meat (no shell or gills)	0.68 H	0.03 H	0.12 H	0.004 H,U	15.6%	4.1%
	Average:	**139**	**416**	**70**			**1.1**	**0.05**	**0.31**			**5.4%**
Samoan crab	SS-HP-S-A-1	150	497	24	Adult	Hepatopancreas (butter)	2.9 H	0.09 H	0.64 H	0.016 U,H	20.2%	2.9%
Samoan crab	SS-HP-S-A-3	132	367	59	Adult	Hepatopancreas (butter)	2.5 H	0.06 H	0.42 H	0.007 H,J,U	21.3%	2.3%
Samoan crab	SS-HP-S-A-4	179	716	67	Adult	Hepatopancreas (butter)	2.7 H	2.4 H	0.51 H	0.008 H,J,U	14.2%	90.3%
Samoan crab	SS-HP-S-A-5	110	173	16	Adult	Hepatopancreas (butter)	1.4 H	0.05 H	0.49 H	0.011 H,B	25.4%	3.4%
Samoan crab	SS-HP-S-A-6	120	275	34	Adult	Hepatopancreas (butter)	4.0 H	0.15 H	1.0 H	0.016 H,J,U	13.2%	3.8%
	Average:	**138**	**406**	**40**			**2.7**	**0.56**	**0.62**			**20.6% (3.1%)**
Samoan crab	SS-HP-S-A-2	143	466	35	Adult	Hepatopancreas (separate)	2.7 H	0.24 H	0.63 H	0.008 H,J,U	20.0%	8.8%
Samoan crab	SS-GI-S-A-2	143	466	49	Adult	Gastrointestinal tract	4.0 H	2.4 H	0.32 H	0.010 H,U	39.9%	59.0%

Note: All data on wet wt. basis; H= All samples received 18.3C, above required 0– 4C; U= <MDL; B=>MDL but <MRL; * Dup. precision issue - estimated; N= Spike recovery off, estimate.

Table 5-4b. Samoan crab data (control sites).

Lili'uokalani (Control site) Biota Species	**Sample ID**	**Length (mm)**	**Whole Weight (g)**	**Sample Weight (g)**	**Age - sex**	**Sample Type**	**Total Arsenic (mg/kg)**	**Inorganic Arsenic (mg/kg)**	**Dimethyl Arsenic (mg/kg)**	**Monomethyl Arsenic mg/kg)**	**Total Solids %**	**% Inorganic Arsenic**
Samoan crab	SS-W-C-J-1	65	67	67	Juv, male	whole	4.9	0.09	1.2	0.004 U	35.1%	1.80%
[1]Samoan crab	SS-W-C-J-2	64	64	64	Gravid female	whole	4.7	0.11	1.1	0.070 U	41.4%	2.30%
	Average:	**65**	**66**	**66**			**4.8**	**0.10**	**1.2**	**-**	**38.3%**	**2.05%**
He'eia Pond Biota Species	**Sample ID**	**Length (mm)**	**Whole Weight (g)**	**Sample Weight (g)**	**Age (sex)**	**Sample Type**	**Total Arsenic (mg/kg)**	**Inorganic Arsenic (mg/kg)**	**Dimethyl Arsenic (mg/kg)**	**Monomethyl Arsenic (mg/kg)**	**Total Solids %**	**% Inorganic Arsenic**
Samoan crab	SS-W-J-HP-1	177	302	302	Juv(male)	whole	2.0	0.052	0.058	0.004 U	30.9%	2.67%
Samoan crab	SS-W-J-HP-2	118	290	290	Juv(male)	whole	1.2	0.045	0.051	0.007 U	33.5%	3.91%
Samoan crab	SS-W-J-HP-3	109	196	196	Juv(male)	whole	0.62	0.034	0.030	0.004 U	24.0%	5.48%
[2]Samoan crab	SS-W-J-HP-4	106	188	188	Juv(female)	whole	2.0	0.081	0.077	0.003 U	29.2%	4.09%
Samoan crab	SS-W-J-HP-5	84	90	90	Juv(female)	whole	2.3	0.065	0.099	0.007 U	38.8%	2.81%
Average:	**Average:**	**119**	**213**	**213**			**1.6**	**0.055**	**0.063**			**3.79%**
Samoan crab	SS-M-A-HP-1A	202	1,920	620	Adult(male)	edible meat	8.6	0.008 B	0.023	0.003 U	17.3%	0.09%
Samoan crab	SS-O-A-HP-1B	202	1,920	142	Adult(male)	internal organs	2.9	0.006 B	0.017	0.004 U	15.8%	0.21%
Samoan crab	SS-M-A-HP-2A	181	1,564	488	Adult(male)	edible meat	9.8	0.009 B	0.037	0.004 U	17.4%	0.09%
Samoan crab	SS-O-A-HP-2B	181	1,564	128	Adult(male)	internal organs	4.2	0.009 B	0.038	0.003 U	13.2%	0.22%
[3]Samoan crab	SS-M-A-HP-3A	190	1,660	518	Adult(male)	edible meat	6.9	0.004 U	0.044	0.004 U	17.0%	0.06%
[4]Samoan crab	SS-O-A-HP-3B	190	1,660	130	Adult(male)	internal organs	3.1	0.011	0.035	0.004 U	21.5%	0.35%
Samoan crab	SS-M-A-HP-4A	176	1,364	453	Adult(male)	edible meat	6.5	0.006 B	0.049	0.003 U	17.7%	0.09%
Samoan crab	SS-O-A-HP-4B	176	1,364	84	Adult(male)	internal organs	3.1	0.013	0.037	0.004 U	16.5%	0.42%
Samoan crab	SS-M-A-HP-5A	163	854	296	Adult(male)	edible meat	8.2	0.004 U	0.172	0.007 U	20.0%	0.05%
Samoan crab	SS-O-A-HP-5B	163	854	108	Adult(male)	internal organs	4.7	0.015	0.083	0.004 U	34.5%	0.32%
[5]Samoan crab	SS-M-A-HP-6A	145	592	192	Adult(male)	edible meat	3.7	0.003 U	0.130	0.007 U	16.0%	0.08%
[6]Samoan crab	SS-O-A-HP-6B	145	592	70	Adult(male)	internal organs	2.9	0.023	0.064	0.004 U	18.1%	0.80%
	Average:	**176**	**1,326**	**269**	**edible meats - 6 adults**		**7.2**	**0.006**	**0.076**			**0.08%**
	Average:				**internal organs - 6 adults**		**3.5**	**0.013**	**0.046**			**0.39%**

Table 5-4b. Samoan crab data (cont.).

Notes:

1. Juvenile size.
2. Missing one front claw.
3. Missing two rear lower leg portions.
4. Missing two rear lower leg portions
5. Missing one rear lower leg portion.
6. Missing one rear lower leg portion.

Table 5-5a. Striped mullet data (Waiakea Pond).

Waiakea Pond Biota Species	Sample ID	Length (mm)	Whole Weight (g)	Sample Weight (g)	Age - sex	Sample Type	Total Arsenic (mg/kg)	Inorganic Arsenic (mg/kg)	Dimethyl Arsenic (mg/kg)	Monomethyl Arsenic (mg/kg)	Total Solids	Inorganic Arsenic
Striped mullet	MC-W-S-J-1	246	186	186	Juv	whole	3.3	0.159	0.043	0.004 U	34.4%	4.8%
Striped mullet	MC-W-S-J-2	234	167	167	Juv	whole	4.2	1.46	0.053	0.011 J,B	24.6%	34.7%
Striped mullet	MC-W-S-J-3	249	206	206	Juv	whole	1.9	0.865	0.088	0.004 U	23.7%	46.0%
Striped mullet	MC-W-S-J-4	256	222	222	Juv	whole	1.7	0.051	0.195	0.004 U	25.6%	3.1%
	Average:	**246**	**195**	**195**			**2.8**	**0.634**	**0.095**			22.1%
Striped mullet	MC-W-S-A-1	330	456	456	Adult	whole	1.4	0.004 U	0.199	0.004 U	27.5%	<0.29%
Striped mullet	MC-W-S-A-2	343	571	571	Adult	whole	2.2	0.009	0.031	0.004 U	31.6%	0.4%
Striped mullet	MC-W-S-A-3	359	595	595	Adult	whole	1.9	0.004 U	0.272	0.004 U	30.2%	<0.21%
Striped mullet	MC-W-S-A-4	350	567	567	Adult	whole	1.7	0.024	0.186	0.004 U	28.3%	1.4%
	Average:	**346**	**547**	**547**			**1.8**	**<0.010**	**0.172**			**<0.58%**
Striped mullet	MC-E-S-A-1	335	515	NA	Adult	scales, gills and organs removed	1.7	0.010	0.049	0.004 U	32.6%	0.6%
Striped mullet	MC-E-S-A-2	378	760	NA	Adult	scales, gills and organs removed	2.0	0.004 U	0.035	0.004 U	31.7%	<0.19%
Striped mullet	MC-E-S-A-3	400	931	NA	Adult	scales, gills and organs removed	2.3	0.004 U	0.057	0.004 U	33.6%	<0.17%
Striped mullet	MC-E-S-A-4	348	584	NA	Adult	scales, gills and organs removed	1.9	0.004 U	0.087	0.004 U	39.4%	<0.21%
	Average:	**365**	**698**				**2.0**	**<0.006**	**0.057**			**<0.29%**
Striped mullet	MC-S-S-A-1	NA	NA	60	Adult	Composite Scales (of 4 above)	0.19	0.130*	0.006 B	0.004 U	59.6%	70.3%
Striped mullet	MC-G-S-A-1	NA	NA	66	Adult	Composite Gills (of 4 above)	2.0	0.025	0.130	0.014 U	25.7%	1.2%
Striped mullet	MC-O-S-A-1	NA	NA	302	Adult	Composite Organs (of 4 above)	3.8	0.176	0.122	0.004 U	33.5%	4.7%

Note: All data on wet wt. basis; H = holding time issues from delayed shipment; U= <MDL; B=>MDL but <MRL; * Duplicate precision issue - estimated; J= estimated.

Table 5-5b. Striped mullet data (control sites).

Lokowaka (Control Site) Biota Species	Sample ID	Length (mm)	Whole Weight (g)	Sample Weight (g)	Age Sex	Sample Type	Total Arsenic (mg/kg)	Inorganic Arsenic (mg/kg)	Dimethyl Arsenic (mg/kg)	Monomethyl Arsenic (mg/kg)	Total Solids	Inorganic Arsenic
Striped mullet	MC-W-C-A-1	356	611	611	Adult	whole	0.67	0.004 U	0.008	0.004 U	36.8%	<0.60%
Striped mullet	MC-W-C-A-2	363	630	630	Adult	whole	0.75	0.004 U	0.005	0.003 U	32.0%	<0.53%
Striped mullet	MC-W-C-A-3	363	576	576	Adult	whole	1.07	0.004 U	0.008	0.004 U	38.0%	<0.37%
Striped mullet	MC-W-C-A-4	345	502	502	Adult	whole	1.10	0.004 U	0.013	0.004 U	36.7%	<0.36%
	Average:	**357**	**580**	**580**			**0.90**	**<0.004**	**0.009**			**<0.46%**
Striped mullet	MC-E-C-A-1	398	786	NA	Adult	scales, gills and organs removed	0.55	0.004 U	0.004 U	0.004 U	32.7%	<0.72%
Striped mullet	MC-E-C-A-2	379	712	NA	Adult	scales, gills and organs removed	0.79	0.004 U	0.010 B	0.004 U	36.2%	<0.50%
Striped mullet	MC-E-C-A-3	384	724	NA	Adult	scales, gills and organs removed	0.61	0.003 U	0.012	0.003 U	29.4%	<0.49%
Striped mullet	MC-E-C-A-4	369	635	NA	Adult	scales, gills and organs removed	1.12	0.003 U	0.023	0.004 U	34.7%	<0.27%
	Average:	**383**	**714**				**0.77**	**<0.004**	**<0.01**			**<0.50%**
Striped mullet	MC-S-C-A-1	NA	NA	60	Adult	Composite Scales (of 4 above)	0.13	0.003 U	0.004 U	0.004 U	57.8%	<2.3%
Striped mullet	MC-G-C-A-1	NA	NA	76	Adult	Composite Gills (of 4 above)	0.98	0.004 U	0.031	0.004 U	29.4%	<0.41%
Striped mullet	MC-O-C-A-1	NA	NA	180	Adult	Composite Organs (of 4 above)	2.0	0.003 U	0.048	0.004 U	35.3%	<0.15%

Note: All data on wet wt. basis; H = holding time issues from delayed shipment; U= <MDL; B=>MDL but <MRL; * Duplicate precision issue - estimated; J= estimated.

Table 5-6a. Marquesan mullet data (Waiakea Pond).

Waiakea Pond Biota Species	Sample ID	Length (mm)	Whole Weight (g)	Sample Weight (g)	Age Sex	Sample Type	Total Arsenic (mg/kg)	Inorganic Arsenic (mg/kg)	Dimethyl Arsenic (mg/kg)	Monomethyl Arsenic (mg/kg)	Total Solids %	% Inorganic Arsenic
Marquesan mullet	VE-W-S-J-1	146	39	39	Juv	whole	1.5 H	0.075 H	0.199 H	0.016 H,U	33.27	5
Marquesan mullet	VE-W-S-J-2	150	46	46	Juv	whole	2.4 H	0.036 H	0.216 H	0.007 H,U	34.5	1.5
Marquesan mullet	VE-W-S-J-3	156	50	50	Juv	whole	2.5 H	0.063 H	0.207 H	0.007 H,U	33.58	2.5
Marquesan mullet	VE-W-S-J-4	164	55	55	Juv	whole	1.7 H	0.097 H	0.137 H	0.007 H,U	34.64	5.7
	Average:	154	48	48			**2.0**	**0.068**	**0.190**			**3.70**
Marquesan mullet	VE-W-S-A-1	200	110	110	Adult	whole	4.5 H	4.60 H	0.114 H	0.068 H,J	31.76	101.8
Marquesan mullet	VE-W-S-A-2	197	97	97	Adult	whole	1.6 H	0.069 H	0.158 H	0.007 H,U	29.14	4.3
Marquesan mullet	VE-W-S-A-3	209	126	126	Adult	whole	1.4 H	0.019 H	0.092 H	0.003 H,U	34.69	1.3
Marquesan mullet	VE-W-S-A-4	203	104	104	Adult	whole	1.7 H	0.035 H	0.170 H	0.004 H,U	33.43	2.1
	Average:	**202**	**109**	**109**			**2.3**	**1.18 (0.041)**	**0.134**			**27.4 (2.6)**
Marquesan mullet	VE-E-SA-1	198	103	NA	Adult	scales, gills and organs removed	1.5	0.060	0.057	0.003 U	29.53	3.9
Marquesan mullet	VE-E-SA-2	195	108	NA	Adult	scales, gills and organs removed	2.4	0.004 U	0.071	0.004 U	35.33	0.17
Marquesan mullet	VE-E-SA-3	207	108	NA	Adult	scales, gills and organs removed	0.82	0.004 U	0.033	0.004 U	28.98	0.49
Marquesan mullet	VE-E-SA-4	204	107	NA	Adult	scales, gills and organs removed	1.5	0.017	0.054	0.004 U	30.01	1.1
	Average:	**201**	**107**				**1.6**	**0.021**	**0.054**			**1.42**
Marquesan mullet	VE-S-S-A-1	NA	NA	18	Adult	Composite Scales (of 4 above)	0.27	0.161	0.006 B	0.004 U	71.73	**59.6**
Marquesan mullet	VE-G-S-A-1	NA	NA	11	Adult	Composite Gills (of 4 above)	1.4	0.199	0.126	0.004 U	27.44	**13.8**
Marquesan mullet	VE-O-S-A-1	NA	NA	49	Adult	Composite Organs (of 4 above)	8.9	4.49	0.121	0.018 J,B	32.62	**50.7**

Note: All data on wet wt. basis; H = holding time issues from delayed shipment; U= <MDL; B=>MDL but <MRL; N= Spike recovery off, estimated value; J= estimated value.

Table 5-7b. Marquesan mullet data (control sites).

Pelekane Bay (Control Site) Biota Species	Sample ID	Length (mm)	Whole Weight (g)	Sample Weight (g)	Age Sex	Sample Type	Total Arsenic (mg/kg)	Inorganic Arsenic (mg/kg)	Dimethyl Arsenic (mg/kg)	Monomethyl Arsenic (mg/kg)	Total Solids %	% Inorganic Arsenic
Marquesan mullet	VE-W-K-J-1	146	42	42	Juv	whole	2.2 H	0.493 H	0.120 H,J	0.004 H,J,U	30.52	20.3
Marquesan mullet	VE-W-K-J-2	146	43	43	Juv	whole	1.9 H	0.384 H	0.050 H,J	0.004 H,U	29.73	20.2
Marquesan mullet	VE-W-K-J-3	146	44	44	Juv	whole	1.1 H	0.390 H	0.042 H,J	0.004 H,J,B	30.1	35.8
Marquesan mullet	VE-W-K-J-4	147	41	41	Juv	whole	1.9 H	0.582 H	0.071 H,J	0.008 H,B	33.22	30.8
	Average:	**146**	**43**	**43**			**1.8**	**0.462**	**0.071**			**26.8**
Marquesan mullet	VE-W-K-A-1	167	68	68	Adult	whole	1.7 H	0.443 H	0.115 H	0.008 H,B	32.4	25.8
Marquesan mullet	VE-W-K-A-2	174	80	80	Adult	whole	1.8 H	0.501 H	0.054 H	0.005 H,B	36.03	28
Marquesan mullet	VE-W-K-A-3	166	70	70	Adult	whole	1.8 H	0.216 H	0.026 H,J	0.004 H,U	34.88	12.3
Marquesan mullet	VE-W-K-A-4	171	74	74	Adult	whole	1.4 H	0.334 H	0.061 H,J	0.004 H,J,U	31.35	23.4
	Average:	**170**	**73**	**73**			**1.7**	**0.374**	**0.064**			**22.3**
Australian mullet	VE-E-K-A-1	200	111	76	Adult	scales, gills and organs removed	0.48	0.013 H	0.035 H,J	0.004 H,N,U	25.75	2.7
Australian mullet	VE-E-K-A-2	176	84	56	Adult	scales, gills and organs removed	0.76	0.018 H	0.071 H,J	0.004 H,U	23.78	2.4
Australian mullet	VE-E-K-A-3	176	82	55	Adult	scales, gills and organs removed	0.71	0.041 H	0.041 H,J	0.004 H,U	27.64	5.8
Australian mullet	VE-E-K-A-4	180	89	60	Adult	scales, gills and organs removed	0.73	0.030 H	0.074 H,J	0.004 H,U	25.48	4.1
	Average:	**183**	**92**	**62**			**0.67**	**0.026**	**0.055**			**3.74**
Marquesan mullet	VE-S-K-A-1	NA	NA	16	Adult	Composite Scales (of 4 above)	0.58 H	0.419 H	0.007 H,B	0.004 H,U	76.37	**72.2**
Marquesan mullet	VE-G-K-A-1	NA	NA	8	Adult	Composite Gills (of 4 above)	0.98 H	0.119 H	0.050 H	0.004 H,U	28.48	**12.2**
Marquesan mullet	VE-O-K-A-1	NA	NA	74	Adult	Composite Organs (of 4 above)	2.4 H	0.487 H	0.047 H	0.005 H,B	35.33	**20.2**

Note: All data on wet wt. basis; H = holding time issues from delayed shipment; U= <MDL; B=>MDL but <MRL; N= Spike recovery off, estimated value; J= estimated value.

Figures

Figure 1-1. Location of Waiakea Pond study site in Hilo, Hawaii.

Figure 1-2. View of Waiakea Pond in Hilo, Hawaii (looking north from footbridge across center of pond).

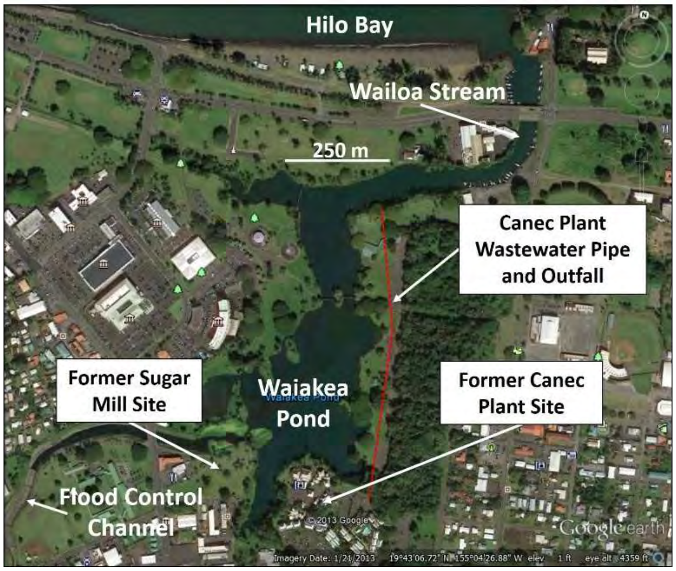


Figure 1-3. Setting and former industrial activities associated with Waiakea pond area.

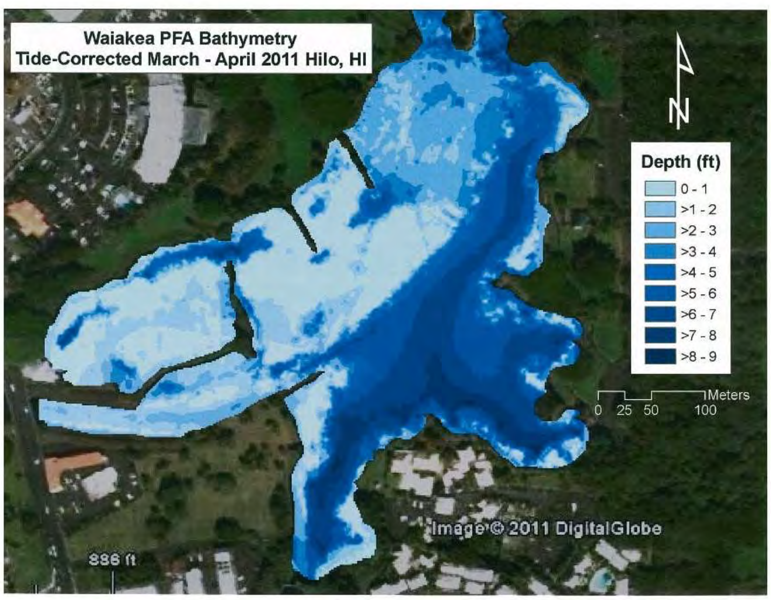


Figure 1-4. Bathometric map of Waiakea Pond (DLNR 2011).

Figure 1-5. 1932 photo of canec plant (lower right) on mauka (south) edge of Waiakea Pond. Waiakea Sugar Mill shown to left of plant.

Figure 2-1. Approximate location of sediment cores and samples collected as part of an investigation carried out by the University of Hawaii-Hilo in 1985 (after Hallacher et al. 1985).

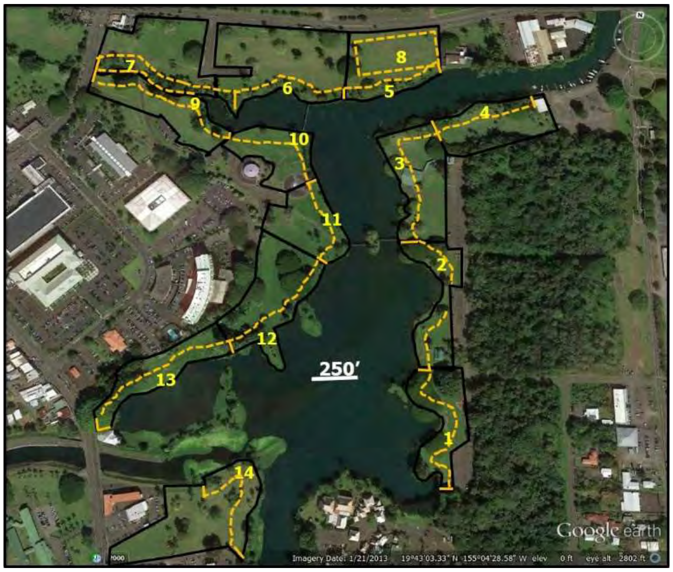


Figure 2-2. Soil Decision Unit areas tested as part of a 2013 Hawaii Department of Health investigation of arsenic in soil around the immediate perimeter of Waiakea Pond in Wailoa River State Recreation Area (HDOH 2013).

Figure 3-1. Decision Units (DU) designated for the collection of Multi Increment sediment samples from Waiakea Pond.

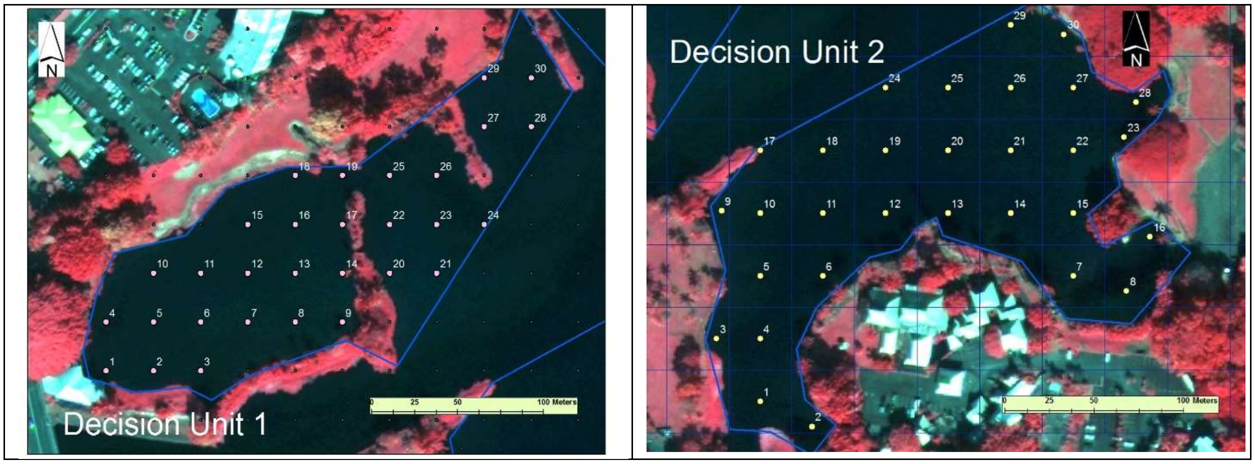


Figure 3-2. Example, computer-generated increment locations for the collection of a Multi Increment sediment sample from DU 1 and DU 2.

Figure 3-3. Use of core sampling tube to collect increments for the preparation of Multi Increment sediment samples. Left Photo: Core sampler attached to valve and push rod. Middle Photo: Manual collection of sediment core increment from skiff. Right Photo: Individual core increments collected from a sediment DU.

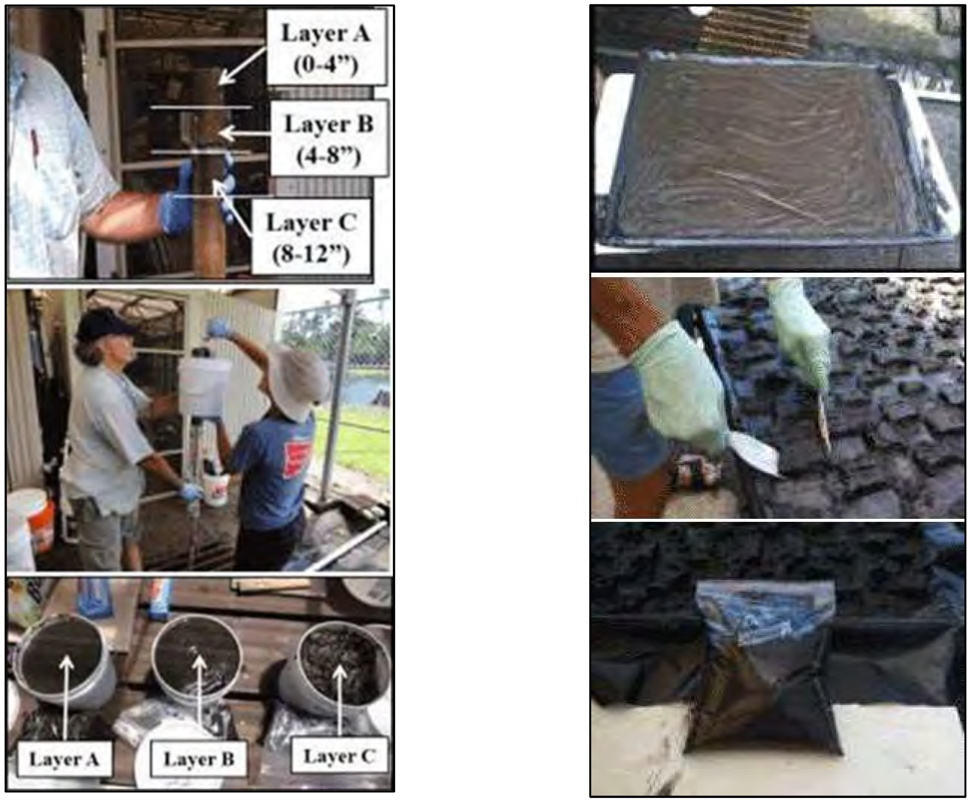


Figure 3-4. Preparation of Multi Increment sediment samples.
Left - Removal and combination of Sediment Core Increments from Sampling Tubes. Upper Photo: Target DU layers in a core increment. Middle Photo: Removal of increment by forcing sampling tube downward on a plunger; target DU layers removed from core and placed in dedicated container for combination with increments from other cores collected from the DU. Lower Photo: initial bulk Multi Increment samples prepared by combination of core increments for each DU layer.

Right- Field Subsampling of a bulk sample to reduce mass for submittal to laboratory. Upper Photo: Sample spread out into a 0.5 inch layer; large rocks and debris removed. Middle Photo: Flat-edge spatulas used to collect subsamples in a systematic, grid fashion. Lower Photo: Bulk Multi Increment sample prepared by representative subsampling, for shipment to the laboratory.

a) 

b) 

c) 

d) 

Figure 3-5. a) Samoan crab, b: brown algae, c) Striped mullet and d) Marquesan mullet. Refer to Appendix D for additional, project-related photos.

Figure 4-1. Lokowaka Pond control site in Hilo on Hawaii Island.

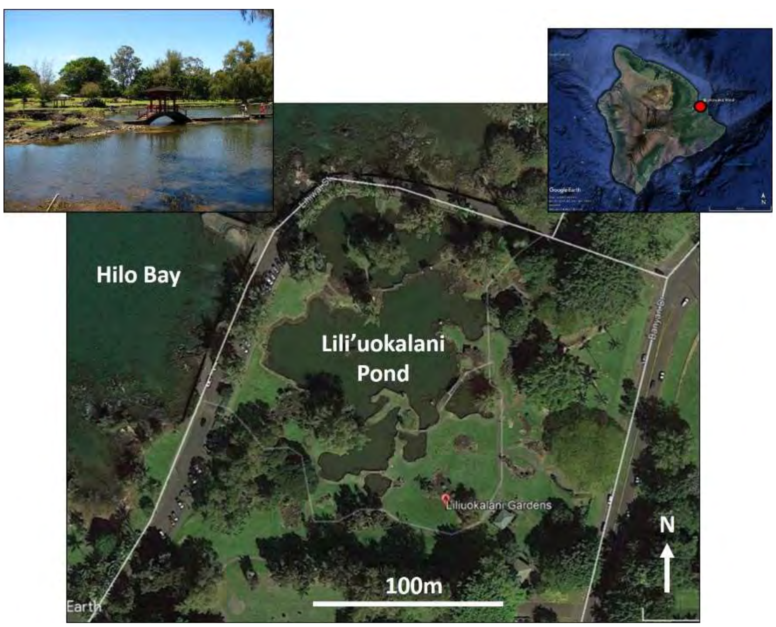


Figure 4-2. Lili'uokalani Pond control site in Hilo on Hawaii Island.

