Table 2-5
Muliwai Sample Location and Analyses Matrix

Sample ID		Sample Date	Depth (feet)	314.0 APCL	335.2 APCL	354.1 APCL	6010B APCL	7471A APCL	8021B APCL	8081A APCL	8151A APCL	8270C APCL	8280A Triangle	8330 APCL	8332 APCL	9045C APCL	D2216 APCL	SM4500 APCL	WBLACK APCL
BMN-01-MX-1	BMN-01	5/22/2003	1				X	X						X			X		
BMN-02-MX-1	BMN-02	5/22/2003	1				X	X						X			X		
BMN-02-MX-1-D	BMN-02	5/22/2003	1				X	X						X			X		
BMN-03-MX-1	BMN-03	5/22/2003	1				X	X						X			X		
BMS-01-MX-2	BMS-01	5/22/2003	2				X	X						X			X		
BMS-02-MX-2	BMS-02	5/22/2003	2				X	X						X			X		
BMS-03-MX-1	BMS-03	5/22/2003	1				X	X						X			X		
BMS-03-MX-1-D	BMS-03	5/22/2003	1				X	X						X			X		
DMM-01-FL-3	DMM-01	5/20/2003	3	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
DMM-02-MX-3	DMM-02	5/20/2003	3				X	X						X			X		
DMM-02-MX-3-D	DMM-02	5/20/2003	3				X	X						X			X		
DMM-03-MX-1	DMM-03	5/20/2003	1				X	X						X			X		
NMM-01-MX-1	NMM-01	5/19/2003	1				X	X						X			X		
NMM-02-MX-1	NMM-02	5/20/2003	1				X	X						X			X		
NMM-03-MX-1	NMM-03	5/20/2003	1				X	X						X			X		
NMM-04-FL-1	NMM-04	5/22/2003	1	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
NMM-05-MX-1	NMM-05	5/22/2003	1				X	X						X			X		
NMM-06-MX-1	NMM-06	5/19/2003	1				X	X						X			X		
NMM-07-MX-3	NMM-07	5/20/2003	3				X	X						X			X		
NMM-08-MX-1	NMM-08	5/20/2003	1				X	X						X			X		
NMM-09-MX-1	NMM-09	5/22/2003	1				X	X						X			X		
NMM-10-FL-1	NMM-10	5/22/2003	1	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
NMM-11-MX-2	NMM-11	5/19/2003	2				X	X						X			X		
NMM-12-FL-3	NMM-12	5/19/2003	3	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NMM-13-MX-3	NMM-13	5/19/2003	3				X	X						X			X		
NMM-14-MX-1	NMM-14	5/20/2003	1				X	X						X			X		
NMM-15-MX-1	NMM-15	5/19/2003	1				X	X						X			X		
NMM-16-FL-3	NMM-16	5/20/2003	3	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
NMM-16-FL-3-D	NMM-16	5/20/2003	3	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
NMM-17-MX-2	NMM-17	5/19/2003	2				X	X						X			X		
NMM-18-MX-3	NMM-18	5/20/2003	3				X	X						X			X		
NMM-19-MX-3	NMM-19	5/19/2003	3				X	X						X			X		
NMM-20-FL-1	NMM-20	5/19/2003	1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NMM-21-MX-3	NMM-21	5/20/2003	3				X	X						X			X		
NMM-22-MX-1	NMM-22	5/19/2003	1				X	X						X			X		
SMM-01-MX-1	SMM-01	5/20/2003	1				X	X						X			X		
SMM-02-FL-1	SMM-02	5/21/2003	1	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
SMM-03-MX-1	SMM-03	5/21/2003	1				X	X						X			X		
SMM-04-MX-1	SMM-04	5/21/2003	1				X	X						X			X		
SMM-05-MX-1	SMM-05	5/21/2003	1				X	X						X			X		
SMM-06-FL-1	SMM-06	5/20/2003	1	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
SMM-07-MX-1	SMM-07	5/20/2003	1				X	X						X			X		
SMM-08-MX-1	SMM-08	5/21/2003	1				X	X						X			X		
SMM-09-MX-1	SMM-09	5/21/2003	1				X	X						X			X		
SMM-11-MX-1	SMM-11	5/21/2003	1				X	X						X			X		
SMM-12-MX-1	SMM-12	5/21/2003	1				X	X						X			X		
SMM-13-FL-3	SMM-13	5/21/2003	3	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
SMM-13-FL-3-D	SMM-13	5/21/2003	3	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
SMM-14-FL-1	SMM-14	5/21/2003	1	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
SMM-15-MX-1	SMM-15	5/21/2003	1				X	X						X			X		
SMM-16-MX-2	SMM-16	5/21/2003	2				X	X						X			X		
SMM-17-MX-1	SMM-17	5/21/2003	1				X	X						X			X		
SMM-18-MX-2	SMM-18	5/21/2003	2				X	X						X			X		
SMM-19-MX-3	SMM-19	5/21/2003	3				X	X						X			X		

SECTION 3
ANALYTICAL RESULTS

3.1 ANALYTICAL RESULTS

All of the analytical results for this muliwai sediment sampling program are presented in the analytical tables in Appendix C. These tables are presented as one table per analytical method, except for the particle size analyses. The particle size results and graphs of these results are presented in Appendix D.

Table 3-1 presents a summary of all of the analytical results by sample area for all of the analytical methods except for the metals analyses and the particle size analyses. Table 3-2 presents a summary of the metals analyses by sample area. Below are discussions of these analytical results by their respective method.

For comparison purposes, the footers in the tables in Appendix C list the 2002 USEPA Region IX PRGs (USEPA 2002), U.S. EPA Generic Soil Screening Levels for groundwater protection (assuming DAF1 – no attenuation by the soil) (USEPA 2002); Hawai'i Tier I Soil Action Levels for areas with annual rainfall less than 200 cm/yr and assuming no drinking water source threatened (HDOH 2000), and U.S. EPA Region 5 Ecological Screening Levels for sediments (USEPA 2003). It should be kept in mind that each of these criteria have important limitations on their applicability to the conditions and environment of the study area, as discussed further below.

3.2 METALS RESULTS (USEPA METHODS 6010B AND 7471A)

Samples were analyzed by USEPA Method 6010B for aluminum, antimony, arsenic, barium, cadmium, chromium, cobalt, copper, lead, selenium, silver, vanadium, zinc. The samples were also analyzed for mercury by USEPA Method 7471A. All of the samples were analyzed for each of these metals. The results of these analyses are presented by their respective method number in the two tables in Appendix C.

Table 3-1
Summary of Analytical Results

May 19, 2003 through May 23, 2003

	Dry Muliwai	North Muliwai	South Muliwai	North Background	South Background
Metals	See Metals Summary	See Metals Summary	See Metals Summary	See Metals Summary	See Metals Summary
Explosives					
RDX	All ND	One = 230 μg/kg	All ND	All ND	All ND
BTEX					
Benzene	All ND	Two = 0.040 to 0.044 μg/kg	All ND	NA	NA
Toluene	One = 0.24 μg/kg	Six = 0.3 to 0.7 μg/kg	Four = 0.3 to 0.6 μg/kg	NA	NA
Ethylbenzene	One = 0.6 μg/kg	Four = 0.3 to 2 μg/kg	Five = 0.6 to 1 μg/kg	NA	NA
Xylenes (total)	One = 0.9 μg/kg	Four = 0.29 to 1 μg/kg	Four = 0.7 to 1.1 μg/kg	NA	NA
OC Pesticides					
4,4-DDT	All ND	One = 0.1 μg/kg	All ND	NA	NA
Chlorinated Herbicides					
Bentazon	All ND	All ND	One = 46 μg/kg	NA	NA
Pentachlorophenol	One = 2 μg/kg	All ND	One = 0.823 μg/kg	NA	NA
Picloram	All ND	All ND	One = 0.4 μg/kg	NA	NA
SVOCs					
bis(2-Ethylhexyl)-phthalate	All ND	One = 22 μg/kg	All ND	NA	NA
Pentachlorophenol	All ND	All ND	One = 230 μg/kg	NA	NA
Pyrene	All ND	All ND	One = 77 μg/kg	NA	NA
Dioxins/Furans					
1,2,3,4,6,7,8,9-OCDD	All ND	One = 0.15 μg/kg	All ND	NA	NA
2,3,7,8-TCDD	All ND	All ND	One = 0.03 μg/kg	NA	NA
Other Analytes					
Nitroglycerin	All ND	All ND	All ND	NA	NA
Perchlorate	All ND	All ND	All ND	NA	NA
Cyanide	All ND	All ND	All ND	NA	NA
Nitrite	All ND	All ND	All ND	NA	NA
Nitrate	One = 10.1 mg/kg	Six = 3.9 to 19.5 mg/kg	Five = 4.1 to 13 mg/kg	NA	NA
TOC	All ND	Three = 510 to 1990 mg/kg	Four = 560 to 3270 mg/kg	NA	NA

