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		Near Shore at Nakua		
	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		
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-13	1.8E-12	TCDD equivalents	2.6E-15	3.8E-15	TCDD equivalents	ND	ND	TCDD equivalents	2.33E-14	6.72E-14	TCDD equivalents	3.6E-14	1.7E-13

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.

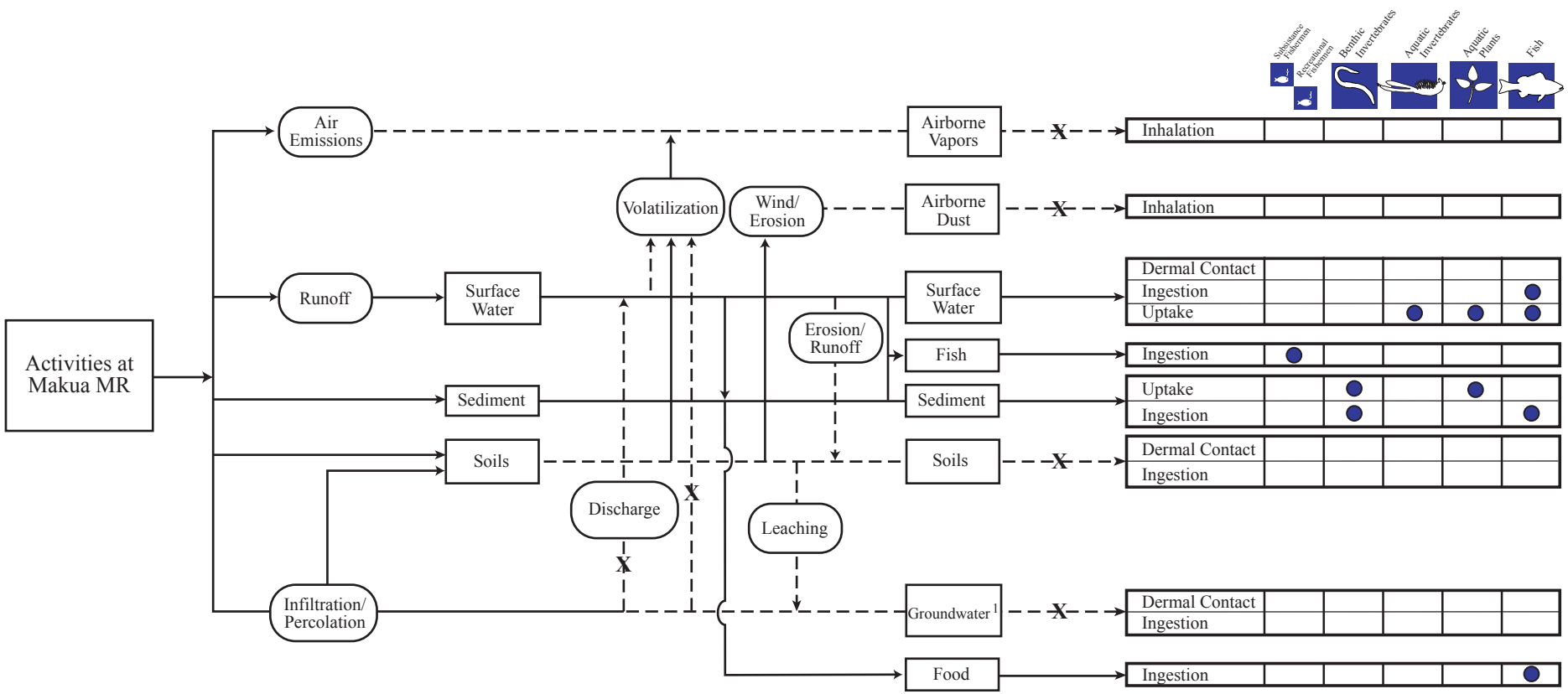
Designation of an exposure pathway as complete indicates that human exposure was possible but does not necessarily mean that exposure will occur or that exposure occurs at the levels estimated in this report. When any one of the factors is missing in a pathway, it is considered to be incomplete. Incomplete 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-11	2.40E-13	9.62E-12	8.09E-14
Total Carcinogenic Risk	1E-05	6E-06	4E-06	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-10	3.51E-13	5.49E-11	1.19E-13
Total Carcinogenic Risk	4E-05	6E-06	1E-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	2E-05	3E-05	7E-06	9E-06
Aluminum	-	-	-	-
Antimony	-	-	-	-
Arsenic, organic	-	-	-	-
Barium	-	-	-	-
BHC, alpha	8E-06	-	3E-06	-
BHC, delta	-	-	-	-
BHC, gamma	2E-06	3E-06	7E-07	1E-06
Beryllium	-	-	-	-
Bis(2-Ethylhexyl)Phthalate	1E-05	5E-07	4E-06	2E-07
Cadmium	-	-	-	-
Chromium	-	-	-	-
Cobalt	-	-	-	-
Copper	-	-	-	-
4,4'-DDT	1E-07	2E-07	3E-08	7E-08
Diethyl phthalate	-	-	-	-
di-n-Butylphthalate	-	-	-	-
Heptachlor	5E-06	8E-06	2E-06	3E-06
Heptachlor epoxide	3E-05	2E-05	1E-05	6E-06
Iron	-	-	-	-
Lead	-	-	-	-
m,p-Xylenes	-	-	-	-
Manganese	-	-	-	-
Mercury	-	-	-	-
Methyl mercury	-	-	-	-
Nitroglycerin	2E-06	-	6E-07	-
Perchlorate	-	-	-	-
RDX	4E-06	-	1E-06	-
Selenium	-	-	-	-
Silver	-	-	-	-
Thallium	-	-	-	-
Vanadium	-	-	-	-
Zinc	-	-	-	-
TCDD equivalents	-	3E-12	-	1E-12
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	3E-06	-	1E-06	-
Perchlorate	-	-	-	-
RDX	4.E-06	-	1.E-06	-
Selenium	-	-	-	-
Silver	-	-	-	-
Thallium	-	-	-	-
Vanadium	-	-	-	-
Zinc	-	-	-	-
TCDD equivalents	-	2.E-11	-	5.E-12
Total Carcinogenic Risk	2.E-04	1.E-04	7.E-05	4.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.

This page intentionally left blank.