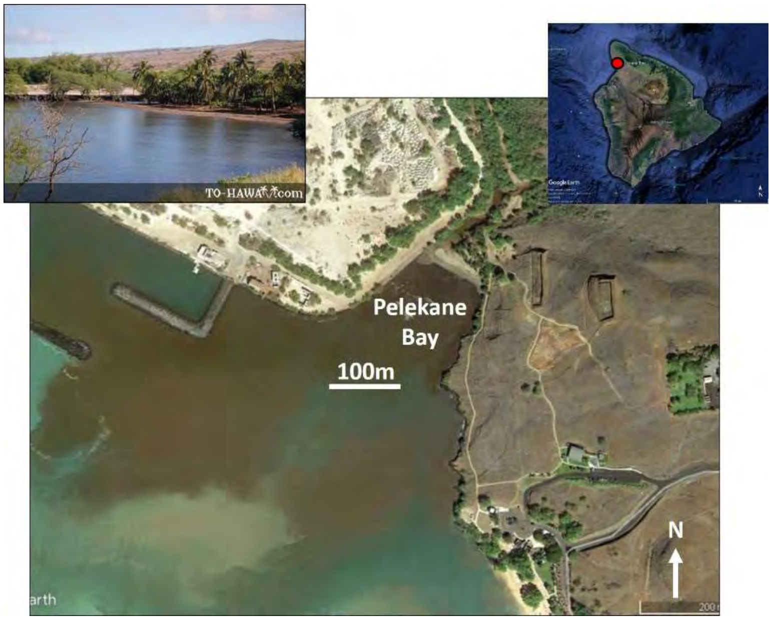
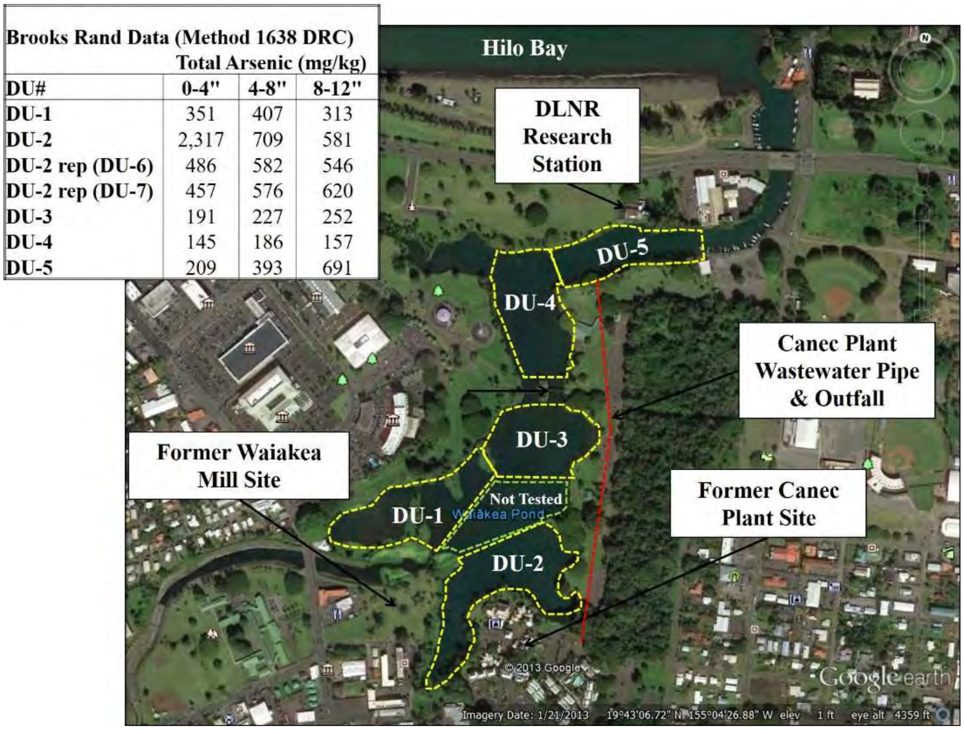


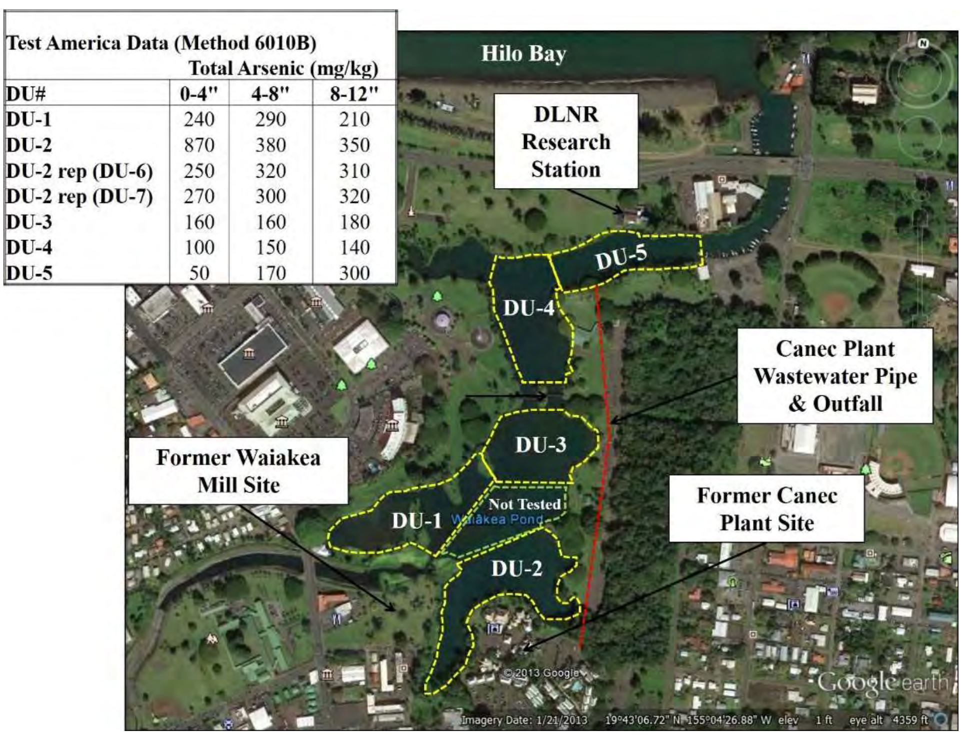
Figure 4-3. Pelekane Bay control site in Kawaihae on the Hawaii Island.

Figure 4-4. He'eia Pond control site in Kane'ohe on O'ahu.



Brooks Rand Data (Method 1638 DRC)	Total Arsenic (mg/kg)		
DU#	0-4"	4-8"	8-12"
DU-1	351	407	313
DU-2	2,317	709	581
DU-2 rep (DU-6)	486	582	546
DU-2 rep (DU-7)	457	576	620
DU-3	191	227	252
DU-4	145	186	157
DU-5	209	393	691

Figure 5-1a. Summary of Test America arsenic data for sediment samples collected from Waiakea Pond as part of this study.



Test America Data (Method 6010B)	Total Arsenic (mg/kg)		
DU#	0-4"	4-8"	8-12"
DU-1	240	290	210
DU-2	870	380	350
DU-2 rep (DU-6)	250	320	310
DU-2 rep (DU-7)	270	300	320
DU-3	160	160	180
DU-4	100	150	140
DU-5	50	170	300

Figure 5-1b. Summary of Brooks Rand arsenic data for sediment samples collected from Waiakea Pond as part of this study.

Appendices

Appendix A

Arsenic Contamination in Waiakea Pond:

Ecological and Human Concerns (HDOH 2019)

The **Hazard Evaluation and Emergency Response (HEER) Office** is part of the Hawaiʻi Department of Health's Environmental Health Administration whose mission is to protect human health and the environment. The HEER Office provides leadership, support, and partnership in preventing, planning for, responding to and enforcing environmental laws relating to releases or threats of releases of hazardous substances.

Arsenic in Waiakea Pond: Ecological and Human Concerns

This fact sheet provides an overview of the potential ecological and human health concerns associated with arsenic in Waiakea Pond. Waiakea Pond is a 40-acre, spring- and stream-fed estuary in Hilo, Hawaiʻi that drains into Hilo Bay. The pond is tidally influenced with a maximum depth of approximately 12 feet. Swimming is not allowed in most areas of Waiakea Pond, however it is a popular area for recreational mullet fishing area. Other fish and crab are also taken for human consumption and Waiakea Pond is an important habitat for many birds.

What is arsenic and why is it in Waiakea Pond?

Arsenic is a naturally occurring element in the earth's crust. The natural background concentration of arsenic in volcanic soils in Hawaiʻi ranges from 5 milligrams per kilogram [mg/kg] to 25 mg/kg. This is roughly equal to a sand grain-sized nugget of arsenic in 1 to 5 double handfuls of soil. These concentrations of arsenic are below levels that pose a health risk to humans.

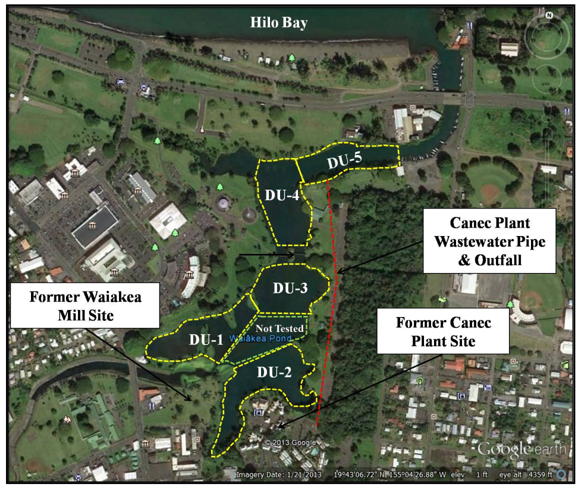
The presence of arsenic in the sediment of Waiakea Pond has been known for some time. Most of this arsenic is related to human activities and is not naturally occurring. The arsenic contamination comes from a mixture of sources, including a former canec plant and former sugar mill on the mauka edges of the pond plus erosion and runoff of soil from former cane fields in upland areas.

Wastewater contaminated with inorganic arsenic was discharged into Waiakea Pond from a canec plant that operated on the southeast corner of the pond from 1932 to 1963. Canec board was made from pressed waste sugarcane fiber and widely used for ceilings or walls in home and commercial buildings in Hawaiʻi (see *Arsenic in Canec Ceilings and Wallboard in Hawaiʻi* fact sheet). Inorganic arsenic was added to the canec as a termiticide. An estimated 500 tons of arsenic compounds were released into Waiakea Pond from the plant's sewer line on the east side of the pond.

Sodium arsenite (an inorganic arsenic compound) and other arsenic-based herbicides and pesticides were used in and around sugarcane fields in the Hilo area from the 1910s through 1940s. Sugarcane harvested from the fields was brought to a sugar mill that operated on the southwest side of the pond during this time period, where it was washed and then processed. Dirt washed from the cane likely contributed to arsenic contamination of sediments in the pond. Erosion and runoff of soil from former cane fields in upland areas contributed to impacts of pond sediment and continues to a lesser degree today.

Does arsenic in the Waiakea Pond sediment pose a health risk?

Several, limited studies of arsenic in the sediment and biota of Waiakea Pond have been carried out over the past 30 years. From 2013 to 2015, HDOH conducted a more detailed study of Waiakea Pond in order to more carefully determine levels of arsenic in sediment, mullet, crabs and algae, and evaluate possible risk to humans and wildlife. A copy of the study report is available from the Department of Health HEER Office in Pearl City.



TOP: Map of Waiakea Pond showing the location of the former sugar mill and canec plant as well as the wastewater pipe and outfall. For sampling purposes, the pond was divided into 5 sections (labeled as "DU"). Sediment from each area was sampled to determine arsenic levels related to the use of arsenic in the mill, plant and nearby cane fields in the early 1900s.

BOTTOM: **Sediment sampling at Waiakea Pond.**

The study included testing of the top three layers of sediment in the pond for arsenic (0-4", 4-8" and 8-12"). Samples were tested for both inorganic arsenic and organic arsenic. Concentrations of >100 mg/kg total arsenic were reported for most of the sediment samples collected from the pond, indicating a significant increase above natural background. Almost all of the arsenic was the inorganic form. The highest total arsenic concentrations were reported for sediment located adjacent to the former canec plant. Deeper sediments near the former canec plant wastewater discharge pipe also had a high concentration of arsenic.

The reported concentrations of are far below any level that might pose immediate health concerns if a young child or adult accidentally ingested some of the sediment in a single episode. The concentrations were high enough, however, to raise initial concerns about repeated exposure to the sediment over many years. More detailed testing of the sediment was therefore carried out to determine the "bioaccessibility" of the arsenic. This determines the ability of the arsenic to leach from the sediment and into a person's body if small amounts of the sediment are swallowed. The test results indicated that the arsenic is too tightly bound to natural iron in the sediment to be released in the stomach or intestines in significant amounts. This means that the arsenic does not get absorbed in the body and is eliminated in feces with other components of the soil. This has also been found for elevated levels of arsenic in other soils associated with former sugarcane fields in the Hilo area. Arsenic in the pond sediment therefore does not pose a health risk to children and adults who regularly use the park.

Am I at risk if I eat fish or shellfish from Waiakea Pond?

Striped mullet (*Mugil cephalus*), Marquesan mullet (*Valamugil engeli*), snapper (*Lutjanus fulvus*), goatfish (*Mulloides vanicolensis*), Hawaiian flagtail (*Kuhlia sandvicensis*), white crab (*Portunus sanguinolentus*) and the Samoan crab (*Scylla serrata*) are all found in Waiakea Pond. At least 25 bird species, including the endangered Hawaiian coot (*Fulica alai*) and the Hawaiian duck (*Anas wyvilliana*) have been documented at the pond.

HDOH collected and tested samples of mullet and crab from the pond as part of the study. The tests used the edible portion of the fish and shellfish to assess human health risk and to make advisory determinations.

Arsenic was measured in the tissue of striped mullet, Marquesan mullet, Samoan crab, and algae (*Melosire* species) in Waiakea Pond. Arsenic levels were compared with the same species collected from other locations in the islands that have not been impacted by arsenic contamination. These species were chosen to determine the potential effects from ingesting plants, fish, shellfish, and the incidental ingestion of sediments from Waiakea Pond.

Despite very high total arsenic and inorganic arsenic levels in sediments at Waiakea Pond, striped and Marquesan mullet species as well as crabs collected from Waiakea Pond and estuary did not have elevated levels of inorganic arsenic compared to natural, reference site locations. In addition, arsenic in shellfish and fish is primarily organic arsenic, a different chemical form than inorganic arsenic used at former sugar plantations, in canec board products and for wood treatment. Organic arsenic in fish and shellfish is not considered toxic to humans. Fish and shellfish taken from Waiakea Pond are therefore considered safe to consume. Arsenic was slightly elevated in samples of brown algae from the pond in comparison to algae from other ponds. While this species of algae is not known to be regularly consumed by humans, concentrations were within the range of arsenic typically found in algae (limu) in marine environments and are not considered to pose a significant health risk to anyone who might occasionally eat small amounts of the algae.

What are the human health concerns of arsenic exposure?

People who have been exposed to very high levels of arsenic over long periods of time have had health problems that include changes in skin pigmentation (dark spots), thickening or warts on 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.

Although elevated above natural background, levels of arsenic reported for sediment and algae in Waiakea Pond are not high enough to pose immediate or long-term health risks to park users. That said, it remains a good idea to practice good hygiene to minimize exposure to sediment and algae in the pond.

Is all arsenic absorbed in the human body?

Not all arsenic is available for absorption into the body if accidentally ingested. Only a certain portion, called the "bioavailable" arsenic fraction, becomes soluble and is taken up into the body, where it could pose a potential health risk. The fraction of bioavailable arsenic in soil (or sediment) is estimated by the use of a laboratory test referred to as the "SBRC gastric-phase assay." The test estimates the amount of "bioaccessible" arsenic in the soil, or the amount or arsenic that would be accessible for uptake in the body if the soil was accidentally swallowed. Tests of arsenic-contaminated soil in Hawaii consistently indicate that the bioaccessibility, and therefore potential bioavailability, is very low. This is because the arsenic is tightly bound to naturally occurring iron in the soil. This helps to reduce risk posed by routine exposure to the soil.

Arsenic does not accumulate in the body (bioaccumulate). Stopping exposure will reduce arsenic levels in the body. For more information on arsenic bioaccessibility and testing, refer to the *Arsenic in Hawaiian Soils: Questions and Answers on Health Concerns* fact sheet.

How can I test to see if I have been exposed to arsenic?

Any arsenic exposure testing should be recommended and conducted by a doctor or trained medical professional. Tests are available to measure arsenic in your urine, blood, hair or fingernails. HDOH has not generally recommended human exposure testing in former sugarcane plantation areas. The urine arsenic test is considered the most reliable but can only determine exposure within the prior few days. The testing can determine if the level of arsenic in the body is higher or lower than the average person. The testing cannot determine the origin of the arsenic (e.g. soil or food) or whether the arsenic levels in the body will affect the individual's health. Urine arsenic testing (by HDOH and the federal Agency for Toxic Substances Disease Registry [ATSDR]) of people living near two Hawaiʻi Island community gardens with elevated soil arsenic found normal arsenic levels in most individuals tested. The tests could not determine if higher inorganic arsenic exposures measured in some older individuals was from soil ingestion or their rice and seafood diets.

What can I do to minimize exposure to arsenic?

If testing reveals elevated levels of inorganic arsenic in urine or you are concerned about exposure to arsenic in the soil and sediment in and around Waiakea Pond, options for limiting exposure include:

- Keep children from playing in bare areas of soil around Waiakea Pond and from contacting sediment in the pond;
- Keep toys, pacifiers and other items that go into children's mouths clean;
- Wash hands and face thoroughly after visiting the pond area, especially before meals and snacks;
- Wash all fish and shellfish from Waiakea Pond to remove any remaining sediment particles before eating;
- Avoid eating algae (limu) from Waiakea Pond.

Further Information

For questions about this fact sheet or further information on HEER Office guidance related to soil arsenic, contact:

Hawaiʻi Department of Health,
Hazard Evaluation and Emergency Response Office
2385 Waimano Home Road, #100
Pearl City, Hawaiʻi 96782
Telephone: (808) 586-4249

To access more detailed information regarding soil arsenic, including detailed reports of studies conducted in Hawaiʻi and elsewhere, please visit the HEER Office website: http://hawaii.gov/doh/heer

Additional references located on HEER Office website:

Homeowner's Guide to Soil Testing for Arsenic HDOH, 2008.

Arsenic in Canec Ceilings and Wallboard in Hawaiʻi (Fact Sheet) HDOH, 2010.

Federal Government

To learn about recommendations from the Federal Government regarding arsenic, you can also contact the Agency for Toxic Substances and Disease Registry, ToxFAQs internet address http://www.atsdr.cdc.gov/toxfaq.html

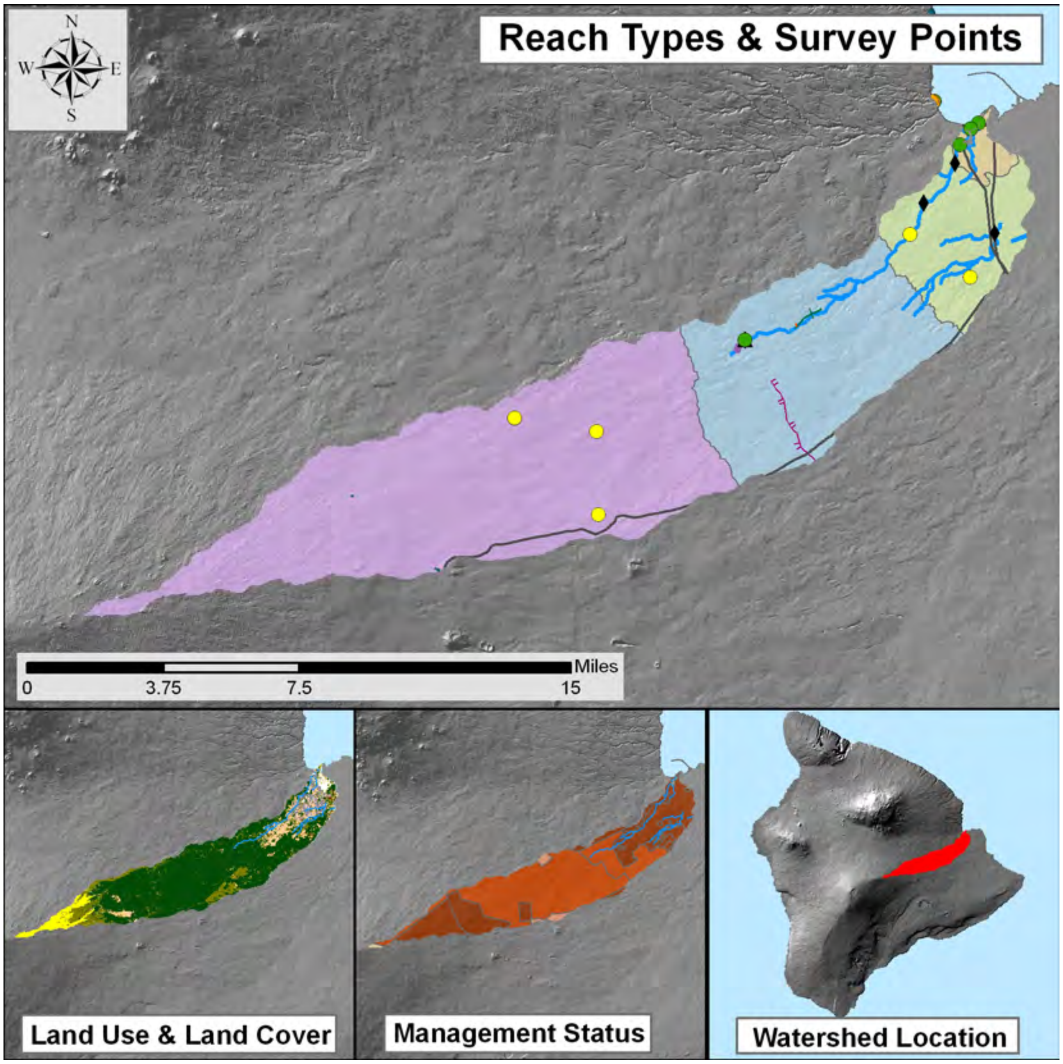
This fact sheet was created with assistance and funding from USEPA's Region 9 Superfund Division.

Appendix B

Summary of Wailoa Watershed (HDLNR-BM 2008)

DAR Watershed Code: 82061

Wailoa River, Hawai‘i



WATERSHED FEATURES

Wailoa River watershed occurs on the island of Hawai‘i. The Hawaiian meaning of the name is “long water”. The area of the watershed is 98.6 square mi (255.4 square km), with maximum elevation of 9724 ft (2964 m). The watershed's DAR cluster code is not yet determined. The percent of the watershed in the different land use districts is as follows: 20.4% agricultural, 70.9% conservation, 0% rural, and 8.7% urban.

Land Stewardship: Percentage of the land in the watershed managed or controlled by the corresponding agency or entity. Note that this is not necessarily ownership.

Military	Federal	State	OHA	County	Nature Conservancy	Other Private
0.0	0.3	71.2	0.0	0.0	0.0	28.4

Land Management Status: Percentage of the watershed in the categories of biodiversity protection and management created by the Hawaii GAP program.

Permanent Biodiversity Protection	Managed for Multiple Uses	Protected but Unmanaged	Unprotected
0.3	1.7	56.5	41.4

Land Use: Areas of the various categories of land use. These data are based on NOAA C-CAP remote sensing project.

	Percent	Square mi	Square km
High Intensity Developed	1.2	1.21	3.13
Low Intensity Developed	2.7	2.64	6.85
Cultivated	0.5	0.50	1.30
Grassland	7.8	7.74	20.05
Scrub/Shrub	14.6	14.43	37.37
Evergreen Forest	67.7	66.80	173.02
Palustrine Forested	0.0	0.00	0.00
Palustrine Scrub/Shrub	0.0	0.00	0.00
Palustrine Emergent	0.0	0.00	0.00
Estuarine Forested	0.0	0.00	0.00
Bare Land	5.3	5.23	13.55
Unconsolidated Shoreline	0.0	0.00	0.00
Water	0.1	0.05	0.13
Unclassified	0.0	0.00	0.00

STREAM FEATURES

Wailoa River is a perennial stream. Total stream length is 25.2 mi (40.6 km). The terminal stream order is 3.

Reach Type Percentages: The percentage of the stream's channel length in each of the reach type categories.

Estuary	Lower	Middle	Upper	Headwaters
4.2	6.3	54.1	35.3	0.0

The following stream(s) occur in the watershed:

flood channel Ka‘ahakini Waiākea Wailoa

BIOTIC SAMPLING EFFORT

Biotic samples were gathered in the following year(s):

1968 1992 1994 1997 2001

Distribution of Biotic Sampling: The number of survey locations that were sampled in the various reach types.

Survey type	Estuary	Lower	Middle	Upper	Headwaters
Damselfly Surveys	0	0	2	0	2
Published Report	3	1	0	1	0

BIOTA INFORMATION

Species List

Native Species

Crustaceans	*Macrobrachium grandimanus*
Fish	*Awaous guamensis*
	Eleotris sandwicensis
	Lentipes concolor
	Sicyopterus stimpsoni
	Stenogobius hawaiiensis
Worms	*Myzobdella lugubris*

Introduced Species

Fish	*Cyprinus carpio*
	Poecilia sphenops
	Xiphophorus helleri
Worms	*Ascocotyle tenuicollis*
	Bothriocephalus acheilognathi
	Camallanus cotti
	Cystobranchus sp.

Native Species

Insects	*Megalagrion blackburni*
	Megalagrion calliphya
	Megalagrion hawaiiense
	Megalagrion xanthomelas

Species Distributions: Presence (P) of species in different stream reaches.

Scientific Name	Status	Estuary	Lower	Middle	Upper	Headwaters
Macrobrachium grandimanus	Endemic		P			
Eleotris sandwicensis	Endemic		P			
Lentipes concolor	Endemic	P				
Sicyopterus stimpsoni	Endemic		P			
Stenogobius hawaiiensis	Endemic		P			
Megalagrion blackburni	Endemic			P		
Megalagrion calliphya	Endemic					P
Megalagrion hawaiiense	Endemic					P
Megalagrion xanthomelas	Endemic			P		
Awaous guamensis	Indigenous	P	P			
Cyprinus carpio	Introduced		P			
Poecilia sphenops	Introduced		P			
Xiphophorus helleri	Introduced		P			

HISTORIC RANKINGS

Historic Rankings: These are rankings of streams from historical studies. "Yes" means the stream was considered worthy of protection by that method. Some methods include non-biotic data in their determination. See Atlas Key for details.

Multi-Attribute Prioritization of Streams - Potential Heritage Streams (1998): No

Hawaii Stream Assessment Rank (1990): Substantial

U.S. Fish and Wildlife Service High Quality Stream (1988): No

The Nature Conservancy- Priority Aquatic Sites (1985): No

National Park Service - Nationwide Rivers Inventory (1982): No

Current DAR Decision Rule Status: The following criteria are used by DAR to consider the biotic importance of streams. "Yes" means that watershed has that quality.

Native Insect Diversity > 19 spp.	Native Macrofauna Diversity > 5 spp.	Absence of Priority 1 Introduced
Yes	Yes	No

Abundance of Any Native Species	Presence of Candidate Endangered Species	Endangered Newcomb's Snail Habitat
Yes	Yes	No

CURRENT WATERSHED AND STREAM RATINGS

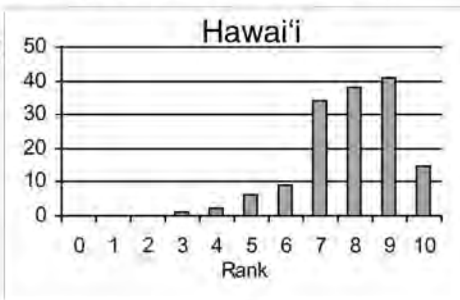
The current watershed and stream ratings are based on the data contained in the DAR Aquatic Surveys Database. The ratings provide the score for the individual watershed or stream, the distribution of ratings for that island, and the distribution of ratings statewide. This allows a better understanding of the meaning of a particular ranking and how it compares to other streams. The ratings are standardized to range from 0 to 10 (0 is lowest and 10 is highest rating) for each variable and the totals are also standardized so that the rating is not the average of each component rating. These ratings are subject to change as more data are entered into the DAR Aquatic Surveys Database and can be automatically recalculated as the data improve. In addition to the ratings, we have also provided an estimate of the confidence level of the ratings. This is called rating strength. The higher the rating strength the more likely the data and rankings represent the actual condition of the watershed, stream, and aquatic biota.

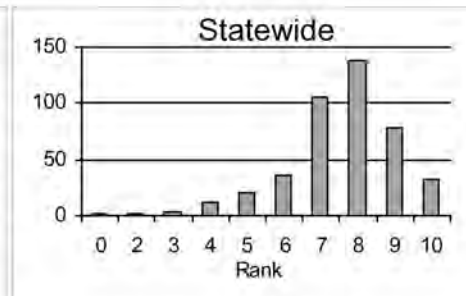
WATERSHED RATING: Wailoa River, Hawai'i

Land Cover Rating: Rating is based on a scoring sytem where in general forested lands score positively and developed lands score negatively.

Watershed Rating

9

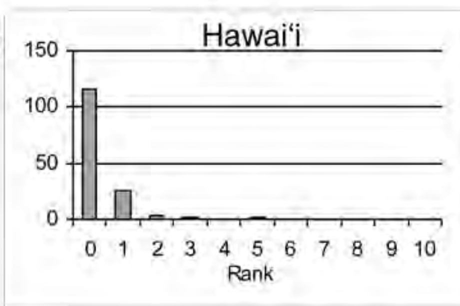


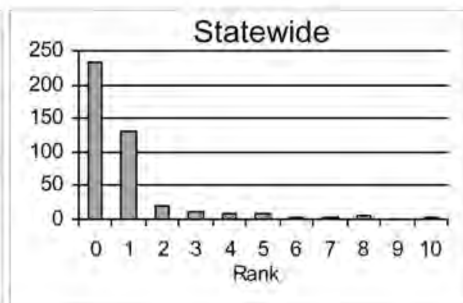


Shallow Waters Rating: Rating is based on a combination of the extent of estuarine and shallow marine areas associated with the watershed and stream.

Watershed Rating

5

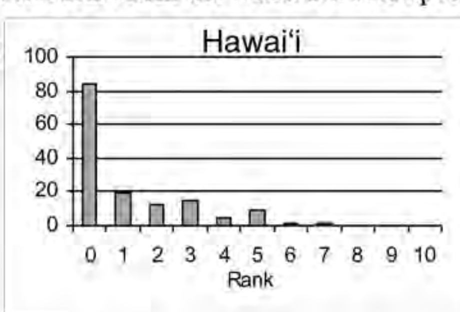


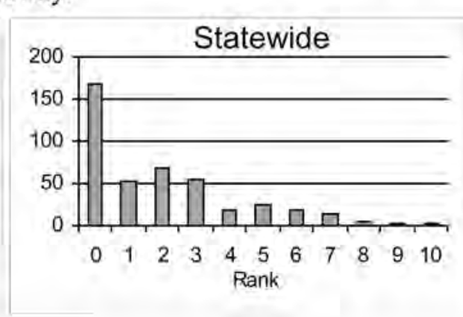


Stewardship Rating: Rating is based on a scoring system where higher levels of land and biodiversity protection within the watershed score positively.

Watershed Rating

2

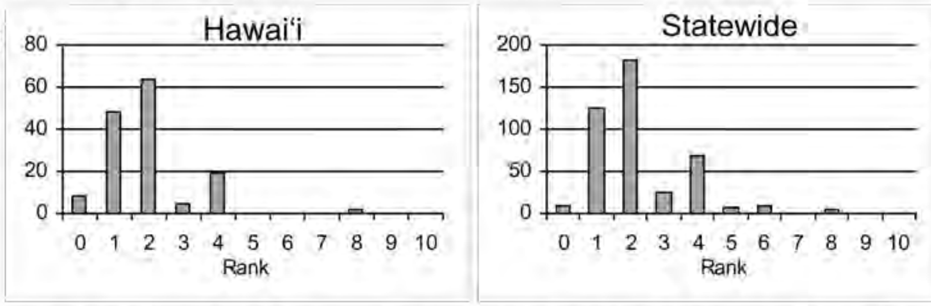




WATERSHED RATING (Cont): Wailoa River, Hawai‘i

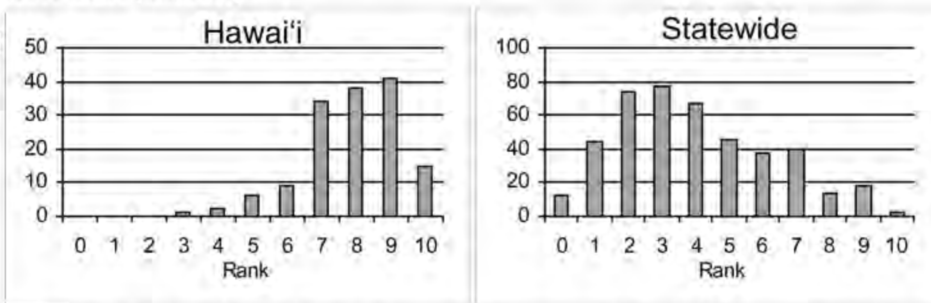
Size Rating: Rating is based on the watershed area and total stream length. Larger watersheds and streams score more positively.