Notes:

1) Fifty-four sediment samples collected for metals and explosives analyses
- Four primary samples and one duplicate sample from the Dry Muliwai
- Twenty-two primary samples and one duplicate sample from the North Muliwai
- Seventeen primary samples and one duplicate sample from the South Muliwai
- Three primary samples and one duplicate sample from the North Background Mākua Site
- Three primary samples and one duplicate sample from the South Background Mākua Site

2) Twelve sediment samples collected for all additional analyses
- One primary sample and no duplicate samples from the Dry Muliwai
- Five primary samples and one duplicate sample from the North Muliwai
- Four primary samples and one duplicate sample from the South Muliwai

Table 3-2
Summary of Metals Results

Off-site Sampling in Muliwai Ponds
May 19, 2003 through May 23, 2003

	Dry Muliwai	North Muliwai	South Muliwai	North Background	South Background
	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
Aluminum	1,100 to 1,550	796 to 49,700	36 to 67,500	22,600 to 25,100	30,200 to 54,700
Antimony	0.94 to 1.80	0.67 to 3.70	0.71 to 1.20	All ND	All ND
Arsenic	5.5 to 6.4	0.26 to 5.60	0.35 to 5.30	ND to 0.15	ND to 1.5
Barium	4.2 to 5.4	3.8 to 123	3.7 to 118	109 to 186	134 to 157
Cadmium	0.038 to 0.057	0.013 to 0.130	0.019 to 0.160	All ND	All ND
Chromium	19.3 to 28.8	15.5 to 176	2.2 to 271	112 to 138	195 to 227
Cobalt	6.9 to 10.8	5.0 to 60.4	1.7 to 74.0	46.7 to 70.9	70.1 to 83.1
Copper	3.4 to 17.6	2.4 to 121	2.5 to 180	50.3 to 56.7	89.9 to 110
Lead	0.3 to 3.4	0.24 to 9.60	0.09 to 26.90	0.32 to 1.70	1.3 to 2.4
Mercury	0.014 to 0.020	0.014 to 0.080	0.008 to 0.082	0.059 to 0.064	0.052 to 0.060
Selenium	0.15 to 0.19	0.3 to 4.0	0.52 to 7.70	All ND	All ND
Silver	All ND	All ND	All ND	All ND	All ND
Vanadium	9.6 to 11.8	7.4 to 185	0.1 to 194	138 to 166	147 to 166
Zinc	11.7 to 16.7	7.6 to 142	0.8 to 188	76.5 to 86.5	103 to 125

3.2.1 Aluminum

Aluminum was found in all of 54 sediment samples. As shown on Table 3-2 and in the Method 6010B table in Appendix C, aluminum concentrations ranged from 35.6 to 67,500 mg/kg. Figure 3-1 shows the distribution frequency of the aluminum concentrations. This figure indicates a bimodal distribution in concentration above 5,000 mg/kg. Nearly half of the samples contained aluminum at concentrations of less than 5,000 mg/kg. A near normal distribution of concentrations ranges from 10,000 to 40,000 mg/kg. Nine samples contained concentrations greater than 45,000 mg/kg. Samples from the north background location fell within the lower range, while samples from the south background location generally fell within the higher range.

Aluminum is a naturally occurring constituent of the igneous rock in Hawai'i, and it (along with several other metals) tends to be concentrated in Hawai'ian and other tropical soils. However, none of the samples collected from any of the areas contained concentrations of aluminum greater than the residential soil PRG of 76,000 mg/kg.

3.2.2 Antimony

Antimony was found in 25 of the 54 sediment samples collected during this program. As shown on Table 3-2 and in the Method 6010B table in Appendix C, the detected antimony concentrations ranged from 0.67 to 3.7 mg/kg, and the other 29 samples did not contain concentrations of antimony greater than the approximate detection limit of 0.26 mg/kg. Figure 3-2 shows the distribution frequency of the antimony data. This figure shows a rapid decrease in the frequencies from 0.0 to 2.0 mg/kg, and three potential high-outlying concentrations greater than 3.0 mg/kg and less than 4.0 mg/kg. All of the background samples contained nondetect concentrations of antimony, and all three of the highest concentrations of antimony were from samples collected at the north muliwai pond.

None of the samples collected from any of the areas contained concentrations of antimony greater than the residential noncancer soil PRG of 31 mg/kg.

3.2.3 Arsenic

Arsenic was found in 35 of the 54 sediment samples collected during this program. As shown on Table 3-2 and in the Method 6010B table in Appendix C, the detected arsenic concentrations ranged from 0.15 to 6.4 mg/kg. Arsenic was not detected above the approximate detection limit of 0.15 mg/kg in the other 19 samples. Figure 3-3 shows the distribution frequency of the arsenic data. This figure shows a nearly normal distribution of detected concentrations between 2.0 and 7.0 mg/kg. All of the sediment samples collected from the background areas were less than 2.0 mg/kg

The 2002 USEPA Region IX PRGs for arsenic distinguish between cancer and non-cancer endpoints, because arsenic presents both a toxic and a carcinogenic risk depending on mode of exposure. None of the samples contained concentrations of arsenic greater than the 2002 residential noncancer soil PRG of 22 mg/kg (US EPA

