APPENDIX G-8

MARINE RESOURCES STUDY FIELD SAMPLING RESULTS AND RISK ASSESSMENT

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MARINE RESOURCES STUDY
FIELD SAMPLING RESULTS AND RISK ASSESSMENT

MĀKUA MILITARY RESERVATION
O`AHU, HAWAI`I

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Honolulu Engineer District
Environmental & Special Projects Branch
Building 252
CEPOH-PP-E
Fort Shafter, Hawai‘i 96858-5440

Prepared by:

Tetra Tech, Inc.
737 Bishop Street, Suite 3020
Honolulu, Hawai‘i 96813

EXECUTIVE SUMMARY

Tetra Tech conducted a marine resources study to address the following objectives defined by the 2007 partial Settlement Agreement (SA) entered into by the Army and Malama Mākua:

- To evaluate whether fish, shellfish, limu (marine algae), and other marine resources near Mākua Beach or muliwai (estuaries or stream mouths), which area residents rely on for subsistence are contaminated by substances associated with proposed military training at Mākua;[1]
- To evaluate whether the potential that activities at Mākua Military Reservation (MMR) have contributed or will contribute to contamination in fish, shellfish, limu and other marine resources; and
- To evaluate whether the proposed training activities pose a human health risk to area residents who rely on marine resources for subsistence.

Multiple natural, civilian, and military sources of contamination exist throughout the state of Hawai‘i (see Section 3.2). To evaluate whether military activities at MMR have contributed to contamination, it is necessary to estimate the contamination that might exist if military activities had not taken place (baseline contamination). Background sites on O‘ahu were selected, and sampling at these sites provided an estimate of baseline contamination. Contamination at Mākua in excess of contamination at the background sites could potentially, but not definitively, be attributed to military activity. Tetra Tech sampled fish, shellfish, and limu[2] in the muliwai and nearshore waters of Mākua and fish and shellfish at the background sites. The background muliwai was at Nanakuli and the background for nearshore waters was next to Sandy Beach. The availability of marine resources for this study was limited by the size of the organisms and their population sizes at Mākua and the availability of equipment capable of collecting intact organisms. Several marine resources

[1]Throughout this document, "Mākua" refers to the general geographic area that includes Mākua Military Reservation, Mākua Beach, and the Mākua muliwai.
[2]Limu (marine algae) were collected only in the nearshore waters at Mākua.

identified as food by area residents were not available in adequate quantities for analysis of all the substances identified for this study; for example, it would require collecting several thousand individuals of snail species that residents are known to consume to supply adequate biomass for laboratory analyses; therefore, the fish, shellfish, and limu samples that were available in sufficient quantities and collected for this study were considered to be representative of the marine resources available at Mākua. Twenty-six fish samples (22 primary and four quality control [QC]), 12 shellfish samples (ten primary and two QC), and four limu samples (three primary and one QC) were collected. The species included striped mullet, Hawaiian flagtail, tilapia complex, medaka (Poeciliidae spp.), Picasso triggerfish, blackspot triggerfish, manybar goatfish, Christmas wrasse, blackspot sergeant, Samoan crab, rock crab, Kona crab, Hawaiian prawn, and helmet urchin.

To assess whether marine resources at MMR are contaminated with compounds potentially associated with proposed military training, all samples, except two shellfish samples, were analyzed for approximately 43 different substances. These included dioxans/furans, volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), organochlorine pesticides, explosives, and metals. The exceedingly small populations of two shellfish species (Hawaiian prawns and rock crabs), and therefore small quantities of biomass collected, limited the analysis of these samples to a subset of the 43 constituents. All the analytes (the suite of substances that the laboratory analyzed) have a wide range of natural and anthropogenic (man-made) sources. Only explosives and several metals are constituents of military munitions; all other analytes were included after public review of previous documents. Following are the results of the laboratory analyses.

Dioxins/furans were detected at a greater frequency in fish at the background site (seven of nine samples) than at Mākua (ten of seventeen samples). They were detected in all three fish samples from the background muliwai and eleven of twelve fish samples from the Mākua muliwai. Dioxins/furans were detected in four of six fish samples from the nearshore waters of the background site and were not detected in any of the five fish samples from the nearshore waters of Mākua. The principal sources of dioxins in air are combustion and incineration sources, such as incineration of solid waste, sewage sludge, and hospital wastes; high temperature steel production, smelting operations, and scrap metal recovery furnaces; and the burning of coal, wood petroleum products, and used tires for energy generation. Chemical manufacturing and process sources, such as manufacture of chlorine and chlorinated organic compounds, may result in emissions to air or water.

Only two VOCs were detected in any of the fish samples, acetone and m,p-xylene. Acetone was found in at least one sample from all five locations (Mākua and background) and is a common laboratory contaminant; it is often recorded as a false positive. Toluene and m,p-xylene were detected in two QC shellfish samples and one limu sample, respectively. Toluene was not detected in the primary shellfish samples, which suggests a false positive. Natural sources of toluene include volcanoes, forest and bush fires, and crude oil; m,p-xylene occurs naturally in petroleum, and VOCs are released into the environment primarily from petroleum refining. Other possible emitters of toluene are spilled gasoline, commercial and household painting and paint, varnish and lacquer removers, tobacco smoke, and consumer products that contain toluene.

The term SVOC is generally applied to organic compounds found in a range of products, including insect repellants, cosmetics, rubbing alcohol, liquid soap, detergents, decorative inks, lacquers, munitions, industrial and lubricating oils, wood preservatives, defoaming agents for paper/paperboard manufacturing, pesticide carriers, photographic film processing, plastic softening agents, and dielectric fluid in capacitors. Three SVOCs, bis(2-ethylhexyl)phthalate, diethyl phthalate, and di-n-butylphthalate, were detected in fish samples collected from the muliwai and nearshore sample locations. Di-n-butylphthalate was detected in all fish samples regardless of origin and is a common lab contaminant. Bis(2-ethylhexyl)phthalate was detected in four of the five samples collected from the Mākua nearshore area. Diethyl phthalate was detected in only the sample collected from the Sandy Beach nearshore area.

Aldrin and heptachlor were generally detected in samples from the nearshore areas but not in the muliwai; heptachlor epoxide was detected at higher concentrations in samples from the nearshore locations than in samples from the muliwai locations. Organochlorine pesticides analytes were not detected in shellfish samples, except for one aldrin detection in a shellfish sample collected in the nearshore area of Mākua. Aldrin, BHC-beta, heptachlor, and heptachlor epoxide were detected in the limu collected in the nearshore area of Mākua. Organochlorine pesticides were used historically throughout O‘ahu and the other main Hawaiian islands for termite control and in agriculture. These compounds can be transported by air and water, so their presence in fish, shellfish, and limu cannot be definitively attributed to activities at MMR.

Common military uses of RDX have been as an ingredient in plastic bonded explosives, or plastic explosives that have been used as explosive fill in almost all types of munition compounds. Civilian applications of RDX include fireworks, demolition blocks, as a heating fuel for food rations, and rodenticide. Perchlorate was detected in fish at both Mākua and the background site and in limu and one shellfish sample from Mākua. Nitroglycerin was detected in two fish samples from Mākua. RDX was detected in one fish sample from Mākua. Because the bioconcentration factor for RDX is so low, a relatively high concentration of RDX would need to be present in the water to account for the RDX detection in the fish tissue. Given the amount of water circulation in the ocean, it is unlikely that the ocean water in the Mākua nearshore area would contain RDX at a sufficient concentration to result in the observed detection of RDX in the fish tissue sample. The possibility that RDX exists at high concentrations in the sediments that could potentially account for the concentrations measured in one fish can not be eliminated. Furthermore, the analysis of RDX in fish tissue is prone to false positive detections resulting from matrix interference.

All metals analyzed in this study are naturally occurring in the environment and are commonly found in plant and animal tissues as a result of natural metabolic processes. Indeed, some of these metals are considered essential nutrients for human health. The primary inputs of trace metals on O‘ahu potentially resulting in concentrations above baseline levels, include volcanic emissions, vehicle emissions, vehicle-associated wear, and agricultural fertilizer and pesticide inputs. The presence of naturally occurring metals in the environment makes it difficult to ascertain whether these metals could have been transported

beyond the boundaries of MMR. Metals concentrations were similar among the fish samples collected from Mākua and the background muliwai. Furthermore, the metals concentrations were similar among the fish samples collected from nearshore areas of both Mākua and the background location. Shellfish metals concentrations in samples collected at Mākua were similar to those found at the background, with a few exceptions. Greater concentrations of aluminum, barium, iron, and manganese were found in shellfish samples from Mākua muliwai, while zinc concentrations were higher in samples from the background. Twelve of 19 metals were detected in all limu samples, at concentrations ranging from less than 0.1 milligrams per kilogram (mg/kg) (thallium) to greater than 1,860 mg/kg (iron). Flegal et al. (1986) found concentrations of thallium in marine plankton similar to those found at Mākua (0.02 to 0.8 mg/kg) in the central Pacific. In the Black Sea of Turkey, Tuzen et al. (2008) found concentrations of iron, ranging from 99 to 3,949 mg/kg in marine algae, similar to those concentrations found at Mākua (67.4 to 1860 mg/kg). At Makua, arsenic was detected in limu in concentrations ranging from 4.56 to 109 mg/kg. These concentrations are comparable to concentrations found in marine algae in pristine regions of Antarctica, ranging from 5.8 to 152 mg/kg (Farias et al. 2007).

The results of laboratory analyses of the samples described above were incorporated into an evaluation of the potential risks to humans who may be exposed to environmental contaminants at Mākua Beach and the Mākua muliwai and compares those risks to risks determined for background locations on O‘ahu. The difference between the risks calculated for the Mākua sites and the background locations is called the incremental risk. Several assumptions were required to complete this human health risk assessment, and they are presented in Table ES-1. These assumptions may greatly overestimate the potential human health risk at Mākua and the background sites. In addition to these assumptions, it is highly unlikely that a subsistence fisherman could rely entirely on the marine resources within the muliwai for 100 grams of fish everyday for 30 years. The muliwai are short-lived environments and are only intermittently open to the ocean. This significantly restricts the movement of marine resources into the muliwai to replenish depleted populations.

A recent study, *Fishing, Ocean Recreation, and Threats to Hawaii's Coral Reefs* (Hamnett, Liu, and Johnson 2006), reports that the actual activities of subsistence fishers are less than assumed in the present Marine Resources Study. Of the 1600 households surveyed in this report, only 10% reported members engaged in subsistence fishing. Of the households identifying themselves as ethnically Hawaiian 20% to 30% reported engaging in subsistence fishing. Only 2% of the subsistence fishers reported fishing > 59 times per year. This fishing effort likely is concentrated in the nearshore waters rather than the muliwai.

Table ES-2 is a summary of the carcinogenic risk aspect of the human health risk assessment. Although potentially overestimated, there are potential carcinogenic risks at both Mākua and the background sites. There are potential carcinogenic risks to consuming shellfish at both Mākua and the background muliwai at subsistence level and to consuming fish in the nearshore waters of both Mākua and the background site at subsistence and recreational levels. The potential risk is greater at Mākua than at the background site leading to an incremental risk. The potential risk is largely due to alpha-BHC, heptachlor epoxide, and

Table ES-1
Data Interpretation Assumptions, Scientific Justifications, and Effects on Risk Analysis

<table>
<tr><th>Assumption</th><th>Scientific Justification</th><th>Effect on Risk Analysis</th></tr>
<tr><td>Assumption No. 1—All detected chemicals in fish, shellfish, and limu were considered as chemicals of potential concern (COPC).</td><td>In its standard guidelines for risk assessment, the US EPA consider only those chemicals with concentrations greater than background as COPCs; however, it was assumed that stakeholders were interested in all potential risks, not simply risks that could be higher at Mākua than the background sites.</td><td>This assumption could considerably overestimate the risks at both Mākua and at the background site.</td></tr>
<tr><td>Assumption No. 2—Chemical concentrations will be maintained at present levels.</td><td>In the absence of a data set describing changes in chemical composition of munitions proposed for use at MMR and the Mākua vicinity over time, the assumption was that current chemical concentrations in fish, shellfish, limu, and other marine resources will be maintained into the future. The assumption of steady state chemical concentrations is based on relatively constant levels of military activities overtime.

Advances in munitions technology will reduce potential future chemical loads from military activity into the Mākua vicinity.

An environmental monitoring program that is proposed to accompany the renewal of live-fire training will identify and minimize or eliminate chemical contaminants that can be attributed to military training from migrating off-site, thereby reducing or avoiding impacts on marine resources.</td><td>It is difficult to assess the effects of these assumptions on the risk analysis. Advances in munitions technology and an environmental monitoring program could reduce the future risk, resulting in overestimation of the risk; however, if compounds that could bioaccumulate were found to be migrating into the surrounding resources, the risk could be underestimated.</td></tr>
<tr><td>Assumption No. 3—Subsistence and recreational fishermen:
• Ingest fish 365 days/year. This is greater than 7 times the average per capita fish and shellfish consumption frequency in the US of 48 days/year;
• Are fishing at the site for 30 years (standard EPA default guidelines);
• Ingest the following quantities of fish, shellfish, limu, and other marine resources:
<table>
<tr><th>Resource</th><th>Subsistence Fishermen</th><th>Recreational Fishermen</th></tr>
<tr><td>Fish</td><td>100.6 g/day</td><td>34.0 g/day</td></tr>
<tr><td>Shellfish</td><td>100.6 g/day</td><td>34.0 g/day</td></tr>
<tr><td>Limu</td><td>18.2 g/day</td><td>5.2 g/day</td></tr>
</table>
These consumption rates are considerably higher than the likely ingestion rate of the species collected in this study and are over 50 times greater than the average ingestion rate for the general US population.</td><td>Data were not readily available quantifying the number of days per year that subsistence and recreational fishermen in Hawai‘i ingest fish, shellfish, or limu, the number of years a fisherman may fish at the site, or the ingestion rates of shellfish, limu, and other marine resources by subsistence and recreational fishermen in Hawai‘i.

The muliwai are short-lived environments and are only intermittently open to the ocean. This significantly restricts the movement of marine resources into the muliwai. It is highly unlikely that sufficient resources exist to provide this quantity of food source to support even one individual every day for thirty years.</td><td>These assumptions could vastly over-estimate the risk of ingesting fish, shell-fish, and limu, but were used to ensure that risks were not underestimated.</td></tr>
</table>

Table ES-1
Data Interpretation Assumptions, Scientific Justifications, and Effects on Risk Analysis

Assumption	Scientific Justification	Effect on Risk Analysis
Assumption No. 4—All arsenic in fish and shellfish is in the nontoxic organic form (versus the toxic inorganic form).	Arsenic is ubiquitously distributed in environmental samples and is well known to be contained in marine organisms at especially high levels in diverse chemical forms (Ninh et al. 2008). Neff (1997), de Gieter et al. (2002), Kirby (2007), and Peshut et al. (2008) suggest that arsenic is present almost exclusively as organic forms in marine fish and invertebrates; however, data are not available on the specific species collected in this study.	This assumption could **underestimate** the risk.
Assumption No. 5—All arsenic in limu is in the toxic inorganic form (arsenic V).	Frankenberger (2002) and Kirby et al. (2005) suggest that arsenic in marine algae (limu) may be greater than 50% arsenic V; however, Farias et al. (2007) found arsenic concentrations of 5.8 to 152 mg/kg (a similar range was found in limu at Mākua), and the percentage of inorganic arsenic was 0.7 to 2.6%. There are no data available on the speciation of arsenic in the species of limu (marine algae) that were collected in this study.	This assumption could **overestimate** the risk by 2 to 100 times.

Table ES-2
Summary of the Incremental Carcinogenic Risk from Ingesting Fish, Shellfish, and Limu at Mākua and the Background Site

Environment	Environmental Media	Fisherman	Risk/Location		Incremental Risk	Contaminant of Potential Concern (COPC) for incremental risks
			Mākua	Background		
Muliwai	Fish	Subsistence				
		Recreational				
	Shellfish	Subsistence	E	E	U	
		Recreational				
Nearshore	Fish	Subsistence	E	E	E	Alpha-BHC, bis(2-ethylhexyl) phthalate, Heptachlor Epoxide
		Recreational	E	E	U	
	Shellfish	Subsistence		E		
		Recreational		E		
	Limu	Subsistence	E		E	Arsenic
		Recreational	E		E	

E = Exceeds the US EPA risk level for fish consumption.
U = Unlikely potential risk; chemical concentrations at both sites are elevated, but the incremental risk is below the US EPA risk level for fish consumption.

bis(2-ethylhexyl) phthalate. Two of these compounds are pesticides and the third, bis(2-ethylhexyl) phthalate is widely used as a plasticizer in manufacturing of articles made of PVC. Plastics may contain 1% to 40% of DEHP. It is also used as a hydraulic fluid and as a dielectric fluid in capacitors. These constituents are not unique to military activities. There is a potential carcinogenic risk associated with shellfish in the nearshore waters of the background site but not at Mākua.

Table ES-3 is a summary of the noncarcinogenic hazard of the human health risk assessment. A noncarcinogenic hazard potentially exists with a hazard index (HI) of greater than 1. A potential noncarcinogenic hazard exists at all sites, for all environmental media, and at both levels of consumption, except for shellfish in the nearshore waters of the background site consumed at recreational levels. Potential incremental hazard (hazard greater at Mākua than background sites) exists for subsistence and recreational consumption of shellfish in the Mākua muliwai. The potential hazard is largely due to manganese and cobalt. A potential incremental hazard exists for subsistence consumption of fish in the nearshore waters of Mākua, largely due to nitroglycerin. A potential noncarcinogenic hazard exists for subsistence and recreational consumption of shellfish in the nearshore waters of Mākua, due to cadmium and perchlorate. A potential noncarcinogenic hazard exists from consuming limu in the nearshore waters of Mākua; the corresponding hazard at the background site is not available. The hazard associated with limu consumption is largely due to arsenic, which is a natural component of the earth's crust and is found in all environmental media. Volcanic action is the second most important natural source of arsenic. Anthropogenic sources of arsenic include smelting nonferrous metals, producing energy from fossil fuels, and manufacturing and using arsenic pesticides and wood preservatives. Elevated levels of arsenic in Hawai'i have been identified in soils from use of arsenic-based pesticides from the 1920s through the 1940s. The hazard attributed to arsenic is likely greatly overestimated because of the assumption that all arsenic in limu is in the toxic inorganic form. Frankenberger (2002) and Kirby et al. (2005) suggest that arsenic in limu may be greater than 50 percent inorganic; however, Farias et al. (2007) found arsenic concentrations of 5.8 to 152 mg/kg in pristine areas of Antarctica and the percentage of inorganic arsenic was 0.7 to 2.6 percent. A similar range was found in limu at Mākua at 4.5 to 109 mg/kg. There are no data available on the speciation of arsenic in the species of limu that were collected in this study.

The potential risks and hazards identified in the human health risk assessment were largely due to eight compounds, including four metals (arsenic, cadmium, cobalt, and manganese), two organochlorine pesticides (alpha-BHC and heptachlor epoxide), and two explosives (nitroglycerin and perchlorate). Using data from this study and previous studies (described in Section 1.2 of this report), Table ES-4 identifies those environmental media in which these compounds were detected at elevated levels at Mākua. These data demonstrate that some of the same substances found at elevated levels in the marine resources at Mākua are also found in other environmental media and are a component of military munitions; however, there are a range of other possible natural and anthropogenic sources of these compounds.

Finally, a screening level ecological risk assessment was conducted to evaluate the potential for adverse effects on ecological receptors that may be exposed to chemicals in muliwai and

Table ES-3
Summary of the Noncarcinogenic Hazard from Ingesting Fish, Shellfish, and Limu at Mākua and the Background Site

Environment	Environmental Media	Fisherman	Hazard		Incremental Hazard	COPCs for Incremental Hazard
			Mākua	Background		
Muliwai	Fish	Subsistence	20	47	--	
		Recreational	7	16	--	
	Shellfish	Subsistence	14	9	5	Manganese, cobalt
		Recreational	5	3	2	
Nearshore	Fish	Subsistence	7	5	2	Nitroglycerin
		Recreational	2	2	--	
	Shellfish	Subsistence	12	3	9	Cadmium, perchlorate
		Recreational	4	1	3	
	Limu	Subsistence	58	--	--	Arsenic
		Recreational	17	--	--	

Shaded = Noncarcinogenic hazard at Mākua is greater than background.

Table ES-4
Summary of Potential Chemical Migration Pathways

Chemical of Potential Concern (COPC)	Military Munitions	Air	Soil	Groundwater	Surface Water	Streambed Sediments	Muliwai Sediments	Fish	Shellfish	Limu
Aldrin						E		E	E	
Alpha-BHC				E		E		E		
Arsenic	✓	✓		E						E
bis(2-ethylhexyl)phthalate				E				E		
Cadmium	✓	✓							E	
Cobalt	✓								E	
Dioxins/furans			E		E	E	E			
Heptachlor epoxide								E		
Manganese	✓								E	
Nitroglycerin	✓							E		
Perchlorate	✓				E				E	

Notes:
E (water and sediments) = Exceeds Preliminary Remediation Goal for soil/sediment or Maximum Contaminant Level for water.
E (fish, shellfish, limu) = Incremental risk exceeds US EPA risk level for fish consumption or a hazard index of 1;
✓ = Present in trace concentrations (i.e., at a concentration slightly above the laboratory's analytical level of detection).

nearshore waters. Data from the fish, shellfish, and limu sampling conducted as part of this study and data from muliwai sediment sampling conducted in 2003 were used in this assessment. Two sets of receptors were evaluated: (1) benthic invertebrates exposed to chemicals of potential ecological concern in sediments and (2) fish exposed to chemicals from multiple pathways, represented by measured concentrations in fish tissues. The results from the screening level ecological risk assessment indicated that there were no hazards to fish in the north muliwai, the south muliwai and the nearshore Mākua area, and that there was a potential hazard to benthic invertebrates from 2,3,7,8-tetrachlorodibenzo-*p*-dioxin in sediments in the south muliwai. The primary sources of dioxins are backyard burning of household refuse, medical waste incinerators, municipal waste combustion, coal-fire utility boilers, cement kilns, and diesel heavy duty trucks.

Hazards to shellfish in the north and south muliwai did not exceed those at the Nanakuli background muliwai. Hazards at the nearshore habitat at Mākua were equivocal in that the hazard index for Kona crabs was greater than that at the Sandy Beach background site, but the hazard index for helmet urchins was less than background. The hazard index for Kona crabs was predominantly due to cadmium, copper, and zinc in tissues. The potential hazard to crabs from copper is uncertain because tissue concentrations in crabs could be compared only to those in sea urchins, which are expected to have lower body burdens of copper than crabs due to their physiology.

Several lines of evidence were considered in evaluating the potential for risks to organisms in the Mākua muliwai and nearshore waters: the number of chemicals with calculated HQs above 1, the magnitudes of HQs above 1, likely sources of chemicals, confidence in toxicity values, cumulative risks represented by HIs, and comparisons of site HIs to HIs from background sites. Based on the weight of evidence, limited hazards were identified:

- North muliwai—No hazards to benthic invertebrates, shellfish, or fish;
- South muliwai—Potential hazard to benthic invertebrates from dioxans/furans in sediments; no hazards to shellfish or fish; and
- Nearshore waters—Potential hazards to Kona crabs from cadmium, copper, and zinc but no hazards to sea urchins; no hazards to fish.

In accordance with the 2007 partial SA entered into by the Army and Malama Mākua, the Army "…shall complete one or more studies to whether fish, limu, shellfish, and other marine resources near Mākua Beach and in the muliwai on which area residents rely for subsistence are contaminated by substances associated with the proposed training activities at MMR… evaluate the potential that activities at MMR have contributed or will contribute to any such contamination and whether the proposed training activities at MMR pose a human health risk to area residents that rely on marine resources for subsistence." This study was an investigation of the resources at Mākua and background sites and provides the information necessary to answer these questions posed in the SA.

1) Determine whether fish, shellfish, limu, and other marine resources near Mākua Beach or muliwai, which area residents rely on for subsistence, are contaminated by substances associated with the proposed training at Mākua.

Fish, shellfish, limu, [and the report assumes that other marine resources] near Mākua Beach and in the muliwai, on which area residents rely for subsistence, are contaminated by substances that are known to be associated with the proposed training at Mākua. The study shows that there are potential chemical migration pathways between MMR and the muliwai and nearshore areas. It also confirms that several substances in the nearshore and muliwai marine resources are associated with military munitions. This study has identified a number of substances in fish, shellfish, and limu that are also known to be by-products of the type of military training being proposed at MMR and may pose a potential health risk. These substances are RDX, perchlorate, arsenic, chromium, cobalt, nitroglycerin, and manganese. Though these and other substances may be by-products of military training at MMR, they are also linked to natural and anthropogenic sources, such as fireworks, rodenticides, gasoline, and volcanic rock. In fact, a comparison of the site data with the available background data shows little if any difference between substances found in the Mākua area and the background sites. Compounds identified for analysis by the SA are not unique to military training and are found at both Mākua and background sites; therefore, proposed military activities are anticipated to have little influence on contaminant levels within marine resources in the Mākua nearshore or muliwai areas.

Although marine resources other than fish, shellfish, and limu were not tested, the sampling was representative of other marine resources within the Mākua area. It is reasonable to suggest that other marine resources occupying similar trophic levels and ecological niches contain similar substances and concentrations as those detected in fish, limu, and shellfish collected as part of this study. Regardless, on authorization to implement the proposed training at MMR, the Army will conduct a long-term monitoring program. A monitoring program will provide the Army with another tool to evaluate potential pathways for substances to migrate beyond the boundaries of MMR.

2) Evaluate the potential that activities at MMR have contributed or will contribute to contamination in fish, shellfish, limu and other marine resources.

There is a potential that activities at MMR have contributed or will contribute to contamination in fish, shellfish, limu and other marine resources. Per the requirements of the 2001 SA, the Army investigated soil, surface water, groundwater, and air for potential contamination associated with proposed training activities at MMR. These studies also evaluated whether there was a potential for contaminants to be transported off of MMR. Based on the data from these studies, there is no obvious pattern or pathway for migration of substances from MMR to the muliwai and nearshore areas. However, several substances detected in the marine resources were also detected in environmental media on MMR (air, soil, or water). This suggests there is a potential but as of yet unsubstantiated pathway for substances to migrate from MMR to marine resources.

Thus, there is some potential for past and future release of substances from activities at MMR. However, the low levels of most substances detected during these investigations support the position that if 60 years of live-fire training has not resulted in significant detectable levels of most substances in the area, then future live-fire activities at MMR would be expected to be likewise insignificant. For those substances detected at higher levels, their occurrence in the area cannot uniquely be attributed to military activities because there are and have been many natural and anthropogenic sources that contribute substances to the Mākua area.

Based on the results of the past investigations, the Army was required to conduct a marine study to determine if contaminants were also found in the marine resources consumed by residents. This study found that a number of substances identified for analysis were detected in these marine resources. Although this and other reports have not provided any definitive evidence that links military training to resource contamination, these reports also do not definitively exclude the possibility that such substances in the fish, shellfish, and limu are a result of activities conducted at MMR. However, it needs to be reemphasized that there are numerous other natural and anthropogenic sources that contribute substances to the Mākua and background areas.

3) Whether the proposed training activities pose a human health risk to area residents who rely on marine resources for subsistence.

This study found that a number of substances detected in the marine resources were at concentration levels that pose a human health risk to area residents who rely on marine resources for subsistence. These substances detected are known to be associated with past and future training activities at MMR. Therefore, the proposed training activities at MMR have the potential to contribute substances to the marine resources and pose a possible human health risk to area residents who rely on these resources for subsistence.

This third question posed by the SA calls for a definitive answer concerning whether future training at MMR will result in the release of substances that will, *with certainty*, contaminate marine resources consumed by local residents for subsistence. This question cannot be answered *with certainty* because it relies on predictions of the effects of future activities and assumptions based on the assessment of effects from past activities at MMR. Therefore, from a scientific standpoint, we must predict whether or not future training at MMR is likely to cause a human health risk from consumption of marine resources.

It is not likely that future training at MMR will result in the release of substances sufficient to contaminate marine resources around Mākua and to cause a risk to area residents who consume marine resources for subsistence. This conclusion is based on the conditions at Makua that have culminated after greater than 60 years of military activities and proposed monitoring activities (see below) that will identify future military releases of contaminants before they pose excessive risk. As stated throughout this section and the overall document, the substances identified for analysis that were found in biota within the Mākua area could be associated with many past and present natural and anthropogenic causes that are not unique to past training at MMR. In addition, based on the general similarity of carcinogenic and

noncarcinogenic health risks between the Mākua area and the background sites, it is apparent that the Army's past activities at MMR are not independently responsible for any human health risks from the substances detected in marine resources. Considering the level of substances found within the Mākua area, the numerous sources with which these substances are associated, and the ability of these substances from multiple sources to be transported by rain flow and ocean currents[3], it is not likely that future activities at MMR alone would contribute substances to the marine environment at a level sufficient to cause a human health risk. Even though it is not likely that future activities at MMR alone would cause this risk to human health, they could add to existing contamination in marine resources.

However, on authorization to resume live-fire training at MMR, the Army would evaluate the potential impacts from the proposed training by conducting a long-term monitoring program to detect if there is a potential for substances to migrate off the installation and into the Mākua nearshore and muliwai areas. If a substance were identified during monitoring, the Army would conduct further analysis to verify the detection. If the identified substance were detected above the USEPA acceptable risk level, then the Army would take appropriate action. In accordance with the requirements of the 2001 SA, before finalizing a long-term monitoring program, the Army would provide a 60-day public comment period on the scope of and protocol for such monitoring.

[3] Current direction and speed data area available at the Naval Research Laboratory Global Ocean Analysis and Modelling website (http://www7320.nrlssc.navy.mil/global_nlom32/navo/arc_list_HAWSP1_ZOOM.html). These data suggest that waters from the Nanakuli area move toward Makua at least seasonally.

TABLE OF CONTENTS

Section Page

EXECUTIVE SUMMARY ES-1

1. INTRODUCTION 1-1

1.1 Site Description 1-2
1.2 Previous Investigations 1-4
1.3 Objectives and Scope of Work 1-6
1.3.1 Objectives 1-6
1.3.2 Scope of Work 1-7

2. METHODS 2-1

2.1 Marine Resources Study Sampling Strategy 2-1
2.2 Site Selection and Chemical Transport Pathways 2-1
2.3 Background Sampling 2-4
2.4 Species of Interest 2-6
2.5 Field Sampling Methods 2-9
2.5.1 Seine Nets 2-9
2.5.2 Gill Nets 2-9
2.5.3 Hook and Line 2-9
2.5.4 Crab Nets 2-9
2.5.5 Lobster Traps 2-10
2.5.6 Crab and Minnow Traps 2-10
2.5.7 Hand-Picked Limu 2-10
2.6 Sample Handling 2-10
2.7 Laboratory Analysis 2-10
2.8 Natural and Anthropogenic Sources of Chemical analytical Groups 2-14
2.9 Human Health and Ecological Risk Assessments 2-14

3. RESULTS AND DISCUSSION 3-1

3.1 Results of Field Sampling 3-1
3.2 Summary of Potential Sources of Chemical Analytical Groups 3-6
3.2.1 Dioxins and Furans 3-7
3.2.2 Volatile Organic Compounds 3-7
3.2.3 Semivolatile Organic Compounds 3-7
3.2.4 Organochlorine Pesticides 3-8
3.2.5 Explosives 3-9
3.2.6 Metals 3-9
3.3 Analytical Results 3-13
3.3.1 Dioxins/Furans 3-13
3.3.2 Volatile Organic Compounds 3-14
3.3.3 Semivolatile Organic Compounds 3-14
3.3.4 Organochlorine Pesticides 3-15
3.3.5 Explosives 3-15
3.3.6 Metals 3-17

4. HUMAN HEALTH RISK ASSESSMENT 4-1

4.1 Selection of Chemicals of Potential Human Health Concern 4-1
4.1.1 Data Review 4-2
4.1.2 Chemicals of Potential Concern in the Mākua Valley Muliwai 4-3
4.1.3 Chemicals of Potential Concern at Mākua Beach 4-3
4.1.4 Determination of Exposure Point Concentrations 4-5
4.2 Identification of Human Receptors 4-5

TABLE OF CONTENTS *(continued)*

Section Page

4.3 Human Exposure Assessment 4-8
4.3.1 Exposure Pathway Analysis 4-8
4.3.2 Estimation of Chemical Intake 4-8
4.4 Human Toxicity Assessment 4-13
4.4.1 Human Toxicity Values 4-14
4.5 Human Health Risk Characterization 4-20
4.5.1 Risk Estimation Procedures 4-20
4.5.2 Risk Estimates 4-22
4.6 Uncertainty Analysis 4-41
4.7 Conclusions 4-45
4.7.1 Mākua Muliwai—Fish Consumption 4-45
4.7.2 Mākua Beach—Fish Consumption 4-46
4.7.3 Mākua Beach—Limu Consumption 4-46
4.7.4 Mākua Muliwai—Shellfish Consumption 4-46
4.7.5 Mākua Beach—Shellfish Consumption 4-47

5. ECOLOGICAL RISK ASSESSMENT 5-1

5.1 Guidance 5-2
5.2 Problem Formulation 5-2
5.3 Areas of Concern 5-3
5.4 Chemicals of Potential Ecological Concern 5-3
5.4.1 Data Review 5-4
5.4.2 Chemicals of Potential Concern in the North Muliwai at MMR 5-7
5.4.3 Chemicals of Potential Concern in the South Muliwai at MMR 5-7
5.4.4 Chemicals of Potential Concern in the Nearshore Habitat off MMR 5-7
5.5 Assessment Endpoints and Measures 5-7
5.5.1 Assessment Endpoints 5-11
5.5.2 Measures 5-11
5.6 Ecological Conceptual Site Model 5-11
5.6.1 Identification of Receptors 5-12
5.6.2 Exposure Pathway Inclusion/Exclusion 5-13
5.7 Analysis 5-14
5.7.1 Exposure Assessment 5-14
5.7.2 Exposure Profile 5-14
5.7.3 Exposure Point Concentrations 5-15
5.7.4 Effects Assessment 5-16
5.7.5 Toxicity Benchmarks and TRVs 5-16
5.8 Risk Characterization 5-22
5.8.1 Risk Estimation 5-22
5.9 Potential Ecological Risks 5-23
5.9.1 Potential Risks at the North Background Area 5-23
5.9.2 Potential Risks at the South Background Muliwai 5-23
5.9.3 Potential Risks at the Nanakuli Background Muliwai 5-25
5.9.4 Potential Risks at the Nearshore at Sandy Beach Background Site 5-25
5.9.5 Potential Risks at the North Muliwai 5-30
5.9.6 Potential Risks at the South Muliwai at MMR 5-35
5.9.7 Potential Risks at the Nearshore 5-40
5.10 Hazard Indices and Incremental Risks 5-44
5.10.1 North Muliwai 5-46
5.10.2 South Muliwai 5-46

TABLE OF CONTENTS *(continued)*

Section Page

5.10.3 Nearshore Habitat 5-52
5.11 Uncertainty Analysis 5-52
5.11.1 Uncertainties in the Exposure Assessment 5-52
5.11.2 Uncertainties in the Effects Assessment 5-58
5.12 Conclusions 5-59

6. DISCUSSION AND CONCLUSIONS 6-1

6.1 Dioxins/Furans 6-1
6.2 VOCs and SVOCs 6-2
6.3 Organochlorine Pesticides 6-2
6.4 Explosives 6-3
6.5 Metals 6-3
6.6 Human Health Risk Assessment 6-4
6.6.1 Risks and Uncertainties Associated with Consuming Fish in the Muliwai 6-4
6.6.2 Risks and Uncertainties Associated with Consuming Shellfish in Mākua Nearshore Waters 6-4
6.6.3 Risks and Uncertainties Associated with Consuming Limu in Mākua Nearshore Waters 6-5
6.7 Ecological Risk Assessment 6-6
6.8 Conclusions 6-6

7. REFERENCES 7-1

LIST OF TABLES

Table

ES-1 Data Interpretation Assumptions, Scientific Justifications, and Effects on Risk Analysis ES-5
ES-2 Summary of the Incremental Carcinogenic Risk from Ingesting Fish, Shellfish, and Limu at Mākua and the Background Site ES-7
ES-3 Summary of the Noncarcinogenic Hazard from Ingesting Fish, Shellfish, and Limu at Mākua and the Background Site ES-9
ES-4 Summary of Potential Chemical Migration Pathways ES-10
2-1 Marine Resources Sampling Locations and Species of Interest at MMR 2-8
2-2 Summary of Fish, Shellfish, and Limu Samples, Makua Military Reservation Marine Resources Study 2-11
2-3 Sample Analytes and Analytical Methods 2-12
3-1 Makua Military Reservation Fish, Shellfish, and Limu Study Analytical Results (all results in mg/kg) 3-2
3-2 Perchlorate in Natural Minerals and Materials (from Trumpolt et al. 2005) 3-10
3-3 Potential Anthropogenic Sources of Selected Trace Elements in the Environment 3-12
3-4 Summary Statistics for Metals and Organochlorine Pesticides in Fish 3-16
3-5 Summary Statistics for Metals in Shellfish 3-18
4-1 Tissue COPCs 4-4
4-2 Fish and Seaweed Tissue EPCs 4-6
4-3 Shellfish Tissue EPCs 4-7
4-4 Oral Carcinogenic Slope Factors 4-15
4-5 Toxicity Equivalency Factors (TEFs) for Dioxins and Furans 4-16
4-6 Chronic Oral Reference Doses 4-17
4-7 Carcinogenic Risk Estimates from Fish Consumption at the Muliwai Using Mean Contaminant Concentrations 4-23
4-8 Carcinogenic Risk Estimates from Fish Consumption at the Muliwai Using Maximum Contaminant Concentrations 4-25
4-9 Non-carcinogenic Hazard Index Estimates from Fish Consumption at the Muliwai Using Mean Contaminant Concentrations 4-26
4-10 Non-carcinogenic Hazard Index Estimates from Fish Consumption at the Muliwai Using Maximum Contaminant Concentrations 4-28
4-11 Carcinogenic Risk Estimates from Fish Consumption at Makua Beach Using Mean Contaminant Concentrations 4-29
4-12 Carcinogenic Risk Estimates from Fish Consumption at Makua Beach Using Maximum Contaminant Concentrations 4-30
4-13 Non-carcinogenic Hazard Index Estimates from Fish Consumption at Makua Beach Using Mean Contaminant Concentrations 4-31
4-14 Non-carcinogenic Hazard Index Estimates from Fish Consumption at Makua Beach Using Maximum Contaminant Concentrations 4-32
4-15 Carcinogenic Risks and Non-carcinogenic Hazards from Consumption of Seaweed (Mean COPC Concentrations) 4-34
4-16 Carcinogenic Risks and Non-carcinogenic Hazards from Consumption of Seaweed (Mean COPC Concentrations) 4-36
4-17 Carcinogenic Risk Estimates from Shellfish Consumption at the Muliwai Using Maximum Contaminant Concentrations 4-37
4-18 Non-carcinogenic Hazard Index Estimates from Shellfish Consumption at the Muliwai Using Maximum Contaminant Concentrations 4-39
4-19 Carcinogenic Risk Estimates from Shellfish Consumption at Makua Beach Using Maximum Contaminant Concentrations 4-40
4-20 Non-carcinogenic Hazard Index Estimates from Shellfish Consumption at Makua Beach Using Maximum Contaminant Concentrations 4-42
5-1(a) Sediment COPECs 5-8
5-1(b) Fish and Limu Tissue COPECs 5-9

LIST OF TABLES *(continued)*

Table

5-1(c) Shellfish Tissue COPECs 5-10
5-2 Toxicity Reference Values for Benthic Invertebrates 5-18
5-3 Shellfish Tissue-Based Toxicity Reference Values 5-19
5-4 Fish Tissue-Based Toxicity Reference Values 5-21
5-5 North and South Background Muliwai Sediment 5-24
5-6 Nanakuli Muliwai Shellfish Tissue 5-26
5-7 Nanakuli Muliwai Fish Tissue 5-27
5-8 Nearshore at Sandy Beach Shellfish Tissue 5-28
5-9 Nearshore at Sandy Beach Fish Tissue 5-29
5-10 North Muliwai Sediment 5-31
5-11 North Muliwai Shellfish Tissue 5-32
5-12 North Muliwai Fish Tissue 5-34
5-13 South Muliwai Sediment 5-36
5-14 South Muliwai Shellfish Tissue 5-38
5-15 South Muliwai Fish Tissue 5-39
5-16(a) Nearshore at Makua Shellfish Tissue (Helmet Urchin) 5-41
5-16(b) Nearshore at Makua Shellfish Tissue (Kona Crab) 5-43
5-17 Nearshore at Makua Fish Tissue 5-45
5-18 North Muliwai HIs Sediment 5-47
5-19 North Muliwai HIs Shellfish Tissue 5-48
5-20 North Muliwai HIs Fish Tissue 5-49
5-21 South Muliwai HIs Sediment 5-50
5-22 South Muliwai HIs Shellfish Tissue 5-51
5-23 South Muliwai HIs Fish Tissue 5-53
5-24(a) Nearshore HIs Shellfish Tissue (Helmet Urchin) 5-54
5-24(b) Nearshore HIs Shellfish Tissue (Kona Crab) 5-55
5-25 Nearshore HIs Fish Tissue 5-56

LIST OF FIGURES

Figure

1-1 Site Location Map 1-3
2-1 Fish, Shellfish, and Limu Sample Location Map 2-3
2-2 Sediment Sampling Location Map 2-7
4-1 Current & Future Conditions Conceptual Site Model for Human & Ecological Receptors 4-9

APPENDICES

Appendix

A Field Sheets
B Laboratory Data
C Analytical Data QA/QC Summary
D HHRA
E ERA
F Response to Comments on the Draft Marine Resources Study

ACRONYMS

μg/dL	micrograms per deciliter
APPL	Agricultural and Priority Pollutants Laboratories, Inc.
COPC	chemicals of potential concern
COPEC	chemicals of potential ecological concern
CSM	conceptual site model
DOD	U.S. Department of Defense
EIS	environmental impact statement
EPCs	exposure point concentrations
ERA	ecological risk assessment
HDOH	Hawai'i Department of Health
HI	hazard index
HI_{High}	high hazard index
HI_{Low}	low hazard index
HQ	hazard quotient
HQ_{High}s	high hazard quotient
HQ_{Low}s	low hazard quotient
mg/kg	milligrams per kilogram
MMR	Mākua Military Reservation
PRGs	preliminary remediation goals
QA/QC	quality assurance/quality control
RDX	Cyclotrimethylenetrinitramine
RfDs	reference doses
SAP	sampling and analysis plan
SEA	supplemental environmental assessment
SVOC	semivolatile organic compound
TCDD	2,3,7,8-tetrachlorodibenzo-*p*-dioxin
TOW	tube-launched, optically-tracked, wire command-link guided
TRVs	toxicity reference values
UCL_{95}	95th percentile upper confidence limit
UCLs	upper confidence limits
USEPA	U.S. Environmental Protection Agency
VOC	volatile organic compounds

SECTION 1
INTRODUCTION

The objectives of this marine resources study were defined by the 2007 partial Settlement Agreement (SA) entered into by the Army and Malama Mākua and were as follows:

- To evaluate whether fish, shellfish, limu (marine algae), and other marine resources near Mākua Beach or muliwai (estuaries or stream mouths), which area residents rely on for subsistence, are contaminated by substances associated with proposed training at Mākua;
- To evaluate if activities at MMR have contributed to or will contribute to contamination detected in the fish, shellfish, and limu; and
- To evaluate whether the proposed training activities pose a health risk to area residents who rely on marine resources for subsistence.

The scope of work and methods for the field sampling and risk assessments were previously presented in the *Marine Resources Study Sampling and Analysis Plan, Mākua Military Reservation, O'ahu, Hawai'i* (the sampling and analysis plan [SAP])(Tetra Tech 2007). Here we report the results of the Marine Resources Study. This report is organized into the following sections:

- **Section 1: Introduction—**A site description, project history and project description, and outlines the objectives and scope of work for this study;
- **Section 2: Methods—**A description of the fish, shellfish, and limu sampling activities performed as part of this marine resources study and a description of the methods used to perform these activities;
- **Section 3: Results and Discussion—**A summary of the results of fish, shellfish, and limu field sampling activities, the potential natural and anthropogenic (man-made) sources of the chemicals of concern, and laboratory analyses ;
- **Section 4: Human Health Risk Assessment—**The human health risk assessment conducted to evaluate the potential risk from consuming fish, shellfish, and limu collected in the muliwai and nearshore area at Mākua, and compares these results to

the potential risk from consuming fish and shellfish collected in background locations on O‘ahu;

- **Section 5: Screening Level Ecological Risk Assessment—**The screening level ecological risk assessment conducted to evaluate the potential risk to marine organisms from contaminants present in the muliwai and nearshore area at Mākua, and compares these results to the potential risk to marine organisms from contaminants present in background locations on O‘ahu;
- **Section 6: Conclusions—**Conclusions regarding the results of the marine resources study; and
- **Section 7: References**.

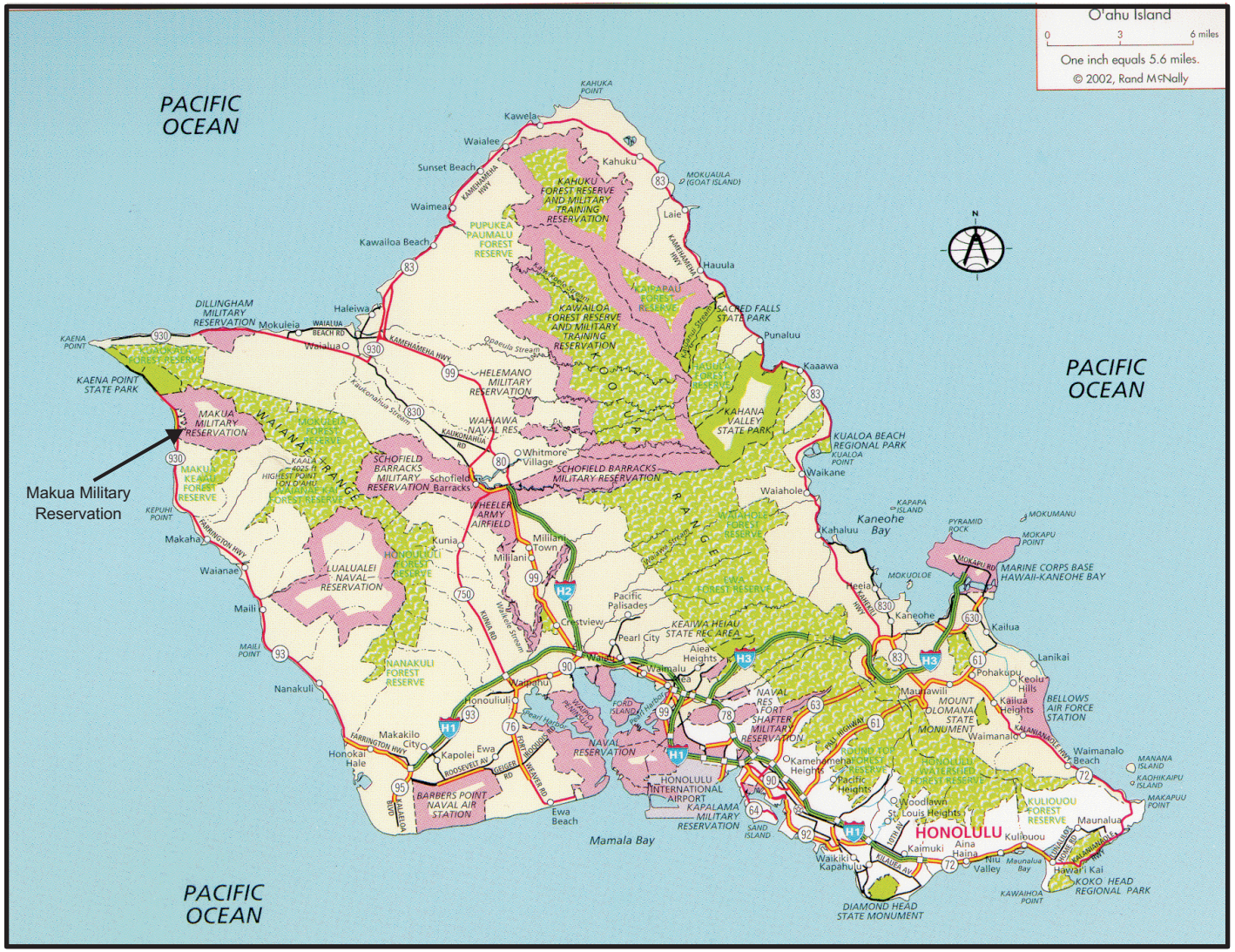
1.1 SITE DESCRIPTION

MMR is approximately 38 miles northwest of Honolulu, on the western shore of O‘ahu, near Ka‘ena Point, and is in the adjoining Mākua and Kahanahāiki Valleys (Figure 1-1). MMR is bordered on the west by the Pacific Ocean and is surrounded by the Wai‘anae Mountains on the north, east, and south. MMR borders Farrington Highway and extends west from the Wai‘anae Mountains ridgeline to the Pacific Ocean; Mākaha, the nearest township, is approximately three miles south. The installation encompasses almost 4,190 acres and is arid, with annual rainfall ranging from about 50 inches toward the head of the valley, to less than 15 inches at the mouth of the valley. The precipitous valley walls surrounding the installation reach heights of 2,100 to 2,900 feet. The broad range in rainfall and topography results in diverse vegetation types within the valley.

There are no isolated wetlands at the MMR, but there are four streams and associated riparian and estuarine wetlands in the Mākua Valley. Mākua Stream and its tributaries, which originate on the western slope of the Waianae Range, drain most of the Mākua Valley. The Mākua Stream system is intermittent and flows only about five percent of the year, rarely flowing for two consecutive days. This is a typical characteristic of streams in arid regions. Three other intermittent streams at Mākua also drain the eastern higher elevations west to the Pacific: 1) Kaluakaula Stream borders the northern boundary of Mākua, 2) Punopahaku Stream is north-central, and 3) the Kaiahi Gulch is found in the southern portion of Mākua.

Muliwai are located at the outlets of Mākua Stream, Punopahaku Stream, and the Kaiahi Gulch, although the muliwai at the mouth of Punopahaku Stream is usually dry. The muliwai are transition zones between the streams and the Pacific Ocean, with water flowing from Mākua Valley or from incoming high tides collecting in the muliwai. The water levels and salinity of the muliwai vary daily, and typically muliwai in the Hawaiian Islands, are completely flushed each year by heavy rainfall; however, muliwai on the leeward sides of all islands, including the Mākua Valley muliwai, are flushed much less frequently. The muliwai in the vicinity of the Mākua Beach that were sampled for this task include the muliwai at the outlet of Mākua Stream (north muliwai) and Kaiahi Gulch (south muliwai).

The geomorphological structure types along the nearshore environment at Makua include flat, low-relief solid carbonate rock with coverage of macrolgae, hard coral, zoanthids, and



Source: Rand McNally 2002

Site Location Map

Mākua Military Reservation
O´ahu, Hawai´i

Tetra Tech, Inc.

Figure 1-1

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other sessile invertebrates that are dense enough to begin to obscure the underlying surface (pavement), solid carbonate blocks and/or boulders or volcanic rock, and coarse sediment (sand) typically found in areas exposed to currents or wave energy (NCC0s 2007) The biological cover types include areas with coral (10% - < 50%), sparse macroalgae (10% - < 50%), turf algae ranging in cover from 10% - 100% (turf algae is a community of low lying species of marine algae composed of any or a combination of algal divisions dominated by filamentous species lacking upright fleshy macroalgal thali), and substrates covered with a minimum of 10% of any biological cover type. During most of the year the currents along the Makua coast travel from the southeast to the northwest at less than 0.3 meters per second (m/s) (Naval Research Laboratory Global Ocean Analysis and Modelling website http://www7320.nrlssc.navy.mil/global_nlom32/navo/arc_list_HAWSP1_ZOOM.html).

1.2 PREVIOUS INVESTIGATIONS

A number of field investigations at MMR have been performed, including the Halliburton NUS study, the Mākua Supplemental Environmental Assessment (SEA), the muliwai sampling conducted by the US Environmental Protection Agency during 1999 (Tetra Tech 2005a), and the muliwai sampling conducted by Tetra Tech in 2003 (Tetra Tech 2005b). In addition, a few studies have been performed along the leeward coast that include or apply to Mākua Valley, including US Geological Survey Professional Paper 1412B and Hydrologic Investigation HA-358.

The Halliburton NUS study evaluated the potential for chemicals associated with past training activities at MMR and with the open burn/open detonation area to migrate from surface water to groundwater beneath the MMR. This study concluded that groundwater samples did not have detectable concentrations of explosive or semivolatile organic compounds (SVOCs), and contained levels of nitrate, nitrite and several metals at concentrations that were below risk-based health criteria and drinking water standards. The study concluded that the basal aquifer at MMR was not impacted by contaminants (Tetra Tech 2005a).

The USEPA sampled the muliwai at Mākua Valley and an adjacent dry streambed for background data in 1999. They concluded that "further investigation does not appear warranted at this time because the overall concentrations of the metals of concern are relatively low, and do not tend to indicate a significant adverse impact on ecoreceptors" (Tetra Tech 2005a).

US Army Corps of Engineers and their contractors performed a hydrogeologic investigation at MMR between 2002 and 2004, as part of the Environmental Impact Statement (EIS) for resumption of live-fire training at MMR (Tetra Tech 2005c). Soil, sediment from streambeds, surface water and groundwater were sampled as part of this investigation. Eighteen areas of concern that were associated with training areas and several background locations were targeted for sampling. Samples were analyzed for a wide variety of chemicals, including explosives and their byproducts, metals, cyanide, dioxins/furans, polychlorinated biphenyls, SVOCs, VOCs and chlorinated herbicides. A summary of the results from this study follow.

Analytical results of 123 shallow soil samples from the areas of concern were compared to USEPA Region IX industrial preliminary remediation goals (PRGs). This comparison indicated the only chemicals detected at concentrations exceeding the PRG were iron (approximately 30 samples), lead (1 sample), dibenzanthracene (2 samples) and 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD), a dioxin (3 samples). Iron is a naturally occurring byproduct of weathered basalt, which is prevalent on O'ahu, and is likely present due to these natural conditions. Iron also exceeded the PRG in one of the five soil samples collected from the background areas at MMR. Dibenzanthracene was detected in laboratory blanks analyzed with the samples that exceeded the PRGs, suggesting dibenzanthracene may not have been present in the soil samples.

Analytical results of 11 streambed sediment samples were compared to the Region IX PRGs, with all of the sample results below the PRGs. No dioxins/furans, PCBs, chlorinated pesticides or cyanide were detected in the samples and 1,3-dinitrobenzene was the only explosive compound detected in the samples (1 sample). Several volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs) were detected in the samples, although dibenzanthracene was not detected. Aldrin, alpha-BHC and gamma-BHC (lindane) were the only pesticides detected in the samples. Many of these sample results were "J-qualified," indicating the detected concentrations were low enough that the laboratory could not accurately quantify the concentration.

A total of 81 surface water samples were collected during three different sampling events from all four of the intermittent streams present in Mākua Valley (Mākua Stream, Kaluakaula Stream Punopahaku Stream and Kaiahi Gulch). Perchlorate (1 sample) and 2,4-dinitrotoluene (2 samples) were the only explosives chemicals detected in the samples. Trace levels of dioxins/furans and trace levels of gasoline-related chemicals were also detected in the surface water samples.

Tetra Tech sampled the sediment from the muliwai at Mākua Valley and in several background muliwai in 2003 (Tetra Tech 2005b). The primary objectives of the sampling program were to evaluate if various chemicals, primarily explosives and metals, were present in the muliwai sediments, and to evaluate if chemicals from the open burn/open detonation area or the range complex at MMR had migrated off-site. Concentrations of metals detected in the muliwai were within the ranges found in the background samples, although arsenic and chromium were detected at concentrations above USEPA Region IX soil preliminary remediation goals (PRGs). Several organic compounds were detected in the sediment samples, but all of the detected concentrations were well below USEPA Region IX residential soil PRGs. Trace concentrations of two dioxin congeners were detected in two of the twelve muliwai sediment samples analyzed for dioxins/furans, with the 2,3,7,8-TCDD congener being the only congener detected at a concentration above the USEPA Region IX industrial soil PRG.

Furthermore, the US Army Corps of Engineers and its contractors performed an air quality investigation at MMR in October 2002, as part of the Environmental Impact Statement (EIS) for resumption of live-fire training at MMR. Some of the objectives of the investigation were to survey the reservation for air quality effects that occur during both a

controlled (i.e., prescribed) burn operation and typical combined arms live-fire exercises (CALFEXs) and to gather background data and identify the presence or absence of airborne pollutants of interest at representative potential on-range and off-range exposure locations, including upwind and downwind locations, during the noted events.

VOCs, SVOCs, and explosives/energetics were considered to be primary pollutants of interest for this investigation. Breakdown products of these explosives materials likewise were included as pollutants of interest for the investigation. Particulate metals from additives and structural components of, common ordnance and explosives, nitrogen and sulfur-based emission gases, and airborne cyanide were also designated as pollutants of interest. Moreover, chlorinated herbicides were included as pollutants of interest due to concerns with previous herbicide and agricultural defoliant use at the reservation. Although data on dioxins and furans suggest these airborne contaminants would not be from ordnance and explosives scheduled for use during daytime MMR training, these compounds were added to the suite of monitored pollutants. The investigation results indicated that there were no SVOCs, chlorinated herbicides, explosives/energetic compounds, or nitrogen-based emission gases detected above analytical detection limits at any air sampling location during either the open burn or CALFEX sampling.

Seven metals were detected during the sampling: aluminum, barium, chromium, magnesium, nickel, lead, and zinc (*note: arsenic, beryllium, and cadmium were not detected above analytical detection limits*). Data for detected metals showed no significant quantitative differences among the field locations, either on-range or off-range. Magnesium and lead were detected at an off-site location. Barium, chromium, magnesium, nickel, lead, and zinc were detected during background sampling (*note: aluminum, arsenic, beryllium, and cadmium were not detected above analytical detection limits*).

1.3 OBJECTIVES AND SCOPE OF WORK

1.3.1 Objectives

The objectives of this marine resources study are to evaluate whether fish, shellfish, limu (marine algae), and other marine resources near Mākua Beach or muliwai (estuaries or stream mouths), which area residents rely on for subsistence, are contaminated by substances associated with proposed training at Mākua; to evaluate if activities at MMR have contributed to or will contribute to contamination detected in the fish, shellfish, and limu; and to evaluate whether the proposed training activities pose a health risk to area residents who rely on marine resources for subsistence.

The primary military activity at MMR has been live fire training. Chemicals associated with proposed training activities include explosive compounds and byproducts of explosives and metals that may be released to the environment from the munitions. In response to public comments on the SAP, samples in this marine resources study were analyzed for these chemicals as well as a large number of additional chemicals, including dioxins/furans, organochlorine pesticides, and volatile and semivolatile organic compounds (VOCs and SVOCs). The additional chemicals included in the investigation provide little evidence that chemicals have migrated beyond the boundaries of MMR because they have a wide range of

natural and anthropogenic sources. Natural and anthropogenic sources (civilian and military) of these compounds are reviewed in Section 2.

1.3.2 Scope of Work

The draft SAP was issued in December 2005, and proposed that fish, shellfish, and limu samples be analyzed only for explosive and energetic compounds, using USEPA Method 8330. These are chemicals that are associated with the proposed training activities at MMR, although there are sources other than military training activities. Based upon comments from the public to the draft SAP, the SAP was modified to include analysis of fish, shellfish, and limu samples for a wide variety of analytes, including 1) explosives, 2) dioxins/furans, 3) metals, 4) organochlorine pesticides, 5) selected VOCs, and 6) selected SVOCs. The final SAP was published in January 2007.