Watershed Rating
4



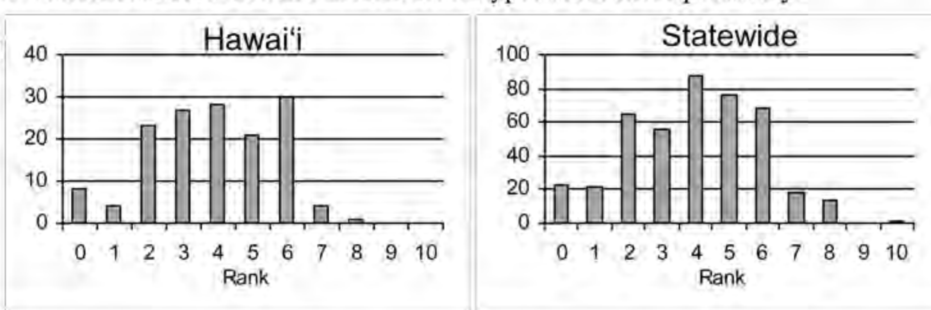
Wetness Rating: Rating is based on the average annual rainfall within the watershed. Higher rainfall totals score more positively.

Watershed Rating
6



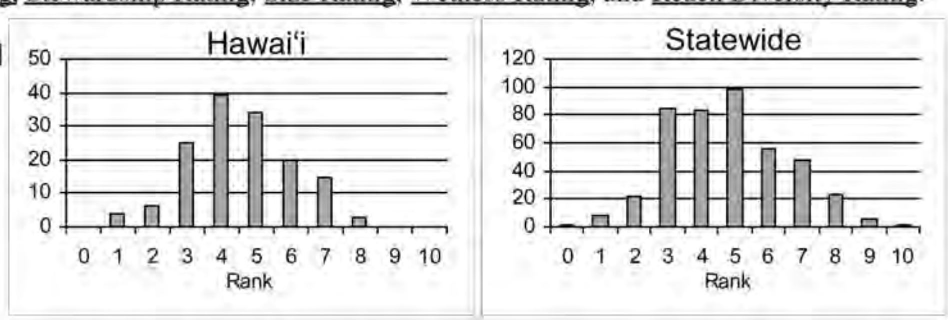
Reach Diversity Rating: Rating is based on the types and amounts of different stream reaches available in the watershed. More area in different reach types score more positively.

Watershed Rating
7



Total Watershed Rating: Rating is based on combination of Land Cover Rating, Shallow Waters Rating, Stewardship Rating, Size Rating, Wetness Rating, and Reach Diversity Rating.

Watershed Rating
8

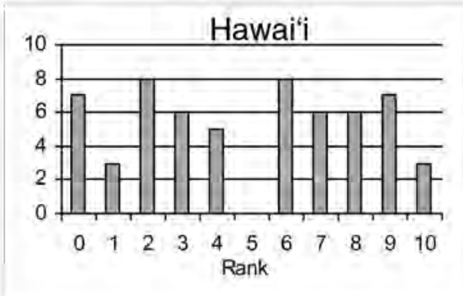


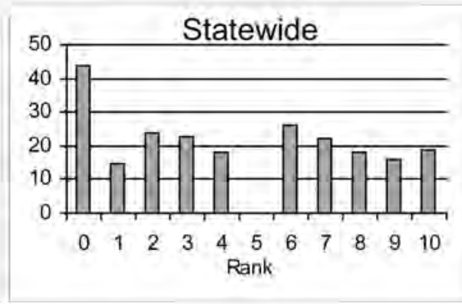
BIOLOGICAL RATING: Wailoa River, Hawai'i

Native Species Rating: Rating is based on the number of native species observed in the watershed.

Stream Rating

9

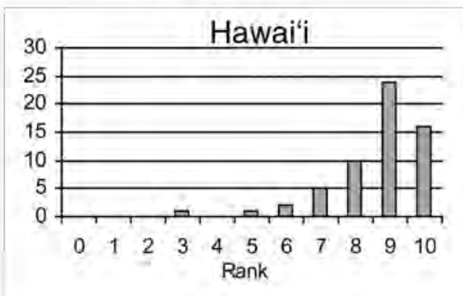


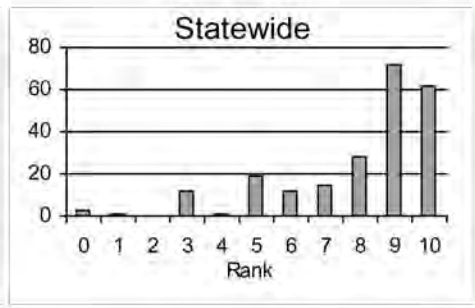


Introduced Genera Rating: Rating is based on the number of introduced genera observed in the watershed.

Stream Rating

3

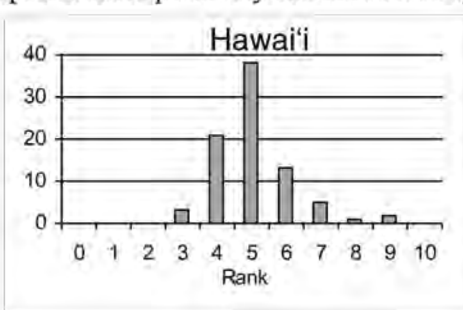


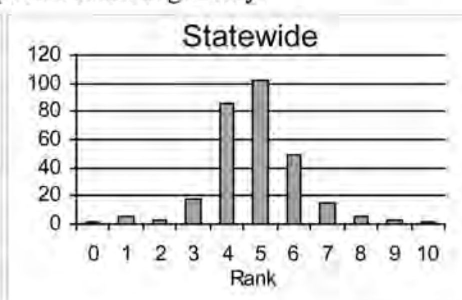


All Species' Score Rating: Rating is based on the Hawaii Stream Assessment scoring system where native species score positively and introduced species score negatively.

Stream Rating

3

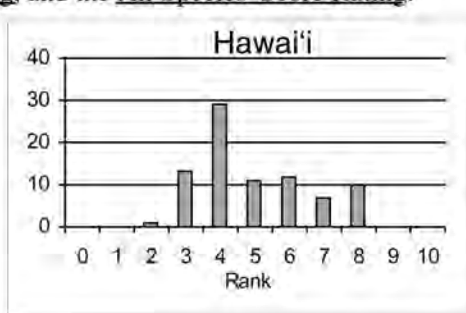


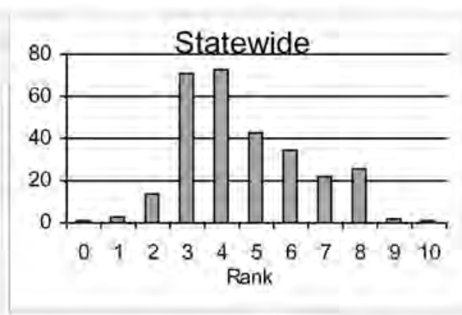


Total Biological Rating: Rating is the combination of the Native Species Rating, Introduced Genera Rating, and the All Species' Score Rating.

Stream Rating

4



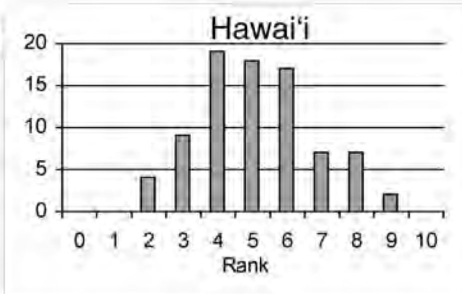


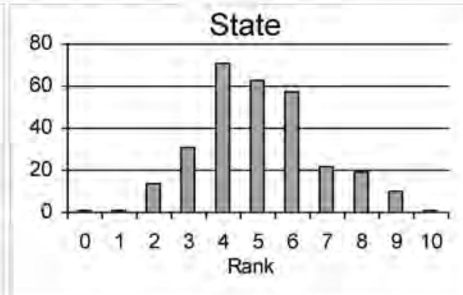
OVERALL RATING: Wailoa River, Hawai‘i

Overall Rating: Rating is a combination of the Total Watershed Rating and the Total Biological Rating.

Watershed Rating

6



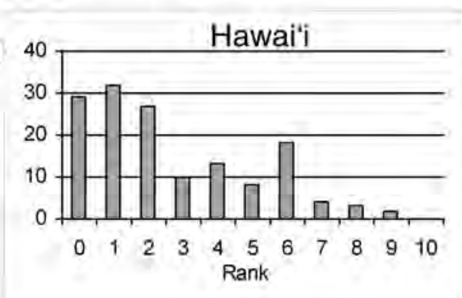


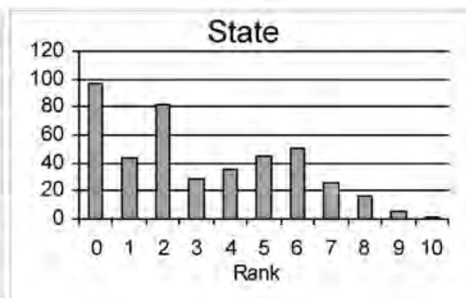
RATING STRENGTH: Wailoa River, Hawai‘i

Rating Strength: Represents an estimate of the overall study effort in the stream and is a combination of the number of studies, number of different reaches surveyed, and the number of different survey types.

Information Rating

7





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Appendix C

Summary Reference Documents

- **Distribution of Arsenic in the Sediments and Biota of Hilo Bay, Hawaii (Hallacher et al. 1985)**
- **Hawaii Cane Products Findings of Fact (NOAA 1990)**
- **Ecological Risk Assessment, Waiakea Pond, Hilo, Hawaii (HDOH 2005)**

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Distribution of Arsenic in the Sediments and Biota of Hilo Bay, Hawaii[1]

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ABSTRACT: Sediment samples collected from the Waiakea Mill Pond, Wailoa River, and Hilo Bay were analyzed for arsenic. Arsenic was detectable in 10 of 11 sediment samples, and ranged in concentration from 2 to 715 ppm. Two species of plant and seven species of animal were collected from the Waiakea Mill Pond and analyzed for arsenic. No arsenic was detected in the plants, whereas four of the seven animal species had arsenic concentrations ranging from a trace to 1.3 ppm.

Sediments of the Wailoa River estuary have much higher concentrations of arsenic than those of Hilo Bay, indicating that most arsenic is located near the original source of pollution, a factory that once operated on the shores of the Waiakea Mill Pond. Much of the arsenic is found in anaerobic regions of the sediment where it has been relatively undisturbed by biological activity. The low levels of arsenic in the biota of the estuary suggest that there is little remineralization of the region's arsenic and that it is trapped in anaerobic sediment layers.

HILO BAY, LOCATED on the northeast coast of the Island of Hawaii, has historically served as a sink for human-related pollutants from numerous point sources (M&E Pacific, Inc. 1980). The bay and adjoining Wailoa River estuary system are severely polluted with arsenic as a result of dumping of arsenic trioxide (used as an antitermite agent) into the Waiakea Mill Pond and Wailoa River by a canec (a building material made from sugar cane waste) manufacturing plant during the years 1932–1963 (Kelly, Nakamura, and Barrere 1981). Arsenic concentrations in the sediments of Hilo Bay have been found to be as high as 6370 ppm, approximately 34 times higher than anywhere else in the state (Department of Health 1978*a*).

In addition to its presence in the sediments of the region, arsenic has been detected in the biota of the Waiakea Mill Pond and Hilo Bay (Department of Health 1978*a*, *b*). The Department of Health examined a filamentous algae (no taxonomic designation listed) commonly consumed by mullet, and found detectable levels of arsenic (1.84 ppm). The tissues and viscera of the Samoan crab (*Scylla serrata*), white crab (*Portunus sanguinolentus*), mullet (*Mugil cephalus*), and a goby (no taxonomic designation listed) were also analyzed. No arsenic was detectable in the goby, but the mullet had arsenic in their viscera (1.67–6.64 ppm), the white crab had detectable levels of arsenic in muscle tissue (0.17 ppm), and the Samoan crab had detectable levels of arsenic in the viscera (0.39 ppm)

The purpose of the present investigation was twofold. First, we sought to determine the extent and pattern of movement of arsenic out of the Wailoa estuary from its original source into Hilo Bay. Second, we wished to examine biota of the Wailoa estuary system for the presence of arsenic in visceral and muscle tissues. Although it is generally hypothesized that arsenic does not concentrate in higher

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trophic levels via food chain magnification (Kennedy 1976, Klumpp and Peterson 1978, Spehar et al. 1980), it can be efficiently passed along to higher trophic levels (Wrench, Fowler, and Unlu 1979). In light of the magnitude of arsenic pollution in the estuary, we suspected that much of the biota of the estuary might have measurable levels of arsenic in their tissues.

MATERIALS AND METHODS

Core samples of sediments were collected in June and July 1983 from nine stations located throughout the Waiakea Mill Pond, the Wailoa River, and Hilo Bay (Figure 1). Cores were collected by means of a 2-in.-diameter piston corer. Each core had a 2-cm subsample removed from the top and bottom for arsenic content analysis. In addition to the core samples, two sediment grab samples were collected in deep water (approx. 20 m) at the mouth of the bay in April 1983. Also, dredge spoils from dredging of the mouth of the Wailoa River were collected in July 1984. All sediment samples were digested directly with a nitric/sulfuric/perchloric acid mixture, and then reacted with hydrazine sulfate/ammonium molybdate solution to produce arsenomolybdenum blue for spectrophotometric analysis (Sandell 1959).

All biological material was collected in the Wailoa River or Waiakea Mill Pond during June and July 1983. Samples were collected by hand, hand net, and hook-and-line. Samples collected included benthonic blue-green algae, which serves as a food base for mullet in the estuary; *Elodea* sp., an aquatic embryophyte; *Theodoxus vespertinus*, a small brackish-water gastropod common to the region; *Eleotris sandwicensis*, a small benthonic fish eaten by larger fishes; and several species regularly consumed by people, including *Mugil cephalus*, a mullet; *Lutjanus fulvus*, a snapper; *Kuhlia sandvicensis*, a moderate-sized perchlike fish; *Mulloides vanicolensis*, a moderate-sized goatfish; and *Portunus sanguinolentus*, the white crab.

Specimens were stored on ice after capture and frozen within 3 hr of capture. They were later thawed for analysis. Specimens were eviscertated and filleted with stainless steel instruments. Viscera (gastrointestinal tract and associated organs) and muscle tissue (epaxial and hypaxial musculature in the fish, foot and part of visceral hump in the gastropod, appendage musculature in the crustaceans) were analyzed separately.

Because of the small size of many of the specimens collected, tissue samples from several individuals were sometimes pooled into larger, monospecific analytical samples. Weights of analytical samples were as follows: 50.1960 g of blue-green alga; 21.0645 g of *Elodea* sp.; 40 specimens of *Theodoxus vespertinus* ranging in size from 19 to 27 mm maximum shell dimension produced a total of 29.3270 g muscle tissue; 4 specimens of *Eleotris sandwicensis* ranging in size from 90 to 120 mm standard length (SL) produced a total of 2.2150 g visceral tissue and 9.0515 g muscle tissue; 6 specimens of *Lutjanus fulvus* ranging in size from 95 to 125 mm SL produced a total of 4.655 g visceral tissue and 29.3515 g muscle tissue; 3 specimens of *Kuhlia sandvicensis* ranging in size from 95 to 110 mm SL produced a total of 5.0180 g visceral tissue and 10.7215 g muscle tissue; 1 specimen of *Mulloides vanicolensis* (155 mm SL) produced 3.6745 g visceral tissue and 19.1450 g muscle tissue; 3 visceral samples from *Mugil cephalus* weighing 63.1490, 63.0405, and 139.7935 g, respectively (donated by a local fisherman, sizes unknown); and 1 specimen of *Portunus sanguinolentus* (95 mm carapace width) produced 17.7435 g visceral tissue and 5.4015 g muscle tissue. All biological material was subjected to the same analytical technique used for sediment samples.

Temperature and salinity changes in the Wailoa estuary system were monitored throughout an entire spring tidal cycle (25 hr) on 25–26 February 1983. Four stations located along the course of the Wailoa River between the Waiakea Mill Pond and the river mouth were monitored every 2 hr (Figure 2).

Temperature and salinity were recorded at 25-cm intervals between the surface and the bottom at each station with a YSI Model #33 S-C-T meter.

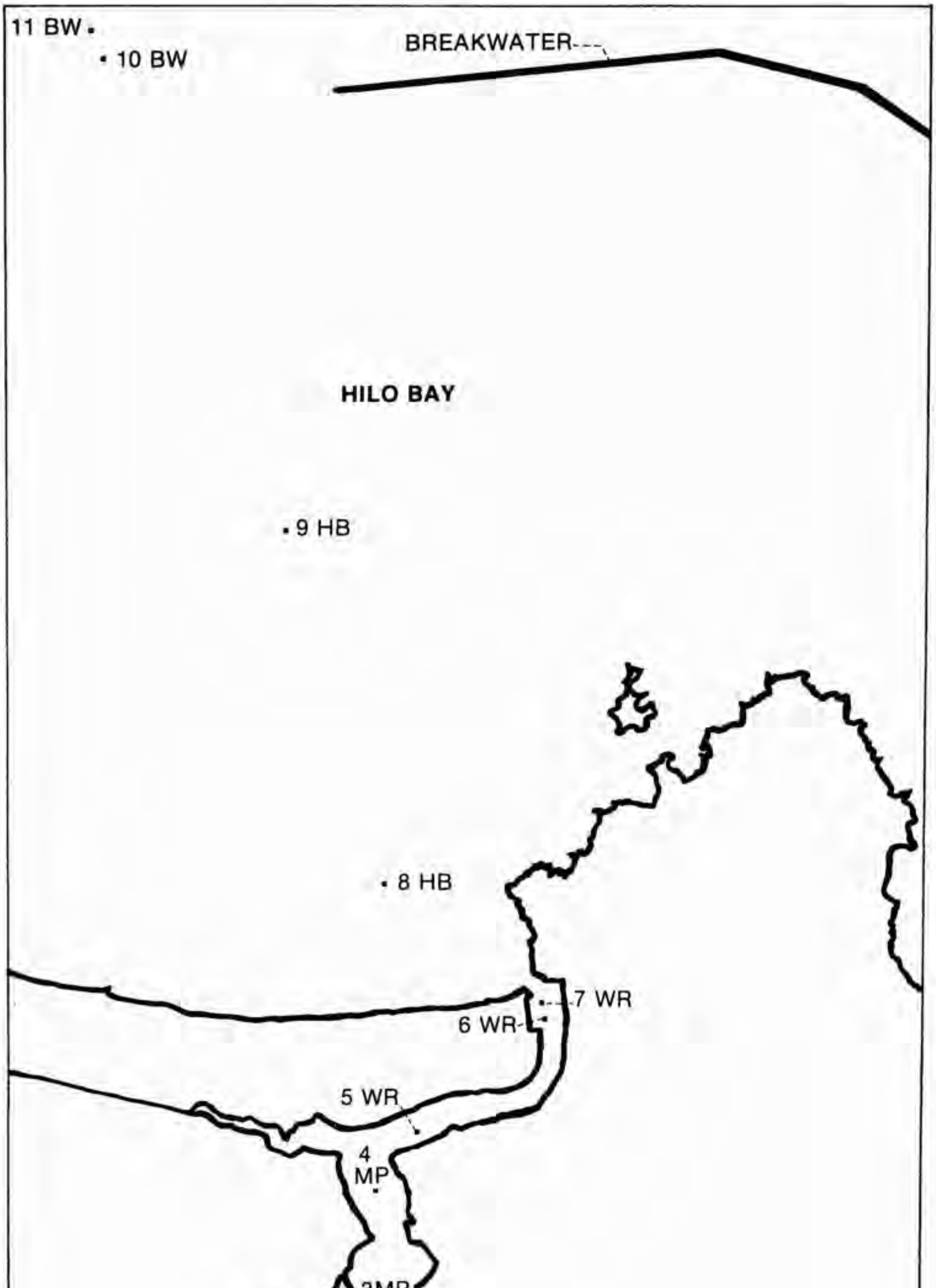

FIGURE 1. Coring station locations in the Waiakea Mill Pond (MP), Wailoa River (WR), Hilo Bay (HB), and the mouth of Hilo Bay (BW).

RESULTS

Detectable levels of arsenic were found in 10 of the 11 sediment samples examined, with 6 cores having arsenic concentrations in excess of 50 ppm (Table 1). Extremely high arsenic concentrations were present in the sediments of the Waiakea Mill Pond and Wailoa River, with cores from those locations registering maximum concentrations of 550 ppm and 715 ppm, respectively (Table 1). Sediments from cores taken in Hilo Bay had much lower levels of arsenic present, the highest concentration being 63 ppm, and generally showed little variation from site to site (Table 1, Figure 3).

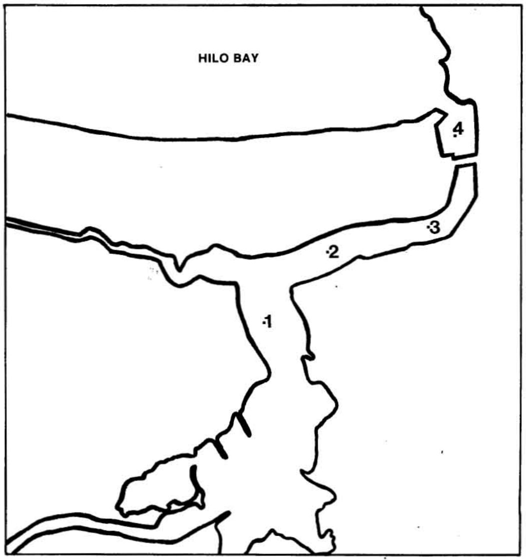

FIGURE 2. The location of tidal cycle monitoring stations from the Wailoa River.

Most cores collected had sediment arsenic concentrations that varied throughout their length. Two cores examined (6-WR and 8-HB) showed slightly higher (26–29 ppm) arsenic concentrations at a depth of approx. 60 cm below the surface than on the surface of the sediment. Two cores (2-MP and 5-WR) showed markedly higher (299–564 ppm) arsenic concentrations at a depth of approx. 60 cm than on the sediment surface. Conversely, five cores (1-MP, 3-MP, 4-MP, 7-WR, and 9-HB) had an inverse relationship between sediment depth and arsenic concentration, with arsenic concentrations showing modest declines (2–115 ppm) with increasing sediment depths of approx. 20–110 cm (Table 1).

All cored sediments were black in color just a few centimeters below the surface, gave off a strong hydrogen sulfide odor, and contained pieces of undecomposed vegetation in the black-colored region. This indicates that the sediments of the Waiakea Mill Pond, Wailoa River, and Hilo Bay are anaerobic just below the sediment surface.

Dredge spoils taken from a mixed sediment depth (max. depth 3–6 m) at the mouth of the

TABLE 1

ARSENIC LEVELS IN SEDIMENTS COLLECTED FROM THE WAIAKEA MILL POND (MP), WAILOA RIVER (WR), HILO BAY (HB), AND THE MOUTH OF HILO BAY (BW)

SAMPLE	TOP	BOTTOM
1-MP	2 ± 0.4 (8–10 cm)	ND (16–18 cm)
2-MP	251 ± 25.7 (4–6 cm)	550 ± 6.1 (56–58 cm)
3-MP	27 ± 6.7 (6–8 cm)	3 ± 1.1 (108–110 cm)
4-MP	115 ± 2.0 (10–12 cm)	ND (52–54 cm)
5-WR	151 ± 10.3 (4–6 cm)	715 ± 32.8 (57–59 cm)
6-WR	34 ± 0.7 (3–5 cm)	60 ± 0.2 (61–63 cm)
7-WR	43 ± 0.6 (3–5 cm)	17 ± 0.1 (103–105 cm)
8-HB	34 ± 0.3 (3–5 cm)	63 ± 0.3 (66–68 cm)
9-HB	56 ± 0.2 (3–5 cm)	19 ± 0.1 (50–52 cm)
10-BW	ND (surface)	
11-BW	40 ± 1.5 (surface)	

NOTE: All values are in parts per million wet weight, and are followed by their standard errors. Numbers in parentheses represent the depths in centimeters below the surface of the sediment from which the analyzed sample was collected. ND = not detected.

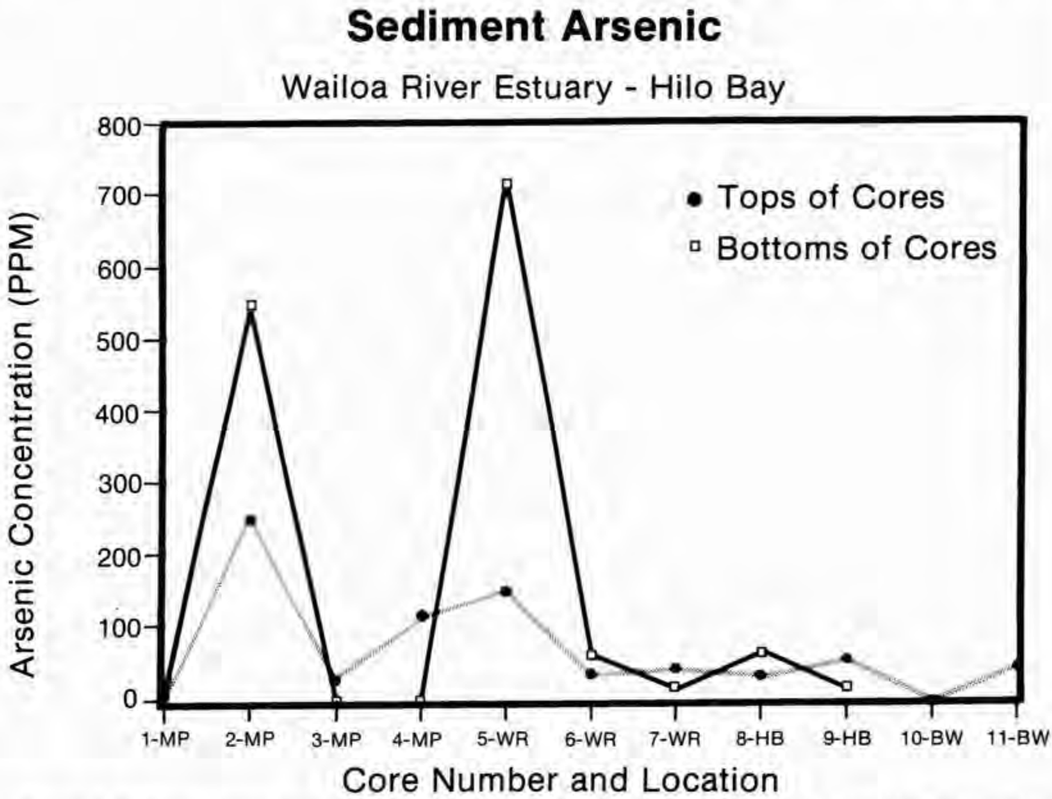

FIGURE 3. Sediment arsenic concentrations from cores collected from the Waiakea Mill Pond (MP), Wailoa River (WR), Hilo Bay (HB), and the mouth of Hilo Bay (BW).

TABLE 2

ARSENIC LEVELS IN ORGANISMS COLLECTED FROM THE WAIAKEA MILL POND AND WAILOA RIVER

SAMPLE	VISCERAL AS CONTENT	TISSUE AS CONTENT
Blue-green algae	NA	ND
Elodea sp.	NA	ND
Theodoxus vespertinus	NS	Trace
Eleotris sandwicensis	1.1	0.2 ± 0.04
Lutjanus fulvus	0.8 ± 0.3	0.2 ± 0.03
Kuhlia sandvicensis	ND	ND
Mulloides vanicolensis	ND	ND
Mugil cephalus, #1	1.3 ± 0.4	NS
Mugil cephalus, #2	1.2 ± 0.02	NS
Mugil cephalus, #3	1.2 ± 0.1	NS
Portunus sanguinolentus	ND	ND

NOTE: All values are in parts per million wet weight. NA = not applicable, ND = not detected, NS = not sampled.

Wailoa River had an arsenic concentration of 13 ppm ± 0.7 ppm standard error (SE).

Of the nine species of organisms examined by us, four had detectable levels of arsenic in their tissues (Table 2). Arsenic levels were much lower than those recorded in the sediment samples, with biological material having arsenic concentrations ranging from trace amounts to 1.3 ppm. Highest biological arsenic levels were obtained from visceral tissue of the mullet *Mugil cephalus* (1.3 ppm max.). Three species had detectable levels of arsenic in their muscle tissue, the brackish water gastropod *Theodoxus vespertinus* (trace), the snapper *Lutjanus fulvus* (0.2 ppm), and the eleotrid *Eleotris sandwicensis* (0.2 ppm). Neither of the plants that thrive in the Wailoa estuary system had detectable levels of arsenic (Table 2).

Salinity changes that occur in the Wailoa

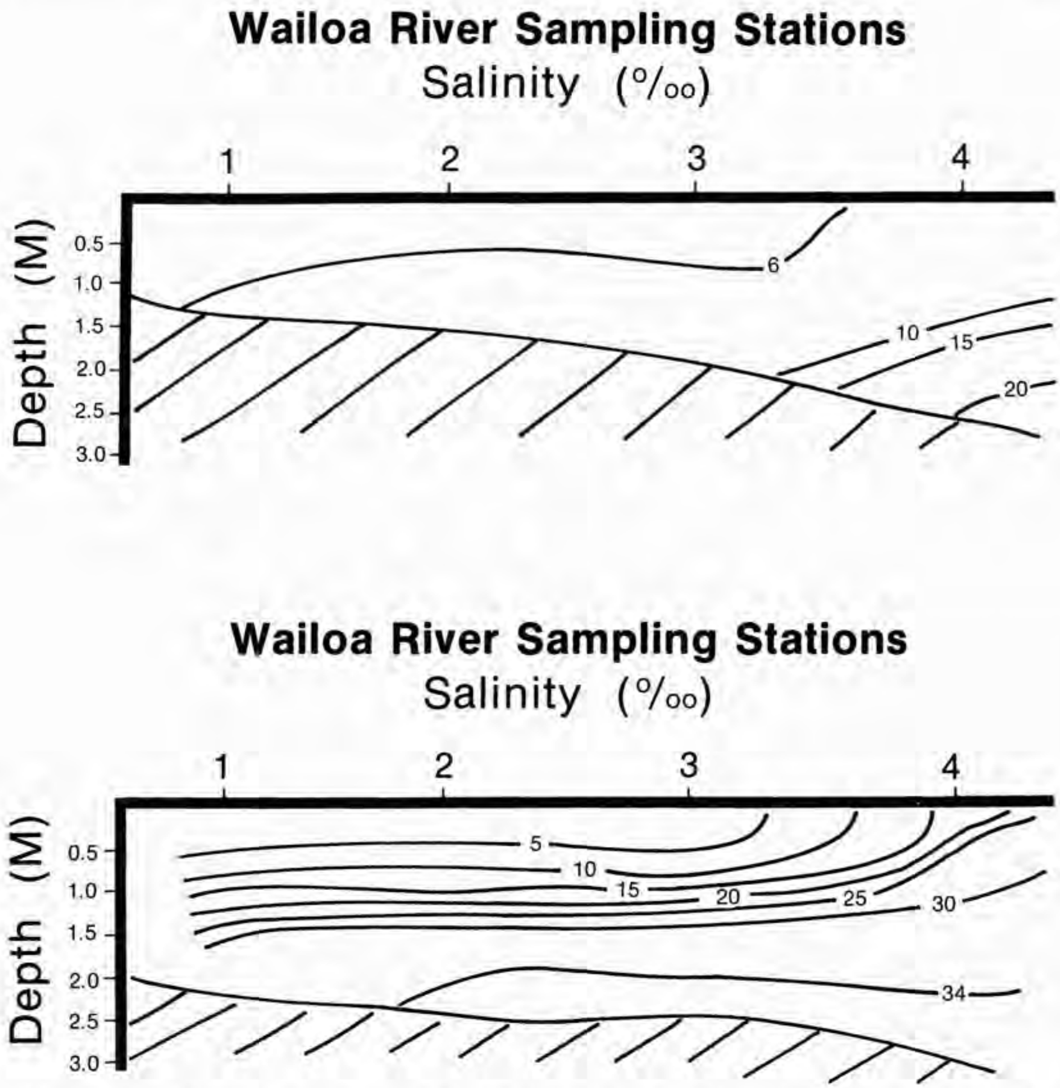

FIGURE 4. Spring tidal range cross sections of water salinity (in parts per thousand) from four stations along the course of the Wailoa River between the Waiakea Mill Pond (station 1) and the mouth of the Wailoa River (station 4) for 25–26 February 1983. The upper profile is at LLW (−7 cm), while the lower profile is at HHW (+70 cm).

estuary during tidal cycles are pronounced, with at least one station (1) showing more than a 25 ppt increase in salinity near the bottom during high tide (Figure 4). During the 25-hr observation period, an extremely well-developed salt wedge was observed to penetrate the estuary, leading to the maintenance of a well-defined stratification. This stratification is apparently tidally controlled under conditions of low input of fresh water.