Figure 3-1
Aluminum - 54 detects, 0 non-detects
Makua Muliwai Sampling May 2003

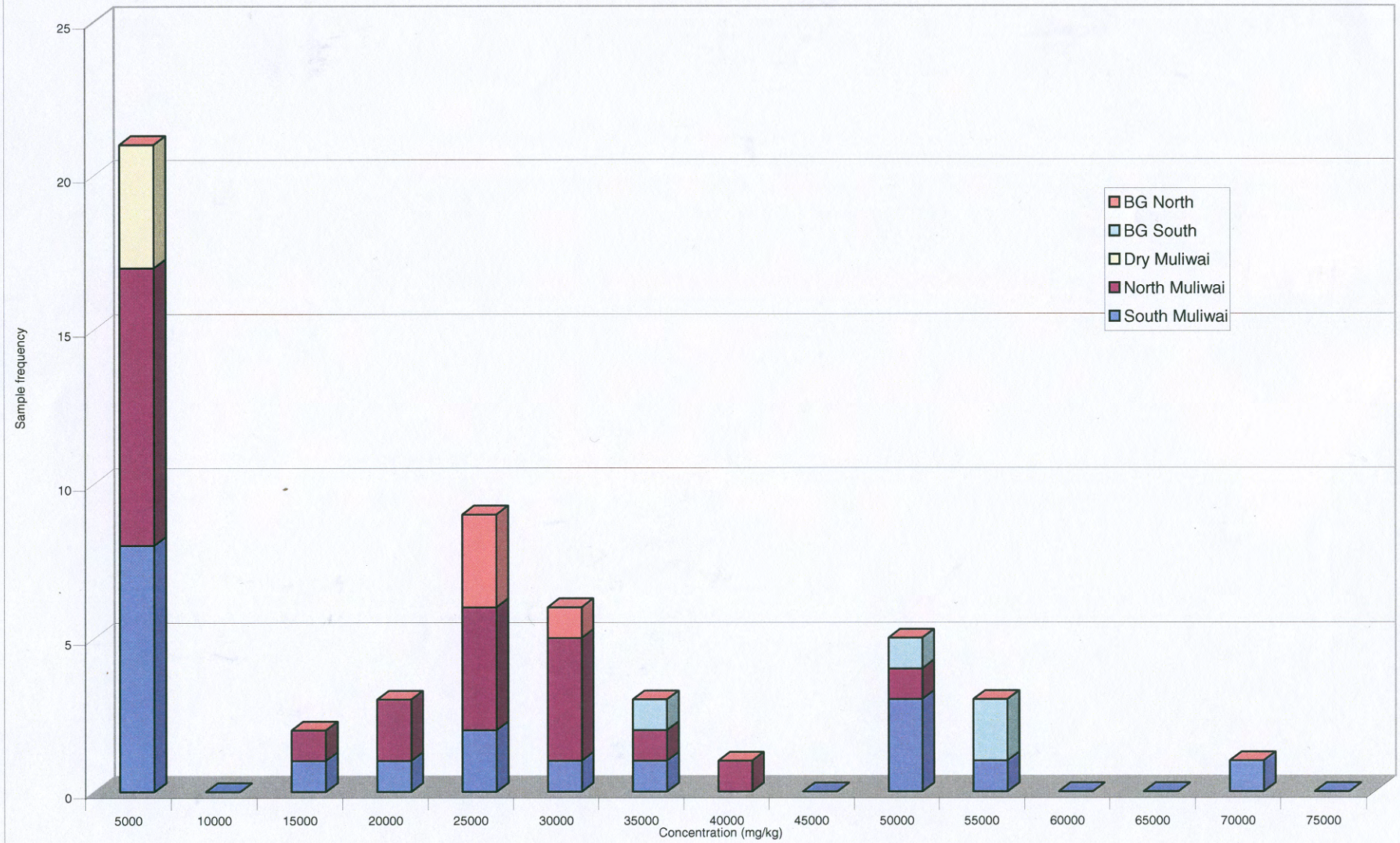


Figure 3-2
Antimony - 25 detects, 29 non-detects
Makua Muliwai Sampling May 2003

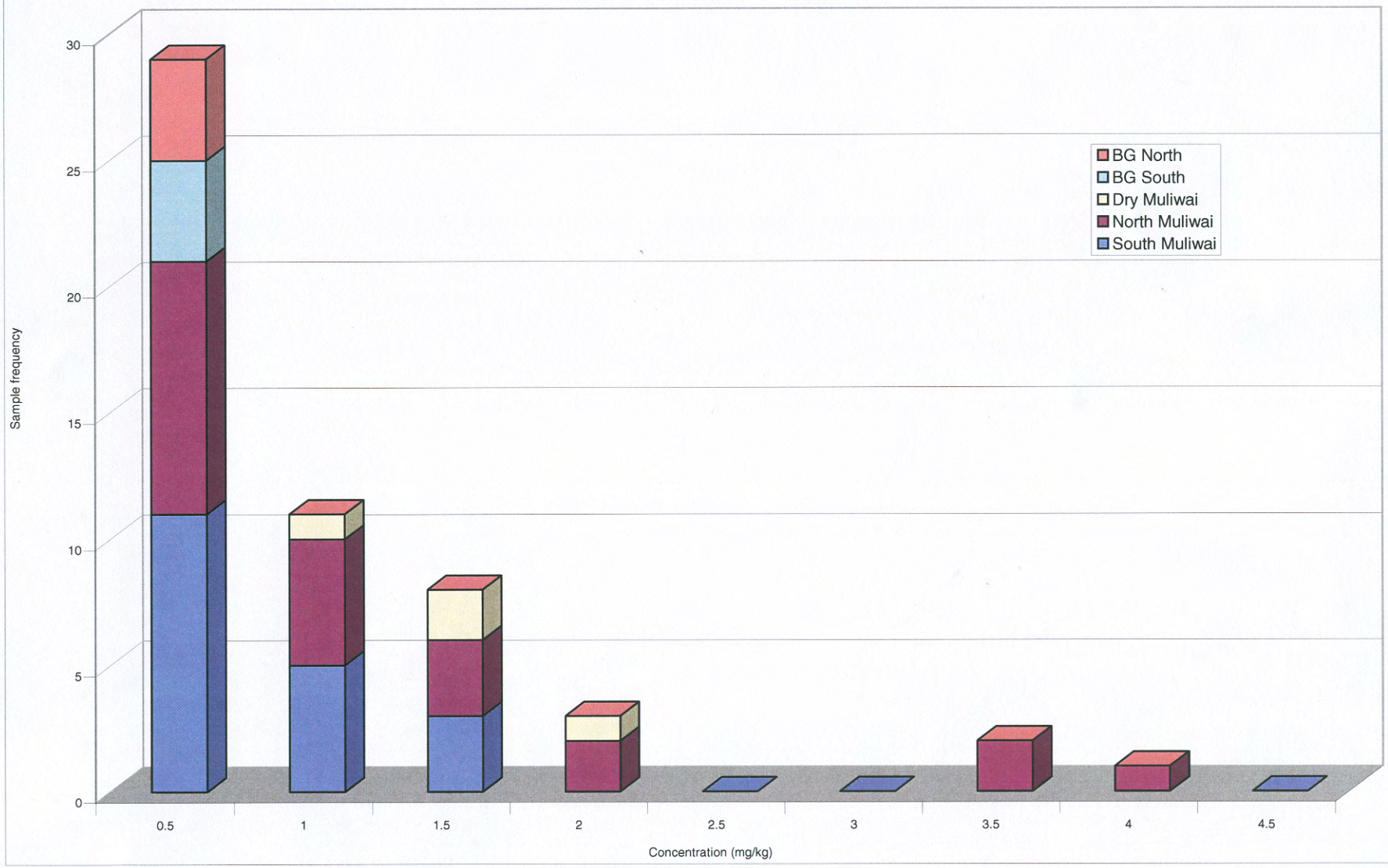
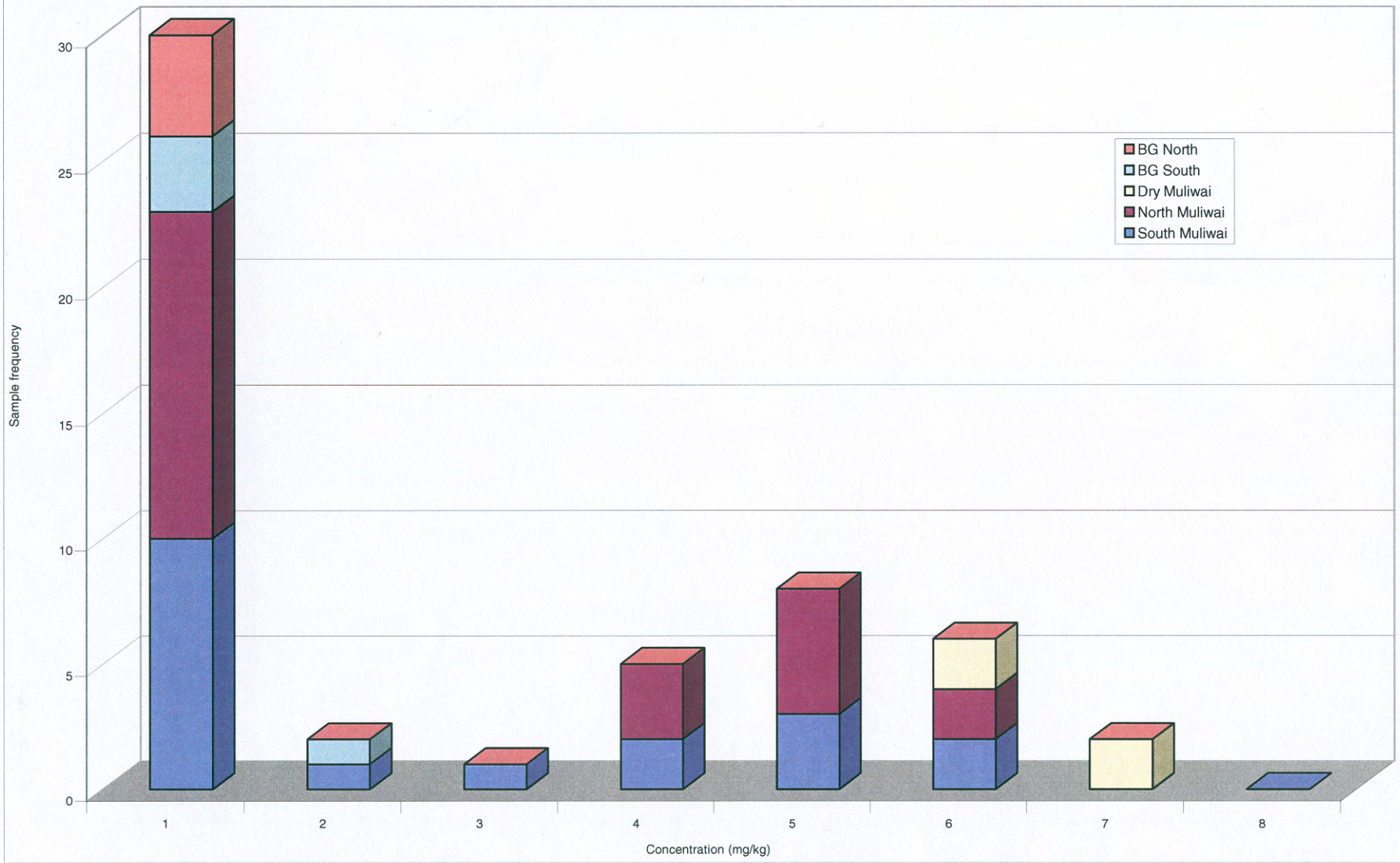