The scope of work for the marine resources study and risk assessments included the following elements:

- ***Sample Collection and Analysis.*** Tetra Tech collected samples of target species in accordance with the SAP, including samples from "background" locations. Samples were analyzed by certified contract laboratories for the analytes specified in the SAP. These analytes are also listed in Section 2 of this report;
- ***Human Health Risk Assessment and Screening Level Ecological Risk Assessment.*** Tetra Tech performed a human health risk assessment for consumption of seafood from both the muliwai and nearshore waters at Mākua and a background site. Ecological risks to fish and shellfish were estimated using sediment data collected during earlier studies, along with tissue data collected as part of the present study; and
- ***Marine Resources Sampling Report.*** Tetra Tech prepared this report, including a description of the methods and procedures used to collect and analyze the samples, a presentation of the results of sample collection and laboratory analyses, the results of the risk assessments, and a discussion of the interpretation and significance of the results.

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SECTION 2
METHODS

2.1 MARINE RESOURCES STUDY SAMPLING STRATEGY

Tetra Tech conducted a sampling program to provide data to evaluate the incremental risks to human health from eating fish and shellfish collected from the muliwai downstream of MMR and in the nearshore waters and limu collected in nearshore waters. This study was designed to compare analytical results of fish and shellfish samples collected in the vicinity of MMR with analytical results for fish and shellfish samples collected from background locations. The data were collected in two phases. Fish and limu samples were collected between August 2 and August 24, 2006, while shellfish samples were collected between September 29 and October 10, 2008. Shellfish were not collected during the first phase due to concerns about the impact that collecting large numbers could have on their population. Limu samples were collected only from the MMR nearshore environment, so these samples were evaluated independently. Furthermore, the ecological risks to several taxonomic groups identified in the muliwai were evaluated. A complete description of the sampling program strategy and objectives is provided in the SAP.

2.2 SITE SELECTION AND CHEMICAL TRANSPORT PATHWAYS

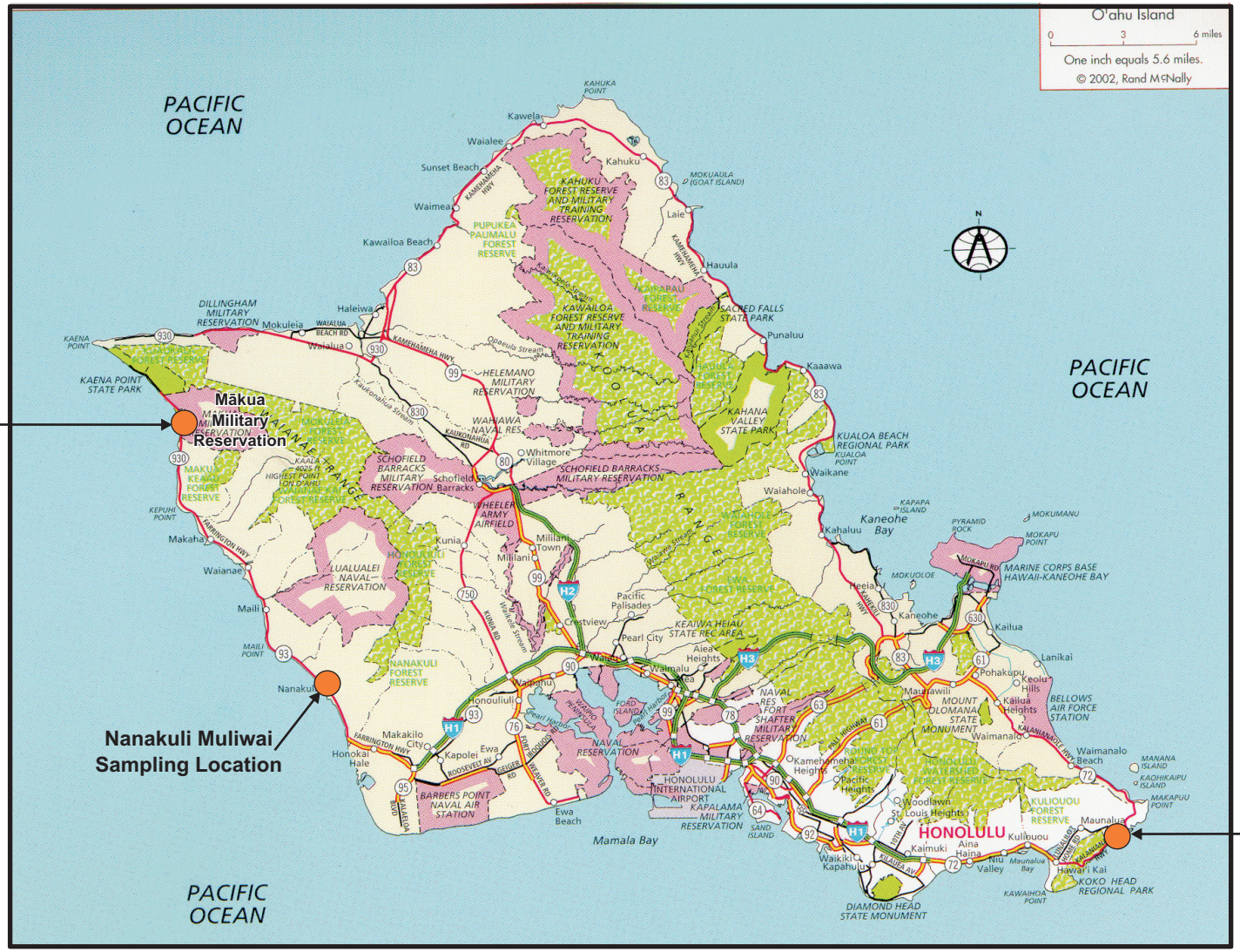
To meet the objectives identified in the SA, the preparers of this study addressed whether chemicals of potential concern have transported beyond the boundaries of MMR. In general, chemicals are transported by air, surface water, and groundwater. Chemical emissions generated from various activities, including military training, could enter the air and be transported downwind. They can be dissolved in water or adsorbed to particles that are transported by permanent or intermittent streams (streams that flow infrequently) or surface water runoff. Furthermore, water underlying the surface (groundwater) can transport chemicals that originate from the earth's crust or infiltrate from the earth's surface. Previous studies have evaluated the presence of chemicals of potential concern in air, soil, streambed sediment, surface water, groundwater, and muliwai sediment at Mākua in the vicinity of MMR. For this marine resources study, sites were selected that could link compounds originating at MMR to marine resources in the Mākua muliwai and nearshore waters. Background sites were selected to evaluate whether chemicals found in the vicinity of MMR were different from chemicals found in other parts of O'ahu.

The north and south muliwai, in the vicinity of the MMR, as shown on Figure 2-1, were selected for sampling. The north muliwai is the pond that results from runoff from Mākua Stream, the principal stream that runs through the center of MMR. The south muliwai is the pond that results from runoff from Kaiahi Gulch, which runs along the south side of MMR. Based on the topography and the drainage ditches along the MMR access road, runoff from most of the live-fire areas and the disposal areas at MMR drains to the south muliwai. Nearshore sampling at MMR was conducted adjacent to the north and south muliwai, as shown on Figure 2-1.

Background locations for the Marine Resources Study were selected after careful consideration of a wide variety of factors. One of the objectives of the Marine Resources Study was to identify if Army activities at MMR have potentially impacted Mākua Valley resources. Using an uncontaminated, pristine, or minimally developed watershed for a background location would hinder distinguishing between the Army and other sources on O‘ahu. This is a significant concern as there are many potential sources of contamination to the muliwai and nearshore environments other than the MMR. To adequately address the Army’s impact alone on Mākua Valley resources, an appropriate control site i.e., background location would be a valley where biotic and abiotic variables are as similar as possible to Mākua. Since inter-watershed transport of contaminants is facilitated by wind and rain, the control valley should have similar wind and rain patterns as that of Mākua. Biogeochemical processes affecting contaminants are a function of temperature and substrate, and these attributes also should be as similar as possible to Mākua Valley in order to identify impacts that can be potentially attributed to Army activity. There are distinct differences in the substrate (mineralogy and age) as well as in the human population and accompanying anthropogenic impacts among the Hawaiian Islands, making the selection of background locations on another island inappropriate.

Because of this, the most appropriate control watersheds are on the leeward (Waianae) coast of O‘ahu. As long as the background sites selected are representative of ambient conditions for the general Mākua vicinity and have not received contamination from the MMR, they are considered acceptable, according to the USEPA (1989, 2002a) risk assessment guidance. It is for this reason that the SAP states “Background muliwai will be located on the Waianae Coast within watersheds that are not subjected to military activity” (Section 2.2). The SAP further states that “Samples will be collected from locations distant enough from Mākua Valley that biota would be unlikely to be affected by target chemicals (explosives, by-products of explosives, and metals) originating from MMR. Background muliwai will be located in watersheds that are not subject to military activity” (Section 2.2.3).

The background muliwai selected for this study was the Nanakuli muliwai, which is located on the Waianae Coast, south of the town of Nanakuli, approximately 15 miles south of MMR. One of the sources of freshwater to the Nanakuli muliwai is runoff from Nanakuli Stream; another likely source of freshwater to the muliwai is groundwater discharge. Other muliwai located on the Waianae Coast were evaluated as potential background sampling locations, but none of these other muliwai contained water during the summer, when the sampling program was implemented.



Source: Rand McNally 2002

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Fish, Shellfish, and Limu Sample Location Map

Mākua Military Reservation
O´ahu, Hawai´i

Tetra Tech, Inc.

Figure 2-1

The background nearshore area was located at Sandy Beach, on the southeast side of O'ahu, as shown on Figure 2-1. Sandy Beach is considered to be similar to the Mākua nearshore area because both support rocky areas and sandy beaches, with very low rainfall. There is much greater movement of water and fish in nearshore areas than in a muliwai, so there is much less need for the background nearshore area to be next to a watershed that is similar to Mākua than the need for the background muliwai to be located in a watershed that is similar to Mākua.

2.3 BACKGROUND SAMPLING

Several factors entered into the process for selecting background sites.

U.S. EPA. Guidelines for Ecological Risk Assessment (EPA/630/R095/002F, 1998) states that "[Although] some reviewers requested that assessments require a comparison of the risks of alternative scenarios (including background or baseline conditions) or an assignment of particular levels of ecological significance to habitats. These decisions would be most appropriately made on a case-by-case basis, or by a program office in response to program-specific needs." These guidelines did not provide guidance for selecting an appropriate location for collecting background or baseline conditions. Therefore, we turned to guidance provided in Section 2.3 of EPA's "Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites" (EPA 540-R-01-003, Sept 2002) which states, "A background reference area should have the same physical, chemical, geological, and biological characteristics as the site being investigated, but has not been affected by activities on the site." RAGS [Risk Assessment Guidance for Superfund Vol. I, Human Health Evaluation Manual (Part A)] states that '…the locations of the background samples must be areas that could not have received contamination from the site, but that do have the same basic characteristics as the medium of concern at the site. Furthermore, RAGS states "The ideal background reference area would have the same concentration of the chemical of concern as those which would be expected on the site if the site had never been impacted. In most situations, this ideal reference area does not exist. If necessary, more than one reference area may be selected if the site exhibits a range of physical, chemical, geological, or biological variability. Background reference areas are normally selected from off-site areas, but are not limited to natural areas undistributed by human activities. It may be difficult to find a suitable background reference area in an industrial complex. In some cases, a non-impacted onsite area may be suitable as a background reference area."

Although not required for an ecological risk assessment or a human health risk assessment, the Marine Resources Study selected a background muliwai and a background nearshore area at which risk was assessed independently of Makua. Independently assessing all locations allowed for comparisons of the potential risk at Makua with the risk at background sites; however, should the background sites be deemed inappropriate the potential risk at Makua could be evaluated independently.

In the selection of a background muliwai for this study, the choice was necessarily limited by a number of factors. The site had to be physically similar to the tested area and in the same micro-scale, biogeographic area as Makua because the muliwai located in-shore the predominant influence will be terrestrial. The ocean influence is primarily seasonal.

Therefore, terrestrial conditions and influences need to be similar. This limited the locations to the leeward side of Oahu. The Army began the search for similar locations by utilizing publically available GIS. The Army looked at eleven different watersheds and muliwai, including Kalihi, Waialaenui, Nanakuli, Wailupe, Ulehawa, Keaau, Kamilonui, Manuwai, Makaha, Kaupini, and Nuuanu. One of the characteristics of the Makua watershed is the presence of intermittent streams with a perennial mouth, and we sought to duplicate this condition in the background muliwai location. At the time of the sampling, a reconnaissance of these muliwai performed by the Army indicated that Nanakuli was the only other muliwai on the southwest coast of Oahu, aside from Makua, that had flowing water, and water present during the summer sampling season and therefore met the condition of a perennial mouth. After determining that Nanakuli muliwai effectively was the only potential background site on Oahu's southwest coast, field reconnaissance was conducted to ascertain whether muliwai were available on the Oahu's windward coast. The available windwind muliwai included several adjacent to Waimanalo Bay, Kailua Bay, and Waimea Bay. The Waimanalo muliwai were considered less preferable because of current training occurring at the beach and in nearshore waters. The Kailua muliwai was eliminated because the waters feeding the muliwai included Enchanted Lake (a human made reservoir), making this system ecological different from Makua. Waimea Bay was also eliminated because it is significantly ecologically different from Makua. As a result, the Nanakuli muliwai was selected because it was physically and ecologically the most representative location available, having similar size, hydrologic, rain, wind and geochemical features as Makua.

Selecting a nearshore background location had far fewer restrictions. The primary criteria for site selection was the existence of both sand (crushed coral) beach and rocky intertidal zones. The entire coast of Oahu was considered, initially. Coastline areas were eliminated using the following criteria.

Coastlines located on bays were not considered because the residence time of water and chemicals in a bay is likely longer than along other coasts. This eliminated coastline along Waimanalo Bay, Kailua Bay, Kaneohe Bay, Waimea Bay, and Maunalua Bay. Oahu's southern coastline was eliminated because of its close proximately to highly urbanized and industrialized areas. The remaining coastlines, including the northern coast from Kaawa to Kaena Point, the southwest coastline, and the east coast remained. Current data available through the the Naval Research Laboratory (NRL) Layered Ocean Model (http://www7320.nrlssc.navy.mil/global_nlom32/navo/arc_list_HAWSP1_ZOOM.html) was consulted to further evaluate the remaining coastlines. During most seasons, currents along the south and southwest coast of Oahu travel from the southeast to the northwest. This movement had the potential to carry chemicals from Makua northward toward Kaena point and chemicals generated along the Oahu's southern coast toward Makua. In fact during the season in which sampling was to occur, NRL current data suggest that currents traveling northwest along the southwest coast can wrap around Kaena Point and become entrained in eddies along the northshore. For this reason the southwestern coast of Oahu and regions of the northshore (e.g. Kaena Point) were eliminated as a potential background site. Seasonal eddies with the potential to entrain chemicals originating from terrestrial land uses were also found along the northern shores of Oahu. The only remaining location, where NRL data suggest that the coastal waters of Oahu are continuously circulated, was the

east coast along Sandy Beach. Chemicals of terrestrial origin including those associated with a sewerline outfall are swept away from Oahu by the winds, currents and waves originating in the Kaiwi Channel. For the same reason, the waters along the east coast are continuously replenished with waters from the open ocean north of Oahu and east of Molokai. Furthermore, NCCOS (2007) suggests nearshore biological cover and geomorphological cover types along Sandy Beach are similar to Makua. Biological cover types at Sandy Beach include coral, turf, macroalgae and uncolonized substrates. Geomorphological structure types at Sandy Beach include rock and boulder, sand, and pavement. The east coast of Oahu (i.e., Sandy Beach) was selected as a background site for the Marine Resources study, indeed the biological, hydrological, geomorphological, and oceanographic characteristics of Sandy Beach made it the best possible background site.

The Hawaiian Islands are geologically different by millions of years, so a site on another island would not be a good choice because it would not be similar in basic characteristics to Makua. There are no "pristine" sites on O'ahu. Finally, a pristine site would not help to differentiate the sources of substances at Makua.

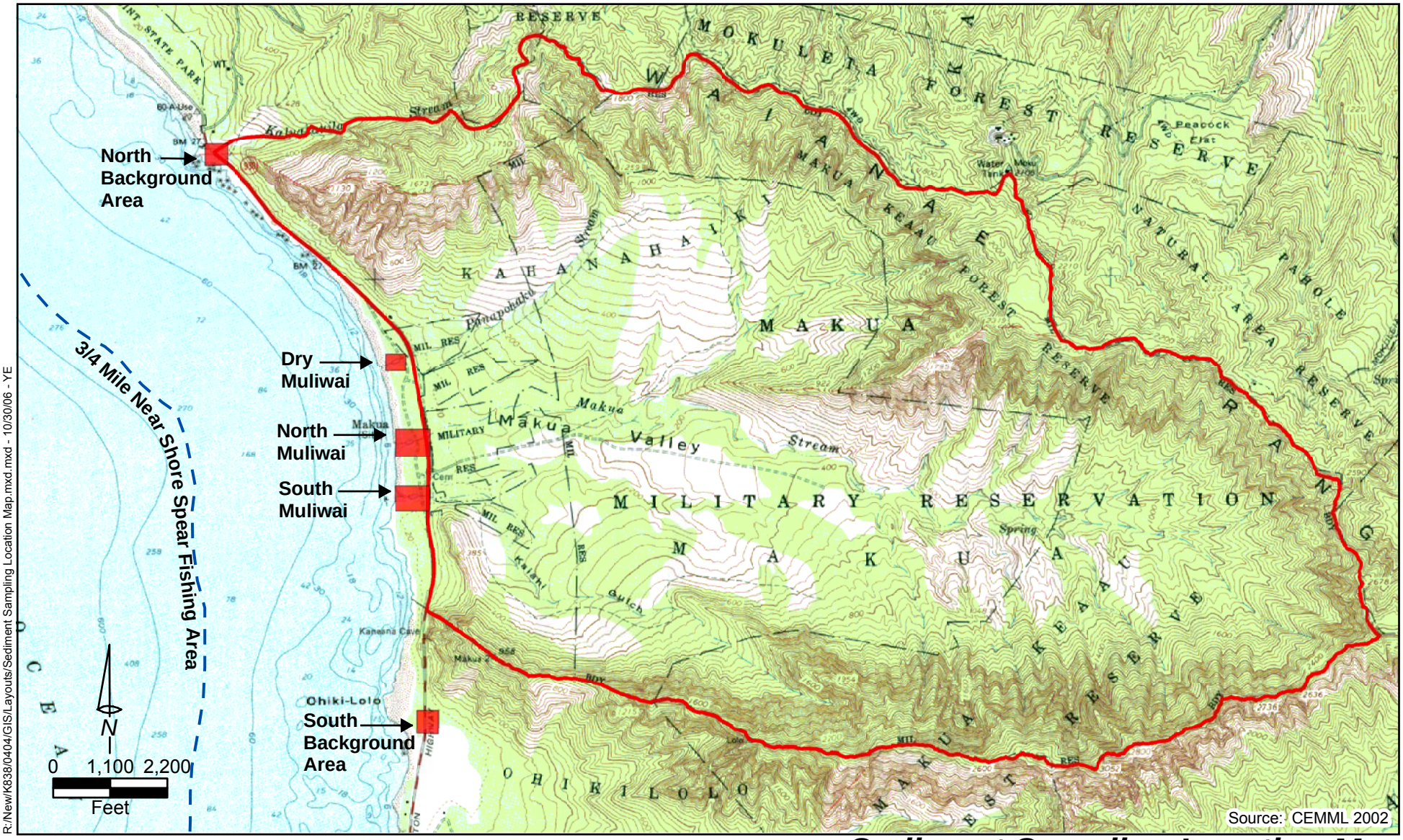
2.4 SPECIES OF INTEREST

One of the goals of the Marine Resources Study was to sample a representative range of species that may be consumed by subsistence and recreational fishermen on the Waianae Coast. Species of interest for this study were identified through discussions with regional commercial fishermen, local recreational fishermen, area divers and spear fishermen, and local residents from the Waianae coast. These discussions indicated that local fishermen are typically opportunists who consume most of the fish they are able to catch and are not selective of species. In addition, a preliminary shellfish survey was conducted to identify species that inhabit the muliwai and nearshore areas of Mākua in sufficient quantities to meet the laboratory analytical requirements. Although the SA stated that the Army should complete one or more studies to determine if fish, shellfish, limu, and other marine resources are contaminated, it is not possible to collect samples of all available marine resources. A substantial effort was made to select and collect marine resources that were representative of and readily available in the habitats of the Mākua muliwai and nearshore waters and similar watersheds where military training exercises have not occurred in the recent past. Since trophic level influences the potential uptake and concentration of contaminants, species from a range of trophic levels (primary producer, herbivore, omnivore and carnivore) were targeted in the study.

Target species were prioritized by the following criteria:

- Serve as a food source for humans;
- Spend part of their life cycle in or near brackish or freshwater (e.g., muliwai); and
- Represent a variety of trophic levels and feeding niches.

Table 2-1 identifies the target species that were collected in each habitat. Every effort was made to collect similar species in all sampling locations, but natural differences in species composition and abundance dictated which species could be collected.



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Sediment Sampling Location Map

Legend

Mākua Military Reservation

Mākua Military Reservation
Oʻahu, Hawaiʻi

Tetra Tech, Inc

Figure 2-2

Table 2-1
Marine Resources Sampling Locations and Species of Interest at MMR

Common Name	***Scientific Name***
Muliwai Target Species	
Hawaiian flagtail (aholehole)	*Kuhlia sandvicensis*
Striped mullet (`ama`ama)	*Mugil cephalus*
Medaka	*Poeciliidae* sp.
Tilapia	*Talapia zillii*, *T. rendalii*, *Oreochromis macrochir*, *O. mossambicus*, *Sarotherdon melanotheron melanotheron*
Samoan crab	*Scylla serrata*
Hawaiian prawn	*Macrobrachium grandimanus*
Malaysian snail	*Thiaridae sp.*
Rock crab	*Pachygrapsus minutus*
Red rock crab	*Plagusia depressa tuberculata*
Nearshore Target Species	
Picasso triggerfish (humuhumu nukunuku a puaa)	*Rhinecanthus rectangulus*
Blackspot sergeant (kupipi)	*Abudefduf sordidus*
Christmas wrasse (hinalea)	*Thalassoma trilobatum*
Saddle wrasse (hinalea lau-wili)	*T. duperry*
Manybar goatfish (moano)	*Parupeneus multifasciatus*
(Limu wawae`iole)	*Codium edule*
(Limu manauea)	*Gracilaria coronopifolia*
Kona crab	*Ranina ranina*
Slipper lobster	*Parribacus antarcticus*
Helmet urchin	*Colobocentrotus atratus*
Oblong urchin	*Echinometra oblonga*
Thin-shelled rock crab	*Grapsus tenuicrustas*
Black purse shell	*Isognomon californicum*
Dotted periwinkle	*Littoraria pintado*
Black nerite	*Nerita picea*
Rock-boring urchin	*Echinometra mathaei*
False `opihi	*Siphonaria normalis*
Purple rock barnacle	*Nesochthamalus interextus*
Pleated rock crab	*Pachygrapsus plicatus*
Snakedhead cowry	*Cypraea caputserpentis*
Blue-back urchin	*Echinotrhix diadema*
Black-foot `opihi	*Cellana exarata*

2.5 FIELD SAMPLING METHODS

Field sampling of fish and limu for the marine resources study occurred between August 2 and August 24, 2006, while field sampling of shellfish occurred between September 29 and October 10, 2008. Field data sheets are provided in Appendix A. Multiple sampling methods were employed to accommodate the irregular shapes and rocky bottoms of the muliwai and the surf conditions in the nearshore waters. Hook and line sampling was used in the nearshore waters, while sampling methods used in the muliwai included seine nets, gill nets, hook and line, crab and minnow traps. Limu was handpicked from the nearshore area. Each of these field methods is described below. A variety of other methods used by local fishermen, including spear fishing, were not used in the study because of the potential to introduce metals and other types of contamination into the fish.

2.5.1 Seine Nets

The seine nets used in this study ranged from 10 to 30 feet long and three feet in depth, with 1/4 inch mesh. The top of the nets were lined with floats and the bottoms of the nets were lined with lead. Each end was tied to a 4 foot pole, which was pulled by two team members through the water, dragging the leaded net bottom across the muliwai bottom and floating the top across the water surface, in effect creating a netted wall which was used to corral fish up to the banks of the muliwai. While two team members pulled the net across the bottom, a third person followed behind to free the net from an assortment of rocks or debris. Seining continued until sufficient biomass was obtained for each sample and no new species were collected.

2.5.2 Gill Nets

Gill nets used in this study were 20 feet long and 5 feet in width, with ½ or ¾ inch mesh. The top length of the net was lined with floats and the bottom length of the net was lined with lead. Gill nets were deployed across the width of the muliwai. The gill nets were used independently and in conjunction with the seine nets. Gill nets were stretched across the muliwai to compartmentalize the muliwai and facilitate seining within a smaller area restricting fish from escaping into the inaccessible areas of the muliwai. Gill nets were deployed for periods ranging from 30 minutes to 1 hour; Tetra Tech personnel remained on site whenever gill nets were deployed. Gill net sampling continued until sufficient biomass was collected for each sample and no new species were recorded.

2.5.3 Hook and Line

The hook and line method was used in the muliwai and in the nearshore fishing areas. Appropriate weight fishing lines and hook size for each target species were used for hook and line sampling in the muliwai and nearshore waters. Bread, limu, aku belly, shrimp, squid, and in some cases live fish were used for bait. Sampling continued until sufficient biomass was collected for each sample and no new species were recorded.

2.5.4 Crab Nets

Crab nets with a two-foot diameter frame and containing either nylon or cotton two-inch stretched mesh, were baited with Kona Kampachi and deployed in both the nearshore and muliwai during daylight hours. Nets were checked every one to two hours.

2.5.5 Lobster Traps

Lobster traps, three feet by two and a half feet by two feet, with rigid two-inch by two-inch rigid mesh and two eight-inch by four-inch funnel openings, were baited with Kona Kampachi, deployed in the early evening, and retrieved the next morning.

2.5.6 Crab and Minnow Traps

Several minnow trap designs with ¼ inch mesh were employed. These traps were baited with aku belly, chicken parts, squid, shrimp, and canned tuna. Traps were placed in a variety of habitats throughout the day. At the end of the day, traps were redeployed and remained in place throughout the night and collected the next morning.

2.5.7 Hand-Picked Limu

Limu was hand picked using clippers and was cut at the stipe above the holdfast and placed in a netted bag or a bucket of water during collection. Before being weighed and identified to species, the limu samples were checked for any accidental removal of holdfasts. Any holdfast that may have been removed was returned to the reef. Scientists at the Bishop Museum identified the limu species.

2.6 SAMPLE HANDLING

Samples were handled in accordance with procedures outlined in the SAP. Once caught, the fish were placed in buckets and brought to the sample station where they were identified, measured, and labeled. Individual fish and shellfish were composited by species and sample location until each composite sample consisted of at least 200 grams wet weight. Fish and limu samples were wrapped in foil and a plastic bag and placed on ice until delivery to the laboratory. Information describing the individual fish was recorded on field data sheets, including the time, date and approximate location of collection, length and weight of the fish, and method of collection. Samples were shipped to the analytical laboratories on dry ice and under chain-of-custody. Shellfish samples were placed in one-liter glass jars and stored on wet ice until being shipped on wet ice to the laboratory for sample preparation and analysis. The time, date, and approximate location of collection, full length, carapace length, and width and mass of the shellfish and method of collection were recorded on field data sheets.

Laboratory technicians homogenized fish, shellfish and limu composite samples before subsamples of each composite were forwarded to the labs identified below for analytical analysis. All components of the fish, Hawaiian prawns, and limu were included in homogenization. All crab species and helmet urchin exoskeletons were removed prior to homogenization.

2.7 LABORATORY ANALYSIS

Chemical parameters and analytes for sample analysis were identified in the SAP and are presented in Table 2-3. Primary fish and limu samples collected in 2006 were submitted to two laboratories, Columbia Analytical Services and Agricultural and Priority Pollutants, Inc. (APPL). Columbia Analytical Services analyzed the samples for the analytes listed in Table 2-2, and APPL analyzed the samples for explosives. APPL, Battelle Marine Sciences Laboratory, and Severn Trent Laboratories analyzed the quality control (QC) samples.

Table 2-2
Summary of Fish, Shellfish, and Limu Samples, Makua Military Reservation Marine Resources Study

Site	Sample ID	Matrix	Species	Sample Type
Makua North Muliwai	1	Fish	Striped mullet	Primary
Makua North Muliwai	3	Fish	Hawaiian flagtail	Primary
Makua North Muliwai	4	Fish	Tilapia	Primary
Makua North Muliwai	1b	Fish	Tilapia	Primary
Makua North Muliwai	5	Fish	Tilapia	Primary
Makua North Muliwai	MNM-04	Shellfish	Samoan crab	Primary
Makua South Muliwai	6	Fish	Striped mullet	Primary
Makua South Muliwai	2fd	Fish	Striped mullet	QC
Makua South Muliwai	7	Fish	Striped mullet	Primary
Makua South Muliwai	Comp 8,8a	Fish	Medaka	Primary
Makua South Muliwai	9	Fish	Tilapia	Primary
Makua South Muliwai	Comp 9fd, 10a	Fish	Tilapia	QC
Makua South Muliwai	10	Fish	Tilapia	Primary
Makua South Muliwai	MSM-01	Shellfish	Rock crab	Primary
Makua South Muliwai	MSM-02	Shellfish	Hawaiian prawn	Primary
Nanakuli Muliwai	12	Fish	Tilapia	Primary
Nanakuli Muliwai	13	Fish	Tilapia	Primary
Nanakuli Muliwai	14	Fish	Tilapia	Primary
Nanakuli Muliwai	NM-01	Shellfish	Hawaiian prawn	Primary
Nanakuli Muliwai	NM-02	Shellfish	Rock crab	Primary
Nanakuli Muliwai	NM-01	Shellfish	Hawaiian prawn	QC
Nearshore waters at Makua	NW2	Fish	Picasso triggerfish	Primary
Nearshore waters at Makua	NW3	Fish	Blackspot sergeant	Primary
Nearshore waters at Makua	NW4	Fish	Manybar goatfish	Primary
Nearshore waters at Makua	NW1fd	Fish	Manybar goatfish	QC
Nearshore waters at Makua	NW5	Fish	Christmas wrasse	Primary
Nearshore waters at Makua	MNS-03	Shellfish	Helmet urchin	Primary
Nearshore waters at Makua	NMS-03	Shellfish	Helmet urchin	QC
Nearshore waters at Makua	MNS-05	Shellfish	Kona crab	Primary
Nearshore waters at Makua	NW1SW3-1	Limu	All four samples are composites of *Acanthophora spicifera, Sargassum muticum*, and *Sargassum polyphyllum*	Primary
Nearshore waters at Makua	NW1SW1-1	Limu		Primary
Nearshore waters at Makua	NW1SW2-2	Limu		Primary
Nearshore waters at Makua	NW1SW1-1fd	Limu		QC
Nearshore waters at Sandy Beach	NW2fd	Fish	Blackspot sergeant	QC
Nearshore waters at Sandy Beach	NW9	Fish	Picasso triggerfish	Primary
Nearshore waters at Sandy Beach	NW10	Fish	Manybar goatfish	Primary
Nearshore waters at Sandy Beach	SBNS-01A	Shellfish	Helmet urchin	Primary
Nearshore waters at Sandy Beach	SBNS-01B	Shellfish	Helmet urchin	Primary
Nearshore waters at Sandy Beach	SBNS-01A	Shellfish	Helmet urchin	QC

Table 2-3
Sample Analytes and Analytical Methods

Analyte	Analytical Procedure	Primary Sample Analysis	QC Sample Analysis
Dioxins/Furans (17 congeners of concern)		**Columbia[1] APPL[2]**	**STL[1] TestAmerica[2]**
HpCDD	USEPA Method 8290		
HpCDF	USEPA Method 8290		
HxCDF	USEPA Method 8290		
OCDD	USEPA Method 8290		
OCDF	USEPA Method 8290		
TCDD	USEPA Method 8290		
Gasoline (Purgeable Organics)		**Columbia[1] APPL[2]**	**APPL[1] TestAmerica[2]**
Ethylbenzene	USEPA Method 8260B		
m-Xylene	USEPA Method 8260B		
p-Xylene	USEPA Method 8260B		
o-Xylene	USEPA Method 8260B		
Toluene	USEPA Method 8260B		
Metals		**Columbia[1] APPL[2]**	**Battelle[1] TestAmerica[2]**
Aluminum	USEPA Method 200.8		
Antimony	USEPA Method 200.8		
Arsenic	USEPA Method 200.8		
Barium	USEPA Method 200.8		
Beryllium	USEPA Method 200.8		
Cadmium	USEPA Method 200.8		
Chromium	USEPA Method 6010B		
Cobalt	USEPA Method 200.8		
Copper	USEPA Method 200.8		
Iron	USEPA Method 6010B		
Lead	USEPA Method 200.8		
Manganese	USEPA Method 200.8		
Mercury	USEPA 7471A (USEPA Method 245.6)		
Methyl Mercury	USEPA Method 1630 modified		
Selenium	USEPA Method 7740		
Silver	USEPA Method 200.8		
Thallium	USEPA Method 200.8		
Vanadium	USEPA Method 6010B		
Zinc	USEPA Method 200.8		
Explosives (Nitroaromatics/Nitramines)		**APPL[1, 2]**	**STL[1] TestAmerica[2]**
2,4-DNT	USEPA Method 8330		
RDX (Cyclonite)	USEPA Method 8330		
Nitroglycerine	USEPA Method 8330 modified		
Perchlorate	USEPA Method 314		

Table 2-3
Sample Analytes and Analytical Methods

Analyte	Analytical Procedure	Primary Sample Analysis	QC Sample Analysis
Organochlorine Pesticides		**Columbia[1]** **APPL[2]**	**APPL[1]** **TestAmerica[2]**
4,4'-DDT	USEPA 8081A		
Aldrin	USEPA 8081A		
alpha BHC	USEPA 8081A		
beta BHC	USEPA 8081A		
delta BHC	USEPA 8081A		
gamma BHC (lindane)	USEPA 8081A		
Heptachlor	USEPA 8081A		
Heptachlor epoxide	USEPA 8081A		
VOCs/SVOCs		**Columbia[1]** **APPL[2]**	**APPL[1]** **TestAmerica[2]**
Styrene	USEPA Method 8260B		
1,2,4-Trimethylbenzene	USEPA Method 8260B		
Pyrene	USEPA Method 8270C		
Phthalate Esters			
Bis(2-ethylhexyl) phthalate	USEPA Method 8270C		
Di-n-butyl phthalate	USEPA Method 8270C		
Diethyl phthalate	USEPA Method 8270C		
Dimethyl phthalate	USEPA Method 8270C		
Di-n-octyl phthalate	USEPA Method 8270C		

1 - Analyzed fish and limu samples
2 – Analyzed shellfish samples

Shellfish samples collected in 2008 were submitted to APPL, where they were composited, and QC samples were forwarded to Test America, Inc. The laboratory sample analysis scheme is presented in Table 2-3.

2.8 NATURAL AND ANTHROPOGENIC SOURCES OF CHEMICAL ANALYTICAL GROUPS

The chemicals of particular concern for the Marine Resources Study were explosives compounds (RDX, nitroglycerin, 2,4-dinitrotoluene, and perchlorate) and several metals. These chemicals are associated with past and proposed training at MMR. The following additional analytical groups were included in this study after public comments were received on the SAP:

- Dioxins/furans;
- Organochlorine pesticides;
- VOCs;
- SVOCs; and
- Additional metals.

The chemicals in these analytical groups have a variety of potential sources and, if detected in the fish, shellfish, and limu samples, would be difficult to attribute to activities at MMR. An extensive literature review was conducted to identify potential natural and man-made sources of each chemical or chemical analytical group. Furthermore, efforts were directed toward identifying anthropogenic sources that were unique to the military because these chemicals could indicate a chemical migration pathway.

2.9 HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENTS

Methods used to conduct the human health and ecological risk assessments are described in Sections 4 and 5, respectively.

SECTION 3
RESULTS AND DISCUSSION

In this section are the results of field sampling, an extensive literature review that identified potential natural and anthropogenic sources of the chemicals analyzed in fish, shellfish, and limu at MMR, and the laboratory analytical results. These results were used to assess whether past or proposed military activities at MMR have the potential to contribute to contamination of fish, shellfish, and limu at Mākua. A summary of the analytical results is presented in Table 3-1, and discussed below. Full analytical results for the fish, shellfish, and limu samples are presented in Appendix B; Appendix C provides QA/QC for the sample results.

3.1 RESULTS OF FIELD SAMPLING

The analytical suite for the fish, shellfish, and limu samples included six analyte groups and approximately 43 compounds. In order to have enough tissue mass for the entire suite of analytes, approximately 200 grams of tissue was required. The laboratories achieved this by compositing multiple individual organisms in all samples except one fish sample.

Twenty-six fish samples (22 primary and four quality control [QC] samples), 12 shellfish samples (eight primary and two QC), and four limu samples (three primary and one QC sample) were analyzed for the full suite of compounds. Three partial shellfish samples were analyzed for explosives or metals only. A list of the fish species and samples collected from each sampling location is provided in Table 2-2.

As part of the 2006 field effort, Tetra Tech attempted to collect shellfish or other invertebrates for analysis as part of the Marine Resources Study. Helmet urchins were collected from the nearshore area, but the total tissue mass of about 200 grams needed for a single sample required collecting upwards of 100 sea urchins. While no specific data are available on the longevity of helmet urchins, sea urchins are generally long-lived in the wild, surviving for five to ten years or more. Although, many sea urchins can reproduce in the second year of life, peak fecundity is related to body size and thus is attained later in life (Ebert 2008; Ebert et al. 2008; Francis et al. 2006; Emlet 2002; MLIN 2008). If an urchin

Table 3-1
Makua Military Reservation
Fish, Shellfish, and Limu Study Analytical Results
(all results in mg/kg)

		Sample Location	North muliwai	North muliwai	North muliwai	North muliwai	North muliwai	North muliwai	South muliwai	South muliwai	South muliwai	South muliwai	South muliwai	South muliwai	South muliwai	South muliwai	South muliwai	Nanakuli muliwai	Nanakuli muliwai	Nanakuli muliwai	Nanakuli muliwai	Nanakuli muliwai	Nanakuli muliwai	Makua near-shore	Makua near-shore	Makua near-shore
		Matrix	Fish	Fish	Fish	Fish	Fish	Shellfish	Fish	Fish	Fish	Fish	Fish	Fish	Fish	Shellfish	Shellfish	Fish	Fish	Fish	Shellfish	Shellfish	Shellfish	Fish	Fish	Fish
Analytical Group	**Chemical**	**Sample ID**	**1**	**1b**	**3**	**4**	**5**	**MNM-04**	**2fd**	**6**	**7**	**Comp 8,8a**	**9**	**9afd and 10a Comp**	**10**	**MSM-01**	**MSM-02**	**12**	**13**	**14**	**NM-01**	**NM-02**	**NM-01A**	**NW1fd**	**NW2**	**NW3**
		Sample type	SMPL	SMPL	SMPL	SMPL	SMPL	SMPL	QC	SMPL	SMPL	SMPL	SMPL	QC	SMPL	SMPL	SMPL	SMPL	SMPL	SMPL	SMPL	SMPL	SMPL	QC	SMPL	SMPL
Dioxins/Furans	1,2,3,4,6,7,8-HpCDD		ND	ND	ND	ND	ND	ND	ND	ND	5.31E-07 J	ND	ND	ND	ND	-	-	ND	ND	ND	ND	-	1.20E-06 J	ND	ND	ND
	1,2,3,4,6,7,8-HpCDF		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.95E-07 J	ND	ND	-	-	2.07E-07 J	1.78E-07 J	3.71E-07 J	ND	-	ND	ND	ND	ND
	1,2,3,4,7,8,9-HpCDF		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	ND	-	ND	ND	ND	ND
	1,2,3,4,7,8-HxCDD		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	ND	-	ND	ND	ND	ND
	1,2,3,4,7,8-HxCDF		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	ND	-	ND	ND	ND	ND
	1,2,3,6,7,8-HxCDD		ND	ND	ND	ND	ND	1.2E-06 J	ND	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	ND	-	5.00E-07 J	ND	ND	ND
	1,2,3,6,7,8-HxCDF		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	ND	-	2.20E-06 J	ND	ND	ND
	1,2,3,7,8,9-HxCDD		ND	ND	ND	ND	ND	8.3E-07 J	ND	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	ND	-	ND	ND	ND	ND
	1,2,3,7,8,9-HxCDF		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	ND	-	ND	ND	ND	ND
	1,2,3,7,8-PeCDD		ND	ND	1.42 E-06 J	4.49 E-07 J	ND	ND	ND	ND	ND	ND	1.76E-06 J	ND	ND	-	-	ND	ND	ND	ND	-	ND	ND	ND	ND
	1,2,3,7,8-PeCDF		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	ND	-	ND	ND	ND	ND
	2,3,4,6,7,8-HxCDF		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	ND	-	ND	ND	ND	ND
	2,3,4,7,8-PeCDF		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	ND	-	ND	ND	ND	ND
	2,3,7,8-TCDD		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	ND	-	ND	ND	ND	ND
	2,3,7,8-TCDF		ND	ND	ND	ND	ND	1.70E-06	5.9E-07 J	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	ND	-	4.60E-07 J	ND	ND	ND
	OCDD		ND	ND	ND	ND	ND	3.00E-06 J	8.7E-06 J	ND	ND	ND	ND	6.90E-06 J	ND	-	-	ND	ND	ND	ND	-	7.10E-06	ND	ND	ND
	OCDF		ND	ND	ND	ND	ND	ND	ND	ND	1.31E-06 J	ND	1.26-06 J	ND	5.49E-07 J	-	-	6.49E-07 J	6.44E-07 J	8.78E-07 J	ND	-	ND	ND	ND	ND
	HpCDD, total		1.40E-06	2.03E-06	1.50E-06	1.02E-05	2.62E-06	-	ND	ND	1.69E-06	3.02E-06	2.04E-06	ND	6.99E-07	-	-	1.73E-06	1.92E-06	2.46E-06	-	-	-	ND	ND	ND
	HPCDF, total		ND	ND	ND	7.99E-07	ND	-	ND	ND	ND	1.35E-06	2.95E-07	ND	ND	-	-	2.07E-07 J	1.78E-07	3.71E-07	-	-	-	ND	ND	ND
	HxCDD, total		ND	ND	ND	ND	ND	-	ND	ND	ND	ND	1.45E-07	ND	ND	-	-	ND	ND	3.69E-07	-	-	-	ND	ND	ND
	HxCDF, total		ND	ND	ND	ND	ND	-	ND	ND	ND	1.29E-07	ND	ND	ND	-	-	ND	ND	1.67E-07	-	-	-	ND	ND	ND
	PeCDD, total		ND	ND	1.42E-06	ND	ND	-	ND	ND	ND	ND	1.76E-06 J	ND	ND	-	-	ND	ND	ND	-	-	-	ND	ND	ND
	PeCDF, total		ND	ND	ND	ND	ND	-	ND	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	-	-	-	ND	ND	ND
	TCDD, total		ND	ND	ND	ND	ND	3.30E-06	ND	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	ND	-	ND	ND	ND	ND
	TCDF, total		ND	ND	ND	ND	ND	1.70E-06	5.90E-07	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	2.3E-07 J	-	1.30E-06 J	ND	ND	ND
Volatiles																										
	Acetone		0.25 J	ND	ND	ND	ND	-	-	0.28 J	0.24 J	0.38	ND	-	0.23 J	-	-	ND	ND	ND	-	-	-	-	0.73 J	0.71 J
	Benzene		ND	ND	ND	ND	ND	-	-	ND	ND	ND	ND	-	ND	-	-	ND	ND	ND	-	-	-	-	ND	ND
	Ethylbenzene		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	ND	-	ND	ND	ND	ND
	Styrene		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	ND	-	ND	ND	ND	ND
	Toluene		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	ND	-	ND	ND	ND	ND
	1,2,4-Trimethylbenzene		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	ND	-	ND	ND	ND	ND
	m,p-Xylenes		ND	ND	ND	ND	ND	ND	0.0016 J	ND	ND	ND	ND	0.017 J	ND	-	-	ND	ND	ND	ND	-	ND	0.02 J	ND	ND
	o-Xylene		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	ND	-	ND	ND	ND	ND
Semi-volatiles																										
	bis(2-ethylhexyl)phthalate		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	3.1	ND	-	-	ND	ND	ND	ND	-	ND	3.5 J	0.63	ND
	Diethyl phthalate		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	ND	-	ND	ND	ND	ND
	Dimethyl phthalate		ND	ND	ND	ND	ND	-	ND	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	-	-	-	ND	ND	ND
	Di-n-butylphthalate		0.011 J	0.01 J	0.011 J	0.015 J	0.0098 J	ND	1.5 J	0.015 J	0.013 J	0.017 J	0.013 J	0.96 J	0.011 J	-	-	0.016 J	0.018 J	0.012 J	ND	-	ND	1.4 J	0.048	0.022 J
	Di-n-octylphthalate		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	ND	-	ND	ND	ND	ND
	Pentachlorophenol		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	ND	-	ND	ND	ND	ND
	Pyrene		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	ND	-	ND	ND	ND	ND
Organochlorine pesticides																										
	Aldrin		ND	ND	0.0009 JP	ND	ND	ND	ND	0.003P	0.001P	ND	ND	ND	ND	-	-	ND	ND	ND	ND	-	ND	ND	0.0027 J	ND
	BHC, alpha		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	ND	-	ND	0.0082 J	ND	ND
	BHC, beta		0.014P	0.0019P	ND	ND	ND	ND	ND	0.0041	ND	ND	0.00081 J	ND	ND	-	-	ND	0.0012P	0.00084 JP	ND	-	ND	ND	0.024P	ND
	BHC, delta		0.00056 JP	ND	ND	ND	0.00031 J	ND	ND	ND	ND	ND	ND	ND	0.00076 JP	-	-	ND	0.0011P	ND	ND	-	ND	ND	ND	0.0003 J
	BHC, gamma		ND	0.00082 JP	ND	0.00089 J	0.0013	ND	ND	0.0016	0.0017	0.0011P	ND	ND	ND	-	-	ND	ND	ND	ND	-	ND	ND	0.0063	ND
	4,4'-DDT		ND	ND	0.00068 JP	0.00074 J	0.0005 J	ND	ND	0.0027	0.0029	0.0012	0.00067 J	ND	0.00088 J	-	-	ND	0.0014	0.0013	ND	-	ND	ND	ND	0.00018 J
	Heptachlor		0.0082P	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	ND	-	ND	0.033P	ND	ND
	Heptachlor epoxide		ND	0.00087 JP	0.00094 JP	0.00051 J	0.0013P	ND	ND	0.00093 J	ND	0.0027P	0.00058 J	ND	0.0013P	-	-	0.00087 JP	0.00098 J	0.0011	ND	-	ND	0.014 J	0.0041 JP	ND
Explosives																										
	2,4-Dinitrotoluene		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Nitroglycerin		ND	ND	ND	ND	ND	ND	0.69	ND	ND	ND	ND	0.95P	ND	ND	-	ND	ND	ND	ND	ND	ND	0.33 J	ND	ND
	Perchlorate		0.0019	ND	ND	ND	ND	ND	0.16	0.097	0.04	0.0042	0.0012	0.021 J	ND	-	-	ND	0.0014	ND	ND	-	ND	0.0088 J	ND	ND
	RDX		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	ND	ND	ND	ND	ND	ND	0.057 J	ND	ND
Metals																										
	Aluminum		2,950	2,840	48.3	2,000	4,240	33.3	1,517	1,250	1,150	1,450	2,880	2,711	2,140	-	143	3,810	5,170	4,420	73.2	-	39.7	21	51	65
	Antimony		ND	ND	0.04 J	ND	ND	ND	0.0527 J	ND	ND	ND	ND	0.0481 J	ND	-	ND	ND	ND	ND	ND	-	ND	ND	ND	ND
	Arsenic		2.25	3.18	2.87	2.53	3.81	2.4 J	1.46 J	2.35	2.18	1.46	1.72	29.8	1.46	-	3.6	2.51	2.57	2.54	2.2 J	-	3.9	25.2	37.3	4.06
	Barium		22.7	26.1	5.53	26.1	23.5	26.3	19.5	16.6	15.1	12.9	21.2	12.5	18.7	-	57.8	39.7	43.6	39.1	4.1	-	14.5	0.62 J	1.27	31.6
	Beryllium		0.037	0.034	ND	0.028	0.051	ND	0.01 J	0.018 J	0.018 J	0.017 J	0.032	0.0261	0.024	-	ND	0.078	0.094	0.082	ND	-	ND	ND	ND	ND
	Cadmium		0.06	0.06	0.02	0.05	0.08	ND	0.0292 J	0.02	0.03	0.03	0.05	0.147	0.05	-	ND	0.11	0.12	0.13	ND	-	ND	0.155	0.21	0.12
	Chromium		11.9	10.5	0.9	8.2	14.7	0.94 J	12.4	23	31.5	8.4	12.4	13.2	10.9	-	1.3 J	22.3	24.7	19.7	1.0 J	-	1.2 J	1.56	8.8	6.8
	Cobalt		2.58	3.25	0.397	2.67	4.17	0.17 J	2.58	2.53	2.39	1.98	2.21	2.23	1.94	-	0.8	4.59	5.25	4.86	0.23 J	-	0.28 J	0.133	0.413	0.324

Table 3-1
Makua Military Reservation
Fish, Shellfish, and Limu Study Analytical Results
(all results in mg/kg)

		Sample Location	North muliwai	North muliwai	North muliwai	North muliwai	North muliwai	North muliwai	South muliwai	South muliwai	South muliwai	South muliwai	South muliwai	South muliwai	South muliwai	South muliwai	South muliwai	Nanakuli muliwai	Nanakuli muliwai	Nanakuli muliwai	Nanakuli muliwai	Nanakuli muliwai	Nanakuli muliwai	Makua near-shore	Makua near-shore	Makua near-shore
		Matrix	Fish	Fish	Fish	Fish	Fish	Shellfish	Fish	Fish	Fish	Fish	Fish	Fish	Fish	Shellfish	Shellfish	Fish	Fish	Fish	Shellfish	Shellfish	Shellfish	Fish	Fish	Fish
Analytical Group	**Chemical**	**Sample ID**	**1**	**1b**	**3**	**4**	**5**	**MNM-04**	**2fd**	**6**	**7**	**Comp 8,8a**	**9**	**9afd and 10a Comp**	**10**	**MSM-01**	**MSM-02**	**12**	**13**	**14**	**NM-01**	**NM-02**	**NM-01A**	**NW1fd**	**NW2**	**NW3**
		Sample type	**SMPL**	**SMPL**	**SMPL**	**SMPL**	**SMPL**	**SMPL**	**QC**	**SMPL**	**SMPL**	**SMPL**	**SMPL**	**QC**	**SMPL**	**SMPL**	**SMPL**	**SMPL**	**SMPL**	**SMPL**	**SMPL**	**SMPL**	**SMPL**	**QC**	**SMPL**	**SMPL**
	Copper		166	45.3	6.39	44.1	48.8	21.3	17.3	20.9	14.2	9.56	109	67.8	67.3	-	39.7	70	64.9	79.9	31	-	65.7	3.32	9.78	3
	Iron		3,460	2,810	122	2,140	4,530	92.2	2,818	2,570	2,690	1,900	3,450	3,460	2,540	-	226	5,410	7,010	5,570	110	-	80.4	71.5	302	258
	Lead		3.16	1.25	5.39	2.04	1.34	ND	1.31	1.2	1.02	0.973	2.6	2.61	2.25	-	0.16 J	2.01	2.02	2.15	ND	-	ND	0.146	0.945	2.01
	Manganese		239	328	11.9	259	386	70.3	125	94.9	113	122	184	150	159	-	122	501	603	611	32.5	-	32.4	2.23	15.7	11.5
	Mercury		0.074	0.029	0.038	0.024	0.03	0.022J	0.0581	0.044	0.034	0.103	0.068	0.0922	0.075	-	ND	0.042	0.047	0.043	ND	-	ND	0.0978	0.055	0.07
	Methyl mercury		0.07	0.021	0.044	0.02	0.012	-	0.0544	0.038	0.04	0.17	0.072	0.0618	0.086	-	-	0.053	0.033	0.032	-	-	-	0.20	0.059	0.084
	Selenium		3.71	1.97	1.83	2.24	2.16	0.68 J	2.14	2.03	1.61	3.59	2.8	2.83	2.65	-	1.2	2.19	2.39	2.57	ND	-	1.7	1.19	1.6	0.79 J
	Silver		1.13	0.245	0.014 J	0.285	0.302	ND	0.0546	0.047	0.046	0.157	0.822	0.61	0.657	-	ND	0.527	0.594	0.703	0.12 J	-	0.24 J	0.0132 J	ND	0.008 J
	Thallium		ND	ND	ND	ND	ND	ND	0.00325 J	ND	ND	ND	ND	0.006 J	ND	-	ND	ND	ND	ND	ND	-	ND	ND	ND	ND
	Vanadium		19.3	15	1.24	11.2	17.3	0.35 J	10.3	9.23	9.19	7.76	18.2	12.9	11.7	-	0.77	19.6	23.6	19.7	0.36 J	-	0.31 J	0.106	1.24	0.9
	Zinc		129	112	98.8	103	127	31.2	104	91.5	85.2	94.6	106	201	117	-	28.4	108	111	116	14.8	-	485	54.2	149	64.9
General																										
	Solids, Total		24.4	28.1	27.7	27.4	26.1	-	-	29	30.6	26.3	26.3	-	25.7	-	-	28.7	28.2	27.3	-	-	-	-	30.3	30.7
	Lipids, Total		2.1	5.1	6.4	4.2	4.3	-	-	6	6.4	2.5	3.3	-	3	-	-	4.8	3.8	3.3	-	-	-	-	4.4	2.6
	Percent Lipids		-	-	-	-	-	0.7	16	-	-	-	-	13.9	-	-	-	-	-	-	1.5	-	1.7	21.3	-	-
	Percent moisture		75.6	71.9	72.3	72.6	73.9	71.3	69.2	71	69.4	73.7	73.7	72.9	74.3	55.9	56.6	71.3	71.8	72.7	74.1	-	-	66.9	69.7	69.3

Table 3-1
Makua Military Reservation
Fish, Shellfish, and Limu Study Analytical Results
(all results in mg/kg)

		Makua near-shore	Makua near-shore	Makua near-shore	Makua near-shore	Makua near-shore	Sandy Beach near-shore	Sandy Beach near-shore	Sandy Beach near-shore	Sandy Beach near-shore	Sandy Beach near-shore	Sandy Beach near-shore	Sandy Beach near-shore	Sandy Beach near-shore	Sandy Beach near-shore	Makua near-shore	Makua near-shore	Makua near-shore	Makua near-shore
		Fish	Fish	Shellfish	Shellfish	Shellfish	Fish	Fish	Fish	Fish	Fish	Fish	Shellfish	Shellfish	Shellfish	Limu	Limu	Limu	Limu
Analytical Group	**Chemical**	**NW4**	**NW5**	**MNS-03**	**MNS-05**	**MNS-03**	**NW2fd**	**NW6**	**NW7**	**NW8**	**NW9**	**NW10**	**SBNS-01-A**	**SBNS-01-B**	**SBNS-01-A**	**NW1SW1-1**	**NW1SW1-1fd**	**NW1SW2-1**	**NW1SW3-1**
		SMPL	**SMPL**	**SMPL**	**SMPL**	**QC**	**QC**	**SMPL**	**SMPL**	**SMPL**	**SMPL**	**SMPL**	**SMPL**	**SMPL**	**QC**	**SMPL**	**QC**	**SMPL**	**SMPL**
Dioxins/Furans	1,2,3,4,6,7,8-HpCDD	ND	ND	ND	ND	ND	ND	ND	7.71E-07 J	2.05E-07 J	ND	ND	ND	ND	7.40E-05	ND	ND	ND	ND
	1,2,3,4,6,7,8-HpCDF	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.13E-06 J	ND	ND	ND
	1,2,3,4,7,8,9-HpCDF	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	1,2,3,4,7,8-HxCDD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	1,2,3,4,7,8-HxCDF	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	3.2E-07 J	ND	8.90E-08 J	ND	1.14E-07 J	ND
	1,2,3,6,7,8-HxCDD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.42E-07 J	ND
	1,2,3,6,7,8-HxCDF	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.3E-07 J	ND	5.70E-08 J	ND	ND	ND
	1,2,3,7,8,9-HxCDD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	3.16E-07 J	ND
	1,2,3,7,8,9-HxCDF	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.3E-07 J	ND	ND	ND	ND	ND	ND
	1,2,3,7,8-PeCDD	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.72E-07 J	ND	ND	ND	ND	ND	ND	ND	ND
	1,2,3,7,8-PeCDF	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	2,3,4,6,7,8-HxCDF	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	2,3,4,7,8-PeCDF	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	2,3,7,8-TCDD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	2,3,7,8-TCDF	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	3.1E-07 J	ND	ND	ND	ND	ND
	OCDD	ND	ND	2.10E-06 J	ND	8.00E-6 J	ND	ND	ND	ND	ND	ND	1.2E-06 J	ND	2.90E-04	ND	ND	ND	ND
	OCDF	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.01E-06 J	ND	ND	ND
	HpCDD, total	ND	ND	-	-	ND	ND	ND	1.62E-06	4.28E-07	6.58E-07	3.06E-07	-	-	1.10E-04	1.25E-06	ND	1.65E-05	3.23E-07
	HPCDF, total	ND	ND	-	-	ND	ND	ND	ND	ND	ND	2.87E-07	-	-	ND	1.76E-06	ND	4.58E-06	ND
	HxCDD, total	ND	ND	-	-	ND	ND	ND	ND	ND	ND	ND	-	-	8.10E-06	ND	ND	1.91E-06	ND
	HxCDF, total	ND	ND	-	-	ND	ND	ND	ND	ND	ND	ND	-	-	ND	8.90E-08	ND	4.30E-07	ND
	PeCDD, total	ND	ND	-	-	ND	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	ND	ND
	PeCDF, total	ND	ND	-	-	ND	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	ND	ND
	TCDD, total	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.9E-07 J	ND	ND	ND	ND	ND	ND
	TCDF, total	ND	ND	4.00E-07 J	ND	ND	ND	ND	ND	ND	2.47E-07	ND	ND	3.9E-07 J	ND	ND	ND	ND	ND
Volatiles																			
	Acetone	ND	0.27 J	-	-	-	-	0.23 J	0.6 J	ND	0.28 J	0.34 J	-	-	-	ND	-	ND	ND
	Benzene	ND	ND	-	-	ND	-	ND	ND	ND	ND	ND	-	-	ND	ND	-	ND	ND
	Ethylbenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Styrene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Toluene	ND	ND	ND	ND	0.0011 J	ND	ND	ND	ND	ND	ND	ND	ND	0.00089	ND	ND	ND	ND
	1,2,4-Trimethylbenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	m,p-Xylenes	ND	ND	ND	ND	ND	0.016 J	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.016 J	ND	ND
	o-Xylene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Semi-volatiles																			
	bis(2-ethylhexyl)phthalate	2.8	0.055 J	ND	ND	ND	ND	ND	ND	ND	ND	0.049 J	ND	ND	ND	ND	ND	ND	0.086 J
	Diethyl phthalate	ND	ND	ND	ND	ND	ND	0.019 J	ND	ND	0.018 J	ND	ND	ND	ND	ND	ND	ND	ND
	Dimethyl phthalate	ND	ND	-	-	-	ND	ND	ND	ND	ND	ND	-	-	-	ND	ND	ND	ND
	Di-n-butylphthalate	0.031 J	0.046	ND	ND	ND	0.61 J	0.047	0.038 J	0.043	0.014 J	0.053	ND	ND	ND	0.02 J	0.48 J	0.02 J	0.024 J
	Di-n-octylphthalate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Pentachlorophenol	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Pyrene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Organochlorine pesticides																			
	Aldrin	0.0024	ND	ND	ND	0.0011 J	ND	ND	ND	ND	ND	0.0064	ND	ND	ND	ND	ND	0.00035 JP	ND
	BHC, alpha	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	BHC, beta	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.00036 JP	ND
	BHC, delta	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	BHC, gamma	ND	0.0054P	ND	ND	ND	ND	0.0025P	0.0019	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	4,4'-DDT	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.0021 J	0.0019 J	ND	ND	ND	ND	ND	ND	ND
	Heptachlor	ND	0.0056	ND	ND	ND	ND	ND	0.0057	0.0045	ND	ND	ND	ND	ND	0.00068 J	ND	0.00041 J	0.00072 J
	Heptachlor epoxide	0.0032	0.0025P	ND	ND	ND	0.0076 J	ND	0.0028	ND	0.003 J	0.0052P	ND	ND	ND	ND	ND	0.00088 JP	ND
Explosives																			
	2,4-Dinitrotoluene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Nitroglycerin	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Perchlorate	ND	ND	1.05	ND	ND	0.01 J	ND	ND	ND	0.11	ND	ND	ND	ND	0.052	ND	ND	0.011
	RDX	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.38P	ND	ND
Metals																			
	Aluminum	6.8	8.9	102	30	72	15.6	3.8	9.1	12.6	4,720	14.9	50.9	61.8	39.4 J	1,120	337	172	58
	Antimony	ND	ND	ND	ND	ND	0.0259 J	ND	ND	ND	ND	ND	ND	ND	ND	0.05 J	0.145	ND	0.04
	Arsenic	23.9	24.6	1.2 J	26.4	0.47 J	6.17	53	6.62	5.13	4.52	36.6	1.2 J	1.2 J	ND	55.4	109	4.56	96
	Barium	0.46	0.97	2.3	1.4	1.1	7.58	1.51	1.66	7.98	14.2	0.96	1.6	1.5	1.3	10.9	13.3	1.48	10.2
	Beryllium	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.069	ND	ND	ND	0.062 J	0.02	0.00559 J	0.004 J	ND
	Cadmium	0.13	0.14	ND	2	ND	0.132	0.2	0.09	0.1	0.04	0.09	ND	ND	ND	0.17	0.265	0.28	0.26
	Chromium	0.8	10.4	1.2 J	1.2 J	1.2	1.49	2.7	4.9	2.2	31.7	0.7	0.92 J	1.2 J	1.1	6	1.59	0.8	ND
	Cobalt	0.107	0.176	0.23 J	0.23 J	0.37 J	0.133	0.109	0.141	0.18	4.31	0.116	0.18 J	0.14 J	0.45 J	1.25	0.791	0.374	0.472

Table 3-1
Makua Military Reservation
Fish, Shellfish, and Limu Study Analytical Results
(all results in mg/kg)

		Makua near-shore	Makua near-shore	Makua near-shore	Makua near-shore	Makua near-shore	Sandy Beach near-shore	Sandy Beach near-shore	Sandy Beach near-shore	Sandy Beach near-shore	Sandy Beach near-shore	Sandy Beach near-shore	Sandy Beach near-shore	Sandy Beach near-shore	Sandy Beach near-shore	Makua near-shore	Makua near-shore	Makua near-shore	Makua near-shore
		Fish	Fish	Shellfish	Shellfish	Shellfish	Fish	Fish	Fish	Fish	Fish	Fish	Shellfish	Shellfish	Shellfish	Limu	Limu	Limu	Limu
Analytical Group	**Chemical**	**NW4**	**NW5**	**MNS-03**	**MNS-05**	**MNS-03**	**NW2fd**	**NW6**	**NW7**	**NW8**	**NW9**	**NW10**	**SBNS-01-A**	**SBNS-01-B**	**SBNS-01-A**	**NW1SW1-1**	**NW1SW1-1fd**	**NW1SW2-1**	**NW1SW3-1**
		SMPL	**SMPL**	**SMPL**	**SMPL**	**QC**	**QC**	**SMPL**	**SMPL**	**SMPL**	**SMPL**	**SMPL**	**SMPL**	**SMPL**	**QC**	**SMPL**	**QC**	**SMPL**	**SMPL**
	Copper	2.75	2.2	2.6	25.7	1.6	2.95	2.87	1.86	2.46	16.5	2.02	1.0	1.9	1.1	4.57	2.34	2.83	0.85
	Iron	62.5	121	84.9	131	47.2	80.5	68.4	83.7	113	6,960	71.5	100	83.6	50.8	1,860	459	296	67.4
	Lead	0.076	0.32	0.33 J	0.13 J	ND	2.24	0.626	0.463	2.75	1.18	1.38	0.63	0.51	0.98	3.88	0.967	0.708	0.529
	Manganese	1.44	7.54	3.5	1.7	3.1	6.27	4.17	4.82	6.68	147	1.4	1.5	1.3	1.8	39	10.1	8.84	5.51
	Mercury	0.044	0.055	ND	0.041 J	ND	0.0285 J	0.035	0.027	0.024	ND	0.043	ND	ND	ND	0.013 J	ND	0.006 J	0.012 J
	Methyl mercury	0.043	0.034	-	-	-	0.05	0.045	0.038	0.027	0.006 J	0.056	-	-	-	ND	ND	ND	ND
	Selenium	1.35	1.09	0.73 J	1.7	0.49 J	0.879	0.98	0.94 J	0.66 J	1.18	1.8	0.87 J	1.2	0.52 J	ND	0.0743	ND	ND
	Silver	0.01 J	0.01 J	ND	0.15 J	ND	ND	ND	ND	ND	0.031	ND	ND	ND	ND	0.141	0.0601	0.061	0.029
	Thallium	ND	ND	ND	ND	ND	0.0126	ND	ND	0.011 J	ND	ND	ND	ND	ND	0.013 J	0.0268	0.024	ND
	Vanadium	0.26	0.56	0.31 J	0.56	ND	0.312	0.35	0.35	0.66	20.3	0.92	0.36 J	0.35 J	ND	13.2	4.42	4.05	2.35
	Zinc	36.8	67.8	11.6	47.4	7.2	73	77	74.5	59.4	69.9	44.7	5.8 J	4.4 J	5.9	12.3	12.1	9.04	8.9
General																			
	Solids, Total	34.2	27.6		-	-	-	27.1	26.5	28.7	31.8	30	-	-	-	18.8	-	11.6	18.1
	Lipids, Total	9.6	2.3		-	-	-	1.7	2.3	3.2	9.1	3.9	-	-	-	0.079	-	ND	ND
	Percent Lipids	-	-	1.3	2.1	0.97	9.09	-	-	-	-	-	2.7	2.2	0.77	-	-	-	-
	Percent moisture	65.8	72.4	48.1	61.5	40	71.2	72.9	73.5	71.3	68.2	70	44.2	44.1	37.7	81.2	75.4	88.4	81.9

Notes:

The Shellfish results are based on wet weight.
The Limu and Fish results have been moisture corrected.