DISCUSSION

Arsenic was present in 10 of 11 of the sediment samples collected from the Wailoa River estuary system and Hilo Bay during this study. This observation suggests that arsenic is a ubiquitous contaminant of the sediments in these systems (Table 1, Figure 3). However, although arsenic is present well out into the bay and is easily measurable in sediments collected beyond the breakwater, it is found in much lower concentrations in sediments of these areas than in the estuarine sediments. The arsenic contamination of the sediments of Hilo Bay that has occurred is apparently the result of transport of some of the arsenic-laden sediments out of the Wailoa estuary.

It has been suggested that arsenic is transported out of the Wailoa estuary system into Hilo Bay during periods of high freshwater runoff (M&E Pacific, Inc. 1980). If this is the case, our data suggest that sediments are not immediately redeposited but instead are transported out of Hilo Bay. Recent studies of salinity profiles from Hilo Bay show surface freshwater plumes extending well past the breakwater at the mouth of Hilo Bay (Bernard et al. 1983). Fine-grained sediments may remain suspended in turbulent low-salinity surface waters until exiting the bay, where reduced flow intensity would permit settling.

We believe that it is also possible that relatively little seaward transport of arsenic has occurred. Although we have observed high seaward freshwater flow rates out of the Wailoa River estuary, much of this flow is confined to a thin surface lens. Conversely, we have recorded the movement of a salt wedge up the Wailoa River into the Waiakea Mill Pond, which during spring tidal cycles has a salinity in excess of 33 ppt near the bottom (Figure 4). Furthermore, the sediments of the estuary are anaerobic just a few centimeters below the surface. This condition results in reduced biological disturbance of the arsenic-contaminated sediments because few organisms burrow into the anaerobic strata. It seems possible that limited seaward transport of sediment by freshwater runoff and low biological disturbance of the anaerobic sediments have resulted in much of the arsenic that has been dumped into the estuary remaining in relatively undisturbed estuarine sediments.

Arsenic in the sediments of the estuary is remarkably localized in its distribution. Core 2-MP had an arsenic concentration that was approx. 5 times higher than any of the other cores taken in the Waiakea Mill Pond (Figure 3). According to historical records, the location of this coring station corresponds to the location of the canec manufacturing plant on the shores of the mill pond (Department of Health 1978*b*). Similarly, core 5-WR, located in an area where an effluent pipe dumped arsenic-laden waste-water from the canec plant into the Wailoa River (Department of Health 1978*b*), had an arsenic concentration approx. 12 times higher than any of the other cores (all downstream) taken in the Wailoa River (Figures 1, 3).

The variation in arsenic concentration with depth suggests that the sediments of the region have been subjected to some degree of localized mechanical disturbance. Four cores (2-MP, 5-WR, 6-WR, and 8-HB) had higher arsenic concentrations at increased depth, whereas five cores (1-MP, 3-MP, 4-MP, 7-WR, and 9-HB) showed the opposite pattern (Table 1). Differences in variation in arsenic concentration with depth can occur between stations that are located close together. Cores 6-WR and 7-WR were taken within 10 m of each other, yet exhibit inverse patterns in the vertical distribution of arsenic. These cores were taken near the mouth of the Wailoa River, an area that is frequently dredged to keep the boat channel open. Therefore, it is possible that dredging may account for the disturbed sediments in this area. Other sources of sediment disturbance in Hilo Bay and the Wailoa River estuary are not as easily identified, although some mixing may have occurred as a result of tsunami action.

To summarize, our data suggest that much of the arsenic remains in sediments located near the sites of the canec mill and its effluent pipe in the Waiakea Mill Pond and Wailoa River, although some arsenic-bearing sediment has been transported to Hilo Bay. Furthermore, much of this arsenic apparently is confined to anaerobic sediment layers, and is probably in a reduced inorganic form that is potentially hazardous to humans (Fowler 1977). Physical disturbance of the sediments, particularly near the old effluent sites, could cause the release of substantial amounts of arsenic into the water or surface sediment layers.

The results of our analyses for arsenic in the tissues of specimens collected from the Waiakea Mill Pond and Wailoa River do not support our early hypothesis that the biota of the region would be severely contaminated with arsenic. Instead, the analyses indicate that remarkably little arsenic has been transferred from the arsenic-contaminated sediments into the biota of the region. Much of the biota sampled by us had no detectable arsenic in their tissues, and those species that did have measurable levels of arsenic had reasonably low concentrations (max. 1.3 ppm; Table 2)

Our analysis of biological material produced results comparable to previous work done by the Department of Health (1978*b*). Three species examined by us and also by the Department of Health were found by us to have lower arsenic concentrations. *Mugil cephalus* had visceral arsenic concentrations that were all approx. 1 ppm, whereas the Department of Health reported a range from 1.67 to 6.64 ppm. The blue-green algae that represents a food base for mullet was reported by the Department of Health to have 1 ppm arsenic, whereas we were unable to detect arsenic in our samples. Furthermore, we did not find detectable arsenic in *Portunus sanguinolentus* (white crab), whereas the Department of Health found 0.17 ppm arsenic in white crab muscle tissue. These data showing low arsenic contamination of biota are compatible with the hypothesis that much of the arsenic of Hilo Bay and the Wailoa River estuary is trapped in relatively undisturbed anaerobic sediment layers.

ACKNOWLEDGMENTS

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
PRELIMINARY NATURAL RESOURCE SURVEY

Hawaiian Cane Products

Hilo, Hawaii
HID 982400475 Site ID:**
September 27, 1990

FINDINGS OF FACT

SITE EXPOSURE POTENTIAL

Site Description

The former Hawaiian Cane Products site is located on Hilo Bay, Hawaii. From 1932 to 1963, Hawaiian Cane Products produced canec, a building material made from sugar cane waste. Products were treated with calcium arsenate and arsenic acid as an anti-termite agent. Approximately 13 million liters per day of wastewater contaminated with arsenic trioxide was discharged into Waiakea Mill Pond and the Wailoa River which drain into Hilo Bay (Hallacher *et al.*, 1985). A preliminary estimate of 538 tons of arsenic was reportedly discharged into the Hilo Bay estuary. Presently, the sediments in these areas are contaminated with arsenic (Ecology & Environment, 1989).

The Preliminary Assessment (PA) (Ecology & Environment, 1989) reported that the Waiakea Plantation and the Waiakea Mill, both adjacent to the site, may have contributed to the arsenic contamination at the site. The Waiakea Plantation conducted a weed control program using a sodium arsenate solution and the Waiakea Mill processed sugar cane from the plantation. The exact locations of these facilities are not known. Specific information regarding their operations or discharges has not been investigated.

Aquatic habitats of the Hilo Bay estuary have also been contaminated by numerous other point sources. Historically, sewage, sugar mill wastewater, petroleum wastes, thermal wastewater, storm drain run-off, and pesticide discharges have occurred and likely contributed to habitat degradation. Several other trace elements and organic chemicals have been detected throughout the estuary. Fish kills of unknown cause have been documented in the Waiakea Mill Pond and the Wailoa River (Hawaii Department of Health, 1978).

The PA is the only document produced within the CERCLA process. The site has not been scored by the Hazard Ranking System, and is not on the National Priorities List (NPL). The old plant site is now occupied by a hotel and condominiums with maintained grounds.

Physical Description

The former Hawaiian Cane Products site is located on the southeastern shore of Waiakea Mill Pond; an 11 hectare impoundment located approximately 800 meters south of Hilo Bay. The PA (Ecology & Environment, 1989) reported that the site is composed of two major areas. The first portion of the site is the former Hawaiian Cane Products property which is approximately 9 hectares in area. The second is the Hilo Bay estuary system which includes Waiakea Mill Pond, the Wailoa River, and Hilo Bay. Waiakea Mill Pond discharges to the

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Wailoa River which flows for approximately 700 meters into Hilo Bay (Figures 1 and 2) (M&E Pacific Inc., 1980). Both Waiakea Mill Pond and the Wailoa River are shallow and tidally influenced. The river and at least the northern portion of the pond experience salinity fluctuations ranging from 1 part per thousand (ppt) at the surface to over 30 ppt at the bottom, depending upon tidal cycle and height. Hilo Bay is an estuarine environment generally less than 20 meters deep with salinities ranging from 5 to 34 ppt (M&E Pacific Inc., 1980; Hallacher *et al.*, 1985). The bay has received large amounts of organic matter, primarily from sewage and sugar milling (M&E Pacific Inc., 1980). The main sediment source to the bay is from the Wailuku River. Sediments within the bay are highly variable; percent fines range from 1.8% to 84% (M&E Pacific Inc., 1980). Nutrient content and redox conditions vary greatly too.

High volumes of groundwater flow under the site and toward Hilo Bay. Flow volumes on the order of 2 billion liters per day discharge in the harbor area as basal springs and are often the dominant freshwater input entering the bay (M&E Pacific Inc., 1980). Although measurements have not been made, groundwater flow is presumed to be rapid due to the porosity of the lava-based aquifers and the small amount of top soil in the area. These conditions are typical of the geology of the Hawaiian Islands. Depth to groundwater at the site ranges from 0 to 3 meters below ground surface (Ecology & Environment, 1989). During a recent site visit (May 10, 1990), basal springs were observed along the edge of Waiakea Mill Pond (Dexter, personal communication, 1990).

Contaminant migration from Hawaiian Cane to Waiakea Mill Pond and the Wailoa River occurred via direct discharge of contaminated effluent. Effluent was discharged directly to nearshore areas of Waiakea Mill Pond, as well as to the Wailoa River via a sewer line outfall. A suspected pathway to Hilo Bay is via the transport of contaminated surface water and sediments from the pond and river (Hallacher *et al.*, 1985). Considerable damage and reforming of shorelines has occurred during past tropical storms and tsunamis (M&E Pacific Inc., 1980). The transport of contaminated sediments within the estuarine system could have been particularly significant during such events. Numerous dredging and construction activities, which tend to redistribute contaminants, have occurred throughout the system as well. Other possible migration pathways such as the erosion of contaminated soils or the discharge of contaminated groundwater have not been investigated.

Habitats and Species Description

The primary habitats of concern to NOAA are Waiakea Mill Pond, the Wailoa River, and Hilo Bay. This shallow estuarine system provides nursery and adult habitat for many economically and ecologically important fish and invertebrate species. Blonde Reef, located in Hilo Bay, supports a coral reef community which provides nursery and foraging habitat for juvenile pelagic and demersal species as well as adult habitat for many coral-reef-dependent species. In the area just seaward of the breakwater on Blonde Reef, an unusual coral community dominated by *Montipora verrucosa* is found at a depth range of 12 to 25 m. This species of coral is normally a minor component of typical Hawaiian reefs (Naughton, personal communication, 1990).

Waiakea Mill Pond and the Wailoa River are part of the Wailoa River State Park and are managed for public recreation and recreational fishing. Important marine fish present in Waiakea Mill Pond and Wailoa River are the mullet, snapper, goatfish, and *Kulia sandivicensis*, a moderate sized perch-like fish. Important invertebrate species are the white crab and Samoan crab (Hallacher *et al.*, 1985; Nishimoto, personal communication 1990). These species can be found in the pond year-round with seasonal peak abundances (Table 1; Nishimoto, personal communication 1990).

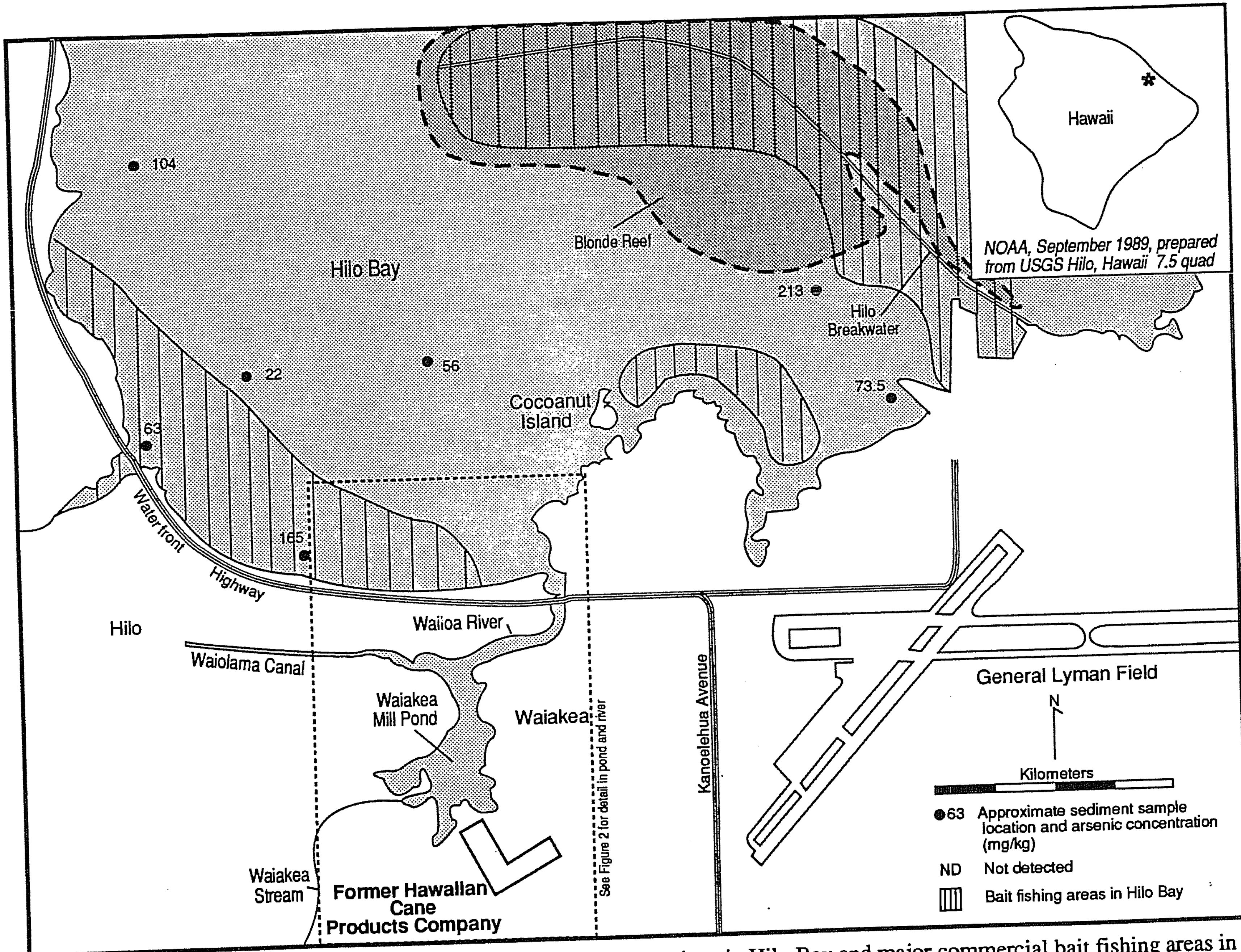

Figure 1. The Hawaiian Cane Products study area, arsenic concentrations in Hilo Bay and major commercial bait fishing areas in the Bay (Hilo, Hawaii) (M & E Pacific 1980; Halacher et al. 1985; Akazawa, personal communication 1989).

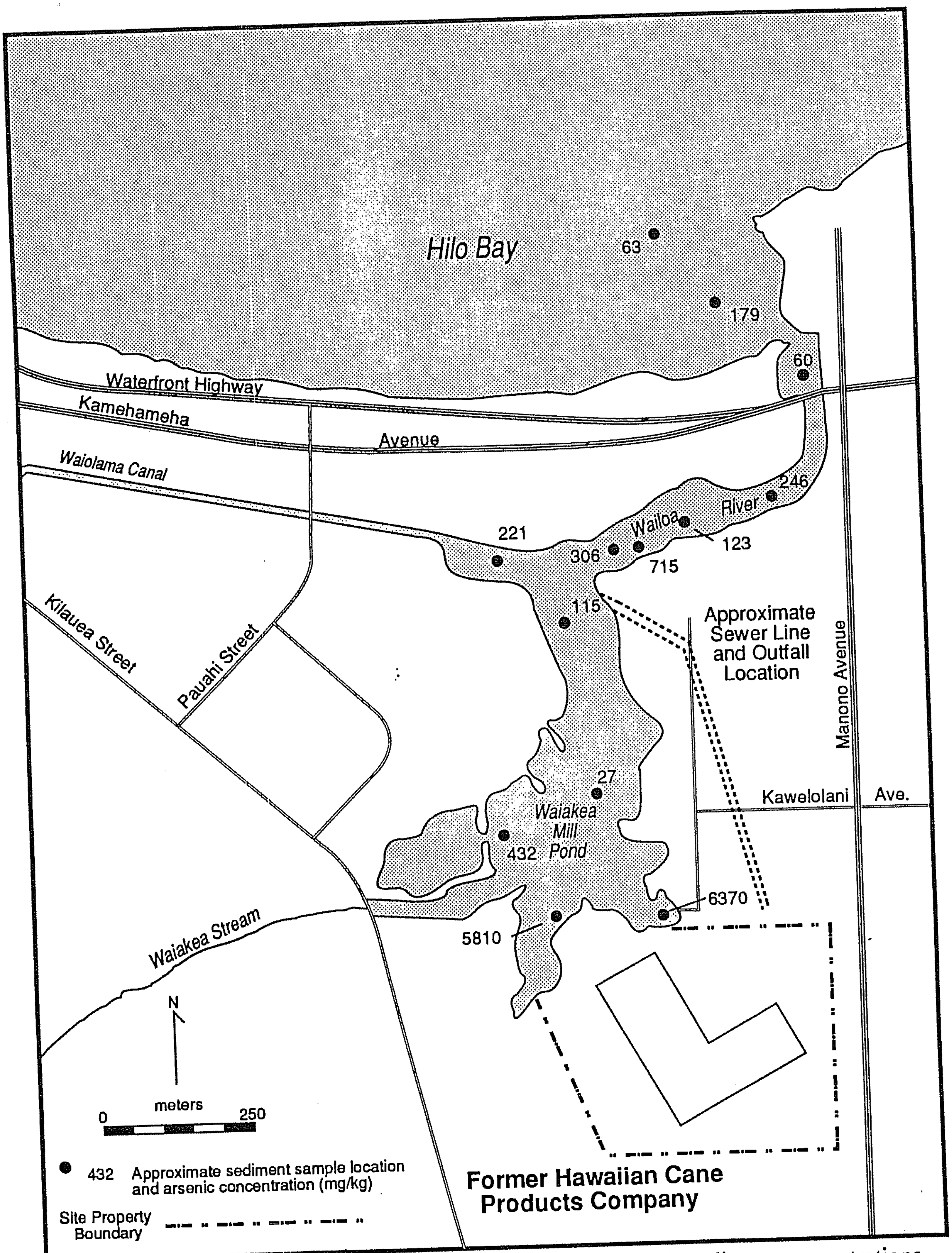

Figure 2. The Hawaiian Cane Products site and maximum arsenic sediment concentrations observed between 1977 and 1986 (Hilo, Hawaii) (Akazawa, personal communication; M & E Pacific 1980)

The same species present in the pond are also present in Hilo Bay as well as several other species of recreational and/or commercial importance. Surveys conducted in 1972, 1977, and 1980 found between 15 and 42 different species of marine fish. The most abundant species observed was the nehu, which occupies the surface layer of nearshore estuaries in Hawaii. Other important species found in the bay include weke, akule, and the spiny lobster (Table 1; M&E Pacific Inc., 1980).

Blonde Reef in Hilo Bay supports numerous reef-associated fish which use this unique habitat for juvenile rearing and adult foraging. Reef species representing several genera have been observed in this area including surgeonfish, butterfly fish, wrasses, and parrot-fish (Table 1). Quantitative surveys of reef populations have not been conducted on Blonde Reef, but an increased level of siltation is believed to be having a damaging effect on the coral reef (M&E Pacific Inc., 1980). Diving surveys have observed less robust or dead coraline species in areas of heavy siltation on the reef. Much of the siltation is attributed to reduced flushing because of the Hilo Breakwater.

Table 1. The major fish and invertebrates observed in Waiakea Mill Pond, Wailoa River, and Hilo Bay, and the primary habitat use for these species (M&E Pacific Inc., 1980; Hallacher *et al.*, 1985; and Nishimoto, personal communication, 1990).

Common Name	Scientific Name	Spawning Ground	Nursery Ground	Adult Forage
WAIAKEA POND and WAILOA RIVER				
Marine Fish				
Mullet	*Kulia sandivicensis*		♦	♦
Goatfish	*Mulloides vanicolensis*		♦	♦
Snapper	*Lutjanus fulvus*		♦	♦
Perch	*Kulia sandivicensis*		♦	♦
Invertebrates				
White crab	*Portunus sanquinolentus*			♦
Samoan crab	*Scylla serrata*			♦
HILO BAY[1]				
Marine Fish				
Surgeonfish	*Acanthurus leucopareius*	♦	♦	♦
	A. sandvicensis	♦	♦	♦
	A. mata	♦	♦	♦
	A. nigroris	♦	♦	♦
Butterfly fish	*Chaetodon lunula*	♦	♦	♦
	C. fremblii	♦	♦	♦
	C. Miliaris	♦	♦	♦
	C. ornatissimus	♦	♦	♦
	C. Auriga	♦	♦	♦
Wrasses	*Thalassoma duperreyi*	♦	♦	♦
	T. ballieui	♦	♦	♦
Parrot fish	*Scarus sordidus*	♦	♦	♦
	S. perspicillatus	♦	♦	♦
Nehu	*Stolophorus purpureus*			♦
Weke	*Mulloidichtys samoensis*			♦
Akule	*Trachiurops crumenophthalmus*			♦
Invertebrates				
Spiny lobster	*Panulirus* sp.			♦

[1] In addition to the above species

Commercial and Recreational Fisheries

No commercial fisheries are present in Waiakea Mill Pond or the Wailoa River. The only commercial fishery present in Hilo Bay is for the bait fish, nehu and mullet, and perhaps the Marquesan sardine (Sardinella marquesenisis). The Marquesan sardine, an introduced species, occurs in all bays around Oahu, and would most likely be present in Hilo Bay as well (Ingoglia, personal communication 1990). These species may be caught and sold to fisherman engaged in the tuna fishery outside Hilo Bay (Table 2; M&E Pacific Inc., 1980; Ingoglia, personal communication 1990).

Waiakea Mill Pond, the Wailoa River, and Hilo Bay are important public recreational fishing areas on the Island of Hawaii. Mullet and crab species are the most popular fish and invertebrates recreationally harvested in Waiakea Mill Pond and the Wailoa River. These species as well as akule (a mackerel-type fish), goatfish, and snapper are caught in the bay. A variety of harvest techniques are employed by recreational fishermen including hook and line, throw nets, and crab nets (Table 2; Nishimoto, personal communication 1990).

Table 2. Commercial and recreational fisheries present in Waiakea Mill Pond, Wailoa River, and Hilo Bay (M&E Pacific Inc., 1980; Hallacher *et al.* 1985; and Nishimoto, personal communication, 1990).

		Fisheries	
Common Name	Scientific Name	Commercial	Recreational
WAIAKEA MILL POND and WAILOA RIVER			
Marine Fish			
Mullet	*Kulia sandivicensis*	♦	♦
Invertebrates			
White crab	*Portunus sanquinolentus*		♦
Samoan crab	*Scylla serrata*		♦
HILO BAY[1]			
Marine Fish			
Nehu	*Stolophorus purpureus*	♦	♦
Weke	*Mulloidichtys samoensis*		♦
Akule			♦
Goatfish	*Mulloides vanicolensis*		♦
Snapper	*Lutjanus fulvus*		♦
Perch	*Kulia sandivicensis*		♦
Marquesan sardine	*Sardinella marquesenisis*	♦	

[1] In addition to the above species

From 1976 to 1979, the National Marine Fisheries Service conducted humpback whale (*Megaptera novaeangliae*) counts throughout the Hawaiian Islands. Humpback whales were consistently sighted in Hilo Bay, with counts usually ranging between 6 to 8 individuals (Naughton, personal communication, 1990). The humpback whale is an endangered species of marine mammal.

CHEMICAL ZARDS

Chemical Contaminants and Concentrations

The primary contaminant of concern to NOAA is the trace element arsenic. Arsenic was observed in the sediment of Waiakea Mill Pond, Wailoa River, and Hilo Bay at concentrations potentially toxic to marine organisms (Hallacher *et al.*, 1985). Secondary contaminants of concern to NOAA are several other trace elements. In the sediment of Waiakea Mill Pond and Wailoa River, seven elements were observed at concentrations that may be toxic to resources of concern.

Sporadic occurrences of several pesticides and PCBs have also been observed at low concentrations. The low concentrations and limited frequency of detection observed in monitoring data to date indicate that these contaminants are not likely to be site-related.

A comprehensive Remedial Investigation/Feasibility Study (RI/FS) process has not yet begun at the Hawaiian Cane Products site. Data used for this Preliminary Natural Resource Survey (PNRS) came primarily from monitoring data collected by the Hawaii Department of Health (Akazawa, personal communication 1989). Data from studies of contamination in sediments and biota (for arsenic only) conducted by Hallacher *et al.* (1985) were also used. This state monitoring program sampled up to 14 sediment stations in Waiakea Mill Pond, Wailoa River, and Hilo Bay between 1977 and 1986. The number of samples per year varies, but six stations were sampled regularly. All samples were analyzed for trace elements. Some were analyzed for PCBs and pesticides. The Hallacher *et al.* study sampled 11 sediment stations throughout the estuary system during 1983 and collected biota in Waiakea Mill Pond and the Wailoa River. Following the 1960 tsunami, the Hawaiian State Division of Fish and Game (HI DFG) sponsored a study of aqueous arsenic at four locations within the pond (HI DFG, 1962). Samples were collected on four separate sampling events during 1961-62, a time when Hawaiian Cane Products was still in operation. No other surface water, and no groundwater or soil investigations have been published to date. Preliminary results from a University of Hawaii study of the pond (in press) have also been employed for this PNRS (Kho, personal communication 1990).

To identify substances that might pose a threat to resources of concern to NOAA, the levels of contamination in water samples were screened by comparing the measured concentrations to the applicable national ambient water quality criteria (AWQC) for the protection of aquatic organisms (EPA, 1986). Because releases from hazardous waste sites are often continuous and long-term, chronic AWQC were used.

Very little information exists regarding the toxicity of contaminated sediments. No criteria similar to the ambient water quality criteria (AWQC) are available for sediments. Concentrations of trace elements in sediments were screened by comparison with the Effective Range-Low (ER-L) values reported by Long and Morgan (1990). The ER-L value is the concentration equivalent to that reported at the lower 10 percentile of the available screened sediment toxicity data. As such, it represents the low end of the range of concentrations at which effects were reported in the studies compiled by those authors. Although freshwater studies were included, predominantly marine and estuarine toxicity studies were used for generating ER-L values. No data for tropical species were available for use by Long and Morgan, but analogs for some species were encountered.

Major Contaminants Present at Site

Arsenic

Arsenic is persistent in aquatic environments with an moderate affinity for sediments, but this element is also more mobile than most of the other trace elements. Arsenic that is already associated with particulates will remain so as it travels through a salinity gradient and accumulate in sediments (Konasewich *et al.*, 1982). Arsenic will also complex with low molecular weight dissolved organic matter and remain in solution when fresh and salt water mix. Arsenic is toxic to marine organisms of interest to NOAA at moderate to low concentrations. The ambient water quality criteria (AWQC) for the protection of aquatic organisms from arsenic exposure is 36 µg/l. Most data indicate that arsenic does not biomagnify to a great degree (Clement Associates, 1985). Arsenic does bioconcentrate though, but at diminishing degrees with increasing trophic levels. Bioconcentration factors (BCF) up to 2000 times have been reported in algae, while factors of only 21 to 34 were reported for fish (Konasewich *et al.*, 1982). Highest BCF have been reported for brown alga (M&E Pacific Inc., 1980). Higher bioconcentration in algae may be partly due to the fact that arsenic is an analog of phosphorous, an essential nutrient for plants.

Water sampling for the HI DFG in 1961-62 found arsenic levels were elevated throughout the pond. Maximum concentrations, up to 200 µg/l, were detected at the two sites closest to the plant. More recent sampling by the University of Hawaii does not suggest significant improvement in water quality has occurred. Concentrations of aqueous arsenic just above pond sediments ranged from 51.6 to 78.1 µg/l, with an average of 60 µg/l (Kho, personal communication 1990). These levels exceeded the AWQC criteria for arsenic. Higher values were observed adjacent to the former plant site and near the old outfall. Arsenic levels in bottom water were greater than in surface waters, indicating that arsenic is leaching out from the sediment. This was further verified by measurements of pore water arsenic. Mean levels of 2470 µg/l were detected in pore water.

Elevated concentrations of arsenic have been detected routinely in sediment samples collected in Waiakea Mill Pond and the Wailoa River. In 1983 samples, Hallacher *et al.* (1985) found arsenic levels near the old plant site that were five times higher than any other site within the pond. Concentrations in sediments collected in the approximate location of the Hawaiian Cane outfall, at the mouth of Wailoa River, were twelve times higher than any other sites downstream. The Hawaii Department of Health has sampled sediments in the estuary system for over a decade (Akazawa, personal communication 1989). All sites indicate large swings in arsenic levels over time. The highest concentrations have been consistently observed in southern portions of the pond near the former Hawaiian Cane building (432 to 6,370 mg/kg) and around the outfall used by the company near the confluence of the pond and Wailoa River (115 to 715 mg/kg). Sediment sampling was also conducted in the University of Hawaii study. Arsenic concentrations of 587 mg/kg and 946 mg/kg were found in samples of sediment collected near the former plant site and the outfall, respectively (Kho, personal communication 1990).

The sediment data indicate that contamination in the pond and river is widespread. The maximum concentrations observed at eight sediment stations located in the pond and river exceed reference levels for arsenic in the Hawaiian Islands (13 mg/kg) and are approximately 34 times higher than anywhere else within the state (Figure 2; Hawaii Department of Health, 1978; Akazawa, personal communication 1989).

Arsenic concentrations observed in the sediments of Hilo Bay have been lower than in the pond and river; but contamination appeared to be widespread (Hallacher *et al.*, 1985; Akazawa, personal communication 1989). Hallacher *et al.* found detectable levels of arsenic at all but one site in the bay (near the mouth). Maximum levels of arsenic in the state data have been observed near the mouth of the Wailoa River and on Blonde Reef. Given the extreme variability in the nature of sediments in Hilo Bay and the lack of normalizing data to accompany arsenic levels, recent data from sites within the bay cannot be evaluated for the degree of association with the site. The maximum concentrations observed at six sediment stations in the bay exceeded reference levels for arsenic (Figure 1; Hawaii Department of Health, 1978; Akazawa, personal communication 1989).

Temporally, concentrations of arsenic appear to be decreasing; but, samples collected in the most contaminated areas generally contain arsenic within an order of magnitude of the highest levels recorded. For example, concentrations of arsenic at the sediment station nearest the former site building were measured at a maximum level of 6,370 mg/kg in 1978. The concentration at the same station in 1986 was 2,496 mg/kg (Hawaii Department of Health, 1978).

Hallacher *et al.* (1985) also reported burial of contaminated sediments, although to a very limited extent. Out of nine sediment cores, four cores had higher arsenic concentrations below the surface while five cores had the highest levels in the surface layers. This was interpreted to indicate that although discharges of effluent contaminated with arsenic have not occurred for over 25 years, sedimentation has not been sufficient to completely bury the contaminated sediments in Waiakea Mill Pond and the Wailoa River. Hallacher *et al.* found maxima in arsenic concentrations up to 68 centimeters deep in some cores from the pond, indicative of a large mass of buried arsenic. They also noted very little bioturbation of the anaerobic sediments. Hallacher *et al.* concluded that the physical disturbance of the sediments, particularly near old effluent discharge sites, could cause the release of substantial amounts of arsenic to the water or surface sediment layers.

Many of the arsenic concentrations observed in the sediments of Waiakea Mill Pond, Wailoa River, and Hilo Bay are potentially toxic to organisms of concern to NOAA. Nearly 80 percent of the sediment samples collected from 1977 to 1986 in Waiakea Mill Pond and the Wailoa River (Akazawa, personal communication 1989) contained arsenic concentrations exceeding the ER-L for arsenic of 33 mg/kg. Arsenic levels in all of the most recent samples (1984-86) exceeded the ER-L values. In Hilo Bay, 67 percent of the sediment samples collected over the decade contained arsenic concentrations exceeding its ER-L. Hallacher *et al.* (1985) conducted a separate sediment investigation in 1983. They found concentrations of arsenic that exceeded the ER-L in 60 percent of their samples collected in the pond, river, and bay.