Figure 3-3
Arsenic - 35 detects, 19 non-detects
Makua Muliwai Sampling May 2003



2002). However, of the 35 samples with detectable arsenic, 29 samples contained concentrations greater than the residential cancer soil PRG of 0.39 mg/kg, and 23 of these samples contained concentrations greater than the industrial cancer soil PRG of 1.6 mg/kg. Two of the samples that contained concentrations of arsenic greater than the residential cancer soil PRG were collected from the south background area.

3.2.4 Barium

Barium was found in all of 54 sediment samples collected during this program. As shown on Table 3-2 and in the Method 6010B table in Appendix C, these barium concentrations ranged from 3.7 to 186 mg/kg. Figure 3-4 shows the distribution frequency of the barium data. Nearly half of the samples contained barium at concentrations of less than 25 mg/kg with the remaining sample frequencies distributed to a maximum of less than 200 mg/kg. The six samples with the greatest barium concentrations were collected from the north and south background areas.

None of the samples collected from any of the areas contained concentrations of barium greater than the residential soil PRG of 5,400 mg/kg.

3.2.5 Cadmium

Cadmium was found in 33 of the samples. As shown on Table 3-2 and in the Method 6010B table in Appendix C, the detected cadmium concentrations ranged from 0.013 to 0.16 mg/kg. Twenty one samples did not contain concentrations of cadmium greater than the approximate detection limit of 0.016 mg/kg. Figure 3-5 shows the distribution frequency of the cadmium data. Nearly half of the muliwai samples contained cadmium at concentrations of less than 0.025 mg/kg, with the remaining sample frequencies distributed to a maximum of less than 0.175 mg/kg. None of the samples from the background areas contained detectable concentrations of cadmium.

None of the samples collected from any of the areas contained concentrations of cadmium greater than the residential soil PRG of 37 mg/kg. The Hawaii Tier I soil Action Level is 38 mg/kg. The U.S. EPA Region 5 ESL for cadmium in sediments is 0.99 mg/kg. None of the sample results exceeded this level.

3.2.6 Chromium

Chromium was found in all samples collected during this program. As shown on Table 3-2 and in the Method 6010B table in Appendix C, the chromium concentrations ranged from 2.2 to 271 mg/kg. Figure 3-6 shows the distribution of the chromium data. Nearly half of the samples contained chromium at concentrations of less than 50 mg/kg with the remaining concentrations distributed to a maximum of less than 300 mg/kg. Three of the five samples with the greatest chromium concentrations were collected from the south background area, and all of the samples collected from the background areas contained chromium at concentrations greater than 100 mg/kg.