SMPL Primary sample
QC Quality control sample submitted to QC laboratory
J Detected below PQL but above PDL.

P The relative percent difference between the HPLC and GC columns was greater than 40% (25% for pesticides). The sample results should not be used.
ND Chemical was not detected in this sample
\- Sample not analyzed for this chemical.
All analytical results are reported as mg/kg.

population was cleared from an area during sampling, there would be little or no immigration of adults from surrounding populations. Instead, a new population, starting with new larvae, would be required to settle the cleared area before the population would have an opportunity to recover. The field team was concerned that continued collection of helmet urchins might negatively impact their population in the nearshore area and could result in the destruction of this living resource, so the team discontinued collecting this species.

Crab traps were set in the muliwai for several days, and although some crabs were collected in this manner, the field team was unable to collect crabs of sufficient size or in sufficient numbers for even a single sample to be analyzed for the complete list of analytes. The only additional species collected using passive traps were a species of freshwater goby and the Hawaiian prawn. Both the goby and the prawn were identified as indigenous, indeed endemic, to Hawaiian waters and reportedly were nonexistent in the lower reaches of many streams on O'ahu. Although these species are assumed to be present statewide and neither of these species is threatened or endangered, they reportedly are not abundant in any one location. Because of this, and because there did not seem to be sufficient numbers of these species present to collect enough tissue for a complete sample, these specimens were returned to the muliwai.

To meet the requirement for assessing shellfish in this study, the team returned to the field in 2008 to sample shellfish and invertebrates in the muliwai and nearshore regions. During the 2008 field effort, nine complete shellfish samples (seven primary and two QC samples) and two partial samples were collected in the muliwai and nearshore areas. One primary sample each of Kona crab (*Ranina ranina*) and helmet urchin were collected in Mākua nearshore waters. The QC sample consisted of helmet urchin. All three nearshore samples, two primary and one QC, consisted of helmet urchin at Sandy Beach. One primary sample of Samoan crab (*Scylla serrata*) was collected from the Mākua north muliwai. Two primary samples (significantly less than the required 200 grams) were collected from Mākua south muliwai; one sample consisted of Hawaiian prawn and the other of rock crab (*Pachygrapsus minutus*). One primary and a QC sample of Hawaiian prawn were collected at Nanakuli muliwai. The second primary sample at Nanakuli muliwai was rock crab (*Pachygrapsus minutus*). Limited diversity and the small size of the populations of the few species living in the muliwai prevented collecting a full suite of primary and QC samples from the muliwai. Those samples containing inadequate biomass for the full suite of analyses were analyzed for a combination of energetics and metals only.

3.2 SUMMARY OF POTENTIAL SOURCES OF CHEMICAL ANALYTICAL GROUPS

The purpose of this study was to evaluate whether there is potential for any contamination to be transported beyond the boundaries of MMR. The chemicals of particular concern for the Marine Resources Study were explosives compounds (RDX, nitroglycerin, 2,4-dinitrotoluene, and perchlorate) and several metals. These chemicals are associated with past and proposed training at MMR. The following additional analytical groups were included in this study after public comments were received on the SAP:

- Dioxins/furans;

- Organochlorine pesticides;
- VOCs;
- SVOCs; and
- Additional metals.

The chemicals in these analytical groups have a wide variety of potential sources and, if detected in the fish, shellfish, and limu samples, would be difficult to attribute to activities at MMR. A discussion of potential sources of each of these analytical groups is provided below.

3.2.1 Dioxins and Furans

Dioxins and furans is a general term that describes a group of hundreds of chemicals that are highly persistent in the environment. Dioxins are formed from combustion processes, such as commercial or municipal waste incineration, and from burning fuels, such as wood, coal or oil. Chlorine bleaching of pulp and paper, certain types of chemical manufacturing and other industrial processes all can create small quantities of dioxins. Uncontrolled combustion, such as burning of household waste ("burn barrels") is expected to become the largest quantified source of dioxin emissions to the environment. (USEPA 2004a). Additional sources are forest fires, and accidental fires involving transformers containing PCBs and chlorinated benzenes (USEPA Technical Fact Sheet on: Dioxin [2,3,7,8-TCDD]).

Combustion causes dioxins to be released into the air, where they can be transported long distances. As a result, dioxins are found in most places in the world (USFDA 2006). Because dioxins are widely distributed throughout the environment in low concentrations and are persistent and bioaccumulated, most people have detectable levels of dioxins in their tissues. These levels, in the low parts per trillion, have accumulated over a lifetime and will persist for years.

3.2.2 Volatile Organic Compounds

VOCs are organic chemicals that have a high vapor pressure and easily form vapors at normal temperature and pressure. The term is generally applied to organic solvents, certain paint additives, aerosol spray can propellants, fuels (such as gasoline, and kerosene), petroleum distillates, dry cleaning products and many other industrial and consumer products ranging from office supplies to building materials. VOCs are also naturally emitted by a number of plants and trees. However, releases into the environment are primarily from petroleum refining (USEPA Technical Fact Sheet on: VOCs); there are at least two petroleum refineries on O'ahu's southwestern coast.

3.2.3 Semivolatile Organic Compounds

Semivolatile organic compounds are organic chemicals that volatilize relatively slowly at standard temperature (20°C) and pressure (1 atm). The term is generally applied to organic compounds found in a wide range of products, including: insect repellants, cosmetics, rubbing alcohol, liquid soap, detergents, decorative inks, lacquers, munitions, industrial and lubricating oils, wood preserving industries, defoaming agents for paper/paperboard manufacturing, pesticide carriers, photographic film processing, as a plastic softening agent, and as a dielectric in capacitors (USEPA Technical Fact Sheets on: bis(2-ethylhexyl)

phthalate, diethyl phthalate, di-n-butylphthalate). Additionally, the polycyclic organic chemical Pyrene is the product of combustion (e.g., cigarette smoke, vehicle exhaust, home heating, laying tar, and grilling meat) (USEPA Technical Fact Sheet on: Polycyclic Organic Matter). Pentachlorophenol was once one of the most widely used biocides in the United States, but it is now a restricted use pesticide and is no longer available to the general public. The principal use for pentachlorophenol is as a wood preservative; it is also used for the formulation of fungicidal and insecticidal solutions and for incorporation into other pesticide products (USEPA Technical Fact Sheet on: Pentachlorophenol).

DEHP (bis(2-ethylhexyl) phthalate is in polyvinyl chloride (PVC) and is found in plastic products like toys, vinyl upholstery, shower curtains, adhesives, and coatings. It is used in some food packaging and medical product containers (including those for blood) and equipment. It is also used in some inks, pesticides, and cosmetics and in vacuum pump oil. Point sources are primarily from emissions or spills from sites that use DEHP in their manufacturing processes. Its wide use, volatility, and persistence mean that DEHP is widely distributed in the environment (NPI 2005).

3.2.4 Organochlorine Pesticides

Organochlorine pesticides were widely and commonly used in the past to protect crops, livestock, buildings and households from the damaging effects of insects. Commonly used organochlorine pesticides were DDT, lindane (gamma BHC), chlordane, dieldrin, aldrin, heptachlor, and pentachlorophenol. These pesticides were used because of their toxicity to pests and persistence in the environment, but these same characteristics led to detrimental effects on human and environmental health and the removal of many organochlorine pesticides from the market.

USEPA has classified chlordane, aldrin, dieldrin, and DDT as Level 1 persistent, bioaccumulative, and toxic (PBT) chemicals. The pesticide uses of all Level 1 PBTs were prohibited by the EPA during the 1970s and 1980s. Most of the pesticide uses of dieldrin were prohibited in 1974, although use for control of subterranean termites was allowed to continue. Most remaining dieldrin products were banned by 1987; the last product was banned in 1989. All surface uses of chlordane were discontinued in 1983, and all other uses were banned by 1988. Technically, chlordane is a mixture of up to approximately 150 compounds, including heptachlor epoxide.

On O‘ahu, organochlorine pesticides such as aldrin, chlordane, and heptachlor were widely used for termite control and for agriculture. For example, approximately 9,000 pounds of aldrin and 150,000 pounds of chlordane and heptachlor were used in Hawai‘i for pest control in 1977 (Pesticide Hazard Assessment Project. 1982). Organochlorine pesticides are typically transported from agricultural and urban areas by soil erosion, surface runoff, and groundwater transport, where they may accumulate in stream bed sediments and in fish tissue. A National Water Quality Assessment study performed by the USGS on O‘ahu between 1992 and 1994 found that the distribution of organochlorine pesticides was associated with land-use practices, with higher concentrations of chlordane and dieldrin detected in samples from urban streams, and the highest concentrations of DDT detected at an agricultural site.

3.2.5 Explosives

RDX has both military and civilian applications. As a military explosive, RDX can be used alone as a base charge for detonators, or it can be mixed with another explosive, such as TNT, to form cyclotols, which produce a bursting charge for aerial bombs, mines, and torpedoes. Common military uses of RDX have been as an ingredient in plastic bonded explosives or plastic explosives, which have been used as explosive fill in almost all types of munition compounds. Civilian applications of RDX include fireworks, in demolition blocks, as a heating fuel for food, and as an occasional rodenticide. Combinations of RDX and HMX, another explosive, have been the chief ingredients in approximately 75 products (GSO 2006).

Perchlorate occurs both naturally (Table 3-2) and as a manufactured compound. Most naturally occurring sources of perchlorate appear to be geographically limited to arid environments. These deposits tend to be of low concentration. In contrast, anthropogenic perchlorate sources can be many times more concentrated than most natural sources. Research is being conducted to develop methods for differentiating between naturally occurring and anthropogenic perchlorate in the environment (Trumpolt et al. 2005).

A current theory regarding the origin of naturally occurring perchlorate in the environment centers on natural atmospheric processes. While the exact mechanism for creating perchlorate is unknown, the theory suggests that chloride, possibly in the form of sodium chloride from the sea or land-based chloride compounds blown in from the atmosphere, reacts with atmospheric ozone. In the atmosphere, photochemical reactions between chloride and ozone create perchlorate. In arid environments, where the rate of deposition exceeds the rate of dissolution by precipitation, perchlorate can be incorporated into certain geologic formations (Trumpolt et al. 2005; Orris 2004).

Seaweed is another potentially naturally occurring source of perchlorate (Trumpolt et al. 2005). Perchlorate has been detected in seaweed at a concentration of 885 ppm in a sample of kelp collected and analyzed by the USGS (Orris et al. 2003).

Before World War II, the most prevalent applications of perchlorate were in fireworks and railroad signal flares. Because it is an exceptional oxidizer with additional useful properties, perchlorate is widely used today by industry, the Department of Defense (DOD), and the National Aeronautics and Space Administration (NASA), and it is used in a few specific medicinal applications. One chemical manufacturer lists 80 perchlorate chemicals in its product line. Efforts are underway to replace perchlorate in at least some munitions. For example, the Army has a preliminary perchlorate replacement program focused on two specific munitions that constitute a large percentage of perchlorate usage (Trumpolt et al. 2005).

3.2.6 Metals

Nineteen different metals were included in the analytical suite for the Marine Resources Study. All metals analyzed in this study are naturally occurring in the environment and are commonly found in plant and animal tissues as a result of natural metabolic processes.

Table 3-2
Perchlorate in Natural Minerals and Materials (from Trumpolt et al. 2005)

Sample Type	Number of Locations	Number of Samples	Percent with Perchlorate	Number with Assoc. Nitrate
Playas	28	57	86[a] (96)	> 11[++]
Soils	7	15	—	—
Soil-caliche	4	10	100	All
Soil-nitrate	—	—	—	All
Older lakebeds	3	3	100[b]	2
Nitrate deposits	3	5	100	All
Evaporites	19	26	27[a]	Unknown
Nonhalite	9	16	44[a]	Unknown[d]
Halite	10	10	0	NA
Related H_2O	2	3	100	Unknown

[a] High detection limit for some samples.

[b] All values < 2 ppb.

[c] Samples other than "pure" halite, commonly mixed salts.

[d] Early samples not tested for nitrate.

Source: Orris (2004).

Indeed, some of these metals are considered essential nutrients for human health. The presence of naturally occurring metals in the environment makes it difficult to ascertain whether these metals could have been transported beyond the boundaries of MMR. Potential anthropogenic sources of selected trace metals are provided in Table 3-3. The primary inputs of trace metals, above baseline levels in O‘ahu, include volcanic emissions, vehicle emissions, vehicle-associated wear, and agricultural fertilizer and pesticide inputs (Sutherland 2000).

Arsenic is a natural component of the earth’s crust and is found in all environmental media. Concentrations of arsenic in open ocean water are typically 1 to 2 micrograms per liter (μg/liter). Concentrations in various types of igneous rock range from less than 1 to 15 milligrams per kilogram (mg/kg). Concentrations in freshwater surface and groundwater are typically in the range of 1 to 10 μg/liter. Marine organisms naturally accumulate considerable quantities of organic arsenic compounds. Volcanic action is the second most important natural source of arsenic. Anthropogenic sources of arsenic include smelting nonferrous metals, producing energy from fossil fuels, and manufacturing and using arsenic pesticides and wood preservatives (WHO 2001).

Cadmium is a naturally occurring element in the crust of the earth and is found in various ores: lead and copper containing zinc, some iron ores, and in sulfide ore. These can result in emissions of cadmium to water. Also, volcanic emissions contain cadmium-enriched particles. Cadmium is obtained as a by-product from the treatment of zinc, copper, lead, and iron ores, so facilities that treat these ores may emit cadmium compounds to the environment, mainly water. Coal- and oil-burning power plants may emit cadmium compounds to the air. Small industrial and domestic use of cadmium products emit low levels of cadmium to the environment. Tobacco smoke is an indoor source of cadmium. Coal and other fossil fuels contain cadmium, and their combustion releases the element into the atmosphere. The combustion of motor fuels in cars, trucks, and planes results in cadmium emission to air, and particles from tire wear emit cadmium to the air, land, and water. Cadmium has many domestic uses, such as in tobacco products, phosphate fertilizers, polyvinyl chloride products, photocells, gasoline, oils, tires, automobile radiators, some textile dyes and colors, electronic components, heating elements in electric kettles and hot water systems, batteries, and ceramic glazes (WHO 2005).

Cobalt is mainly emitted to the air, land, or water from sources where it is used in the production of steel and other alloys.. Automotive repair shops may be significant emitters of cobalt to the air. It is also emitted to air, land, and water during the mining or refining of nickel, copper, silver, lead, and iron. Cobalt may be emitted to the air, land, or water from the manufacture, use, or disposal of paints and varnishes. It may also be emitted to the air, land, or water from the manufacture, use, or disposal of ceramics, inks, and enamels. Small amounts of cobalt have been found in motor vehicle exhaust. Consumer products containing cobalt and its compounds include vitamin B-12, animal feeds, fertilizers, paints, varnishes, enamels, and ceramics. It is in metals that are used at high temperatures, for example, some car parts. Natural sources of cobalt include soil, dust, seawater, volcanic emissions, and smoke from forest and brush fires (WHO 2006).

Table 3-3
Potential Anthropogenic Sources of Selected Trace Elements in the Environment

Trace element	Potential anthropogenic sources
Barium	Rubber production, lubricating oil additives, fuel synthesis, fuel combustion, phosphate fertilizers, sewage sludges
Cadmium	Lubricating oils, diesel oils, tires, phosphate fertilizers, sewage sludge, insecticides, electroplating, pigments, batteries, coal and oil combustion, non-ferrous metal production, refuse incineration, iron and steel manufacturing
Copper	Metal plating, bearing and brushing wear, fungicides and insecticides, anti-foulants, corrosion of copper plumbing, algaecides, concrete and asphalt, rubber, phosphate fertilizers, sewage sludges
Mercury	Insecticides, fungicides, electrical equipment, paint, plastics, cosmetics, anti-fouling and mildew-proofing paints, phosphate fertilizers, batteries, and fireworks
Nickel	Diesel fuel and vehicle exhaust, lubricating oil, metal plating, brushing wear, brake lining wear, asphalt paving, phosphate fertilizers, storage batteries
Lead	Leaded gasoline, automobile exhaust, tire wear, lubricating oil and grease, bearing wear, brake lining, rubber, concrete, paint manufacturing, battery manufacturing, insecticides, phosphate fertilizers, sewage sludges
Zinc	Vulcanization of rubber and tire wear, motor oil, grease, batteries, galvanizing, plating, air-conditioning ducts, pesticides, phosphate fertilizers, sewage sludges, transmission fluid, under coating, brake linings, asphalt, concrete, coal combustion, smelting operations, incineration and wood combustion

Manganese is a naturally occurring element that is found in rock, soil, and water. It is ubiquitous in the environmental and makes up 0.1 percent of the earth's crust. Crustal rock is the major source of manganese in the atmosphere. Ocean spray, forest fires, vegetation, and volcanic activity are other major natural atmospheric sources of manganese. Important sources of dissolved manganese are anaerobic environments where particulate manganese oxides are reduced, the direct reduction of particulate manganese oxides in aerobic environments, the natural weathering of manganese-containing minerals, and acidic environments. Most manganese in soils originates from crustal sources; other sources include direct atmospheric deposition, wash-off from plants and other surfaces, leaching from plant tissues, and the shedding or excretion of material such as leaves, dead plant and animal material, and animal excrement. The major anthropogenic sources of environmental manganese are municipal wastewater, sewage sludge, mining and mineral processing, emissions from alloy, steel, and iron production, combustion of fossil fuels, and, to a much lesser extent, emissions from the combustion of fuel additives (WHO 2004).

The data presented in the 2005 draft EIS for Military Training Activities at Mākua Military Reservation, Hawai'i (Tetra Tech, 2005) indicated that most of the metals detected in soils at MMR are present at concentrations that are within the background range for soils in Hawai'i (Tetra Tech, 2005). Some of these metals, such as aluminum, chromium, cobalt, iron and manganese, occur in the rock of the Waianae Mountain Range, and subsequent weathering of the mountains cause these metals to be present in relatively high concentrations in the soil on O'ahu. Exceptions to this are arsenic, lead and selenium, which were present in soils at concentrations in excess of expected background concentrations. Past and proposed munitions used by the US military contain arsenic, cadmium, cobalt, and manganese in varying concentrations.

3.3 ANALYTICAL RESULTS

3.3.1 Dioxins/Furans

Samples were analyzed for seventeen individual dioxin and furan congeners and eight total congener groups. Thirteen of these were not detected in any of the fish samples. Concentrations of the remaining twelve ranged between $1.29 \times 10^{--7}$ to 8.7×10^{-6} mg/kg. The US Environmental Protection Agency reports background levels as values in the low parts per trillion (1 part per trillion is equivalent to 1×10^{-6} mg/kg, which are the units used in this report.) These data indicate the following:

- Dioxins/furans were detected more frequently in fish samples collected from the muliwai than the nearshore locations.
- Dioxins/furans were detected at a greater frequency in fish at the background site (seven out of nine samples) than at Mākua (ten out of seventeen samples). Dioxins/furans were detected in all three fish samples in the background muliwai and 11 of 12 fish samples collected from the Mākua muliwai. Dioxins/furans were detected in four of six fish samples collected from the nearshore waters of the background site and were not detected in any of the five fish samples collected from the nearshore waters of Mākua.

- HpCDD, a dioxin/furan congener, was found most frequently in fish samples with detections in 12 of the 15 muliwai samples and 4 of 11 nearshore samples.

Primary shellfish samples were analyzed for nineteen congeners/congener groups. Ten of the 19 congeners/congener groups were detected in shellfish samples. Six additional total congener groups were included in the QC sample analysis and two of those six were detected. Concentrations ranged from 1.9×10^{-7} to 2.9×10^{-4} mg/kg. OCDD was the most frequently detected compound in shellfish and was found in 5 of the 9 shellfish samples that were analyzed for dioxins/furans. (This analysis was not conducted for three shellfish samples because there was insufficient biomass.) Dioxins and furans were detected in 3 of 4 samples at Mākua and 4 of 5 samples at background sites. At Mākua these compounds were more frequently detected in the shellfish samples from the muliwai than from the nearshore.

Nine of the 25 congeners/congener groups were detected in the limu samples, at concentrations ranging from between 5.7×10^{-8} and 1.65×10^{-5} mg/kg. Similar to the fish samples, HpCDD was the dioxin detected most frequently and was detected in three of the four limu samples.

3.3.2 Volatile Organic Compounds

Eight analytes were included in the VOC analysis, and only two of these, acetone and m,p-xylene, were detected in any of the fish samples collected from the muliwai and nearshore sample locations. There is no obvious detection pattern for either of these analytes, with at least one sample from all five locations having an acetone detection and only samples from the south muliwai, Mākua nearshore, and Sandy Beach nearshore locations having an m,p-xylene detection. The acetone detections ranged from 0.23 to 0.73 mg/kg, while the m,p-xylene detections ranged from 0.016 to 0.02 mg/kg. Acetone is a common lab contaminant.

VOCs were detected in only one of the limu samples and two shellfish QC samples, with concentrations of 0.016 mg/kg m,p-xylene, 0.0011 mg/kg toluene, and 0.00089 mg/kg toluene. Toluene was not detected in the corresponding primary samples analyzed by APPL.

3.3.3 Semivolatile Organic Compounds

Seven analytes were included in the SVOC analysis, and only three of these, bis(2-ethylhexyl)phthalate, diethyl phthalate, and di-n-butylphthalate, were detected in any of the fish samples collected from the muliwai and nearshore sample locations.

Di-n-butylphthalate was detected in all of the fish samples. The 22 primary samples analyzed by Columbia Analytical Services had concentrations ranging from 0.0098 to 0.053 mg/kg. The four quality control samples analyzed by APPL had di-n-butylphthalate concentrations, ranging between 0.61 and 1.5 mg/kg. Bis(2-ethylhexyl)phthalate was detected in four of the five samples collected from the Mākua nearshore area, with concentrations ranging between 0.055 and 3.5 mg/kg, and was only detected at a concentration of 3.1 mg/kg in a sample collected from the south muliwai. Diethyl phthalate was detected, at a concentration of 0.19 mg/kg, in only the sample collected from the Sandy Beach nearshore area. There is no obvious explanation for this pattern of detections of SVOCs in the fish samples.

The SVOC compounds analyzed as part of this study were not detected in any of the shellfish samples. Bis(2-ethylhexyl)phthalate and di-n-butylphthalate were the only SVOCs detected in the limu samples. Similar to the fish samples, di-n-butylphthalate was detected in all of the limu samples, with the primary sample concentrations ranging from 0.02 to 0.024 mg/kg. The quality control sample analyzed by APPL had a concentration of 0.48 mg/kg.

3.3.4 Organochlorine Pesticides

All fish and limu samples and eight of the ten shellfish samples were analyzed for eight organochlorine pesticides. Insufficient biomass was collected for organochlorine pesticide analysis for three shellfish samples. A comparison of the analytical results presented in Table 3-1 indicates that organochlorine pesticide concentrations were similar among the samples collected from Mākua and the background sampling locations. Table 3-4 presents the average, maximum, and minimum concentrations of each organochlorine pesticide in fish collected from each of the five sampling locations. These data indicate that aldrin and heptachlor were generally detected in samples from the nearshore areas, but not in the muliwai, and that heptachlor epoxide was detected at higher concentrations in samples from the nearshore locations than in samples from the muliwai locations. Analysis of samples from all locations detected 4,4'-DDT.

Organochlorine pesticides analytes were not detected in shellfish samples, except for one aldrin detection in a shellfish sample collected in the nearshore area of Mākua. Aldrin, BHC-beta, heptachlor, and heptachlor epoxide were detected in the limu collected in the nearshore area of Mākua.

Organochlorine pesticides were used historically throughout O'ahu and the other main Hawaiian islands for termite control and in agriculture. These compounds can be transported by air and water, so their presence in fish, shellfish, and limu cannot be definitively attributed to activities at MMR.

3.3.5 Explosives

Four analytes were included in the explosives analysis, 2,4-dinitrotoluene, nitroglycerin, perchlorate, and cyclotrimethylenetrinitramine (RDX). The BCFs for RDX calculated for catfish and fathead minnow ranged between 0.5 and 2.1 ml/g (Belden et al. 2005; Lotufo and Lydy 2005). By contrast, bioconcentration factors for some dioxins are as high as 2,000 to 3,000 ml/g, and for organochlorine pesticides such as heptachlor, as high as 10,000 ml/g (USEPA 1999). Because the BCF for RDX is so low, a relatively high concentration of RDX would need to be present in the water to account for the RDX detection in the fish tissue. Given the amount of water circulation in the ocean, it is unlikely that the ocean water in the Mākua nearshore area would contain RDX at a sufficient concentration to result in the observed detection of RDX in the fish tissue sample. Indeed, US Department of Health and Human Services (1995) stated that "RDX does not build up in fish or in people."

Nitroglycerin and RDX, potentially originating from both military and civilian uses such as fireworks or rodenticides, were detected in fewer than 8% of the samples. RDX was detected in one sample, NW1fd, at a concentration of 0.057 mg/kg. This result was flagged by the

Table 3-4
Summary Statistics for Metals and Organochlorine Pesticides in Fish

	Average Concentration Muliwai			Average Conc. Near-shore		Maximum Concentration Muliwai			Max. Conc. Near-shore		Minimum Concentration Muliwai			Min. Conc. Near-shore	
Chemicals	**North**	**South**	**Nanakuli**	**Makua**	**Sandy Beach**	**North**	**South**	**Nanakuli**	**Makua**	**Sandy Beach**	**North**	**South**	**Nanakuli**	**Makua**	**Sandy Beach**
Organochlorine pesticides															
Aldrin	ND	ND	ND	0.0027	0.0064	ND	ND	ND	0.0027	0.0064	ND	ND	ND	0.0027	0.0064
BHC, alpha	ND	ND	ND	0.0082	ND	ND	ND	ND	0.0082	ND	ND	ND	ND	0.0082	ND
BHC, beta	ND	0.0025	ND	ND	ND	ND	0.0041	ND	ND	ND	ND	0.0008	ND	ND	ND
BHC, delta	0.0003	ND	ND	0.0003	ND	0.0003	ND	ND	0.0003	ND	0.0003	ND	ND	0.0003	ND
BHC, gamma	0.0011	0.0017	ND	0.0063	0.0019	0.0013	0.0017	ND	0.0063	0.0019	0.0009	0.0016	ND	0.0063	0.0019
4,4'-DDT	0.0006	0.0017	0.0014	0.0002	0.0020	0.0007	0.0029	0.0014	0.0002	0.0021	0.0005	0.0007	0.0013	0.0002	0.0019
Heptachlor	ND	ND	ND	0.0056	0.0051	ND	ND	ND	0.0056	0.0057	ND	ND	ND	0.0056	0.0045
Heptachlor epoxide	0.0005	0.0008	0.0010	0.0086	0.0045	0.0005	0.0009	0.0011	0.0140	0.0076	0.0005	0.0006	0.0010	0.0032	0.0028
Metals															
Aluminum	2415.66	1871.14	4466.67	30.64	796.00	4240.00	2880.00	5170.00	65.00	4720.00	48.30	1150.00	3810.00	6.80	3.80
Antimony	0.04	0.05	ND	ND	0.03	0.04	0.05	ND	ND	0.03	0.04	0.05	ND	0.00	0.03
Arsenic	2.93	5.78	2.54	23.01	18.67	3.81	29.80	2.57	37.30	53.00	2.25	1.46	2.51	4.06	4.52
Barium	20.79	16.64	40.80	6.98	5.65	26.10	21.20	43.60	31.60	14.20	5.53	12.50	39.10	0.46	0.96
Beryllium	0.04	0.02	0.08	ND	0.07	0.05	0.03	0.09	0.07	0.07	0.03	0.01	0.08	0.00	0.07
Cadmium	0.05	0.05	0.12	0.15	0.11	0.08	0.15	0.13	0.21	0.20	0.02	0.02	0.11	0.12	0.04
Chromium	9.24	15.97	22.23	5.67	7.28	14.70	31.50	24.70	10.40	31.70	0.90	8.40	19.70	0.80	0.70
Cobalt	2.61	2.27	4.90	0.23	0.83	4.17	2.58	5.25	0.41	4.31	0.40	1.94	4.59	0.11	0.11
Copper	62.12	43.72	71.60	4.21	4.78	166.00	109.00	79.90	9.78	16.50	6.39	9.56	64.90	2.20	1.86
Iron	2612.40	2775.43	5996.67	163.00	1229.52	4530.00	3460.00	7010.00	302.00	6960.00	122.00	1900.00	5410.00	62.50	68.40
Lead	2.64	1.71	2.06	0.70	1.44	5.39	2.61	2.15	2.01	2.75	1.25	0.97	2.01	0.08	0.46
Manganese	244.78	135.41	571.67	7.68	28.39	386.00	184.00	611.00	15.70	147.00	11.90	94.90	501.00	1.44	1.40
Mercury	0.04	0.07	0.04	0.06	0.03	0.07	0.10	0.05	0.10	0.04	0.02	0.03	0.04	0.04	0.02
Methyl mercury	0.03	0.07	0.04	0.08	0.04	0.07	0.17	0.05	0.20	0.06	0.01	0.04	0.03	0.03	0.01
Selenium	2.38	2.52	2.38	1.20	1.07	3.71	3.59	2.57	1.60	1.80	1.83	1.61	2.19	0.79	0.66
Silver	0.40	0.34	0.61	0.01	0.03	1.13	0.82	0.70	0.01	0.03	0.01	0.05	0.53	0.01	0.03
Thallium	ND	0.00	ND	ND	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01
Vanadium	12.81	11.33	20.97	0.61	3.82	19.30	18.20	23.60	1.24	20.30	1.24	7.76	19.60	0.11	0.31
Zinc	113.96	114.19	111.67	74.54	66.42	129.00	201.00	116.00	149.00	77.00	98.80	85.20	108.00	36.80	44.70

Note: All analytical results are reported as mg/kg.

laboratory (STL) as an estimated (J) value, because it was below the lab reporting limit of 0.25 mg/kg. This sample is a field duplicate for sample NW4, which was analyzed by APPL. RDX was not detected in NW4 at a reporting limit of 0.6 mg/kg. Of all the fish sampled, only one came up positive for RDX. It should be noted that the other Goatfish sample came up non-detect for RDX, as did all samples from other trophic levels at Makua. The detection of RDX may be a false positive, and this is supported by the BCF data cited above, which would require a relatively high concentration of RDX in the ocean water to result in the concentration of RDX detected in the fish tissue sample. Nitroglycerin was detected in two muliwai fish samples. The nitroglycerin results were considered invalid, because QA/QC issues precluded quantification of this analyte (see Appendix C).

Perchlorate was the explosive compound detected most frequently, in 11 of the 26 fish samples, at concentrations of between 0.0012 and 0.16 mg/kg and in one shellfish sample. RDX was detected in only one of the limu samples, and perchlorate was detected in two of the four limu samples. Perchlorates are used in fireworks, as well as in the munitions used at MMR. Their presence in fish tissue in both background and Mākua area locations suggests that there are likely multiple sources of perchlorate in these areas.

3.3.6 Metals

Samples were analyzed by a variety of USEPA methods for 19 metals. The full list of analytes and analytical methods is provided in Table 2-2. A comparison of the analytical results presented in Table 3-1 indicates that metals concentrations were similar among the fish samples collected from the Mākua muliwai and the background muliwai. Furthermore, the metals concentrations were similar among the fish samples collected from nearshore areas of both Mākua and the background location. Metals concentrations in fish tended to be higher in samples from the muliwai compared to the nearshore samples, although arsenic concentrations were higher in the nearshore samples than in the muliwai samples. Table 3-4 presents the average, maximum, and minimum concentrations of each metal in fish collected from each of the five sampling locations.

Shellfish metals concentrations in samples collected at Mākua were similar to those found at the background, with a few exceptions (Table 3-5). Greater concentrations of aluminum, barium, iron, and manganese were found in shellfish samples from the Mākua muliwai, while zinc concentrations were higher in samples from the background. Metals concentrations in shellfish tended to be higher in samples from the muliwai than in the nearshore area. Metals were more also more frequently detected in samples collected from the muliwai than in those samples collected from the nearshore. Arsenic, cadmium, and mercury were more frequently detected at Mākua than at background sites. The differences in metals concentrations between the muliwai and nearshore and between Mākua and the background sites may be a function of the different species collected at each site rather than a function of location.

Twelve of 19 metals were detected in all limu samples, at concentrations ranging from less than 0.1 mg/kg (thallium) to greater than 1,860 mg/kg (iron). Flegal et al. (1986) found concentrations of thallium in marine plankton similar to those found at Mākua (0.02 to 0.8 mg/kg) in the central Pacific. In the Black Sea of Turkey, Tuzen et al. (2008) found

Table 3-5
Summary Statistics for Metals in Shellfish

	Average Concentration				
Chemical	**All**	**Nearshore**	**Muliwai**	**Makua**	**Background**
Metals					
Aluminum	63.60	59.40	72.00	76.12	47.95
Antimony	ND	ND	ND	ND	ND
Arsenic	5.05	6.09	3.30	6.81	2.10
Barium	11.98	1.53	32.87	17.78	4.73
Beryllium	0.06	0.06	ND	ND	0.06
Cadmium	2.00	2.00	ND	2.00	ND
Chromium	1.14	1.14	1.15	1.17	1.11
Cobalt	0.32	0.27	0.42	0.36	0.26
Copper	17.84	5.65	42.23	18.18	17.43
Iron	99.57	82.92	132.87	116.26	78.70
Lead	0.46	0.52	0.16	0.21	0.71
Manganese	26.40	2.15	74.90	40.12	9.25
Mercury	0.03	0.04	0.02	0.03	ND
Methyl mercury	ND	ND	ND	ND	ND
Selenium	1.01	0.92	1.19	0.96	1.07
Silver	0.20	0.15	0.24	0.15	0.24
Thallium	ND	ND	ND	ND	ND
Vanadium	0.43	0.40	0.48	0.50	0.34
Zinc	69.66	13.72	181.53	25.16	125.28

Note: All analytical results are reported as mg/kg.

concentrations of iron ranging from 99 to 3,949 in marine algae, similar to those concentrations found at Mākua (67.4 to 1,860 mg/kg). Arsenic was detected in limu in concentrations ranging from 4.56 to 109 mg/kg. These concentrations are comparable to concentrations found in marine algae in pristine regions of Antarctica, ranging from 5.8 to 152 mg/kg (Farias et al. 2007).

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SECTION 4
HUMAN HEALTH RISK ASSESSMENT

This section is an evaluation of the potential risks to humans who may be exposed to environmental contaminants at Mākua Beach and the Mākua muliwai and compares those risks to risks determined for background locations on Oʻahu. The difference between the risks calculated for the Mākua sites and the background locations is called the incremental risk. Potential human exposures to contaminants in fish, shellfish, and limu are evaluated below.

The risk assessment consists of six major components:

- Selection of chemicals of potential concern (COPCs);
- Identification of human receptors;
- Assessment of potential chemical exposures;
- Assessment of chemical toxicity;
- Characterization of risk; and
- Analysis of sources of uncertainty in the predicted risk estimates.

The risk assessment is consistent with guidance developed by the USEPA in the *Risk Assessment Guidance for Superfund* (USEPA 1989, 1990, 1991a, 1992a, 1996, 1997a, 2002a) and the Hawaiʻi Department of Health (HDOH) Screening for Environmental Concerns at Sites with Contaminated Soil and Groundwater (HDOH 2006a).

4.1 SELECTION OF CHEMICALS OF POTENTIAL HUMAN HEALTH CONCERN

COPCs are those chemicals detected in environmental media at the Mākua Beach and muliwai for which human contact may result in adverse health effects. The four environmental media sampled at the Mākua Beach and muliwai were fish tissue, shellfish, and limu. Tissue sample analyses were discussed in Section 2, and tissue sample analytical results were discussed in Section 3:

All chemical data collected for each environmental medium were reviewed during the selection of COPCs. Although EPA guidelines recommend that only chemicals exceeding background concentrations should be considered COPCs, all detected chemicals were identified as COPCs as a conservative measure in this case (see Table ES-1 for justification).

4.1.1 Data Review

All of the analytical results from the tissue samples collected during 2006 and 2008 (see Sections 2 and 3) were reviewed and evaluated in the selection of COPCs. Soil, sediment, groundwater, and surface water data collected from 2002 to 2004 from the Mākua Valley were not used in this risk assessment. These data were collected upstream of the muliwai and represent locations that could serve as sources of contaminants to the muliwai and Mākua Beach. Additionally, sediment samples collected in 2003 (Tetra Tech 2005) were not evaluated in this risk assessment.

Sample locations used in the risk assessment are shown in Figures 2-1 and 2-2. Descriptions of the analytical methods used for tissue samples are provided in Tetra Tech (2005).

Data validation efforts classified the data through the use of several qualifiers. Data without qualifiers were considered appropriate for risk assessment purposes. Following USEPA guidance (1989), data with J qualifiers (i.e., estimated values) were used for risk assessment purposes. U and UJ qualified data were considered to be nondetected but usable for risk assessment purposes. B and BJ qualified data were treated as nondetected chemicals because the estimated chemical concentrations were not significantly higher than levels in quality assurance/quality control (QA/QC) blanks associated with the samples. R qualified data (rejected data) were excluded from the risk assessment. P qualifiers indicate pesticide target compounds with greater than 25 percent difference for detected concentrations between the two columns of the gas chromatography system. In the case of 8330 explosives, the P qualifier indicates that there was a greater than 40 percent difference for detected concentrations between the two columns of the high performance liquid chromatography HPLC system.

Areas of Concern

The muliwai that were sampled for fish and shellfish include the north and south muliwai at the base of the Mākua Valley (see Figure 2-1) and the muliwai at Nanakuli (see Figure 2-1). As both of the muliwai in the Mākua Valley are fed by streams that run through the MMR, both of these muliwai could be impacted should MMR be identified as a potential source of contaminants. Therefore, for the purposes of this risk assessment, both of the muliwai in the Mākua Valley were considered as a single area of concern and were evaluated together. The Nanakuli muliwai was considered to be a background location for the muliwai in the Mākua Valley. Background samples will be used to determine if exposures at the Mākua muliwai are higher than background conditions.

Fish and shellfish were also collected nearshore at Mākua Beach and the background location, and limu was collected from nearshore at Mākua Beach (see Figure 2-1). The nearshore samples from Mākua Beach could show impacts from the releases to the streams in the Mākua Valley. The samples from the background are assumed to be representative of

nearshore background conditions. Background samples were used to determine if exposures in the nearshore waters of Mākua Beach, which are higher than background conditions. (The nearshore waters of Mākua Beach are hereafter referred to simply as Mākua Beach.)

Evaluation of Tissue Samples

Tissue samples consisted of fish, shellfish, and limu, each of which is described below.

Fish were collected from the two muliwai at the MMR (see Figure 2-1) and were composited into twelve samples. The species collected included striped mullet, tilapia, Hawaiian flagtail, and medaka; each composite sample except one consisted of multiple individuals but only one type of fish. Three composite fish samples were collected from the background muliwai at Nanakuli (see Figure 2-1). All of the fish samples collected at Nanakuli were tilapia.

Six composite fish samples were collected from the Mākua Beach (see Figure 2-1), consisting of goatfish (i.e., sidespot and manybar), Picasso triggerfish, blackspot triggerfish, and Christmas wrasse. These same fish species were collected in six samples at the nearshore background location (i.e., Sandy Beach; see Figure 2-1), with the addition of saddle wrasse. The fish tissue sample data were collected in 2006.

Shellfish were collected from the two muliwai at the MMR and were composited into three samples. The species collected included Samoan crab, rock crab, and Hawaiian prawn, although each composite sample consisted of only one type of shellfish. Three composite shellfish samples were collected from the background muliwai at Nanakuli, rock crab and Hawaiian prawn.

Two composite shellfish samples were collected from at Mākua Beach, helmet urchin and Kona crab. Helmet urchin was the only species collected (two composite samples) at Sandy Beach, the nearshore background location.

Four limu samples were collected from the nearshore waters at Mākua and are listed by location in Section 3.

4.1.2 Chemicals of Potential Concern in the Mākua Valley Muliwai

The COPCs for fish from the Mākua muliwai included 19 metals, 5 organochlorine pesticides, 2 VOCs, 2 SVOCs, 1 explosive, as well as dioxins/furans. No limu was collected from the muliwai. The COPCs for shellfish from the Mākua muliwai included 13 metals, as well as dioxins/furans. The COPCs for fish, limu, and shellfish are listed in Table 4-1.

4.1.3 Chemicals of Potential Concern at Mākua Beach

The COPCs for fish from Mākua Beach included 16 metals, 7 organochlorine pesticides, 2 VOCs, 2 SVOCs, and 3 explosives. Dioxins/furans were not detected in the fish samples collected from Mākua Beach. .

The COPCs for limu from Mākua Beach included 17 metals, one organochlorine pesticide, one VOC, 2 SVOCs, one explosive, and dioxins/furans.

Table 4-1
Tissue COPCs

	North and South Muliwai		Near Shore at Makua		
	Fish Tissue	**Shellfish Tissue**	**Fish Tissue**	**Shellfish Tissue**	**Seaweed Tissue**
Metals					
Aluminum	X	X	X	X	X
Antimony	X				X
Arsenic	X	X	X	X	X
Barium	X	X	X	X	X
Beryllium	X				X
Cadmium	X		X	X	X
Chromium	X	X	X	X	X
Cobalt	X	X	X	X	X
Copper	X	X	X	X	X
Iron	X	X	X	X	X
Lead	X	X	X	X	X
Manganese	X	X	X	X	X
Mercury	X	X	X	X	
Methyl Mercury	X		X		
Selenium	X	X	X	X	X
Silver	X		X	X	X
Thallium	X				X
Vanadium	X	X	X	X	X
Zinc	X	X	X	X	X
Organochlorine pesticides					
4,4'-DDT	X		X		
Aldrin			X	X	
BHC, alpha			X		
BHC, beta	X				
BHC, delta	X		X		
BHC, gamma	X		X		
Heptachlor			X		X
Heptachlor epoxide	X		X		
Volatiles					
Acetone	X		X		
m,p-Xylenes	X		X		X
Toluene				X	
Semi-Volatiles					
Bis(2-ethylhexyl)phthalate	X		X		X
Di-n-butylphthalate	X		X		X
Explosives					
Nitroglycerin	X		X		
Perchlorate	X		X	X	X
RDX			X		
Dioxins/furans					
1,2,3,4,6,7,8-HpCDD	X				
1,2,3,4,6,7,8-HpCDF	X				X
1,2,3,4,7,8-hxcdf					X
1,2,3,6,7,8-hxcdd					X
1,2,3,6,7,8-hxcdf		X			X
1,2,3,7,8,9-hxcdd		X			X
1,2,3,7,8-PeCDD	X				
2,3,7,8-TCDF	X	X			
HpCDD,total	X				X
HpCDF,total	X				X
HxCDD,total	X				X
HxCDF,total	X				X
OCDD	X	X		X	
OCDF	X				X
PeCDD,total	X				
TCDD,Total		X		X	
TCDF,Total	X	X		X	

The COPCs for shellfish from Mākua Beach included 15 metals, one organochlorine pesticide, one VOC, one explosive, and dioxins/furans. The COPCs for fish, limu, and shellfish are listed in Table 4-1.

4.1.4 Determination of Exposure Point Concentrations

In order to have enough fish and shellfish mass to analyze the samples for the full analytical suite, the samples were composited, as described in Section 2. The use of composite samples to assess exposures is consistent with USEPA (2000a) and HDOH (2006) guidance. Composite samples are used to determine the mean concentration in the environmental medium sampled (USEPA 2000b). As is consistent with this aim, the mean concentrations in fish and limu samples were used as the exposure point concentrations. In the calculation of the mean of several fish or limu composites, nondetects were replaced with one-half of the method detection limit (USEPA 1992b). For the locations where more than one fish species was sampled, the samples that were collected were representative of what a typical fisherman would catch and, therefore, the unweighted means were used as the exposure point concentrations. To provide additional perspective on the risk estimates, the maximum detected concentrations in fish and limu were also used to assess exposures and risks. The EPCs for fish and limu are listed in Table 4-2. For shellfish, risk estimates were determined by use of the maximum concentration (Table 4-3) because the shellfish mass collected in several locations was generally sufficient only to analyze for limited sets of analytes. Also, generally insufficient samples were collected to estimate mean concentrations.

Field duplicates for fish were collected as part of the QA/QC process. Since the field duplicates represent different individual fish, the analytical results of the field duplicates were treated as unique samples in the calculation of exposure point concentrations.

4.2 IDENTIFICATION OF HUMAN RECEPTORS

Human receptors potentially at risk from chemicals at Mākua Beach and the Mākua muliwai were identified by characterizing population groups in the area. The potential human receptors are discussed below.

Soldiers training at MMR are stationed at Schofield Barracks Military Reservation (SBMR) and are transported to MMR by ground or air. From 1988 to September 1998, the number of training days at the MMR ranged from 153 to 259 days per year, with a 10-year annual average of 210 days. Thus, there is a steady population of soldiers at the MMR that could conceivably visit Mākua Beach and the muliwai. These receptors, however, are unlikely to rely on fish or shellfish from the muliwai or beach for subsistence; rather, they are more likely to fish recreationally for these species.

In addition to military personnel, there are several towns to the southeast of the MMR, the closest of which is Makaha, which is approximately three miles south of MMR. According to the US Census Bureau (2001), the populations of Makaha and Makaha Valley were 7,753 and 1,289. Additional urban areas are southeast of Makaha and Makaha Valley (see Figure 1-1). Residents of these locations may travel to the Mākua area and fish or harvest shellfish at Mākua Beach and the Mākua muliwai. These include both recreational fishermen as well as subsistence fishermen, so potential health risks were evaluated for these two groups.

Table 4-2
Fish and Seaweed Tissue EPCs

North and South Muliwai Fish Tissue			Muliwai Background (Nanakuli) Fish Tissue			Nearshore Makua Beach Fish Tissue			Nearshore Makua Beach Seaweed Tissue			Nearshore Background (Sandy Beach) Fish Tissue		
Chemical	**Arithmetic Mean**	**MaxD**	**Chemical**	**Arithmetic Mean**	**MaxD**	**Chemical**	**Arithmetic Mean**	**MaxD**	**Chemical**	**Arithmetic Mean**	**MaxD**	**Chemical**	**Arithmetic Mean**	**MaxD**
4,4'-DDT	0.001	0.003	4,4'-DDT	0.001	0.001	4,4'-DDT	0.0005	0.0002	4,4'-DDT	-	-	4,4'-DDT	0.001	0.002
Acetone	0.35	0.38	Acetone	-	-	Acetone	0.48	0.73	Acetone	-	-	Acetone	0.33	0.60
Aldrin	-	-	Aldrin	-	-	Aldrin	0.002	0.003	Aldrin	-	-	Aldrin	0.003	0.01
Aluminum	-	-	Aluminum	4467	5170	Aluminum	31	65	Aluminum	422	1,120	Aluminum	796	4720
Antimony	0.02	0.05	Antimony	-	-	Antimony	-	-	Antimony	0.06	0.15	Antimony	0.02	0.03
Arsenic, organic	4.6	30	Arsenic, organic	2.5	2.6	Arsenic, organic	23	37	Arsenic, inorganic	66	109	Arsenic, organic	19	53
Barium	18	26	Barium	41	44	Barium	7.0	32	Barium	9.0	13	Barium	5.6	14
Beryllium	0.02	0.05	Beryllium	0.08	0.09	Beryllium	-	-	Beryllium	0.01	0.02	Beryllium	0.01	0.07
BHC, alpha	-	-	BHC, alpha	-	-	BHC, alpha	0.002	0.008	BHC, alpha	-	-	BHC, alpha	-	-
BHC, beta	0.001	0.004	BHC, beta	-	-	BHC, beta	-	-	BHC, beta	-	-	BHC, beta	-	-
BHC, delta	0.001	0.0003	BHC, delta	-	-	BHC, delta	0.001	0.0003	BHC, delta	-	-	BHC, delta	-	-
BHC, gamma	0.001	0.002	BHC, gamma	-	-	BHC, gamma	0.003	0.006	BHC, gamma	-	-	BHC, gamma	0.004	0.002
Bis(2-ethylhexyl)phthalate	0.35	3.1	Bis(2-ethylhexyl)phthala	-	-	Bis(2-ethylhexyl)phthalate	1.4	3.5	Bis(2-ethylhexyl)phthalate	0.08	0.09	Bis(2-ethylhexyl)phthalate	0.06	0.05
Cadmium	0.05	0.15	Cadmium	0.12	0.13	Cadmium	0.15	0.21	Cadmium	0.24	0.28	Cadmium	0.11	0.20
Chromium	13	32	Chromium	22	25	Chromium	5.7	10	Chromium	2.2	6.0	Chromium	7.3	32
Cobalt	2.4	4.2	Cobalt	4.9	5.3	Cobalt	0.23	0.41	Cobalt	0.72	1.3	Cobalt	0.83	4.3
Copper	51	166	Copper	72	80	Copper	4.2	9.8	Copper	2.6	4.6	Copper	4.8	17
Diethyl phthalate	-	-	Diethyl phthalate	-	-	Diethyl phthalate	-	-	Diethyl phthalate	-	-	Diethyl phthalate	0.04	0.02
di-n-Butylphthalate	0.22	1.5	di-n-Butylphthalate	0.02	0.02	di-n-Butylphthalate	0.31	1.4	di-n-Butylphthalate	0.14	0.48	di-n-Butylphthalate	0.13	0.61
Heptachlor	-	-	Heptachlor	-	-	Heptachlor	0.002	0.01	Heptachlor	0.001	0.001	Heptachlor	0.003	0.01
Heptachlor epoxide	0.001	0.001	Heptachlor epoxide	0.001	0.001	Heptachlor epoxide	0.01	0.01	Heptachlor epoxide	-	-	Heptachlor epoxide	0.003	0.01
Iron	2708	4530	Iron	5997	7010	Iron	163	302	Iron	671	1,860	Iron	1230	6960
Lead	2.1	5.4	Lead	2.1	2.2	Lead	0.70	2.0	Lead	1.5	3.9	Lead	1.4	2.8
m,p-Xylenes	0.01	0.02	m,p-Xylenes	-	-	m,p-Xylenes	0.01	0.02	m,p-Xylenes	0.02	0.02	m,p-Xylenes	0.01	0.02
Manganese	181	386	Manganese	572	611	Manganese	7.7	16	Manganese	16	39	Manganese	28	147
Mercury	0.06	0.10	Mercury	0.04	0.05	Mercury	0.06	0.10	Mercury	-	-	Mercury	0.03	0.04
Methyl mercury	0.06	0.17	Methyl mercury	0.04	0.05	Methyl mercury	0.08	0.20	Methyl mercury	-	-	Methyl mercury	0.04	0.06
Nitroglycerin	-	-	Nitroglycerin	-	-	Nitroglycerin	0.17	0.33	Nitroglycerin	-	-	Nitroglycerin	-	-
Perchlorate	0.03	0.16	Perchlorate	0.0006	0.001	Perchlorate	0.002	0.01	Perchlorate	0.02	0.05	Perchlorate	0.02	0.11
RDX	-	-	RDX	-	-	RDX	0.06	0.06	RDX	-	-	RDX	-	-
Selenium	2.5	3.7	Selenium	2.4	2.6	Selenium	1.2	1.6	Selenium	0.28	0.07	Selenium	1.0	1.8
Silver	0.36	1.1	Silver	0.61	0.70	Silver	0.01	0.01	Silver	0.07	0.14	Silver	0.01	0.03
Thallium	0.01	0.01	Thallium	-	-	Thallium	-	-	Thallium	0.02	0.03	Thallium	0.01	0.01
Vanadium	12	19	Vanadium	21	24	Vanadium	0.61	1.2	Vanadium	6.0	13	Vanadium	3.8	20
Zinc	114	201	Zinc	112	116	Zinc	75	149	Zinc	11	12	Zinc	66	77
TCDD equivalents	3.1E-07	1.8E-06	TCDD equivalents	2.6E-09	3.8E-09	TCDD equivalents	ND	ND	TCDD equivalents	2.33E-08	6.72E-08	TCDD equivalents	3.6E-08	1.7E-07

Note: All analytical results are reported as mg/kg.