Other Trace Elements

It appears that the sediments of the Hilo Bay estuary, in particular Waiakea Mill Pond, have been moderately enriched by several other trace elements (Table 3; Akazawa, personal communication 1989). It is not known, however, if these elements were discharged from the former Hawaiian Cane Products Company or were discharged from the other numerous sources on the estuary.

Cadmium, chromium, copper, lead, mercury, nickel, and zinc were observed in the sediment of Waiakea Mill Pond and Wailoa River (Akazawa, personal communication 1989) at concentrations exceeding reference levels observed by the Hawaii Department of Health (1978). All seven elements in both the pond and river exceeded their respective ER-L values. Five trace elements in the sediment of Hilo Bay exceeded reference concentrations and all exceeded their respective ER-L values (Table 3). However, comparison of these seven trace elements to reference or ER-L values should be viewed with caution. Sampling throughout the islands indicates that mean concentrations for many elements in Hawaiian sediments are high compared to soils in other parts of the United States (Hawaii Department of Health, 1978), and are also higher than their respective ER-L values (Table 3) for all seven elements. However, these mean "reference" concentrations for Hawaii are not natural baseline levels since they were calculated as averages of concentrations from sediment samples collected in both urban and non-urban estuaries (Hawaii Department of Health, 1978); and, therefore, reflect some anthropogenic enrichment.

Concentrations of trace elements greater than Hawaiian reference concentrations were widespread in samples from Waiakea Mill Pond, Wailoa River, and Hilo Bay. Between 1977 and 1986, the percentage of sediment samples in Waiakea Mill Pond and the Wailoa River that contained individual trace element concentrations above Hawaiian reference levels ranged from 9 percent (cadmium) to 42 percent (zinc). Lower percentages were observed in Hilo Bay samples, ranging from 0 percent (copper and zinc) to 26 percent (cadmium).

Table 3. Maximum concentrations (mg/kg) of trace elements observed in sediment samples collected in Waiakea Mill Pond, Wailoa River and Hilo Bay from 1977 to 1986 (Akazawa, personal communication 1989) compared to reference levels in Hawaiian sediments (Hawaii Department of Health, 1978) and ER-L values (Long and Morgan, 1990).

	Sediments				ER-L
	Waiakea Mill Pond	Wailoa River	Hilo Bay	Hawaiian Reference [a]	Comparison values [b]
Contaminants	Max	Max	Max	Ave	
Arsenic	6,370.0	306.0	213.0	13.6	33 (16)
Cadmium	110.0	32.0	44.0	8.7	5 (36)
Chromium	454.0	281.0	430.4	181.8	80 (21)
Copper	348.0	243.0	99.0	116.6	70 (51)
Lead	600.0	405.0	320.1	158.1	35 (47)
Mercury	1.28	2.2	1.7	0.53	0.15 (30)
Nickel	511.2	442.6	670.0	241.5	30 (18)
Zinc	756.0	290.8	205.0	213.6	120 (46)

[a] Hawaii is known for high natural concentrations of trace elements in soils and nearshore sediments, notably for copper, chromium, nickel, and zinc. The reference concentrations presented are from sediment samples collected in both urban and non-urban estuaries, therefore may reflect some anthropogenic enrichment (Hawaii Department of Health, 1978).

[b] (Number of values of effects used to derive ER-Ls and ER-Ms.)

Effects on Habitats and Species

Aquatic life in Waiakea Mill Pond, Wailoa River, and Hilo Bay have, and are, experiencing chronic exposure to arsenic and to several other trace elements in the sediments. Levels of eight trace elements detected throughout the estuary exceeded levels shown to be toxic to aquatic life in other studies.

Bioassessment Studies and Observed Effects in the Hilo Bay Estuary

Sediment bioassays or other toxicological investigations have not been conducted at the Hawaiian Cane Products site. Bioassessment studies have been limited and only preliminary conclusions can be drawn from the data, as summarized below.

Sporadic fish kills, up to several days in duration, have been reported in the Hilo Bay estuary, primarily in Waiakea Mill Pond. These kills, however, may be on the decline. A documented kill has not occurred since 1978 (Ecology & Environment, 1989). Limited organic chemical analyses of tissue, as well as limited pathological investigations, have not determined the cause of these kills. The 1978 kill occurred immediately following the first heavy rainfall of the year.

Measurement of the levels of arsenic and the other elements in fish indicate that these elements are not bioaccumulating in epibenthic or pelagic fish and invertebrate species inhabiting the Hilo estuary. Tissue concentrations measured in biota near the site were generally lower than the sediment concentrations in the Hilo Bay estuarine system. Arsenic concentrations in the viscera of the mullet (*Mugil cephalus*) ranged from 1.2 to 6.64 mg/kg, ten times higher than samples from Kauai. Arsenic concentrations in white crab muscle (*Portunus sarguinolentus*) ranged from below the detection limit (detection limit not presented) to 0.17 mg/kg (Hallacher *et al.*, 1985).

Contaminated sediments in Waiakea Mill Pond and the Wailoa River have been described as anaerobic and largely devoid of benthic life (Hallacher *et al.*, 1985). Whether this lack of biological activity is due to the highly anaerobic and nutrient-rich nature of the sediments, or whether arsenic and other contamination has rendered the sediments uninhabitable, has not been determined.

Sediment Toxicity

There are relatively few studies describing the toxicity of trace elements in sediments to aquatic organisms. The majority of the studies describe either behavioral alterations of benthic invertebrates or impacts on benthic communities that have been exposed to contaminated sediments. Because of the many variables affecting the bioavailability and toxicity of contaminants in sediments, it is difficult to generalize about the toxicity of sediment-bound contaminants.

Long and Morgan (1990) summarized the data regarding the toxicity of sediment-bound arsenic to several marine benthic invertebrates. Arsenic in the sediments have been found to be acutely toxic to the benthic amphipod *Rhepoxynius abronius* in bioassays at concentrations ranging from 15 to 2,257 mg/kg. In bioassays with the oyster larvae, *Crassostrea gigas*, acute toxicity responses were observed at concentrations ranging from 59 to 690 mg/kg. Half of the observations (16 values) of adverse effects compiled by Long and Morgan to determine Effects Range values were reporting responses at arsenic concentrations below 100 mg/kg (Table 3). Alteration of marine benthic communities have been observed in the field at sediment concentrations of 57 and 85 mg/kg. Both the bioassay responses and benthic community impacts were observed at concentrations well below the concentrations of arsenic observed in the sediments of Waiakea Mill pond, Wailoa River, and Hilo Bay (see Figures 1 and 2) (Long and Morgan, 1990).

Numerous other trace elements have been detected in Waiakea Mill Pond, Wailoa River and Hilo Bay at elevated levels. Maximum concentrations of cadmium, chromium, copper, lead, mercury, nickel, and zinc observed in the pond, river, and Hilo Bay all exceeded the Hawaiian reference values for each of these elements. With the exception of zinc and copper in Hilo Bay, the maximum concentrations observed for all three areas not only exceed ER-L values, but also exceeded the ER-M values (Table 3).

Other studies have involved behavioral effects. For example, the burrowing times of littleneck clams (*Protothaca staminea*) were reported to increase logarithmically with increasing copper concentrations above 5.8 mg/kg (dry weight) of copper in sediments (Phelps *et al.*, 1983). The effects of zinc on aquatic species include behavioral changes at levels from 51 to 124 mg/kg, decreased species richness of benthic communities at 117 mg/kg, and acute mortality to crustacea at 121 mg/kg.

Since no information concerning use of these metals at former Hawaiian Cane Products site is available, the association of these contaminants with the old site is unknown at this point. Concentrations of all seven of the above trace elements were found in the sediments of the Hilo Bay estuary at concentrations reported in other studies to have toxic effects in some organisms. It is therefore possible that these sediments are toxic to resources of concern to NOAA.

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ECOLOGICAL RISK ASSESSMENT
WAIAKEA POND
HILO, HAWAII

Prepared for: Hawaii Department of Health,
Office of Hazard Evaluation and Emergency Response

March 2005

Prepared by: The Environmental Co., Inc.

ECOLOGICAL RISK ASSESSMENT
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Contract 02-132 Modification Number 4
Work Order 04-010

March 2005

Prepared by
The Environmental Company, Inc.

ECOLOGICAL RISK ASSESSMENT, WAIAKEA POND

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ACRONYMS AND ABBREVIATIONS

BAF	Bioaccumulation Factor
COPEC	Chemicals of Potential Ecological Concern
DLNR	Department of Land and Natural Resources
E&E	Ecology and Environment
ERA	Ecological Risk Assessment
ER-L	Effects Range – Low
ER-M	Effects Range - High
ha	Hectare
HDOH	Hawaii Department of Health
HQ	Hazard Quotient
LOAEL	Lowest Observed Adverse Effect Level
mg/kg-day	milligram per killogram per day
NOAA	National Oceanic and Atmospheric Administration
NOAEL	No Observed Adverse Effect Level
ppt	part per trillion
SERA	Screening Ecological Risk Assessment
SMDP	Scientific Management Decision Point
SUF	Site Use Factor
TRV	Toxicity Reference Values
UH	University of Hawaii
US	United States
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
USFWS	United States Fish and Wildlife Service

SECTION 1
INTRODUCTION

1.1 INTRODUCTION

This screening ecological risk assessment (SERA) assesses the risk of ecological harm due to arsenic in Waiakea Pond located in Hilo, Hawaii (Figure 1-1). The SERA evaluates data collected during previous samplings of the pond.

This SERA was conducted according to guidance published by the United States Environmental Protection Agency (USEPA 1997). A full ecological risk assessment is an eight-step process in the EPA guidance. The Tier 1 USEPA SERA process is the first two steps of the process. Step 1 includes a site description, pathway identification/problem formulation, and toxicity evaluation. This step describes the ecological setting of the site and determines whether complete ecological exposure pathways are present. If complete pathways exist, then the SERA proceeds to Step 2.

Step 2 of the USEPA ecological risk assessment (ERA) process estimates exposure based on conservative assumptions. Then, risk is estimated by comparing the pathway-specific chronic daily intake to conservative, screening-level, toxicity reference values (TRVs) by calculating a hazard quotient (HQ). Chemicals with HQ values that exceed 1 are chemicals of potential ecological concern (COPECs) and at this point a scientific management decision point is necessary to determine how to proceed. The options for a decision include the following:

- There is no need for remediation on the basis of ecological risk because the SERA determined that ecological risks are negligible.

- The ERA process will continue to Step 3a of the ERA process because the SERA indicated a potential for adverse impacts.

- There is not enough information available to make a decision whether there is a significant ecological risk.

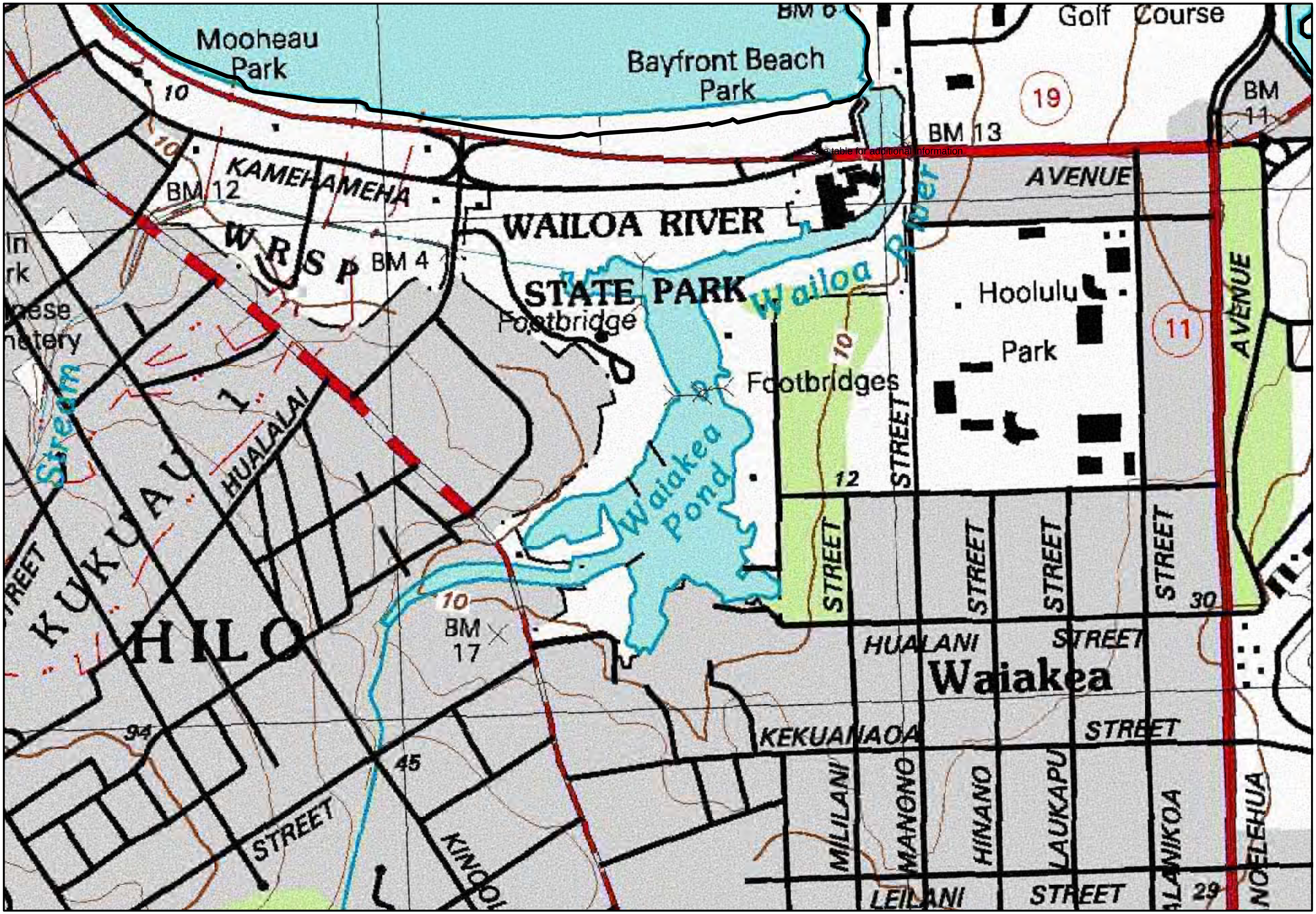

Figure 1-1
Waiakea Pond and Vicinity
Hilo, Hawaii

The Environmental Company, Inc.

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Creation Date: December 2004

SECTION 2
SCREENING LEVEL PROBLEM FORMULATION

2.1 SITE HISTORY AND DESCRIPTION

From 1932 to 1963 a canec board (a type of structural insulation) plant operated on what is now the Waiakea Villas and Village Resort, at the corner of Mililani and Hualani Streets (NOAA 1990). The plant used sugarcane bagasse waste products. In the process arsenic (arsenic trioxide) was used as a termite treatment agent in canec boards (HDOH 1978). It is estimated that 558 tons of arsenic compound (calcium arsenate until the early 1950s and then arsenic trioxide) was released into Waiakea Pond in the discharge water of the canec plant (E&E 1989). Effluent from the plant was discharged to Waiakea Pond through a sewer line that ran about 0.5 miles along the east side of Waiakea Pond to near the boundary between the pond and Wailoa River (E&E 1989). In 1970 the plant was demolished and extensive regrading of the site was completed for the construction of the Villas and Resort (Woodward-Clyde 1989).

2.2 SUMMARY OF PREVIOUS INVESTIGATIONS

A number of investigations have been conducted that provide information on Waiakea Pond or the immediate area. These include the following:

- 1977-78. Hawaii Department of Health (HDOH) sampling of sediments and biota in Waiakea Pond, Wailoa River, and Hilo Bay (HDOH 1978);
- 1983. University of Hawaii (UH) sampling and study of sediments and biota in Waiakea Pond, Wailoa River, and Hilo Bay (Hallacher et al. 1985);
- 1986. UH sampling of surface water and sediments in Waiakea Pond and Wailoa River (Kho 1991);
- 1989. Woodward Clyde sediment and surface water sampling and human health risk assessment for the Hawaiian Cane Products site, including Waiakea Pond (Woodward Clyde 1989);
- 1989. Ecology and Environment (E&E) study (no sampling) of the Hawaiian Cane Products site on behalf of the EPA (E&E 1989);
- 1990. National Oceanic and Atmospheric Administration (NOAA) Preliminary Natural Resource Survey assessment for the Hawaiian Cane Products site (NOAA 1990); and
- Other miscellaneous sampling results by HDOH with limited documentation.

2.3 DESCRIPTION OF WAIAKEA POND

2.3.1 General Information

Waiakea Pond is 30 acres of open water and Wailoa River is 16 acres (E&E 1989). Waiakea Pond is described as shallow (NOAA 1990) but no specific depths have been identified. Hallacher et al. (1985) mentions depths in the Wailoa River up to 9 feet (3 meters). Based on visual observations in November 2004, the sides of the pond drop off abruptly in most places to depths of 2-4 feet with only a few small benches where emergent aquatic plants occur. Water was observed to be very clear throughout the pond in November 2004. Wailoa River and at least the northern portion of the pond experience major salinity fluctuations ranging from 1 parts per thousand (ppt) at the surface to 30 ppt at the bottom (Hallacher et al. 1985). Springs are reported to occur in the upper (southern ends) of Waiakea Pond (NOAA 1990). Photographs of several areas at the pond are provided in Appendix A.

2.3.2 Flora and Fauna

Observations in November 2004 revealed very little emergent vegetation, primarily California grass (*Brachyaria mutica*). No floating or submerged vascular plants were observed. There was a substantial growth of filamentous algae seen on the bottom of the pond. According to Hallacher et al. (1985) the two plants that thrive in the Wailoa estuary system are blue-green algae and an *Elodea* sp.

Important marine fish species present in the pond and river are mullet (*Mugil cephalus*), snapper (*Lutjanus fulvus*), goatfish (*Mulloides vanicolensis*), and Hawaiian flagtail (*Kuhlia sandvicensis*), a moderate-sized perch-like fish (NOAA 1990). The pond and river system serve as nursery grounds and adult foraging areas (NOAA 1990). Observations in November 2004 showed large populations of small fish around the pond margins. Important invertebrate species are the white crab (*Portunus sanguinolentus*) and Samoan crab (*Scylla serrata*) (Hallacher et al. 1985; NOAA 1990).

Sporadic abrupt fish kills of unknown causes and short duration have been reported for Waiakea Pond and Wailoa River up to 1978 (Hawaii District Health Office Report on Water Quality Concerns for Island of Hawaii, 1978, as reported in E&E 1989).

Waiakea Pond is a significant location for birds. Records provided by the United States Geological Survey (USGS) on bird counts (Hoy 2004) are provided in Appendix B. At least 25 different species have been documented. Among the species noted are the endangered Hawaiian coot. The most abundant birds are domestic mallards and other ducks.

2.3.3 Sensitive Resources

Waterbirds are the sensitive species evaluated in the SERA. Sensitive waterbirds that are known to occur at Waiakea Pond are the Federal and State endangered Hawaiian coot (*Fulica americana alai*) and Federal and state endangered Hawaiian duck (*Anas wyvilliana*), based on United States Fish and Wildlife Service (USFWS) bird count records (Hoy 2004; see Appendix A). There is one sighting of two Federal and State endangered nene (*Branta sandvicensis*) in January of 2004 (BirdingHawaii 2004; records from 1998 to 2004). There are unofficial sightings of the Federal and State endangered black-necked stilt *(Himantopus mexicanus knudseni*) (Hoy 2004). The Hawaii Department of Land and Natural Resources (DLNR) has proposed a project to enhance habitat for waterbirds in Waiakea Pond and the project description states that the pond is habitat for endangered stilts, nene, and koloa ducks (DLNR 2002). The project description also states that nene, stilts, and coots have attempted, but rarely succeed, in nesting and raising broods.

2.3.4 Arsenic Measurements

Arsenic has been measured in sediments, surface water, and tissue of algae, invertebrates, and fish in the Waiakea Pond area (see Section 2.2 for a list of the studies). Results from these studies are summarized in Table 2-1 (sediment), Table 2-2 (tissue) and Table 2-3 (water). Locations for the sediment samples (where given in the reports) are shown on figures obtained from these reports (provided in Appendix C). Most of the tissue data is taken from the Hallacher et al. (1985) report. Some of the data in that report cites HDOH as the source of the information, but the original data source could not be located.

A summary of sediment data, published and unpublished, was also developed by NOAA (1990) and shown on Figure 2 of that report (the figure is provided in Appendix C).

Some of the data in the tables are incomplete in that the method, number of samples, or detection limits are not specified (missing information is noted in the tables). The quality of the data is difficult to assess with the information available.

2.4 EXPOSURE PATHWAY ANALYSIS

The primary source of arsenic for the exposure pathways at Waiakea Pond are contaminated sediment. Surface water is also a source. The receptors evaluated in this SERA are threatened and endangered waterbirds described in Section 2.3.3.

The major aquatic pathways between the sources and receptors are:

a) Intake of arsenic from surface water through ingestion for all waterbird receptor species.

b) Intake of arsenic from sediment by intentional sediment ingestion or incidental ingestion when consuming plants or prey species for all waterbird receptor species.

c) Intake of arsenic from ingested invertebrates for all waterbird receptor species. Invertebrates ingest arsenic contained in vegetation or prey items they consume.

d) Intake of arsenic from ingested vegetation for black-necked stilt and Hawaiian coot only. Plants take in arsenic with the primary pathway from sediments through the roots.

e) Intake of arsenic from food items including fish for black-necked stilt and black-crowned night heron only. Fish ingest arsenic contained in vegetation or prey items they consume.

The air exposure pathway is not considered in this SERA because of the location and physical state of the contaminant.

Table 2-1. Arsenic Measurements for Sediments of Waiakea Pond, Wailoa River, and Hilo Bay

Location[1]	Sample Designation	Upper Sediment Conc. (mg/kg)[2]	Lower Sediment Conc. (mg/kg)[2]	Test	Date Sampled	Source	Notes
Tributary to WP	SED-2	7.6	NS	a	May 1989	Woodward-Clyde (1989)	Sample depth not specified; assumed to be surface
Concrete Pipe outfall to WP	SED-3	7.5	NS	a	May 1989	Woodward-Clyde (1989)	Sample depth not specified; assumed to be surface
Active spring to WP	SED-4	80	NS	a	May 1989	Woodward-Clyde (1989)	Sample depth not specified; assumed to be surface
Drainage from waterfalls area	SED-5	3.1	NS	a	May 1989	Woodward-Clyde (1989)	Sample depth not specified; assumed to be surface
Discharge from waterfalls area	SED-6	18	NS	a	May 1989	Woodward-Clyde (1989)	Sample depth not specified; assumed to be surface
Discharge from waterfalls area	SED-7	22	NS	a	May 1989	Woodward-Clyde (1989)	Sample depth not specified; assumed to be surface
Active spring discharge into WP	SED-8	64	NS	a	May 1989	Woodward-Clyde (1989)	Sample depth not specified; assumed to be surface
Active spring discharge into WP	SED-9	1.8	NS	a	May 1989	Woodward-Clyde (1989)	Sample depth not specified; assumed to be surface
Discharge from unpaved area	SED-10	39	NS	a	May 1989	Woodward-Clyde (1989)	Sample depth not specified; assumed to be surface
From concrete outfall area	SED-11	65	NS	a	May 1989	Woodward-Clyde (1989)	Sample depth not specified; assumed to be surface
Nonactive PVC outfall to WP	SED-12	36	NS	a	May 1989	Woodward-Clyde (1989)	Sample depth not specified; assumed to be surface
Waiakea Pond	1-MP	2	ND	b	June/July 1983	Hallacher et al. (1985)	4-10/16-18 cm depths; reported value is wet weight basis
Waiakea Pond	2-MP	251	550	b	June/July 1983	Hallacher et al. (1985)	4-6/56-58 cm depths; reported value is wet weight basis
Waiakea Pond	3-MP	27	3	b	June/July 1983	Hallacher et al. (1985)	6-8/108-110 cm depths; reported value is wet weight basis
Waiakea Pond	4-MP	115	ND	b	June/July 1983	Hallacher et al. (1985)	10-12/52-54 cm depths; reported value is wet weight basis
Waiakea Pond	22	2496	NS	NI	Aug 1986	HDOH Health Lab sheets	Sample depth not specified; assumed to be surface
Waiakea Pond	21	856	NS	NI	Aug 1986	HDOH Health Lab sheets	Sample depth not specified; assumed to be surface
Waiakea Pond	20	234	NS	NI	Aug 1986	HDOH Health Lab sheets	Sample depth not specified; assumed to be surface
Waiakea Pond	5	55	NS	NI	Aug 1986	HDOH Health Lab sheets	Sample depth not specified; assumed to be surface
Waiakea Pond	NI	21.9-6370	NS	NI	NI	HDOH (1978)	Sample depth not specified (<35 cm); 8 samples; reported on a dry weight basis
Waiakea Pond	1 MP	323.50	587, 527.1	d	June/July 1986	Kho (1991)	0-20/43-73 and 100-120 cm depths
Wailoa River	18	588	NS	NI	Aug 1986	HDOH Health Lab sheets	Sample depth not specified; assumed to be surface
Wailoa River	5-WR	151	715	b	June/July 1983	Hallacher et al. (1985)	4-6/57-59 cm depths; reported value is wet weight basis

Location[1]	Sample Designation	Upper Sediment Conc. (mg/kg)[2]	Lower Sediment Conc. (mg/kg)[2]	Test	Date Sampled	Source	Notes
Wailoa River	6-WR	34	60	b	June/July 1983	Hallacher et al. (1985)	3-5/61-63 cm depths; reported value is wet weight basis
Wailoa River	7-WR	43	17	b	June/July 1983	Hallacher et al. (1985)	3-5/103-105 cm depths; reported value is wet weight basis
Wailoa River	SED-1	16.00	NS	a	May 1989	Woodward-Clyde (1989)	Sample depth not specified; assumed to be surface
Wailoa River	2 WR	401.40	946.4	d	June/July 1986	Kho (1991)	0-25/25-40 cm depths
Wailoa River	Stations 1-4	9-6-54.1	9-6-54.1	c	February 2004	(Sea Engineering 2004)	Cores (4-8 feet in length from the surface were composited)
Mouth of Hilo Bay	8-HB	34	63	b	June/July 1983	Hallacher et al. (1985)	3-5/66-68 cm depths; reported value is wet weight basis
Mouth of Hilo Bay	9-HB	56	19	b	June/July 1983	Hallacher et al. (1985)	3-5/50-52 cm depths; reported value is wet weight basis
Mouth of Hilo Bay	NI	131.3		NI	NI	HDOH (1978)	Sample depth not specified (< 35 cm); reported on a dry weight basis
Hilo Bay	10-BW	ND	NT	b	June/July 1983	Hallacher et al. (1985)	Sample from surface; reported value is wet weight basis
Hilo Bay	11-BW	40	NT	b	June/July 1983	Hallacher et al. (1985)	Sample from surface; reported value is wet weight basis
Hilo Bay	NI	21.9-32.9		NI	NI	HDOH (1978)	Sample depth not specified (<35 cm); 13 samples; reported on a dry weight basis

NI - Not Indicated

NT - Not tested

[1] See Appendix C for sample locations (where available).

[2] Not specified whether sample results are wet weight or dry weight unless indicated in notes.

a - EPA Method SW7060.

b - Spectrophotometric (total inorganic).

c - EPA method 200.8 (ICP-MS).

d - Total arsenic measured using atomic absorpton spectrophotometry, hydride method.

Table 2-2. Arsenic Measurements for Organisms in Waiakea Pond and Wailoa River

Sample Designation	Species	Organism Category	Tissue Conc. (mg/kg)[1]	Visceral Content (mg/kg)	Test Type	Date Sampled	Citation	Notes
NI	Blue-green algae	non-vascular plant	ND	NA	b	June/July 1983	Hallacher et al. (1985)	Detection limit not reported; location specified as pond or river and presumed to be from numerous locations
NI	Elodea	vascular plant	ND	NA	b	June/July 1983	Hallacher et al. (1985)	Detection limit not reported; location specified as pond or river and presumed to be from numerous locations
NI	Theodoxus vespertinus	gastropod, brackish water	Trace	NS	b	June/July 1983	Hallacher et al. (1985)	Detection limit not reported
NI	Eleotris sandwicensis	fish, small benthic	0.2	1.1	b	June/July 1983	Hallacher et al. (1985)	
NI	Lutjanus fulvus	fish, snapper	0.2	0.8	b	June/July 1983	Hallacher et al. (1985)	
NI	Kuhlia sandvicensis	fish, perch-like	ND	ND	b	June/July 1983	Hallacher et al. (1985)	Detection limit not reported
NI	Mulloides vanicolensis	fish, goatfish	ND	ND	b	June/July 1983	Hallacher et al. (1985)	Detection limit not reported
#1	Mugil cephalus	fish, mullet	NS	1.3	b	June/July 1983	Hallacher et al. (1985)	
#2	Mugil cephalus	fish, mullet	NS	1.2	b	June/July 1983	Hallacher et al. (1985)	
#3	Mugil cephalus	fish, mullet	NS	1.2	b	June/July 1983	Hallacher et al. (1985)	
NI	Portunus sanguinolentus	crab, white	ND	ND	b	June/July 1983	Hallacher et al. (1985)	Detection limit not reported
NI	Portunus sanguinolentus	crab, white	0.17	NT	NI	NI	Hallacher et al. (1985)	Source of information cited is a study by HDOH; number of samples not indicated
NI	Scylla serrata	crab, Samoan	ND	0.39	NI	NI	Hallacher et al. (1985)	Source of information cited is a study by HDOH; number of samples not indicated
NI	Mugil cephalus	fish, mullet	ND	1.67-6.64	NI	NI	Hallacher et al. (1985)	Source of information cited is a study by HDOH; number of samples not indicated
NI	NI	filamentous algae	1.84	NA	NI	NI	Hallacher et al. (1985)	Source of information cited is a study by HDOH; number of samples not indicated
#1 WP	NI	Fish	.0065/<.0008/.0049	NT	c	May 2000	AECOS data sheet	Testing by Battelle; test on gutted fish, species not indicated
#1 WP repl	NI	Fish	.0071/<.0008/.0058	NT	c	May 2000	AECOS data sheet	Testing by Battelle; test on gutted fish, species not indicated
#2 WP	NI	Fish	.028/<.0008/.071	NT	c	May 2000	AECOS data sheet	Testing by Battelle; test on gutted fish, species not indicated
#3 WP	NI	Fish	.023/<.0008/.058	NT	c	May 2000	AECOS data sheet	Testing by Battelle; test on gutted fish, species not indicated
#4 WP	NI	Fish	.019/<.0008/.059	NT	c	May 2000	AECOS data sheet	Testing by Battelle; test on gutted fish, species not indicated
#5 WP	NI	Fish	.0029/<.0008/.0064	NT	c	May 2000	AECOS data sheet	Testing by Battelle; test on gutted fish, species not indicated
#9 Australian	NI	eggs specified	.055/<.00008/.112	NA	c	May 2000	AECOS data sheet	Species not indicated
#10 Australian	NI	eggs specified	.027/<.00008/.092	NA	c	May 2000	AECOS data sheet	Species not indicated
NI	Mullet		0.82		NI	1991	HDOH (1998); memo	Species not indicated

NI = Not indicated
NT = Not tested
NS = Not sampled
NA = Not applicable
ND = Not detected

[1] Results are specified as wet weight in Hallacher et al. (1985); other sources not specified but assumed to be wet weight.

a - ICAP with AA confirmation (Water 206.2, atomic absorption-furnace; sediment 7060).
b - Spectrophotometric (total inorganic).
c - Analytical test method not indicated but the 3 reported concentrations are listed as Arsenic, Monomethy arsenic (MMA), and Dimethyl Arsenic.

