

SECTION 3

RESULTS AND DISCUSSION

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

3.1 RESULTS OF FIELD SAMPLING

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

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

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

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

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

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

		Makua near-shore	Sandy Beach near-shore	Makua near-shore	Makua near-shore	Makua near-shore	Makua near-shore													
		Fish	Fish	Shellfish	Shellfish	Shellfish	Fish	Fish	Fish	Fish	Fish	Fish	Shellfish	Shellfish	Shellfish	Limu	Limu	Limu	Limu	
Analytical Group	Chemical	NW4	NW5	MNS-03	MNS-05	MNS-03	NW2fd	NW6	NW7	NW8	NW9	NW10	SBNS-01-A	SBNS-01-B	SBNS-01-A	NW1SW1-1	NW1SW1-1fd	NW1SW2-1	NW1SW3-1	
		SMPL	SMPL	SMPL	SMPL	QC	QC	SMPL	QC	SMPL	QC	SMPL	SMPL							
Dioxins/Furans	1,2,3,4,6,7,8-HpCDD	ND	ND	ND	ND	ND	ND	ND	ND	7.71E-07]	2.05E-07]	ND	ND	ND	7.40E-05	ND	ND	ND	ND	
	1,2,3,4,6,7,8-HpCDF	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.13E-06]	ND	ND	ND	
	1,2,3,4,7,8,9-HpCDF	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
	1,2,3,4,7,8-HxCDD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
	1,2,3,4,7,8-HxCDF	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	3.2E-07]	ND	8.90E-08]	ND	1.14E-07]	ND	
	1,2,3,6,7,8-HxCDD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.42E-07]	ND	
	1,2,3,6,7,8-HxCDF	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.3E-07]	ND	5.70E-08]	ND	ND	ND	
	1,2,3,7,8,9-HxCDD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	3.16E-07]	ND	
	1,2,3,7,8,9-HxCDF	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.3E-07]	ND	ND	ND	ND	ND	ND	
	1,2,3,7,8-PeCDD	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.72E-07]	ND	ND	ND	ND	ND	ND	ND	ND	
	1,2,3,7,8-PeCDF	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
	2,3,4,6,7,8-HxCDF	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
	2,3,4,7,8-PeCDF	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
	2,3,7,8-TCDD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
	2,3,7,8-TCDF	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	3.1E-07]	ND	ND	ND	ND	ND	
	OCDD	ND	ND	2.10E-06]	ND	8.00E-6]	ND	ND	ND	ND	ND	ND	1.2E-06]	ND	2.90E-04	ND	ND	ND	ND	
	OCDF	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.01E-06]	ND	ND	ND	
	HpCDD, total	ND	ND	-	-	ND	ND	ND	ND	1.62E-06	4.28E-07	6.58E-07	3.06E-07	-	-	1.10E-04	1.25E-06	ND	1.65E-05	3.23E-07
	HpCDF, total	ND	ND	-	-	ND	ND	ND	ND	ND	ND	2.87E-07	-	-	-	ND	1.76E-06	ND	4.58E-06	ND
	HxCDD, total	ND	ND	-	-	ND	ND	ND	ND	ND	ND	ND	ND	-	-	8.10E-06	ND	ND	1.91E-06	ND
	HxCDF, total	ND	ND	-	-	ND	ND	ND	ND	ND	ND	ND	ND	-	-	ND	8.90E-08	ND	4.30E-07	ND
	PeCDD, total	ND	ND	-	-	ND	ND	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	ND	ND
	PeCDF, total	ND	ND	-	-	ND	ND	ND	ND	ND	ND	ND	ND	-	-	ND	ND	ND	ND	ND
	TCDD, total	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.9E-07]	ND	ND	ND	ND	ND	ND	ND
	TCDF, total	ND	ND	4.00E-07]	ND	ND	ND	ND	ND	ND	2.47E-07	ND	ND	3.9E-07]	ND	ND	ND	ND	ND	ND
Volatiles																				
	Acetone	ND	0.27]	-	-	-	-	0.23]	0.6]	ND	0.28]	0.34]	-	-	-	ND	-	ND	ND	
	Benzene	ND	ND	-	-	ND	-	ND	ND	ND	ND	ND	-	-	ND	ND	-	ND	ND	
	Ethylbenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
	Styrene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
	Toluene	ND	ND	ND	ND	0.0011]	ND	0.00089	ND	ND	ND	ND								
	1,2,4-Trimethylbenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
	m,p-Xylenes	ND	ND	ND	ND	ND	0.016]	ND	ND	0.016]	ND	ND								
	o-Xylene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
Semi-volatiles																				
	bis(2-ethylhexyl)phthalate	2.8	0.055]	ND	ND	ND	ND	ND	ND	ND	ND	0.049]	ND	ND	ND	ND	ND	ND	0.086]	
	Diethyl phthalate	ND	ND	ND	ND	ND	ND	0.019]	ND	ND	0.018]	ND	ND	ND	ND	ND	ND	ND	ND	
	Dimethyl phthalate	ND	ND	-	-	-	ND	ND	ND	ND	ND	-	-	-	-	ND	ND	ND	ND	
	Di-n-butylphthalate	0.031]	0.046	ND	ND	ND	0.61]	0.047	0.038]	0.043	0.014]	0.053	ND	ND	ND	0.02]	0.48]	0.02]	0.024]	
	Di-n-octylphthalate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
	Pentachlorophenol	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
	Pyrene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
Organochlorine pesticides																				
	Aldrin	0.0024	ND	ND	ND	0.0011]	ND	ND	ND	ND	ND	0.0064	ND	ND	ND	ND	ND	0.00035]P	ND	
	BHC, alpha	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
	BHC, beta	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.00036]P	ND	
	BHC, delta	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
	BHC, gamma	ND	0.0054P	ND	ND	ND	ND	0.0025P	0.0019	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
	4,4'-DDT	ND	ND	ND	ND	ND	ND	ND	ND	0.0021]	0.0019]	ND	ND	ND	ND	ND	ND	ND	ND	
	Heptachlor	ND	0.0056	ND	ND	ND	ND	ND	0.0057	0.0045	ND	ND	ND	ND	ND	0.00068]	ND	0.00041]	0.00072]	
	Heptachlor epoxide	0.0032	0.0025P	ND	ND	ND	0.0076]	ND	0.0028	ND	0.003]	0.0052P	ND	ND	ND	ND	ND	0.00088]P	ND	
Explosives																				
	2,4-Dinitrotoluene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
	Nitroglycerin	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
	Perchlorate	ND	ND	1.05	ND	ND	0.01]	ND	ND	ND	0.11	ND	ND	ND	ND	0.052	ND	ND	0.011	
	RDX	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.38P	ND	ND	
Metals																				
	Aluminum	6.8	8.9	102	30	72	15.6	3.8	9.1	12.6	4.720	14.9	50.9	61.8	39.4]	1,120	337	172	58	
	Antimony	ND	ND	ND	ND	ND	0.0259]	ND	0.05]	0.145	ND	0.04								
	Arsenic	23.9	24.6	1.2]	26.4	0.47]	6.17	53	6.62	5.13	4.52	36.6	1.2]	1.2]	ND	55.4	109	4.56	96	
	Barium	0.46	0.97	2.3	1.4	1.1	7.58	1.51	1.66	7.98	14.2	0.96	1.6	1.5	1.3	10.9	13.3	1.48	10.2	
	Beryllium	ND	ND	ND	ND	ND	ND	ND	ND	0.069	ND	ND	ND	ND	0.062]	0.02	0.00559]	0.004]	ND	
	Cadmium	0.13	0.14	ND	2	ND	0.132	0.2	0.09	0.1	0.04	0.09	ND	ND	ND	0.17	0.265	0.28	0.26	
	Chromium	0.8	10.4	1.2]	1.2]	1.2]	1.49	2.7	4.9	1.2	31.7	0.7	0.92]	1.2]	1.1	6	1.59	0.8	ND	
	Cobalt	0.107	0.176	0.23]	0.23]	0.37]	0.133	0.109	0.141	0.18	4.31	0.116	0.18]	0.14]	0.45]	1.25	0.791	0.374	0.472	