Table 4-3
Shellfish Tissue EPCs

Chemical	North and South Muliwai Shellfish Tissue	Muliwai Background (Nanakuli) Shellfish Tissue	Nearshore Makua Beach Shellfish Tissue	Nearshore Background (Sandy Beach) Shellfish Tissue
Aldrin	-	-	0.0011	-
Aluminum	143	73.2	102	61.8
Arsenic, organic	3.6	3.9	26.4	1.2
Barium	57.8	14.5	2.3	1.6
Beryllium	-	-	-	0.062
Cadmium	-	-	2	-
Chromium	1.3	1.2	1.2	1.2
Cobalt	0.8	0.28	0.37	0.45
Copper	39.7	65.7	25.7	1.9
Iron	226	110	131	100
Lead	0.16	-	0.33	0.98
Manganese	122	32.5	3.5	1.8
Mercury	0.022	-	0.041	-
Perchlorate	-	-	1.05	-
Selenium	1.2	1.7	1.7	1.2
Silver	-	0.24	0.15	-
Toluene	-	-	0.0011	8.90E-04
Vanadium	0.77	0.36	0.56	0.36
Zinc	31.2	485	47.4	5.9
TCDD equivalents	3.74E-07	3.3E-07	2.4E-09	8.27E-07

Notes:
All analytical results are reported as mg/kg. The maximum detected concentrations are shown as the EPCs.

4.3 HUMAN EXPOSURE ASSESSMENT

An exposure assessment was conducted to estimate the magnitude of exposures resulting from eating fish, shellfish, and limu collected from the Mākua Beach area and the Mākua muliwai. The primary goals of the exposure assessment were to identify potentially complete exposure pathways resulting in human receptor exposure to COPCs and quantitative evaluation of potential chemical exposure using measured and predicted chemical concentrations and estimates of the frequency and duration of potential chemical exposure.

Exposures were evaluated for both current and potential future site conditions.

4.3.1 Exposure Pathway Analysis

An exposure pathway describes the course that a chemical takes from a source to an exposed individual. A complete exposure pathway consists of the following four factors:

- A source of potentially toxic chemicals;
- A contaminated medium, such as fish, shellfish, or limu;
- An exposure or contact point with the contaminated medium, such as fish, shellfish, or limu consumption; and
- An exposure route for chemical intake by a receptor, such as uptake through the gastro-intestinal tract.

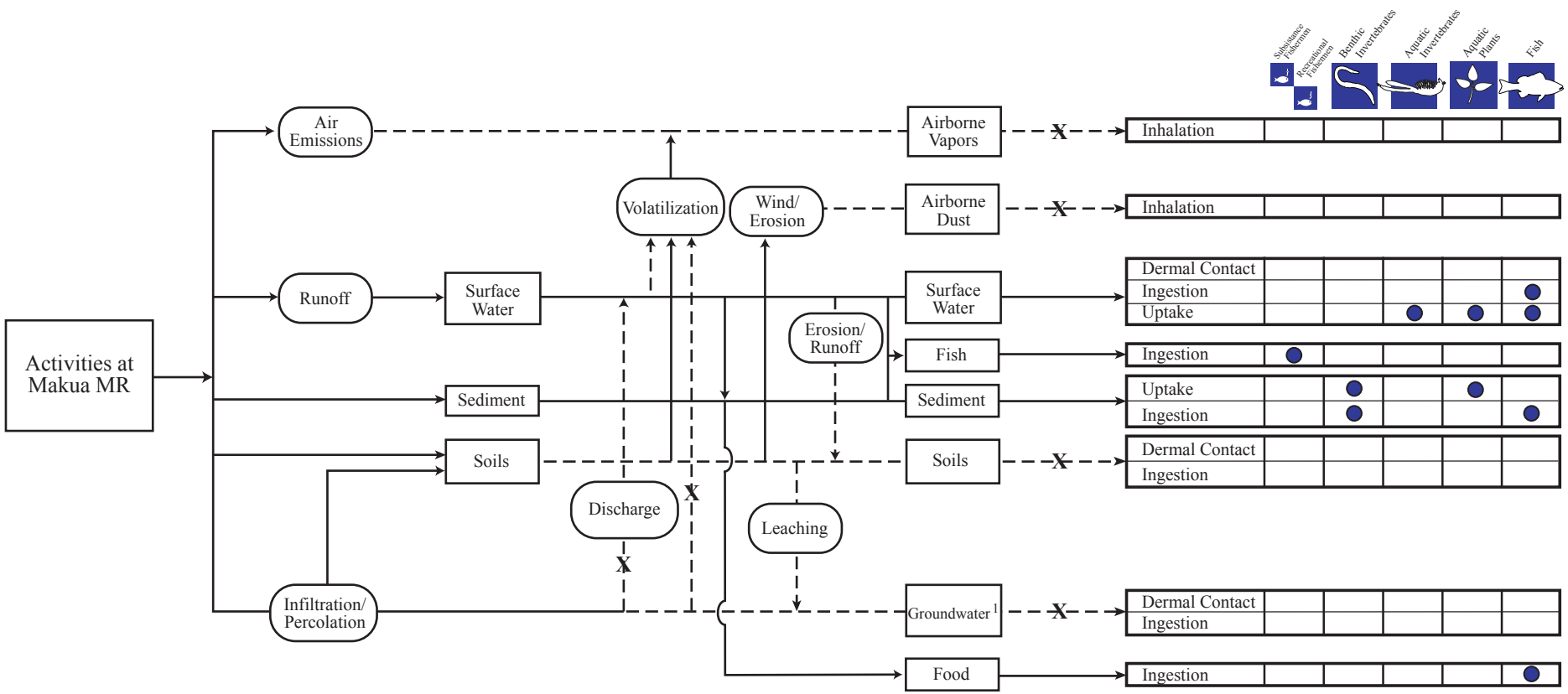
Designation of an exposure pathway as complete indicates that human exposure was possible but does not necessarily mean that exposure will occur or that exposure occurs at the levels estimated in this report. When any one of the factors is missing in a pathway, it is considered to be incomplete. Incomplete exposure pathways do not pose health hazards and were not evaluated in this risk assessment.

The conceptual site model (CSM) provides the basis for identifying and evaluating the potentially complete exposure pathways at Mākua Beach and the Mākua muliwai. As shown in the CSM diagram (Figure 4-1), potential sources of COPCs include surface water, sediments, fish, shellfish, and limu. The CSM shown also illustrates the potential chemical migration pathways, exposure points, and exposure routes evaluated at Mākua Beach and the Mākua muliwai. Chemical fate and transport processes were used to define the potential migration pathway, and included transfer of COPCs between environmental media, such as surface water and fish tissue, and transport of COPCs through movement of an environmental medium by natural dispersive processes, such as surface water flow.

An exposure pathway is complete when there is a point at which chemical uptake by a human receptor may occur. Exposure routes considered in this human health risk assessment are limited to fish, shellfish, and limu consumption.

4.3.2 Estimation of Chemical Intake

Chemical exposure is a result of the intake or uptake of a chemical from the environment. This section is a description of the methods used to quantitatively evaluate potential receptor exposures at Mākua Beach and the Mākua muliwai.



Legend

- Potentially complete exposure pathway
- Potentially incomplete exposure pathway
- Incomplete exposure pathway
- Potentially complete exposure route
- 1 Groundwater not used for water supply at this site.

Current & Future Conditions
Conceptual Site Model for Human & Ecological Receptors

Tetra Tech, Inc. San Francisco, CA
180 Howard Street, Suite 250
San Francisco, CA 94105

TASK NO.	DATE	DRAWN BY	FILE NAME	FIGURE NO.
	11/20/06	Rigby		4-1

Exposure Models

Potential chemical exposures were quantitatively estimated using an exposure model defined by the USEPA guidance for fish consumption (1989). The model results in exposures normalized for time and body weight and are expressed as the amount of chemical taken into the body per unit body weight per unit time (i.e., mg/kg/day):

$$Intake = \frac{C_{sf} \times CR \times EF \times ED}{BW \times AT}$$

where

Intake = Effective ingested dose (mg/kg/day);
C_{sf} = Chemical concentration in seafood (mg/kg);
CR = Consumption rate per unit time (kg/day);
EF = Exposure frequency (days/year)
ED = Exposure duration (days);
BW = Body weight (kg); and
AT = Averaging time (days).

The exposure parameters are discussed below for each of the two receptor groups at Mākua Beach and the Mākua muliwai: recreational fishermen and subsistence fishermen (including fisherman that consume fish, shellfish, or limu).

Exposure Frequency

For both subsistence and recreational fishermen, it is assumed that fish, limu, and shellfish are consumed every day of the year, that is, 365 days per year. This exceeds the standard residential exposure frequency of 350 days per year (USEPA 1989, 1991a, 2002a) and the average per capita fish and shellfish consumption frequency in the US of 48 days a year (USEPA 1989).

Exposure Duration

Standard USEPA guidance is to assume that residents may be present at a site for 30 years (1989, 1991a, 2002a).

Body Weight

Standard USEPA guidance is to assume that adults weigh 70 kg (1989, 1991a, 2000a, 2002a).

Consumption Rate

In order to characterize human exposure to contaminated seafood, the potentially exposed population must be identified, and the likely types and quantities of seafood consumed must be determined. The default consumption rates that have been proposed for the general US population may not be representative of the local consumption patterns and population characteristics for the population of Hawai‘i. For this risk assessment, it is desirable to use a seafood consumption rate that is protective of the multiple ethnic groups and lifestyles in Hawai‘i.

USEPA has guidance for fish consumption rates to be used for national risk assessments and the calculation of fish advisories (1991a, 1997a, 2002c). The USEPA Superfund Program guidance assumes an ingestion rate of 54 grams of fish per day (g/day) for high consumers of locally caught fish (USEPA 1991a). For the general US population, the USEPA Exposure Factors Handbook recommends a mean marine fish consumption rate of 14.1 g/day for the general US population and a mean of 70 g/day and 95th percentile of 170 g/day fish consumption rate for Native American subsistence populations (USEPA 1997a). Based on a sample size of 20,607 individuals, later USEPA (2002c) guidance provides a mean uncooked fish consumption rate for the general US population of 12.59 g/day, with a 95th percentile rate of 81.75 g/day.

For marine shellfish, the USEPA Exposure Factors Handbook (USEPA 1997a) provides a mean ingestion rate of 1.6 grams per day (g/day) and a 99 percentile of 50.3 g/day for uncooked shellfish and a mean consumption rate of 1.2 g/day and a 99 percentile of 37 g/day for cooked shellfish for the general US population. Later USEPA (2002c) guidance provides mean consumption rates of 1.97 g/day for uncooked marine shellfish and 2.03 g/day for cooked marine shellfish, with 99th percentile rates of 80.57 for uncooked marine shellfish and 84.74 g/day for cooked marine shellfish.

No guidance on fish or shellfish consumption rates is available for the State of Hawai‘i. However, fish consumption survey data are available for California, Hawai‘i, and Washington, and shellfish consumption survey data are available for California and Washington.

In California, there are two notable seafood consumption studies: one from the Santa Monica Bay (OEHHA 2001) and one for the San Francisco Bay (SFEI 2000). The Santa Monica Bay study recommended that a seafood consumption rate of "21 grams per day for the median, 50 grams per day for the mean, 107 grams per day for the 90th percentile, and 161 grams per day for the 95th percentile…be used to estimate consumption from both marine and freshwater sources of sport fish and shellfish in California. These values are most applicable to fishermen that consume sport fish and shellfish on a regular and frequent basis (i.e., at least once a month). For cases where the target population is the general fishing population and fish is not a major exposure pathway, the adjusted (weighted) results of 30.5 grams per day for the mean value and 85.2 grams per day at the 95th percentile can be used" (OEHHA 2001). OEHHA (1997) also provides a shellfish consumption rate for people in the Pacific Region (California, Oregon, and Washington) of 4 g/day for the mean, and 11.64 g/day for the 90th percentile.

The San Francisco Estuary Institute (2000) surveyed people fishing in the San Francisco Bay and reported fish consumption rates among those that had recently consumed fish (n = 448) of 14 g/day (geometric mean) with a 95th percentile upper confidence limit (UCL_{95}) of 15.2 g/day. When the data was separated by ethnic groups, several groups were found to have higher fish consumption rates than the overall mean, with the most notable being Pacific Islanders (n = 70, geometric mean 22.4 g/day, UCL_{95} 44.7 g/day) and "other" (n = 7, geometric mean 27.5 g/day, UCL_{95} 55.0 g/day), with "other" being Russians, Middle Easterners, and individuals of unspecified mixed ethnicity.

Several fish consumption surveys have recently been conducted in Hawai'i. The relevant scientific studies are reviewed here and used to derive a health-protective estimate of fish consumption rates. However, UCL_{95s} are often not presented for these studies.

Koizumi et al. (2002) surveyed fish consumption rates of people in Pacific Rim countries, including the United States. The authors reported results for Americans from the mainland US and for Japanese-Americans living in Hawai'i, as well as for residents of several other countries. For this risk assessment, the most interesting result is the average consumption rate of fish by Japanese-Americans living in Hawai'i, which was based on survey results from 369 households and was determined to be 65 g/day. This value was higher than the consumption rates determined for Australia, Japan, and the mainland US (50.7, 42.4, and 38.5 g/day, respectively), but lower than fish consumption rates in some Asian countries, such as China, Taiwan, and Thailand (95.6, 78.3, and 178.4 g/day). Only mean consumption rates were provided.

Kolonel et al. (1990) surveyed 632 residents of all major ethnic groups from O'ahu and reported consumption rates for shellfish, fish, and limu, as well as all seafood combined. The average rate of seafood consumption for all respondents was found to be 49.1 g/day. Fish consumption rates were not reported for separate ethnic groups. The average rate of shellfish consumption for all respondents was found to be 6.8 g/day. The limu consumption rate was estimated at 2.1 g/day. Only mean consumption rates were provided.

Sharma et al. (2003) surveyed Japanese Americans (n = 54,248), native Hawaiians (n = 13,629), and whites (n = 47,236) in Hawai'i. Average fish consumption rates were found to be 25.5 ± standard deviation of 22.7, 34.0 ± 34, and 17.0 ± 17.0 g/day, respectively. From these, the 95th percentile can be calculated using the following formula:

$$95^{th}\,\text{percentile} = \text{mean} + (\text{standard deviation} \times 1.96)$$

Using this formula, the 95th percentile fish consumption rates are 70.0 g/day for Japanese-Americans, 100.6 g/day for Hawaiians, and 50.3 g/day for whites.

Lastly, Sechena et al. (2003) surveyed 202 members of the Asian American and Pacific Islander community, of various ethnic backgrounds, living in Washington State. Although none were Hawaiian, respondents included many ethnic groups that are also present in Hawai'i, including Vietnamese, Chinese, Filipinos, Japanese, and Koreans. The average fish consumption rate across all Asian American and Pacific Islanders was 117.2 g/day, with a UCL_{95} of 122.5 g/day, and a 90th percentile of 242 g/day. The ethnic group in Washington with the highest fish consumption rate was the Vietnamese, with a mean consumption rate of 161.1 g/day (n=26). Therefore, the 90th percentile fish consumption rate in this study is likely to have been influenced by Vietnamese fish consumption rates.

Sechena et al. (2003) also surveyed shellfish consumption rates of Asian Americans and Pacific Islanders living in the state of Washington. The study reported a mean shellfish consumption rate of 53.8 g/day and a 90th percentile of 107 g/day. These values are higher

than the consumption rates determined by US EPA for the general US population and by OEHHA for people in the Pacific Region.

Sechena et al. also provided a seaweed/kelp consumption rate of 5.2 g/day, with a UCL_{95} of 5.8 g/day, and a 90th percentile of 18.2 g/day for Asian American and Pacific Islander community living in Washington State.

The studies summarized above show that there are substantial ethnic and geographic differences in fish consumption rates. Therefore, to represent the most likely consumption of all potential groups fishing at the muliwai, a fish consumption rate of 100.6 g/day is used to assess the potential risks to subsistence fishermen. This consumption rate was derived from the 95th percentile fish consumption rate of Hawaiians living in O‘ahu (Sharma et al. 2003). The fish consumption rate used here is higher than the 95th percentile fish consumption rates for Japanese-Americans and whites (i.e., 70.0 and 50.3 g/day, respectively) living in Hawai‘i (Sharma et al. 2003). To estimate the most likely exposures for recreational fishermen, a consumption rate of 34.0 g/day was used, which is the average fish consumption rate for Hawaiians living in O‘ahu (Sharma et al. 2003).

The assumption is that the fish consumption rates of Hawaiians living in O‘ahu are the most applicable to the population consuming shellfish (Sharma et al. 2003). Hence, a consumption rate of 100.6 g/day (the 95th percentile) was used to assess the potential risks to subsistence Shellfish fishermen. For recreational shellfish fishermen, a consumption rate of 34.0 g/day was used. These rates are higher than the consumption rates determined by US EPA for the general US population (with a 99th percentile rate up to 84.74 g/day) and by OEHHA for people in the Pacific Region (with a 90th percentile rate of 11.64 g/day). In addition, it should be noted that these consumption rates are considerably higher than consumption rates specific to the species of shellfish collected. USEPA (2002c) reported mean ingestion rates (prepared) of 2 g/day and 1.63 g/day for crab and shrimp, respectively, for the general US population. No consumption rate is reported for urchins.

To estimate exposures from the consumption of limu, the 90th percentile seaweed/kelp consumption rate of Asian-Pacific Islanders living in Washington state of 18.2 g/day was used for subsistence fishermen (Sechena et al. 2003), and the mean rate of 5.2 g/day was used for recreational fishermen (Sechena et al. 2003).

4.4 HUMAN TOXICITY ASSESSMENT

The toxicity assessment provides information on the potential for COPCs at Mākua Beach and the Mākua muliwai to cause either carcinogenic or noncarcinogenic adverse health effects. The toxicity assessment is primarily a data compilation task that relies heavily on the hazard identification and dose-response evaluations performed by the USEPA and the HDOH. The toxicity assessment consists primarily of tabular presentations of specific toxicity for potential carcinogenic and noncarcinogenic health effects of the COPCs. These presentations consist of cancer slope factors and chronic reference doses (RfDs).

4.4.1 Human Toxicity Values

Key dose-response variables (critical toxicity values) used in quantitative risk assessments are cancer potency (or slope factors) for carcinogens and RfD values for noncarcinogens or noncarcinogenic endpoints of carcinogens. Toxicity values were obtained from several sources, according to the following order of priority: (1) the USEPA's Integrated Risk Information System (USEPA 2006a), (2) the annual version of the USEPA's Health Effects Assessment Summary Tables (USEPA 1997b), and (3) the USEPA (2004b) Region IX PRG tables. In the evaluation of the shellfish samples collected in 2008, consideration was given to toxicological data available in 2008 (see Tables 4-4 to 4-6).

Carcinogenic Slope Factors

The USEPA's Carcinogen Assessment Group has developed slope factors for estimating the individual upper bound excess lifetime cancer risks associated with various levels of lifetime exposure to potential human carcinogens. In practice, slope factors (expressed in units of $[mg/kg/day]^{-1}$) are derived from the results of human epidemiology studies or chronic animal bioassays. Based on evaluations of these studies, chemicals are placed into one of the following categories:

Group	Category
A	Human carcinogen
B	Probable human carcinogen: • B1 indicates limited human evidence; • B2 indicates sufficient evidence in animals or no evidence in humans
C	Possible human carcinogen
D	Not classifiable as to human carcinogenicity

The oral slope factors used in assessing potential carcinogenic health effects are shown in Table 4-4. Potential health risks were evaluated for the Class A, B, and C carcinogens detected at Mākua Beach and the Mākua muliwai for which slope factors were available. Table 4-4 also provides the tumor type caused by each COPC, the experimental test species, and the source of each slope factor.

Toxicity values (i.e., cancer slope factors and noncarcinogenic reference doses) have not been developed for most of the polychlorinated dibenzodioxins and -furans. The USEPA has developed a slope factor for only 2,3,7,8-TCDD. However, by using toxicity equivalency factors given in Table 4-5 (USEPA 2000a), the measured concentrations of the dioxins and furans were converted to an estimated 2,3,7,8-TCDD-equivalent concentration for each sample. For nondetected concentrations, a result of zero was used. The exposure point concentrations (EPCs) for TCDD-equivalents were then used in evaluating the risks from potential exposures to dioxins and furans at the site.

Noncarcinogenic Reference Doses

The toxicity values used to assess noncarcinogenic health risks were the chronic RfDs (Table 4-6). The table also provides information on the health effect of concern or critical effect for each chemical and the test species in which the effect was demonstrated. The USEPA (1989) assigns several measures of confidence to each RfD, as follows:

Table 4-4
Oral Carcinogenic Slope Factors

Chemical	Oral Slope Factor $(mg/kg/day)^{-1}$	Weight of Evidence	Tumor	Test Species	Slope Factor Source	Date
Acetone	-	-	-	-	-	-
Aldrin	1.70E+01	B2	Liver carcinoma	Mouse	IRIS	Nov-06
Aluminum	-	-	-	-	1	-
Antimony	-	-	-	-	1	-
Arsenic, inorganic	1.50E+00	A	Skin	Human	IRIS	Nov-06
Arsenic, organic	-	-	-	-	1	-
Barium	-	D	-	-	1	-
Beryllium	-	B1	-	-	2	-
BHC, alpha	6.30E+00	B2	Hepatic nodules and hepatocellular carcinomas	Mouse	IRIS	Nov-06
BHC, beta	1.80E+00	C	Hepatic nodules and hepatocellular carcinomas	Mouse	IRIS	Nov-06
BHC, delta	-	D	-	-	-	-
BHC, gamma	1.30E+00	B2	Liver tumors	Mouse	HEAST	Jul-97
bis(2-ethylhexyl)phthalate	1.40E-02	B2	Liver tumors	Mouse	IRIS	Nov-06
Cadmium	-	B1	-	-	2	-
Chromium	-	D	-	-	-	-
Cobalt	-	B1	-	-	2	-
Copper	-	D	-	-	-	-
4,4'-DDT	3.40E-01	B2	Liver tumors	Rat	IRIS	Nov-06
Diethyl phthalate	-	D	-	-	-	-
Di-n-butylphthalate	-	D	-	-	-	-
Ethylbenzene	-	D	-	-	-	-
Heptachlor	4.50E+00	B2	Liver tumors	Mouse	IRIS	Nov-06
Heptachlor epoxide	9.10E+00	B2	Hepatocellular carcinomas	Mouse	IRIS	Nov-06
Iron	–	–	-	-	1	–
Lead	-	B2	–	–	3	–
Manganese	-	D	-	-	-	-
Mercury	-	D	-	-	-	-
Methyl mercury	-	-	-	-	1	-
Nitroglycerin	1.70E-02	-	-	-	PPRTV; 4	Sep-05
Perchlorate	-	NA	-	-	-	-
RDX	1.10E-01	C	Liver, hepatocellular carcinoma, and adenomas	Mouse	IRIS	Nov-06
Selenium	-	D	-	-	-	-
Silver	-	D	-	-	-	-
TCDD equivalents	1.50E+05	B2	Respiratory and liver tumors	Rat	HEAST	Jul-97
Thallium	-	D	-	-	-	-
Toluene	-	D	-	-	-	-
Vanadium	-	-	-	-	1	-
m,p-Xylenes	-	NA	-	-	1	-
o-Xylene	-	NA	-	-	1	-
Zinc	-	D	-	-	-	-

Definitions:

A - Chemical cancer classification (human carcinogen).
B1 - Chemical cancer classification (probable human carcinogen; limited human evidence).
B2 - Chemical cancer classification (probable human carcinogen; sufficient animal evidence and/or no human evidence).
C - Chemical cancer classification (possible human carcinogen).
Cal/EPA - California Environmental Protection Agency.
D - Chemical cancer classification (not classifiable as to carcinogenicity).
IRIS - Integrated Risk Information System.
$(mg/kg/day)^{-1}$ - Risk per milligrams per kilogram per day.
NC - not classified
PPRTV - Provisional Peer Reviewed Toxicity Value
SF - slope factor

Notes:

All weight of evidence classifications were obtained from U.S. EPA (2004) Integrated Risk Information System (IRIS), except for cobalt, which is from the PPRTV web page.

1 - This chemical has not been demonstrated to be carcinogenic.
2 - Has not been demonstrated to be carcinogenic via the oral route of exposure.
3 - Lead is also evaluated using the DTSC lead spreadsheet, LeadSpread v 7.0.
4 - PPRTV, as per the USEPA (2008) Regional Screening Levels

Table 4-5
Toxicity Equivalency Factors (TEFs) for Dioxins and Furans

Chemical	TEF-98
Dioxins	
2,3,7,8-TCDD	1.00
1,2,3,7,8-PeCDD	1.00
1,2,3,4,7,8-HxCDD	0.10
1,2,3,6,7,8-HxCDD	0.10
1,2,3,7,8,9-HxCDD	0.10
1,2,3,4,6,7,8-HpCDD	0.01
OCDD	0.0001
Furans	
2,3,7,8-TCDF	0.10
1,2,3,7,8-PeCDF	0.05
2,3,4,7,8-PeCDF	0.50
1,2,3,4,7,8-HxCDF	0.10
1,2,3,6,7,8-HxCDF	0.10
1,2,3,7,8,9-HxCDF	0.10
2,3,4,6,7,8-HxCDF	0.10
1,2,3,4,6,7,8-HpCDF	0.01
1,2,3,4,7,8,9-HpCDF	0.01
OCDF	0.0001

Note:

The 2008 shellfish sample TCCD-equivalents were calculated using updated USEPA TEFs (Van den Berg 2006), specifically: OCDD (0.0003); 1,2,3,7,8-PeCDF (0.03); 2,3,4,7,8-PeCDF (0.3); and OCDF (0.0003).

Table 4-6
Chronic Oral Reference Doses

Chemical	RfD (mg/kg/day)	Confidence	MF	UF	Critical Effect	Test Species	Source	Date
Acetone	9.00E-01	Medium	1	1,000	Nephropathy	Rat	IRIS	Nov-06
Aldrin	3.00E-05	Medium	1	1,000	Liver toxicity	Rat	IRIS	Nov-06
Aluminum	1.00E+00	-	-	-	-	-	PPRTV	-
Antimony	4.00E-04	Low	1	1,000	Longevity, blood glucose, and cholesterol	Rat	IRIS	Nov-06
Arsenic, inorganic	3.00E-04	Medium	1	3	Hyperpigmentation, keratosis and possible vascular complications	Human	IRIS	Nov-06
Arsenic, organic	-	-	-	-	-	-	1	-
Barium	7.00E-02	High	-	300	Nephropathy	Mouse	IRIS; 2	Nov-06
Beryllium	2.00E-03	Medium	1	300	Small intestinal lesions	Dog	IRIS	Nov-06
BHC, alpha	3.00E-04	-	-	-	-	-	3	-
BHC, beta	3.00E-04	-	-	-	-	-	3	-
BHC, delta	3.00E-04	-	-	-	-	-	3	-
BHC, gamma	3.00E-04	Medium	1	1,000	Liver and kidnet toxicity	Rat	IRIS	Nov-06
bis(2-ethylhexyl)phthalate	2.00E-02	Medium	1	1,000	Increased relative liver weight	Guinea pig	IRIS	Nov-06
Cadmium	5.00E-04	-	1	10	Significant proteinuria	Human	IRIS	Nov-06
Chromium	1.50E+00	Low	10	100	No effects observed	Rat	IRIS	Nov-06
Cobalt	2.00E-02	Low/Medium	1	10	Hematological effects (increased hemoglobin)	Human	PPRTV; 4	Jul-97
Copper	4.00E-02	-	-	-	Gastrointestinal irritation	Human	HEAST	Jul-97
4,4'-DDT	5.00E-04	Medium	1	100	Liver lesions	Rat	IRIS	Nov-06
Diethyl phthalate	8.00E-01	Medium	1	1,000	Decreased growth rate, food consumption and altered organ weights	Rat	IRIS	Nov-06
Di-n-butylphthalate	1.00E-01	Low	1	1,000	Increased mortality	Rat	IRIS	Nov-06
Ethylbenzene	1.00E-01	Low	1	1,000	Liver and kidnet toxicity	Rat	IRIS	Nov-06
Heptachlor	5.00E-04	Low	1	300	Liver weight increases in males	Rat	IRIS	Nov-06
Heptachlor epoxide	1.30E-05	Low	1	1,000	Increased liver-to-body weight ration	Dog	IRIS	Nov-06
Iron	-	-	-	-	-	-	5	-
Lead	-	-	-	-	-	-	6	-
Manganese	2.40E-02	Medium	1	1	CNS effects	Human	IRIS	Nov-06
Mercury	3.00E-04	Medium	1	3,000	Hand tremor, increases in memory disturbance; slight subjective and objective evidence of autonomic dysfunction	Human	IRIS	Nov-06

Table 4-6
Chronic Oral Reference Doses

Chemical	RfD (mg/kg/day)	Confidence	MF	UF	Critical Effect	Test Species	Source	Date
Methyl mercury	1.00E-04	High	1	10	Developmental neuropsychological impairment	Human	IRIS	Nov-06
Nitroglycerin	1.00E-04	-	-	-	-	-	PPRTV; 7	Aug-06
Perchlorate	7.00E-04	Medium/High	-	10	Radioactive iodide uptake inhibition	Human	IRIS	Nov-06
RDX	3.00E-03	High	1	100	Inflammation of the prostate	Rat	IRIS	Nov-06
Selenium	5.00E-03	Medium	1	3	Clinical seleniosis	Human	IRIS	Nov-06
Silver	5.00E-03	Medium	1	3	Argyria	Human	IRIS	Nov-06
TCDD equivalents	-	-	-	-	-	-	1	-
Thallium	8.00E-05	Low	1	3,000	No adverse effects	Rat	IRIS	Nov-06
Toluene	8.00E-02	Medium	-	3,000	Increased kidney weight	Rat	IRIS	Nov-08
Vanadium	2.00E-02	-	-	100	No adverse effects	Rat	HEAST; 8	Jul-97
m,p-Xylenes	2.00E-01	Medium	1	1,000	Decreased body weight, increased mortality	Rat	IRIS; 9	Nov-06
o-Xylene	2.00E-01	Medium	1	1,000	Decreased body weight, increased mortality	Rat	IRIS; 9	Nov-06
Zinc	3.00E-01	Medium	-	3	Decrease in erythrocyte superoxide dismutase (ESOD) concentration	Human	IRIS	Nov-06

Definitions:

DTSC - Department of Toxic Substances Control
HEAST - Health Effects Assessment Summary Tables
IRIS - Integrated Risk Information System
MF - modifying factor
mg/kg/day - milligram per kilogram per day
PPRTV - Provisional Peer Reviewed Toxicity Value
RfD - reference dose
UF - uncertainty factor

Notes:

1 - No RfDs developed by IRIS USEPA 2004a), HEAST (USEPA 1997b), or the PPRTVs (USEPA 2004b).
2 - Shellfish consumption evaluated using updated RfD of 0.2 mg/kg/day (IRIS 2008)
3 - gamma-BHC used as a surrogate
4 - Shellfish consumption evaluated using updated RfD of 0.0003 mg/kg/day (PPRTV 2008)
5 - Shellfish consumption evaluated using updated RfD of 0.7 mg/kg/day (PPRTV, September 2006)
6 - Lead is evaluated using the DTSC lead spreadsheet, LeadSpread v 7.0.
7 - PPRTV, as per the USEPA (2008) Regional Screening Levels
8 - Vanadium sulfate values were used.
9 - Xylene toxicity values were used.

- Confidence levels are categorical measures of the uncertainty associated with the experimental procedures used as the basis of an RfD;
- The USEPA uses uncertainty factors and modifying factors to reflect scientific judgment regarding the data used to estimate RfD values
  - The USEPA uses an uncertainty factor of 10 to account for variations in human sensitivity when extrapolating from human studies involving subchronic or chronic exposures of average healthy subjects,
  - Additional factors of 10 are applied for extrapolations from long-term animal studies and for extrapolations from subchronic exposure experiments to chronic exposures, and
  - Finally, the USEPA assigns values between 0 and 10 for the modifying factor to quantify professional assessment of the uncertainties of the data used to calculate the RfD. The default value for the modifying factor is 1.

The confidence levels, uncertainty factors, and modifying factors assigned to each RfD are also shown in Table 4-6.

Chemicals for Which the USEPA Has Not Developed Toxicity Values

Surrogate toxicity values were determined by assuming that certain chemical isomers have similar toxic effects. Chemicals evaluated with surrogate toxicity values are noted in Tables 4-4 and 4-6.

A review of the published literature shows that arsenic is present almost exclusively as organic forms in marine fish and invertebrate tissues (Neff 1997; de Gieter et al. 2002; Kirby and Maher 2002; Frankenberger 2002; Kirby et al. 2002; Sloth et al. 2005; Schoof and Yager 2007; Peshut et al. 2008). Bacteria and algae tend to methylate inorganic arsenic and convert it to simple organo-arsenic compounds (e.g., arseno-sugars) (Tamaki and Frankenberger 1989). Marine animals subsequently convert these simple organic arsenic compounds to more complex organic forms (Kirby and Maher 2002; Neff 1997). Additionally, there is little evidence for biomagnification along the food chain (Neff 1997; De Gieter et al. 2002; Frankenberger 2002; Kirby and Maher 2002). In marine fish and invertebrates, arsenobetaine may represent 70 to 90 percent of the total arsenic present in tissue (de Gieter et al. 2002; Kirby and Maher 2002; Peshut et al. 2008), with the rest being almost completely other organic forms of arsenic (Frankenberger 2002; Sloth et al. 2005). Organic arsenic species are considered nontoxic to both marine fish and invertebrates and to their predators, including humans (Neff 1997). Therefore, the arsenic measured in fish and shellfish tissues was assumed to be a nontoxic form and was not evaluated here. In contrast, the arsenic in marine algae may be greater than 50 percent arsenic V (Frankenberger 2002; Kirby et al. 2005), which is toxic; therefore, arsenic in limu was evaluated as inorganic arsenic.

The USEPA has not developed an RfD for lead, primarily because there is considerable controversy regarding the threshold at which adverse health effects from lead occur. The USEPA has determined that lead exposure can result in various health effects, depending on the level of exposure. Also, potential health effects differ, depending on whether exposure

occurs to an adult or a child. At blood-lead levels of 10 to 15 micrograms per deciliter (μg/dL), or possibly lower, health effects may include inhibited activity of enzymes involved in red blood cell metabolism, interference with heme synthesis, interference with vitamin D hormone synthesis, altered brain wave activity, deficits in intelligence quotient and other mental indices, early childhood growth reductions, and small increases in blood pressure (*Federal Register* 56[110]:26460-26564). To evaluate potential risks from exposures to lead, a computer spreadsheet application developed by the State of California was used, and the predicted blood-lead levels were compared to an action level of 10 μg/dL. Defaults were used for all model inputs, with the exception of "homegrown produce," which was assumed to be the fish or shellfish consumed by subsistence fishermen and were therefore assumed to be 100 percent. Additionally, the concentration of "lead in homegrown produce" was modified to that of the maximum detected lead concentration in fish or shellfish sampled in each of the four areas.

4.5 HUMAN HEALTH RISK CHARACTERIZATION

Risk characterization integrates the exposure assessment and chemical toxicity information to quantitatively estimate potential health risks from COPCs. Risk estimates were determined for individual routes of chemical exposure as well as for additive effects. The results of the risk characterization will be taken into account through the environmental impact statement process for decisions on the use of MMR.

4.5.1 Risk Estimation Procedures

Because of fundamental differences in the calculation of critical toxicity values, the estimates of potential individual carcinogenic risks and noncarcinogenic health effects were developed separately.

Carcinogenic Risk Probabilities

For carcinogens, the risk of cancer is assumed to be proportional to dose and that any exposure results in a nonzero probability of risk. Carcinogenic risk probabilities were calculated by multiplying the estimated exposure level by the route-specific cancer slope factor for each carcinogen:

$$R = E \times SF$$

where

R = Estimated individual lifetime cancer risk;
E = Exposure or intake level for each chemical of potential concern (mg/kg/day); and
SF = Route- and chemical-specific slope factor ($(mg/kg/day)^{-1}$).

Risk probabilities determined for each carcinogen were also considered to be additive over all exposure pathways so that an overall risk of cancer was estimated for each group of potentially exposed receptors.

Risk probabilities can be compared to the generally acceptable risk range specified by the USEPA. According to the revised National Contingency Plan (USEPA 1990), carcinogenic risks from exposures at Superfund sites are considered to be unacceptable at a level greater

than 1 x 10^{-4}, whereas risks less than 1 x 10^{-6} are considered to be of minimal concern. For Superfund sites, action may not be necessary in the risk range of 10^{-6} to 10^{-4}. This is supported in the directive *Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions* (USEPA 1991b), which indicates action is generally warranted at a Superfund site when the cumulative carcinogenic risk for any *medium* is greater than 10^{-4}. In general, a potential individual lifetime cancer risk of 1 x 10^{-5} (i.e. 1 person out of 100,000 people may develop cancer) is used when determining whether chemical exposures for fish consumption represent a potentially unacceptable level of risk to public health (USEPA 2000a). Altogether, this range of potentially acceptable risks helps put the numerical risk estimates into perspective. MMR is not on the National Priorities List, and therefore is not in the Superfund program. However, the risk assessment was performed in accordance with Superfund guidance documents.

Noncarcinogenic Hazard Quotients and Hazard Indices

In contrast to carcinogens, noncarcinogens are considered to be threshold chemicals: a critical chemical dose must be exceeded before a health effect is observed. The likelihood of a potential adverse health effect is represented by the ratio of a chemical exposure level and the route-specific RfD:

$$HQ = E / RfD$$

where

HQ	= Hazard Quotient for each chemical of potential concern;
E	= Exposure or intake level for chemical of potential concern; and
RfD	= Route- and chemical-specific Reference Dose.

Also, in a manner similar to carcinogens, HQ values were summed across exposure pathways and for all chemical exposures to develop hazard index (HI) values. An HQ or HI value greater than 1 indicates that an adverse health effect may occur due to a chemical exposure. HQs and HIs are not risk probabilities, but the USEPA currently accepts them as quantitative levels of risk for noncarcinogens or the noncarcinogenic endpoints of carcinogens.

Background

Chemicals at the Mākua muliwai and Mākua Beach may originate from releases attributable to the MMR, as well as from other sources, including natural and anthropogenic sources not attributable to the MMR (USEPA 1989, 2002d). The chemicals most likely attributable to the MMR are explosive compounds, although a wide variety of other chemicals were included in the risk assessment. A discussion of the sources of many of these chemicals is provided in Section 3. When the source of chemicals in the environment cannot be determined, one approach is to quantify the risks from exposures both at the site and under background conditions (USEPA 1989, 2002d). To distinguish the contribution to the risk estimates from background exposures, as recommended by the USEPA (2002d), the risk estimates are presented for exposures at the site minus the risks from exposures under background conditions.

Lead Risk Evaluations

An RfD has not been developed for lead, so a different approach was used to evaluate potential health risks from lead exposure. The blood-lead level predicted for receptors potentially exposed to lead at the Mākua muliwai and Mākua Beach was compared to a blood-lead level of concern. A clear no-observed-effect level has not been established for many adverse health effects associated with lead exposure. Dose-response curves for some of these health effects appear to extend down to a blood-lead level of 10 μg of lead per dL of whole blood (10 μg/dL) or less. USEPA typically considers that action may be warranted if the 95th percentile of predicted blood-lead levels exceeds 10 μg/dL; that is, action may be considered if there is a five percent chance that a receptor exposed to lead could have a blood-lead level greater than 10 μg/dL. The results of the model indicate that the maximum predicted 95th percentile blood lead concentration for adults and children consuming fish from the Mākua muliwai and Mākua Beach is 3.8 μg/dL, which does not exceed the action level. For shellfish, the maximum predicted 95th percentile blood lead concentration for adults and children consuming shellfish from the Mākua muliwai and Mākua Beach is 3.1 μg/dL, which also does not exceed the action level. The lead spread spreadsheets are provided in Appendix D.

4.5.2 Risk Estimates

Using likely fish and shellfish consumption rates for Hawai'i, the total carcinogenic risks and overall noncarcinogenic HI values were estimated for each receptor of potential concern (i.e., subsistence fishermen and recreational fishermen) in the two areas of concern at Mākua, i.e., the Mākua muliwai and Mākua Beach. Risks are provided for each receptor group and each COPC in fish and shellfish. Each set of risk analyses is accompanied by the risks from exposures under background conditions. The risk analyses, therefore, provide an indication of the contributing influence of background exposures to the risk estimates. Detailed exposure and risk calculations are provided in Appendix D.

Risks estimated for each group of receptors evaluated are described below.

Mākua Muliwai—Fish Consumption

Subsistence Fishermen

Using likely fish consumption rates for Hawai'i, carcinogenic risk probabilities were calculated for current and future subsistence fishermen potentially exposed to the mean concentrations of COPCs in fish caught at the Mākua muliwai. Table 4-7 shows that the overall risk estimate is approximately 4 x 10^{-5}, with background contribution of 6 x 10^{-6}. Therefore, the incremental risks (i.e., over background) from fish consumption at the muliwai is approximately 3.5 x 10^{-5} for subsistence fishermen. This risk estimate exceeds the 1 x 10^{-5} risk level (one person in 100,000 people may develop cancer) used in assessing fish consumption (USEPA 2000a), although it is within the USEPA (1990) target risk range of 10^{-6} to 10^{-4}. The incremental risks over background are largely due to assumed exposures to dioxins/furans.

Table 4-7
Carcinogenic Risk Estimates from Fish Consumption at the Muliwai Using Mean Contaminant Concentrations

	Subsistence Fishers		Recreational Fishers	
Chemical	**Site**	**Background**	**Site**	**Background**
Acetone	-	-	-	-
Aluminum	-	-	-	-
Antimony	-	-	-	-
Arsenic, organic	-	-	-	-
Barium	-	-	-	-
Beryllium	-	-	-	-
BHC, beta	1.35E-06	-	4.56E-07	-
BHC, delta	-	-	-	-
BHC, gamma	8.14E-07	-	2.75E-07	-
Bis(2-ethylhexyl)phthalate	2.98E-06	-	1.01E-06	-
Cadmium	-	-	-	-
Chromium	-	-	-	-
Cobalt	-	-	-	-
Copper	-	-	-	-
4,4'-DDT	2.35E-07	2.58E-07	7.94E-08	8.71E-08
di-n-Butylphthalate	-	-	-	-
Heptachlor epoxide	7.51E-06	5.83E-06	2.54E-06	1.97E-06
Iron	-	-	-	-
Lead	-	-	-	-
m,p-Xylenes	-	-	-	-
Manganese	-	-	-	-
Mercury	-	-	-	-
Methyl mercury	-	-	-	-
Perchlorate	-	-	-	-
Selenium	-	-	-	-
Silver	-	-	-	-
Thallium	-	-	-	-
Vanadium	-	-	-	-
Zinc	-	-	-	-
TCDD equivalents	2.85E-05	2.40E-07	9.62E-06	8.09E-08
Total Carcinogenic Risk	4E-05	6E-06	1E-05	2E-06

As an upper bound on these risk estimates, note that if subsistence fishermen are assumed to be exposed to the maximum concentrations of COPCs in fish caught at the Mākua muliwai, the overall risk estimate is approximately 2 x 10^{-4}, with a background contribution of 7 x 10^{-6}, giving an incremental risk from fish consumption at the muliwai of 1.9 x 10^{-4} (Table 4-8). This risk estimate exceeds the 1 x 10^{-5} risk level used in assessing fish consumption (USEPA 2000a), although it is within the USEPA (1990) target risk range of 10^{-6} to 10^{-4}. The incremental risks over background are largely due to assumed exposures to dioxins/furans.

Noncarcinogenic hazards were also calculated for subsistence fishermen potentially exposed to the mean concentrations of COPCs in fish caught at the Mākua muliwai. Table 4-9 shows that the overall HI was estimated at approximately 20, with a background contribution of 47. Therefore, there is no incremental hazard (i.e., over background) from fish consumption at the muliwai.

As an upper bound on these hazard estimates, it should be noted that if subsistence fishermen are assumed to be exposed to the maximum concentrations of COPCs in fish caught at the Mākua muliwai, the overall HI is estimated at approximately 44, with a background contribution of 51. Therefore, there is no incremental hazard (i.e., over background) from fish consumption at the muliwai.

Recreational Fishermen

Using likely fish consumption rates for Hawai'i, carcinogenic risk probabilities were calculated for current and future recreational fishermen potentially exposed to the mean concentrations of COPCs in fish caught at the Mākua muliwai. Table 4-7 shows that the overall risk estimate is approximately 1 x 10^{-5}, with a background contribution of 2 x 10^{-6}. Therefore, the incremental risks (i.e., over background) from fish consumption at the muliwai is approximately 1 x 10^{-5} for recreational fishermen. This risk estimate, therefore, does not exceed the 1 x 10^{-5} risk level used in assessing fish consumption (USEPA 2000a).

As an upper bound on these risk estimates, it should be noted that if recreational fishermen are assumed to be exposed to the maximum concentrations of COPCs in fish caught at the Mākua muliwai, the overall risk estimate is approximately 7 x 10^{-5}, with a background contribution of 2 x 10^{-6}; giving an incremental risk from fish consumption at the muliwai of 6.6 x 10^{-5} (Table 4-8). This risk estimate exceeds the 1 x 10^{-5} risk level used in assessing fish consumption (USEPA 2000a), although it is within the USEPA (1990) target risk range of 10^{-6} to 10^{-4}. The incremental risks over background are largely due to assumed exposures to dioxins/furans.

Noncarcinogenic hazards were also calculated for recreational fishermen potentially exposed to the mean concentrations of COPCs in fish caught at the Mākua muliwai. Table 4-9 shows that the overall HI was estimated at approximately 7, with a background contribution of 16. Therefore, there is no incremental hazard (i.e., over background) from fish consumption at the muliwai.

Table 4-8
Carcinogenic Risk Estimates from Fish Consumption at the Muliwai Using Maximum Contaminant Concentrations

	Subsistence Fishers		Recreational Fishers	
Chemical	**Site**	**Background**	**Site**	**Background**
Acetone	-	-	-	-
Aluminum	-	-	-	-
Antimony	-	-	-	-
Arsenic, organic	-	-	-	-
Barium	-	-	-	-
Beryllium	-	-	-	-
BHC, beta	4.55E-06	-	1.54E-06	-
BHC, delta	-	-	-	-
BHC, gamma	1.36E-06	-	4.60E-07	-
Bis(2-ethylhexyl)phthalate	2.67E-05	-	9.03E-06	-
Cadmium	-	-	-	-
Chromium	-	-	-	-
Cobalt	-	-	-	-
Copper	-	-	-	-
4,4'-DDT	6.07E-07	2.93E-07	2.05E-07	9.91E-08
di-n-Butylphthalate	-	-	-	-
Heptachlor epoxide	5.21E-06	6.17E-06	1.76E-06	2.08E-06
Iron	-	-	-	-
Lead	-	-	-	-
m,p-Xylenes	-	-	-	-
Manganese	-	-	-	-
Mercury	-	-	-	-
Methyl mercury	-	-	-	-
Perchlorate	-	-	-	-
Selenium	-	-	-	-
Silver	-	-	-	-
Thallium	-	-	-	-
Vanadium	-	-	-	-
Zinc	-	-	-	-
TCDD equivalents	1.63E-04	3.51E-07	5.49E-05	1.19E-07
Total Carcinogenic Risk	2E-04	7E-06	7E-05	2E-06

Table 4-9
Non-carcinogenic Hazard Index Estimates from Fish Consumption at the Muliwai Using Mean Contaminant Concentrations

	Subsistence Fishers		Recreational Fishers	
Chemical	**Site**	**Background**	**Site**	**Background**
Acetone	6E-04	-	2E-04	-
Aluminum	3E+00	6E+00	1E+00	2E+00
Antimony	8E-02	-	3E-02	-
Arsenic, organic	-	-	-	-
Barium	4E-01	8E-01	1E-01	3E-01
Beryllium	2E-02	6E-02	6E-03	2E-02
BHC, beta	6E-03	-	2E-03	-
BHC, delta	4E-03	-	1E-03	-
BHC, gamma	5E-03	-	2E-03	-
Bis(2-ethylhexyl)phthalate	2E-02	-	8E-03	-
Cadmium	1E-01	3E-01	5E-02	1E-01
Chromium	1E-02	2E-02	4E-03	7E-03
Cobalt	2E-01	4E-01	6E-02	1E-01
Copper	2E+00	3E+00	6E-01	9E-01
4,4'-DDT	3E-03	4E-03	1E-03	1E-03
di-n-Butylphthalate	3E-03	2E-04	1E-03	7E-05
Heptachlor epoxide	1E-01	1E-01	5E-02	4E-02
Iron	-	-	-	-
Lead	-	-	-	-
m,p-Xylenes	9E-05	-	3E-05	-
Manganese	1E+01	3E+01	4E+00	1E+01
Mercury	3E-01	2E-01	9E-02	7E-02
Methyl mercury	8E-01	6E-01	3E-01	2E-01
Perchlorate	6E-02	1E-03	2E-02	4E-04
Selenium	7E-01	7E-01	2E-01	2E-01
Silver	1E-01	2E-01	4E-02	6E-02
Thallium	1E-01	-	4E-02	-
Vanadium	9E-01	2E-01	3E-01	5E-02
Zinc	5E-01	5E-01	2E-01	2E-01
TCDD equivalents	-	-	-	-
Total HI	20	47	7	16

As an upper bound on these hazard estimates, it should be noted that if recreational fishermen are assumed to be exposed to the maximum concentrations of COPCs in fish caught at the Mākua muliwai, the overall HI is estimated at approximately 15, with a background contribution of 17 (Table 4-10). Therefore, there is no incremental hazard (i.e., over background) from fish consumption at the muliwai.

Nearshore Mākua Beach—Fish Consumption

Subsistence Fishermen

Using likely fish consumption rates for Hawai'i, carcinogenic risk probabilities were calculated for current and future subsistence fishermen potentially exposed to the mean concentrations of COPCs in fish caught in the shallow nearshore waters at Mākua Beach. Table 4-11 shows that the overall risk estimate is approximately 9×10^{-5}, with background contribution of 6×10^{-5}. The incremental risks (i.e., over background) from fish consumption is approximately 3×10^{-5} for subsistence fishermen. This risk estimate exceeds the risk level used in assessing fish consumption of 1×10^{-5} (USEPA 2000a), although it is within the USEPA (1990) target risk range of 10^{-6} to 10^{-4}. The incremental risks over background are largely due to assumed exposures to alpha-BHC, bis(2-ethylhexyl)phthalate, and heptachlor epoxide.

As an upper bound on these risk estimates, it should be noted that if subsistence fishermen are assumed to be exposed to the maximum concentrations of COPCs in fish caught in the shallow nearshore waters at Mākua Beach, the overall risk estimate is approximately 2×10^{-4}, with a background contribution of 1×10^{-4}. The incremental risks (i.e., over background) from fish consumption is approximately 5×10^{-5} for subsistence fishermen. This risk estimate exceeds the risk level used in assessing fish consumption of 1×10^{-5} (USEPA 2000a), although it is within the USEPA (1990) target risk range of 10^{-6} to 10^{-4}. These incremental risks over background are largely due to assumed exposures to alpha-BHC, bis(2-ethylhexyl)phthalate, and heptachlor epoxide (Table 4-12).

Noncarcinogenic hazards were also calculated for subsistence fishermen potentially exposed to the mean concentrations of COPCs in fish caught in the shallow nearshore waters at Mākua Beach. Table 4-13 shows that the overall HI was estimated at approximately 4, with a background contribution of 5. Therefore, there is no incremental hazard (i.e., over background) from fish consumption.

As an upper bound on these hazard estimates, it should be noted that if subsistence fishermen are assumed to be exposed to the maximum concentrations of COPCs (Table 4-14), the overall HI is estimated at approximately 9 with a background contribution of 23. Therefore, there is no incremental hazard (i.e., over background).

Recreational Fishermen

Using likely fish consumption rates for Hawai'i, carcinogenic risk probabilities were calculated for current and future recreational fishermen potentially exposed to the mean concentrations of COPCs in fish caught in the shallow nearshore waters at Mākua Beach.

Table 4-10
Non-carcinogenic Hazard Index Estimates from Fish Consumption at the Muliwai Using Maximum Contaminant Concentrations

	Subsistence Fishers		Recreational Fishers	
Chemical	**Site**	**Background**	**Site**	**Background**
Acetone	6E-04	-	2E-04	-
Aluminum	6E+00	7E+00	2E+00	3E+00
Antimony	2E-01	-	6E-02	-
Arsenic, organic	-	-	-	-
Barium	5E-01	9E-01	2E-01	3E-01
Beryllium	4E-02	7E-02	1E-02	2E-02
BHC, beta	2E-02	-	7E-03	-
BHC, delta	1E-03	-	5E-04	-
BHC, gamma	8E-03	-	3E-03	-
Bis(2-ethylhexyl)phthalate	2E-01	-	8E-02	-
Cadmium	4E-01	4E-01	1E-01	1E-01
Chromium	3E-02	2E-02	1E-02	8E-03
Cobalt	3E-01	4E-01	1E-01	1E-01
Copper	6E+00	3E+00	2E+00	1E+00
4,4'-DDT	8E-03	4E-03	3E-03	1E-03
di-n-Butylphthalate	2E-02	3E-04	7E-03	9E-05
Heptachlor epoxide	1E-01	1E-01	3E-02	4E-02
Iron	-	-	-	-
Lead	-	-	-	-
m,p-Xylenes	1E-04	-	4E-05	-
Manganese	2E+01	4E+01	8E+00	1E+01
Mercury	5E-01	2E-01	2E-01	8E-02
Methyl mercury	2E+00	8E-01	8E-01	3E-01
Perchlorate	3E-01	3E-03	1E-01	1E-03
Selenium	1E+00	7E-01	4E-01	2E-01
Silver	3E-01	2E-01	1E-01	7E-02
Thallium	1E-01	-	4E-02	-
Vanadium	1E+00	2E-01	5E-01	6E-02
Zinc	1E+00	6E-01	3E-01	2E-01
TCDD equivalents	-	-	-	-
Total HI	44	51	15	17

Table 4-11
Carcinogenic Risk Estimates from Fish Consumption at Makua Beach Using Mean Contaminant Concentrations

	Subsistence Fishers		Recreational Fishers	
Chemical	**Site**	**Background**	**Site**	**Background**
Acetone	-	-	-	-
Aldrin	2.06E-05	2.80E-05	6.96E-06	9.45E-06
Aluminum	-	-	-	-
Antimony	-	-	-	-
Arsenic, organic	-	-	-	-
Barium	-	-	-	-
BHC, alpha	7.97E-06	-	2.69E-06	-
BHC, delta	-	-	-	-
BHC, gamma	2.14E-06	3.09E-06	7.22E-07	1.04E-06
Beryllium	-	-	-	-
Bis(2-Ethylhexyl)Phthalate	1.21E-05	4.83E-07	4.09E-06	1.63E-07
Cadmium	-	-	-	-
Chromium	-	-	-	-
Cobalt	-	-	-	-
Copper	-	-	-	-
4,4'-DDT	1.03E-07	2.07E-07	3.48E-08	7.00E-08
Diethyl phthalate	-	-	-	-
di-n-Butylphthalate	-	-	-	-
Heptachlor	5.18E-06	8.13E-06	1.75E-06	2.75E-06
Heptachlor epoxide	3.42E-05	1.66E-05	1.16E-05	5.61E-06
Iron	-	-	-	-
Lead	-	-	-	-
m,p-Xylenes	-	-	-	-
Manganese	-	-	-	-
Mercury	-	-	-	-
Methyl mercury	-	-	-	-
Nitroglycerin	1.47E-06	-	4.97E-07	-
Perchlorate	-	-	-	-
RDX	3.84E-06	-	1.30E-06	-
Selenium	-	-	-	-
Silver	-	-	-	-
Thallium	-	-	-	-
Vanadium	-	-	-	-
Zinc	-	-	-	-
TCDD equivalents	-	3.36E-06	-	1.14E-06
Total Carcinogenic Risk	9.E-05	6.E-05	3.E-05	2.E-05

Table 4-12
Carcinogenic Risk Estimates from Fish Consumption at Makua Beach Using Maximum Contaminant Concentrations

	Subsistence Fishers		Recreational Fishers	
Chemical	**Site**	**Background**	**Site**	**Background**
Acetone	-	-	-	-
Aldrin	3.E-05	7.E-05	1.E-05	2.E-05
Aluminum	-	-	-	-
Antimony	-	-	-	-
Arsenic, organic	-	-	-	-
Barium	-	-	-	-
Beryllium	-	-	-	-
BHC, alpha	3.E-05	-	1.E-05	-
BHC, delta	-	-	-	-
BHC, gamma	5.E-06	2.E-06	2.E-06	5.E-07
Bis(2-Ethylhexyl)Phthalate	3.E-05	4.E-07	1.E-05	1.E-07
Cadmium	-	-	-	-
Chromium	-	-	-	-
Cobalt	-	-	-	-
Copper	-	-	-	-
4,4'-DDT	4.E-08	4.E-07	1.E-08	1.E-07
Diethyl phthalate	-	-	-	-
di-n-Butylphthalate	-	-	-	-
Heptachlor	2.E-05	2.E-05	5.E-06	5.E-06
Heptachlor epoxide	8.E-05	4.E-05	3.E-05	1.E-05
Iron	-	-	-	-
Lead	-	-	-	-
m,p-Xylenes	-	-	-	-
Manganese	-	-	-	-
Mercury	-	-	-	-
Methyl mercury	-	-	-	-
Nitroglycerin	3.E-06	-	1.E-06	-
Perchlorate	-	-	-	-
RDX	4.E-06	-	1.E-06	-
Selenium	-	-	-	-
Silver	-	-	-	-
Thallium	-	-	-	-
Vanadium	-	-	-	-
Zinc	-	-	-	-
TCDD equivalents	-	2.E-05	-	5.E-06
Total Carcinogenic Risk	2.E-04	1.E-04	7.E-05	5.E-05

Table 4-13
Non-carcinogenic Hazard Index Estimates from Fish Consumption at Makua Beach Using Mean Contaminant Concentrations

	Subsistence Fishers		Recreational Fishers	
Chemical	**Site**	**Background**	**Site**	**Background**
Acetone	8.E-04	2.E-04	3.E-04	2.E-04
Aldrin	9.E-02	4.E-02	3.E-02	4.E-02
Aluminum	4.E-02	4.E-01	1.E-02	4.E-01
Antimony	-	2.E-02	-	2.E-02
Arsenic, organic	-	-	-	-
Barium	1.E-01	4.E-02	5.E-02	4.E-02
Beryllium	-	3.E-03	-	3.E-03
BHC, alpha	1E-02	-	3E-03	-
BHC, delta	5.E-03	-	2.E-03	-
BHC, gamma	1.E-02	2.E-02	4.E-03	6.E-03
Bis(2-Ethylhexyl)Phthalate	1.E-01	4.E-03	3.E-02	1.E-03
Cadmium	4.E-01	3.E-01	1.E-01	1.E-01
Chromium	5.E-03	7.E-03	2.E-03	2.E-03
Cobalt	2.E-02	6.E-02	6.E-03	2.E-02
Copper	2.E-01	2.E-01	5.E-02	6.E-02
4,4'-DDT	1.E-03	3.E-03	5.E-04	1.E-03
Diethyl phthalate	-	7.E-05	-	2.E-05
di-n-Butylphthalate	4.E-03	2.E-03	2.E-03	7.E-04
Heptachlor	5.E-03	2.E-05	2.E-03	7.E-06
Heptachlor epoxide	7.E-01	3.E-01	2.E-01	1.E-01
Iron	-	-	-	-
Lead	-	-	-	-
m,p-Xylenes	1.E-04	1.E-04	4.E-05	3.E-05
Manganese	5.E-01	2.E+00	2.E-01	6.E-01
Mercury	3.E-01	1.E-01	1.E-01	4.E-02
Methyl mercury	1.E+00	5.E-01	4.E-01	2.E-01
Nitroglycerin	2E+00	-	8.29E-01	-
Perchlorate	3.E-03	4.E-02	1.E-03	1.E-02
RDX	3.E-02	-	9.E-03	-
Selenium	3.E-01	3.E-01	1.E-01	1.E-01
Silver	3.E-03	3.E-03	9.E-04	1.E-03
Thallium	-	1.E-01	-	5.E-02
Vanadium	4.E-02	3.E-01	1.E-02	9.E-02
Zinc	4.E-01	3.E-01	1.E-01	1.E-01
Total HI	7	5	2	2

Table 4-14
Non-carcinogenic Hazard Index Estimates from Fish Consumption at Makua Beach Using Maximum Contaminant Concentrations

	Subsistence Fishers		Recreational Fishers	
Chemical	**Site**	**Background**	**Site**	**Background**
Acetone	1.E-03	1.E-03	4.E-04	3.E-04
Aldrin	1.E-01	3.E-01	4.E-02	1.E-01
Aluminum	9.E-02	7.E+00	3.E-02	2.E+00
Antimony	-	9.E-02	-	3.E-02
Arsenic, organic	-	-	-	-
Barium	6.E-01	3.E-01	2.E-01	1.E-01
Beryllium	-	5.E-02	-	2.E-02
BHC, alpha	3.93E-02	-	1.33E-02	-
BHC, delta	1.E-03	-	5.E-04	-
BHC, gamma	3.E-02	9.E-03	1.E-02	3.E-03
Bis(2-Ethylhexyl)Phthalate	3.E-01	4.E-03	9.E-02	1.E-03
Cadmium	6.E-01	6.E-01	2.E-01	2.E-01
Chromium	1.E-02	3.E-02	3.E-03	1.E-02
Cobalt	3.E-02	3.E-01	1.E-02	1.E-01
Copper	4.E-01	6.E-01	1.E-01	2.E-01
4,4'-DDT	5.E-04	6.E-03	2.E-04	2.E-03
Diethyl phthalate	-	3.E-05	-	1.E-05
di-n-Butylphthalate	2.E-02	9.E-03	7.E-03	3.E-03
Heptachlor	2.E-02	4.E-05	5.E-03	1.E-05
Heptachlor epoxide	2.E+00	8.E-01	5.E-01	3.E-01
Iron	-	-	-	-
Lead	-	-	-	-
m,p-Xylenes	1.E-04	1.E-04	5.E-05	4.E-05
Manganese	9.E-01	9.E+00	3.E-01	3.E+00
Mercury	5.E-01	2.E-01	2.E-01	7.E-02
Methyl mercury	3.E+00	8.E-01	1.E+00	3.E-01
Nitroglycerin	4.74E+00	-	1.60E+00	-
Perchlorate	2.E-02	2.E-01	6.E-03	8.E-02
RDX	3.E-02	-	9.E-03	-
Selenium	5.E-01	5.E-01	2.E-01	2.E-01
Silver	4.E-03	9.E-03	1.E-03	3.E-03
Thallium	-	2.E-01	-	8.E-02
Vanadium	9.E-02	1.E+00	3.E-02	5.E-01
Zinc	7.E-01	4.E-01	2.E-01	1.E-01
Total HI	10	23	5	8

Table 4-11 shows that the overall risk estimate is approximately 3 x 10^{-5}, with background contribution of 2 x 10^{-5}. Therefore, the incremental risks (i.e., over background) from fish consumption in nearshore waters at Mākua is approximately 9 x 10^{-6} for recreational fishermen. This risk estimate does not exceed the risk level used in assessing fish consumption of 1 x 10^{-5} (USEPA 2000a).