Table 2-3. Arsenic Measurements for Surface Water at Waiakea Pond

Location	Sample Designation	Conc. (ug/L)[1]	Test	Date Sampled	Source	Notes
Tributary to Waiakea Pond	W-2	ND (5.0)	a	May 1989	Woodward-Clyde (1989)	Sample location in water column not specified
Concrete pipe outfall to WP	W-3	ND (5.0)	a	May 1989	Woodward-Clyde (1989)	Sample location in water column not specified
Active spring to WP	W-4	ND (5.0)	a	May 1989	Woodward-Clyde (1989)	Sample location in water column not specified
Active water supply well	W-5	ND (5.0)	a	May 1989	Woodward-Clyde (1989)	Sample location in water column not specified
Inactive water supply well	W-6	ND (5.0)	a	May 1989	Woodward-Clyde (1989)	Sample location in water column not specified
Waterfall adjacent to well shed	W-7	ND (5.0)	a	May 1989	Woodward-Clyde (1989)	Sample location in water column not specified
Active waterfall area	W-8	ND (5.0)	a	May 1989	Woodward-Clyde (1989)	Sample location in water column not specified
Active waterfall area	W-9	ND (5.0)	a	May 1989	Woodward-Clyde (1989)	Sample location in water column not specified
Active waterfall area	W-10	ND (5.0)	a	May 1989	Woodward-Clyde (1989)	Sample location in water column not specified
Drainage from waterfalls area	W-11	ND (5.0)	a	May 1989	Woodward-Clyde (1989)	Sample location in water column not specified
Discharge drainage from waterfalls area	W-12	ND (5.0)	a	May 1989	Woodward-Clyde (1989)	Sample location in water column not specified
Active spring discharge into WP	W-14	ND (5.0)	a	May 1989	Woodward-Clyde (1989)	Sample location in water column not specified
Active spring discharge into WP	W-15	ND (5.0)	a	May 1989	Woodward-Clyde (1989)	Sample location in water column not specified
Discharge from unpaved area	W-16	ND (5.0)	a	May 1989	Woodward-Clyde (1989)	Sample location in water column not specified
WP surface water	NI	50.2-78.1	b	June/July 1986	E.B Kho (1991)	Concentrations reported as just above pond sediments
WP sediment pore water	NI	2280-2810	b	June/July 1986	E.B Kho (1991)	Concentrations reported for surface sediments
Wailoa River	W-1	ND (5.0)	a	May 1989	Woodward-Clyde (1989)	Sample location in water column not specified

Note: Data from the HDOH collected in 1961 and 1962 is not included due to the age of the data.

NI - Not indicated.

ND - Not detected.

NT - Not tested.

a - EPA Water Method 206.2 (atomic absorption-furnace).

b - Total arsenic measured using atomic absorpton spectrophotometry, hydride method.

[1] Detection limits given in parentheses.

2.4.1 Fate and Transport

Inorganic species of arsenic are typically predominant in the aquatic environment, occurring mainly as arsenates (As+5) in oxidizing environments such as surface water, and arsenites (As+3) under reducing conditions such as hypoxic or anoxic sediments (USGS 2002). Based on coring completed in the Hallacher et al. study (1985), sediments in Waiakea Pond are anoxic just below the sediment surface.

Transport and partitioning of arsenic in water depends upon the oxidation state of the arsenic and on interactions with other materials present. Generally, factors that tend to increase arsenic availability are anthropogenic source (e.g., pesticides), low clay content, low redox potential (reducing conditions) and high pH (EPA 2000). In acidic and neutral waters, As(+5) is extensively adsorbed onto particulates, while As(+3) is relatively weakly adsorbed and in waters with a high pH, adsorption is much lower for both oxidation states (ATSDR 2000).

Sediment-bound arsenic may be released back into the water by chemical or biological interconversions of arsenic species. Hallacher et al. (1985) suggest that the anoxic conditions of the sediments may result in reduced biological colonization and disturbance of the contaminated sediment and also speculate that physical disturbance of the sediments could release substantial amounts of arsenic into the water column. The oxidation of arsenite (to less toxic forms) that would occur upon exposure to oxidizing conditions (e.g. sediments being suspended in the water column) is moderately slow with a half-life 0.4–7 days in coastal systems according to sources cited by ATSDR (2000). In addition to physical releases, reduction of arsenates (As+5) to other forms by microorganisms could lead to increased mobilization of arsenic, since As(+3) and organic arsenicals are less reactive and more mobile than arsenates (ATSDR 2000).

Arsenic can move from water and sediment into a biofilm layer of attached algae, bacteria, and associated fine detrital material, and then into invertebrates and fish (ATSDR 2000). The consensus in the literature is that 85% to greater than 90% of arsenic found in edible portions of marine fish and shellfish is organic arsenic (USEPA 2003). Although arsenic may bioaccumulate in animals, it does not biomagnify between aquatic tropic levels (USEPA 2003). See Section 3.1.1 for additional discussion on bioaccumulation.

2.5 CONCEPTUAL SITE MODEL

The known sources of analytes in the site media and potential exposure pathways to ecological receptors are summarized in the conceptual site model presented in Figure 2-2.

2.6 ASSESSMENT ENDPOINTS

The assessment endpoint for a SERA is an adverse effect on an ecological receptor (EPA 1997). Ecological receptors are plant and animal populations, communities. habitats, or sensitive environments. The assessment endpoints for this SERA are reproduction success of local individuals or populations of waterbirds that use Waiakea Pond. Population-level effects will have effects at higher organizational levels. Therefore, local population-level assessment endpoints should be good indicators of overall ecological health of the pond.

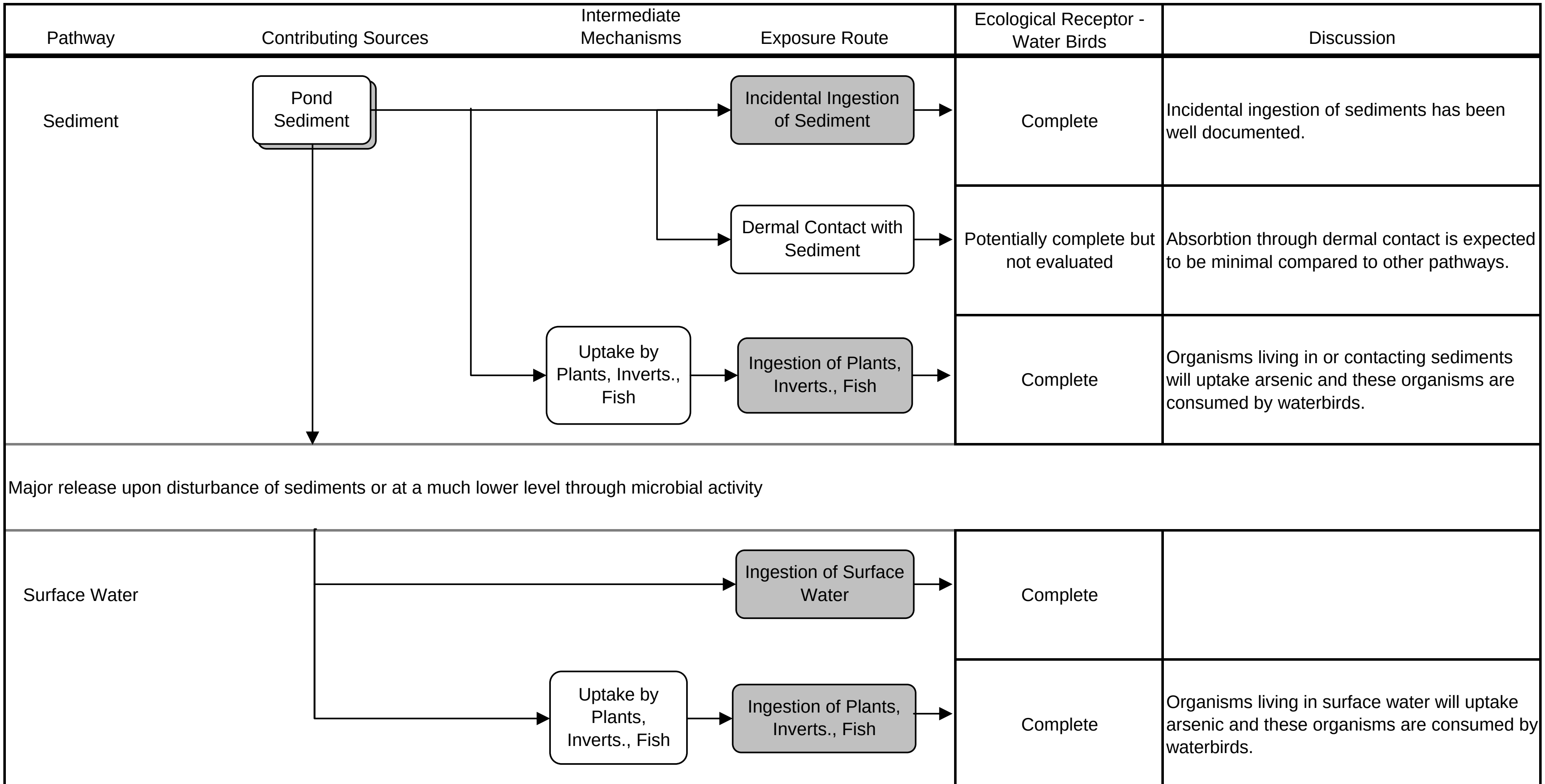

Figure 2-1
Conceptual Site Model
Waiakea Pond
Hilo, Hawaii

2.7 MEASUREMENT ENDPOINTS

Measurement endpoints are the actual measurements used to evaluate ecological risk and are selected to represent mechanisms of toxicity and exposure pathways. Measurement endpoints generally include measured or modeled concentrations of chemicals in water, sediment, soil, fish or other animals. Sometimes laboratory toxicity studies and/or field surveys are used.

The measurement endpoint for this SERA is exceedance of effect-level intake thresholds based on TRVs. Arsenic chronic intake through food chain exposure are based on animal models from studies conducted in Hawaii and elsewhere and on measured fish tissue, sediment, and surface water concentrations.

Measurement endpoints corresponding to the assessment endpoint were identified for the representative species or their surrogates. The measurement endpoint was determined to be an adverse effect of arsenic exposure on the survival or reproduction/development of a representative species or its surrogate. The measurement endpoint was evaluated by comparing intakes for representative receptor species to TRVs reported in guidance documents or obtained from peer-reviewed publications. TRV studies evaluate effects to individuals. It is assumed that if effects are judged insignificant for the average individual receptor, they will be considered insignificant at the population level. However, it should be noted that if risks are present at the individual receptor level, risks may or may not be important at the local population level.

Intakes were calculated based on measured sediment and surface water concentrations, measured food tissue concentrations, and wildlife exposure factors from the literature.

Three species of waterbirds were selected as receptors to represent the fauna of the pond. Selection was based largely on the species' ecological importance and their potential for exposure to sediment contamination. It is believed that the evaluation of risk to these species will represent risk evaluated for the breeding population in the local environment, in particular Waiakea pond. The three species are of ecological importance at Waiakea Pond or the region. The selected representative species of concern at the site include the black-necked stilt, Hawaiian coot, and black-crowned night heron. Information on these species is provided below. Additional information on these species can be found in the ecological profiles in Appendix D.

Black-necked stilt *(Himantopus mexicanus knudseni).* This is a Hawaiian subspecies of stilt. The stilt is a medium-size wading bird that may use Waiakea Pond occasionally. There are unofficial sightings at Waiakea Pond (Hoy 2004). Its diet consists almost entirely of animal material (e.g., aquatic organisms, worms, and snails), with a minimum of vegetable matter (see Table 2-2).

The stilt population on the island of Hawaii is primarily on the Kona coast (USFWS 1999). The present population on the island of Hawaii is estimated at 130 birds along the Kona coast (Birding Hawaii 2004; based on Ducks Unlimited surveys 1996 to 1997). The maximum size of the feeding territory of black-necked stilts has been estimated as 24 hectares (ha) (Schoener 1968). Although large expanses of its preferred feeding habitat (shallows less than 6 inches deep) are not found at Waiakea Pond, it is included as a receptor species because of its endangered status and the lack of other suitable habitat in east Hawaii.

Hawaiian coot (*Fulica americana alai*). This is a subspecies of the American coot. The Hawaiian coot is smaller in body size than the mainland species (USFWS 1999). Coots are generalists, obtaining food near the surface of the water, diving, or foraging in mud or sand (see Table 2-2). They also graze on upland grassy sites. They can disperse and exploit seasonally flooded wetlands. Coots typically forage in water less than 12 inches (30 centimeters) deep and large, deep ponds provide only limited habitat for coots (USFWS 1999). Coots will loaf on open bodies of water (USFWS 1999) and this may be the primary use of Waiakea Pond for the coot.

There were 75 birds on the Hilo coast in Waikea and Loko Waka Pond according to Ducks Unlimited survey data in 1995-96 (USFWS 1999). Sightings reported by BirdingHawaii (2004) often refer to a single individual. In a site visit in November 2004, a single individual was seen. Because of its presence at the pond and its endangered status this species is included as a receptor in the SERA.

Black-crowned night heron *(Nycticorax nycticorax hoactli).* This is a medium-size heron that feeds at Waiakea Pond. It is a piscivorous species although it also eats amphibians and limited amounts of benthic invertebrates if they are available (see Table 2-2). There is some habitat at the pond and an abundance of small fish prey. This species is regularly seen at the pond. For these reasons it is included as a receptor.

2.8 ARSENIC TOXICITY EVALUATION

The toxicity evaluation for arsenic consists of the development of TRVs for screening food chain pathways and an evaluation of the bioaccumulation potential of arsenic for the food items of aquatic waterbirds.

It is known that arsenites tend to have greater toxicity to wildlife than other forms (Sample et al. 1996). Recent research summarized by USEPA (2003) indicates that when compared to arsenite, trivalent methylated arsenic metabolites exert a number of unique biological effects, are more cytotoxic and genotoxic, and are more potent inhibitors of the activities of some enzymes. However, this SERA does not separate the various forms of arsenic because the information is not available; all studies evaluated to support this SERA reported total arsenic or did not specify which forms were measured.

2.8.1 Toxicity Reference Values

A TRV, as used in this risk assessment, is a dosage (in milligram of chemical per kilogram of body weight per day [mg/kg-day]) of a chemical that is believed to have little or no effect on the long-term health of the representative species of concern. The TRV of a chemical is derived from studies and literature that report no-observed-adverse-effect levels (NOAELs) and lowest-observed effect levels (LOAELs) for arsenic administered orally to particular test species.

Taxonomic extrapolation is used in the development of the TRVs because of the lack of toxicity data for the specific target species. This principal assumes that toxicological effects reported for one species can be used to predict the toxicological effects in a taxonomically related species.

TRVs for arsenic have been developed in other studies or guidance documents. Relevant studies that were selected for this SERA are shown in Table 2-4. The first source (USN 2002), is based on an extensive baseline ERA for Pearl Harbor, Oahu completed for the U.S. Navy. Two values from that study are provided in the table, the bounded NOAEL (below the lowest LOAEL), and the lowest LOAEL. The second source is from a SERA protocol document published by Region 6 of EPA (EPA 1999). The third source is from an extensive study that developed toxicological benchmarks for wildlife, conducted by researchers at the Oak Ridge National Laboratory (Sample et al. 1996).

For the purposes of this SERA, the TRVs shown in Table 2-4 are considered applicable to the three waterbird receptor species at Waiakea Pond. Although the brown-headed cowbird is not a waterbird, TRVs for this species were considered appropriate for screening in this SERA, primarily based on the extensive literature review of toxicity values associated with the Pearl Harbor sediment study (USN 2002).

Table 2-4. TRVs for Arsenic for the Receptors at Waiakea Pond

TRV (mg/kg-day)	Measurement Endpoint	Test Species	Source of TRV	Original Study[1]
1.85	NOAEL	Brown-headed cowbird	Pearl Harbor Sediment Study (USN 2002)	USFWS (1969)
3.88	LOAEL	Mallard	Pearl Harbor Sediment Study (USN 2002)	Camardese et al. (1990)
2.46	NOAEL	Brown-headed cowbird	Screening TRVs, EPA Region 6 (EPA 1999)	USFWS (1969)
5.1	NOAEL	Mallard	ORNL Screening TRVs (Sample et al. 1996)	USFSW (1964)

[1] As documented in the source listed in the previous column.

2.8.2 Bioaccumulation Potential

Bioaccumulation of arsenic in the food chain of waterbirds is evaluated in this section. For plants, substantial information is available only for terrestrial plants (versus aquatic plants) and results from these are summarized here. In general, numerous studies of highly polluted soil or soil naturally high in arsenic indicate that the arsenic taken up by plants is comparatively low (ATSDR 2000). Bechtel Jacobs (1998) summarized arsenic bioaccumulation factors (BAFs) obtained in numerous plant BAF studies. The geometric mean BAF for 122 observations they reported was 0.0371 (with a range of 0.00006 to 9.074). The geometric mean BAF for arsenic in plants in another often-cited study for terrestrial plants was similar at 0.04 (Baes et al. 1984). Applying this BAF to a mean sediment arsenic concentration of 1300 mg/kg for Waiakea Pond (see Section 3.1.1 for an explanation of this value) results in a plant tissue concentration of 52 mg/kg.

Although no study was found evaluating bioaccumulation from sediment to aquatic plant, one study was found with data on bioconcentration of arsenic from water to plant in the marine environment and these results are summarized here for comparison to the BAFs from terrestrial plants.. Arsenic bioconcentration factors at three locations in Hawaiian marine systems and for three different seaweed species were measured by Galvez (1990). She found bioconcentration factors ranging from 16 to 176. Using the high bioconcentration value and a concentration in seawater in Waiakea Pond of 0.078 mg/L (Table 2-3; source is Kho [1991]), the tissue concentration would be 13.7 mg/kg wet weight (86 mg/kg dry weight based on a water content of 84% [Sample et al. 1994]). This comparison shows that both methods of calculating plant tissue concentrations yields roughly similar results (52 mg/kg versus 86 mg/kg).

A study by Bechtel Jacobs (1998b) evaluated arsenic bioaccumulation in aquatic invertebrates. The geometric mean arsenic BAF (sediment to organism) for 55 observations was 0.47 (with a range of 0.018 to 4.33) (Bechtel Jacobs 1998b). Studies conducted in Pearl Harbor (USN 2004) also provide information on BAFs. They determined harborwide arsenic BAFs for composite macroinfauna (0.85), blue-clawed stone crab (0.75), tilapia (0.30), and bandtail goatfish (0.18). These results are remarkably similar given the inherent variability in these types of measurements. A comparison of arsenic concentrations in white crab (*Portunus sanguinolentus*) and the sediments in which the crab lived was reported for samples collected in Hilo Bay (HDOH 1978). The value reported for arsenic in sediment was 82.2 mg/kg and the corresponding concentration in white crab tissue was 0.17 mg/kg wet weight (0.65 mg/kg dry weight based on a water content of 74% [Sample et al. 1994]) resulting in a BAF of 0.008. This comparison indicates that BAFs for arsenic in Waiakea Pond may be lower than is typical in other areas. Based on this information, a BAF of 0.47 would be conservative for use at Waiakea Pond.

BAFs for arsenic in fish from the literature are not evaluated in this SERA because substantial fish tissue data is available for Waiakea Pond. Fish tissue data will be used in calculations of arsenic intake for the waterbirds that are being evaluated.

It is important to note that typical background total arsenic levels in marine bivalves are in the range of 1 to 2 mg/kg wet weight and for flounder are in the range of 0.75 to 2.5 mg/kg wet weight (USEPA 2003), therefore, based on measured concentrations in organisms at Waiakea Pond (Table 2-2), there appears to be minimal bioaccumulation occurring.

2.8.3 Arsenic Screening Concentrations for Surface Water and Sediment

The State of Hawaii has a Water Quality Standard for arsenic to protect aquatic life in surface waters (HDOH 2004). For saltwater the acute standard is 69 µg/L and the chronic standard is 36 µg/L (values refer to the dissolved fraction). The only detected arsenic concentrations reported for surface water at Waiakea Pond (Table 2-3) are from Kho (1991) and range from 50.2 to 78.1 µg/L (these values reported as total arsenic), near or slightly exceeding the surface water standards. These results indicate possible but not severe adverse effects on some food organisms of the waterbirds being evaluated in this SERA.

Various sediment screening reference values to evaluate potential impacts to aquatic life have been developed for arsenic (Long et al. 1995). For marine sediments screening reference values range from 8.2, the effects range-low (ER-L) concentration, to 70 mg/kg, the effects range-median (ER-M) concentration. Measured concentrations in many areas greatly exceed these values (Table 2-1). These results indicate potential severe adverse effects on at least some food organisms of the waterbirds being evaluated in this SERA. However, an examination of the data from Long et al. (1995) show that the incidence of effects is 5.9 percent below the ERL, 11.1 percent between the ERL and ERM, and 63 percent above the ERM.

SECTION 3
EXPOSURE ESTIMATION AND RISK CHARACTERIZATION

3.1 ESTIMATION OF ARSENIC INTAKES

Step 2 of the SERA process is a quantitative risk analysis. The exposure estimation determines the concentration that receptor species are exposed to or the intake of a substance. It uses conservative exposure assumptions.

3.1.1 Calculation of Exposure Concentrations

The calculation of exposure concentrations for the three representative waterbirds uses historical data collected from Waiakea Pond sediments, surface water, and fish tissue (See Section 2.2 for a list). The measured concentrations reported in Tables 2-1 to 2-3 are used in the calculations. Bioaccumulation factors (geometric means of data sets; see Section 2.8.2) were used to calculate the amount of arsenic potentially available in plants and invertebrates. Although a few measurements of tissue levels in algae and invertebrates were available, it was assumed that there were too few measurements available (and collection locations were not specified) to represent a conservative screening estimate of the amount of arsenic available in plants and fish.

The sediment concentration used to estimate the exposure point concentration for calculation of intakes was the mean of all the numbers shown in Figure 2 of the NOAA Natural Resources report (NOAA 1990) (a copy of the figure is provided in Appendix C). The arsenic concentrations shown in that figure are a compilation of the maximum arsenic concentrations measured in different areas of the pond and river to the mouth of Hilo Bay. The values in the figure represent the published data (shown in Table 2-1) and additional unpublished data that was obtained from UH researchers and HDOH personnel. Because the arsenic data shown in this figure covers the aerial extent of the entire pond and river system (the likely home range of the waterbirds being evaluated) reasonably thoroughly, and because maximum concentrations were used for each area of the pond and river system, the arithmetic mean of all concentrations shown in this figure in Waiakea Pond and Wailoa River is used as a reasonable conservative estimate of the exposure concentration for arsenic in sediments. This mean arsenic concentration is 1300 mg/kg.

Concentrations of arsenic in plants were determined using the plant BAF discussed in Section 2.8.2. To calculate the concentration of a arsenic that bioaccumulates in plants the sediment concentration was multiplied by the BAF of 0.04. Similarly, concentrations of arsenic in invertebrates were determined using the aquatic invertebrate BAF discussed in Section 2.8.2. To calculate the concentration of a arsenic that bioaccumulates in aquatic invertebrates the sediment concentration was multiplied by the BAF of 0.47.

For fish, directly measured fish tissue arsenic concentrations were used in the calculations. Fish tissue sampling was conducted prior to 1978 by HDOH (1978), in 1985 by UH (Hallacher et al. 1985), and in 1991 by HDOH (HDOH 1998). Additional samples of whole fish (gutted) collected for HDOH were analyzed in 2000 (AECOS 2000). The tissue concentrations in fish prey of the waterbirds were estimated using the maximum concentrations (in either muscle tissue or viscera) that have been measured in samples of fish tissue: small benthic fish (1.1 mg/kg) for the black-necked stilt and large fish (5.65 mg/kg in mullet) for the black-crowned night heron.

Although many of the fish tissue measurements were for mullet, the species most likely to be consumed by humans, there were samples of other potential prey species and viscera tissue samples from the mullet in the Hallacher et al. (1985) study. It is assumed that all these measurements adequately represent the amounts in fish tissue of actual prey species for the receptor waterbirds.

3.1.2 Exposure Parameters

The equations used to calculate intakes and all the exposure parameters used in the calculation are shown in Table 3-1.

The diet of the three birds is from three major exposure pathways:

- Incidental or deliberate sediment- ingestion;
- Ingestion of contaminated food consisting of plant material, invertebrates, and/or fish; and
- Ingestion of water.

The site use factor (SUF) incorporates less than full-time exposure for animals with foraging areas exceeding the area of contamination or that do not use the site exclusively for one reason or other. The foraging area of the Hawaiian coot and black-crowned night heron are less than the size of the site, therefore it is assumed that each of these species could occupy the site 100 percent of the time, and the SUF is equal to 1. The SUF is assumed to be 0.25 for the black-necked stilt. Even though the foraging area of this species is less than the size of Waiakea Pond, a lesser value is assumed for the stilt because the pond is not ideal habitat for this species and it would require other feeding areas.

The proportion of different food types was obtained from the literature. The total from food ingestion plus sediment ingestion equals 100 percent of the diet.

3.2 RISK CHARACTERIZATION

Results of the risk calculations are shown in Table 3-2. Intakes are presented for each exposure pathway to allow for the comparison of the relative effect of each. The overall result of the calculations is an HQ that is the ratio of the total intake for all pathways to the TRV. The TRVs used are the highest and lowest values used from the sources listed in Table 2-3. HQs that exceed one indicate a potential for adverse effects. For each receptor species two calculations are shown, one using the estimated high level concentration of arsenic in sediments throughout the pond and river (1300 mg/kg) and a second concentration that was obtained by adjusting the sediment concentrations in the calculation equation until the HQ of one (HQ=1) was reached (using the low TRV in the calculation).

The analysis and calculations show that, with the current sediment arsenic concentrations, the primary pathways of exposure to arsenic for the black-necked stilt are through the incidental ingestion of sediment that contains arsenic and through the ingestion of invertebrates. For the Hawaiian coot, the intakes of arsenic are similar for incidental sediment ingestion, ingestion of plants, and ingestion of invertebrates.

Table 3-1. Intake Equations and Exposure Factors

Food and Sediment Ingestion

CDI = (Cf x F x TFI x SUF)/(BW)

Parameter		Value - Stilt	Value - Coot	Value - Heron	Units
CDI	Chronic daily intake	(See Table 3-2)	(See Table 3-2)	(See Table 3-2)	mg/kg-day
Cf	Concentration in food being eaten				
	Sediment	1300	1300	1300	mg/kg dry weight
	Sediment (HQ=1)	300	250	125	mg/kg dry weight
	Plants (based on high sediment conc.)	52 a	52 a	52 a	mg/kg dry weight
	Plants (HQ=1.)	12	10	5	mg/kg dry weight
	Invertebrates (based on high sed. conc.)	605.80 b	605.80 b	605.80 b	mg/kg dry weight
	Invertebrates (HQ=1)	139.8	116.5	58.25	mg/kg dry weight
	Fish (measured)	4.4 c	NA	26.56 d	mg/kg dry weight
F	Conversion factor	1.0E-06	1.0E-06	1.0E-06	kg/mg
TFI	Total food intake (Mean)	16093 e	39902 e	49089 e	mg/day, dry weight
FT	Fraction of total food intake per food source				
	Sediment	0.18 f	0.033 j	0.02 k	unitless
	Plants	0.01 g	0.89 n	0 l	unitless
	Invertebrates	0.24 g	0.08 n	0.5 l	unitless
	Fish	0.57 g	0 n	0.5 l	unitless
SUF	Site Use Factor	0.25 h	1	1	unitless
BW	Body Weight (Mean)	0.20 i	0.56 i	0.883 m	kg

Water Ingestion

CDI = (Csw x WI x SUF)/(BW)

Parameter		Value - Stilt	Value - Coot	Value - Heron	Units
CDI	Chronic daily intake	0.002	0.006	0.005	mg/kg-day
Csw	Concentration in surface water	0.0781	0.0781	0.0781	mg/L
WI	Water Intake	0.02 e	0.040 e	0.054 e	L/day
SUF	Site Use Factor	0.25 h	1	1	unitless
BW	Body Weight	0.20 i	0.56 i	0.883 m	kg

NA - not available

a Value calculated using a BAF of 0.04 (see text).

b Value calculated using a BAF of 0.47 (see text).

c Value is for small benthic fish, visceral tissue; wet weight of 1.1 (Hallacher et al. 1985) converted to dry weight using 75% water (Sample et al. 1994).

d Value is for mullet, visceral tissue; wet weight of 6.64 (Hallacher et al. 1985 citing HDOH data) converted to dry weight using 75% water (Sample et al. 1994).

e EPA (1993); TFI (kg/day) = $0.0582BW^{0.651}$; WI=$0.059BW^{0.67}$; dry weight basis.

f Beyer et al. (1994); value is the mean (range from 7-30 percent) for the 4 sandpiper species tested in that study.

g Derived from the statement that HI stilts spend 70% of their time foraging for fish; only 1.1% of diet is vegetative matter (Robinson et al. 1999).

h SUF assumed to be 25% based on the poor habitat available.

i Body weights are mean values for adults of a species from Dunning (1993).

j Beyer et al. (1994); value used is for the mallard.

k It is assumed to be low because of its prey items; <2% is the lowest value reported by Beyer et al. (1994) for waterbirds.

l Gross (1923) but assume half is invertebrates, half is fish.

m Palmer (1962).

n USGS (2004); value reported as 89% plant food for the American coot.

Table 3-2. Calculated Intakes of Arsenic and Hazard Quotient Values

Sediment Arsenic Level	Conc. in Sediment (mg/kg)	Incidental Ingestion Sed. Pathway (mg/kg-day)	Food Pathway: Plants (mg/kg-day)	Food Pathway: Invertebrates (mg/kg-day)	Food Pathway: Fish (mg/kg-day)	Water Pathway (mg/kg-day)	Total Daily Intake (mg/kg-day)	TRV-low[a] (mg/kg-day)	TRV-high[a] (mg/kg-day)	HQ-low TRV	HQ-high TRV
Black-necked Stilt											
Estimated Mean	1300	4.71	0.01	2.92	0.05	0.002	7.69	1.85	3.88	**4.2**	**2.0**
HQ=1	300	1.09	0.00	0.67	0.00	0.002	1.77	1.85	3.88	1.0	
Hawaiian Coot											
Estimated Mean	1300	3.06	3.30	3.45	0.00	0.006	9.81	1.85	3.88	**5.3**	**2.5**
HQ=1	250	0.59	0.63	0.66	0.00	0.006	1.89	1.85	3.88	1.0	
Black-crowned Night Heron											
Estimated Mean	1300	1.45	0.00	16.84	0.74	0.005	19.03	1.85	3.88	**10.3**	**4.9**
HQ=1	125	0.14	0.00	1.62	0.00	0.005	1.76	1.85	3.88	1.0	

Bold values have an HQ greater than 1.

For the black-crowned night heron the primary intake pathway is invertebrate ingestion. Intakes of fish and water are not significant pathways for any species.

For the HQ=1 calculations the primary pathways of arsenic ingestion are similar to the existing conditions calculations. However, note that because fish intake was determined by measured tissue concentrations, the HQ=1 calculation would not have automatically adjusted fish intakes (through the use of a BAF). Therefore, for this calculation it was assumed that the fish intake pathway did not contribute any arsenic. This adjustment has only a small impact on the outcome of the HQ=1 calculation because the primary arsenic intakes for all three species are not through fish – they are through incidental sediment ingestion and invertebrate intake for the black-necked stilt and invertebrate food for the black-crowned night heron (fish are not a significant portion of the Hawaiian coot diet).

The overall results (Table 3-2) show that the HQ significantly exceeds 1.0 for all three species and is highest for the night heron. Results show that the sediment concentrations that would result in an HQ equal to one would be as low as 125 mg/kg (for the night heron).

3.3 UNCERTAINTY ANALYSIS

Uncertainty results from a number of sources, including but not limited to the following:

- Accuracy and adequacy of sampling;
- Uncertainties in the exposure estimation; and
- Limitations associated with input data for the development of the TRV dataset.

3.3.1 Accuracy and Adequacy of Sampling

This SERA uses data from a number of existing sources. Source data is from numerous agencies or groups and widely varying dates. Methodology and sample locations are absent in some of the reports, in particular the 1978 HDOH data. The distribution of arsenic within the pond-river complex sediments is poorly known. The most important locations for sediment and invertebrate tissue sampling to evaluate the risk are shallow areas where the waterbirds primarily feed, but the data does not allow an adequate evaluation of whether these areas were adequately represented.

3.3.2 Uncertainties in the Exposure Estimation

Exposure estimates in this SERA are based on the highest measured contaminant concentration for tissue concentrations in fish and the mean concentration of the highest measured sediment concentrations in each area of Waiakea Pond. This assumes that the receptors present at the site are ingesting the maximum concentrations of arsenic in their food items at all times and that they are exposed to the highest levels of arsenic in sediments, even though these highest levels of arsenic may not be present in the uppermost sediment layer. In addition, this analysis assumes that all the arsenic taken in is bioavailable and is in the most toxic form (arsenites). This is a very conservative approach and ensures that no potential threat to ecological receptors is missed. These assumptions are a major source of uncertainty in the analysis.