Figure 3-4
Barium - 54 detects, 0 non-detects
Makua Muliwai Sampling May 2003

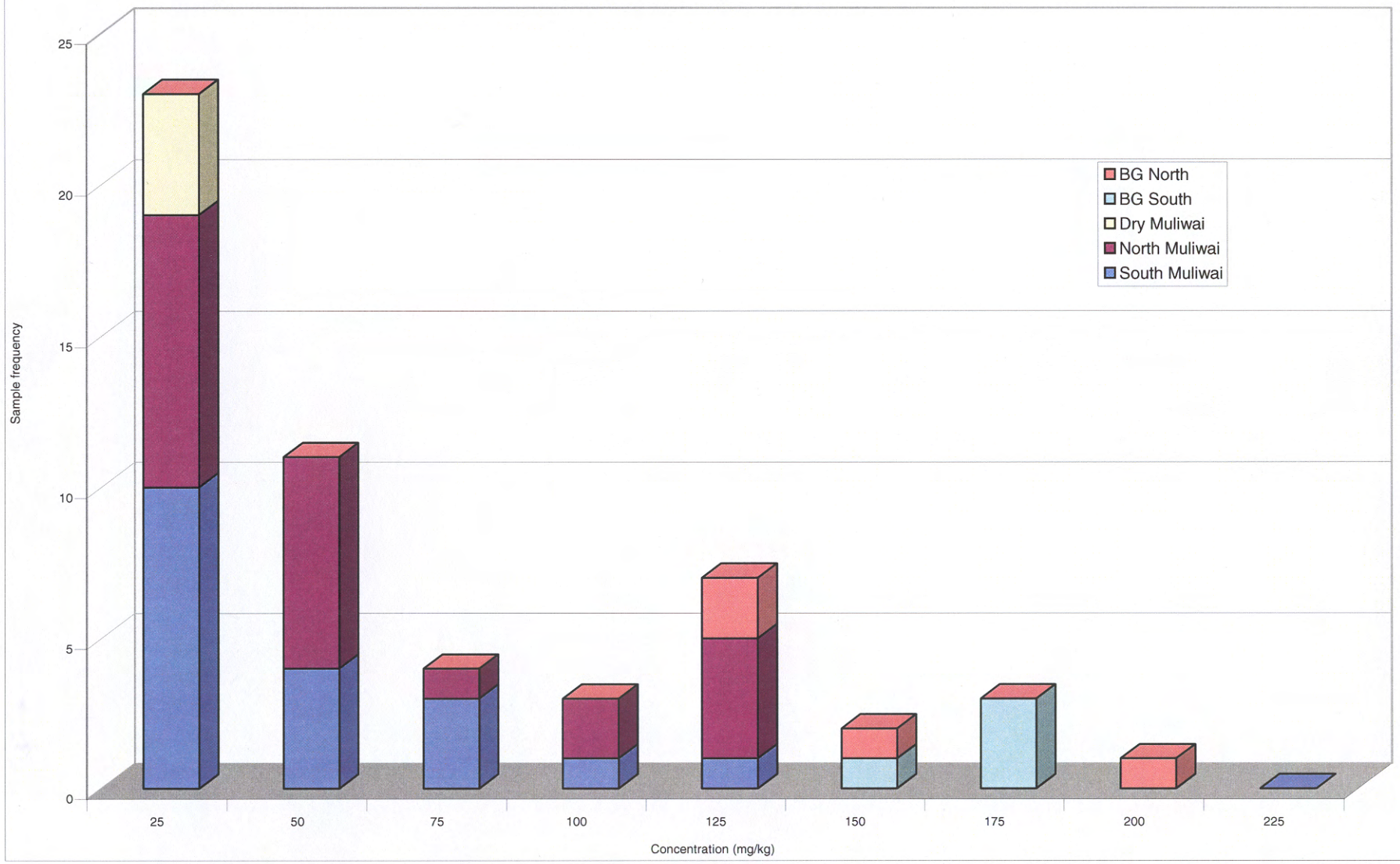


Figure 3-5
Cadmium - 33 detects, 21 non-detects
Makua Muliwia Sampling May 2003

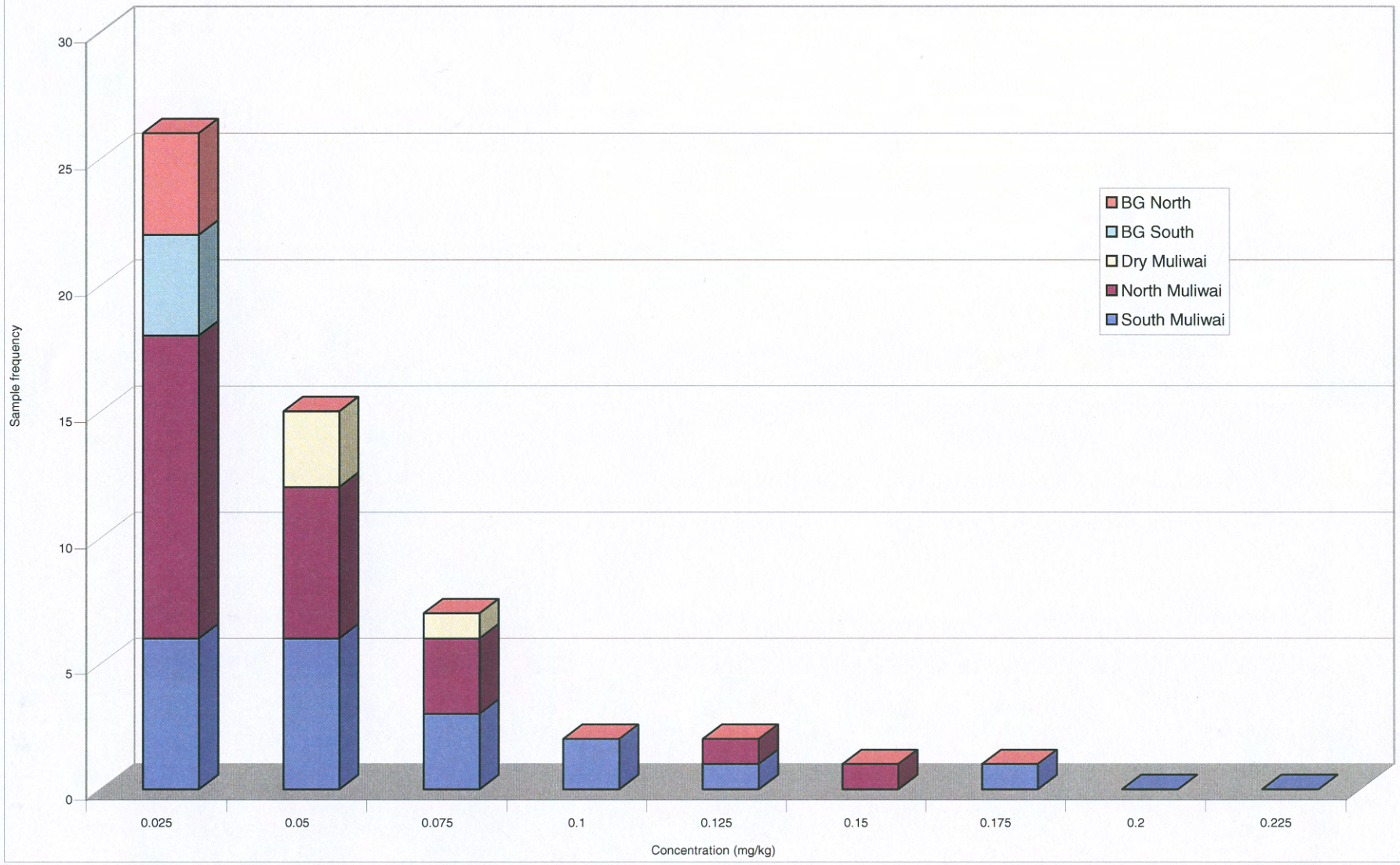
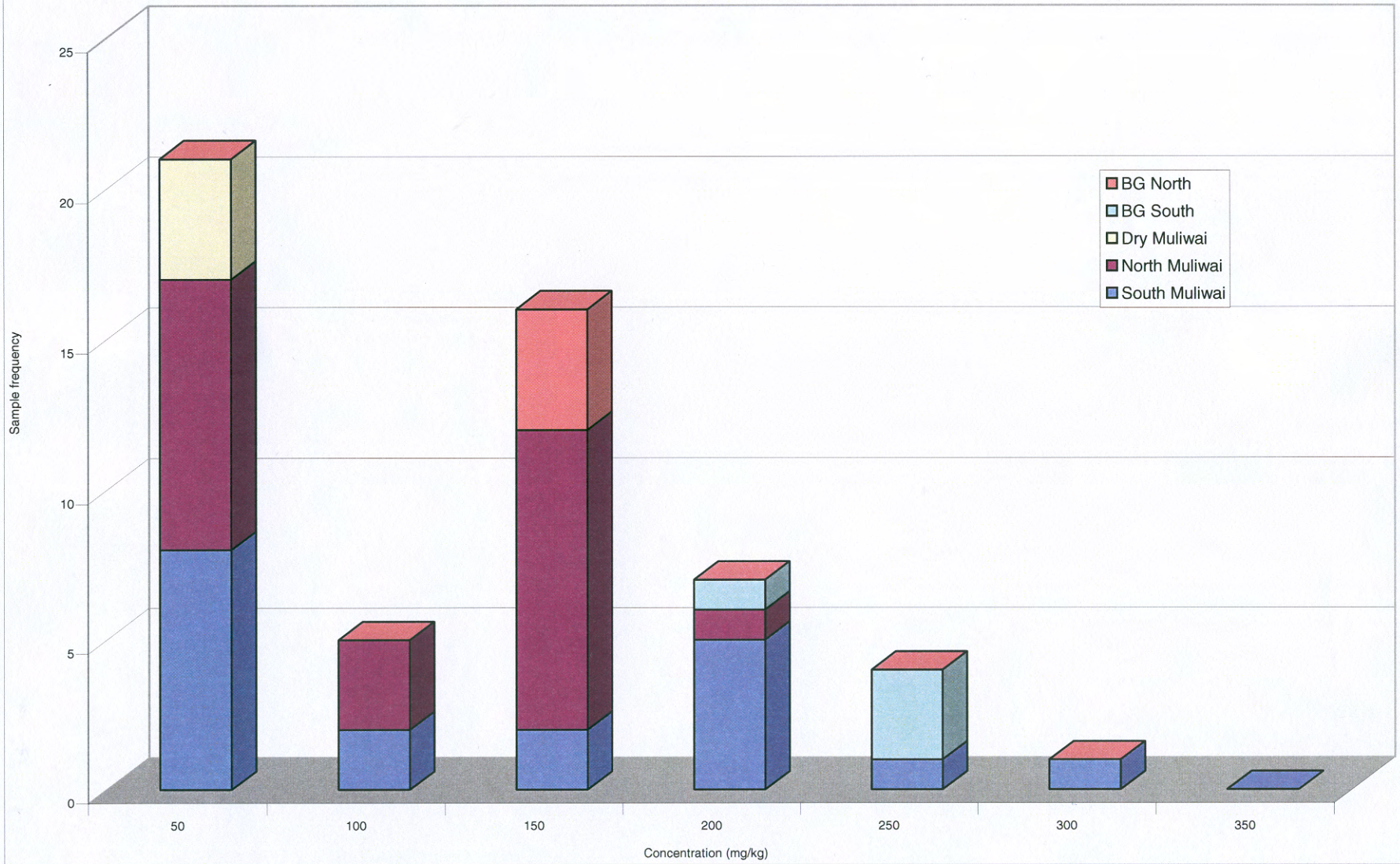