As an upper bound on these risk estimates and to err on the side of extreme caution, note that if recreational fishermen are assumed to be exposed to the maximum concentrations of COPCs in fish caught at the Mākua Beach, the overall risk estimate is approximately 7 x 10^{-5}, with background contribution of 5 x 10^{-5}; giving an incremental risk from fish consumption of 2 x 10^{-5} (Table 4-12). This risk estimate exceeds the risk level used in assessing fish consumption of 1 x 10^{-5} (USEPA 2000a), although it is within the USEPA (1990) target risk range of 10^{-6} to 10^{-4}. These incremental risks over background are largely due to assumed exposures to alpha-BHC, bis(2-ethylhexyl)phthalate, and heptachlor epoxide (Table 4-12). However, these compounds cannot be traced back exclusively to activities MMR.

Noncarcinogenic hazards were also calculated for recreational fishermen potentially exposed to the mean concentrations of COPCs in fish caught at Mākua Beach. Table 4-13 shows that the overall HI was estimated at approximately 2, with background contribution of 2. Therefore, there is no incremental hazard (i.e., over background) from fish consumption.

As an upper bound on these hazard estimates, note that if subsistence fishermen are assumed to be exposed to the maximum concentrations of COPCs in fish caught at the Mākua muliwai, the overall HI is estimated at approximately 3, with background contribution of 8. Therefore, there is no incremental hazard (i.e., over background) from fish consumption (Table 4-14).

Nearshore Mākua Beach—Limu Consumption

Subsistence Fishermen

Carcinogenic risk probabilities were calculated for current and future subsistence fishermen potentially exposed to the mean concentrations of COPCs in limu harvested from the shallow nearshore waters at Mākua Beach. Table 4-15 shows that the overall risk estimate is approximately 1 x 10^{-2}. This risk estimate exceeds the risk level used in assessing fish consumption of 1 x 10^{-5} (USEPA 2000a) and the USEPA (1990) target risk range of 10^{-6} to 10^{-4}. This risk estimate is almost entirely due to assumed exposures to arsenic in limu, which was up to 109 mg/kg.

The arsenic in limu was assumed to be entirely inorganic; however, the arsenic was not speciated and the limu was not identified to species. In many limu species, arsenic can be present entirely in nontoxic organic forms, although it is present in some species in inorganic forms at up to 50 percent or more (Frankenberger 2002). Therefore, it is likely that at least some of the arsenic present in the limu harvested from the shallow nearshore waters at Mākua Beach is present in nontoxic organic forms, indicating that the risks here are overestimated to a certain degree. Further, since no background samples were collected, it is

Table 4-15
Carcinogenic Risks and Non-carcinogenic Hazards from Consumption of Seaweed (Mean COPC Concentrations)

	Carcinogenic Risk		Hazard Index (HI)	
Chemical	**Subsistence fisher**	**Recreational fisher**	**Subsistence fisher**	**Recreational fisher**
Aluminum	-	-	1.E-01	3.E-02
Antimony	-	-	4.E-02	1.E-02
Arsenic, inorganic	1.11E-02	3.16E-03	6.E+01	2.E+01
Barium	-	-	3.E-02	1.E-02
Beryllium	-	-	1.E-03	3.E-04
Bis(2-Ethylhexyl)Phthalate	1.30E-07	3.70E-08	1.E-03	3.E-04
Cadmium	-	-	1.E-01	4.E-02
Chromium	-	-	4.E-04	1.E-04
Cobalt	-	-	9.E-03	3.E-03
Copper	-	-	2.E-02	5.E-03
di-n-Butylphthalate	-	-	4.E-04	1.E-04
Heptachlor	6.26E-07	1.79E-07	6.E-04	2.E-04
Iron	-	-	-	-
Lead	-	-	-	-
m,p-Xylenes	-	-	3.E-05	8.E-06
Manganese	-	-	2.E-01	5.E-02
Perchlorate	-	-	6.E-03	2.E-03
Selenium	-	-	1.E-02	4.E-03
Silver	-	-	4.E-03	1.E-03
Thallium	-	-	5.E-02	2.E-02
Vanadium	-	-	8.E-02	2.E-02
Zinc	-	-	9.E-03	3.E-03
TCDD equivalents	3.90E-13	1.11E-13	-	-
Total	**1E-02**	**3E-03**	**58**	**17**

not possible to determine whether the arsenic levels detected in limu at Mākua Beach are elevated over background. The levels detected at Mākua Beach may well be naturally occurring.

As an upper bound on these risk estimates, note that if subsistence fishermen are assumed to be exposed to the maximum concentrations of COPCs in limu harvested at Mākua Beach, the overall risk estimate is approximately 2 x 10^{-2} (Table 4-16). Again, this is almost entirely due to arsenic.

Noncarcinogenic hazards were also calculated for subsistence fishermen potentially exposed to the mean concentrations of COPCs in limu harvested in the shallow nearshore waters at Mākua Beach. Table 4-15 shows that the overall HI was estimated at approximately 58, which exceeds the threshold HI of 1. As for the carcinogenic risk estimates presented above, this is almost entirely due to assumed exposures to arsenic. As an upper bound on these hazard estimates, note that if subsistence fishermen are assumed to be exposed to the maximum concentrations of COPCs (Table 4-16), the overall HI is estimated at approximately 96.

Recreational Fishermen

Carcinogenic risk probabilities were calculated for current and future recreational fishermen potentially exposed to the mean concentrations of COPCs in limu harvested from the shallow nearshore waters at Mākua Beach. Table 4-15 shows that the overall risk estimate is approximately 3 x 10^{-3}. This risk estimate exceeds the risk level used in assessing fish consumption of 1 x 10^{-5} (USEPA 2000a) and the USEPA (1990) target risk range of 10^{-6} to 10^{-4}. This risk estimate is almost entirely due to assumed exposures to arsenic in limu. As an upper bound on these risk estimates, note that if recreational fishermen are assumed to be exposed to the maximum concentrations of COPCs in limu from Mākua Beach, the overall risk estimate is approximately 5 x 10^{-3} (Table 4-16).

Noncarcinogenic hazards were also calculated for recreational fishermen potentially exposed to the mean concentrations of COPCs in fish caught at the Mākua muliwai. Table 4-15 shows that the overall HI was estimated at approximately 17. This HI is almost entirely due to assumed exposures to arsenic and exceeds the threshold HI of 1. As an upper bound on these hazard estimates, note that if subsistence fishermen are assumed to be exposed to the maximum concentrations of COPCs in limu from Mākua Beach, the overall HI is estimated at approximately 27 (Table 4-16).

Mākua Muliwai—Shellfish Consumption

Subsistence Shellfish Fishermen

Using likely shellfish consumption rates for Hawai'i, carcinogenic risk probabilities were calculated for current and future subsistence shellfish fishermen potentially exposed to the upperbound (maximum) concentrations of COPCs in shellfish harvested at the Mākua muliwai. Table 4-17 shows that the overall risk estimate is approximately 3.5 x 10^{-5}, with a background contribution also of 3.1 x 10^{-5}. The incremental risk (i.e., over background) from

Table 4-16
Carcinogenic Risks and Non-carcinogenic Hazards from Consumption of Seaweed (Mean COPC Concentrations)

	Carcinogenic Risk		Hazard Index (HI)	
Chemical	**Subsistence fisher**	**Recreational fisher**	**Subsistence fisher**	**Recreational fisher**
Aluminum	-	-	3.E-01	8.E-02
Antimony	-	-	9.E-02	3.E-02
Arsenic, inorganic	1.82E-02	5.21E-03	9.E+01	3.E+01
Barium	-	-	5.E-02	1.E-02
Beryllium	-	-	3.E-03	7.E-04
Bis(2-Ethylhexyl)Phthalate	1.34E-07	3.83E-08	1.E-03	3.E-04
Cadmium	-	-	1.E-01	4.E-02
Chromium	-	-	1.E-03	3.E-04
Cobalt	-	-	2.E-02	5.E-03
Copper	-	-	3.E-02	8.E-03
di-n-Butylphthalate	-	-	1.E-03	4.E-04
Heptachlor	3.61E-07	1.03E-07	4.E-04	1.E-04
Iron	-	-	-	-
Lead	-	-	-	-
m,p-Xylenes	-	-	2.E-05	6.E-06
Manganese	-	-	4.E-01	1.E-01
Perchlorate	-	-	2.E-02	6.E-03
Selenium	-	-	4.E-03	1.E-03
Silver	-	-	7.E-03	2.E-03
Thallium	-	-	9.E-02	2.E-02
Vanadium	-	-	2.E-01	5.E-02
Zinc	-	-	1.E-02	3.E-03
TCDD equivalents	1.12E-12	3.21E-13	-	-
Total	**2E-02**	**5E-03**	**96**	**27**

Table 4-17
Carcinogenic Risk Estimates from Shellfish Consumption at the Muliwai Using Maximum Contaminant Concentrations

	Subsistence Fishers		Recreational Fishers	
Chemical	**Site**	**Background**	**Site**	**Background**
Aluminum	-	-	-	-
Arsenic, organic	-	-	-	-
Barium	-	-	-	-
Chromium	-	-	-	-
Cobalt	-	-	-	-
Copper	-	-	-	-
Iron	-	-	-	-
Lead	-	-	-	-
Manganese	-	-	-	-
Mercury	-	-	-	-
Selenium	-	-	-	-
Silver	-	-	-	-
Vanadium	-	-	-	-
Zinc	-	-	-	-
TCDD equivalents	3.45E-05	3.05E-05	1.17E-05	1.03E-05
Total Carcinogenic Risk	3E-05	3E-05	1E-05	1E-05

shellfish consumption at the muliwai is approximately 4 x 10^{-6} for subsistence shellfish fishermen. The incremental risk estimate is below the 1 x 10^{-5} risk level (one person in 100,000 people may develop cancer) used in assessing fish consumption (USEPA 2000a).

Noncarcinogenic hazards were also calculated for recreational shellfish fishermen potentially exposed to the maximum concentrations of COPCs in shellfish harvested at the Mākua muliwai. Table 4-18 shows that the overall HI was estimated at approximately 14, with a background contribution of 9. The incremental hazard (i.e., over background) from shellfish consumption for the muliwai was estimated at 5. The incremental hazard over background is largely due to assumed exposures to manganese and possibly cobalt.

Recreational Shellfish Fishermen

Using likely shellfish consumption rates for Hawai'i, carcinogenic risk probabilities were calculated for current and future recreational shellfish fishermen potentially exposed to the maximum concentrations of COPCs in shellfish harvested at the Mākua muliwai. Table 4-17 shows that the overall risk estimate is approximately 1.2 x 10^{-5}, with a background contribution also of approximately 1 x 10^{-5}. The incremental risks (i.e., over background) from shellfish consumption for the muliwai is approximately 1 x 10^{-6} for recreational shellfish fishermen. This risk estimate is below the 1 x 10^{-5} risk level used in assessing fish consumption (USEPA 2000a).

Noncarcinogenic hazards were also calculated for recreational shellfish fishermen potentially exposed to the maximum concentrations of COPCs in shellfish harvested at the Mākua muliwai. Table 4-18 shows that the overall HI was estimated at approximately 5, with a background contribution of 3. Therefore, the incremental hazard (i.e., over background) from shellfish consumption for the muliwai was estimated at 2. The incremental hazard over background is largely due to assumed exposure to manganese.

Nearshore Mākua Beach—Shellfish Consumption

Subsistence Shellfish Fishermen

Using likely shellfish consumption rates for Hawai'i, carcinogenic risk probabilities were calculated for current and future subsistence shellfish fishermen potentially exposed to the maximum concentrations of COPCs in shellfish harvested in the shallow nearshore waters at Mākua Beach. Table 4-19 shows that the overall risk estimate is approximately 1 x 10^{-5}, with a background contribution of 8 x 10^{-5}. Accordingly, there is no incremental cancer risk (i.e., over background) for shellfish harvested at Mākua Beach because the risk estimated for background is higher than that estimated for shellfish harvested at Mākua Beach.

Noncarcinogenic hazards were also calculated for subsistence shellfish fishermen potentially exposed to the maximum concentrations of COPCs in shellfish harvested in the shallow nearshore waters at Mākua Beach. Table 4-20 shows that the overall HI was estimated at approximately 12, with a background contribution of 3. Therefore, the incremental hazard (i.e., over background) from shellfish consumption for nearshore waters at Mākua Beach was estimated at 9. The incremental hazard over background is largely due to assumed exposure

Table 4-18
Non-carcinogenic Hazard Index Estimates from Shellfish Consumption at the Muliwai Using Maximum Contaminant Concentrations

	Subsistence Fishers		Recreational Fishers	
Chemical	**Site**	**Background**	**Site**	**Background**
Aluminum	2E-01	1E-01	7E-02	4E-02
Arsenic, organic	-	-	-	-
Barium	4E-01	1E-01	1E-01	4E-02
Chromium	1E-03	1E-03	4E-04	4E-04
Cobalt	4E+00	1E+00	1E+00	5E-01
Copper	1E+00	2E+00	5E-01	8E-01
Iron	5E-01	2E-01	2E-01	8E-02
Lead	-	-	-	-
Manganese	7E+00	2E+00	2E+00	7E-01
Mercury	1E-01	-	4E-02	-
Selenium	3E-01	5E-01	1E-01	2E-01
Silver	-	7E-02	-	2E-02
Vanadium	6E-02	3E-02	2E-02	9E-03
Zinc	1E-01	2E+00	5E-02	8E-01
TCDD equivalents	-	-	-	-
Total HI	14	9	5	3

Table 4-19
Carcinogenic Risk Estimates from Shellfish Consumption at Makua Beach Using Maximum Contaminant Concentrations

	Subsistence Fishers		Recreational Fishers	
Chemical	**Site**	**Background**	**Site**	**Background**
Aldrin	1.15E-05	-	3.89E-06	-
Aluminum	-	-	-	-
Arsenic, organic	-	-	-	-
Barium	-	-	-	-
Cadmium	-	-	-	-
Chromium	-	-	-	-
Cobalt	-	-	-	-
Copper	-	-	-	-
Iron	-	-	-	-
Lead	-	-	-	-
Manganese	-	-	-	-
Mercury	-	-	-	-
Perchlorate	-	-	-	-
Selenium	-	-	-	-
Silver	-	-	-	-
Toluene	-	-	-	-
Vanadium	-	-	-	-
Zinc	-	-	-	-
TCDD equivalents	2.22E-07	7.64E-05	7.49E-08	2.58E-05
Total Carcinogenic Risk	1E-05	8E-05	4E-06	3E-05

to cadmium and perchlorate. Notably, the maximum concentrations of cadmium and perchlorate were found in different types of shellfish in the Kona crab (cadmium) and the helmet urchin (perchlorate) at Mākua Beach.

Recreational Shellfish Fishermen

Using likely shellfish consumption rates for Hawai'i, carcinogenic risk probabilities were calculated for current and future recreational fishermen potentially exposed to the maximum concentrations of COPCs in shellfish harvested in the shallow nearshore waters at Mākua Beach. Table 4-19 shows that the overall risk estimate is approximately 4×10^{-6}, with background contribution of 3×10^{-5}. Accordingly, there is no incremental cancer risks (i.e., over background) for shellfish harvested at Mākua Beach because the risk estimated for background is higher than that estimated for shellfish harvested at Mākua Beach.

Noncarcinogenic hazards were also calculated for recreational shellfish fishermen potentially exposed to the maximum concentrations of COPCs in shellfish harvested in the shallow nearshore waters at Mākua Beach. Table 4-20 shows that the overall HI was estimated at approximately 3, with a background contribution of 1. Therefore, the incremental hazard (i.e., over background) from shellfish consumption for Mākua Beach was estimated at 2. The incremental hazard over background is largely due to assumed exposure to cadmium.

4.6 UNCERTAINTY ANALYSIS

Uncertainties associated with the identification of COPCs and with the exposure and toxicity assessment all contribute to the level of confidence that can be placed on the risk estimates presented above. Several sources of potential uncertainty in the risk estimates are summarized below.

COPCs

As described in Section 3.2, there may be numerous sources of many of the COPCs identified in fish, shellfish, and limu tissue that are not uniquely associated with the MMR. In particular, this was the case for as many as eight of the COPCs, with risk estimates contributing to incremental risks greater than the 1×10^{-5} risk level used in assessing fish consumption. Specifically, these sources are as follows:

- Bis(2-ethylhexyl) phthalate (DEHP) is in PVC and is found in plastic products, such as toys, adhesives, coatings, some food packaging, medical product containers and equipment, some inks, pesticides, and cosmetics. DEHP's wide use and persistence mean that it is widely distributed in the environment;
- Organochlorine pesticides, including alpha-BHC and heptachlor epoxide, were widely used on O'ahu for termite control and for agriculture because of their toxicity to pests and persistence in the environment. This persistence and transport by water of soil particulates has also led to the presence of pesticides in a variety of environmental media, in addition to the soil where they were initially applied;
- Perchlorate occurs both naturally (Table 3-2) and as a manufactured compound; and

Table 4-20
Non-carcinogenic Hazard Index Estimates from Shellfish Consumption at Makua Beach Using Maximum Contaminant Concentrations

	Subsistence Fishers		Recreational Fishers	
Chemical	**Site**	**Background**	**Site**	**Background**
Aldrin	5E-02	-	2E-02	-
Aluminum	1E-01	9E-02	5E-02	3E-02
Arsenic, organic	-	-	-	-
Barium	2E-02	1E-02	6E-03	4E-03
Beryllium		4E-02	-	2E-02
Cadmium	6E+00	-	2E+00	-
Chromium	1E-03	1E-03	4E-04	4E-04
Cobalt	2E+00	2E+00	6E-01	7E-01
Copper	9E-01	7E-02	3E-01	2E-02
Iron	3E-01	2E-01	9E-02	7E-02
Lead	-	-	-	-
Manganese	2E-01	1E-01	7E-02	4E-02
Mercury	2E-01	-	7E-02	-
Perchlorate	2E+00	-	7E-01	-
Selenium	5E-01	3E-01	2E-01	1E-01
Silver	4E-02	2E-05	1E-02	5E-06
Toluene	2E-05	3E-02	7E-06	9E-03
Vanadium	4E-02	3E-02	1E-02	1E-02
Zinc	2E-01	-	8E-02	-
TCDD equivalents	-	- -	-	-
Total HI	12	3	4	1

- Trace metals, including arsenic, cadmium, cobalt, and manganese above baseline levels on Oʻahu, may originate from volcanic emissions, vehicle emissions, vehicle-associated wear, and agricultural fertilizer and pesticide inputs (Sutherland 2000). The data presented in the 2005 draft EIS for Military Training Activities at Mākua Military Reservation, Hawaiʻi (Tetra Tech 2005) indicated that most of the metals, except for arsenic, detected in soils at MMR are present at concentrations that are within the background range for soils in Hawaiʻi (Tetra Tech 2005). Elevated levels of arsenic in Hawaiʻi have been identified in soils from former sugar cane fields due to the use of arsenic-based pesticides from the 1920s through the 1940s (HDOH 2006b). However, past and proposed munitions used by the US military contain arsenic, cadmium, cobalt, and manganese in varying concentrations.

Therefore, because there are various possible sources of the COPCs identified in fish, shellfish, and limu tissues that are not unique to military training, there may be considerable uncertainty that the risks estimated for fishermen are related to activities at the MMR.

Uncertainty was also introduced into the identification of COPCs due to the laboratory analytical results. Some of the analytical data for the organochlorine pesticides was flagged by the analytical laboratory as having unacceptable relative percent differences between the high pressure liquid chromatography and gas chromatograph columns. This indicates that there was either interference from polychlorinated biphenyl compounds or co-elution of a nontarget compound on one of the columns. This provides an unacceptable level of uncertainty to the results flagged in this manner, so all analytical results flagged by the analytical laboratories this way were considered suspect and were not used.

The analytical laboratory flagged some metals data from the fish and limu samples as having matrix spike sample recoveries outside of acceptable limits. US EPA (1989) guidance states that data flagged in this way is usable in a risk assessment.

The laboratory flagged the highest detected concentration of nitroglycerin in fish tissue from the muliwai as follows: "There was a positive detection for nitroglycerin on the primary analysis. Nitroglycerin was tentatively confirmed on the confirmation column analysis although a large interference peak eluted at the retention time of the analyte. There is a shoulder on the side of the peak that could possibly be the analyte. The analyte is being reported as positively identified in a conservative approach to protecting the environment." Therefore, the laboratory may have overestimated the concentration of nitroglycerin in fish tissues at the Mākua muliwai.

Exposure Assessment

It was necessary to make a large number of assumptions to estimate potential chemical exposures. To ensure that risks were not underestimated, many of the assumptions made in the exposure analyses were selected because they were considered to be health protective; consequently, risks may have been overestimated.

One major source of uncertainty in this risk assessment was the assumption that fishermen and shellfish fishermen could rely on the muliwai for all of their fishing. The muliwai are

generally the size of a small pond, so it is unlikely that the two muliwai evaluated here could hold enough fish or shellfish to support even one subsistence fisher. Before long, a subsistence fisher would depopulate the muliwai and be forced to go fishing or shellfishing elsewhere. In addition, the barrier separating the muliwai from the ocean is occasionally breached due to either heavy stream flows or strong waves. In either case, the fish and shellfish population of the muliwai can change dramatically at that time, with new species appearing and other species disappearing. When heavy rainfall leads to a breach in the barrier separating the muliwai from the ocean, the fish and likely also the shellfish, such as the prawns and crabs, in the muliwai also get expelled into the ocean, leading to a period of lower fish and shellfish abundance in the muliwai. Both of these factors indicate that the assumption of a subsistence fisher relying exclusively on the muliwai is unrealistic and, therefore, the risk estimates for the subsistence fisher at the muliwai should be regarded as an artificial scenario that overestimates exposures to chemicals present in the muliwai fish and shellfish.

Fishermen were assumed to eat whatever fish were caught as part of this study, rather than just fish of a specific species; however, some fishermen may target only certain species. The same type of preferential harvesting of shellfish may also occur. Preferential harvesting of shellfish may be particularly pertinent for Mākua Beach because perchlorate was found only in the helmet urchin and not the Kona crab. Therefore, depending on the preference of the individual fisherman, exposures and potential health risks could vary from that presented here (i.e., either overestimated or underestimated).

For shellfish, the risk and hazard estimates were based on the likely fish consumption rate for Hawai‘i (i.e., 100.6 g/day). This rate is higher than the shellfish consumption rate estimated for the US population in general, particularly the rate reported for prepared crab and shrimp (mean of approximately 2 g/day) (USEPA 2002c). Further, risk and hazard estimates were calculated using the maximum concentrations of COPCs in shellfish, given the limited data with which to estimate mean concentrations. In combination, these assumptions likely resulted in overestimation of risks and hazards due to shellfish consumption.

Fishermen were assumed to eat fish whole and not remove the skin, head, gonads, or gastro-intestinal tract. Many fishermen do not eat whole fish, only fish fillets. In the process of filleting and cooking a fish, the concentrations of some contaminants may be reduced. Therefore, the risk estimates presented here may overestimate the exposures and risks for fishermen that do not eat whole fish. The shells for all of the shellfish except for the Hawaiian prawns were removed prior to laboratory analysis. However, all of the remainder of the shellfish (crabs, urchins, and prawns) were composited and assumed to be consumed by shellfish fishermen. The removal of the prawn shells or the selective consumption of certain components of the other shellfish could affect the estimates of COPC exposures by shellfish fishermen. Therefore, exposures and resulting risks or hazards could vary depending on the portions of the shellfish consumed.

Toxicity Assessment

Toxicity data provided by the US EPA (in IRIS, HEAST, or the PPRTVs) are typically the result of data extrapolations from animal experiments. To the extent that humans differ from animals, the risk estimates based on these animal toxicity data may not reflect actual risks to humans potentially exposed to COPCs.

The toxicity of arsenic may also have resulted in the underestimation or overestimation of risks because of uncertainty about the form present in fish, shellfish, or limu tissues. As discussed in Section 4.4.1, the arsenic in marine fish and shellfish was assumed to be almost exclusively organic arsenic, which is nontoxic to humans. Although these assumptions are supported by the scientific literature, fish and shellfish from the site were not specifically analyzed for inorganic versus organic arsenic. Therefore, there is a possibility that the arsenic in the fish and shellfish at the site may be in the toxic inorganic form. While the assumption that the arsenic in the fish and shellfish is organic reflects the best available scientific information, the assumption may have resulted in underestimating risks.

The limu samples collected in the nearshore waters off Mākua Beach were not identified to species. In some species of brown algae and red algae, arsenic may occur in inorganic forms at more than 50 percent (Frankenberger 2002; Kirby et al. 2005); however, there are many species of algae in which all arsenic is present in nontoxic organic forms (Frankenberger 2002). Therefore, the assumption that the arsenic in the limu was inorganic may have resulted in overestimating risks. Additionally, limu was not collected from background locations as part of this study, so it is unknown whether arsenic in the limu collected off Mākua Beach is elevated over background conditions.

4.7 CONCLUSIONS

The potential risks to subsistence and recreational fishermen were evaluated for the consumption of fish and shellfish caught at the Mākua muliwai and Mākua Beach. The potential risks to subsistence and recreational shellfish fishermen were similarly evaluated. The consumption of limu harvested off Mākua Beach was also evaluated. The results of the assessment are shown below.

4.7.1 Mākua Muliwai—Fish Consumption

Subsistence Fishermen

The incremental risk (assuming mean concentrations in fish) is approximately 3.5×10^{-5}, which exceeds the risk level used in assessing fish consumption of 1×10^{-5} (USEPA 2000a). The noncarcinogenic HI from fish consumption does not exceed background.

Recreational Fishermen

The incremental risk (assuming the more likely fish consumption rate and mean concentrations in fish) is approximately 9×10^{-6}, which is below the risk level used in assessing fish consumption of 1×10^{-5} (USEPA 2000a). The noncarcinogenic HI from fish consumption does not exceed background.

4.7.2 Mākua Beach—Fish Consumption

Subsistence Fishermen

The incremental risk (assuming mean concentrations in fish) is approximately 3 x 10^{-5}, which exceeds the risk level used in assessing fish consumption of 1 x 10^{-5} (USEPA 2000a). This was primarily due to assumed exposures to alpha-BHC, bis(2-ethylhexyl)phthalate and heptachlor epoxide. The noncarcinogenic HI from fish consumption does not exceed background.

Recreational Fishermen

The incremental risk (assuming the more likely fish consumption rate and mean concentrations in fish) is approximately 1 x 10^{-5}, which does not exceed the risk level used in assessing fish consumption of 1 x 10^{-5} (USEPA 2000a). The noncarcinogenic HI from fish consumption does not exceed background.

4.7.3 Mākua Beach—Limu Consumption

The risk estimates for both subsistence and recreational fishermen assumed to be consuming limu from Mākua Beach exceeded the risk level used in assessing fish consumption of 1 x 10^{-5} (USEPA 2000a) and the USEPA (1990) target risk range of 10^{-6} to 10^{-4}. Similarly, the HIs for both subsistence and recreational fishermen assumed to be consuming limu from Mākua Beach exceeded the threshold HI of 1. However, it should be noted that there is significant uncertainty in these estimates; for example, all of the arsenic detected in the limu was assumed to be inorganic, even though the arsenic in the limu was not speciated. Further, the incremental risks from limu consumption could not be determined because background limu samples were not collected.

4.7.4 Mākua Muliwai—Shellfish Consumption

Subsistence Shellfish Fishermen

The incremental risk (based on maximum concentrations in shellfish) is approximately 4 x 10^{-6}. The risk estimate does not exceed the risk level used in assessing fish consumption of 1 x 10^{-5} (USEPA 2000a). The noncarcinogenic HI from shellfish consumption exceeds background. The incremental hazard exceeds the threshold HI of 1. This is primarily due to assumed exposures to manganese and cobalt.

Recreational Shellfish Fishermen

The incremental risk (based on maximum concentrations in shellfish) is approximately 1 x 10^{-6}. The risk estimate does not exceed the risk level used in assessing fish consumption of 1 x 10^{-5} (USEPA 2000a). The noncarcinogenic HI from shellfish consumption exceeds background. The incremental hazard exceeds the threshold HI of 1. This is primarily due to assumed exposure to manganese.

4.7.5 Mākua Beach—Shellfish Consumption

Subsistence Shellfish Fishermen

There is no incremental cancer risk (i.e., over background) for shellfish harvested at Mākua Beach because the risk estimated for background is higher than that estimated for shellfish harvested at Mākua Beach. The noncarcinogenic HI from shellfish consumption exceeds background. The incremental hazard exceeds the threshold HI of 1. This is primarily due to assumed exposures to cadmium and perchlorate, with the latter found only in helmet urchins and not Kona crab collected at Mākua Beach.

Recreational Shellfish Fishermen

There is no incremental cancer risk (i.e., over background) from shellfish harvested at Mākua Beach because the risk estimated for background is higher. The noncarcinogenic HI from shellfish consumption exceeds background. The incremental hazard exceeds the threshold HI of 1. This is primarily due to assumed exposure to cadmium.

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SECTION 5
ECOLOGICAL RISK ASSESSMENT

This risk assessment addresses the potential ecological risks associated with current and future exposures to environmental media at the Mākua muliwai and nearshore habitat. A screening level ERA evaluates the potential for adverse ecological effects that might occur as a result of assumed exposures to a variety of chemicals at these locations. The ERA process systematically evaluates and organizes data, assumptions, and uncertainties to help understand and predict the relationships between chemical stressors and ecological effects in a way that is useful for decision making. The screening level ERA for the Mākua muliwai and nearshore habitat was conducted in accordance with federal guidance (USEPA 1992b, 1997, 1998, 2006a) and consists of the following elements:

- Problem formulation;
- Analysis; and
- Risk characterization.

Each of these elements of the screening level ERA is explained below.

Problem Formulation

The problem formulation establishes the scope of the screening level ecological risk assessment, identifies the major factors to be considered, and ensures that both the ecological receptors most likely to be exposed and the exposure scenarios most likely to contribute to ecological risks are evaluated. The problem formulation consists of the following tasks, each of which is discussed in further detail in Section 5.3:

- Identify potentially affected areas of concern;
- Identify chemicals of potential ecological concern (COPECs);
- Identify potentially complete exposure pathways; and
- Establish assessment endpoints.

Analysis

The analysis phase consists of an evaluation of the data required to estimate exposures and to characterize effects (USEPA 1992b, 1998). The analysis phase consists of the following tasks, each of which is discussed in further detail in Section 5.4:

- Select indicator species and wildlife exposure factors;
- Characterize bioaccumulation of chemicals through the food chain; and
- Establish toxicity reference values (TRVs).

Risk Characterization

The risk characterization integrates the results of the analysis phase (i.e., exposure and effects) to evaluate the likelihood of adverse ecological impacts associated with exposure to COPECs (USEPA 1992). The risk characterization consists of the following subtasks:

- Calculate risk estimates (i.e., hazard quotients);
- Identify and characterize sources of uncertainty; and
- Conduct risk interpretation.

5.1 GUIDANCE

This ERA was performed according to the following guidance documents and work plans:

- *Guidelines for Ecological Risk Assessment* (USEPA 1998);
- *Ecological Risk Assessment Guidance for Superfund Sites: Process for Designing and Conducting Ecological Risk Assessments—Interim Final* (USEPA 1997c);
- *Framework for Ecological Risk Assessment* (USEPA 1992b);
- *Assessing Risks to Populations at Superfund and RCRA Sites Characterizing Effects on Populations* (USEPA 2006b).

5.2 PROBLEM FORMULATION

The problem formulation presents and evaluates information that is used to develop and focus the analysis component of the ERA. The problem formulation phase is a process for generating and evaluating preliminary hypotheses about why ecological effects have occurred, or may occur, from environmental conditions at the site in question. As such, the problem formulation lays the foundation for the risk assessment and, therefore, requires the careful integration of many pieces of information. The information evaluated includes a description of the following:

- Areas evaluated for potential risks;
- Preliminary identification of COPECs, based on the sampling efforts, including preliminary evaluations of data usability and comparisons of preliminary data to screening effect levels to identify COPECs;

- Development of assessment endpoints (i.e., important aspects of the site to be protected), risk hypotheses (i.e., statements of how potential exposure to stressors could occur at the site and potential adverse effects), and measures (of exposure, effect, and of ecosystem and receptor characteristics).

A principal result of the problem formulation phase is an ecological conceptual site model (CSM) that describes potential ecological receptors that may be affected at the site. This conceptual site model is also used to guide the development of the analysis plan which delineates the assessment design, data needs, measures, and methods for conducting the analysis phase of the risk assessment. Upon completion of the problem formulation, the next step in the ERA process is the analysis.

5.3 AREAS OF CONCERN

The muliwai evaluated for potential risks consist of the north and south muliwai at the base of the Mākua Valley (Figure 2-1). The muliwai are estuarine ponds that are typically cut off from direct contact with the ocean but that periodically become open to tidal flow. As both of the muliwai in the Mākua Valley are fed by streams that run through the MMR, both may be impacted by potential upstream releases at MMR. For the purposes of this risk assessment, each of the muliwai in the Mākua Valley were considered individual areas of concern. The north and south background areas and the muliwai at Nanakuli (Figure 2-1) were considered representative background locations for the muliwai in the Mākua Valley and were used to compare exposures under background conditions to those downstream from the MMR.

Fish, shellfish, and limu were also collected in the nearshore areas off MMR and Sandy Beach (Figure 2-1). The nearshore samples off MMR could show impacts from the releases to the streams in the Mākua Valley. Sandy Beach was considered to be a background location for the nearshore samples from Mākua and was used to compare exposures under background conditions to those nearshore of the MMR.

5.4 CHEMICALS OF POTENTIAL ECOLOGICAL CONCERN

COPECs are chemicals detected in environmental media at the Mākua muliwai and nearshore habitat that may adversely impact the identified receptors of concern. The four environmental media sampled at the Mākua muliwai and nearshore area were sediment, fish tissue, shellfish tissue, and limu.

Sediment samples were analyzed for metals (USEPA methods 314.0, 6010B, and 7471A), cyanide (USEPA method 335.2), VOCs (USEPA method 8021B), SVOCs (USEPA method 8270C), organochlorine pesticides (USEPA method 8081A), chlorinated herbicides (USEPA method 8151A), dioxins/furans (USEPA method 8280/8290), explosives (USEPA methods 8330A and 8332), and general chemistry parameters (USEPA methods 354.1 and 9045C and SM4500).

Fish and limu tissue samples were analyzed for metals (USEPA methods 200.7, 200.8, 245.6, 270.3, 6010B, 6020, 7471A, and 7740), methylmercury (USEPA method 1630), VOCs (USEPA method 8260B), SVOCs (USEPA method 8270C), organochlorine pesticides

(USEPA method 8081A), dioxins/furans (USEPA method 8280/8290), explosives (USEPA method 8330A), and perchlorate (DOD method).

Shellfish tissue samples were analyzed with the same methods, except for metals (USEPA methods 6020 and 7471A), dioxins/furans (USEPA method 8290), and perchlorate (USEPA methods 314.0 and 8321A).

All chemical data collected for each environmental medium were reviewed during the selection of COPECs.

5.4.1 Data Review

All of the analytical results from the sediment samples collected in 2003 (Tetra Tech 2005b) and tissue samples collected during 2006 and 2008 (see Sections 2.3) were reviewed and evaluated in the selection of COPECs. Soil, sediment, groundwater, and surface water data collected in 2002-2004 from the Mākua Valley (Geotechnical and Structures Laboratory et al. 2005) were not used in this risk assessment. These data were collected upstream of the muliwai and represent locations that could serve as sources of contaminants to the muliwai and the nearshore habitat off MMR, but no samples were collected from either the muliwai or the ocean.

Sample locations where fish, shellfish, and limu were collected for use in the risk assessment are shown in Figures 2-1 and 2-2. Detailed descriptions of the analytical methods used for sediment and tissue samples are provided in Tetra Tech (2005) and Section 2, respectively.

Data validation efforts classified the data through the use of several qualifiers. Data without qualifiers were considered appropriate for risk assessment purposes. Following USEPA guidance (1989), data with J qualifiers were used for risk assessment purposes. U and UJ qualified data were considered to be nondetected but usable for risk assessment purposes. B and BJ qualified data were treated as nondetected chemicals because the estimated chemical concentrations were not significantly higher than levels in QA/QC blanks associated with the samples. R qualified data were excluded from the risk assessment.

Evaluation of Sediment Samples

Twenty-two sediment samples were collected from the north muliwai at MMR (Figure 2-1). These samples were from 19 locations from one to three feet deep. All samples were analyzed for metals, and six were also analyzed for organic constituents.

Twelve sediment samples were collected from the south muliwai at MMR (Figure 2-1) from 12 locations, from on to three feet deep. All samples were analyzed for metals, and three to five samples were also analyzed for organic constituents.

Four sediment samples were collected from each of the north and south background areas (Figure 2-1). These samples were from one to two feet deep. All samples were analyzed for metals and explosives.

The sediment samples collected are listed by location in Tetra Tech (2005). As part of the QA/QC process, laboratory duplicates were analyzed for some samples. Since the laboratory duplicates are duplicates of sediment samples, the difference among the duplicates should include heterogeneous variations in the sediment matrix. Therefore, the laboratory duplicates were included in the ecological risk assessment.

Background Comparisons

Metals at concentrations equivalent to or lower than background concentrations do not need to be considered in the risk assessment. Therefore, the metal COPECs were selected by comparing metal concentrations detected in muliwai sediments to local background metal concentrations (Appendix E.2). Section 2.1 identifies the background site selection criteria for the Marine Resources Study.

The site dataset consisted of metals concentrations in 35 sediment samples (including one duplicate) collected from the north and south muliwai at MMR combined. The background dataset consisted of metal concentrations from eight sediment samples (including two duplicate samples) collected from the north and south background areas combined. The background comparison consisted of the following steps:

1. Metals detected in less than 50 percent of the samples from either background or the site were conservatively assumed to be elevated at the site over background; however, metals that were not detected in any site samples were not evaluated;
2. The distributions of the data for each metal in both background and site samples were determined using the Shapiro-Wilk's test (USEPA 2002a, 2006b); as a result of this test, the distribution of the data for each metal was classified as normal, log-normal, or neither.
3. The types of distributions determined which statistical tests were used to compare the concentrations of each metal in sediments from the background and the site, as follows:
    a. Normal in both the background and site samples; the mean concentrations were compared (i.e., background versus site) using the *t*-test (USEPA 2002a, 2006b);
    b. Log-normal in both the background and site samples; the data were natural logarithm transformed and then the mean concentrations were compared (i.e., background versus site) using the *t*-test (USEPA 2002a, 2006b)
    c. Log-normal in either background or site samples and normal in the other; the data were natural logarithm transformed and then the mean concentrations were compared (i.e., background versus site) using the *t*-test (USEPA 2002a, 2006b); and
    d. Neither distribution in either background or site samples or in both locations; the median concentrations were compared using the Wilcoxon rank sum test (also known as the Mann-Whitney U test) (USEPA 2002a, 2006b).

4. The Behrens-Fisher version of the *t*-test was used for all cases. This version accounts for differences in variance between the two populations, and the results are the same as the student's *t*-test when the variances are equal (Zar 1999);
5. The results of the *t*-tests or Wilcoxon rank sum tests were interpreted as follows:
   a. $p > 0.05$: background and site metal concentrations do not significantly differ,
   b. $p < 0.05$: background and site metal concentrations do significantly differ; the direction of the difference (i.e., whether site concentrations were greater than or less than background) was determined using a box plot (i.e., mean ± standard error for normally or log-normally distributed data and median ± 25 percentiles for non-normally and non-log-normally distributed data) (see Appendix E.2).

For these statistical evaluations, nondetects were replaced by one-half of the method detection limit. Metals not detected in site sediments were not evaluated. The results of these comparisons are shown in Appendix E.2. Antimony was identified as a COPEC because it was not detected in the background sediments but was detected in site sediments, though infrequently. Cadmium and selenium were identified as COPECs because they were not detected in the background sediments but were detected in site sediments. Lead was identified as a COPEC because it was less than 50 percent detected in the site sediments. Thus, four metals were identified as elevated over background in the north and south muliwai sediments. These COPECs are also listed in Table 5-1(a).

Evaluation of Tissue Samples

Twelve composite fish samples were collected from the two muliwai at the MMR (Figure 2-1). The species collected included striped mullet, tilapia, Hawaiian flagtail, and medaka. Three composite fish samples were collected from the background muliwai at Nanakuli (Figure 2-1). All of the fish samples collected at Nanakuli were tilapia.

Six composite fish samples were collected from the nearshore habitat off MMR (Figure 2-1), consisting of goatfish (i.e., sidespot and manybar), Picasso triggerfish, blackspot triggerfish, and Christmas wrasse. These same fish species were collected in six samples at Sandy Beach, the nearshore background location (Figure 2-1), with the addition of saddle wrasse.

One composite shellfish sample of Samoan crab (*Scylla serrata*) was collected from the north muliwai. Two composite shellfish samples, one of Hawaiian prawn (*Macrobrachium grandimanus*) and the other of rock crab (*Pachygrapsus minutus*), were collected from the south muliwai. Two composite samples of Hawaiian prawn were collected from the background muliwai at Nanakuli. One composite sample of Kona crab (*Ranina ranina*) and two composite samples of helmet urchin (*Colobocentrotus atratus*) were collected from the nearshore habitat off MMR. Finally, three composite samples of helmet urchin were collected at the nearshore background location at Sandy Beach.

Additionally, four limu samples were collected from the nearshore waters at Mākua.

The tissue samples collected are listed by location in Section 3. Limited shellfish sample mass was collected from three locations: the north and south muliwai and the Nanakuli muliwai.

Only one sample was collected from the north muliwai. The Hawaiian prawn sample from the south muliwai (MSM-02) was analyzed only for metals, while the rock crab sample (MSM-01) was analyzed only for explosives. Likewise, the rock crab sample from the Nanakuli muliwai (NM-02) was analyzed for explosives only. As part of the QA/QC process, interlaboratory split samples were also analyzed.

5.4.2 Chemicals of Potential Concern in the North Muliwai at MMR

In sediments, the COPECs for the north muliwai included four metals, five VOCs, one SVOC, one organochlorine pesticide, one explosive, and one dioxin. The COPECs are listed in Table 5-1(a).

In fish tissues, the COPECs for the north muliwai included 18 metals, one VOC, one SVOC, four organochlorine pesticides, one explosive, and dioxins and furans (Table 5-1[b]). The COPECs in shellfish tissues (Samoan crab) consisted of 12 metals and four dioxins and furans (Table 5-1[c]). No limu was collected from the north muliwai.

5.4.3 Chemicals of Potential Concern in the South Muliwai at MMR

In sediments, the COPECs for the south muliwai included four metals, four VOCs, two SVOCs, one chlorinated herbicide, and one dioxin. The COPECs are listed in Table 5-1(a).

In fish tissues, the COPECs for the south muliwai included 19 metals, two VOCs, two SVOCs, four organochlorine pesticides, one explosive, and dioxins and furans (Table 5-1[b]). The COPECs in shellfish tissues (Hawaiian prawn) consisted of 12 metals (Table 5-1[c]). No explosives were detected in the rock crab sample. No limu samples were collected from the south muliwai.

5.4.4 Chemicals of Potential Concern in the Nearshore Habitat off MMR

Sediments were not collected from the nearshore habitat off MMR.

The COPECs in fish from the nearshore habitat included 16 metals, two VOCs, two SVOCs, seven organochlorine pesticides, and three explosives (Table 5-1[b]). Dioxins and furans were not detected in the fish samples collected from the nearshore area off MMR.

The COPECs in limu from the nearshore habitat included 17 metals, one VOC, two SVOCs, one organochlorine pesticide, one explosive, and dioxins and furans (Table 5-1[b]).

The COPECs in shellfish tissues (helmet urchin and Kona crab) consisted of 15 metals, one VOC, one organochlorine pesticide, perchlorate, and one dioxin and furan (Table 5-1[c]).

5.5 Assessment Endpoints and Measures

A key goal of an ERA is to identify and characterize the potential for significant adverse impacts resulting from exposures at a site, so that methods to reduce, avoid, or eliminate these impacts may be considered. Assessment endpoints link the risk assessment to management concerns to ensure that the ERA provides information to assist in risk management decision making. To support the risk evaluation, assessment endpoints for this ERA help define significant adverse impacts and to focus ERA analyses.

Table 5-1(a)
Sediment COPECs

Chemical	North Muliwai	South Muliwai
Metals		
Antimony	X	X
Cadmium	X	X
Lead	X	X
Selenium	X	X
Volatile Organic Compounds		
Benzene	X	X
Ethylbenzene	X	X
Toluene	X	X
m,p-Xylenes	X	X
o-Xylene	X	
Semi-volatile Organic Compounds		
Bis(2-ethylhexyl)phthalate	X	X
Pentachlorophenol		X
Organochlorine Pesticides		
4,4'-DDT	X	
Chlorinated Herbicides		
Picloram		X
Explosives		
RDX	X	
Dioxins and Furans		
OCDD	X	
2,3,7,8-TCDD		X

Table 5-1(b)
Fish and Limu Tissue COPECs

Chemical	North Muliwai	South Muliwai	Near Shore at Makua	
	Fish Tissue	Fish Tissue	Fish Tissue	Limu Tissue
Metals				
Aluminum	X	X	X	X
Antimony	X	X		X
Arsenic	X	X	X	X
Barium	X	X	X	X
Beryllium	X	X		X
Cadmium	X	X	X	X
Chromium	X	X	X	X
Cobalt	X	X	X	X
Copper	X	X	X	X
Iron	X	X	X	X
Lead	X	X	X	X
Manganese	X	X	X	X
Mercury	X	X	X	
Methyl Mercury	X	X	X	
Selenium	X	X	X	X
Silver	X	X	X	X
Thallium		X		X
Vanadium	X	X	X	X
Zinc	X	X	X	X
Volatile Organic Compounds				
Acetone	X	X	X	
m,p-Xylenes		X	X	X
Semi-volatile Organic Compounds				
Bis(2-ethylhexyl)phthalate		X	X	X
Di-n-butylphthalate	X	X	X	X
Organochlorine Pesticides				
4,4'-DDT	X	X	X	
Aldrin			X	
BHC, alpha			X	
BHC, beta		X		
BHC, delta	X		X	
BHC, gamma	X	X	X	
Heptachlor			X	X
Heptachlor Epoxide	X	X	X	
Explosives				
Nitroglycerin			X	
Perchlorate	X	X	X	X
RDX			X	
Dioxins and Furans				
TCDD equivalent	X	X		X

Table 5-1(c)
Shellfish Tissue COPECs

Chemical	North Muliwai (Samoan Crab)	South Muliwai (Hawaiian Prawn/Rock Crab)	Near Shore at Makua	
			Helmet Urchin	Kona Crab
Metals				
Aluminum	X	X	X	X
Antimony				
Arsenic	X	X	X	X
Barium	X	X	X	X
Beryllium				
Cadmium				X
Chromium	X	X	X	X
Cobalt	X	X	X	X
Copper	X	X	X	X
Iron	X	X	X	X
Lead		X	X	X
Manganese	X	X	X	X
Mercury	X			X
Methyl Mercury				
Selenium	X	X	X	X
Silver				X
Thallium				
Vanadium	X	X	X	X
Zinc	X	X	X	X
Volatile Organic Compounds				
Toluene			X	
Organochlorine Pesticides				
Aldrin			X	
Other				
Perchlorate			X	
Dioxins and Furans				
1,2,3,6,7,8-HxCDD	X			
1,2,3,7,8,9-HxCDD	X			
2,3,7,8-TCDF	X			
OCDD	X		X	

Measures of exposure are contaminant concentrations in environmental media to which ecological receptors may be exposed (USEPA 1998), including contaminant concentrations in sediments and tissues at the sites. Receptor exposures were estimated from contaminant concentrations measured in environmental media.

Measures of effect are measurable responses by ecological receptors to contaminants (USEPA 1998). The measures of effect used in this ERA were sediment screening benchmarks and fish tissue-based toxicity data.

5.5.1 Assessment Endpoints

A key task of problem formulation is the establishment of assessment endpoints. Assessment endpoints are "explicit expressions of the actual environmental value that is to be protected" (USEPA 1992b, 1998) and provide the basis for all subsequent ERA efforts. Assessment endpoints were established to protect potentially affected benthic invertebrates, limu, shellfish, and fish in the muliwai and nearshore waters. Assessment endpoints are composed of the receptor of concern and a characteristic of that receptor that is important to protect and is potentially at risk (USEPA 1992b).

Assessment endpoints for the muliwai and nearshore habitat off MMR were survival and persistence of limu and benthic invertebrates exposed to COPECs and survival, reproduction, development, and growth of shellfish and fish exposed to COPECs.

5.5.2 Measures

The three measure categories that are predictive of the assessment endpoints are measures of exposure, measures of effect, and measures of ecosystem and receptor characteristics (USEPA 1998). In this ERA, the measures below were used to determine the assessment endpoints.

- **Measures of Exposure:** The concentration of COPECs in sediments, limu tissues, shellfish tissues, and fish tissues;
- **Measures of Effects:** The adverse effects in benthic invertebrates, limu, shellfish, and fish in response to exposure to a COPEC. For benthic invertebrates, adverse effects were based on toxicity observed in sediment bioassays or reduced abundance of invertebrates. Applicable measures of effects on limu based on tissue concentrations were not identified due to the absence of toxicity data. For shellfish and fish, different adverse effects may have been selected in the development of the TRV_{Low} (based on the no observed effects concentration) and the TRV_{High} (based on the lowest observed effects concentration). These effects include reductions in survival, reproduction, development, and growth.

5.6 ECOLOGICAL CONCEPTUAL SITE MODEL

The ecological CSM combines information about the COPECs, potential ecological receptors, and potential exposure pathways to provide an overall picture of site-related exposures that is used to refine and focus the ERA. An ecological CSM for the north and south muliwai and nearshore habitat off MMR is presented in Figure 5-1.

5.6.1 Identification of Receptors

As it is impractical to evaluate all receptors at a site, this screening-level ERA evaluated risks for a set of representative receptors. Risks estimated for representative receptors are subsequently used to infer the potential for adverse impacts on taxonomically and functionally related receptors of concern.

Representative ecological receptors were identified as the biological organisms most likely to be exposed to the COPECs. Representative receptors were selected to fulfill as many of the following criteria as possible:

- Organisms that have been observed, or are likely to occur, in the muliwai or nearshore waters;
- Organisms that are likely to be maximally exposed to the COPECs;
- Organisms that are likely to play an integral role in the ecological community structure at the sites; and
- Organisms that are representative of specific foraging guilds or serve as food items for higher trophic levels.

The representative ecological receptors selected for the ERA areas follows:

- Aquatic plants, including limu;
- Benthic invertebrates;
- Aquatic invertebrates; and
- Fish.

Shellfish receptors are included among both benthic and aquatic invertebrates. Each of the representative receptors is described below.

Aquatic plants: Marine limu is potentially present in the muliwai or nearshore habitat. Marine plants could be exposed to constituents in water but could not be assessed due to the lack of surface water data or limu tissue-based toxicity data.

Benthic invertebrates: Sediment-dwelling organisms in the muliwai and nearshore waters include crustaceans, bivalves, polychaetes, echinoderms (sea urchins, sea stars), and other estuarine or marine biota. Benthic invertebrates were assumed to be exposed to COPECs in sediments at the sites. Exposures to shellfish (e.g., sea urchins and crabs) were assessed on the basis of their tissue concentrations.

Aquatic invertebrates: Invertebrates in the water column in the muliwai and nearshore waters may include plankton, jellyfish, crustaceans and other estuarine or marine biota. Potential exposures to some receptors in the water column (e.g., plankton and jellyfish) could not be assessed due to the absence of surface water quality data. Exposures to shellfish (e.g., shrimp) were assessed on the basis of their tissue concentrations.

Fish: Several species of fish are present in the muliwai, including striped mullet, tilapia, Hawaiian flagtail, and medaka. Numerous species are potentially present in the nearshore habitat off MMR, including goatfish (i.e., sidespot and manybar), Picasso triggerfish, blackspot triggerfish, and Christmas wrasse. Exposures to fish were assessed on the basis of their tissue concentrations.

5.6.2 Exposure Pathway Inclusion/Exclusion

The exposure pathway inclusion/exclusion evaluation is based on information gathered from the problem formulation (Section 5.4), COPEC selection (Section 5.6), representative species selection (Section 5.7.1), the probable completeness of each exposure pathway, and the potential for that pathway to be a major or minor route of exposure and risk.

An exposure pathway describes the course that a chemical takes from a source to an exposed individual. A complete exposure pathway consists of the following four factors:

- A source of potentially toxic chemicals;
- A contaminated medium, such as sediment;
- An exposure or contact point with the contaminated medium; and
- An exposure route for chemical intake by a receptor, such as uptake across gills or membranes.

Designation of an exposure pathway as complete indicates that ecological exposure is possible but does not necessarily mean that exposure will occur or that exposure will occur at the levels estimated in this report. When any one of the factors is missing in a pathway, it is considered to be incomplete. Incomplete exposure pathways do not pose hazards and were not evaluated in this risk assessment.

The CSM provides the basis for identifying and evaluating the potentially complete exposure pathways at the muliwai and nearshore habitat off MMR. As shown in the CSM diagram (Figure 4-1), potential sources of COPECs include surface water, sediments, and fish. The CSM also illustrates the potential chemical migration pathways, exposure points, and exposure routes evaluated at the Mākua muliwai and nearshore habitat. Chemical fate and transport processes were used to define the potential migration pathway, and included transfer of COPECs between environmental media, such as surface water and fish tissue, and transport of COPECs through movement of an environmental medium by natural dispersive processes, such as surface water flow.

An exposure pathway is complete when there is a point at which chemical uptake by an ecological receptor may occur. Exposure routes considered in this ecological risk assessment consist of uptake from sediments (benthic invertebrates), uptake from surface water (such as across membranes of invertebrates or gills of fish), and ingestion of sediment, water, and food (by invertebrates and fish).

5.7 ANALYSIS

The analysis phase provides the information necessary to determine or predict ecological responses to COPECs under exposure conditions of interest. This phase consists of exposure and effects assessment (USEPA 1992b). Potential risks to receptors were estimated using exposure point concentrations. To evaluate the effects of the COPECs on the representative receptors, TRVs were selected.

5.7.1 Exposure Assessment

The exposure assessment includes an exposure analysis for the selected representative receptors and an exposure profile. The exposure analysis describes the relationships between the concentrations of COPECs at the site and the ecological receptors. Information used to establish this link includes the pathway by which the receptors are exposed to the COPECs in each medium and estimates of EPCs.

To estimate exposures of COPECs to ecological receptors, three essential inputs were needed:

- Representative receptors;
- Exposure profile; and
- EPCs for each COPEC;

The selection of representative receptors was previously discussed in Section 5.7.1. The following sections describe the technical approach for quantifying the exposures to COPECs by each of the receptors.

5.7.2 Exposure Profile

The exposure profile describes the complete exposure pathways between COPECs and receptors based on the potential for exposure under conditions at the sites. Complete exposure pathways were established through identification of ecological receptors and identification of COPECs in the media at the site. The pathways are evaluated by calculating EPCs for each COPEC in each environmental medium.

The potential exposure pathways for various receptors in the north and south muliwai and nearshore habitat off MMR were evaluated in the CSM presented in Section 5.6. The identified receptors and the pathways by which they are assumed to be exposed to the COPECs are listed below:

Limu—Contact with and uptake of COPECs in surface water;

Benthic invertebrates (including shellfish)—Contact with and uptake of COPECs in sediment; ingestion of COPECs in surface water or food;

Aquatic invertebrates—Contact with and uptake of COPECs in surface water; ingestion of COPECs in food; and

Fish—Contact with and uptake or ingestion of COPECs in sediment, surface water, and food.

Exposures of limu may also be estimated as the measured concentrations of COPECs in limu tissue (mg_{COPEC}/kg_{tissue}). However, these exposures were not evaluated further due to the absence of applicable tissue-based toxicity data. For benthic invertebrates, exposures to COPECs were estimated as the measured concentrations of COPECs in sediment ($mg_{COPEC}/kg_{sediment}$). Exposures of shellfish (e.g., sea urchins, shrimp, and crabs) were estimated as the measured concentrations of COPECs in shellfish tissue (mg_{COPEC}/kg_{tissue}). Exposures of other aquatic invertebrates (e.g., plankton and jellyfish) could not be assessed due to the lack of surface water data. Exposures of fish were estimated as the measured concentrations of COPECs in fish tissue (mg_{COPEC}/kg_{tissue}).