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

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

Notes:

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

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

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

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

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

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

3.2 SUMMARY OF POTENTIAL SOURCES OF CHEMICAL ANALYTICAL GROUPS

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

- Dioxins/furans;

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

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

3.2.1 Dioxins and Furans

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

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

3.2.2 Volatile Organic Compounds

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

3.2.3 Semivolatile Organic Compounds

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

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

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

3.2.4 Organochlorine Pesticides

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

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

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

3.2.5 Explosives

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

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

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

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

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

3.2.6 Metals

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

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

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

^a High detection limit for some samples.

^b All values < 2 ppb.

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

^d Early samples not tested for nitrate.

Source: Orris (2004).

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

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

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

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

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

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

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

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

3.3 ANALYTICAL RESULTS

3.3.1 Dioxins/Furans

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

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

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

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

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

3.3.2 Volatile Organic Compounds

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

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

3.3.3 Semivolatile Organic Compounds

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

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

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

3.3.4 Organochlorine Pesticides

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

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

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

3.3.5 Explosives

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

RDX was detected in one sample, NW1fd, at a concentration of 0.057 mg/kg. This result was flagged by the laboratory (STL) as an estimated (J) value, because it was below the lab reporting limit of 0.25 mg/kg. This sample is a field duplicate for sample NW1, which was

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

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

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

analyzed by APPL. RDX was not detected in NW1 at a reporting limit of 0.6 mg/kg. These data suggest that the RDX result for NW1fd reported by STL may be a false positive, and this suggestion is supported by the BCF data cited above, which would require a relatively high concentration of RDX in the ocean water to result in the concentration of RDX detected in the fish tissue sample.

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

3.3.6 Metals

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

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

Twelve of 19 metals were detected in all limu samples, at concentrations ranging from less than 0.1 mg/kg (thallium) to greater than 1,860 mg/kg (iron). Flegal et al. (1986) found concentrations of thallium in marine plankton similar to those found at Mākua (0.02 to 0.8 mg/kg) in the central Pacific. In the Black Sea of Turkey, Tuzen et al. (2008) found concentrations of iron ranging from 99 to 3,949 in marine algae, similar to those concentrations found at Mākua (67.4 to 1,860 mg/kg). Arsenic was detected in limu in concentrations ranging from 4.56 to 109 mg/kg. These concentrations are comparable to concentrations found in marine algae in pristine regions of Antarctica, ranging from 5.8 to 152 mg/kg (Farias et al. 2007).

**Table 3-5
Summary Statistics for Metals in Shellfish**

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

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