Figure 3-6
Chromium - 54 detects, 0 non-detects
Makua Muliwai Sampling May 2003



USEPA Region IX identifies PRGs for both non-cancer and cancer endpoints for chromium. The cancer endpoint is associated with hexavalent chromium (chromium VI), which is a soluble form of chromium that is favored by conditions of high pH (basic rather than acidic). The cancer PRGs for total chromium assume a mixture of chromium "VI" and the more common from, chromium "III" in a ratio of one-to-six. None of the samples collected from any of the areas contained concentrations of chromium greater than the total chromium industrial cancer soil PRG of 450 mg/kg, but four samples contained concentrations greater than the residential cancer soil PRG of 210 mg/kg. Two of these four samples exceeding the residential cancer soil PRG were collected from the south background area and all of the samples from the north background area contained concentrations of chromium between 110 and 140 mg/kg. Thus, the chromium concentrations in the muliwai samples do not appear to be significantly different from the background concentrations.

3.2.7 Cobalt

Cobalt was found in all of the 54 sediment samples collected during this program. As shown on Table 3-2 and in the Method 6010B table in Appendix C, the concentrations ranged from 1.7 to 83.1 mg/kg. Figure 3-7 shows the distribution of the cobalt data. Nearly one-third of the samples contained cobalt at concentrations of less than 10 mg/kg, with the remaining sample frequencies distributed to a maximum of less than 90 mg/kg. Five of the six samples with the highest cobalt concentrations were collected from the north and south background areas, and all of the samples collected from the background areas contained cobalt at concentrations greater than 40 mg/kg. Thus, cobalt concentrations in the muliwai samples do not appear to be higher than background concentrations.

None of the samples collected from any of the areas contained concentrations of cobalt greater than the residential soil PRG of 900 mg/kg. The U.S. EPA Region 5 ESL for cobalt in sediment is 50 mg/kg. This level was exceeded in 12 of the samples. Most of the background muliwai samples contained concentrations above the Region 5 ESL. Cobalt is a trace constituent of igneous rocks. The background range of cobalt in Hawaiian soils is above 50 mg/kg (Halbig et al 1985), and the 95 percent upper confidence limit for the concentration in surface soil samples on the Makua installation is 71 mg/kg (WES 2004). Therefore, the concentrations observed in the muliwai sediments likely are due to natural, rather than man-made sources.

3.2.8 Copper

Copper was found in 53 of the 54 sediment samples collected during this program. As shown on Table 3-2 and in the Method 6010B table in Appendix C, the detected copper concentrations ranged from 2.4 to 121 mg/kg. The one remaining sample did not contain copper at a concentration greater than the detection limit of 0.12 mg/kg. Figure 3-8 shows the distribution of the cadmium concentration. Nearly half of the samples contained copper at concentrations of less than 25 mg/kg with the remaining sample frequencies distributed to a maximum of less than 125 mg/kg. Two of the five samples with concentrations of copper greater than 100 mg/kg were collected from the south

Figure 3-7
Cobalt - 54 detects, 0 non-detects
Makua Muliwai Sampling May 2003

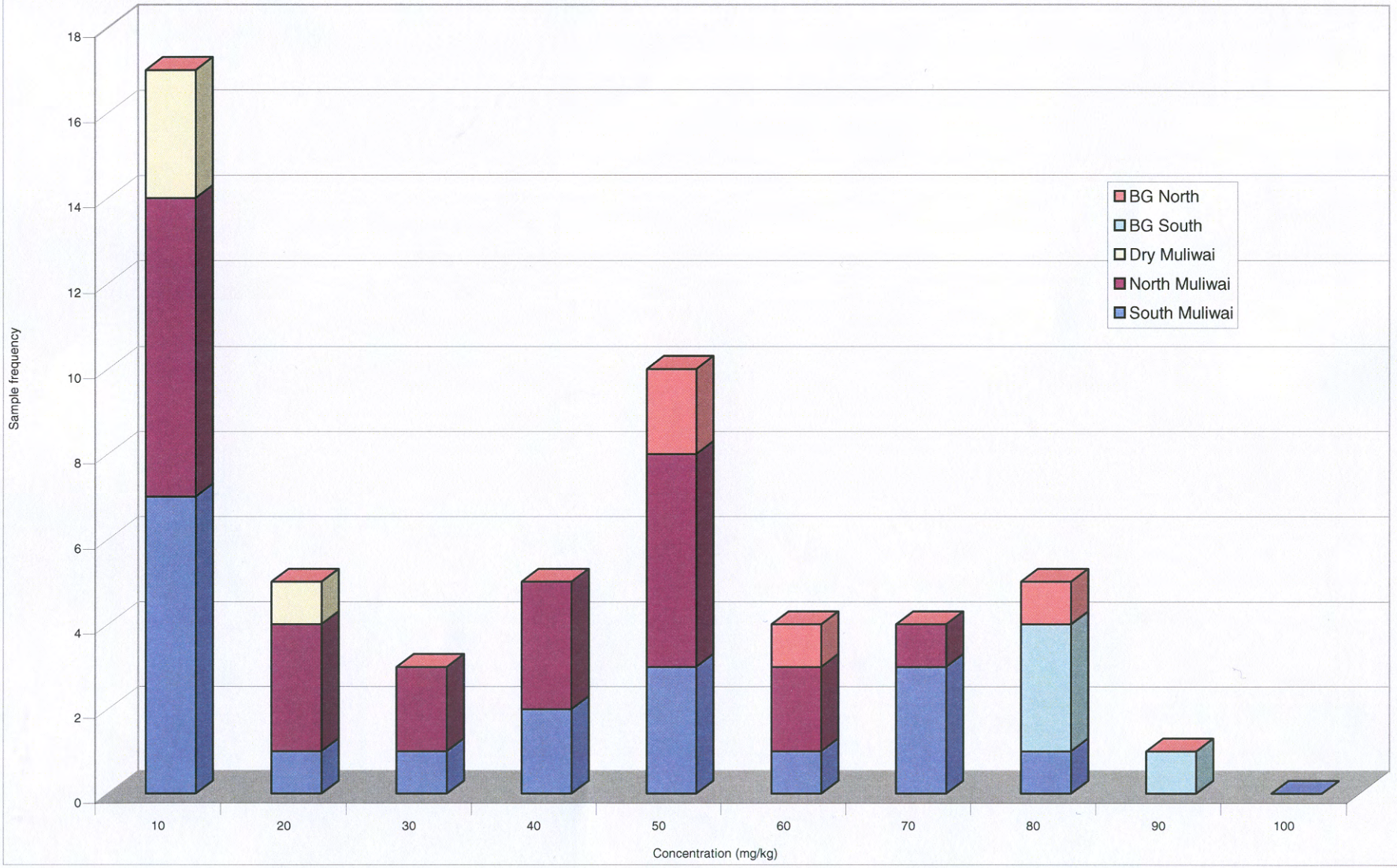
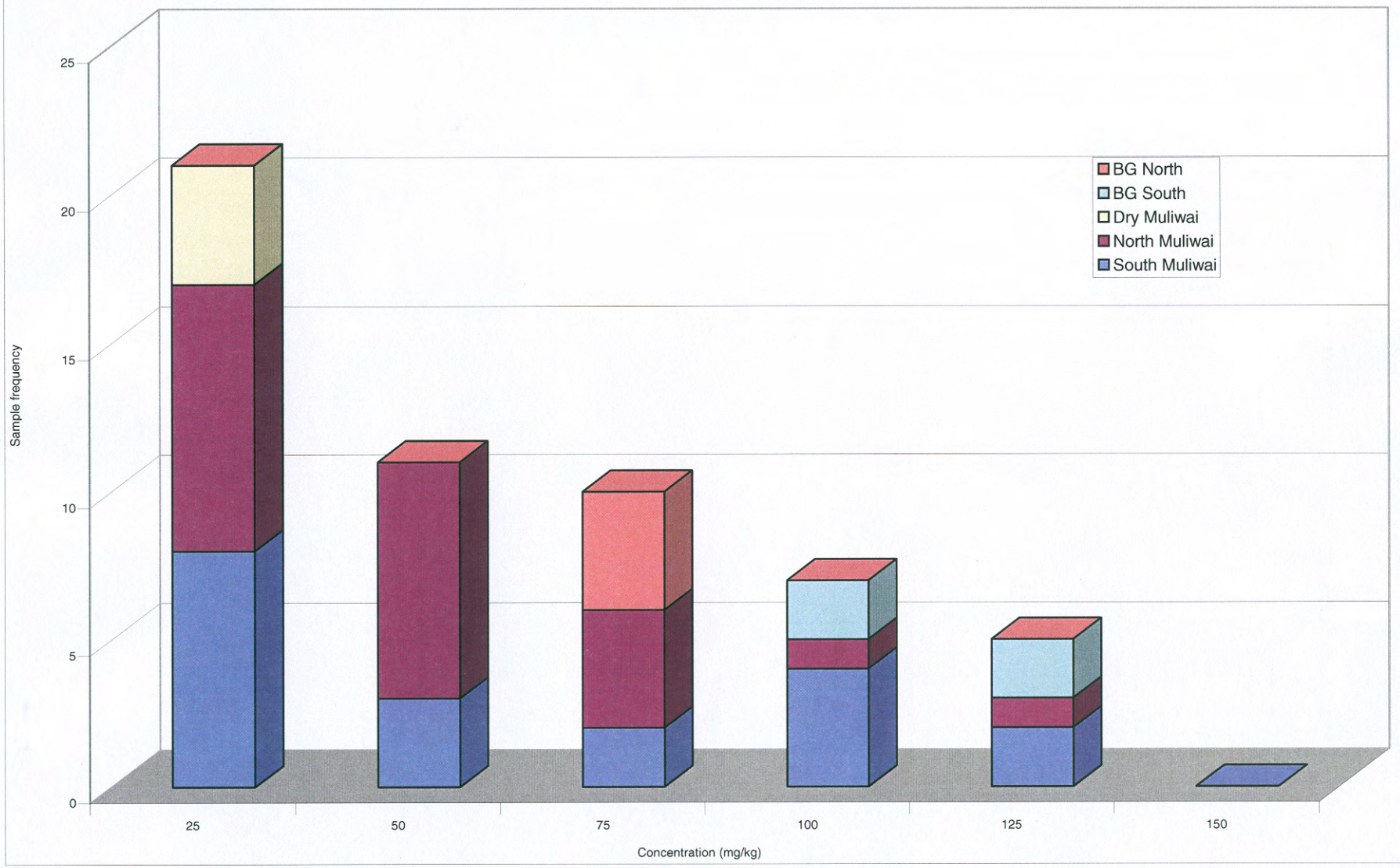


