SECTION 5
ECOLOGICAL RISK ASSESSMENT

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

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

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

Problem Formulation

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

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

Analysis

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

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

Risk Characterization

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

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

5.1 GUIDANCE

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

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

5.1 PROBLEM FORMULATION

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

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

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

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

5.2 AREAS OF CONCERN

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

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

5.3 CHEMICALS OF POTENTIAL ECOLOGICAL CONCERN

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

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

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

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

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

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

5.3.1 Data Review

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

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

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

Evaluation of Sediment Samples

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

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

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

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

Background Comparisons

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

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

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

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

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

Evaluation of Tissue Samples

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

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

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

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

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

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

5.3.2 Chemicals of Potential Concern in the North Muliwai at MMR

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

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

5.3.3 Chemicals of Potential Concern in the South Muliwai at MMR

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

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

5.3.4 Chemicals of Potential Concern in the Nearshore Habitat off MMR

Sediments were not collected from the nearshore habitat off MMR.

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

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

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

5.4 Assessment Endpoints and Measures

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

Table 5-1(a)
Sediment COPECs

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

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

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

Table 5-1(c)
Shellfish Tissue COPECs

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

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

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

5.4.1 Assessment Endpoints

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

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

5.4.2 Measures

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

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

5.5 ECOLOGICAL CONCEPTUAL SITE MODEL

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

5.5.1 Identification of Receptors

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

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

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

The representative ecological receptors selected for the ERA areas follows:

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

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

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

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

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

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

5.5.2 Exposure Pathway Inclusion/Exclusion

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

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

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

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

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

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

5.6 ANALYSIS

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

5.6.1 Exposure Assessment

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

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

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

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

5.6.2 Exposure Profile

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

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

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

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

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

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

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

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

5.6.3 Exposure Point Concentrations

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

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

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

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

5.6.4 Effects Assessment

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

5.6.5 Toxicity Benchmarks and TRVs

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

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

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

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

Selection of Studies

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

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

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

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

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

Shellfish TRVs were selected from studies satisfying the following criteria:

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

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

Table 5-2
Toxicity Reference Values for Benthic Invertebrates

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

Notes:

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

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

A dash indicates the absence of an applicable TRV.

Source: Buchman (1999).

Table 5-3
Shellfish Tissue-Based Toxicity Reference Values

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

Table 5-3
Shellfish Tissue-Based Toxicity Reference Values

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

Definitions:

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

Notes:

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

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

Table 5-4
Fish Tissue-Based Toxicity Reference Values

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

Definitions:

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

Notes:

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

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

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

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

5.7 RISK CHARACTERIZATION

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

5.7.1 Risk Estimation

Hazard Quotient and Other Lines of Evidence

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

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

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

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

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

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

Ecological Significance of Potential Risks

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

Risk Estimates

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

5.8 POTENTIAL ECOLOGICAL RISKS

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

5.8.1 Potential Risks at the North Background Area

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

Potential Risks to Benthic Invertebrates

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

5.8.2 Potential Risks at the South Background Muliwai

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

Potential Risks to Benthic Invertebrates

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

Table 5-5
North and South Background Muliwai Sediment

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

Definitions:

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

Notes:

A dash indicates the absence of an applicable TRV.

5.8.3 Potential Risks at the Nanakuli Background Muliwai

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

Potential Risks to Shellfish

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

Potential Risks to Fish

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

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

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

5.8.4 Potential Risks at the Nearshore at Sandy Beach Background Site

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

Potential Risks to Shellfish

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

Potential Risks to Fish

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

Table 5-6
Nanakuli Muliwai
Shellfish Tissue

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

Definitions:

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

Notes:

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

Table 5-7
Nanakuli Muliwai
Fish Tissue

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

Definitions:

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

Notes:

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

A dash indicates the absence of an applicable TRV.

Shaded values indicate HQs greater than 1.

Table 5-8
Nearshore at Sandy Beach
Shellfish Tissue

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

Definitions:

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

Notes:

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

Table 5-9
Nearshore at Sandy Beach
Fish Tissue

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

Definitions:

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

Notes:

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

A dash indicates the absence of an applicable TRV.

Shaded values indicate HQs greater than 1.

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

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

5.8.5 Potential Risks at the North Muliwai

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

Potential Risks to Benthic Invertebrates

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

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

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

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

Potential Risks to Shellfish

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

Table 5-10
North Muliwai Sediment

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

Definitions:

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

Notes:

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

Table 5-11
North Muliwai
Shellfish Tissue

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

Definitions:

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

Notes:

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

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

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

Potential Risks to Fish

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

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

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

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

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

Table 5-12
North Muliwai
Fish Tissue

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

Definitions:

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

Notes:

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

A dash indicates the absence of an applicable TRV.

Shaded values indicate HQs greater than 1.

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

5.8.6 Potential Risks at the South Muliwai at MMR

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

Potential Risks to Benthic Invertebrates

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

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

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

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

Table 5-13
South Muliwai Sediment

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

Definitions:

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

Notes:

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

Potential Risks to Shellfish

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

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

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

Potential Risks to Fish

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

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

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

Table 5-14
South Muliwai
Shellfish Tissue

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

Definitions:

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

Notes:

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

Table 5-15
South Muliwai
Fish Tissue

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

Definitions:

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

Notes:

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

A dash indicates the absence of an applicable TRV.

Shaded values indicate HQs greater than 1.

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

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

5.8.7 Potential Risks at the Nearshore

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

Potential Risks to Shellfish (Helmet Urchins)

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

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

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

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

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

Definitions:

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

Notes:

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

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

Potential Risks to Shellfish (Kona Crabs)

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

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

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

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

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

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

Definitions:

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

Notes:

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

Potential Risks to Fish

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

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

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

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

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

5.9 HAZARD INDICES AND INCREMENTAL RISKS

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

Table 5-17
Nearshore at Makua
Fish Tissue

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

Definitions:

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

Notes:

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

Shaded values indicate HQs greater than 1.

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

5.9.1 North Muliwai

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

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

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

5.9.2 South Muliwai

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

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

Table 5-18
North Muliwai HIs
Sediment

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

Definitions:

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

Notes:

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

Table 5-19
North Muliwai HIs
Shellfish Tissue

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

Definitions:

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

Notes:

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

Table 5-20
North Muliwai HIs
Fish Tissue

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

Definitions:

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

Notes:

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

Table 5-21
South Muliwai HIs
Sediment

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

Definitions:

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

Notes:

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

Table 5-22
South Muliwai HIs
Shellfish Tissue

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

Definitions:

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

Notes:

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

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

5.9.3 Nearshore Habitat

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

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

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

5.10 UNCERTAINTY ANALYSIS

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

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

5.10.1 Uncertainties in the Exposure Assessment

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

Table 5-23
South Muliwai HIs
Fish Tissue

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

Definitions:

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

Notes:

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

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

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

Definitions:

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

Notes:

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

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

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

Definitions:

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

Notes:

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

Table 5-25
Nearshore HIs
Fish Tissue

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

Definitions:

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

Notes:

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

Uncertainty in COPEC Concentrations

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

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

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

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

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

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

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

Uncertainty in Exposures

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

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

5.10.2 Uncertainties in the Effects Assessment

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

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

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

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

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

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

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

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

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

5.11 CONCLUSIONS

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

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

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

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

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