This exposure information was used, along with the ecological effects information described in Section 5.8.2, to estimate the potential risks to receptors presented in the risk characterization (Sections 5.9 and 5.10).

5.7.3 Exposure Point Concentrations

For sediments, EPCs were estimated using the reasonable maximum exposure concentration. This method ensures that the potential risks calculated from these concentrations are conservative and will not underestimate the possible risks. The reasonable maximum exposure concentration is defined as the UCL_{95} of the mean concentration or the maximum observed concentration, whichever is less (USEPA 1989, 2002b). The UCL_{95} was calculated following current USEPA (2002b) guidance using the latest version of ProUCL (USEPA 2004b).

In order to have enough shellfish and fish mass to analyze the samples for the full analytical suite, the samples were composited, as described in Section 2. The use of composite samples to assess exposures is consistent with USEPA (2000a) and HDOH (2006) guidance. Composite samples are used to determine the mean concentration in the environmental medium sampled (USEPA 2000b). However, it is not possible to calculate upper confidence limits (UCLs) from composited samples because the variance (which is used in the calculation of UCLs) of the individual samples that were composited is not available. Instead of using the UCL_{95} of the mean concentration as the EPC, the maximum detected concentrations in composite shellfish and fish samples were used as the EPCs, which is more conservative than using the UCL_{95}.

Field duplicates were collected as part of the QA/QC process. Since the field duplicates represent different sample material (i.e., different individual fish), the analytical results of the field duplicates were treated as unique samples in exposure point concentration calculations. Laboratory duplicates of sediment samples were excluded from the calculation of UCL_{95}s of the mean concentration because the laboratory duplicates should show the variance due to analytical error and not due to differences in the actual environmental medium sampled. Interlaboratory split samples were included in the determination of the maximum detected concentration among composite tissue samples.

The EPCs are provided in the risk tables (Tables 5-5 to 5-17). The distributions for each chemical detected in sediment and tissues are provided in Appendix E.1. Also provided in Appendix E.1 are tabulations of each COPEC's detection frequency, concentration range, mean, minimum, maximum, and UCL_{95} concentration, when available. The summary statistics are provided separately for each COPEC detected in each of the areas evaluated.

5.7.4 Effects Assessment

The effects assessment identifies and quantifies potential adverse effects caused by exposures to the COPECs at the site and, where possible, evaluates cause-and-effect relationships (USEPA 1992b). This screening level ERA used toxicity data obtained from the primary literature, review documents, and available toxicity databases. Potential adverse effects are quantitatively calculated as HQs, which are calculated by dividing a receptor's exposure to a COPEC by the COPEC's TRV.

5.7.5 Toxicity Benchmarks and TRVs

For benthic invertebrates, the measures of exposure used to calculate risks is the EPC in sediment for each COPEC, and the TRV is a concentration in sediment. Both are in units of mg/kg. Likewise, for fish and shellfish the measure of exposure is the EPC in tissue, and the TRV is a concentration in fish or shellfish tissue that is protective, both in mg/kg.

TRVs for ecological receptors were calculated for metals and organic compounds identified as COPECs. TRVs were derived for each receptor as follows:

- Benthic invertebrates—TRVs were selected from relevant screening benchmarks; and
- Fish and shellfish tissues—TRVs were selected from relevant toxicity studies, followed by the application of an uncertainty factor, if warranted.

Where possible, both a TRV_{Low} and TRV_{High} were selected to provide a range of protectiveness for the risk estimates. Tissue-based screening level TRVs for aquatic plants, such as limu, were not identified.

Selection of Studies

The benthic invertebrate TRVs used in this ERA were selected from the sediment screening benchmark compilation in the National Oceanic and Atmospheric Administration (NOAA) Screening Quick Reference Tables (Buchman 2006). Screening benchmarks for marine sediments were used to correspond to the brackish conditions in the estuarine muliwai. The TRV_{Low} was based on the threshold effects level or, if none was available, the apparent effects threshold. The threshold effects level is a conservative screening value defined as the concentration below which adverse effects would be rarely observed. It does not necessarily predict toxicity. The apparent effects level is a test species-specific concentration observed in the highest nontoxic sample. It represents the concentration above which adverse effects would always be expected for that biological indicator (bioassay or population abundance) due to exposure to that contaminant alone. The apparent effects level is also a conservative screening value because it was selected from the lowest apparent effects level among

individual indicators. The TRV_{High} was based on the probable effect level, the concentration above which adverse effects are expected to occur frequently. Benthic invertebrate TRVs are presented in Table 5-2.

Fish and shellfish tissue-based TRVs were developed to assess potential risks to fish and shellfish based on measured concentrations in their tissues. Accumulation of chemicals in fish and shellfish can occur via food ingestion, sediment and water ingestion, or uptake across gills. Tissue concentrations therefore represent the end result of different exposure routes and kinetics. Interspecies differences in bioaccumulation and sensitivity also contributes to the variation observed in the range of tissue-based toxicity values. Fish TRVs were selected from studies satisfying the following:

- Saltwater or freshwater fish;
- Adult, juvenile, fingerling, or fry life stages (not embryos or alevin);
- Whole body, carcass, or muscle tissues; and
- Survival, growth, or reproduction endpoints.

Test endpoints based on survival, reproduction, and to some extent, growth are indirect indicators of potential population-level effects on fish. The TRV_{Low} represents the upper end of the range of tissue levels associated with no adverse effects (i.e., no effect levels). No effect levels that were higher than the selected TRV_{High} were excluded from final consideration. If no-effect level data were not available, then the TRV_{Low} was extrapolated from the TRV_{High} using an uncertainty factor of 10. The TRV_{High} represents the lower end of the range of tissue levels corresponding to adverse effects (i.e., effect levels). The lowest effect level across all species that satisfied the above criteria was typically selected as the TRV_{Low}. Fish tissue TRVs are provided in Appendix E.4 and are summarized in Table 5-4.

Shellfish TRVs were selected from studies satisfying the following criteria:

- Saltwater invertebrates were preferred over freshwater invertebrates;
- Taxonomic relatedness to collected shellfish;
- Whole body, carcass, or muscle tissues; and
- Survival, reproduction, development, or growth endpoints.

When sufficient data were available, studies on saltwater species were preferred over freshwater species for consistency with the receptors at MMR. Saltwater environments are richer in metals than freshwater environments, leading to higher metals tolerance in saltwater species. Toxicity data were focused on species as taxonomically related to the collected shellfish as possible (i.e., crustaceans and echinoderms). Crustaceans in the selected studies consisted mostly of shrimp, mysids, and amphipods. Separate TRVs were developed for crustaceans and echinoderms if sufficient data were identified. Data on adults were preferred over juveniles or larvae.

Table 5-2
Toxicity Reference Values for Benthic Invertebrates

Chemical	TRV_{Low}[a] ($mg/kg_{sediment}$)	TRV_{High}[b] ($mg/kg_{sediment}$)
Metals		
Antimony	9.3[c]	-
Cadmium	0.676	4.21
Lead	30.2	112
Selenium	1.0[c]	-
Organics		
Benzene	-	-
bis(2-ethylhexyl)phthalate	0.182	2.65
4,4'-DDT	0.00119	0.00477
Ethylbenzene	0.004[c]	-
OCDD	-	-
Pentachlorophenol	0.017[c]	-
Picloram	-	-
RDX	-	-
2,3,7,8-TCDD	3.6E-6[c]	-
Toluene	-	-
m,p-Xylenes	0.004[c]	-
o-Xylene	0.004[c]	-

Notes:

a - Threshold effects level (TEL) for marine sediment, unless otherwise noted.
b - Probable effects level (PEL) for marine sediment.
c - Apparent effects threshold (AET) for marine sediment.

$mg/kg_{sediment}$ - milligram (chemical) per kilogram (sediment)

A dash indicates the absence of an applicable TRV.

Source: Buchman (1999).

Table 5-3
Shellfish Tissue-Based Toxicity Reference Values

		NOEC			LOEC			
Chemical	**Receptor Group**	**Test Species**	**NOEC (mg/kg wet wt.)**	**Type**	**Test Species**	**LOEC (mg/kg wet wt.)**	**Type**	**Reference**
Metals								
Aluminum	All	Mussel (*Mytilus edulis*)	31.0	NOEC - Survival, growth	-	310[a]	-	USACE, 2008
Arsenic	All	Grass shrimp (*Palaemonetes pugio*)	6.4	NOEC - Growth		64[a]	-	Jarvinen and Ankley, 1999
Barium	-	-	-	-	-	-	-	-
Beryllium	-	-	-	-	-	-	-	-
Cadmium	Crustaceans	-	0.13[b]	-	Mysid (*Mysidopsis bahia*)	1.29	LOEC - Reduced growth	USACE, 2008
	Echinoderms	Sea urchin (*Paracentrotus lividus*)	4.78	NOEC - Survival	Sea urchin (*Paracentrotus lividus*)	8.76	LOEC - Survival, development	USACE, 2008
Chromium	All	Sand crab (*Portunus pelagicus*)	1.0	NOEC - Growth	Sand crab (*Portunus pelagicus*)	3.2	LOEC - Growth	Jarvinen and Ankley, 1999
Cobalt	All	-	0.11[b]	-	Amphipod (*Hyalella azteca*)	1.06	EC - Survival	USACE, 2008; Jarvinen and Ankley, 1999
Copper	Crustaceans	-	0.59[b]	-	Opossum shrimp (*Mysis relicta*)	5.9	EC - Survival	USACE, 2008
	Echinoderms	Sea urchin (*Paracentrotus lividus*)	1.32	NOEC - Survival	Sea urchin (*Paracentrotus lividus*)	8.74	LOEC - Survival, development	USACE, 2008
Iron	All	Mussel (*Mytilus edulis*)	68	NOEC - Survival, growth	-	680[a]	-	USACE, 2008
Lead	Crustaceans	Amphipod (*Monoporeia affinis*)	4.0	NOEC - Survival	Copepod (*Calanus hyperboreus*)	40.7	LOEC - Survival	USACE, 2008
	Echinoderms	Sea urchin (*Paracentrotus lividus*)	0.58	NOEC - Survival	Sea urchin (*Paracentrotus lividus*)	31.4	LOEC - Survival, development	USACE, 2008
Manganese	All	Burrowing clam (*Macoma balthica*)	15.5	NOEC - Survival	Amphipod (*Hyalella azteca*)	53.6	EC - Survival	USACE, 2008; Jarvinen and Ankley, 1999
Mercury	All	Grass shrimp (*Palaemonetes pugio*)	2.1	NOEC - Survival	Fiddler crab (*Uca pugnax*)	12.3	LOEC - Development	USACE, 2008; Jarvinen and Ankley, 1999
Selenium	All	-	0.29[b]	-	Water flea (*Daphnia magna*)	2.94	LOEC - Growth	USACE, 2008
Silver	All	Gastropod (*Crepidula fornicata*)	5.36	NOEC - Reproduction	Slipper Limpet (*Crepidula fornicata*)	6.44	EC - Reproduction	USACE, 2008; Jarvinen and Ankley, 1999
Vanadium	Crustaceans	Shore crab (*Carcinus maenas*)	0.6	NOEC - Survival	-	6.0[a]	-	USACE, 2008
	Echinoderms	Sea urchin (*Paracentrotus lividus*)	0.74	NOEC - Survival	-	7.4[a]	-	USACE, 2008
Zinc	Crustaceans	Crayfish (*Orconectes virilis*)	12.7	NOEC - Survival	Amphipod (*Allorchestes compressa*)	24	EC - Survival, growth	Jarvinen and Ankley, 1999
	Echinoderms	Sea urchin (*Paracentrotus lividus*)	37	NOEC - Development	Sea urchin (*Paracentrotus lividus*)	40.6	LOEC - Development	USACE, 2008

Table 5-3
Shellfish Tissue-Based Toxicity Reference Values

		NOEC			LOEC			
Chemical	**Receptor Group**	**Test Species**	**NOEC (mg/kg wet wt.)**	**Type**	**Test Species**	**LOEC (mg/kg wet wt.)**	**Type**	**Reference**
Pesticides								
Aldrin	All	-	-	-	Ostracod (*Chlamydotheca arcuata*)	1.0	LOEC - Immobility, Mortality	Kawatski, J.A., and J.C. Schmulbach. 1971.
Dieldrin (as surrogate for Aldrin)	All	Pink Shrimp (*Penaeus duorarum*)	0.01	NOEC - Mortality	Pink Shrimp (*Penaeus duorarum*)	0.08	LOEC - Mortality	USACE, 2008
VOCs								
Toluene	All	-	1.6[b]	-	Mussel (*Mytilus edulis*)	15.60	EC50 - Behavior, feeding	USACE, 2008
Other								
Perchlorate	-	-	-	-	-	-	-	-
Dioxins and Furans								
2,3,7,8-TCDD	All	Grass shrimp (*Palaemonetes* pugio)	0.000138	NOEC - Mortality	-	0.00138[a]	-	U.S. EPA, 2000c
2,3,7,8-TCDF	All	Grass shrimp (*Palaemonetes pugio*)	0.0000588	NOEC - Mortality	-	0.000588[a]	-	U.S. EPA, 2000c

Definitions:

NOEC	-	No Observable Effect Concentration
LOEC	-	Lowest Observable Effect Concentration
mg/kg	-	Milligrams per kilogram

Notes:

a - LOEC estimated from NOEC using an uncertainty factor of 10.

b - NOEC estimated from LOEC using an uncertainty factor of 10.

Table 5-4
Fish Tissue-Based Toxicity Reference Values

	NOEC		LOEC		
Chemical	**NOEC (mg/kg dry wt.)[a]**	**Type**	**LOEC (mg/kg dry wt.)[a]**	**Type**	**Reference**
Metals					
Aluminum	42.7	NOEC - Survival	100	LOEC - Reduced survival	Jarvinen and Ankley, 1999
Antimony	25	NOEC - Survival	45	LOEC - Reduced survival 50%	Jarvinen and Ankley, 1999
Arsenic	10	NOEC - Survival	15	LOEC - Reduced survival 50%	Jarvinen and Ankley, 1999
Cadmium	0.375	NOEC - Survival	0.70	LOEC - Reduced survival 20%	Jarvinen and Ankley, 1999
Chromium	2.9	NOEC - Survival	-	-	Jarvinen and Ankley, 1999
Copper	5.0	NOEC - Survival	8.0	LOEC - Reduced survival 80-100%	Jarvinen and Ankley, 1999
Lead	13	NOEC - Growth	20	LOEC - Reduced growth	Jarvinen and Ankley, 1999
Mercury	15	NOEC - Behavioral, reproductive, physiological effects	25	LOEC - Behavioral, reproductive, physiological effects	Weiner and Spry, 1996
Silver	0.30	NOEC - Survival, growth	-	-	Jarvinen and Ankley, 1999
Selenium	3.96	NOEC - Mortality (estimated)	39.6	LOEC - Mortality	U.S. EPA, 2004
Vanadium	0.10	NOEC - Growth	2.1	LOEC - Reduced growth	Jarvinen and Ankley, 1999
Zinc	57.0	NOEC - Survival	68.0	LOEC - Reduced survival; immobilized	Jarvinen and Ankley, 1999
Pesticides					
Aldrin	10.7	NOEC - Survival, growth	28.3	LOEC - Reduced survival 50%	Jarvinen and Ankley, 1999
alpha-BHC	210	NOEC - Survival, growth	850	LOEC - Reduced survival/ immobilization	Jarvinen and Ankley, 1999
beta-BHC	24.3	NOEC - Survival (estimated)	243	LOEC - Reduced survival 50%	Jarvinen and Ankley, 1999
delta-BHC	24.3	NOEC - Survival (estimated)	243	LOEC - Reduced survival 50%	Jarvinen and Ankley, 1999
gamma-BHC	0.065	NOEC - Survival	5.35	LOEC - Reduced survival 50%	Jarvinen and Ankley, 1999
4,4'-DDT	13.3	NOEC - Survival (estimated)	133	LOEC - Reduced survival 50%	Jarvinen and Ankley, 1999
Heptachlor	27	NOEC - Survival	57.5	LOEC - Reduced survival	Jarvinen and Ankley, 1999
Dioxins and Furans					
2,3,7,8-TCDD	0.00049	NOEC - Survival (estimated)	0.0049	LOEC - Reduced survival 45%	Jarvinen and Ankley, 1999

Definitions:

NOEC No Observable Effect Concentration
LOEC Lowest Observable Effect Concentration
mg/kg Milligrams per kilogram

Notes:

[a]Tissue concentrations were converted from wet weight to dry weight assuming a moisture content of 80 percent (Stephen et al., 1985).
A dash indicates the absence of an applicable LOEC.

Test endpoints based on survival, reproduction, and, to some extent, development and growth are indirect indicators of potential population-level effects on shellfish. The TRV_{Low} represents the upper end of the range of tissue levels associated with no adverse effects (i.e., no effect levels). The TRV_{High} represents the lower end of the range of tissue levels corresponding to adverse effects (i.e., effect levels). If no-effect level data were not available, then the TRV_{Low} was extrapolated from the TRV_{High} using an uncertainty factor of 10. Likewise, if effect level data were not available, then the TRV_{High} was extrapolated from the TRV_{Low} by applying an uncertainty factor of 0.1.

Shellfish tissue toxicity data were not available for barium or beryllium.

Shellfish tissue TRVs are provided in Appendix E.5 and are summarized in Table 5-3.

5.8 RISK CHARACTERIZATION

Risk characterization integrates available exposure and effects information to evaluate the likelihood of adverse ecological impacts associated with exposure to COPECs (USEPA 1992b, 1998). This risk characterization describes the risk estimates for receptors in the north and south muliwai at MMR, nearshore habitat at MMR, and associated background areas. This section also includes a discussion of the uncertainty associated with the risk estimates. As identified in current ERA guidance (USEPA 1998), professional judgment plays a significant role when characterizing potential risks.

5.8.1 Risk Estimation

Hazard Quotient and Other Lines of Evidence

HQs were used to estimate the potential for adverse ecological impacts when sufficient exposure and toxicity data existed. An HQ is the ratio of the exposure to the TRV:

$$HQ = \frac{Exposure}{TRV}$$

An HQ less than 1 indicates that there is a negligible potential for adverse ecological impacts due to exposure to a particular COPEC, whereas an HQ greater than 1 indicates that there is a potential for adverse ecological impacts due to exposure to that COPEC. However, there are a large number of conservative assumptions that are incorporated in the estimated HQs. Therefore, HQs that are in the single digits are often not considered to represent significant risks.

Where possible, both TRV_{Low}s and TRV_{High}s were derived and were used to calculate corresponding HQ_{High}s and HQ_{Low}s. An HQ_{High} gives a conservative estimate of the comparison between exposure at site conditions and maximum safe exposure levels. An HQ_{High} of less than 1 would indicate that no risks are likely to occur from that particular exposure. The HQ_{Low} represents a comparison of exposure at site conditions with doses known to result in effects. An HQ_{Low} greater than or equal to 1 would indicate that a potential for risks exists. If the HQ_{High} is greater than or equal to 1, and the HQ_{Low} is less than 1, a conclusion must be drawn by close evaluation of several factors (including exposure

parameters, magnitude of the HQ, source of the TRV, and probability of site use by the receptor).

In addition to HQs, potential cumulative impacts from multiple chemicals were assessed based on hazard indices (HIs). An HI is the sum of HQs for a given receptor across all applicable COPECs and exposure pathways. The HIs are further described and presented in Section 5.9.

Ecological Significance of Potential Risks

Several lines of evidence were examined in order to evaluate the ecological significance of risks. Risks are generally not considered to warrant remedial action if exposures are comparable to or less than background conditions. HQs calculated for the north and south background muliwai, Nanakuli muliwai, and sandy beach nearshore site are representative of background risks and are discussed to place potential risks at the sites in perspective.

Risk Estimates

Risk tables are provided for each receptor evaluated at the north and south muliwai, nearshore habitat at MMR, and representative background areas (Tables 5-5 to 5-17). These risk tables present the EPCs, TRVs, and HQs for all COPECs and receptors considered in each area.

5.9 POTENTIAL ECOLOGICAL RISKS

The risks from potential exposures to each of the COPECs in each of the areas identified in Section 5.5 are discussed here.

5.9.1 Potential Risks at the North Background Area

Risk estimates for sediments in the north background area are indicative of local background conditions for sediments in the north muliwai at MMR.

Potential Risks to Benthic Invertebrates

HQs for benthic invertebrates that are exposed to sediments in the north background area are shown in Table 5-5. Lead was the only chemical detected at the north background area that was also identified as a COPEC in the north muliwai. The HQ for lead was less than 1, indicating that adverse effects are unlikely.

5.9.2 Potential Risks at the South Background Muliwai

Risk estimates for sediments in the south background area are indicative of local background conditions for sediments in the south muliwai.

Potential Risks to Benthic Invertebrates

HQs for benthic invertebrates that are exposed to sediments in the south background area are shown in Table 5-5. Lead was the only chemical detected at the south background area that was also identified as a COPEC in the south muliwai. The HQ for lead was less than 1.

Table 5-5
North and South Background Muliwai Sediment

Chemical	RME Concentration (mg/kg)	TRV_{Low}	HQ_{High}	TRV_{High}	HQ_{Low}
North Background Muliwai					
Metals					
Lead	1.6	30.24	0.05	112	0.01
South Background Muliwai					
Metals					
Lead	2.4	30.24	0.08	112	0.02

Definitions:

HQ - Hazard Quotient
mg/kg - milligrams per kilogram
RME - Reasonable maximum exposure
TRV - Toxicity Reference Value

Notes:

A dash indicates the absence of an applicable TRV.

5.9.3 Potential Risks at the Nanakuli Background Muliwai

Risk estimates for shellfish and fish in the Nanakuli background muliwai are indicative of local background conditions for shellfish and fish in both the north and south muliwai.

Potential Risks to Shellfish

HQs for shellfish in the Nanakuli background muliwai are shown in Table 5-6. Of the 16 COPECs for which tissue-based TRVs were available, eight had HQs exceeding 1. The HQ_{High}s exceeded 1 for aluminum, chromium, cobalt, copper, iron, manganese, selenium, and zinc. The HQ_{Low}s exceeded 1 for copper and zinc. HQs for barium could not be calculated due to the absence of shellfish tissue-based TRVs.

Potential Risks to Fish

HQs for fish in the Nanakuli background muliwai are shown in Table 5-7. Of the 15 COPECs for which tissue-based TRVs were available, all but six had HQs less than 1. The HQs for aluminum, chromium, copper, silver, vanadium, and zinc exceeded 1, as described below:

- Aluminum, copper, vanadium, and zinc—Both the HQ_{High}s and HQ_{Low}s exceeded the threshold value of 1.
- Chromium and silver—The HQ_{High}s exceeded 1. HQ_{Low}s were not calculated due to the absence of TRV_{High}s.

HQs for barium, beryllium, cobalt, iron, manganese, di-*n*-butylphthalate, and perchlorate could not be calculated due to the absence of fish tissue-based TRVs.

5.9.4 Potential Risks at the Nearshore at Sandy Beach Background Site

Risk estimates for shellfish and fish at the nearshore at Sandy Beach background site are indicative of background conditions for shellfish and fish at the nearshore site.

Potential Risks to Shellfish

HQs for shellfish at the nearshore at Sandy Beach background site are shown in Table 5-8. Of the 18 COPECs for which tissue-based TRVs were available, eight had HQs greater than 1. The HQ_{High}s exceeded 1 for aluminum, chromium, cobalt, copper, iron, lead, selenium, and OCDD. For no COPECs did the HQ_{Low} exceed 1. HQs for barium, beryllium, and perchlorate could not be calculated due to the absence of shellfish tissue-based TRVs.

Potential Risks to Fish

HQs for fish at the nearshore at Sandy Beach background site are shown in Table 5-9. Of the 19 COPECs for which tissue-based TRVs were available, all but six had HQs less than 1. The HQs for aluminum, arsenic, chromium, copper, vanadium, and zinc exceeded 1, as described below:

Table 5-6
Nanakuli Muliwai
Shellfish Tissue

Chemical	Maximum Detected Concentration (mg/kg)[a]	TRV_{Low}	HQ_{High}	TRV_{High}	HQ_{Low}
Metals					
Aluminum	73.2	31	2.4	310	0.24
Arsenic	3.9	6.4	0.61	64	0.06
Barium	14.5	-	-	-	-
Chromium	1.2	1.0	1.2	3.2	0.38
Cobalt	0.28	0.11	2.5	1.06	0.26
Copper	65.7	0.59	111	5.9	11
Iron	110	68	1.6	680	0.16
Manganese	32.5	15.5	2.1	53.6	0.61
Selenium	1.7	0.29	5.9	2.94	0.58
Silver	0.24	5.36	0.04	6.44	0.04
Vanadium	0.36	0.6	0.60	6.0	0.06
Zinc	485	12.7	38	24	20
Organics					
1,2,3,4,6,7,8-Hpcdd	1.20E-06	1.38E-4	0.009	1.38E-3	0.0009
1,2,3,6,7,8-Hxcdd	5.00E-07	1.38E-4	0.004	1.38E-3	0.0004
1,2,3,6,7,8-Hxcdf	2.20E-06	5.88E-5	0.04	5.88E-4	0.004
2,3,7,8-TCDF	4.60E-07	5.88E-5	0.008	5.88E-4	0.0008
OCDD	7.10E-06	1.38E-4	0.05	1.38E-3	0.005

Definitions:

mg/kg - milligrams per kilogram
TRV - Toxicity Reference Value
HQ - Hazard Quotient

Notes:

[a]Based on two samples of Hawaiian prawn and one sample of rock crab tissues.
A dash indicates the absence of an applicable TRV.
Shaded values indicate HQs greater than 1.

Table 5-7
Nanakuli Muliwai
Fish Tissue

Chemical	Maximum Detected Concentration (mg/kg)	TRV_{Low}	HQ_{High}	TRV_{High}	HQ_{Low}
Metals					
Aluminum	5170	42.65	121	100	52
Arsenic	2.57	10	0.26[a]	15	0.17[a]
Barium	43.6	-	-	-	-
Beryllium	0.094	-	-	-	-
Cadmium	0.13	0.375	0.35	0.7	0.19
Chromium	24.7	2.9	8.5	-	-
Cobalt	5.25	-	-	-	-
Copper	79.9	5	16	8	10.0
Iron	7010	-	-	-	-
Lead	2.15	12.5	0.17	20	0.11
Manganese	611	-	-	-	-
Mercury	0.047	15	0.003	25	0.002
Methyl Mercury	0.053	15	0.004	25	0.002
Selenium	2.57	3.955	0.65	39.55	0.06
Silver	0.703	0.3	2.3	-	-
Vanadium	23.6	0.1	236	2.05	12
Zinc	116	57	2.0	68	1.7
Organics					
4,4'-DDT	0.0014	13.25	0.0001	132.5	0.00001
di-n-Butylphthalate	0.018	-	-	-	-
Heptachlor Epoxide	0.0011	26.5	0.00004	57.5	0.00002
Perchlorate	0.0014	-	-	-	-
TCDD Equivalent	3.80E-09	0.00049	7.8E-6	0.0049	7.8E-7

Definitions:

mg/kg - milligrams per kilogram
TRV - Toxicity Reference Value
HQ - Hazard Quotient

Notes:

[a]Arsenic concentrations in fish tissues likely consist of organic arsenic only, which is nontoxic. The HQ for arsenic is assumed to overestimate the risk since the TRVs are based on inorganic arsenic.

A dash indicates the absence of an applicable TRV.

Shaded values indicate HQs greater than 1.

Table 5-8
Nearshore at Sandy Beach
Shellfish Tissue

Chemical	Maximum Detected Concentration (mg/kg)[a]	TRV_{Low}[b]	HQ_{High}	TRV_{High}[b]	HQ_{Low}
Inorganics					
Aluminum	61.8	31.0	2.0	310	0.20
Arsenic	1.2	6.4	0.19	64	0.02
Barium	1.6	-	-	-	-
Beryllium	0.062	-	-	-	-
Chromium	1.2	1.0	1.2	3.2	0.38
Cobalt	0.45	0.11	4.1	1.06	0.42
Copper	1.9	1.32	1.4	8.74	0.22
Iron	100	68	1.5	680	0.15
Lead	0.98	0.58	1.7	31.4	0.03
Manganese	1.8	15.5	0.12	53.6	0.03
Selenium	1.2	0.29	4.1	2.94	0.41
Vanadium	0.36	0.74	0.49	7.4	0.05
Zinc	5.9	37	0.16	40.6	0.15
Volatile Organic Compounds					
Toluene	8.90E-04	1.6	0.001	15.6	0.0001
Dioxins and Furans					
1,2,3,4,6,7,8-Hpcdd	7.40E-5	1.38E-4	0.54	1.38E-3	0.05
1,2,3,4,7,8-Hxcdf	3.20E-7	5.88E-5	0.005	5.88E-4	0.0005
1,2,3,6,7,8-Hxcdf	2.30E-7	5.88E-5	0.004	5.88E-4	0.0004
1,2,3,7,8,9-Hxcdf	2.30E-7	5.88E-5	0.004	5.88E-4	0.0004
2,3,7,8-TCDF	3.10E-7	5.88E-5	0.005	5.88E-4	0.0005
OCDD	2.90E-4	1.38E-4	2.1	1.38E-3	0.21

Definitions:

mg/kg - milligrams per kilogram
TRV - Toxicity Reference Value
HQ - Hazard Quotient

Notes:

[a]Based on three samples of helmet urchin tissues.
[b]TRVs for copper, lead, vanadium, and zinc are specific to echinoderms.
A dash indicates the absence of an applicable TRV.
Shaded values indicate HQs greater than 1.

Table 5-9
Nearshore at Sandy Beach
Fish Tissue

Chemical	Maximum Detected Concentration (mg/kg)	TRV_{Low}	HQ_{High}	TRV_{High}	HQ_{Low}
Metals					
Aluminum	4720	42.65	111	100	47
Antimony	0.0259	25	0.001	45	0.0006
Arsenic	53	10	5.3[a]	15	3.5[a]
Barium	14.2	-	-	-	-
Beryllium	0.069	-	-	-	-
Cadmium	0.2	0.375	0.53	0.7	0.29
Chromium	31.7	2.9	11	-	-
Cobalt	4.31	-	-	-	-
Copper	16.5	5	3.3	8	2.1
Iron	6960	-	-	-	-
Lead	2.75	12.5	0.22	20	0.14
Manganese	147	-	-	-	-
Mercury	0.043	15	0.003	25	0.002
Methyl Mercury	0.056	15	0.004	25	0.002
Selenium	1.8	3.955	0.46	39.55	0.05
Silver	0.031	0.3	0.10	-	-
Thallium	0.0126	-	-	-	-
Vanadium	20.3	0.1	203	2.05	9.9
Zinc	77	57	1.4	68	1.1
Organics					
4,4'-DDT	0.0021	13.25	0.0002	132.5	0.00002
Acetone	0.6	-	-	-	-
Aldrin	0.0064	10.65	0.0006	28.25	0.0002
BHC,gamma	0.0019	0.065	0.03	5.35	0.0004
Bis(2-ethylhexyl)phthalate	0.049	-	-	-	-
Diethyl phthalate	0.019	-	-	-	-
di-n-Butylphthalate	0.61	-	-	-	-
Heptachlor	0.0057	26.5	0.0002	57.5	0.0001
Heptachlor Epoxide	0.0076	26.5	0.0003	57.5	0.0001
m,p-Xylenes	0.016	-	-	-	-
Perchlorate	0.11	-	-	-	-
TCDD Equivalent	1.72E-07	0.00049	3.5E-4	0.0049	3.5E-5

Definitions:

mg/kg - milligrams per kilogram
TRV - Toxicity Reference Value
HQ - Hazard Quotient

Notes:

[a]Arsenic concentrations in fish tissues likely consist of organic arsenic only, which is nontoxic. The HQ for arsenic is assumed to overestimate the risk since the TRVs are based on inorganic arsenic.

A dash indicates the absence of an applicable TRV.

Shaded values indicate HQs greater than 1.

- Aluminum, arsenic, copper, vanadium, and zinc: Both the HQ_{High}s and HQ_{Low}s exceeded the threshold value of 1.
- Chromium: The HQ_{High} exceeded 1. An HQ Low was not calculated due to the absence of a TRV_{High} for chromium.

HQs for barium, beryllium, cobalt, iron, manganese, thallium, acetone, *bis*(2-ethylhexyl)phthalate, diethyl phthalate, di-*n*-butylphthalate, *m,p*-xylenes, and perchlorate could not be calculated due to the absence of fish tissue-based TRVs.

5.9.5 Potential Risks at the North Muliwai

Potential ecological risks at the north muliwai were estimated from assumed exposures of benthic invertebrates to COPECs in sediments and shellfish and fish to COPECs accumulated in tissues.

Potential Risks to Benthic Invertebrates

HQs for benthic invertebrates that are exposed to sediments in the north muliwai are shown in Table 5-10. Of the nine COPECs for which tissue-based TRVs were available, all but one had HQs less than 1. For selenium, the HQ_{Low} exceeded 1 the threshold value of 1. An HQ_{Low} was not calculated due to the absence of a TRV_{High}.

HQs for benzene, toluene, octachlorodibenzodioxin, and RDX could not be calculated due to the absence of fish tissue-based TRVs.

These results suggest that potential risks due to chemical exposures in sediments at the north muliwai do not represent imminent hazards to benthic invertebrates, given the following:

- Selenium was the only chemical with an HQ greater than 1.
- The HQ for selenium (4.0) does not greatly exceed 1. The TRV was based on the apparent effects level for amphipods, which is the lowest of the apparent effects levels among different biological indicators (Buchman 2006). There is uncertainty in the apparent effects level because the apparent effects levels were developed for use in Puget Sound, Washington, and are not easily compared to other sediment benchmarks. No threshold effects levels or probable effect levels have been developed for selenium.
- Selenium levels in the north muliwai may not be associated with anthropogenic releases at MMR but may be a natural result of accumulation and concentration in sediments over time due to repeated evaporation.

Potential Risks to Shellfish

HQs for shellfish in the north muliwai are shown in Table 5-11. Of the 15 COPECs for which tissue-based TRVs were available, seven had HQs exceeding 1. The HQ_{High}s exceeded 1 for aluminum, cobalt, copper, iron, manganese, selenium, and zinc. The HQ_{Low}s exceeded 1 for copper, manganese, and zinc. HQs for barium could not be calculated due to the absence of shellfish tissue-based TRVs.

Table 5-10
North Muliwai Sediment

Chemical	RME Concentration (mg/kg)	TRV_{Low}	HQ_{High}	TRV_{High}	HQ_{Low}
Metals					
Antimony	3.7	9.3	0.39	-	-
Cadmium	0.11	0.676	0.16	4.21	0.03
Lead	5.8	30.2	0.19	112	0.05
Selenium	4.0	1.0	4.0	-	-
Organics					
4,4'-DDT	0.0001	0.00119	0.08	0.00477	0.02
Benzene	0.00004	-	-	-	-
bis(2-ethylhexyl)phthalate	0.02	0.182	0.10	2.65	0.007
Ethylbenzene	0.001	0.004	0.31	-	-
m,p-Xylenes	0.001	0.004	0.25	-	-
OCDD	0.0002	-	-	-	-
o-Xylene	0.0001	0.004	0.03	-	-
RDX	0.05	-	-	-	-
Toluene	0.001	-	-	-	-

Definitions:

HQ - Hazard Quotient
mg/kg - milligrams per kilogram
RME - Reasonable maximum exposure
TRV - Toxicity Reference Value

Notes:

A dash indicates the absence of an applicable TRV.
Shaded values indicate HQs greater than 1.

Table 5-11
North Muliwai
Shellfish Tissue

Chemical	Maximum Detected Concentration (mg/kg)[a]	TRV_{Low}	HQ_{High}	TRV_{High}	HQ_{Low}
Metals					
Aluminum	33.3	31	1.1	310	0.11
Arsenic	2.4	6.4	0.38	64	0.04
Barium	26.3	-	-	-	-
Chromium	0.94	1.0	0.94	3.2	0.29
Cobalt	0.17	0.11	1.5	1.06	0.16
Copper	21.3	0.59	36	5.9	3.6
Iron	92.2	68	1.4	680	0.14
Manganese	70.3	15.5	4.5	53.6	1.3
Mercury	0.022	2.1	0.01	12.3	0.002
Selenium	0.68	0.29	2.3	2.94	0.23
Vanadium	0.35	0.6	0.58	6.0	0.06
Zinc	31.2	12.7	2.5	24	1.3
Dioxins and Furans					
1,2,3,6,7,8-Hxcdd	1.20E-06	1.38E-4	0.009	1.38E-3	0.0009
1,2,3,7,8,9-Hxcdd	8.30E-07	1.38E-4	0.006	1.38E-3	0.0006
2,3,7,8-TCDF	1.70E-06	5.88E-5	0.03	5.88E-4	0.003
OCDD	3.00E-06	1.38E-4	0.02	1.38E-3	0.002

Definitions:

mg/kg - milligrams per kilogram
TRV - Toxicity Reference Value
HQ - Hazard Quotient

Notes:

[a]Based on one sample of Samoan crab tissues.
A dash indicates the absence of an applicable TRV.
Shaded values indicate HQs greater than 1.

These results suggest that potential risks due to chemical exposures at the north muliwai do not represent imminent hazards to shellfish, given the following:

- The shellfish tissue HIs for the north muliwai were lower than the HIs for the Nanakuli background muliwai, indicating that overall hazards are less than background (see Section 5.10.1);
- HQs exceeding 1 for aluminum, cobalt, copper, iron, manganese, selenium, and zinc also exceeded 1 for shellfish tissues collected at the Nanakuli background muliwai (Table 5-6);
- HQ_{High}s for aluminum (1.1), cobalt (1.5), iron (1.4), manganese (4.5), selenium (2.3), and zinc (2.5) do not greatly exceed 1 (i.e., were less than 5). HQ_{High}s represent potential hazards based on no-effect levels, which are lower than the levels at which adverse effects begin to occur;
- The HQ_{High}s for aluminum and iron were based on TRVs for no-effect levels, but effect levels at higher concentrations were not identified for these chemicals;
- The HQ_{High}s for cobalt, copper, and selenium were based on estimated no-effect levels; their TRV_{Low}s were extrapolated from TRV_{High}s using an uncertainty factor of 10; and
- No other shellfish tissue COPECs in the north muliwai had HQs greater than 1.

Potential Risks to Fish

HQs for fish in the north muliwai are shown in Table 5-12. Of the 18 COPECs for which tissue-based TRVs were available, all but six had HQs less than 1. The HQs for aluminum, chromium, copper, silver, vanadium, and zinc exceeded 1 as described below:

- Aluminum, copper, vanadium, and zinc—Both the HQ_{High}s and HQ_{Low}s exceeded the threshold value of 1; and
- Chromium and silver—The HQ_{High} exceeded 1. HQ_{Low}s were not calculated due to the absence of TRV_{High}s.

HQs for barium, beryllium, cobalt, iron, manganese, acetone, di-*n*-butylphthalate, and perchlorate could not be calculated due to the absence of fish tissue-based TRVs.

These results suggest that potential risks due to chemical exposures at the north muliwai do not represent imminent hazards to fish, given the following:

- HQ_{High}s for chromium (5.1), silver (3.8), and zinc (2.3) do not greatly exceed 1 (i.e., were less than or comparable to 5). HQ_{High}s represent potential hazards based on no-effect levels, which are lower than the levels at which adverse effects begin to occur;
- The HQ_{High}s for chromium and silver were based on TRVs for no-effect levels, but no effect levels at higher concentrations were identified for these chemicals;

Table 5-12
North Muliwai
Fish Tissue

Chemical	Maximum Detected Concentration (mg/kg)	TRV_{Low}	HQ_{High}	TRV_{High}	HQ_{Low}
Metals					
Aluminum	4240	42.7	99	100	42
Antimony	0.04	25	0.002	45	0.001
Arsenic	3.81	10	0.38[a]	15	0.25[a]
Barium	26.1	-	-	-	-
Beryllium	0.051	-	-	-	-
Cadmium	0.08	0.375	0.21	0.70	0.11
Chromium	14.7	2.9	5.1	-	-
Cobalt	4.17	-	-	-	-
Copper	166	5.0	33	8.0	21
Iron	4530	-	-	-	-
Lead	5.39	13	0.43	20	0.27
Manganese	386	-	-	-	-
Mercury	0.074	15	0.005	25	0.003
Methyl Mercury	0.07	15	0.005	25	0.003
Selenium	3.71	3.96	0.94	39.6	0.09
Silver	1.13	0.30	3.8	-	-
Vanadium	19.3	0.10	193	2.1	9.4
Zinc	129	57.0	2.3	68.0	1.9
Organics					
4,4'-DDT	0.00074	13.3	0.0001	133	0.00001
Acetone	0.25	-	-	-	-
BHC,delta	0.00031	24.3	0.00001	243	0.000001
BHC,gamma	0.0013	0.065	0.020	5.35	0.0002
di-n-Butylphthalate	0.015	-	-	-	-
Heptachlor Epoxide	0.00051	27	0.00002	57.5	0.00001
Perchlorate	0.0019	-	-	-	-
TCDD Equivalent	1.42E-06	0.00049	2.9E-3	0.0049	2.9E-4

Definitions:

mg/kg - milligrams per kilogram
TRV - Toxicity Reference Value
HQ - Hazard Quotient

Notes:

[a]Arsenic concentrations in fish tissues likely consist of organic arsenic only, which is nontoxic. The HQ for arsenic is assumed to overestimate the risk since the TRVs are based on inorganic arsenic.

A dash indicates the absence of an applicable TRV.

Shaded values indicate HQs greater than 1.

- Fish tissue TRVs for chromium, copper, and zinc were based on muscle concentrations, which may differ from whole-body concentrations measured at the site;
- No other fish tissue COPECs in the north muliwai had HQs greater than 1;
- HQs exceeding 1 for aluminum, chromium, copper, silver, vanadium, and zinc also exceeded 1 for fish tissues collected at the Nanakuli background muliwai (Table 5-7); and
- The fish tissue HIs for the north muliwai were lower than the HIs for the Nanakuli background muliwai, indicating that overall hazards are less than background (see Section 5.10.1).

5.9.6 Potential Risks at the South Muliwai at MMR

Potential ecological risks at the south muliwai were estimated from assumed exposures of benthic invertebrates to COPECs in sediments and of shellfish and fish to COPECs accumulated in tissues.

Potential Risks to Benthic Invertebrates

HQs for benthic invertebrates that are exposed to sediments in the south muliwai are shown in Table 5-13. Of the eight COPECs for which tissue-based TRVs were available, all but two had HQs less than 1. For selenium and 2,3,7,8-TCDD, the HQ_{Low}s exceeded the threshold value of 1. HQ_{Low}s were not calculated due to the absence of TRV_{High}s for these chemicals.

HQs for picloram and toluene could not be calculated due to the absence of fish tissue-based TRVs.

These results suggest that the potential risk due to selenium in sediments does not represent imminent hazards to benthic invertebrates, given the following:

- The HQ for selenium (4.7) is less than or comparable to 5.
- The TRV for selenium was based on the apparent effects level for amphipods, which is the lowest of the apparent effects levels among different biological indicators (Buchman 2006). There is uncertainty in the apparent effects level because the apparent effects levels were developed for use in Puget Sound, Washington, and are not easily compared to other sediment benchmarks (Buchman 2006). No threshold effects levels or probable effect levels have been developed for selenium.
- Selenium levels in the south muliwai may not be associated with anthropogenic releases at MMR but may be a natural result of accumulation and concentration in sediments over time due to repeated evaporation.
- 2,3,7,8-TCDD, which occurred at a maximum concentration of 0.00003 mg/kg in sediments, may represent a hazard to benthic invertebrates. Although the TRV for 2,3,7,8-TCDD was also based on the lowest apparent effects level (for the *Neanthes* polychaete) and subject to uncertainty, the HQ (8.3) approached 10.

Table 5-13
South Muliwai Sediment

Chemical	RME Concentration (mg/kg)	TRV_{Low}	HQ_{High}	TRV_{High}	HQ_{Low}
Metals					
Antimony	0.63	9.3	0.07	-	-
Cadmium	0.09	0.676	0.13	4.2	0.02
Lead	19	30.2	0.63	112	0.17
Selenium	4.7	1.0	4.7	-	-
Organics					
2,3,7,8-TCDD	0.00003	3.6E-6	8.3	-	-
Ethylbenzene	0.001	0.004	0.25	-	-
m,p-Xylenes	0.001	0.004	0.18	-	-
Pentachlorophenol	0.001	0.017	0.05	-	-
Picloram	0.0004	-	-	-	-
Toluene	0.001	-	-	-	-

Definitions:

HQ - Hazard Quotient
mg/kg - milligrams per kilogram
RME - Reasonable maximum exposure
TRV - Toxicity Reference Value

Notes:

A dash indicates the absence of an applicable TRV.
Shaded values indicate HQs greater than 1.

Potential Risks to Shellfish

HQs for shellfish in the south muliwai are shown in Table 5-14. Of the 11 COPECs for which tissue-based TRVs were available, nine had HQs greater than 1. The HQ_{High}s exceeded 1 for aluminum, chromium, cobalt, copper, iron, manganese, selenium, and vanadium, and zinc. The HQ_{Low}s exceeded 1 for copper, manganese, and zinc. HQs for barium could not be calculated due to the absence of shellfish tissue-based TRVs.

These results suggest that potential risks due to chemical exposures at the south muliwai do not represent imminent hazards to shellfish, given the following:

- The shellfish tissue HIs for the south muliwai were lower than the HIs for the Nanakuli background muliwai, indicating that overall hazards are less than background (see Section 5.10.2);
- HQs exceeding 1 for aluminum, chromium, cobalt, copper, iron, manganese, selenium, and zinc also exceeded 1 for shellfish tissues collected at the Nanakuli background muliwai (Table 5-6);
- HQ_{High}s for aluminum (4.6), chromium (1.3), iron (3.3), selenium (4.1), vanadium (1.3), and zinc (2.2) do not greatly exceed 1 (i.e., were less than 5). HQ_{High}s represent potential hazards based on no-effect levels, which are lower than the levels at which adverse effects begin to occur;
- The HQ_{High}s for aluminum, iron, and vanadium were based on TRVs for no-effect levels, but effect levels at higher concentrations were not identified for these chemicals;
- The HQ_{High}s for cobalt, copper, and selenium were based on estimated no-effect levels; their TRV_{Low}s were extrapolated from TRV_{High}s using an uncertainty factor of 10; and
- No other shellfish tissue COPECs in the south muliwai had HQs greater than 1.

Potential Risks to Fish

HQs for fish in the south muliwai are shown in Table 5-15. Of the 18 COPECs for which tissue-based TRVs were available, all but seven had HQs less than 1. The HQs for aluminum, arsenic, chromium, copper, silver, vanadium, and zinc exceeded 1, as described below:

- Aluminum, arsenic, copper, vanadium, and zinc—Both the HQ_{High}s and HQ_{Low}s exceeded the threshold value of 1; and
- Chromium and silver—The HQ_{High} exceeded 1. HQ_{Low}s were not calculated due to the absence of TRV_{High}s.

HQs for barium, beryllium, cobalt, iron, manganese, thallium, acetone, *m,p*-xylenes, *bis*(2-ethylhexyl)phthalate, di-*n*-butylphthalate, and perchlorate could not be calculated due to the absence of fish tissue-based TRVs.

Table 5-14
South Muliwai
Shellfish Tissue

Chemical	Maximum Detected Concentration (mg/kg)[a]	TRV_{Low}	HQ_{High}	TRV_{High}	HQ_{Low}
Metals					
Aluminum	143	31	4.6	310	0.46
Arsenic	3.6	6.4	0.56	64	0.06
Barium	57.8	-	-	-	-
Chromium	1.3	1.0	1.3	3.2	0.41
Cobalt	0.8	0.11	7.3	1.06	0.75
Copper	39.7	0.59	67	5.9	6.7
Iron	226	68	3.3	680	0.33
Lead	0.16	4.0	0.04	40.7	0.004
Manganese	122	15.5	7.9	53.6	2.3
Selenium	1.2	0.29	4.1	2.94	0.41
Vanadium	0.77	0.6	1.3	6.0	0.13
Zinc	28.4	12.7	2.2	24	1.2

Definitions:

mg/kg - milligrams per kilogram
TRV - Toxicity Reference Value
HQ - Hazard Quotient

Notes:

[a]Based on one sample each of rock crab and Hawaiian prawn tissues.
A dash indicates the absence of an applicable TRV.
Shaded values indicate HQs greater than 1.

Table 5-15
South Muliwai
Fish Tissue

Chemical	Maximum Detected Concentration (mg/kg)	TRV_{Low}	HQ_{High}	TRV_{High}	HQ_{Low}
Metals					
Aluminum	2880	42.7	68	100	29
Antimony	0.0527	25	0.002	45	0.001
Arsenic	29.8	10	3.0[a]	15	2.0[a]
Barium	21.2	-	-	-	-
Beryllium	0.032	-	-	-	-
Cadmium	0.147	0.375	0.39	0.7	0.21
Chromium	31.5	2.9	11	-	-
Cobalt	2.58	-	-	-	-
Copper	109	5	22	8	14
Iron	3460	-	-	-	-
Lead	2.61	12.5	0.21	20	0.13
Manganese	184	-	-	-	-
Mercury	0.103	15	0.007	25	0.004
Methyl Mercury	0.17	15	0.01	25	0.007
Selenium	3.59	3.955	0.91	39.55	0.09
Silver	0.822	0.3	2.7	-	-
Thallium	0.00586	-	-	-	-
Vanadium	18.2	0.1	182	2.05	8.9
Zinc	201	57	3.5	68	3.0
Organics					
4,4'-DDT	0.0029	13.25	0.0002	132.5	0.00002
Acetone	0.38	-	-	-	-
BHC,delta	0.0041	24.3	0.0002	243	0.00002
BHC,gamma	0.0017	0.065	0.03	5.35	0.0003
Bis(2-ethylhexyl)phthalate	3.1	-	-	-	-
di-n-Butylphthalate	1.5	-	-	-	-
Heptachlor Epoxide	0.00093	26.5	0.00004	57.5	0.00002
m,p-Xylenes	0.017	-	-	-	-
Perchlorate	0.16	-	-	-	-
TCDD Equivalent	1.76E-06	0.00049	3.6E-3	0.0049	3.6E-4

Definitions:

mg/kg - milligrams per kilogram
TRV - Toxicity Reference Value
HQ - Hazard Quotient

Notes:

[a]Arsenic concentrations in fish tissues likely consist of organic arsenic only, which is nontoxic. The HQ for arsenic is assumed to overestimate the risk since the TRVs are based on inorganic arsenic.

A dash indicates the absence of an applicable TRV.

Shaded values indicate HQs greater than 1.

These results suggest that potential risks due to chemical exposures at the south muliwai do not represent imminent hazards to fish, given the following:

- HQ_{High}s for arsenic (3.0), silver (2.7), and zinc (3.5), and HQ_{Low}s for arsenic (2.0), and zinc (3.0), do not greatly exceed 1. HQ_{High}s represent potential hazards based on no-effect levels, which are lower than the levels at which adverse effects begin to occur;
- The HQ_{High}s for chromium and silver were based on TRVs for no-effect levels, but no effect levels at higher concentrations were identified for these chemicals;
- Arsenic concentrations in fish tissues likely consist of organic arsenic only, which is nontoxic. The HQs for arsenic likely greatly overestimate the risk since the TRVs are based on inorganic arsenic;
- Fish tissue TRVs for chromium, copper, and zinc were based on muscle concentrations, which may differ from whole-body concentrations measured at the site;
- No other fish tissue COPECs in the south muliwai had HQs greater than 1;
- HQs exceeding 1 for aluminum, arsenic, chromium, copper, silver, vanadium, and zinc also exceeded 1 for fish tissues collected at the Nanakuli background muliwai (Table 5-7); and
- The fish tissue HIs for the south muliwai were lower than the HIs for the Nanakuli background muliwai, indicating that overall hazards are less than background (see Section 5.10.2).

5.9.7 Potential Risks at the Nearshore

Potential ecological risks at the nearshore site were estimated from assumed exposures of shellfish and fish to COPECs accumulated in tissues. Potential risks to limu could not be calculated due to the absence of applicable tissue-based TRVs.

Potential Risks to Shellfish (Helmet Urchins)

HQs for shellfish at the nearshore area are shown separately for helmet urchins and Kona crabs because separate echinoderm and crustacean toxicity data were available for some chemicals. HQs for helmet urchins are presented in Table 5-16(a). Of the 13 COPECs for which tissue-based TRVs were available, six had HQs greater than 1. The HQ_{High}s exceeded 1 for aluminum, chromium, cobalt, copper, iron, and selenium. For no COPECs did the HQ_{Low}s exceed the threshold value of 1. HQs for barium, perchlorate, and toluene could not be calculated due to the absence of shellfish tissue-based TRVs.

These results suggest that potential risks due to chemical exposures at the nearshore habitat do not represent imminent hazards to helmet urchins, given the following:

- The helmet urchin tissue HIs for the nearshore habitat off MMR were lower than the HIs for the background nearshore habitat off Sandy Beach, indicating that overall hazards are less than background (see Section 5.10.3);

Table 5-16(a)
Nearshore at Makua
Shellfish Tissue (Helmet Urchin)

Chemical	Maximum Detected Concentration (mg/kg)[a]	TRV_{Low}[b]	HQ_{High}	TRV_{High}[b]	HQ_{Low}
Metals					
Aluminum	102	31	3.3	310	0.33
Arsenic	1.2	6.4	0.19	64	0.02
Barium	2.3	-	-	-	-
Chromium	1.2	1.0	1.2	3.2	0.38
Cobalt	0.37	0.11	3.4	1.06	0.35
Copper	2.6	1.32	2.0	8.74	0.30
Iron	84.9	68	1.2	680	0.12
Lead	0.33	0.58	0.57	31.4	0.01
Manganese	3.5	15.5	0.23	53.6	0.07
Selenium	0.73	0.29	2.5	2.94	0.25
Vanadium	0.31	0.74	0.42	7.4	0.04
Zinc	11.6	37	0.31	40.6	0.29
Perchlorate	1.05	-	-	-	-
Volatile Organic Compounds					
Toluene	0.0011	1.6	0.001	15.6	0.0001
Organochlorine Pesticides					
Aldrin	0.0011	0.01	0.11	1	0.001
Dioxins and Furans					
OCDD	8.00E-6	1.38E-4	0.06	1.38E-3	0.01

Definitions:

mg/kg - milligrams per kilogram
TRV - Toxicity Reference Value
HQ - Hazard Quotient

Notes:

[a]Based on two samples of helmet urchin tissues.
[b]TRVs for copper, lead, vanadium, and zinc are specific to echinoderms.
Shaded values indicate HQs greater than 1.

- HQs exceeding 1 for aluminum, chromium, cobalt, copper, iron, and selenium also exceeded 1 for shellfish tissues collected at the background nearshore habitat off Sandy Beach (Table 5-8);
- HQ_{High}s for aluminum (3.3), chromium (1.2), cobalt (3.4), copper (2.0), iron (1.2), and selenium (2.5) do not greatly exceed 1 (i.e., were less than 5). HQ_{High}s represent potential hazards based on no-effect levels, which are lower than the levels at which adverse effects begin to occur;
- The HQ_{High}s for aluminum and iron were based on TRVs for no-effect levels, but effect levels at higher concentrations were not identified for these chemicals;
- The HQ_{High}s for cobalt and selenium were based on estimated no-effect levels; their TRV_{Low}s were extrapolated from TRV_{High}s using an uncertainty factor of 10; and
- No other helmet urchin tissue COPECs in the nearshore habitat had HQs greater than 1.

Potential Risks to Shellfish (Kona Crabs)

HQs for Kona crabs are presented in Table 5-16(b). Of the 14 COPECs for which tissue-based TRVs were available, eight had HQs less than 1. The HQ_{High}s exceeded 1 for arsenic, cadmium, chromium, cobalt, copper, iron, selenium, and zinc. The HQ_{Low}s exceeded the threshold value of 1 for cadmium, copper, and zinc. HQs for barium could not be calculated due to the absence of shellfish tissue-based TRVs.

These results suggest that potential risks for most COPECs at the nearshore habitat do not represent imminent hazards to Kona crabs, given the following:

- HQs exceeding 1 for chromium, cobalt, copper, iron, and selenium also exceeded 1 for shellfish tissues collected at the background nearshore habitat off Sandy Beach (Table 5-8);
- HQ_{High}s for arsenic (4.1), chromium (1.2), cobalt (2.1), iron (1.9), and zinc (3.7) do not greatly exceed 1 (i.e., were less than 5). HQ_{High}s represent potential hazards based on no-effect levels, which are lower than the levels at which adverse effects begin to occur;
- The HQ_{High}s for arsenic and iron were based on TRVs for no-effect levels, but effect levels at higher concentrations were not identified for these chemicals;
- The HQ_{High}s for cadmium, cobalt, copper, and selenium were based on estimated no-effect levels; their TRV_{Low}s were extrapolated from TRV_{High}s using an uncertainty factor of 10; and
- No other shellfish tissue COPECs in the nearshore habitat had HQs greater than 1.

Based on the weight of evidence including their HQ_{Low}s, cadmium, copper, and zinc concentrations in Kona crab tissues may represent potential hazards.

Table 5-16(b)
Nearshore at Makua
Shellfish Tissue (Kona Crab)

Chemical	Maximum Detected Concentration (mg/kg)[a]	TRV_{Low}	HQ_{High}	TRV_{High}	HQ_{Low}
Metals					
Aluminum	29.9	31	0.96	310	0.10
Arsenic	26.4	6.4	4.1	64	0.41
Barium	1.4	-	-	-	-
Cadmium	2	0.13	15	1.29	1.6
Chromium	1.2	1.0	1.2	3.2	0.38
Cobalt	0.23	0.11	2.1	1.06	0.22
Copper	25.7	0.59	44	5.9	4.4
Iron	131	68	1.9	680	0.19
Lead	0.13	4.0	0.03	40.7	0.003
Manganese	1.7	15.5	0.11	53.6	0.03
Mercury	0.041	2.1	0.02	12.3	0.003
Selenium	1.7	0.29	5.9	2.94	0.58
Silver	0.15	5.36	0.03	6.44	0.02
Vanadium	0.56	0.6	0.93	6.0	0.09
Zinc	47.4	12.7	3.7	24	2.0

Definitions:

mg/kg - milligrams per kilogram
TRV - Toxicity Reference Value
HQ - Hazard Quotient

Notes:

[a]Based on one sample of Kona crab tissues.
Shaded values indicate HQs greater than 1.

Potential Risks to Fish

HQs for fish at the nearshore area are shown in Table 5-17. Of the 19 COPECs for which tissue-based TRVs were available, all but six had HQs less than 1. The HQs for aluminum, arsenic, chromium, copper, vanadium, and zinc exceeded 1, as described below:

- Arsenic, copper, and zinc—Both the HQ_{High}s and HQ_{Low}s exceeded the threshold value of 1; and
- Aluminum, chromium, and vanadium—Only the HQ_{High} exceeded 1. An HQ_{Low} was not calculated for chromium due to the absence of a TRV_{High}.

HQs for barium, cobalt, iron, manganese, acetone, *m,p*-xylenes, *bis*(2-ethylhexyl)phthalate, di-*n*-butylphthalate, nitroglycerin, RDX, and perchlorate could not be calculated due to the absence of fish tissue-based TRVs.