Figure 3-8
Copper - 53 detects, 1 non-detects
Makua Muliwai Sampling May 2003



background area, and all of the samples collected from the background areas contained copper at concentrations greater than 50 mg/kg. Thus, concentrations of copper in the muliwai samples appear to be within the range of background concentrations.

None of the samples collected from any of the areas contained concentrations of copper greater than the residential soil PRG of 3,100 mg/kg. The Region 5 ESL for copper is 31.6 ppm. The copper concentrations in 30 of the 51 samples analyzed (including duplicates and background samples) exceeded the Region 5 ESL. It is noteworthy that the background muliwai sediments contained some of the highest concentrations of copper. The concentrations in the muliwai sediments are within the range of concentrations observed in surface soils within the Makua installation.

3.2.9 Lead

Lead was detected in 32 of the 54 sediment samples collected during this program. As shown on Table 3-2 and in the Method 6010B table in Appendix C, the detected lead concentrations ranged from 0.087 to 26.9 mg/kg, and the other 22 samples did not contain concentrations of lead greater than the approximate detection limit of 0.051 mg/kg. Figure 3-9 shows the distribution of the lead concentrations. This figure shows that all but one of the samples contained lead concentrations of less than 10 mg/kg; one sample contained 26.9 mg/kg collected from the south muliwai.

None of the samples collected from any of the areas contained concentrations of lead greater than the residential soil PRG of 400 mg/kg.

The Hawai'i Tier I Soil Action Level for lead in soils is the same as the Region IX residential soil PRG (400 mg/kg). The Region 5 Ecological Screening Level (ESL) for lead is 35.8 mg/kg. None of the concentrations in the muliwai samples exceeded this level.

3.2.10 Mercury

Mercury was found in 51 of the 54 sediment samples collected during this program. As shown on Table 3-2 and in the Method 7471A table in Appendix C, the detected mercury concentrations ranged from 0.008 to 0.082 mg/kg, and the other 3 samples did not contain concentrations of mercury greater than the approximate detection limit of 0.01 mg/kg. Figure 3-10 shows the distribution of the mercury concentration. This figure shows a near logarithmic distribution frequency configuration. Nearly half of the samples contained mercury at concentrations of less than 0.025 mg/kg with the remaining sample frequencies distributed to a maximum of less than 0.1 mg/kg. All of the background samples contained concentrations of mercury between 0.05 and 0.065 mg/kg. Thus, the concentrations in the muliwai samples appear to be within the range of background concentrations.

None of the samples collected from any of the areas contained concentrations of mercury greater than the residential soil PRG of 23 mg/kg. The U.S. EPA Region 5 sediment ESL for mercury is 0.174 mg/kg. None of the sample results exceeded this level.