Concentrations of arsenic in plants and invertebrates that are food items of the receptors (waterbirds) are estimated using mean BAFs from the literature. These BAFs introduce considerable uncertainty because they are not specific for the Waiakea Pond system. At least for invertebrates, the BAF used appears to be a conservative assumption based on one measurement in Hilo Bay of sediment concentrations and crabs living in that sediment (HDOH 1978). The BAF for plants is less certain, but given its probable much lower magnitude compared to the invertebrate BAF, it is probably not a major uncertainty.

The exposure models used to predict uptake of arsenic by the receptors via various pathways depend on species-specific exposure factors including body weight, daily food and water intake, and the percentage of soil, plant, and prey material constituting the food intake. These factors have uncertainty associated with them, although probably minor when compared to other uncertainties.

Other factors that the models do not account for may affect exposure of representative species. For example, the receptors may avoid contaminated areas if there is little to forage or prey on in those areas. The prey items themselves may be adversely affected by arsenic.

3.3.3 Limitations Associated with Input Data for the Development of the TRV Dataset

The lack of data for the specific receptor species used in this SERA is the greatest limitation in developing an accurate TRV. This lack for data requires taxonomic extrapolation. Other extrapolations required for generating TRVs from a toxicity database include extrapolation from one toxicological endpoint to another and extrapolation of toxicity values measured for one form of arsenic to another. In addition, laboratory studies used as a basis for generating TRVs may not accurately represent the complexities of potential exposure under field conditions. Use of this toxicity data and the extrapolations required are a major source of uncertainty in the analysis.

3.4 SCREENING ERA CONCLUSIONS

The HQ methodology results in an estimate of the potential for adverse effects based on conservative assumptions. HQ values for the black-necked stilt, Hawaiian coot, and black-crowned night heron all exceed 1 for arsenic. HQ values range from 2.0 (black-necked stilt using the high range TRV) to 10.3 (black-crowned night heron using the low range TRV). The greatest risk occurs through the incidental ingestion of sediment and the ingestion of invertebrates from the Waiakea Pond complex, and plants for the Hawaiian coot. Overall, there is a risk of adverse impacts to the waterbird receptors evaluated based on the conservative exposure and toxicity assumptions that were made in this analysis.

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APPENDIX A

Site Photographs


Southern end of Pond looking north. November 5, 2004.


Southern end of Pond showing thick vegetation. Springs reported in this area. November 5, 2004.

Upper end of Pond showing shoreline and emergent vegetation. November 5, 2004.

Water clarity of the pond; water depth approximately 2 feet. November 5, 2004.


Wailoa River portion near bridge. November 5, 2004.


Hawaiian coot. November 5, 2004.

APPENDIX B

Bird Count Data for Waiakea Pond and Wailoa River

USFWS Waiakea Pond and Wailoa River Bird Counts

Wetland	Island	Date	Year	Month	Day	Season	Surveyed	Time Start	Time End	Duration	Minutes	Koloa - ad	Koloa - ch	Coot - sub	Coot - ad	Coot-unk	Gall - sub	Gall - ad	Gall-unk	Stilt - sub	Stilt - ad	Stilt-unk	Koloa hybrid	Mallard - dom	Muscovy	Other dom duck	Dom geese	Night Heron	Cattle Egret	A. Wigeon	Canvasback
Waiakea Pond	Hawaii	1/15/2003	2003	1	15	Winter	Y	9:15	10:50	1:35	95	0	0	0	2	0	0	0	0	0	0	0	0	43	21	118	25	0	0	0	0
Waiakea Pond	Hawaii	1/16/2002	2002	1	16	Winter	Y	8:40	10:25	1:45	105	0	0	0	2	0	0	0	0	0	0	0	0	57	18	141	32	6	0	0	0
Waiakea Pond	Hawaii	8/15/2001	2001	8	15	Summer	Y	6:15	7:45	1:30	90	0	0	0	0	0	0	0	0	0	0	0	0	0	22	35	17	3	0	0	0
Waiakea Pond	Hawaii	1/17/2001	2001	1	17	Winter	Y	6:30	9:30	3:00	180	0	0	0	0	0	0	0	0	0	0	0	0	41	0	0	33	1	0	0	4
Waiakea Pond	Hawaii	8/21/2000	2000	8	21	Summer	Y	5:30	6:30	1:00	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	207	30	3	0	0	0
Waiakea Pond	Hawaii	1/19/2000	2000	1	19	Winter	Y	7:00	8:00	1:00	60	0	0	0	5	0	0	0	0	0	0	0	0	11	12	22	15	0	0	0	0
Waiakea Pond	Hawaii	8/18/1999	1999	8	18	Summer	Y	8:00	10:00	2:00	120	0	0	0	0	0	0	0	0	0	0	0	0	38	0	82	16	4	0	0	0
Waiakea Pond	Hawaii	8/19/1998	1998	8	19	Summer	Y	8:40	10:40	2:00	120	0	0	0	2	0	0	0	0	0	0	0	1	110	0	57	24	2	0	0	0
Waiakea Pond	Hawaii	3/4/1998	1998	3	4	Winter	Y	6:30	8:30	2:00	120	0	0	0	0	4	0	0	0	0	0	0	0	22	30	15	20	2	1	0	0
Waiakea Pond	Hawaii	9/3/1997	1997	9	3	Summer	N	999	999	999	999														999	999	999	999	999	999	999
Waiakea Pond	Hawaii	1/28/1997	1997	1	28	Winter	Y	6:00	7:30	1:30	90	0	0	0	1	0	0	0	0	0	0	0	0	22	27	22	25	0	0	0	0
Waiakea Pond	Hawaii	1/23/1996	1996	1	23	Winter	Y	6:15	9:00	2:45	165	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	1	0	3	0
Waiakea Pond	Hawaii	8/22/1995	1995	8	22	Summer	U	999	999	999	999														999	999	999	999	999	999	999
Waiakea Pond	Hawaii	1/26/1995	1995	1	26	Winter	U	999	999	999	999														999	999	999	999	999	999	999
Waiakea Pond	Hawaii	8/24/1994	1994	8	24	Summer	Y	6:00	7:00	1:00	60	0	0	0	0	0	0	0	0	0	0	0	0	2	0	66	0	0	0	0	0
Waiakea Pond	Hawaii	1/19/1994	1994	1	19	Winter	N	999	999	999	999														999	999	999	999	999	999	999
Waiakea Pond	Hawaii	8/26/1993	1993	8	26	Summer	Y	999	999	999	999	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Waiakea Pond	Hawaii	1/20/1993	1993	1	20	Winter	Y	7:30	8:30	1:00	60	0	0	0	12	0	0	0	0	0	0	0	0	6	15	10	11	1	0	0	0
Waiakea Pond	Hawaii	8/5/1992	1992	8	5	Summer	Y	5:45	6:15	0:30	30	0	0	0	8	3	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0
Waiakea Pond	Hawaii	1/29/1992	1992	1	29	Winter	Y	6:30	7:10	0:40	40	0	0	0	0	5	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0
Waiakea Pond	Hawaii	8/28/1991	1991	8	28	Summer	Y	999	999	999	999	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Waiakea Pond	Hawaii	1/10/1991	1991	1	10	Winter	Y	6:30	7:00	0:30	30	0	0	0	3	0	0	0	0	0	0	0	0	9	0	17	7	2	0	0	0
Waiakea Pond	Hawaii	8/20/1990	1990	8	20	Summer	Y	6:40	7:30	0:50	50	0	0	0	1	1	0	0	0	0	0	0	0	7	0	0	0	2	0	0	0
Waiakea Pond	Hawaii	1/17/1990	1990	1	17	Winter	Y	999	999	999	999	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26	0	0	0	7	0
Waiakea Pond	Hawaii	8/8/1989	1989	8	8	Summer	Y	11:00	12:15	1:15	75	2	0	0	3	0	0	0	0	0	0	0	0	22	0	1	8	2	0	0	0
Waiakea Pond	Hawaii	1/27/1989	1989	1	27	Winter	Y	9:30	11:00	1:30	90	0	0	0	5	0	0	0	0	0	0	0	0	11	0	15	0	0	0	0	0
Waiakea Pond	Hawaii	7/30/1988	1988	7	30	Summer	N	999	999	999	999														999	999	999	999	999	999	999
Waiakea Pond	Hawaii	2/19/1988	1988	2	19	Winter	Y	11:00	11:20	0:20	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Waiakea Pond	Hawaii	1/6/1988	1988	1	6	Winter	Y	999	999	999	999	0	0	0	0	2	0	0	0	0	0	0	0	20	0	0	0	2	0	1	0
Waiakea Pond	Hawaii	7/29/1987	1987	7	29	Summer	N	999	999	999	999														999	999	999	999	999	999	999
Waiakea Pond	Hawaii	1/14/1987	1987	1	14	Winter	N	999	999	999	999														999	999	999	999	999	999	999
Waiakea Pond	Hawaii	7/29/1986	1986	7	29	Summer	N	999	999	999	999														999	999	999	999	999	999	999
Waiakea Pond	Hawaii	1/15/1986	1986	1	15	Winter	N	999	999	999	999														999	999	999	999	999	999	999
Wailoa	Hawaii	1/15/2003	2003	1	15	Winter	N	999	999	999	999														999	999	999	999	999	999	999
Wailoa	Hawaii	1/16/2002	2002	1	16	Winter	N	999	999	999	999														999	999	999	999	999	999	999
Wailoa	Hawaii	8/15/2001	2001	8	15	Summer	Y	6:15	7:45	1:30	90	0	0	0	0	0	0	0	0	0	0	0	0	0	22	35	17	3	0	0	0
Wailoa	Hawaii	1/17/2001	2001	1	17	Winter	N	999	999	999	999														999	999	999	999	999	999	999
Wailoa	Hawaii	8/16/2000	2000	8	16	Summer	N	999	999	999	999														999	999	999	999	999	999	999

999 = No Data

Wetland	Island	Date	Year	Month	Day	Season	Surveyed	Time Start	Time End	Duration	Minutes	Koloa - ad	Koloa - ch	Coot - sub	Coot - ad	Coot-unk	Gall - sub	Gall - ad	Gall-unk	Stilt - sub	Stilt - ad	Stilt-unk	Koloa hybrid	Mallard - dom	Muscovy	Other dom duck	Dom geese	Night Heron	Cattle Egret	A. Wigeon	Canvasback
Wailoa	Hawaii	1/19/2000	2000	1	19	Winter	N	999	999	999	999														999	999	999	999	999	999	999
Wailoa	Hawaii	8/19/1999	1999	8	19	Summer	N	999	999	999	999														999	999	999	999	999	999	999
Wailoa	Hawaii	8/19/1998	1998	8	19	Summer	N	999	999	999	999														999	999	999	999	999	999	999
Wailoa	Hawaii	3/4/1998	1998	3	4	Winter	N	999	999	999	999														999	999	999	999	999	999	999
Wailoa	Hawaii	9/3/1997	1997	9	3	Summer	N	999	999	999	999														999	999	999	999	999	999	999
Wailoa	Hawaii	1/28/1997	1997	1	28	Winter	N	999	999	999	999														999	999	999	999	999	999	999
Wailoa	Hawaii	1/24/1996	1996	1	24	Winter	N	999	999	999	999														999	999	999	999	999	999	999
Wailoa	Hawaii	8/22/1995	1995	8	22	Summer	N	999	999	999	999														999	999	999	999	999	999	999
Wailoa	Hawaii	1/26/1995	1995	1	26	Winter	Y	999	999	999	999	0	0	0	7	0	0	0	0	0	0	0	0	0	12	35	0	0	0	0	0
Wailoa	Hawaii	8/17/1994	1994	8	17	Summer	N	999	999	999	999														999	999	999	999	999	999	999
Wailoa	Hawaii	1/19/1994	1994	1	19	Winter	N	999	999	999	999														999	999	999	999	999	999	999
Wailoa	Hawaii	8/26/1993	1993	8	26	Summer	N	999	999	999	999														999	999	999	999	999	999	999
Wailoa	Hawaii	1/19/1993	1993	1	19	Winter	N	999	999	999	999														999	999	999	999	999	999	999
Wailoa	Hawaii	8/6/1992	1992	8	6	Summer	N	999	999	999	999														999	999	999	999	999	999	999
Wailoa	Hawaii	1/30/1992	1992	1	30	Winter	N	999	999	999	999														999	999	999	999	999	999	999
Wailoa	Hawaii	8/28/1991	1991	8	28	Summer	N	999	999	999	999														999	999	999	999	999	999	999
Wailoa	Hawaii	1/10/1991	1991	1	10	Winter	N	999	999	999	999														999	999	999	999	999	999	999
Wailoa	Hawaii	8/20/1990	1990	8	20	Summer	N	999	999	999	999														999	999	999	999	999	999	999
Wailoa	Hawaii	1/17/1990	1990	1	17	Winter	N	999	999	999	999														999	999	999	999	999	999	999
Wailoa	Hawaii	8/7/1989	1989	8	7	Summer	N	999	999	999	999														999	999	999	999	999	999	999
Wailoa	Hawaii	1/27/1989	1989	1	27	Winter	N	999	999	999	999														999	999	999	999	999	999	999
Wailoa	Hawaii	8/1/1988	1988	8	1	Summer	Y	10:00	11:00	1:00	60	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wailoa	Hawaii	1/25/1988	1988	1	25	Winter	N	999	999	999	999														999	999	999	999	999	999	999
Wailoa	Hawaii	7/29/1987	1987	7	29	Summer	Y	7:30	999	999	999	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wailoa	Hawaii	1/14/1987	1987	1	14	Winter	Y	10:00	999	999	999	0	0	0	1	0	0	0	0	0	0	0	0	25	11	0	0	1	0	0	0
Wailoa	Hawaii	7/29/1986	1986	7	29	Summer	Y	999	999	999	999	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wailoa	Hawaii	1/15/1986	1986	1	15	Winter	Y	999	999	999	999	0	0	0	3	0	0	0	0	0	0	0	0	22	0	1	0	1	4	0	0

999 = No Data

Wetland	Island	Date	Year	Month	Day	Season	Surveyed	Time Start	Time End	Duration	Minutes	Pintail	Shoveler	R. Turnstone	Sanderling	Golden Plover	W. Tattler	B.T. Curlew	L.Scaup	Nene	Aleutian Goose	Cackling Goose	Canada Goose	G. B. Heron	Redhead	Scaup sp	White Fronted Goose
Waiakea Pond	Hawaii	1/15/2003	2003	1	15	Winter	Y	9:15	10:50	1:35	95	0	0	0	0	16	0	0	5	0		1	6				1
Waiakea Pond	Hawaii	1/16/2002	2002	1	16	Winter	Y	8:40	10:25	1:45	105	0	1	0	0	8	0	0	1	0		1	2				1
Waiakea Pond	Hawaii	8/15/2001	2001	8	15	Summer	Y	6:15	7:45	1:30	90	0	0	0	0	5	0	0	0	0	1		3				
Waiakea Pond	Hawaii	1/17/2001	2001	1	17	Winter	Y	6:30	9:30	3:00	180	0	2	0	0	9	0	0	13	0	1		3		2		1
Waiakea Pond	Hawaii	8/21/2000	2000	8	21	Summer	Y	5:30	6:30	1:00	60	0	0	0	3	4	2	0	0	0	1						
Waiakea Pond	Hawaii	1/19/2000	2000	1	19	Winter	Y	7:00	8:00	1:00	60	6	0	0	0	7	0	0	3	0							
Waiakea Pond	Hawaii	8/18/1999	1999	8	18	Summer	Y	8:00	10:00	2:00	120	0	0	0	0	2	0	0	0	0							
Waiakea Pond	Hawaii	8/19/1998	1998	8	19	Summer	Y	8:40	10:40	2:00	120	0	0	0	0	9	0	0	0	0							
Waiakea Pond	Hawaii	3/4/1998	1998	3	4	Winter	Y	6:30	8:30	2:00	120	2	0	0	0	8	0	0	0	0	3						
Waiakea Pond	Hawaii	9/3/1997	1997	9	3	Summer	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Waiakea Pond	Hawaii	1/28/1997	1997	1	28	Winter	Y	6:00	7:30	1:30	90	0	0	0	0	1	0	0	1	0							
Waiakea Pond	Hawaii	1/23/1996	1996	1	23	Winter	Y	6:15	9:00	2:45	165	0	5	0	0	9	0	0	0	0				1			
Waiakea Pond	Hawaii	8/22/1995	1995	8	22	Summer	U	999	999	999	999	999	999	999	999	999	999	999	999	999							
Waiakea Pond	Hawaii	1/26/1995	1995	1	26	Winter	U	999	999	999	999	999	999	999	999	999	999	999	999	999							
Waiakea Pond	Hawaii	8/24/1994	1994	8	24	Summer	Y	6:00	7:00	1:00	60	0	0	0	0	2	0	0	0	0							
Waiakea Pond	Hawaii	1/19/1994	1994	1	19	Winter	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Waiakea Pond	Hawaii	8/26/1993	1993	8	26	Summer	Y	999	999	999	999	0	0	0	0	5	0	0	0	0							
Waiakea Pond	Hawaii	1/20/1993	1993	1	20	Winter	Y	7:30	8:30	1:00	60	0	0	0	0	9	0	0	0	0							
Waiakea Pond	Hawaii	8/5/1992	1992	8	5	Summer	Y	5:45	6:15	0:30	30	0	0	0	0	0	0	0	0	0							
Waiakea Pond	Hawaii	1/29/1992	1992	1	29	Winter	Y	6:30	7:10	0:40	40	0	4	0	0	0	0	0	4	0							
Waiakea Pond	Hawaii	8/28/1991	1991	8	28	Summer	Y	999	999	999	999	4	4	0	0	6	0	0	0	0							
Waiakea Pond	Hawaii	1/10/1991	1991	1	10	Winter	Y	6:30	7:00	0:30	30	0	0	0	0	6	0	0	0	0							
Waiakea Pond	Hawaii	8/20/1990	1990	8	20	Summer	Y	6:40	7:30	0:50	50	0	0	0	0	0	0	0	0	0							
Waiakea Pond	Hawaii	1/17/1990	1990	1	17	Winter	Y	999	999	999	999	0	0	0	0	3	0	0	0	0			1				
Waiakea Pond	Hawaii	8/8/1989	1989	8	8	Summer	Y	11:00	12:15	1:15	75	2	0	0	0	0	0	0	0	0							
Waiakea Pond	Hawaii	1/27/1989	1989	1	27	Winter	Y	9:30	11:00	1:30	90	6	4	0	0	7	0	0	0	0						5	
Waiakea Pond	Hawaii	7/30/1988	1988	7	30	Summer	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Waiakea Pond	Hawaii	2/19/1988	1988	2	19	Winter	Y	11:00	11:20	0:20	20	0	0	0	0	0	0	0	0	0							
Waiakea Pond	Hawaii	1/6/1988	1988	1	6	Winter	Y	999	999	999	999	1	0	0	0	0	0	0	0	0							
Waiakea Pond	Hawaii	7/29/1987	1987	7	29	Summer	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Waiakea Pond	Hawaii	1/14/1987	1987	1	14	Winter	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Waiakea Pond	Hawaii	7/29/1986	1986	7	29	Summer	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Waiakea Pond	Hawaii	1/15/1986	1986	1	15	Winter	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Wailoa	Hawaii	1/15/2003	2003	1	15	Winter	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Wailoa	Hawaii	1/16/2002	2002	1	16	Winter	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Wailoa	Hawaii	8/15/2001	2001	8	15	Summer	Y	6:15	7:45	1:30	90	0	0	0	0	5	0	0	0	0	1		3				
Wailoa	Hawaii	1/17/2001	2001	1	17	Winter	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Wailoa	Hawaii	8/16/2000	2000	8	16	Summer	N	999	999	999	999	999	999	999	999	999	999	999	999	999							

999 = No Data

Wetland	Island	Date	Year	Month	Day	Season	Surveyed	Time Start	Time End	Duration	Minutes	Pintail	Shoveler	R. Turnstone	Sanderling	Golden Plover	W. Tattler	B.T. Curlew	L.Scaup	Nene	Aleutian Goose	Cackling Goose	Canada Goose	G. B. Heron	Redhead	Scaup sp	White Fronted Goose
Wailoa	Hawaii	1/19/2000	2000	1	19	Winter	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Wailoa	Hawaii	8/19/1999	1999	8	19	Summer	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Wailoa	Hawaii	8/19/1998	1998	8	19	Summer	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Wailoa	Hawaii	3/4/1998	1998	3	4	Winter	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Wailoa	Hawaii	9/3/1997	1997	9	3	Summer	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Wailoa	Hawaii	1/28/1997	1997	1	28	Winter	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Wailoa	Hawaii	1/24/1996	1996	1	24	Winter	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Wailoa	Hawaii	8/22/1995	1995	8	22	Summer	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Wailoa	Hawaii	1/26/1995	1995	1	26	Winter	Y	999	999	999	999	0	6	0	0	4	1	0	6	0							
Wailoa	Hawaii	8/17/1994	1994	8	17	Summer	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Wailoa	Hawaii	1/19/1994	1994	1	19	Winter	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Wailoa	Hawaii	8/26/1993	1993	8	26	Summer	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Wailoa	Hawaii	1/19/1993	1993	1	19	Winter	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Wailoa	Hawaii	8/6/1992	1992	8	6	Summer	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Wailoa	Hawaii	1/30/1992	1992	1	30	Winter	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Wailoa	Hawaii	8/28/1991	1991	8	28	Summer	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Wailoa	Hawaii	1/10/1991	1991	1	10	Winter	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Wailoa	Hawaii	8/20/1990	1990	8	20	Summer	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Wailoa	Hawaii	1/17/1990	1990	1	17	Winter	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Wailoa	Hawaii	8/7/1989	1989	8	7	Summer	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Wailoa	Hawaii	1/27/1989	1989	1	27	Winter	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Wailoa	Hawaii	8/1/1988	1988	8	1	Summer	Y	10:00	11:00	1:00	60	0	0	0	0	4	0	0	0	0							
Wailoa	Hawaii	1/25/1988	1988	1	25	Winter	N	999	999	999	999	999	999	999	999	999	999	999	999	999							
Wailoa	Hawaii	7/29/1987	1987	7	29	Summer	Y	7:30	999	999	999	0	0	0	0	0	0	0	0	0							
Wailoa	Hawaii	1/14/1987	1987	1	14	Winter	Y	10:00	999	999	999	0	0	0	0	2	0	0	0	0							
Wailoa	Hawaii	7/29/1986	1986	7	29	Summer	Y	999	999	999	999	0	0	0	0	0	0	0	0	0							
Wailoa	Hawaii	1/15/1986	1986	1	15	Winter	Y	999	999	999	999	8	0	0	0	1	0	0	0	0			3				

999 = No Data

APPENDIX C

Sample Location and Results Figures

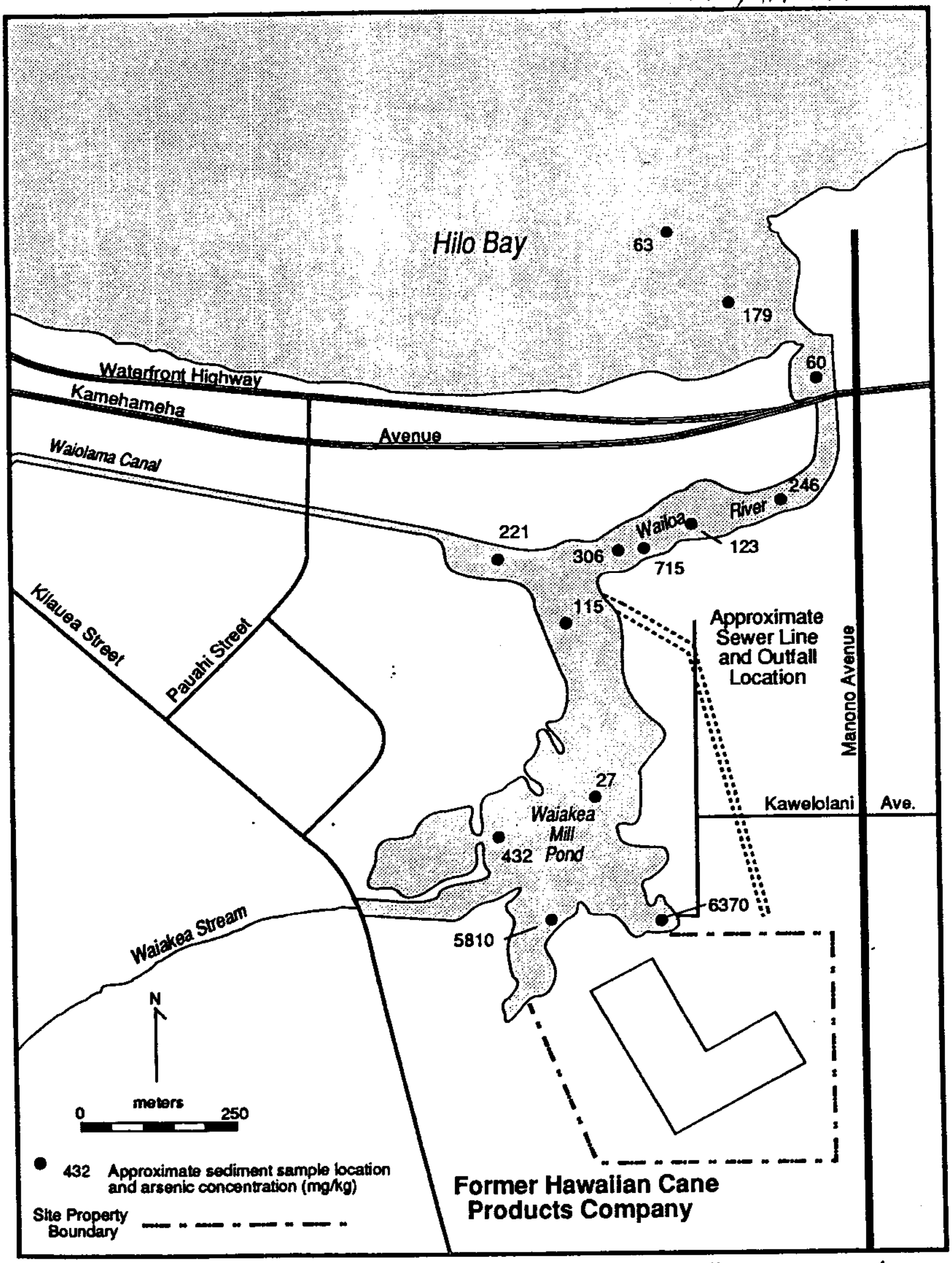


Figure 2. The Hawaiian Cane Products site and maximum arsenic sediment concentrations observed between 1977 and 1986 (Hilo, Hawaii) (Akazawa, personal communication; M & E Pacific 1980)

PACIFIC SCIENCE, Volume 39, July 1985

Hallacher et al. 1985

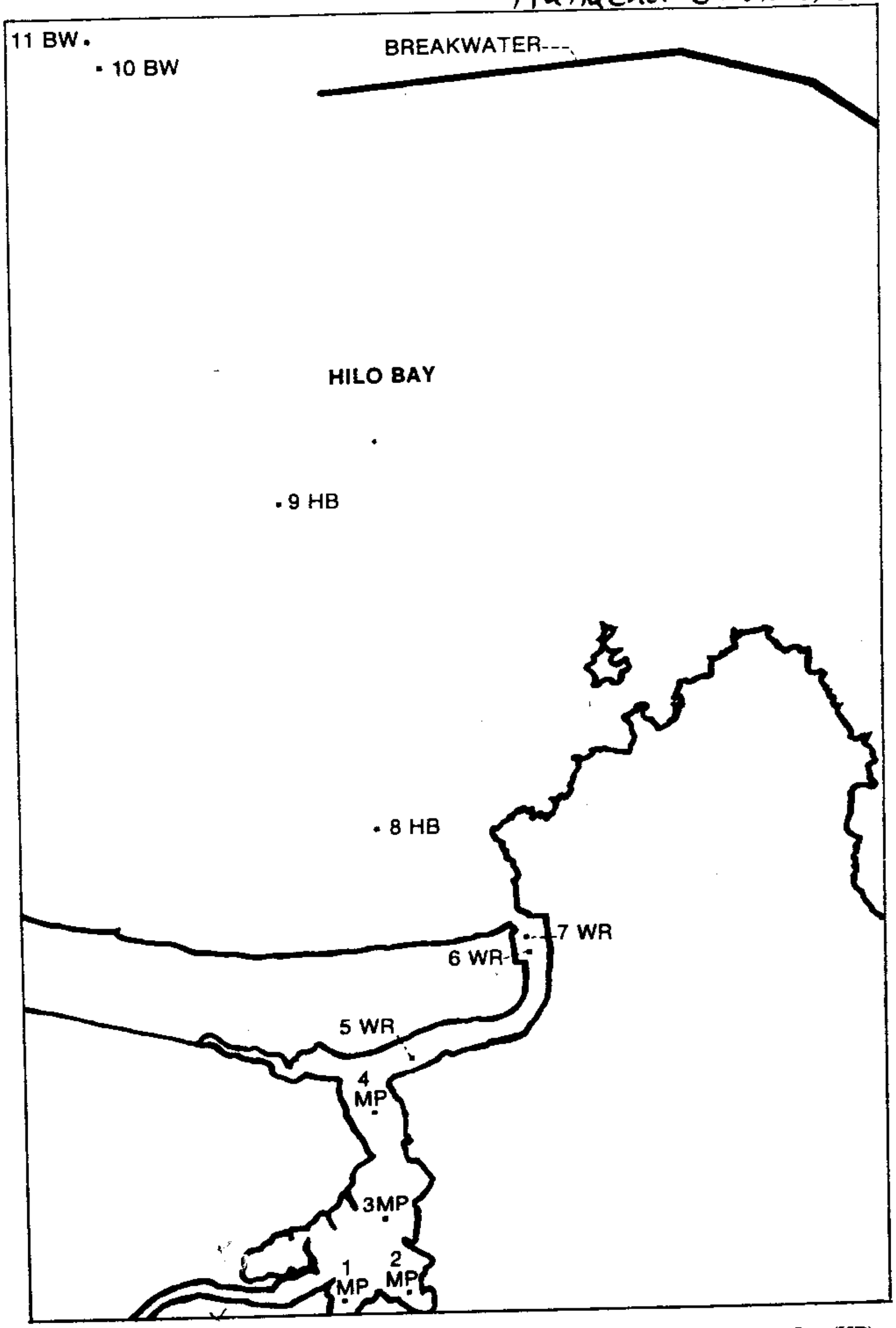


FIGURE 1. Coring station locations in the Waiakea Mill Pond (MP), Wailoa River (WR), Hilo Bay (HB), and the mouth of Hilo Bay (BW).