These results suggest that potential risks due to chemical exposures at the nearshore habitat do not represent imminent hazards to fish, given the following:

- HQ_{High}s for aluminum (1.5), arsenic (3.7), chromium (3.6), copper (2.0), and zinc (2.6), and HQ_{Low}s for arsenic (2.5), copper (1.2), and zinc (2.2), do not greatly exceed 1. HQ_{High}s represent potential hazards based on no-effect levels, which are lower than the levels at which adverse effects begin to occur;
- The HQ_{High} for chromium was based on a TRV for no-effect levels, but no effect levels at higher concentrations were identified for chromium;
- Arsenic concentrations in fish tissues likely consist of organic arsenic only, which is nontoxic. The HQs for arsenic likely greatly overestimate the risk since the TRVs are based on inorganic arsenic;
- Fish tissue TRVs for chromium, copper, and zinc were based on muscle concentrations, which may differ from whole-body concentrations measured at the site;
- No other fish tissue COPECs in nearshore habitat off MMR had HQs greater than 1;
- HQs exceeding 1 for aluminum, chromium, copper, vanadium, and zinc also exceeded 1 for fish tissues collected at the background nearshore habitat off Sandy Beach (Table 5-9); and
- The fish tissue HIs for the nearshore habitat off MMR were lower than the HIs for the background nearshore habitat off Sandy Beach, indicating that overall hazards are less than background (see Section 5.10.3).

5.10 HAZARD INDICES AND INCREMENTAL RISKS

HIs were calculated by summing the HQs for all COPECs at a given site to identify if multiple chemical exposures could have a cumulative impact on receptors (Tables 5-18 to 5-25). For comparative purposes, HIs for both sites and background areas were calculated. Separate HIs were tabulated as the sums of HQ_{High}s and HQ_{Low}s.

Table 5-17
Nearshore at Makua
Fish Tissue

Chemical	Maximum Detected Concentration (mg/kg)	TRV_{Low}	HQ_{High}	TRV_{High}	HQ_{Low}
Metals					
Aluminum	65	42.65	1.5	100	0.65
Arsenic	37.3	10	3.7[a]	15	2.5[a]
Barium	31.6	-	-	-	-
Cadmium	0.21	0.375	0.56	0.7	0.30
Chromium	10.4	2.9	3.6	-	-
Cobalt	0.413	-	-	-	-
Copper	9.78	5	2.0	8	1.2
Iron	302	-	-	-	-
Lead	2.01	12.5	0.16	20	0.10
Manganese	15.7	-	-	-	-
Mercury	0.0978	15	0.007	25	0.004
Methyl Mercury	0.20009	15	0.01	25	0.008
Selenium	1.6	3.955	0.40	39.55	0.04
Silver	0.0132	0.3	0.04	-	-
Vanadium	1.24	0.1	12	2.05	0.60
Zinc	149	57	2.6	68	2.2
Organics					
4,4'-DDT	0.00018	13.25	0.00001	132.5	0.000001
Acetone	0.73	-	-	-	-
Aldrin	0.0027	10.65	0.0003	28.25	0.0001
BHC,alpha	0.0082	210	0.00004	850	0.00001
BHC,delta	0.0003	24.3	0.00001	243	0.000001
BHC,gamma	0.0063	0.065	0.10	5.35	0.001
Bis(2-ethylhexyl)phthalate	3.5	-	-	-	-
di-n-Butylphthalate	1.4	-	-	-	-
Heptachlor	0.0056	26.5	0.0002	57.5	0.0001
Heptachlor Epoxide	0.014	26.5	0.0005	57.5	0.0002
m,p-Xylenes	0.02	-	-	-	-
Nitroglycerin	0.33	-	-	-	-
Perchlorate	0.0088	-	-	-	-
RDX	0.057	-	-	-	-

Definitions:

mg/kg - milligrams per kilogram
TRV - Toxicity Reference Value
HQ - Hazard Quotient

Notes:

[a]Arsenic concentrations in fish tissues likely consist of organic arsenic only, which is nontoxic. The HQ for arsenic is assumed to overestimate the risk since the TRVs are based on inorganic arsenic.

Shaded values indicate HQs greater than 1.

In fish tissues, both mercury and methylmercury were measured. Since virtually all of the mercury in biological tissues is methylmercury, by including both mercury and methylmercury in the calculated HI, it would overestimate the sum of risks. Therefore, the higher HQ between mercury and methylmercury was used in each case.

5.10.1 North Muliwai

The HI_{High} for benthic invertebrates at the north muliwai was 5.51, driven primarily by the HQ_{High} for selenium (Table 5-18). As noted previously, selenium in sediments is not expected to be anthropogenic but is likely naturally occurring. Thus, the HI for benthic invertebrates in the north muliwai likely does not represent cumulative hazards from releases associated with the MMR. Incremental risks were calculated as the HIs for the north muliwai minus the HIs for the north background area. Due to the relatively fewer number of chemicals detected in the background sediments, the incremental risk for invertebrates in the north muliwai was only slightly lower than that indicated by north muliwai HI (Table 5-18).

The HI_{High} and HI_{Low} for shellfish in the north muliwai were 51 and 7.3, indicating a potential for cumulative impacts from multiple COPECs (Table 5-19). However, the HIs for shellfish in the Nanakuli background muliwai (167 and 34) exceeded those at the north muliwai. Therefore, the overall potential for hazards to shellfish in the north muliwai was lower than under background conditions, and the incremental risk was zero.

The HI_{High} and HI_{Low} for fish in the north muliwai were 338 and 75, indicating a potential for cumulative impacts from multiple COPECs (Table 5-20). However, the HIs for fish in the Nanakuli background muliwai were comparable or higher. Thus, the overall potential for hazards to fish in the north muliwai was similar to or lower than that under background conditions, and the incremental risk was zero. Potential cumulative impacts as represented by background conditions would exist even in the absence of MMR.

5.10.2 South Muliwai

The HI_{High} for benthic invertebrates at the south muliwai was 14.4, driven mainly by the HQ_{High}s for selenium and 2,3,7,8-TCDD (Table 5-21). As noted previously, selenium in sediments is not expected to be anthropogenic but is likely naturally occurring. Incremental risks were calculated as the HIs for the north muliwai minus the HIs for the south background area. Due to the relatively fewer number of chemicals detected in the background sediments, the incremental risk for invertebrates in the south muliwai was only slightly lower than that indicated by south muliwai HI (Table 5-21). The HI for benthic invertebrates in the south muliwai represents potential cumulative hazards, primarily a result of 2,3,7,8-TCDD.

The HI_{High} and HI_{Low} for shellfish in the south muliwai were 100 and 13, indicating a potential for cumulative impacts from multiple COPECs (Table 5-22). However, the HIs for shellfish in the Nanakuli background muliwai (167 and 34) exceeded those at the south muliwai. Therefore, the overall potential for hazards to shellfish in the south muliwai was lower than under background conditions, and the incremental risk was zero. As such, potential cumulative impacts as determined for background conditions would exist even in the absence of MMR.

Table 5-18
North Muliwai HIs
Sediment

Chemical	North Muliwai		North Background Muliwai		North Muliwai Incremental Risk	
	HQ_{High}	HQ_{Low}	HQ_{High}	HQ_{Low}	High	Low
Metals						
Antimony	0.39	-	-	-	-	-
Cadmium	0.16	0.03	-	-	-	-
Lead	0.19	0.05	0.05	0.01	-	-
Selenium	4.0	-	-	-	-	-
Organics						
4,4'-DDT	0.08	0.02	-	-	-	-
Benzene	-	-	-	-	-	-
bis(2-ethylhexyl)phthalate	0.10	0.007	-	-	-	-
Ethylbenzene	0.31	-	-	-	-	-
m,p-Xylenes	0.25	-	-	-	-	-
OCDD	-	-	-	-	-	-
o-Xylene	0.03	-	-	-	-	-
RDX	-	-	-	-	-	-
Toluene	-	-	-	-	-	-
HI	5.51	0.10	0.05	0.01	5.46	0.09

Definitions:

HI - Hazard Index
HQ - Hazard Quotient
mg/kg - milligrams per kilogram
RME - Reasonable maximum exposure
TRV - Toxicity Reference Value

Notes:

A dash indicates the absence of an applicable HQ.
Shaded values indicate HQs and HIs greater than 1.

Table 5-19
North Muliwai HIs
Shellfish Tissue

Chemical	North Muliwai		Nanakuli Background Muliwai		North Muliwai Incremental Risk	
	HQ_{High}	HQ_{Low}	HQ_{High}	HQ_{Low}	High	Low
Metals						
Aluminum	1.1	0.11	2.4	0.24	N/A	N/A
Arsenic	0.38	0.04	0.61	0.06	N/A	N/A
Barium	-	-	-	-	N/A	N/A
Chromium	0.94	0.29	1.2	0.38	N/A	N/A
Cobalt	1.5	0.16	2.5	0.26	N/A	N/A
Copper	36	3.6	111	11	N/A	N/A
Iron	1.4	0.14	1.6	0.16	N/A	N/A
Manganese	4.5	1.3	2.1	0.61	N/A	N/A
Mercury	0.01	0.002	-	-	N/A	N/A
Selenium	2.3	0.23	5.9	0.58	N/A	N/A
Silver	-	-	0.04	0.04	N/A	N/A
Vanadium	0.58	0.06	0.60	0.06	N/A	N/A
Zinc	2.5	1.3	38	20	N/A	N/A
Organics						
1,2,3,4,6,7,8-Hpcdd	-	-	0.009	0.0009	N/A	N/A
1,2,3,6,7,8-Hxcdd	0.0087	0.0009	0.004	0.0004	N/A	N/A
1,2,3,6,7,8-Hxcdf	-	-	0.04	0.004	N/A	N/A
1,2,3,7,8,9-Hxcdd	0.00601	0.00060	-	-	N/A	N/A
2,3,7,8-TCDF	0.029	0.0029	0.008	0.0008	N/A	N/A
OCDD	0.022	0.002	0.05	0.005	N/A	N/A
HI	51	7.3	167	34	0	0

Definitions:

HI - Hazard Index
HQ - Hazard Quotient
mg/kg - milligrams per kilogram
N/A - Not applicable
RME - Reasonable maximum exposure
TRV - Toxicity Reference Value

Notes:

A dash indicates the absence of an applicable HQ.
Shaded values indicate HQs and HIs greater than 1.

Table 5-20
North Muliwai HIs
Fish Tissue

Chemical	North Muliwai		Nanakuli Background Muliwai		North Muliwai Incremental Risk	
	HQ_{High}	HQ_{Low}	HQ_{High}	HQ_{Low}	High	Low
Metals						
Aluminum	99	42	121	52	N/A	N/A
Antimony	0.002	0.001	-	-	N/A	N/A
Arsenic[a]	-	-	-	-	N/A	N/A
Barium	-	-	-	-	N/A	N/A
Beryllium	-	-	-	-	N/A	N/A
Cadmium	0.21	0.11	0.35	0.19	N/A	N/A
Chromium	5.1	-	8.5	-	N/A	N/A
Cobalt	-	-	-	-	N/A	N/A
Copper	33	21	16	10.0	N/A	N/A
Iron	-	-	-	-	N/A	N/A
Lead	0.43	0.27	0.17	0.11	N/A	N/A
Manganese	-	-	-	-	N/A	N/A
Mercury/Methyl Mercury	0.005	0.003	0.004	0.002	N/A	N/A
Selenium	0.94	0.09	0.65	0.06	N/A	N/A
Silver	3.8	-	2.3	-	N/A	N/A
Vanadium	193	9.4	236	12	N/A	N/A
Zinc	2.3	1.9	2.0	1.7	N/A	N/A
Organics						
4,4'-DDT	0.0001	0.00001	0.0001	0.00001	N/A	N/A
Acetone	-	-	-	-	N/A	N/A
BHC,delta	0.00001	0.000001	-	-	N/A	N/A
BHC,gamma	0.020	0.0002	-	-	N/A	N/A
di-n-Butylphthalate	-	-	-	-	N/A	N/A
Heptachlor Epoxide	0.00002	0.00001	0.00004	0.00002	N/A	N/A
Perchlorate	-	-	-	-	N/A	N/A
TCDD Equivalent	2.9E-3	2.9E-4	7.8E-6	7.8E-7	N/A	N/A
HI	338	75	387	75	0	0

Definitions:

HI - Hazard Index
HQ - Hazard Quotient
mg/kg - milligrams per kilogram
N/A - Not applicable
RME - Reasonable maximum exposure
TRV - Toxicity Reference Value

Notes:

[a]HQs for arsenic were excluded from HIs, since arsenic concentrations in fish tissues likely consist of organic arsenic only, which is nontoxic.
A dash indicates the absence of an applicable HQ.
Shaded values indicate HQs and HIs greater than 1.

Table 5-21
South Muliwai HIs
Sediment

Chemical	South Muliwai		South Background Muliwai		South Muliwai Incremental Risk	
	HQ_{High}	HQ_{Low}	HQ_{High}	HQ_{Low}	High	Low
Metals						
Antimony	0.07	-	-	-	-	-
Cadmium	0.13	0.02	-	-	-	-
Lead	0.63	0.17	0.08	0.02	-	-
Selenium	4.7	-	-	-	-	-
Organics						
2,3,7,8-TCDD	8.3	-	-	-	-	-
Ethylbenzene	0.25	-	-	-	-	-
m,p-Xylenes	0.18	-	-	-	-	-
Pentachlorophenol	0.05	-	-	-	-	-
Picloram	-	-	-	-	-	-
Toluene	-	-	-	-	-	-
HI	14.4	0.19	0.08	0.02	14.3	0.17

Definitions:

HI - Hazard Index
HQ - Hazard Quotient
mg/kg - milligrams per kilogram
RME - Reasonable maximum exposure
TRV - Toxicity Reference Value

Notes:

A dash indicates the absence of an applicable HQ.
Shaded values indicate HQs and HIs greater than 1.

Table 5-22
South Muliwai HIs
Shellfish Tissue

Chemical	South Muliwai		Nanakuli Background Muliwai		South Muliwai Incremental Risk	
	HQ_{High}	HQ_{Low}	HQ_{High}	HQ_{Low}	High	Low
Metals						
Aluminum	4.6	0.46	2.4	0.24	N/A	N/A
Arsenic	0.56	0.06	0.61	0.06	N/A	N/A
Barium	-	-	-	-	N/A	N/A
Chromium	1.3	0.41	1.2	0.38	N/A	N/A
Cobalt	7.3	0.75	2.5	0.26	N/A	N/A
Copper	67	6.7	111	11.1	N/A	N/A
Iron	3.3	0.33	1.6	0.16	N/A	N/A
Lead	0.04	0.004	-	-	N/A	N/A
Manganese	7.9	2.3	2.1	0.61	N/A	N/A
Selenium	4.1	0.41	5.9	0.58	N/A	N/A
Silver	-	-	0.04	0.04	N/A	N/A
Vanadium	1.3	0.13	0.60	0.06	N/A	N/A
Zinc	2.2	1.2	38	20	N/A	N/A
Organics						
1,2,3,4,6,7,8-Hpcdd	-	-	0.0087	0.00087	N/A	N/A
1,2,3,6,7,8-Hxcdd	-	-	0.004	0.0004	N/A	N/A
1,2,3,6,7,8-Hxcdf	-	-	0.04	0.004	N/A	N/A
2,3,7,8-TCDF	-	-	0.01	0.001	N/A	N/A
OCDD	-	-	0.05	0.01	N/A	N/A
HI	100	13	167	34	0	0

Definitions:

HI - Hazard Index
HQ - Hazard Quotient
mg/kg - milligrams per kilogram
N/A - Not applicable
RME - Reasonable maximum exposure
TRV - Toxicity Reference Value

Notes:

A dash indicates the absence of an applicable HQ.
Shaded values indicate HQs and HIs greater than 1.

The HI_{High} and HI_{Low} for fish in the south muliwai were 290 and 55, indicating a potential for cumulative impacts from multiple COPECs (Table 5-23). However, the HIs for fish in the Nanakuli background muliwai were higher. Thus, the overall potential for hazards to fish in the south muliwai was lower than under background conditions, and the incremental risk was zero.

5.10.3 Nearshore Habitat

Risks were calculated for shellfish as represented by both helmet urchins and Kona crabs in the nearshore habitat off MMR. The HI_{High} and HI_{Low} for helmet urchins in the nearshore habitat were 15 and 2.2, indicating a potential for cumulative impacts from multiple COPECs (Table 5-24[a]). However, the HIs for shellfish in the background nearshore habitat off Sandy Beach (20 and 2.3) were higher. Therefore, the overall potential for hazards to helmet urchins at the nearshore habitat was lower than under background conditions, and the incremental risk was zero.

The HI_{High} and HI_{Low} for Kona crabs in the nearshore habitat were 80 and 9.9, indicating a potential for cumulative impacts (Table 5-24[b]). These HIs exceeded those for shellfish in the background nearshore habitat off Sandy Beach (20 and 2.3). The resulting high and low incremental risks to Kona crabs in the nearshore habitat were 65 and 8.1, respectively (Table 5-24[b]). These hazards were primarily due to tissue concentrations of copper and cadmium. The background tissue concentrations of copper were based on helmet urchins, which are expected to have lower body burdens of copper than crabs, as the blood of crabs is copper based. Therefore, crabs at the nearshore habitat are expected to have higher body burdens of copper.

The HI_{High} and HI_{Low} for fish in the nearshore habitat off MMR were 23 and 5.1, indicating a potential for cumulative impacts from multiple COPECs (Table 5-25). However, the HIs for fish in the background nearshore habitat off Sandy Beach were substantially higher. Thus, the overall potential for hazards to fish in the nearshore waters was lower than under background conditions, and the incremental risk was zero.

5.11 UNCERTAINTY ANALYSIS

The uncertainty analysis identifies the key assumptions and data gaps associated with the analyses performed. The three major types of uncertainties in all risk assessments are variability, uncertainty of the true value (i.e., measurement error), and data gaps (USEPA 1998). Topics included in this uncertainty analysis address all three types of uncertainties.

The approach used in this risk assessment was designed to mitigate the effects of uncertainties that may result in the underestimation of risks. Conservative assumptions were used throughout the exposure and effects analyses to minimize the probability of underestimating ecological risks.

5.11.1 Uncertainties in the Exposure Assessment

Sources of uncertainty in the exposure assessment include COPEC concentrations, exposure concentrations, and bioavailability. These are discussed below, along with whether they are likely to under or overestimate exposures to COPECs.

Table 5-23
South Muliwai HIs
Fish Tissue

Chemical	South Muliwai		Nanakuli Background Muliwai		South Muliwai Incremental Risk	
	HQ_{High}	HQ_{Low}	HQ_{High}	HQ_{Low}	High	Low
Metals						
Aluminum	68	29	121	52	N/A	N/A
Antimony	0.002	0.001	-	-	N/A	N/A
Arsenic[a]	-	-	-	-	N/A	N/A
Barium	-	-	-	-	N/A	N/A
Beryllium	-	-	-	-	N/A	N/A
Cadmium	0.39	0.21	0.35	0.19	N/A	N/A
Chromium	11	-	8.5	-	N/A	N/A
Cobalt	-	-	-	-	N/A	N/A
Copper	22	14	16	10.0	N/A	N/A
Iron	-	-	-	-	N/A	N/A
Lead	0.21	0.13	0.17	0.11	N/A	N/A
Manganese	-	-	-	-	N/A	N/A
Methyl Mercury	0.01	0.007	0.004	0.002	N/A	N/A
Selenium	0.91	0.09	0.65	0.06	N/A	N/A
Silver	2.7	-	2.3	-	N/A	N/A
thallium	-	-	-	-	N/A	N/A
Vanadium	182	8.9	236	12	N/A	N/A
Zinc	3.5	3.0	2.0	1.7	N/A	N/A
Organics						
4,4'-DDT	0.0002	0.00002	0.0001	0.00001	N/A	N/A
Acetone	-	-	-	-	N/A	N/A
BHC,delta	0.0002	0.00002	-	-	N/A	N/A
BHC,gamma	0.03	0.0003	-	-	N/A	N/A
Bis(2-ethylhexyl)phthalate	-	-	-	-	N/A	N/A
di-n-Butylphthalate	-	-	-	-	N/A	N/A
Heptachlor Epoxide	0.00004	0.00002	0.00004	0.00002	N/A	N/A
m,p-Xylenes	-	-	-	-	N/A	N/A
Nitroglycerin	-	-	-	-	N/A	N/A
Perchlorate	-	-	-	-	N/A	N/A
TCDD Equivalent	3.6E-3	3.6E-4	7.8E-6	7.8E-7	N/A	N/A
HI	290	55	387	75	0	0

Definitions:

HI - Hazard Index
HQ - Hazard Quotient
mg/kg - milligrams per kilogram
N/A - Not applicable
RME - Reasonable maximum exposure
TRV - Toxicity Reference Value

Notes:

[a]HQs for arsenic were excluded from HIs, since arsenic concentrations in fish tissues likely consist of organic arsenic only, which is nontoxic.
A dash indicates the absence of an applicable HQ.
Shaded values indicate HQs and HIs greater than 1.

Table 5-24(a)
Nearshore HIs
Shellfish Tissue (Helmet Urchin)

Chemical	Near Shore at Makua		Sandy Beach Background		Near Shore at Makua Incremental Risk	
	HQ_{High}	HQ_{Low}	HQ_{High}	HQ_{Low}	High	Low
Inorganics						
Aluminum	3.3	0.33	2.0	0.20	N/A	N/A
Arsenic	0.19	0.02	0.19	0.02	N/A	N/A
Barium	-	-	-	-	N/A	N/A
Beryllium	-	-	-	-	N/A	N/A
Chromium	1.2	0.38	1.2	0.38	N/A	N/A
Cobalt	3.4	0.35	4.1	0.42	N/A	N/A
Copper	2.0	0.30	1.4	0.22	N/A	N/A
Iron	1.2	0.12	1.5	0.15	N/A	N/A
Lead	0.57	0.01	1.7	0.03	N/A	N/A
Manganese	0.23	0.07	0.12	0.03	N/A	N/A
Selenium	2.5	0.25	4.1	0.41	N/A	N/A
Vanadium	0.42	0.04	0.49	0.05	N/A	N/A
Zinc	0.31	0.29	0.16	0.15	N/A	N/A
Perchlorate	-	-	-	-	N/A	N/A
Organics						
1,2,3,4,6,7,8-Hpcdd	-	-	0.54	0.05	N/A	N/A
1,2,3,4,7,8-Hxcdf	-	-	0.005	0.0005	N/A	N/A
1,2,3,6,7,8-Hxcdf	-	-	0.004	0.0004	N/A	N/A
1,2,3,7,8,9-Hxcdf	-	-	0.004	0.0004	N/A	N/A
2,3,7,8-TCDF	-	-	0.005	0.0005	N/A	N/A
Aldrin	0.11	0.001	-	-	N/A	N/A
OCDD	0.06	0.01	2.1	0.21	N/A	N/A
Toluene	0.001	0.0001	0.0006	0.00006	N/A	N/A
HI	15	2.2	20	2.3	0	0

Definitions:

HI - Hazard Index
HQ - Hazard Quotient
mg/kg - milligrams per kilogram
N/A - Not applicable
RME - Reasonable maximum exposure
TRV - Toxicity Reference Value

Notes:

A dash indicates the absence of an applicable HQ.
Shaded values indicate HQs and HIs greater than 1.

Table 5-24(b)
Nearshore HIs
Shellfish Tissue (Kona Crab)

Chemical	Near Shore at Makua		Sandy Beach Background		Near Shore at Makua Incremental Risk	
	HQ_{High}	HQ_{Low}	HQ_{High}	HQ_{Low}	High	Low
Inorganics						
Aluminum	0.96	0.10	2.0	0.20	N/A	N/A
Arsenic	4.1	0.41	0.19	0.02	N/A	N/A
Barium	-	-	-	-	N/A	N/A
Beryllium	-	-	-	-	N/A	N/A
Cadmium	15	1.6	-	-	N/A	N/A
Chromium	1.2	0.38	1.2	0.38	N/A	N/A
Cobalt	2.1	0.22	4.1	0.42	N/A	N/A
Copper	44	4.4	1.4	0.22	N/A	N/A
Iron	1.9	0.19	1.5	0.15	N/A	N/A
Lead	0.03	0.003	1.7	0.03	N/A	N/A
Manganese	0.11	0.03	0.12	0.03	N/A	N/A
Mercury	0.02	0.003	-	-	N/A	N/A
Selenium	5.9	0.58	4.1	0.41	N/A	N/A
Silver	0.03	0.02	-	-	N/A	N/A
Vanadium	0.93	0.09	0.49	0.05	N/A	N/A
Zinc	3.7	2.0	0.16	0.15	N/A	N/A
Perchlorate	-	-	-	-	N/A	N/A
Organics						
1,2,3,4,6,7,8-Hpcdd	-	-	0.54	0.05	N/A	N/A
1,2,3,4,7,8-Hxcdf	-	-	0.005	0.0005	N/A	N/A
1,2,3,6,7,8-Hxcdf	-	-	0.004	0.0004	N/A	N/A
1,2,3,7,8,9-Hxcdf	-	-	0.004	0.0004	N/A	N/A
2,3,7,8-TCDF	-	-	0.005	0.0005	N/A	N/A
OCDD	-	-	2.1	0.21	N/A	N/A
Toluene	-	-	0.0006	0.00006	N/A	N/A
HI	80	9.9	20	2.3	60	7.6

Definitions:

HI - Hazard Index
HQ - Hazard Quotient
mg/kg - milligrams per kilogram
N/A - Not applicable
RME - Reasonable maximum exposure
TRV - Toxicity Reference Value

Notes:

A dash indicates the absence of an applicable HQ.
Shaded values indicate HQs and HIs greater than 1.

Table 5-25
Nearshore HIs
Fish Tissue

Chemical	Near Shore at Makua		Sandy Beach Background		Near Shore at Makua Incremental Risk	
	HQ_{High}	HQ_{Low}	HQ_{High}	HQ_{Low}	High	Low
Metals						
Aluminum	1.5	0.65	111	47	N/A	N/A
Antimony	-	-	0.001	0.0006	N/A	N/A
Arsenic[a]	-	-	-	-	N/A	N/A
Barium	-	-	-	-	N/A	N/A
Beryllium	-	-	-	-	N/A	N/A
Cadmium	0.56	0.30	0.53	0.29	N/A	N/A
Chromium	3.6	-	11	-	N/A	N/A
Cobalt	-	-	-	-	N/A	N/A
Copper	2.0	1.2	3.3	2.1	N/A	N/A
Iron	-	-	-	-	N/A	N/A
Lead	0.16	0.10	0.22	0.14	N/A	N/A
Manganese	-	-	-	-	N/A	N/A
Methyl Mercury	0.01	0.008	0.004	0.002	N/A	N/A
Selenium	0.40	0.04	0.46	0.05	N/A	N/A
Silver	0.04	-	0.10	-	N/A	N/A
Thallium	-	-	-	-	N/A	N/A
Vanadium	12	0.60	203	9.9	N/A	N/A
Zinc	2.6	2.2	1.4	1.1	N/A	N/A
Organics						
4,4'-DDT	0.00001	0.000001	0.0002	0.00002	N/A	N/A
Acetone	-	-	-	-	N/A	N/A
Aldrin	0.0003	0.0001	0.0006	0.0002	N/A	N/A
BHC,alpha	0.00004	0.00001	-	-	N/A	N/A
BHC,delta	0.00001	0.000001	-	-	N/A	N/A
BHC,gamma	0.10	0.001	0.03	0.0004	N/A	N/A
Bis(2-ethylhexyl)phthalate	-	-	-	-	N/A	N/A
Diethyl phthalate	-	-	-	-	N/A	N/A
di-n-Butylphthalate	-	-	-	-	N/A	N/A
Heptachlor	0.0002	0.0001	0.0002	0.0001	N/A	N/A
Heptachlor Epoxide	0.0005	0.0002	0.0003	0.0001	N/A	N/A
m,p-Xylenes	-	-	-	-	N/A	N/A
Nitroglycerin	-	-	-	-	N/A	N/A
Perchlorate	-	-	-	-	N/A	N/A
RDX	-	-	-	-	N/A	N/A
TCDD Equivalent	-	-	3.5E-4	3.5E-5	N/A	N/A
HI	23	5.1	331	61	0	0

Definitions:

HI - Hazard Index
HQ - Hazard Quotient
mg/kg - milligrams per kilogram
N/A - Not applicable
RME - Reasonable maximum exposure
TRV - Toxicity Reference Value

Notes:

[a]HQs for arsenic were excluded from HIs, since arsenic concentrations in fish tissues likely consist of organic arsenic only, which is nontoxic.
A dash indicates the absence of an applicable HQ.
Shaded values indicate HQs and HIs greater than 1.

Uncertainty in COPEC Concentrations

COPEC concentrations in media were based on samples collected in single sampling events, and the results were used to assess the risks under those conditions at the time of sampling. Exposure estimates are based on these results and do not take into account possible fluctuations in COPEC concentrations that may occur over time or vary with other environmental factors.

Chemical analyses of tissues (e.g., limu, shellfish, fish) were subject to limitations in availability during field sampling. The species composition in the muliwai may vary considerably between wet and dry seasons. Characterization of COPEC concentrations in biota may be biased in favor of organisms that were more abundantly collected at each site at the time of sampling. The assumption that concentrations measured in these tissues are representative of those dominant at the sites is uncertain.

A key assumption was that differences in tissue concentrations between the Mākua sites and their respective background sites were primarily a consequence of differences in chemical concentrations or bioavailability in sediments or surface water. However, differences in species collected between the sites could also contribute to differences in relative exposures. For example, shellfish samples collected from the background Nanakuli muliwai consisted of Hawaiian prawns, whereas both prawns and crabs were sampled at the north and south muliwai. While the background Sandy Beach shellfish data consisted exclusively of helmet urchins, the Mākua nearshore site data also included Kona crab.

The risk assessment data set represented the conditions at site and background sites under specific time periods. Factors such as concentrations of constituents, bioavailability, and sequestration can vary over seasons and among years. This uncertainty applies to both sites and background sites evaluated in this study.

Limited shellfish sample mass collected from the south muliwai did not allow for all analytes to be measured in these samples. The Hawaiian prawn sample (MSM-02) was analyzed only for metals, while the rock crab sample (MSM-01) was analyzed only for explosives. As a result, risks to shellfish in the south muliwai could be underestimated. Similarly, the rock crab sample from the background Nanakuli muliwai (NM-02) was analyzed for explosives only. Therefore, background risks to shellfish could be underestimated, resulting in a potential overestimate of the relative risks to shellfish at the north muliwai.

Surface water was not sampled from the north muliwai, south muliwai, or the nearshore waters off MMR. Since surface water represents a potential exposure route to aquatic invertebrates and fish, this constitutes a data gap for the ecological risk assessment. This data gap was to some extent mitigated by the collection of shellfish and fish tissue samples. Likewise, limu was not sampled from either the north or south muliwai and thus was not assessed as a receptor at these sites.

Chemicals that were not detected above laboratory detection limits were not included in the analysis. This may result in an underestimation of the risks to receptors.

Uncertainty in Exposures

An EPC was computed for each chemical in sediments, shellfish, and fish tissues. This value was used in risk calculations to estimate potential risks by comparison to TRVs. For sediments, the EPCs used were the UCL_{95} of the mean, unless the UCL_{95} exceeded the maximum detected concentration, in which case the maximum detected concentration was used as the EPC. Using the maximum detected value as the EPC could result in an overestimation of the risks. For shellfish and fish tissues, the EPCs applied were the maximum concentrations detected. This approach was followed because shellfish and fish tissue samples consisted of composites of multiple species. To ensure a protective evaluation, the maximum detects across all samples were used.

All COPECs in sediments were assumed to be 100 percent bioavailable to benthic invertebrates, which could overestimate exposure. Depending on differences in sediment parameters between the muliwai and those sediments used to derive toxicity benchmarks (e.g., grain size, total organic carbon, pH), bioavailability could differ.

5.11.2 Uncertainties in the Effects Assessment

When it was necessary to fill a data gap, conservative assumptions were used to minimize the probability of underestimating ecological risks. Assumptions used to characterize estimates of COPEC effects are as follows:

- Use of both TRV_{Low}s (i.e., threshold effects level s for benthic invertebrates and no observed effect concentrations for shellfish and fish tissues) and TRV_{High}s (i.e., probable effect levels for benthic invertebrates and lowest observed effects concentrations for shellfish and fish tissues) to calculate HQs;
- Use of species-to-species toxicity extrapolations;
- Use of laboratory-to-field toxicity extrapolations;
- Use of individual-to-population level effect extrapolations;
- Use of chemical-to-chemical extrapolations;
- Lack of relevant tissue-based toxicity data for limu; and
- Lack of relevant toxicity data for specific chemicals in sediments, shellfish, and fish tissues.

A key assumption of this risk assessment is that tissue concentrations are reliable indicators of toxicity. The use of critical tissue concentrations as predictors of toxic effects has shown promise for some chemicals such as neutral organic compounds and other chemicals that are not rapidly metabolized (USEPA 2000c). However, this approach is not necessarily broadly applicable across all chemical classes. Tissue concentrations may have limitations in reflecting internal doses at target organs, representing variability in sensitivity between species and indicating toxicity of environmentally modified or biotransformed compounds (Barron et al. 2002).

Shellfish and fish tissue-based TRVs were developed as described in Section 5.7.5. One source of uncertainty is interspecies variability in sensitivity and accumulation. In general, the lowest effect level across all species was selected as the lowest observed effects concentration. In many cases, no-effect levels were identified for the same or different endpoints that were higher than the selected lowest observed effects concentration. To provide a protective assessment, only no-effect levels that were lower than the selected lowest observed effects concentration were considered in deriving the no observed effect concentration.

Another source of uncertainty in fish tissue TRVs is the potential variability in concentrations between whole body, carcass, and muscle. All three were used in deriving TRVs, though whole body data were given preference since whole fish samples from the sites were analyzed.

Test endpoints considered in selecting shellfish and fish toxicity values were survival, growth, reproduction, and development. TRVs based on growth are more difficult to relate to population-level responses than those based on survival, reproduction, or development. Finally, some shellfish and fish TRVs were based on limited data sets, which could result in an overestimation or underestimation of toxicity. These included aluminum, antimony, chromium, lead, vanadium, zinc, heptachlor, and aldrin for fish; and aluminum, arsenic, cobalt, iron, manganese, and selenium for shellfish.

The echinoderm TRVs for cadmium, copper, lead, and zinc were based on the larval life stage. Larvae develop in the water column, whereas adult echinoderms live on the bottom sediments or rocks. As a result, these echinoderm TRVs may not be fully representative of toxicity thresholds for the sea urchins at the Mākua nearshore site.

Shellfish tissue TRVs for dioxins and furans were based on studies that primarily examined bioaccumulation (USEPA 2000c). Observations that no toxic effects occurred were used to infer no-effect levels. However, because no-effect levels could also occur at higher exposure levels, these TRVs are considered conservative.

The above sources of uncertainty should be taken into account when making decisions based on the risk estimates presented here.

5.12 CONCLUSIONS

This screening level ecological risk assessment was an evaluation of the potential for adverse effects on ecological receptors that may be exposed to chemicals in muliwai and nearshore waters as a result of past releases from MMR. The north and south muliwai and nearshore habitat off MMR were assessed as potentially impacted sites. Due to the absence of aquatic habitat at the dry muliwai, this site was not evaluated for ecological risks. Risk estimates at each site were compared to risk estimates from representative background areas.

Three sets of receptors were evaluated: benthic invertebrates exposed to COPECs in sediments and shellfish and fish exposed to chemicals from multiple potential pathways, represented by measured concentrations in shellfish and fish tissues.

Several lines of evidence were considered in evaluating the potential for risks: the number of chemicals with calculated HQs above 1, the magnitudes of HQs above 1, likely sources of chemicals, confidence in toxicity values, cumulative risks represented by HIs, and comparisons of site HIs to HIs from background sites. Based on the weight of evidence, limited hazards were identified:

- North muliwai—No hazards to benthic invertebrates, shellfish, or fish;
- South muliwai—Potential hazard to benthic invertebrates from 2,3,7,8-TCDD in sediments; no hazards to shellfish or fish; and
- Nearshore waters—Potential hazards to Kona crabs from cadmium, copper, and zinc but no hazards to sea urchins; no hazards to fish.

Three data gaps contributed uncertainty to the ecological risk assessment. First, surface water quality data for the two muliwai and nearshore waters were not available and therefore could not be compared to ambient water quality criteria. As a result, potential exposures of aquatic invertebrates and fish to constituents in surface water could not be directly assessed. Second, potential risks to limu collected in the nearshore waters were not evaluated due to the absence of applicable tissue-based toxicity data. Limu was not collected from the two muliwai. Third, TRVs were not available for some chemicals in sediments and shellfish and fish tissues. In general, these TRV data gaps are unlikely to result in a significant underestimation of risks, due to the relatively low concentrations of organic constituents detected.

SECTION 6
DISCUSSION AND CONCLUSIONS

The objectives of this marine resources study, defined by the 2007 partial SA entered into by the Army and Malama Mākua, were as follows:

- To evaluate whether fish, shellfish, limu (marine algae), and other marine resources near Mākua Beach or muliwai (estuaries or stream mouths), which area residents rely on for subsistence are contaminated by substances associated with proposed military training at Mākua;
- To evaluate whether the potential that activities at MMR have contributed or will contribute to contamination in fish, shellfish, limu and other marine resources; and
- To evaluate whether the proposed training activities pose a human health risk to area residents who rely on marine resources for subsistence.

Tetra Tech sampled fish, shellfish, and limu in the muliwai or nearshore waters of Mākua and fish and shellfish at the background sites. All samples, except three shellfish samples, were analyzed for approximately 43 different constituents to assess whether marine resources at MMR are contaminated with compounds potentially associated with past military training at MMR. The exceedingly small populations of two shellfish species (Hawaiian prawns and rock crabs), and therefore small quantities of biomass collected, limited the analysis of these samples to a subset of the 43 constituents.

6.1 DIOXINS/FURANS

Only 18 of the 25 dioxin/furan or total congener groups from the standard EPA 8290 analyte list were detected in the fish, shellfish, and limu from either Mākua or background sites. Four or fewer dioxin/furan congeners were detected in greater than 25% of the fish, shellfish, or limu samples. All remaining congeners were detected in fewer than 15% of the samples of fish, shellfish, or limu. Seven dioxin/furan congeners were detected in the muliwai that were not detected in the nearshore environment. Three dioxin/furan congeners were detected at Mākua that were not detected at the background sites. Chemicals are differentially accumulated depending on the species and different species were collected in the muliwai and the nearshore environment. There were also differences between species

collected at Mākua and the background sites. Differences in dioxins/furans concentrations between Mākua and the background site and between the muliwai and nearshore waters may be a function of the different species collected in each of these locations. Finally, note that nearshore species may have larger ranges and may have accumulated contaminants from regions other than where they were collected.

Elevated levels of dioxins/furans were detected in soil, muliwai sediment, streambed sediments, surface water, and fish samples in the Mākua Valley; however, dioxins/furans are not constituents of past or proposed military munitions. Major sources of dioxins/furans are listed in Section 3.2.1 and include natural, civilian, and industrial sources. There are several potential sources of dioxans/furans on the Waianae Coast that could contribute to the concentrations at Mākua that exceed background.

6.2 VOCs AND SVOCs

Volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs) were detected in the fish, shellfish, or limu samples, but, when detected, these compounds were typically present at only trace concentrations. Two of the eight VOCs and three of seven SVOCs analyzed were detected in fish. Di-n-butylphthalate was detected in 100% of fish and limu samples both at Mākua and the background locations. Acetone was detected in 47% and 44% of the fish samples from Mākua and background sites, respectively. Acetone and di-n-butylphthalte are common lab contaminants and are not likely attributable to transport from MMR. All other VOCs and SVOCs were detected in fewer than 25% of the fish, shellfish, or limu samples. There are both natural and anthropogenic sources of most VOCs and SVOCs.

The SVOC that contributed to the risk to subsistence and recreational fishermen was bis(2-ethylhexyl)phthalate (DEHP). DEHP was also detected in groundwater during previous studies but is not a constituent of past or proposed military munitions. Natural, civilian, and industrial sources are provided in Section 3.2.3.

6.3 ORGANOCHLORINE PESTICIDES

Multiple organochlorine pesticides were detected in fish and limu samples, but aldrin was detected in only one shellfish sample. Several factors may contribute to these results. First, environmental conditions likely have changed between the fish and limu sampling in 2006 and shellfish in 2008. The 2006 sampling occurred in the summer following a severe rainy winter in which O‘ahu was subjected to 40 consecutive days of heavy rains. A rain of this magnitude could have washed greater than normal quantities of contaminants into the muliwai. No additional severe rain events occurred between the 2006 and 2008 sampling events. In addition, Columbia Analytical Laboratory analyzed organochlorine pesticide in the fish and limu samples in 2006, while APPL, Inc., analyzed these compounds in the shellfish study in 2008 (this was unavoidable given the timeline for this study and the laboratories' schedules). Furthermore, pesticides, including organochlorine pesticides, have been used historically throughout the islands for agriculture and termite control and therefore are difficult to trace to a source, particularly during periods of high levels of transport from upland environments to the coastal wetlands and nearshore environments.

Aldrin, alpha-BHC, and heptachlor expoxide were detected in several environmental media in the Mākua Valley, including groundwater, streambed sediments, fish, and shellfish. However, organochlorine pesticides are not a constituent of military munitions. Major sources of these compounds are provided in Section 3.2.4.

6.4 EXPLOSIVES

Nitroglycerin and RDX, potentially originating from both military and civilian uses such as fireworks or rodenticides, were detected in fewer than 8% of the samples. Perchlorate, which is found in both military ordnance and fireworks, was detected in 42%, 9%, and 50% of the fish, shellfish, and limu samples, regardless of origin. Detection of perchlorate in fish was similar between Mākua (47%) and background sites (33%). Perchlorate was more commonly sampled in the shellfish samples at the Mākua sites (one detection) than at the background site where there was no detection. Perchlorate was sampled in 53% of the muliwai samples and only 27% of the nearshore samples, suggesting that the muliwai served the typical wetland function of filtering contaminants.

The only explosive-related chemical detected in the muliwai sediment samples was RDX, while 1,3-dinitrobenzene was the only explosive-related chemical detected in the streambed sediment samples and perchlorate and 2,4-dinitrotoluene were the only explosive-related chemicals detected in the surface water samples. Nitroglycerin (2 samples), and perchlorate (6 samples) were detected in muliwai fish samples, while 2,4-dinitrotoluene and RDX were not. The nitroglycerin results were considered invalid, because QA/QC issues precluded quantification of this analyte (see Appendix C).

Perchlorate was the only explosive compound that contributed to noncarcinogenic hazards. While perchlorate is a constituent of military munitions, it is also a constituent of fireworks and over 80 other manufactured products used by civilians and industry. Natural and anthropogenic sources of perchlorate are provided in Section 3.2.5.

6.5 METALS

Samples from the muliwai locations tended to have higher concentrations of metals than the nearshore samples, although the nearshore samples typically had higher concentrations of arsenic. The scientific literature suggests that organic nontoxic forms of arsenic dominate that found in marine organisms. Differences in metals concentrations between habitats (muliwai versus nearshore) may result from differences in sample species composition between the two habitats rather than differences in environmental concentration of metals. All metals except antimony, beryllium, mercury, silver, and thallium were detected in 100% of the samples, including both Mākua and background sites. Of these metals only thallium was in a greater percentage of samples at background sites than at Mākua. In addition to the species listed above, chromium and selenium were detected in less than 100% of the limu samples. No metals were detected in greater than 75% of the shellfish samples, and less than 50% of the metals analyzed were detected in greater than 50% of the shellfish samples. Again, the differences in detection between the fish and limu and the shellfish samples may have resulted from changes in environmental conditions between 2006 and 2008 or analytical laboratories. There are natural and anthropogenic sources of metals other than military munitions. These sources are provided in Section 3.2.6.

The analytical data for the fish samples do not appear to follow any obvious geographic pattern. The results from the Mākua samples were similar to the results from the background location samples. Samples from the muliwai locations tended to have higher concentrations of metals than the nearshore samples, although the nearshore samples typically had higher concentrations of arsenic. Based on these results, there is no definitive link between the training activities at MMR and the presence of contaminants detected in the marine resources.

6.6 HUMAN HEALTH RISK ASSESSMENT

6.6.1 Risks and Uncertainties Associated with Consuming Fish in the Muliwai

The human health risk assessment indicated that the carcinogenic incremental risks (i.e., over background) from fish consumption at the muliwai is approximately 3.5×10^{-5} for subsistence fishermen. This risk estimate exceeds the 1×10^{-5} risk level (one person in 100,000 people may develop cancer) used in assessing fish consumption (USEPA 2000a), although it is within the USEPA (1990) target risk range of 10^{-6} to 10^{-4}. The incremental risks over background are largely due to assumed exposures to dioxins/furans. The incremental risks (i.e., over background) from fish consumption from the nearshore waters at Mākua is approximately 3×10^{-5} for subsistence fishermen. The incremental risks over background are largely due to assumed exposures to alpha-BHC, heptachlor epoxide, and bis(2-ethylhexyl)phthalate (DEHP). The first two compounds are organochlorine pesticides with primarily agricultural and urban sources. The third, DEHP is in polyvinyl chloride (PVC) plastic products like toys, vinyl upholstery, shower curtains, adhesives, and coatings. It is used in some food packaging, and medical product containers (including those for blood) and equipment. It is also used in some inks, pesticides, and cosmetics and in vacuum pump oil. The noncarcinogenic hazards exceeded 1 at both Mākua and the background sites, but the hazard was greater at the background site.

There are several sources of uncertainty in the risk estimates that tend to indicate that the risk estimates are high. One source of uncertainty is the assumption of fish consumption rates. A second source of uncertainty in this risk estimate is the assumption that a subsistence fisherman could rely only on the muliwai for fish. The 95th percentile fish consumption rate for Hawaiians from a 2003 study of 100.3 grams per day (g/day) was used in the human health risk assessment to provide a health-protective estimate of risk from consuming fish caught in the muliwai and nearshore areas of MMR. Furthermore, the muliwai are generally the size of a small pond, having a maximum water surface area of less than one acre. It is unlikely that the two muliwai evaluated here could hold enough fish to support even one subsistence fisherman, let alone a population of subsistence fishermen. The assumption of a subsistence fisherman relying exclusively on the muliwai is unrealistic, so the risk estimate likely overestimates exposures to chemicals in the fish.

6.6.2 Risks and Uncertainties Associated with Consuming Shellfish in Mākua Nearshore Waters

The incremental risk (i.e., over background) to subsistence and recreational fisherman from shellfish consumption at the muliwai is below the 1×10^{-5} risk level (one person in 100,000 people may develop cancer) used in assessing fish consumption (USEPA 2000a). The

noncarcinogenic hazard index (HI) from muliwai shellfish subsistence and recreational consumption exceeds background. The incremental hazard exceeds the threshold HI of 1, primarily due to assumed exposures to manganese and cobalt. There is no incremental cancer risk (i.e., over background) for shellfish harvested at Mākua Beach because the risk estimated for background is higher than that estimated for shellfish harvested at Mākua Beach. The noncarcinogenic HI from shellfish consumption exceeds background, and the incremental risk exceeds the threshold HI of 1. This is primarily due to assumed exposures to cadmium and perchlorate, with the latter found only in helmet urchins and not Kona crab collected at Mākua Beach.

For shellfish, the risk and hazard estimates were based on the likely fish consumption rate for Hawai'i (i.e., 100.6 g/day). This rate is higher than the shellfish consumption rate estimated for the US population in general, particularly the rate reported for prepared crab and shrimp (mean of approximately 2 g/day) (USEPA 2002c). Further, risk and hazard estimates were calculated using the maximum concentrations of COPCs in shellfish, given the limited data with which to estimate mean concentrations. In combination, these assumptions likely resulted in overestimation of risks and hazards due to shellfish consumption.

6.6.3 Risks and Uncertainties Associated with Consuming Limu in Mākua Nearshore Waters

The human health risk assessment indicated that the combined cumulative risk for current and future subsistence fishermen potentially exposed to the chemicals of potential concern in limu harvested from the shallow nearshore waters at Mākua Beach is approximately 8×10^{-3}. This risk estimate exceeds the risk level used in assessing fish consumption of 1×10^{-5} (USEPA 2000a) and the USEPA (1990) target risk range of 10^{-6} to 10^{-4}. This risk estimate is almost entirely due to assumed exposures to arsenic in limu, which was present at concentrations up to 109 mg/kg in the limu samples. The arsenic in limu was assumed to be entirely inorganic, which can be toxic. In many limu species, arsenic can be present entirely in nontoxic organic forms, although it is present in some species in inorganic forms at up to 50 percent or more. A review of the scientific literature did not indicate if the limu collected in this study typically contained arsenic in organic or inorganic form. It is likely that at least some of the arsenic in the limu harvested from the shallow nearshore waters at Mākua Beach is present in nontoxic organic forms, indicating that the risks here may be overestimated. Limu samples were not collected from the background location (Sandy Beach), so it is not possible to determine whether the arsenic levels detected in limu at Mākua Beach are elevated over background.

The primary source of uncertainty in the limu consumption risk estimate is the assumption that all arsenic in the limu was inorganic and toxic. However, there are many species of algae in which nearly all arsenic is present in nontoxic organic forms. The limu were identified to species and a review of the scientific literature did not identify the type of arsenic (organic or inorganic) that is expected to be present in the limu samples. Therefore, depending on the species actually consumed by fishermen, the risks may be much lower than estimated here.

6.7 ECOLOGICAL RISK ASSESSMENT

A screening level ecological risk assessment was conducted to evaluate the potential for adverse effects on ecological receptors that may be exposed to chemicals in muliwai and nearshore waters. Data from the fish, shellfish, and limu sampling conducted as part of this study and data from muliwai sediment sampling conducted in 2003 were used in this assessment. Two sets of receptors were evaluated: (1) benthic invertebrates exposed to chemicals of potential ecological concern in sediments and (2) fish exposed to chemicals from multiple pathways, represented by measured concentrations in fish tissues. The results from the screening level ecological risk assessment indicated that there were no hazards to fish in the north muliwai, the south muliwai and the nearshore Mākua area, and that there was a potential hazard to benthic invertebrates from 2,3,7,8-tetrachlorodibenzo-*p*-dioxin in sediments in the south muliwai. The primary sources of dioxins are backyard burning of household refuse, medical waste incinerators, municipal waste combustion, coal-fire utility boilers, cement kilns, and diesel heavy duty trucks.

Hazards to shellfish in the north and south muliwai did not exceed those at the Nanakuli background muliwai. Hazards at the nearshore habitat at Mākua were equivocal in that the hazard index for Kona crabs was greater than that at the Sandy Beach background site, but the hazard index for helmet urchins was less than background. The hazard index for Kona crabs was predominantly due to cadmium, copper, and zinc in tissues. The potential hazard to crabs from copper is uncertain because tissue concentrations in crabs could be compared only to those in sea urchins, which are expected to have lower body burdens of copper than crabs due to their physiology.

Several lines of evidence were considered in evaluating the potential for risks to organisms in the Mākua muliwai and nearshore waters: the number of chemicals with calculated HQs above 1, the magnitudes of HQs above 1, likely sources of chemicals, confidence in toxicity values, cumulative risks represented by HIs, and comparisons of site HIs to HIs from background sites. Based on the weight of evidence, limited hazards were identified:

- North muliwai—No hazards to benthic invertebrates, shellfish, or fish;
- South muliwai—Potential hazard to benthic invertebrates from dioxans/furans in sediments; no hazards to shellfish or fish; and
- Nearshore waters—Potential hazards to Kona crabs from cadmium, copper, and zinc but no hazards to sea urchins; no hazards to fish.

6.8 CONCLUSIONS

In accordance with the 2007 partial SA entered into by the Army and Malama Mākua, the Army "…shall complete one or more studies to whether fish, limu, shellfish, and other marine resources near Mākua Beach and in the muliwai on which area residents rely for subsistence are contaminated by substances associated with the proposed training activities at MMR… evaluate the potential that activities at MMR have contributed or will contribute to any such contamination and whether the proposed training activities at MMR pose a human health risk to area residents that rely on marine resources for subsistence." This study was an

investigation of the resources at Mākua and background sites and provides the information necessary to answer these questions posed in the SA.

1) Determine whether fish, shellfish, limu, and other marine resources near Mākua Beach or muliwai, which area residents rely on for subsistence, are contaminated by substances associated with the proposed training at Mākua.

Fish, shellfish, limu, [and the report assumes that other marine resources] near Mākua Beach and in the muliwai, on which area residents rely for subsistence, are contaminated by substances that are known to be associated with the proposed training at Mākua. The study shows that there are potential chemical migration pathways between MMR and the muliwai and nearshore areas. It also confirms that several substances in the nearshore and muliwai marine resources are associated with military munitions. This study has identified a number of substances in fish, shellfish, and limu that are also known to be by-products of the type of military training being proposed at MMR and may pose a potential health risk. These substances are RDX, perchlorate, arsenic, chromium, cobalt, nitroglycerin, and manganese. Though these and other substances may be by-products of military training at MMR, they are also linked to natural and anthropogenic sources, such as fireworks, rodenticides, gasoline, and volcanic rock. In fact, a comparison of the site data with the available background data shows little if any difference between substances found in the Mākua area and the background sites. Compounds identified for analysis by the SA are not unique to military training and are found at both Mākua and background sites; therefore, proposed military activities are anticipated to have little influence on contaminant levels within marine resources in the Mākua nearshore or muliwai areas.

Although marine resources other than fish, shellfish, and limu were not tested, the sampling was representative of other marine resources within the Mākua area. It is reasonable to suggest that other marine resources occupying similar trophic levels and ecological niches contain similar substances and concentrations as those detected in fish, limu, and shellfish collected as part of this study. Regardless, on authorization to implement the proposed training at MMR, the Army will conduct a long-term water quality monitoring. A monitoring program will provide the Army with another tool to evaluate potential pathways for substances to migrate beyond the boundaries of MMR.

2) Evaluate the potential that activities at MMR have contributed or will contribute to contamination in fish, shellfish, limu and other marine resources.

There is a potential that activities at MMR have contributed or will contribute to contamination in fish, shellfish, limu and other marine resources. Per the requirements of the 2001 SA, the Army investigated soil, surface water, groundwater, and air for potential contamination associated with proposed training activities at MMR. These studies also evaluated whether there was a potential for contaminants to be transported off of MMR. Based on the data from these studies, there is no obvious pattern or pathway for migration of substances from MMR to the muliwai and nearshore areas. However, several substances detected in the marine resources were also detected in environmental media on MMR (air,

soil, or water). This suggests there is a potential but as of yet unsubstantiated pathway for substances to migrate from MMR to marine resources.

Thus, there is some potential for past and future release of substances from activities at MMR. However, the low levels of most substances detected during these investigations support the position that if 60 years of live-fire training has not resulted in significant detectable levels of most substances in the area, then future live-fire activities at MMR would be expected to be likewise insignificant. For those substances detected at higher levels, their occurrence in the area cannot uniquely be attributed to military activities because there are and have been many natural and anthropogenic sources that contribute substances to the Mākua area.

Based on the results of the past investigations, the Army was required to conduct a marine study to determine if contaminants were also found in the marine resources consumed by residents. This study found that a number of substances identified for analysis were detected in these marine resources. Although this and other reports have not provided any definitive evidence that links military training to resource contamination, these reports also do not definitively exclude the possibility that such substances in the fish, shellfish, and limu are a result of activities conducted at MMR. However, it needs to be reemphasized that there are numerous other natural and anthropogenic sources that contribute substances to the Mākua and background areas.

3) Whether the proposed training activities pose a human health risk to area residents who rely on marine resources for subsistence.

This study found that a number of substances detected in the marine resources were at concentration levels that pose a human health risk to area residents who rely on marine resources for subsistence. These substances detected are known to be associated with past and future training activities at MMR. Therefore, the proposed training activities at MMR have the potential to contribute substances to the marine resources and pose a possible human health risk to area residents who rely on these resources for subsistence.

This third question posed by the SA calls for a definitive answer concerning whether future training at MMR will result in the release of substances that will, *with certainty*, contaminate marine resources consumed by local residents for subsistence. This question cannot be answered *with certainty* because it relies on predictions of the effects of future activities and assumptions based on the assessment of effects from past activities at MMR. Therefore, from a scientific standpoint, we must predict whether or not future training at MMR is likely to cause a human health risk from consumption of marine resources.

It is not likely that future training at MMR will result in the release of substances sufficient to contaminate marine resources around Mākua and to cause a risk to area residents who consume marine resources for subsistence. This conclusion is based on the conditions at Makua that have culminated after greater than 60 years of military activities and proposed monitoring activities (see below) that will identify future military releases of contaminants before they pose excessive risk. As stated throughout this section and the overall document,

the substances identified for analysis that were found in biota within the Mākua area could be associated with many past and present natural and anthropogenic causes that are not unique to past training at MMR. In addition, based on the general similarity of carcinogenic and noncarcinogenic health risks between the Mākua area and the background sites, it is apparent that the Army's past activities at MMR are not independently responsible for any human health risks from the substances detected in marine resources. Considering the level of substances found within the Mākua area, the numerous sources with which these substances are associated, and the ability of these substances from multiple sources to be transported by rain flow and ocean currents[4], it is not likely that future activities at MMR alone would contribute substances to the marine environment at a level sufficient to cause a human health risk. Even though it is not likely that future activities at MMR alone would cause this risk to human health, they could add to existing contamination in marine resources.

However, on authorization to resume live-fire training at MMR, the Army would evaluate the potential impacts from the proposed training by conducting a long-term monitoring program to detect if there is a potential for substances to migrate off the installation and into the Mākua nearshore and muliwai areas. If a substance were identified during monitoring, the Army would conduct further analysis to verify the detection. If the identified substance were detected above the USEPA acceptable risk level, then the Army would take appropriate action. In accordance with the requirements of the 2001 SA, before finalizing a long-term monitoring program, the Army would provide a 60-day public comment period on the scope of and protocol for such monitoring.

[4] Current direction and speed data area available at the Naval Research Laboratory Global Ocean Analysis and Modelling website (http://www7320.nrlssc.navy.mil/global_nlom32/navo/arc_list_HAWSP1_ZOOM.html). These data suggest that waters from the Nanakuli area move toward Makua at least seasonally.

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SECTION 7
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APPENDIX A

FIELD SHEETS

Codes for Fish Tissue Sampling

Location codes

Location	Name	code
Muliwai 1	North Muliwai	M1
Muliwai 2	South Muliwai	M2
Muliwai 3	Nānākuli Muliwai	M3
Muliwai 4		M4
Muliwai 5		M5
Nearshore Waters 1	off south Muliwai	NW1
Nearshore Waters 2	Sandy Beach	NW2
Nearshore Waters 3		NW3
Seaweed 1	Limu kala	SW1
Seaweed 2	Limu 2	SW2
Seaweed 3		SW3
Seaweed 4		SW4
Fish 1	Striped mullet	F1
Fish 2	Aholehole	F2
Fish 3	Medaka	F3
Fish 4	"Tilapia"	F4
Fish 5	Moana (Parupeneus multifasciatus)	F5
Fish 6	Hinalea (Thalassoma trilobatum)	F6 Christmas wrass
Fish 7	hmanhuma hi ukole (Melichthys vidua)	F7 Brown trigger
Fish 8	a'awa (Bodianus bilunulatus)	F8 Haw. Hogfish
Fish 9	hinalea lau-wili (T. duperrey)	F9 – Saddle wrasse
Fish 10	Taape (Lutjanus kasmira)	F10 Lutjanus fulvus (to'au)
Fish 11	Moano2 (P. pleurostigma)	F11
Fish 12	Fistularia commersonii	F12 Cornet fish
Fish 13	Sufflumen fraenatus	F13 Bridled triggerfish
Fish 14	Rhinecanthus rectangulus	F14 Picasso "
Fish 15	Reef lizardfish	F15 Synodus variegatus
Fish 16	Hou (Surge wrasse)	F16 T. purpureum
Fish 17	Kupipi (A. sordidus)	F17 Blackspot sergeant
Fish 18	Nenue (K. bigibbus)	F18 gray chub
Fish 19	Po'opa'a (Cirrhitus pinnulatus)	F19 stocky hawkfish
Fish 20	Humuhumu lei Sufflamen bursa	F20

Urchin | Hā ukeuke'e = ul kaupali (Colobocentrotus atratus)

Example: M2F1-15S

second muliwai, first fish species on list, sequential composite number 15, S=standard sample.