Kho 1991

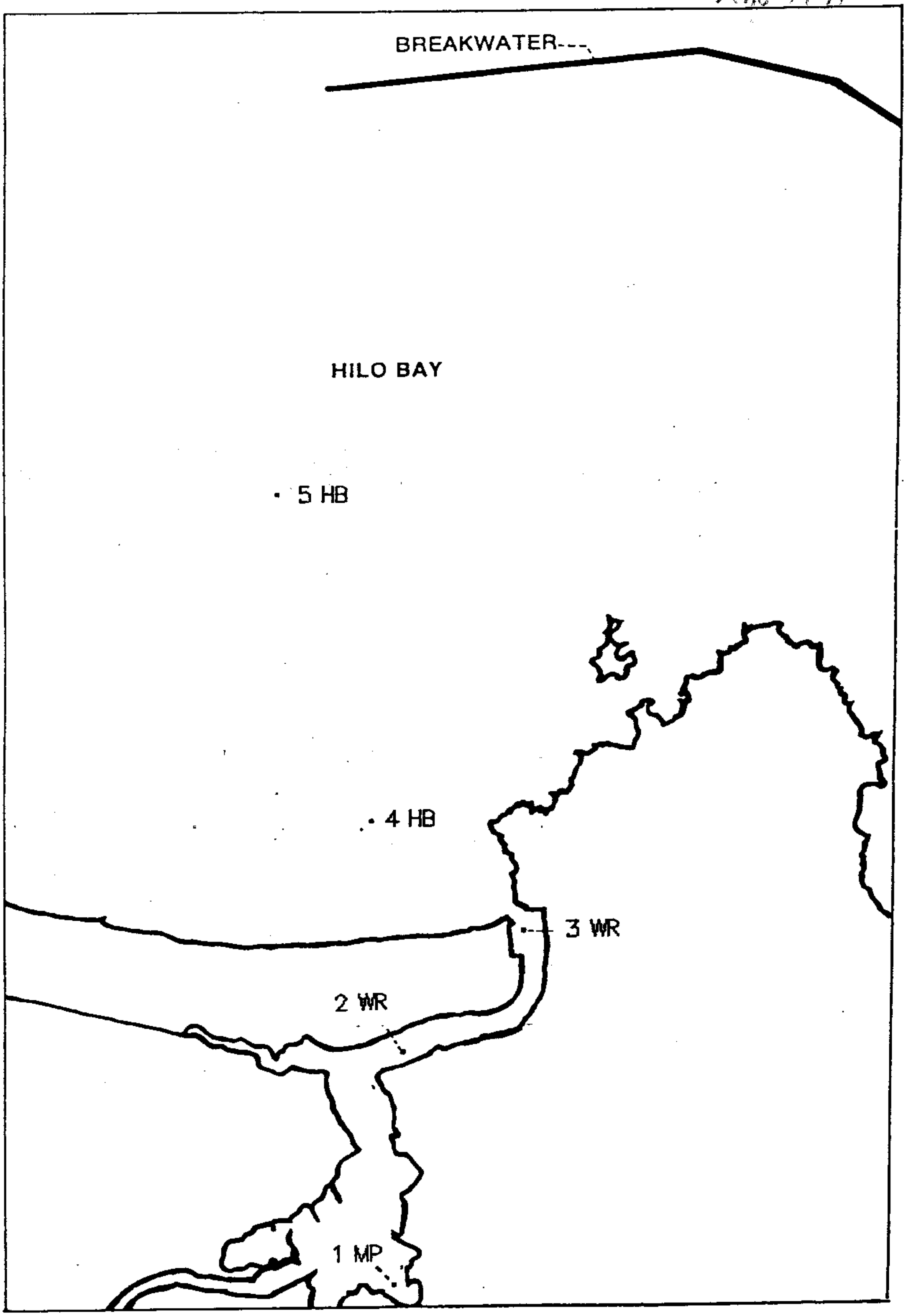
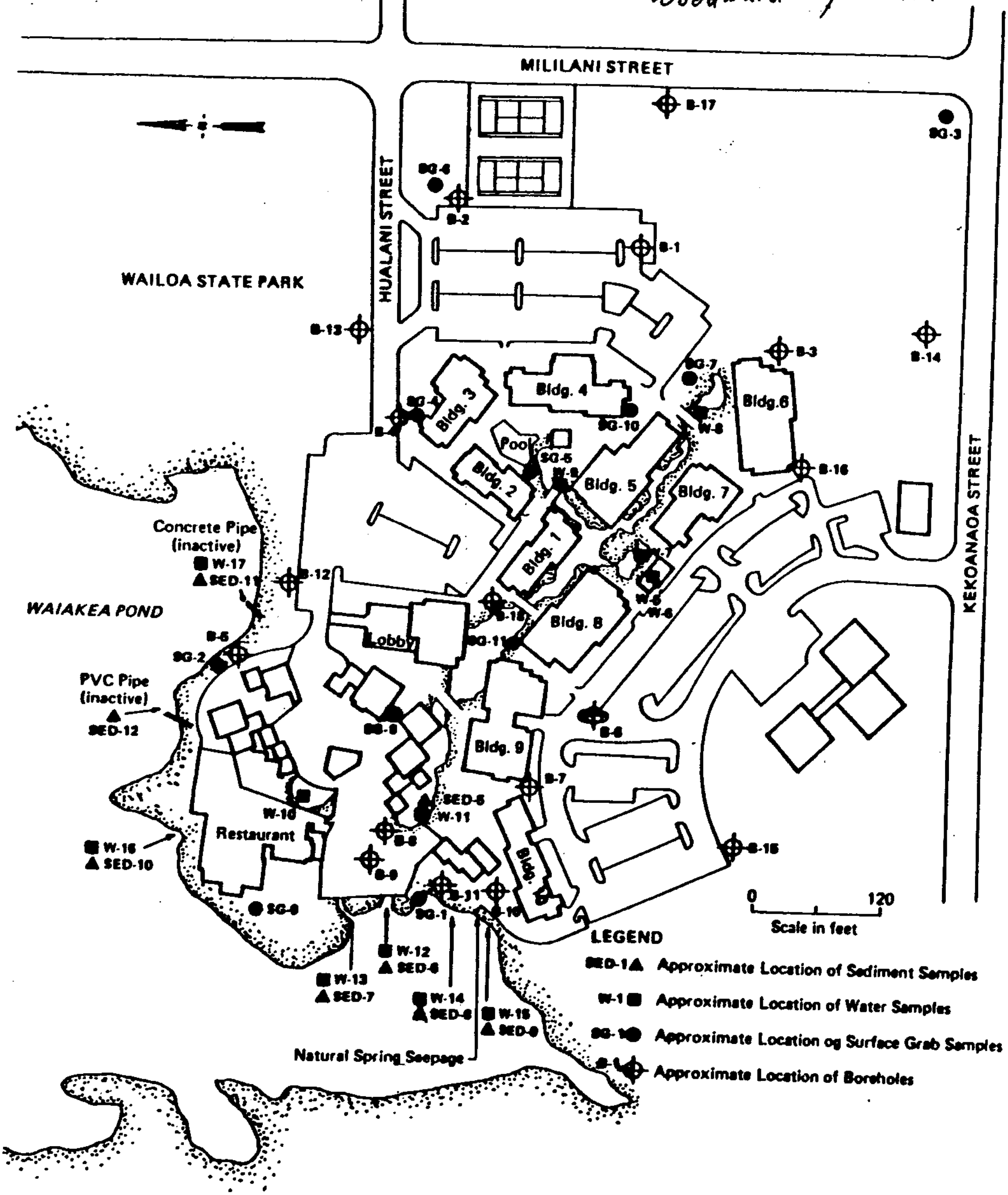


Figure 1

Woodward-Clyde 1989



Project No. 8910098A	Waiakea Village	LOCALITY MAP FOR ON-SITE SAMPLE LOCATIONS AT WAIAKEA VILLAGE IN HILO, ISLAND OF HAWAII, HAWAII	Figure 4
Woodward-Clyde Consultants			

HDOH 1978

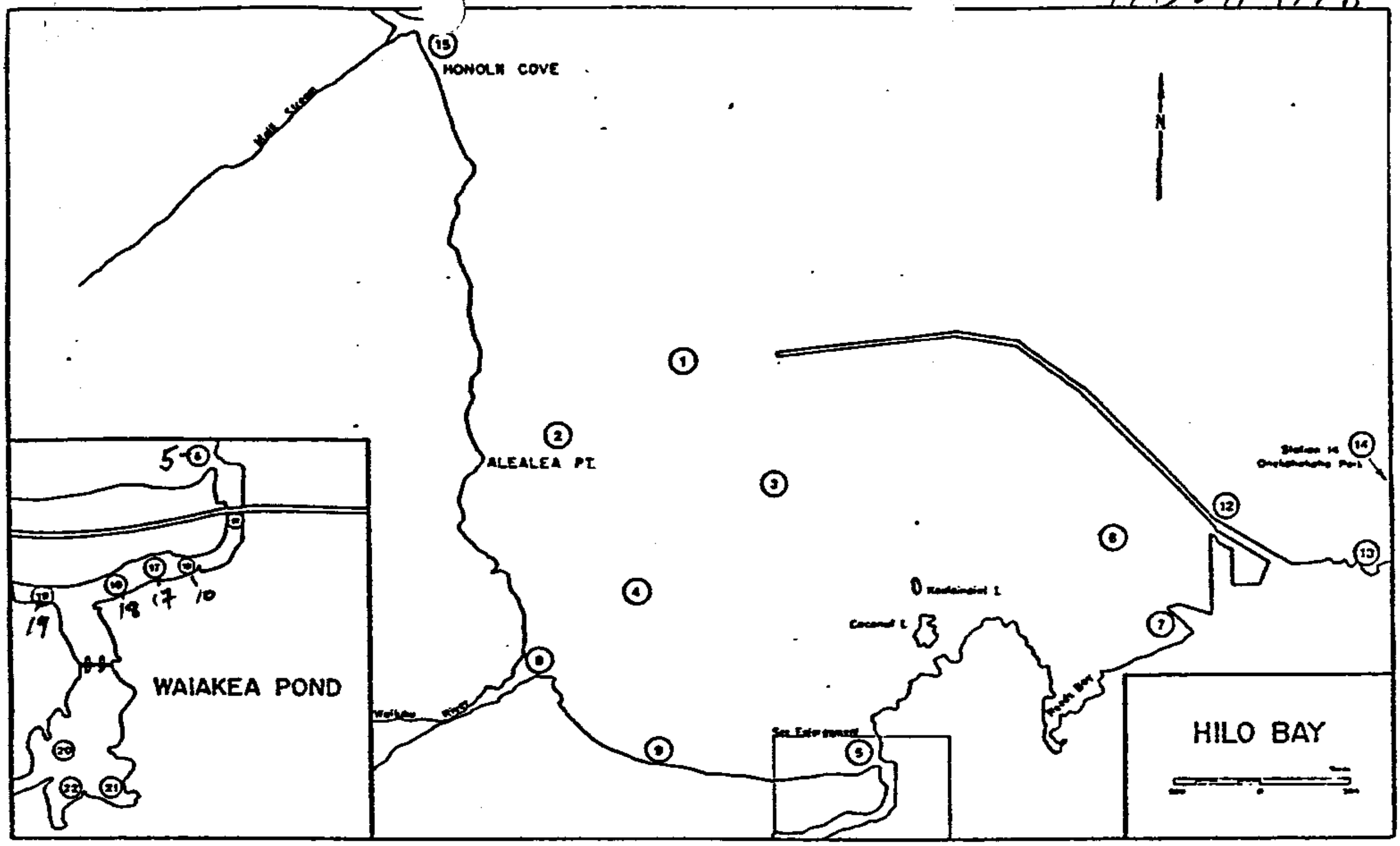


FIGURE 2-E

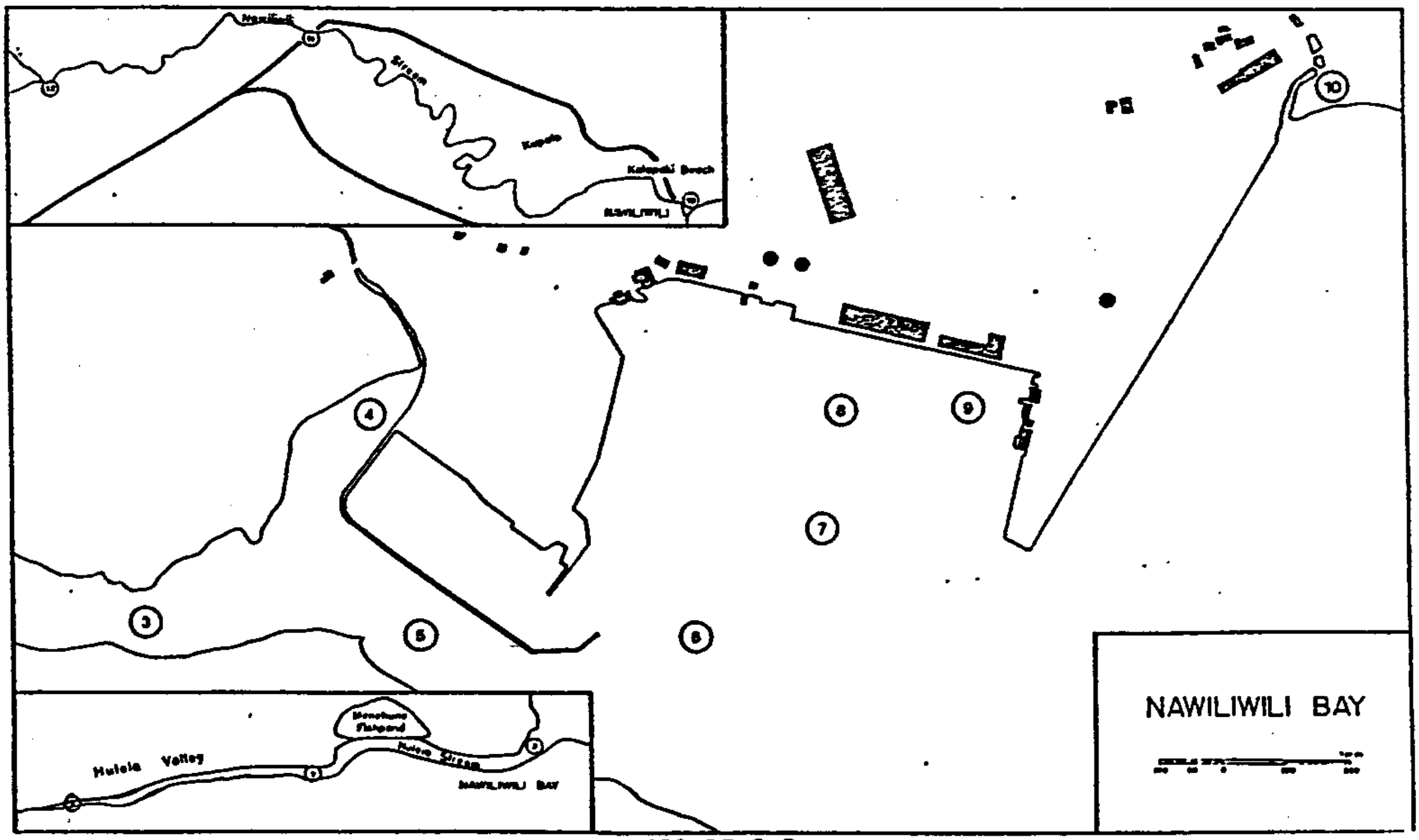


FIGURE 2-F

APPENDIX D

Receptor Species Profiles

Hawaiian stilt
Himantopus mexicanus knudseni

Information Source: USFWS Endangered Species Website, November 3, 2004

SPECIES CODE: B04C V01

STATUS:
Listed Endangered (35 FR 16047-16048, 1970 October 13) in entire range.

SPECIES DESCRIPTION:
The Hawaiian stilt is a slender wading bird, black above (except for the forehead), white below and with distinctive long, pink legs. The Hawaiian stilt differs from the black-necked stilt by having black extending lower on the forehead as well as around to the sides of the neck, and by having a longer bill, tarsus (leg), and tail (Coleman 1981). Sexes are distinguished by the color of the back feathers (brownish female, black male) as well as by voice (females having a lower voice). Downy chicks are well camouflaged, tan with black speckling. Immatures have a brownish back and white patches on their cheeks (Pratt *et al*. 1987). The total length of adult Hawaiian stilts is about 40 centimeters (16 inches).
Stilts are opportunistic feeders. They eat a wide variety of invertebrates and other aquatic organisms as they are available in shallow water and mudflats. Feeding typically occurs on shallowly flooded wetlands. These types of wetlands are ephemeral in nature and may appear at any time of the year, but primarily in winter.

REPRODUCTION AND DEVELOPMENT:
Stilts prefer to nest on freshly exposed mudflats, interspersed with low growing vegetation. The nest itself is a simple scrape on the ground. They have also been observed using grass stems and rocks for nesting material (Coleman 1981). Stilts defend an area 20 to 30 meters (66 to 99 feet) around the nest and are semi-colonial. The nesting season normally extends from mid-February through August. Stilts usually lay 3 to 4 eggs that are incubated for approximately 24 days (Coleman 1981, Chang 1990). Chicks are precocial, leaving the nest within 24 hours of hatching. Young may remain with both parents for several months after hatching (Coleman 1981). Parents are extremely aggressive toward foreign young.

RANGE AND POPULATION LEVEL:
Stilts were historically known from all of the major Hawaiian Islands except Lanai and Kahoolawe (Paton and Scott 1985). The Hawaiian stilt was a popular game bird, and hunting contributed to local population declines until waterbird hunting was prohibited in 1939 (Schwartz and Schwartz 1949). Stilts are now found on all of the main Hawaiian Islands except Kahoolawe. The first stilts on Lanai were documented in 1989 at the Lanai City wastewater treatment ponds. Long term census data indicate that statewide populations have been relatively stable or slightly increasing for the last 30 years (Reed

and Oring 1993). Hawaiian stilts readily disperse between islands and constitute a homogeneous metapopulation (Reed *et al*. 1994, Reed *et al*. 1998).
As with the other Hawaiian waterbirds, estimates of historic numbers are undocumented. Prior to 1961, documented records of Hawaiian stilt on the island of Hawaii were limited to three collected by S.B. Wilson in the late 1800's and possibly one collected by Collett prior to 1893 (Banko 1979). It has been suggested that the population had declined to approximately 200 birds by the early 1940's (Munro 1960). This number, however, may have been an underestimation of the population, as other estimates from the late 1940's place the population at approximately 1,000 birds (Schwartz and Schwartz 1949). From 1983 to 1996, statewide surveys documented a minimum of 1,000 stilts in the State (Hawaii Department of Land and Natural Resources waterbird surveys 1983 to 1996). Recent estimates place the population at approximately 1,200 to 1,600 birds (Griffin *et al*. 1989, Engilis and Pratt 1993).

HABITAT:
Stilts use a variety of aquatic habitats but are limited by water depth and vegetation cover. However, extensive wetlands and aquatic agriculture lands provided a sizeable amount of habitat. Stilts generally forage and nest in different wetland sites, moving between these areas daily. Adults with three-day-old chicks have been observed to move 0.5 kilometers (0.3 miles) from the nest site (Reed and Oring 1993). Nesting sites are adjacent to or on low-relief islands within bodies of fresh, brackish, or salt water. These bodies of water include irrigation reservoirs and settling basins, natural or man-made ponds, marshes, taro patches, silted ancient fish ponds, salt evaporation pans, and other wetlands.

PAST THREATS:
The primary cause of the decline of this species has been the loss of wetland habitat. This species requires wetlands for its survival. Hunting is another factor that contributed to the historic decline of waterbird populations but does not pose a threat presently.

CURRENT THREATS:
Because of their exposes nest sites, stilts appear to be more susceptible to avian predators than other Hawaiian waterbirds. Predators on Hawaiian stilts include the short-eared owl, black-crowned night heron (*Nycticorax nycticorax*), laughing gull (*Larus atricilla*), ruddy turnstone (*Arenaria interpres*), cattle egret, common mynah (*Acridotheres tristis*), mongoose, black rat (*Rattus rattus*), domestic cat, domestic dog, and the bullfrog. Factors that continue to be detrimental to the Hawaiian stilt include predation by introduced mammals, including mongooses, feral cats, dogs, and rats; invasion of wetlands by alien plants and fish; hybridization; disease; altered hydrology; and possibly environmental contaminants (USFWS 1999).

CONSERVATION MEASURES:

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Hawaiian coot

Fulica Americana alai

Information Source: USFWS Endangered Species Website, November 3, 2004

SPECIES CODE: B04G V01

STATUS:

Listed Endangered (35 FR 16047 16048, 1970 October 13) in the entire range.

SPECIES DESCRIPTION:

The Hawaiian coot is smaller in body size than the related mainland species, but has a bulbous, white frontal shield distinctly larger than that of the American coot (Shallenberger 1977). A small percentage of the population has a red bulbous lobe at the top of the frontal shield and deep maroon markings at the tip of the bill, similar to the mainland species (Pratt 1978). A third form of Hawaiian coot has a full red frontal lobe. Coots have relatively long legs, with large, lobed toes. Male and female coots are similar in color. Adult coots have dark, slate-gray plumage and white undertail feathers. Immature coots are slate gray with buff-tipped contour feathers, smaller, dull white bills, and they usually lack a well-developed frontal shield.

Coots typically feed close to their nesting areas but will travel long distances when food is not locally available (Shallenberger 1977). Intra-island movements occur when reservoirs are drawn down and food sources become concentrated. Coots are generalists, obtaining food near the surface of the water, diving, or foraging in mud or sand. They also graze on upland grassy sites and may invade golf courses that are adjacent to wetlands during times of drought and when food is unavailable elsewhere. Food items include seeds and leaved of aquatic plants; various invertebrates including snails, crustaceans, and aquatic or terrestrial insects; tadpoles; and small fish (Schwartz and Schwartz 1949). The Hawaiian coot is an active and, at times, gregarious species. The Hawaiian coot forms dense flocks in the summer and disperses in winter.

REPRODUCTION AND DEVELOPMENT:

Nesting occurs primarily from March through September, although some nesting occurs in all months of the year (Shallenberger 1977). The timing of nesting appears to correspond with seasonal weather conditions (Byrd et al. 1985, Engilis and Pratt 1993). Water levels are critical for nest initiation and success. Taro ponds provide good nesting habitat since they are shallow and have limited water fluctuation as compared to other sites.

Clutch size ranges from 3 to 10 eggs, with an average of 5 eggs (Byrd et al. 1985). The incubation period ranges from 23 to 27 days, and chicks leave the nest soon after hatching. Renesting has been observed on Oahu.

RANGE AND POPULATION LEVEL:

The Hawaiian coot is endemic to the Hawaiian Islands. This species is non migratory and originated presumably from stray migrants from continental North America that remained as residents in the islands (USFWS 1983). Hawaiian coots currently inhabit all of the main Hawaiian Islands except Kahoolawe.

The statewide coot population in Hawaii is estimated to range between 2,000 and 4,000 birds, with Kauai, Oahu, and Maui supporting 80 percent of these birds (Engilis and Pratt 1993). Data from 1976 through 1996 indicate short-term fluctuations, but a long term stable population trend in the State, based on the Hawaii Department of Land and Natural Resources waterbird survey records. The coot's ability to disperse and exploit seasonally flooded wetlands has led biologists to the conclusion that populations will naturally fluctuate according to climatic and hydrologic conditions (Engilis and Pratt 1993). Survey highs of 2,000 or more birds (exceeding 3,300 birds in 1983) have occurred eight times in the past three decades (Engilis 1988).

HABITAT:

The Hawaiian coot prefers wetland habitats with suitable emergent plant growth interspersed with open water. Hawaiian coots prefer freshwater wetlands, but will frequent freshwater reservoirs, brackish wetlands, or, rarely, saline water. Coots typically forage in water less than 30 centimeters (12 inches) deep, but can dive in water up to 120 centimeters (48 inches) deep. Loafing sites include logs, rafts of vegetation, narrow dikes, mud bars, artificial islands, and “false nests.” Coots also loaf on open bodies of water such as reservoirs. Because of their ability to disperse to find suitable foraging habitat, ephemeral wetlands may support large numbers of coots during the nonbreeding season (Coleman 1978, Engilis 1988).

Coots nest on open fresh water and brackish ponds, taro ponds, shallow reservoirs, irrigation ditched, and small openings of marsh vegetation (Udvardy 1960, Shallenberger 1977). They construct floating nests of aquatic vegetation in open water, or semi-floating nests anchored to emergent vegetation, or in clumps of wetland vegetation (Byrd *et al*. 1985). Open-water nests are typically anchored or semi-floating mats of vegetation, constructed usually from water hyssop (*Bacopa monnieri*) and Hilo grass (*Paspalum conjugatum*). Nests in emergent vegetation are platforms constructed from buoyant stems of nearby vegetation, such as bulrush (*Scirpus* sp.) (Byrd *et al*. 1985). Nests have also been documented on shorelines or rocky islets. Additional “false nests” may be constructed near the actual nest and are often used as loafing or brooding platforms.

PAST THREATS:

The primary cause of the decline of this Hawaiian native waterbird has been loss of wetland habitat. Hunting is another factor that contributed to the historic decline of waterbird populations but does not pose a threat presently.

CURRENT THREATS:

Factors that continue to be detrimental include predation by introduced mammals, including mongooses, feral cats, dogs, and rats; invasion of wetlands by alien plants and fish; hybridization; disease; altered hydrology; and possibly environmental contaminants (USFWS 1999).

CONSERVATION MEASURES:

LITERATURE CITED:

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Nycticorax nycticorax - Black-crowned Night-Heron

Information Source: Nature Serve website, November 3, 2004

Unique Identifier: ABNGA11010
Informal Taxonomy: Animals, Vertebrates - Birds - Wading Birds

Kingdom	Phylum	Class	Order	Family	Genus
Animalia	Craniata	Aves	Ciconiiformes	Ardeidae	Nycticorax

Genus Size: B - Very small genus (2-5 species)
Taxonomic Comments: Constitutes a superspecies with N. CALEDONICUS (AOU 1998).

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Conservation Status

NatureServe Status

Global Status: G5 (20Nov1996)
Rounded Global Status: G5
Reasons:

Very large range (southern Canada to southern South America; Old World); fairly common in many local areas.

Nation: United States

National Status: N5B,N5N

Nation: Canada

National Status: N4B (12Jun2000)

U.S. & Canada State/Province Status	
United States	Alabama (S3B,S4N), Arizona (S3), Arkansas (S2B,S3N), California (S3), Colorado (S3B), Connecticut (S2B), Delaware (S1B), District of Columbia (S3B), Florida (S3), Georgia (S3S4), Hawaii (SNR), Idaho (S3B), Illinois (S2), Indiana (S1B), Iowa (S3B,S3N), Kansas (S2B), Kentucky (S1S2B), Louisiana (S3N,S5B), Maine (S2B), Maryland (S3B,S2N), Massachusetts (S2), Michigan (S2S3), Minnesota (SNRB), Mississippi (S3?B), Missouri (S2), Montana (S2S3B), Navajo Nation (S3?), Nebraska (S2), Nevada (S5B), New Hampshire (SHB), New Jersey (S3B,S4N), New Mexico (S4B,S4N), New York (S3), North Carolina (S4B,S4N), North Dakota (SNRB), Ohio (S1), Oklahoma (S3B), Oregon (S4), Pennsylvania (S2S3B), Rhode Island (S2B),

	South Carolina (SNRB,SNRN), South Dakota (S3S4B), Tennessee (S2S3B), Texas (S4B), Utah (S3N,S3S4B), Vermont (S1B,S2N), Virginia (S3B,S4N), Washington (S3B,S3N), West Virginia (SHB,S1N), Wisconsin (S2B), Wyoming (S3B)
Canada	Alberta (S3B), British Columbia (S1N), Manitoba (S3S4B), New Brunswick (S2B), Nova Scotia (S1B), Ontario (S3B), Quebec (S4), Saskatchewan (S5B)

Other Statuses

NatureServe Conservation Status Factors

Global Abundance: GH

Estimated Number of Element Occurrences: E

Global Short Term Trend: E
Global Short Term Trend Comments: Stable or increasing in most areas of North America, but has declined in some areas (Herkert 1992). Populations in the south-central U.S. may be benefiting from crayfish aquaculture; bird population increases may be related to favorable foraging opportunities afforded by expanding crayfish aquaculture (Fleury and Sherry 1995). Hawaiian population was a few hundred and increasing in the mid-1980s (Scott et al. 1988); summer counts declined in the mid- and late 1980s, apparently due to a control program instituted by federal and state agencies at the request of aquaculture farmers on Oahu (Engilis and Pratt 1993).

Threats: Has declined in some areas due to disturbance, degradation, and/or destruction of nesting and foraging areas (Herkert 1992). Particularly sensitive to disturbance just before and during laying (Tremblay and Ellison 1979). Certain U.S. breeding populations in the intermountain west have high DDT levels and exhibit low productivity; DDT may be accumulated in southwestern U.S. wintering areas. Custer et al. (1983) found that environmental contaminants had a minimal impact on overall reproductive success of U.S. Atlantic coast populations.

---Jump to Section---

Economic Attributes

Economic Comments: Predation on shrimp and fishes in aquaculture ponds in Oahu, Hawaii, has resulted in control actions (Engilis and Pratt 1993).

---Jump to Section---

Management Summary

Management Requirements: In Illinois, a public viewing area used once a week by humans 229 m from a rookery did not cause any overt responses from nesting birds (DeMauro 1993).

Predation on shrimp and fishes in aquaculture ponds in Oahu, Hawaii, has resulted in control actions (Engilis and Pratt 1993).

Ecology and Life History

General Description: A medium-sized wading bird with a short neck, short legs (yellowish, greenish, or pink; in flight, barely extend beyond tail), and a stout, straight, pointed bill; breeding adults have a black crown and back, with white hindneck plumes, gray wings, and white to grayish underparts; immatures are brown, spotted and streaked with white and buff, gradually changing to adult plumage over three years; average length 64 cm, wingspan 112 cm (NGS 1983). In flight, utters a loud, guttural "quock" or "quark," especially at dusk or after dark.

Diagnostic Characteristics: Adult differs from adult yellow-crowned night-heron in having a black back that contrasts with the gray wings (vs. back and wings same color). Immature differs from immature yellow-crowned nigh-heron in browner upperparts with bolder white spotting, thicker neck, paler face, and longer thinner bill with the lower mandible mostly pale (vs. dark). All ages have shorter legs than does yellow-crowned night-heron (in flight, legs extend barely beyond tail vs. well beyond tail). Immature differs from American bittern in having flight feathers that are not conspicuously darker than the brown areas of the back.

Reproduction Comments: Breeding season varies geographically, occurs in spring-early summer in north, earlier in Florida. Clutch size usually is 3-5 in north, 2-4 in south. Incubation lasts apparently 24-26 days, by both sexes. Young are tended by both sexes, first fly at about 42 days. Usually first breeds at 2-3 years. Nests in small to large colonies. See Custer et al. (1983) for data on certain Atlantic coast colonies.

Non-Migrant: Y

Locally Migrant: Y

Long Distance Migrant: Y

Mobility and Migration Comments: Arrives in northern breeding areas March-May, departs by September-November. Extensive postbreeding dispersal to areas outside breeding range (Palmer 1962).

Estuarine Habitat(s): Bay/sound, Herbaceous wetland, Lagoon, River mouth/tidal river, Scrub-shrub wetland, Tidal flat/shore

Riverine Habitat(s): Low gradient, Moderate gradient, Pool

Lacustrine Habitat(s): Shallow water

Palustrine Habitat(s): FORESTED WETLAND, HERBACEOUS WETLAND, Riparian

Terrestrial Habitat(s): Sand/dune

Habitat Comments: Marshes, swamps, wooded streams, mangroves, shores of lakes, ponds, lagoons; salt water, brackish, and freshwater situations. Roosts by day in mangroves or swampy woodland. Eggs are laid in a platform nest in groves of trees near coastal marshes or on marine islands, swamps, marsh vegetation, clumps of grass on dry ground, orchards, and in many other situations. Nests usually with other heron species.

Adult Food Habits: Carnivore, Invertivore, Piscivore

Immature Food Habits: Carnivore, Invertivore, Piscivore

Food Comments: Feeds opportunistically on small animals; usually fishes, amphibians, and invertebrates obtained in shallow water but also small mammals and young birds on land.

Adult Phenology: Crepuscular, Nocturnal

Immature Phenology: Crepuscular, Nocturnal

Phenology Comments: Sometimes feeds by day (especially immatures), usually crepuscular and nocturnal.

Colonial Breeder: Y

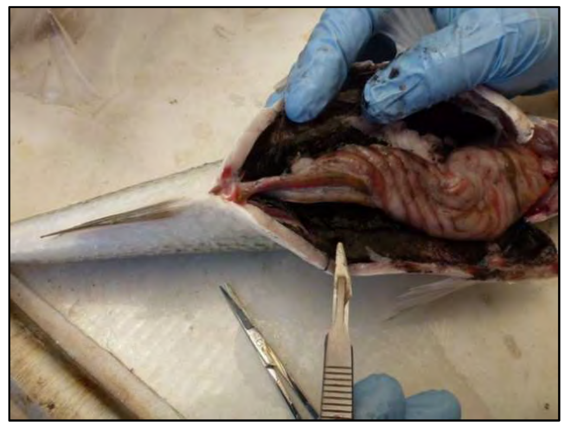
Length: 64 centimeters

Weight: 883 grams

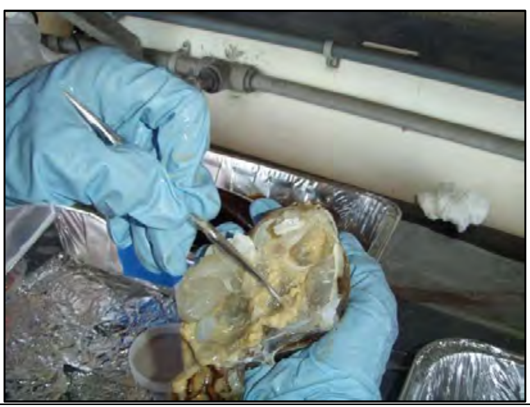
Appendix D

Photo Log

Fish and Crab Dissection



Fish and Crab Dissection



Sediment Sample Collection

Sediment Sample Collection

Appendix E

Sediment Laboratory Reports

(Appendices E-H provided in separate document)

Appendix F

Biota Laboratory Reports

(Appendices E-H provided in separate document)

Appendix G

Sample Chain of Custody Forms

(Appendices E-H provided in separate document)

Appendix H

Sediment Subsample Replicate Data Summary

(Appendices E-H provided in separate document)