Field Record for Study of Chemical Residues in Fish Tissue

Sampling Date: 2 Aug 2006
Collection Method: Beach Seine
Colector Name: Andy Jahn
Affiliation: Tetra Tech contractor Phone: 707-468-7432
Address: 1000 Riverside Dr. Ukiah, CA 95482

Site Location County: Hono

Sidt Name: North Mulkwai
Description:
Mākua Beach

Composite Sample ID: MI FI F1 - 1 S
site matrix seq. S/D

Species: Striped Mullet

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	0925	115mm					
2	1040	205	140	99	75	72	
3		74	65	75			
4							
5							
6							
7							
8							

Number of fish in composite: Total Weight (g):

Composite Sample ID: MI F2 - 2
site matrix seq. S/D

Species: Ahole hole

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	0925	75mm	90	89	106	75	
2	↓	109	68	67	74	75	
3	↓	61	63	67	80	65	
4	0930	77	67	62	69		
5	0940	85	85	75	62	65	
6							
7							
8							

Number of fish in composite: Total Weight (g):

Notes/Diagrams:

Continuation sheet. Date: Location:

Composite Sample ID: M1 ___ F2 - 3 S
site matrix seq. S/D

Species: Aholehole

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1050	63	75	60	79	62	
2		66	64	72	65	60	
3		64	65	67	70	64	
4		63	63	65	75	65	
5	1100	85	110	87	65	64	
6	1	103	90	91	67		
7							
8							

Number of fish in composite: Total Weight (g):

Composite Sample ID: M1 ___ F1 - 4 ___
site matrix seq. S/D

Species: Striped Mullet

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1050	72	74	69			
2	1310	193	60	77	74	71	
3		60	67	66	211		
4							
5							
6							
7							
8							

Number of fish in composite: Total Weight (g):

Composite Sample ID: M1 F0 - ~~1~~5 ___
site matrix seq. S/D

Species: Medaka

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1050	82	69	48	50	52	
2		78	78	69	55		
3							
4							
5							
6							
7							
8							

Number of fish in composite: Total Weight (g):

Continuation sheet. Date: Location:

Composite Sample ID: M 1 F4 - 6 S
site matrix seq. S/D

Species: Tilapia

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1145	173	199	155	153	137	
2		193	200	176	155	190	
3		147					
4							
5							
6							
7							
8							

Number of fish in composite: Total Weight (g):

Composite Sample ID: M 1 F4 - 7 ___
site matrix seq. S/D

Species: Tilapia

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1145	110	93	126	135	107	
2		110	112	112	101	117	
3		140	140	130	127	127	
4		134	105				
5	1245	124					
6							
7							
8							

Number of fish in composite: Total Weight (g):

Composite Sample ID: MT ___ F2-8 ___
site matrix seq. S/D

Species: Aholehole

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1200	100	95	95	89	104	
2		91	107	105	113	100	
3		101	91				
4	1310	72	108	104	102	106	
5		59	105				
6							
7							
8							

Number of fish in composite: Total Weight (g):

Field Record for Study of Chemical Residues in Fish Tissue

Sampling Date: August 3, 2010
Collection Method: Seine / hook + line
Colector Name: Andy Jahr
Affiliation: contractor - TetraTech Phone: 707-468-7432
Address: 1000 Riverside Dr. Ukiah, CA 95482

Site Location County: Hono.

Sidt Name: South Muliwai
Description:
Mākua Beach

Composite Sample ID: M 2 F1 - 1 ___
site matrix seq. S/D

Species: Striped Mullet

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1130	145	164	145	147	157	RBT 530g
2		161	176	146	170	151	
3		185	169				
4							
5							
6							
7							
8							

Number of fish in composite: Total Weight (g):

Composite Sample ID: M 2 F4 - 2 ___
site matrix seq. S/D

Species: Tilapia

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1130	144	121	124	119	124	BGadj. 900g
2		125	115	125	125	119	
3		109	123	115	115	112	
4		109	122	131	122	115	
5		109	120	114	111		
6							
7							
8							

Number of fish in composite: Total Weight (g):

Notes/Diagrams:

Continuation sheet. Date: Location:

Composite Sample ID: M 2 F4- 3 ____
site matrix seq. S/D

Species: Tilapia

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1130	90	~~72~~	107	106	106	
2		95	105	94	96	97	
3		94	101	90	97	99	
4		100	~~105~~	95	97	111	
5		101	95	97	97	94	
6		94	92	99			
7							
8							

BG Adg 500

Number of fish in composite: Total Weight (g):

Composite Sample ID: M 2 F3 -4 ____
site matrix seq. S/D

Species: Medaka

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1130	61	63	62	60	59	
2		70	70	70	71	64	
3		56	71	66	65	63	
4		65	59	55	59	55	
5		67	67	65	59	56	
6		60	63	62	60	67	
7		59	60	55	59	67	
8		55	57	64	57	55	

Number of fish in composite: Total Weight (g):

Composite Sample ID: M 2 F3 -4 ____
site matrix seq. S/D

Species: Medaka (continued)

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1130	57	55	59	70	59	
2		59	63	59	56	64	
3		60					
4							
5							
6							
7							
8							

RBT 119g

51 fish
55-77 mm

Number of fish in composite: Total Weight (g):

Field Record for Study of Chemical Residues in Fish Tissue

Sampling Date: August 3, 2006
Collection Method: Hand
Colector Name: Landin Johnson
Affiliation: Tetra Tech Phone: (808) 533-3366
Address: 820 Mililani St Suite 700 Honolulu 96813

Site Location: Makua Beach County: _____

Sidt Name: _____
Description:

Composite Sample ID: NW1 ML-1 ____
site matrix seq. S/D

Species: _____

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1330						
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: _____ Total Weight (g): _____

Composite Sample ID: ____ ____ ____ ____ ____
site matrix seq. S/D

Species: _____

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1							
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: _____ Total Weight (g): _____

Notes/Diagrams:

Field Record for Study of Chemical Residues in Fish Tissue

Sampling Date: 4 August 2006
Collection Method: hook + line
Colector Name: Andy Jahn
Affiliation: Tetra Tech contractor Phone: 707-468-7452
Address: 1000 Riverside Dr. Ukiah, CA 95482

Site Location County: Humo

Sidt Name: South Mulinni
Description: Mākua Beach

Composite Sample ID: M2 F4 - 5 D
site matrix seq. S/D

Species: Tilapia

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1030	102	121	119	120	136	
2		106	100	115	141	130	
3		120	132	114	119	130	
4		109	106	106	105		
5							
6							
7							
8							

BG
1117g

Number of fish in composite: Total Weight (g):

Composite Sample ID: ___ ___ ___ ___ ___
site matrix seq. S/D

Species:

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1							
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: Total Weight (g):

Notes/Diagrams:

Field Record for Study of Chemical Residues in Fish Tissue

Sampling Date 4 August 2010
Collection Method Hook & line
Colector Name Dawn A. Leeds
Affiliation: Tetra Tech Phone: (808) 533-3366
Address: 820 Mililani St. Suite 700 Honolulu Hi 96813

Site Location County:

Sidt Name: Nānākuli Muliwai
Description:

Nānākuli Beach Park

Composite Sample ID: M 3 F4-1 ___
site matrix seq. S/D

Species: tilapia

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1500	125	115	130	115	119	1290-2099
2		120	120	117	115	136	
3		139	117	119	120	110	
4		110	119	113	116	119	
5		130	122	119	120	111	
6		121	120	113	115	135	
7		120	121	131	111		
8							

Number of fish in composite: Total Weight (g):

Composite Sample ID: ___ ___ ___ ___ ___
site matrix seq. S/D

Species:

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1							
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: Total Weight (g):

Notes/Diagrams:

(Seq 2 is Aug 6)

Field Record for Study of Chemical Residues in Fish Tissue

Sampling Date 5 Aug '06
Collection Method Seine
Colector Name A Jahn
Affiliation: Tetra tech contractor Phone: 707-468-7432
Address: 1000 Riverside Dr. Ukiah, CA 95482

Site Location County: Hono

Sidt Name: South Muliwai
Description:
Makua Beach

Composite Sample ID: M 2 F1 5 ___
site matrix seq. S/D

Species: Striped mullet

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1000	192	195	200	197	203	
2		153					
3							
4							
5							
6							
7							
8							

Number of fish in composite: Total Weight (g):

Composite Sample ID: NW 1 U1 7 ___
site matrix seq. S/D

Species: Urchin - Hāuke'uke

Specimen/Lot Number	time	Lengths (mm TL)					Notes 43 urchin
1	1000						
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: Total Weight (g):

Notes/Diagrams:

Continuation sheet. Date: Location:

Composite Sample ID: NW 1 FG - 1 ___
site matrix seq. S/D

Species: Mpana (Parapeneus

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1300	191	~~202~~ 210	290	208	217	
2		190	177	176	177		
3							
4							
5							
6							
7							
8							

~ 2.5 lb

Number of fish in composite: Total Weight (g):

Composite Sample ID: NW 1 FG - 1 ___
site matrix seq. S/D

Species: Hinalea

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1300	213					
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: Total Weight (g):

Composite Sample ID: NW 1 ~~FG~~ F7 - 1 ___
site matrix seq. S/D

Species: Humuhumu hinukolu - Brown humu

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1		199	182				
2							
3							
4							
5							
6							
7							
8							

~ 3/4 lb

Number of fish in composite: Total Weight (g):

Continuation sheet. Date: Location:

Composite Sample ID: NW1 F8 1 ___
site matrix seq. S/D

Species: ___

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1300	175					
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: ___ Total Weight (g): ___

Composite Sample ID: NW1 F9 - 1 ___
site matrix seq. S/D

Species: Hinalea lau-wili (Saddle wrasse)

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1		165					
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: ___ Total Weight (g): ___

Composite Sample ID: NW1 F10 1 ___
site matrix seq. S/D

Species: ~~Iacpe~~ To'au

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1300	176					
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: ___ Total Weight (g): ___

+6 (seq. 2 to 6 tag)

Continuation sheet. Date: 5 Aug 06 Location: Makua Beach

Composite Sample ID: NW1 F4 - 1 ____
site matrix seq. S/D

Species: moana 2 (P. pleurostigma)

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1300	179					
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: ____ Total Weight (g): ____

Composite Sample ID: NW1 F11 - 2 ____
site matrix seq. S/D

Species: moana 2

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	0900	199	190				
2	1000	205					
3	1230	212					
4							
5							
6							
7							
8							

Number of fish in composite: ____ Total Weight (g): ____

Composite Sample ID: NW1 F5 - 2 ____
site matrix seq. S/D

Species: moana

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	0900	231	212	190	256		
2	1000	190	195				
3	1230	211					
4							
5							
6							
7							
8							

Number of fish in composite: ____ Total Weight (g): ____

Continuation sheet. Date: Location:

Composite Sample ID: NW1 F12-2 ___
site matrix seq. S/D

Species: Fistularia commersonii (cornet fish)

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1000	415					Measurement does not include tail filament.
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: ___ Total Weight (g): ___

Composite Sample ID: NW1 F14-2 ___ ___
site matrix seq. S/D

Species: Rhinecan ~~Humumum~~ Humuhumunukunuku apua'a

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1000	172					
2	1230	212					
3							
4							
5							
6							
7							
8							

Number of fish in composite: ___ Total Weight (g): ___

Composite Sample ID: NW1 F13-2 ___
site matrix seq. S/D

Species: ~~Fistularia commersonii~~ Bridled triggerfish

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1000	190	147	130			
2	1230	235					
3							
4							
5							
6							
7							
8							

Number of fish in composite: ___ Total Weight (g): ___

Continuation sheet. Date: Location:

Composite Sample ID: NW1 F15 -2 ____
site matrix seq. S/D

Species: Lizzard Fish

Specimen/Lot Number	time	Lengths (mm TL)				Notes
1	1000	240				
2						
3						
4						
5						
6						
7						
8						

Number of fish in composite: Total Weight (g):

Composite Sample ID: NW1 F16- 2 ____
site matrix seq. S/D

Species: Surgeon Wrasse

Specimen/Lot Number	time	Lengths (mm TL)				Notes
1	1130	202	204	163	151	
2						
3						
4						
5						
6						
7						
8						

Number of fish in composite: Total Weight (g):

Composite Sample ID: ~~F~~NW1 F6- 2 ____
site matrix seq. S/D

Species: Hinalea

Specimen/Lot Number	time	Lengths (mm TL)				Notes
1	1130	166	175			
2						
3						
4						
5						
6						
7						
8						

Number of fish in composite: Total Weight (g):

Continuation sheet. Date: Location:

Composite Sample ID: NW1 ___ F17-2 ___ ___
site matrix seq. S/D

Species: Blackspot Sergeant

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1130	180	171				
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: ___ Total Weight (g): ___

Composite Sample ID: NW1 ___ F20-2 ___ ___
site matrix seq. S/D

Species: Humuhumu ki

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1130	177					
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: ___ Total Weight (g): ___

Composite Sample ID: NW1 ___ F10-2 ___ ___
site matrix seq. S/D

Species: Nenue

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1130	174					
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: ___ Total Weight (g): ___

Continuation sheet. Date: Location:

Composite Sample ID: NW1 ___ F19-2 ___
site matrix seq. S/D

Species: Stocky Hawkfish

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1130	159					
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: Total Weight (g):

Composite Sample ID: ___ ___ ___ ___ ___
site matrix seq. S/D

Species:

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1							
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: Total Weight (g):

Composite Sample ID: ___ ___ ___ ___ ___
site matrix seq. S/D

Species:

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1							
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: Total Weight (g):

Field Record for Study of Chemical Residues in Fish Tissue

Sampling Date 8 Aug 2006
Collection Method Seine
Colector Name Dawn Llieces
Affiliation: Tetra Tech Phone:
Address:

Site Location County:

Sidt Name: Nanakuli muliwai
Description:
S. end Nanakuli Beach Park

Composite Sample ID: M3 F2 - 1
site matrix seq. S/D

Species: Ahole hole

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1000	89	89	99	95	87	
2		84	86	88			
3	1300	99					
4							
5							
6							
7							
8							

Number of fish in composite: Total Weight (g):

Composite Sample ID: M3 F2 - 2
site matrix seq. S/D

Species: Ahole hole

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1130	128					
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: Total Weight (g):

Notes/Diagrams:

Continuation sheet. Date: 8 Aug 06 Location: South Muliwai

Composite Sample ID: M2 F3 - 80 ___
site matrix seq. S/D

Species: Medaka

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1600						59 fish, 53-71mm measured in range 53-71
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: ___ Total Weight (g): ___

Composite Sample ID: M2 F1 - 81 ___
site matrix seq. S/D

Species: mullet

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1		172	171	155	159	170	
2		155	152	150	175	175	
3							
4							
5							
6							
7							
8							

Number of fish in composite: ___ Total Weight (g): ___

Composite Sample ID: M2 F1 - 82 ___
site matrix seq. S/D

Species: Mullet

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1700	195	190	205	190	~~190~~	
2		103					
3							
4							
5							
6							
7							
8							

Number of fish in composite: ___ Total Weight (g): ___

Continuation sheet. Date: 8 Aug 010 Location: South Muliwai - Makua Beach

Composite Sample ID: M2 0 F1-02 ___
site matrix seq. S/D

Species: Mullet

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1300	160	142	145	135	155	
2		144	153	165	125	140	
3		144	151	153	157	139	
4		140	142	153			
5							
6							
7							
8							

Number of fish in composite: ___ Total Weight (g): ___

Composite Sample ID: ___ ___ ___ ___ ___
site matrix seq. S/D

Species: ___

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1							
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: ___ Total Weight (g): ___

Composite Sample ID: ___ ___ ___ ___ ___
site matrix seq. S/D

Species: ___

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1							
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: ___ Total Weight (g): ___

Field Record for Study of Chemical Residues in Fish Tissue

Sampling Date: 9 August 06
Collection Method: Hand U
Colector Name: Dawn A. Lieces
Affiliation: Tetra Tech, Inc Phone: (808) 533-3166
Address: 820 Mililani St, Honolulu, Hawaii 96813

Site Location: Near shoreburters of South Multiway County: Honolulu
Sidt Name: Makua Beach
Description:

Composite Sample ID: NW1 (site) SW1-1 (matrix seq.) ___ (S/D)

Species: Limu kala

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1400						
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: Total Weight (g):

Composite Sample ID: NW1 (site) SW1-1 (matrix seq.) ___ (S/D)

Species: Limu 2

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1400						
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: Total Weight (g):

Notes/Diagrams:

Field Record for Study of Chemical Residues in Fish Tissue

Sampling Date 8-19-06
Collection Method Hook and line
Colector Name Landin
Affiliation: Tetra Tech, Inc. Phone: (808) 533-3366
Address: 820 Mililani St, Ste 700, Honolulu, HI 96813

Site Location Sandy Beach County: Honolulu, Hawaii

Sidt Name:
Description: Rocks east of Sandy Beach.

Composite Sample ID: NW 2 FI7-1 S
site matrix seq. S/D

Species: Blackspot sergeant

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1100	145	136				weights: 190, 150 (g)
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: 2 Total Weight (g): 340

Composite Sample ID: NW 2 FI7-2 D
site matrix seq. S/D

Species: Blackspot sergeant

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1130	153	146				weights: 160, 150 (g)
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: 2 Total Weight (g): 310

Notes/Diagrams:

Continuation sheet. Date: 8-19-06 Location: Sandy Beach (Cranks)

Composite Sample ID: NW 2 F9-1 S
site matrix seq. S/D

Species: Saddle wrasse

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1200	146	144	153	119	130	Weights (g): 50, 45, 75, 30, 30, 30
2	1700	130					
3							
4							
5							
6							
7							
8							

Number of fish in composite: 6 Total Weight (g): 260

Composite Sample ID: NW 2 F6-1 S
site matrix seq. S/D

Species: Christmas wrasse

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1230	192	151	158	165		Weights (g): 115, 55, 65, 75
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: 4 Total Weight (g): 310

Composite Sample ID: NW 2 F18-1 S
site matrix seq. S/D

Species: Gray chub

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1400	178					Weight (g): 130
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: 1 Total Weight (g): 130

Continuation sheet. Date: 8-19-06 Location: Sandy Beach (rocks)

Composite Sample ID: NW2 F14-1 S
site matrix seq. S/D

Species: Picasso triggerfish

Specimen/Lot Number	time	Lengths (mm TL)					Notes weight (g): 320
1	1700	276					
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: 1 Total Weight (g): 320

Composite Sample ID: ___ ___ ___ ___ ___
site matrix seq. S/D

Species: _____

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1							
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: _____ Total Weight (g): _____

Composite Sample ID: ___ ___ ___ ___ ___
site matrix seq. S/D

Species: _____

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1							
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: _____ Total Weight (g): _____

Field Record for | Study of Chemical Residues in | Fish Tissue

Sampling Date: 8-20-06
Collection Method: Hook & Line
Colector Name: Landin
Affiliation: Tetra Tech, Inc Phone: 808-533-3366
Address:

Site Location: Sandy Beach County: Honolulu
Sidt Name: Bamboo Ridge
Description: West of Sandy Beach

Composite Sample ID: NW2 F5 F3-1 S
site matrix seq. S/D
Species: Manybar goatfish

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1200	252	160				Weights (g) 280, 125
2	weight	280	125				grams
3							
4							
5							
6							
7							
8							

Number of fish in composite: 2 Total Weight (g): 405

Composite Sample ID: NW2 F13-1 S
site matrix seq. S/D
Species: Bridled Triggerfish

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1		176					Weight (g) 150
2	weight	150					
3							
4							
5							
6							
7							
8							

Number of fish in composite: 1 Total Weight (g): 150

Notes/Diagrams:

Field Record for Study of Chemical Residues in Fish Tissue

Sampling Date 09/07/06
Collection Method Hook and line
Colector Name L. Johnson, G. Flood
Affiliation: Tetra Tech, Inc. Phone: (808) 533-3316
Address: 820 Mililani St, Suite 700, Honolulu, HI 96813

Site Location Makua (NW) County: Honolulu

Sidt Name: Makua reef
Description:

Composite Sample ID: NW 1 FG-2 S
site matrix seq. S/D

Species: Saddle wrasse

Specimen/Lot Number	time	Lengths (mm TL)					Notes Weight (g):
1	1300	156	126	105	114	96	60, 20, 15, 15, 10
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: 5 Total Weight (g): 120

Composite Sample ID: ___ ___ ___ ___ ___
site matrix seq. S/D

Species: ___

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1							
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: ___ Total Weight (g): ___

Notes/Diagrams:

Field Record for | Study of Chemical Residues in | Fish Tissue

Sampling Date: 09-07-06
Collection Method: Gill net, minnow trap, throw net
Colector Name: L. Johnson + G. Pleyl
Affiliation: Tetra Tech, Inc. Phone: (808) 533-3366
Address: 820 Mililani St, Suite 700, Honolulu, HI 96813

Site Location NANAKULI MULIWAI (M3) County: Honolulu

Sidt Name:
Description:

Composite Sample ID: M3 F3-1 S
site matrix seq. S/D

Species: MEDAKA

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1500	57	65	60	70	61	Continued below
2	1500	51	54	57	52	75	
3	↓	45	45	59	60	62	
4		62	43	67	48	65	
5		57	47	43	47	56	
6		56	65	57	66	55	
7		58	42	46	60	55	
8	↓	46	62	55	57	56	

Number of fish in composite: See next Total Weight (g): See next

Composite Sample ID: — — — —
site matrix seq. S/D

Continued from above.

Species: — (See above)

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1500	59	46	47	55	58	
2	↓	52	65	48	44	55	
3	↓	44	40	40			
4							
5							
6							
7							
8							

Number of fish in composite: 53 Total Weight (g): 150

Notes/Diagrams:

Continuation sheet. Date: Location: NANAKULI MOKUWAI

Composite Sample ID: M3 - F1 - 2 S
site matrix seq. S/D

Species: Hawaiian flagtail ("Ahole holy")

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1	1500	123	78				
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: 2 Total Weight (g): 40g

Composite Sample ID: M3 F1-1 S
site matrix seq. S/D

Species: Striped mullet

Specimen/Lot Number	time	Lengths (mm TL)					Notes weight
1	0730	250					170(g)
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: 1 Total Weight (g): 170

Composite Sample ID: ___ ___ ___ ___ ___
site matrix seq. S/D

Species: _____

Specimen/Lot Number	time	Lengths (mm TL)					Notes
1							
2							
3							
4							
5							
6							
7							
8							

Number of fish in composite: _____ Total Weight (g): _____

Field Record: Makua Shellfish Study	
Sample Processor	SUSAN CARSTENN, MAREN ANDERSON
Data Recorder	YVONNE PARRY
Additional Personnel and Duties	DAWN LLECES
Environmental Conditions	see field notes

Date	Time	Location	Species	Length/Width (cm)	Mass (g)	Composite ID	
9/29/2008	11:45	M1	COLATR	6.9	35	MNS-03	
				7.4	45		
				6.4	32		
				7.1	45		
				6.0	32		
				5.4	20		
				6.0	27		
				6.1	25		
				6.3	31		
				6.8	34		
				6.9	35		1 jar
9/29/2008	11:45	M1	COLATR	6.3	26		
				5.8	22		
				6.3	29		
				5.7	21		
				6.2	25		
				6.3	31		
				~~7.2~~ 6.5 YKP	26		
				5.6	19		
				6.3	32		
				6.6	37		
				6.5	43		
				6.0	29		
				5.9	27		
				5.2	21		2 jar

Field Record: Makua Shellfish Study						
Sample Processor	SUSAN CARSTENN, MAREN ANDERSON					
Data Recorder	YVONNE PARRY					
Additional Personnel and Duties	DAWN LLECES - FIELD NOTES					
Environmental Conditions						
Date	Time	Location	Species	Length/Width (cm)	Mass (g)	Composite ID
9/29/2008	11:45	M1	COLATR	6.1	21	MNS-03
				6.3	26	
				4.8	29	
				6.2	31	
				5.4	19	
				5.5	28	
				6.0	22	
				6.9	37	
				5.9	28	
				6.0	27	
				5.4	24	
				6.4	28	3rd jar
9/29/2008	11:45	M1	COLATR	6.4	32	MNS-03 4th
				7.3	52	
				5.8	25	
				6.3	24	
				5.7	29	
				4.9	23	
				5.1	17	
				5.2	16	
				5.4	19	
				5.7	29	
				5.7	24	
				5.5	32	
				5.5	24	4th

Field Record: Makua Shellfish Study						
Sample Processor	SUSAN CARSTENN, MAREN ANDERSON					
Data Recorder	YVONNE PARRY					
Additional Personnel and Duties	DAWN LLELES ~ FIELD NOTES					
Environmental Conditions						
Date	Time	Location	Species	Length/Width (cm)	Mass (g)	Composite ID
9/29/2008	1145	M1	COLATR	5.3	18	MNS-Ø3
				6.2	22	
				4.5	11	
				5.6	19	
				5.7	24	
				5.4	18	
9/29/2008	1145	M1	COLATR	5.1	18	MNS-03
				6.6	35	
				6.2	26	
				4.6	17	
				4.7	15	
				5.4	21	
				4.6	16	
				6.0	28	
				5.4	20	
				53	21	
				5.5	29	
				5.0	17	
				52	17	
				5.6	19	
				4.2	11	
				6.0	23	
				5.1	22	
				5.6	19	
				5.2	15	

4th jar

5th jar

Field Record: Makua Shellfish Study	
Sample Processor	SUSAN CARLSTENN, MAREN ANDERSON
Data Recorder	YVONNE PARRY
Additional Personnel and Duties	DAWN LLECES - FIELD NOTES
Environmental Conditions	

Date	Time	Location	Species	Length/Width (cm)	Mass (g)	Composite ID
9/29/2008	1145	M1	COLATR	6.0	24	MNS-Ø3
				5.4	18	
				5.0	15	
9/29/2008	11:45	M1	COLATR	5.3	18	MNS-Ø3
				4.8	15	
				3.4	7	
				5.7	22	
				4.5	11	
				5.2	22	
				4.0	10	
				5.0	13	
				5.7	27	
				4.9	15	
				4.9	19	
				4.5	13	
				4.0	16	
				4.4	12	
				4.6	14	
				4.5	13	
				4.0	16	
				5.2	15	
				4.5	9	
				4.8	10	
				3.6	8	
				5.2	15	

5th / 6th

Field Record: Makua Shellfish Study						
Sample Processor	SUSAN CARSTENN, MAREN ANDERSON					
Data Recorder	YVONNE PARRY					
Additional Personnel and Duties	DAWN LLECES - FIELDNOTES					
Environmental Conditions						
Date	Time	Location	Species	Length/Width (cm)	Mass (g)	Composite ID
9/29/2008	1145	M1	COLATR	4.4	14	MNS-Ø3
			COLATR	5.5	31	
				5.0	14	
				4.5	10	
				5.1	18	
				4.3	10	
				3.6	7	
				4.9	16	
				4.0	8	
				4.5	10	
				4.3	8	
				5.0	16	
				5.6	22	6th
9/29/2008	1145	M1	COLATR	5.0	15	MNS-Ø3 7th
				5.0	19	
				5.2	18	
				4.8	9	
				5.2	18	
				4.6	14	
				4.8	14	
				4.6	11	
				4.9	19	
				5.0	15	
				4.8	13	
				5.1	18	

~~195~~ 972
~~1389~~ 1716
501
2217
666
2883
788
3671

6/8

Field Record: Makua Shellfish Study	
Sample Processor	SUSAN CARSTENN, MAREN ANDERSON
Data Recorder	YVONNE PARRY
Additional Personnel and Duties	DAWN LLEZES - FIELD NOTES
Environmental Conditions	

Date	Time	Location	Species	Length/Width (cm) ~~(g)~~	~~Mass (g)~~ cm	Composite ID	
9/29/2008	1145	M1	COLATR	4.5/10	4.6/16	MNS-03	
				6.1/28	4.2/11		
				4.5/14	5.1/20		
				5.4/24	4.9/10		
				4.8/14	5.5/18		
				4.9/18	4.6/19		
				4.2/10	4.5/14		
				4.7/15	6.2/20		
				4.4/9	4.3/11		7th
9/29/2008	1145	M1	COLATR	4.8/18	4.5/16	MNS-03	8th
				5.0/18	4.9/10		
				5.9/23	4.2/16		
				5.0/25	4.0/8		
				4.9/17	4.5/13		
				4.6/13	5.1/16		
				4.8/15	4.3/12		
				4.0/15	4.0/6		
				4.0/13	4.6/20		
				4.9/15	4.3/11		
				4.4/10	5.0/20		
				4.7/19	5.8/27		
				4.9/15	5.2/18		
				5.0/19	5.1/16		8th
9/29/2008	1145	M1	COLATR	5.8/26	4.9/15	MNS-03	9th
				4.8/17	4.1/10		

Field Record: Makua Shellfish Study	
Sample Processor	SUSAN CARSTENN, MAREN ANDERSON
Data Recorder	YVONNE PARRY
Additional Personnel and Duties	DAWN LLECES- FIELD NOTES
Environmental Conditions	

Date	Time	Location	Species	Length/Width (cm) / Mass	Length/Width Mass (g)	Composite ID	
9/29/2008	1145	M1	COLATR	4.4 / 15	4.3 / 11	MNS-Ø3	9th
				4.4 / 11	5.4 / 26		
				4.2 / 8	4.9 / 20		
				3.8 / 9	5.5 / 22		
				4.8 / 18	4.9 / 15		
				4.9 / 13	4.5 / 11		
				3.4 / 21	4.0 / 32		
				3.3 / 22	4.9 / 30		
				3.5 / 15	3.4 / 15		
				3.4 / 17	4.7 / 29		
				3.4 / 16	3.4 / 19		
				3.5 / 15	9/29/2008 YKP		9th jar
9/29/2008	1145	M1	COLATR	3.4 / 19	3.1 / 14	MNS-Ø3	10th jar
				3.5 / 21	3.4 / 11		
				2.9 / 10	3.6 / 16		
				4.0 / 21	3.3 / 13		
				3.1 / 11	3.5 / 15		
				4.0 / 23	4.0 / 19		
				3.7 / 17	3.3 / 17		
				4.0 / 15	4.0 / 18		
				2.6 / 13	3.5 / 19		
				4.3 / 24	3.5 / 15		
				3.5 / 20	2.5 / 13		
				3.6 / 13	2.9 / 9		
				3.1 / 11	YKP 3.9 ~~3.9~~ / 16		10th jar

YKP see back of page

Date	Time	Location	Species	Length/width	Mass [g]	Composite ID
9/29/2008	1145	M1	COLATR	3.4	16	MNS03
				3.5	17	
				4.0	15	
				3.7	17	
				3.4	14	
				2.7	10	
				2.5	9	
				2.5	7	
				2.6	12	
				3.2	14	
				3.4	21	
				2.2	15	
				3.0	10	
				3.7	15	
				3.6	18	
				4.0	20	
				3.2	14	
				4.1	21	
				4.2	26	

11th ja

Field Record: Makua Shellfish Study						
Sample Processor	SUSAN CARSTENN, MAREN ANDERSON					
Data Recorder	YVONNE PARRY					
Additional Personnel and Duties	DAWN LLECES - FIELD NOTES					
Environmental Conditions						
Date	Time	Location	Species	Length/Width (cm)	Mass (g)	Composite ID
9/29/2008	11:55	M1	GRATEN	1.0	7	~~MNS~~ MNS-02

Field Record: Makua Shellfish Study						
Sample Processor	MAREN ANDERSON, SUSAN CARSTENN					
Data Recorder	YVONNE PARRY					
Additional Personnel and Duties	DAWN LLECES					
Environmental Conditions						
Date	Time	Location	Species	Length/Width (cm)	Mass (g)	Composite ID
9/29/2008	11:45	M, ~~MNS~~ MN inner tidal	~~PACPL~~ MP	3.3	19	MNS-01
9/29/2008	12:57	North Muliwai	PLADEP SCYSER	7.1	163	MNM-04 jar 1
9/29/2008	12:57	North Muliwai	SCYSER	9.0	224	MNM-04 Ziplock 1

Field Record: Makua Shellfish Study	
Sample Processor	Maren Anderson
Data Recorder	Jason A. Lleces
Additional Personnel and Duties	
Environmental Conditions	See field notes

Date	Time	Location	Species	Length/Width (cm)	Mass (g)	Composite ID	
10/1/08	1200	SBNS/Habitat	COLATR	7.1	62	SBNS-01	
				6.2	43		
				6.6	45		
				5.4	38		
				6.9	67		Jar 1
				4.9	20		348
				5.4	22		
				6.2	47		
				6.2	40		
				5.8	44		
				6.5	42		
				6.0	51		Jar 2
				5.1	24		410
				5.2	23		
				7.5	55		
				6.9	54		
				5.6	47		
				6.5	30		
				6.8	43		
				6.2	25		Jar 3
				6.9	60		
				7.4	39		
				6.5	36		
				5.9	30		
				5.4	25		

Field Record: Makua Shellfish Study	
Sample Processor	Maren Anderson
Data Recorder	Dawn A. Lleces
Additional Personnel and Duties	
Environmental Conditions	See field notes

Date	Time	Location	Species	Length/Width (cm)	Mass (g)	Composite ID	
10/1/09	1200	SBNS/Habitat	COLATR	6.7	50	SBNS-01	Jar 3
↓	↓	↓	↓	6.7	30	↓	(cont)
				6.9	50		
				6.5	36		451
				4.0	19		
				7.0	39		Jar 4
				4.5	10		
				3.7	5		
				4.6	11		
				3.6	9		
				5.1	22		
				5.5	22		
				4.5	12		
				5.1	15		
				6.2	29		
				5.0	15		
				4.1	11		
				4.5	19		
				4.1	10		
				4.9	14		
				3.7	9		
				5.0	14		
				5.2	34		
				4.0	7		
↓	↓	↓	↓	4.6	13	↓	

513

Field Record: Makua Shellfish Study							
Sample Processor	Maren Anderson						
Data Recorder	Dawn A. Lleces						
Additional Personnel and Duties							
Environmental Conditions	See field notes						
Date	Time	Location	Species	Length/Width (cm)	Mass (g)	Composite ID	
10/1/09	1200	SBNS/Habitat	COLATR	3.7	10	SBNS-01	Jar 4
↓	↓	↓	↓	5.8	26	↓	(cont.)
↓	↓	↓	↓	5.2	15	↓	371
				3.9	6		Jar 5
				5.5	21		
				5.4	17		
				5.0	15		
				3.7	10		
				5.4	28		
				3.6	6		
				4.7	14		
				4.0	9		
				5.3	17		
				4.7	12		
				4.4	8		
				4.5	10		
				5.5	19		
				4.0	9		
				4.9	19		
				5.0	24		
				4.0	8		
				4.3	12		
				4.9	19		
				5.9	24		
↓	↓	↓	↓	4.7	14	↓	

Field Record: Makua Shellfish Study							
Sample Processor	Maren Anderson						
Data Recorder	Dawn Lieces						
Additional Personnel and Duties							
Environmental Conditions	See Field notes						
Date	Time	Location	Species	Length/Width (cm)	Mass (g)	Composite ID	
10/01/08	12:00	SBNS/Habitat	COLATR	5.6	25	SBNS-01	Jar 5 (cont.)
				4.1	10		
				4.8	15		
				4.3	9		
				4.2	9		453
				4.3	15		
				4.2	14		
				4.3	8		
				5.6	29		sample 1
				5.2	15		Jar 6
				3.6	7		
				4.8	16		
				4.5	16		
				5.3	17		
				3.8	10		
				6.9	46		
				5.6	25		
				4.8	15		
				4.9	13		
				4.7	15		
				5.3	21		
				5.5	16		
				5.5	20		
				3.4	8		
				5.1	19		

Field Record: Makua Shellfish Study	
Sample Processor	Maren Anderson
Data Recorder	Dawn A. Lleces
Additional Personnel and Duties	
Environmental Conditions	See field notes

Date	Time	Location	Species	Length/Width (cm)	Mass (g)	Composite ID	
10-01-08	1200	SBNS/Habitat	COLATR	4.7	10	SBNS-01	Jar 6
				4.7	19		(cont.)
				3.8	10		
				4.3	13		398
				4.4	15		
				5.3	24		
				6.0	20		
				4.7	14		Jar 7
				4.0	8		
				4.2	11		
				5.7	30		
				3.5	6		
				4.1	10		
				3.4	9		
				5.2	17		
				5.5	23		
				5.5	26		
				4.9	15		
				4.8	15		
				4.7	14		
				4.9	17		
				4.7	17		
				3.9	5		
				4.7	16		
				4.1	15		

Field Record: Makua Shellfish Study	
Sample Processor	Maren Anderson
Data Recorder	Dawn Lleces
Additional Personnel and Duties	
Environmental Conditions	See field notes

Date	Time	Location	Species	Length/Width (cm)	Mass (g)	Composite ID	
10-01-00	12:00	SBNS/Habitat	COLATR	4.4	9	SBNS-01	Jar 7
↓	↓	↓	↓	5.1	27	↓	(cont.)
				5.4	17		
				4.9	13		
				4.6	14		409
				5.1	15		
				6.6	30		
				5.3	16		
				5.0	17		Jar 8
				4.3	10		
				4.6	14		
				4.3	11		
				4.5	12		
				4.5	10		
				4.5	14		
				5.0	17		
				4.7	12		
				5.7	24		
				5.7	22		
				5.3	19		
				5.7	29		
				5.1	18		
				3.9	8		
				4.2	11		
				4.7	15		

Field Record: Makua Shellfish Study							
Sample Processor	Maren Anderson						
Data Recorder	Dawn A. Ueces						
Additional Personnel and Duties							
Environmental Conditions	See field notes						
Date	Time	Location	Species	Length/Width (cm)	Mass (g)	Composite ID	
10/01/08	12:00	SBNS/Habitat	COLATR	5.9	24	SBNS-01	Jar 8
↓	↓	↓	↓	3.4	9	↓	(cont.)
				4.1	14		
				4.7	17		
				4.9	18		
				5.1	16		417
				4.2	11		
				4.8	13		
				3.7	8		
				4.4	12		
				4.7	12		
				6.0	35		Jar 9
				5.7	20		
				5.7	26		
				4.2	14		
				4.8	12		
				4.3	14		
				4.9	13		
				6.3	37		
				5.5	24		
				6.6	34		
				5.2	17		
				6.4	29		
				5.2	12		
				4.8	14		

Field Record: Makua Shellfish Study							
Sample Processor	Maren Anderson						
Data Recorder	Dawn A. Lleces						
Additional Personnel and Duties							
Environmental Conditions	See field notes						
Date	Time	Location	Species	Length/Width (cm)	Mass (g)	Composite ID	
10/01/09	1200	SBNS/Habitat	COLATR	4.3	7	SBNS-01	Jar 9
↓	↓	↓	↓	4.4	10	↓	
				6.7	35		
				5.0	10		
				3.7	7		448
				4.2	19		
				3.5	9		
				5.6	28		
				~~5.~~ 4.7	14		
				5.0	15		Jar 10
				4.6	16		
				7.2	53		
				5.9	25		
				6.6	43		
				5.9	23		
				4.3	15		
				4.3	12		
				6.1	25		
				4.2	9		
				4.9	15		
				4.1	13		
				4.6	11		
				4.6	15		
				4.8	11		
↓	↓	↓	↓	4.5	13	↓	

Field Record: Makua Shellfish Study	
Sample Processor	Maren Anderson
Data Recorder	Dawn A. Lleces
Additional Personnel and Duties	
Environmental Conditions	See ~~on~~ field notes

Date	Time	Location	Species	Length/Width (cm)	Mass (g)	Composite ID	
10/01/00	12:00	SBNS/Habitat	COLATR	4.0	11	SBNS-01	Jar 10
				4.6	10		(cont)
				3.8	9		
				3.9	8		
				4.3	13		
				3.5	5		467
				5.4	18		
				4.2	13		
				5.2	13		
				6.0	30		
				4.6	10		
				3.8	7		
				4.1	6		
				4.5	10		Jar 11
				6.2	20		
				4.7	15		
				4.5	15		
				4.6	19		
				5.0	15		
				4.4	12		
				3.9	8		
				6.9	43		
				5.3	16		
				4.9	15		
				4.1	9		

Field Record: Makua Shellfish Study	
Sample Processor	Maren Anderson
Data Recorder	Dawn A. Lleces
Additional Personnel and Duties	
Environmental Conditions	See a field notes

Date	Time	Location	Species	Length/Width (cm)	Mass (g)	Composite ID	
10-01-08	1200	SBNS/Habitat	COLATR	4.3	14	SBNS-01	Jar 11
				3.7	7		(cont.)
				5.4	20		
				4.8	14		
				4.0	10		
				3.9	7		
				4.0	12		
				4.4	10		491
				~~5.4~~ 5.5	25		
				5.4	19		
				4.8	14		
				4.6	11		
				5.4	24		
				3.7	~~4~~ 7		
				4.9	14		
				5.1	16		
				4.7	19		
				6.3	45		
				6.2	30		Jar 12
				5.5	24		
				6.2	32		
				5.2	30		
				7.3	63		
				5.7	40		
				5.7	26		

11 05 12

Field Record: Makua Shellfish Study							
Sample Processor	Maren Anderson						
Data Recorder	Yvonne Parry / Dawn A. Lieces						
Additional Personnel and Duties							
Environmental Conditions	See Field Notes						
Date	Time	Location	Species	Length/Width (cm)	Mass (g)	Composite ID	
10/01/08	1200	SBNS / ~~Hawk~~ DAL	COLATR	6.2	47	SBNS-01	Jar 12 (cont.)
↓	↓	↓	↓	6.2	43	↓	
				6.3	45		
				6.2	45		511
				6.4	33		
				6.0	26		
↓	↓	↓	↓	6.0	27	↓	
10/02/08	1115	SBNS	COLATR	6.5	37	SBNS-01	517.0g Jar 13
↓	↓	↓	↓	6.0	32	↓	
				6.6	38		
				7.9	62		
				6.6	45		
				7.3	58		
				7.5	55		
				6.1	27		
				6.0	26		
				6.2	40		
				6.8	41		
	↓	↓	↓	6.7	42	↓	503
	1115	SBNS	COLATR	6.0	30	SBNS-01	↓ Jar 14
↓	↓	↓	↓	6.4	33	↓	
				6.0	26		
				7.1	42		
				5.8	25		
↓	↓	↓	↓	6.0	20	↓	

Field Record: Makua Shellfish Study	
Sample Processor	Maren Anderson
Data Recorder	Yvonne Parry
Additional Personnel and Duties	
Environmental Conditions	see Field notes

Date	Time	Location	Species	Length/Width (cm)	Mass (g)	Composite ID	
10/2/08	1115	SBNS	COLATR	6.2	30	SBNS-01	
				6.5	39		
				6.7	21		
				6.5	26		
				5.5	25		
				6.0	30		
				6.7	50		
				6.6	40		
				6.5	28		
				5.8	31		
				5.0	16		
				5.6	40		
				6.2	44		
				5.2	21		↑ 617

Field Record: Makua Shellfish Study						
Sample Processor	March Anderson					
Data Recorder	Dawn A. Lieces					
Additional Personnel and Duties						
Environmental Conditions	See field notes					
Date	Time	Location	Species	Length/Width (cm)	Mass (g)	Composite ID
10/01/08	1200	SBNS / Habitat	PLADEP	3.0	32	SBNS - 02

Field Record: Makua Shellfish Study	
Sample Processor	Maren Anderson
Data Recorder	Dawn Lleces
Additional Personnel and Duties	
Environmental Conditions	see Field Notes

Date	Time	Location	Species	Length/Width (cm)	Mass (g)	Composite ID
10/3/00	~~1300~~ 1400	MNS	RANRAN	7.8 / 6.2	156	MNS-05
				9.0 / 6.8	236	-
				9.0 / 7.0	223	-
				7.4 / 6.0	132	-

Field Record: Makua Shellfish Study	
Sample Processor	Maren Anderson
Data Recorder	Dawn A. Lleces
Additional Personnel and Duties	Susan Carstenn
Environmental Conditions	See ~~envir data~~ Field notes

Date	Time	Location	Species	Length/Width (cm) (Full length/carapace length)	Mass (g)	Composite ID	
10-6-08	1225	NM	MACGRA	7.3/3.4	9	NM-01	Jar 1
10-7-08	1442	NM	MACGRA	7.2/ 3.4	9	NM-01	
				7.5/3.6	9		
				6.9/2.3	8		
				7.2/3.4	9		
				7.1/3.5	5		
				7.4/3.5	5		
				7.5/3.6	8		
				7.2/3.5	6		
				7.3/3.6	6		
				7.1/3.4	5		
				7.6/3.7	6		
				6.5/3.1	4		
				7/3.3	3		
				7.5/3.6	6		
10-6-08	1555	NNS	RENREN	6.75/5.3	94	NNS-01	
10-7-08	1442	NM	MACGRA	7.1/3.5	9	NM-01	Jar 1 (cont)
				6.2/2.7	4		
				7.0/3.3	6		
				6.4/3.0	3		
				4.9/2.2	0.5		
				5.3/2.4	1		
				5.7/2.5	2		
				6.8/3.4	5		
				5.4/2.6	1		

Field Record: Makua Shellfish Study							
Sample Processor	Maren Anderson						
Data Recorder	Dawn A. Lees						
Additional Personnel and Duties							
Environmental Conditions	See field notes						
Date	Time	Location	Species	Length/Width (cm)	Mass (g)	Composite ID	
10-7-08	1442	NM	MACGRA	5.4 / 2.5	1	NM-01	Jar 1 (cont.)
↓	↓	↓	↓	5.0 / 2.4	1	↓	
				5.3 / 2.5	1		
				5.4 / 2.5	3		
				4.9 / 2.2	2		
				6.0 / 2.6	3		
				5.0 / 2.3	0.5		
				3.6 / 1.7	0.25		
				4.3 / 2.0	0.25		
				3.9 / 1.6	0.25		
				5.6 / 2.5	2		
				5.7 / 2.5	3		
				5.7 / 2.4	3		
				4.5 / 1.9	2		
				6.0 / 2.7	3		
				5.4 / 2.5	2		
				4.5 / 2.0	0.5		
				5.6 / 2.6	2		
				4.0 / 1.9	1.5		
				4.9 / 2.3	0.5		
				5.0 / 2.3	1		
				4.7 / 2.1	1		
				5.2 / 2.4	2		
				3.4 / 1.7	~~0.25~~ 1		
↓	↓	↓	↓	3.2 / 1.5	~~0.25~~ 1	↓	

Field Record: Makua Shellfish Study							
Sample Processor	Maren Anderson						
Data Recorder	Dawn A. Lleces						
Additional Personnel and Duties							
Environmental Conditions	see Field Notes						
Date	Time	Location	Species	Length/Width (cm)	Mass (g)	Composite ID	
10-07-08	1442	NM	MACGRA	7.1 / 3.5	8	NM-01	Jar 1 (cont.)
↓	↓	↓	↓	6.5 / 2.9	7	↓	
				7.8 / 3.6	6		
				6.7 / 3.2	6		
↓	↓	↓	↓	7.3 / 3.7	7	↓	
10-07-08	1442	NM	MACGRA	6.9 / 3.6	8	NM-01	Jar 2
				6.9 / 3.1	5		
				5.6 / 2.5	2		
				7.3 / 3.5	7		
				4.9 / 2.3	1		
				7.0 / 3.3	5		
				5.5 / 2.5	2		
				5.3 / 2.5	2		
				5.2 / 2.5	1		
				5.2 / 2.4	1		
				5.7 / 2.6	3		
				5.0 / 2.7	2		
				6.7 / 3.3	5		
				5.5 / 2.5	2		
				5.9 / 2.6	3		
				4.6 / 2.2	1		
				7.0 / 3.5	5		
				4.7 / 2.3	1		
				5.2 / 2.5	2		
				5.1 / 2.4	1		

Field Record: Makua Shellfish Study						
Sample Processor	Marin Anderson					
Data Recorder	Dawn A. Lecos					
Additional Personnel and Duties						
Environmental Conditions	See field notes.					
Date	Time	Location	Species	Length/Width (cm)	Mass (g)	Composite ID
10.07.08	1442	NM	MACGRA	4.4/2.2	2	NM-01
↓	↓	↓		5.2/2.5	1	↓
10.08.08	1000	NM	MACGRA	7.5/3.8	6	
				7.0/3.3	5	
				7.4/3.6	10	
				7.5/3.7	7	
				7.8/3.8	9	
				7.4/3.6	9	
				7.8/3.7	7	
				7.2/3.3	8	
				8.3/4.0	9	
				7.0/3.4	5	
				5.4/2.5	3	
				5.8/2.8	2	
				5.2/2.4	3	
				4.7/2.4	2	
				6.4/3.2	4	
				5.4/2.4	1	
				5.8/2.8	3	
				5.2/2.3	2	
				3.7/1.8	0.5	
				5.7/2.8	3	
				5.4/2.3	3	
				5.6/2.5	3	
				4.8/2.2	2	

Jar 2 (cont.)

170.5

Field Record: Makua Shellfish Study						
Sample Processor	Maren Anderson					
Data Recorder	Dawn A. Lleces					
Additional Personnel and Duties						
Environmental Conditions	See field notes					
Date	Time	Location	Species	Length/Width (cm)	Mass (g)	Composite ID
10-07-00	1625	NM	PACMIN	3.1	27	NM-02
				2.4	12	-
				1.5	3	
				2.3	10	

Field Record: Makua Shellfish Study						
Sample Processor	Maren Anderson					
Data Recorder	Tom Ogawa / Susan Carstenn					
Additional Personnel and Duties						
Environmental Conditions	see Field Notes					
Date	Time	Location	Species	Length/Width (cm)	Mass (g)	Composite ID
10.08.08						

Field Record: Makua Shellfish Study						
Sample Processor	Maren Anderson					
Data Recorder	Dawn A. Lleras					
Additional Personnel and Duties						
Environmental Conditions	See field notes					
Date	Time	Location	Species	Length/Width (cm)	Mass (g)	Composite ID
10-9-09	11:34	MSM	PACMIN	3.3	28	MSM-01
				3.2	27	-
				3.0	19	
10-9-09	11:45	MSM		8.4/4.0	14	MSM-02
				6.8/3.2	5	

Makua Shellfish Study - Sample Codes and Species List
September 26, 2008

Location	Habitat	Composite ID
Makua	North Muliwai	MNM
Makua	South Muliwai	MSM
~~Makua~~	~~Intertidal~~	~~MI~~
Makua	Nearshore	MNS
Nanakuli	Muliwai	NM
Sandy Beach	Intertidal - Bamboo Ridge	SBBRI
Sandy Beach	Intertidal	SBI
Sandy Beach	Nearshore	SBNS

Species	Common Name	Species Code
Muliwai		
Thiaridae	Malaysian snail	THI
Nearshore		
Parribacus antarcticus	slipper lobster	PARANT
Ranina ranina	kona crab	RANRAN
Intertidal		
Colobocentrotus atratus	helmet urchin	COLATR
Echinometra oblonga	oblong urchin	ECHOBL
Grapsus tenuicrustas	thin-shelled rock crab	GRATEN
Isognomon californicum	black purse shell, nahawele, papaua	ISOCAL
Littoraria pintado	dotted periwinkle, pipipi kolea	LITPIN
Nerita picea	black nerite, pipipi	NERPIC
Echinometra mathaei (MI only)	rock-boring urchin	ECHMAT
Siphonaria normalis (MI only)	false `opihi, opihi-awa	SIPNOR
Nesochthamalus interextus (MI only)	purple rock barnacle	NESINT
Pachygrapsus plicatus (MI only)	pleated rock crab	PACPLI
Cypraea caputserpentis (MI only)	snakehead cowry	CYPCAP
Echinothrix diadema (MI only)	blue-black urchin	ECHDIA
Cellana exarata (SBBR only)	black-foot opihi	CELEXA
Plagusia depressa tuberculata		PLADEP, - Ø1
Scylla Serrata - Samoan Crab		SCYSER

Sept. 29, 2008

9:43 Tetra Tech team arrives at Mākua Military Reservation Range Control. to sign in and check out Mākua Beach keys and Range Control

10:05 Tetra Tech and Oceanic Institute enter Malama ~~Mak~~ Beach State Park and secure gates behind cars.

Tetra Tech	Oceanic Institute
Susan Carstenn	Tom Ogawa
Dawn A. Lieces	Don De Lepena
Yvonne Parry	
Maren Anderson	
(2 vehicles)	

10:00 Tail gate safety brief for field team and sample station set up near south muliwai and sample gear preparation

10:30 Gear for sampling. 1 minnow traps (square), 2 cirular/cylindricle minnow traps, 4 crab nets. Nets and traps deployed at south muliwai.

10:51 Tetratech team arrives at north muliwai.

11:20 Tetra Tech at reef area, rocky near shore area, to deploy 5 gallon bucket crab traps and to start harvesting urchins

~~10~~ 11:49 Field team starting to process samples

11:55 Crab species

MNS-01 – Plagusia depressa tuberculata

MNS-02 – Grapsus tenuicrustas

12:30 Crab net brought up empty. Minnow traps contained mosquito fish only. Net and trap redeployed

12:36 2nd crab net brought up empty. 2nd minnow trap contained akupa.

12:45 Team arrives at north muliwai to check crab nets and minnow traps. The first attempt at retrieving the first crab net ended up with no crabs, However the line for the net was pulled taut so Don decided to redeploy the net and check before mobilizing to rocky area. Minnow traps were pulled up with akupa and mosquito fish. Crab nets were checked before leaving. Both crab nets contained one samoan crab each.

13:10 Field crew mobilizes to rocky near shore area and rig up fishing poles with sugi line to catch crabs

13:20 Field conditions. Sunny with light trade winds, temperature at approximately 85° F. waters are flat.

14:40 Crab net from south muliwai pulled, empty. Minnow traps contained mosquito fish. Mosquito fish were emptied from minnow traps, traps were re-baited and redeployed

14:55 North muliwai. Crab traps were pulled up ~~of~~ empty. Minnow traps contained juvenile akupa. Minnow traps were rebaited and redeployed.

15:05 Tetra Tech team break down sample station and load equipment into vehicles

"Rite in the Rain" ALL-WEATHER WRITING PAPER

Sept 29, 2009

Salinity

South Muliwai (Makai) 10:45

DO 3.91 mg/L

% Sat 52

Salinity 3.5 ppt

Temperature - 29.1°C

Cond. 6.45 uS/cm

South Muliwai (Mauka) I)

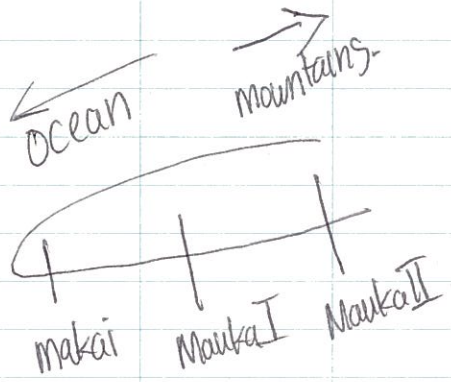
DO 2.91 mg/L

% Sat 39.8

Salinity 3.4 ppt

Temperature 28.1°C

Cond. 6.7 mS/cm



South Muliwai Mauka II 10:53am

DO 2.30 mg/L

% Sat 31

Salinity 3.4 ppt

Temperature 28.1°C

Cond 6.6 uS/cm

1535 Tetra Tech team leaves south muliwai area

1545 Tetra Tech team returns to Range Control to return gate keys and radio.

15:46 Team leaves site.

Sept 29, 2008

Photo Log

100-3263		Salinity monitor being deployed. Facing NW	Time 10:35
100-3264		Crab trap being deployed at south muliwai. Facing NW	Time 10:36
100-3265	10:36	Same. Crab trap being deployed with Kahala as bait. Facing NW	
100-3266	10:36	Minnow trap being deployed in ~~fort~~ south muliwai. Facing NW	
100-3267	10:39	Second set of crab traps and minnow traps being deployed in South muliwai. This location is NW of the first set of traps deployed.	
100-3268	10:51	Minnow trap being deployed at north muliwai. Facing south	
100-3269	10:5~~0~~53	North muliwai. Facing east	
100-3270	10:53	Crab trap being deployed. Facing east.	
100-3271	10:54	Second minnow trap being deployed east end of north muliwai. Facing east	
100-3272	10:59	Second crab trap being deployed at north east end of north muliwai. Facing east.	
100-3273	11:13	Crab traps. 5 gallon bucket with bait. Passive method.	
100-3274	11:21	Harvesting Helmet urchins at, near shore rocky area. Facing East	
100-3275	11:24	Picture of the helmet urchins	
100-3276	11:27	Picture of 5 gallon bucket passive crab trap, rocky near shore area	
100-3277	~~10~~ 11:34	Picture of 'a'ama crab, caught by hand. in rocky near shore area.	
100-3278	~~10~~ 11:49	Field crew processing samples.	
100-3279	1206	Net being used to catch rock crab in rocky near shore area. Facing SE.	
100-3280	1208	Net being used to catch rock crab in rocky near shore area. Facing NE.	
100-3281	1233	1st minnow trap at south muliwai contained mosquito fish	
100-3282	12:30	Akupa at south muliwai in second minnow trap.	
100-3283	12:30	Akupa from minnow trap	
100-3284	12:46	1st minnow trap at north muliwai contained akupa only	
100-3285	12:46	Non fused pectoral fins of akupa from North muliwai.	
100-3286	12:50	Second crab trap at north muliwai. Bait is missing	
100-3287	12:51	Second minnow trap at north muliwai with mosquito fish. Facing north	
100-3288	12:57	Samoan crab from 1st crab net at north muliwai	
100-3289	12:57	Samoan crab in bucket. 1st crab trap in north muli	
100-3290	13:01	Second samoan crab caught from north muliwai.	
100-3291	1326	Rocky near shore area for crab catching. Equipment being used include hook and line on a pole with a scoop net.	
100-3292	14:13	Pipi wai located at rocky near shore area	
100-~~32~~3293	14:42	First minnow trap from south muliwai being emptied of mosquito fish Facing South	
100-3294	1443	Second crab trap from ~~N~~ south muliwai pulled up empty. Facing South	
100-3295	1444	Second minnow trap from south muliwai pulled up with mosquito fish	
100-3296	1445	Minnow traps rebaited and redeployed.	
100-3297	1456	~~F~~ First crab net in north muliwai pulled up empty. Facing south.	
100-3298	1458	Second crab net in north muliwai pulled up empty. Facing south east	
100-3299	1500	Second minnow trap pulled up with single juvenile akupa Facing ~~N~~ south	

"Rite in the Rain" ALL-WEATHER WRITING PAPER

Field Record: Makua Shellfish Study	
Sample Processor	SUSAN CARSTENN, MAREN ANDERSON
Data Recorder	YVONNE PARRY
Additional Personnel and Duties	DAWN LLECES
Environmental Conditions	see field notes

Date	Time	Location	Species	Length/Width (cm)	Mass (g)	Composite ID	
9/29/2008	11:45	M1	COLATR	6.9	35	MNS-03	
				7.4	45		
				6.4	32		
				7.1	45		
				6.0	32		
				5.4	20		
				6.0	27		
				6.1	25		
				6.3	31		
				6.8	34		
				6.9	35		1 jar
9/29/2008	11:45	M1	COLATR	6.3	26		
				5.8	22		
				6.3	29		
				5.7	21		
				6.2	25		
				6.3	31		
				~~7.2~~ 6.5 YKP	26		
				5.6	19		
				6.3	32		
				6.6	37		
				6.5	43		
				6.0	29		
				5.9	27		
				5.2	21		2 jar