Figure 3-9
Lead - 32 detects, 22 non-detects
Makua Muliwai Sampling May 2003

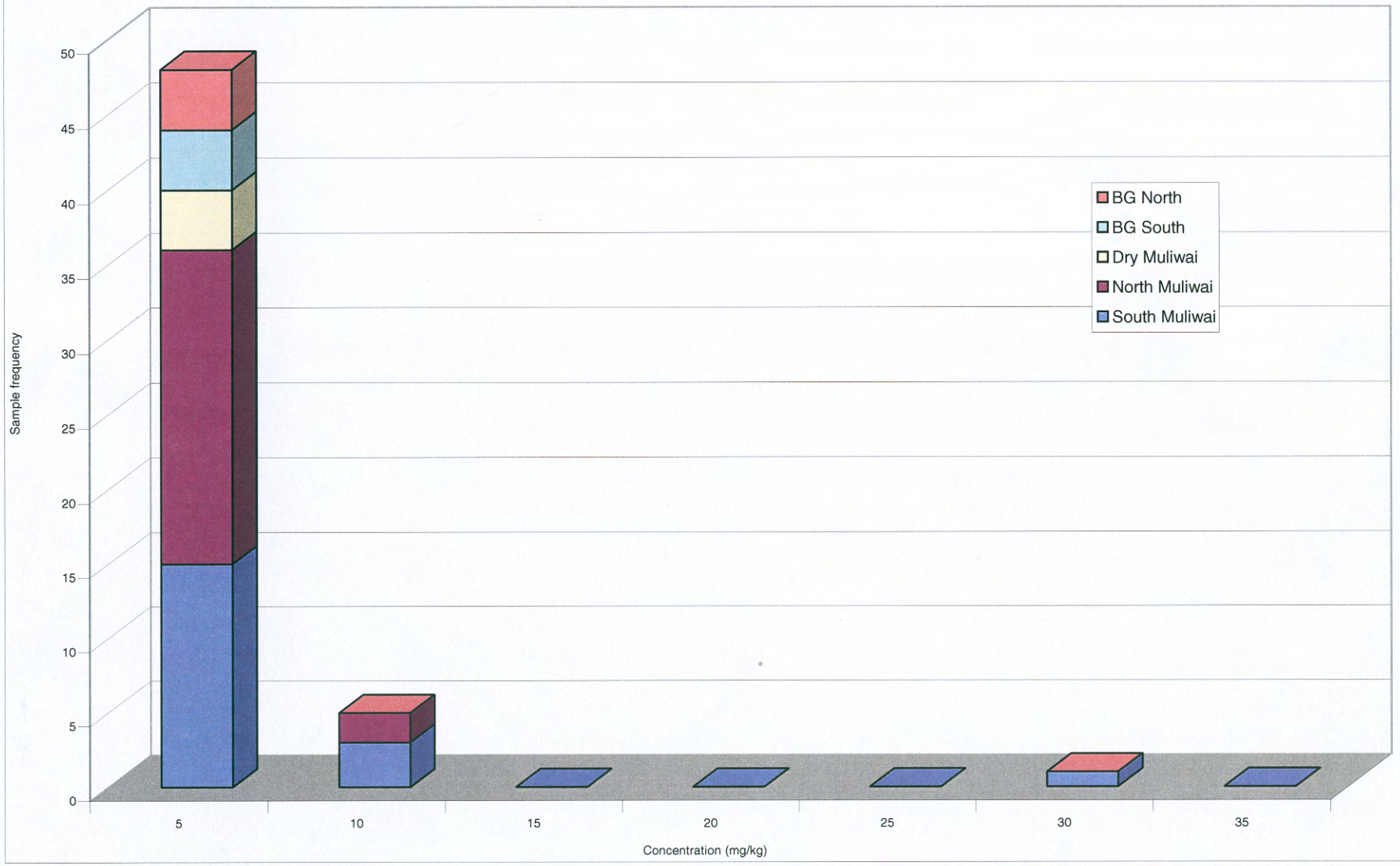
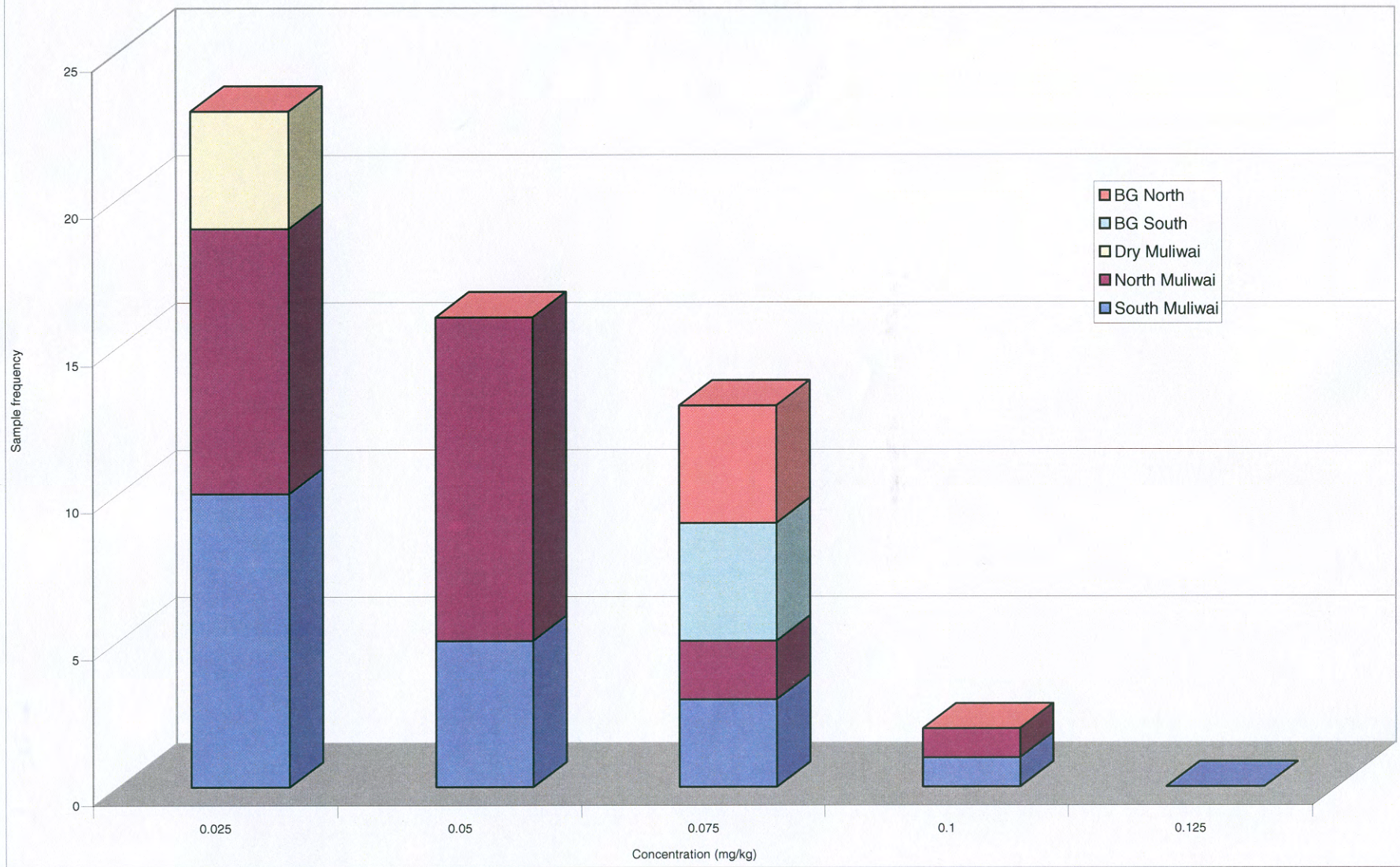


Figure 3-10
Mercury - 51 detects, 3 non-detects
Makua Muliwai Sampling May 2003



3.2.11 Selenium

Selenium was found in 26 of the 54 sediment samples collected during this program. As shown on Table 3-2 and in the Method 6010B table in Appendix C, the detected selenium concentrations ranged from 0.15 to 7.7 mg/kg. The other 28 samples did not contain concentrations of selenium greater than the approximate detection limit of 0.080 mg/kg. Figure 3-11 shows the distribution of the selenium concentrations. Over half of the muliwai samples contained selenium at concentrations of less than 2 mg/kg, with the remaining sample frequencies distributed to a maximum of less than 8 mg/kg. None of the samples from the background areas contained detectable concentrations of selenium.

None of the samples collected from any of the areas contained concentrations of selenium greater than the residential soil PRG of 390 mg/kg. The U.S. EPA Generic Soil Screening Level (SSL) for protection of groundwater, assuming no attenuation by soils, is 0.13 mg/kg. The SSL was exceeded in 19 of the muliwai samples, The SSL is based on protection of groundwater in areas where groundwater may ultimately discharge, or be discharged, to surface water. Elevated concentrations of selenium have been identified as a potential hazard to birds. By contrast, groundwater beneath the muliwai ponds is brackish and discharges directly to the ocean, where selenium concentrations are naturally elevated relative to fresh water. Therefore, exceedance of the Generic SSL for selenium in the muliwai sediments is not indicative of an environmental or ecological hazard.

3.2.12 Silver

Silver was not detected in any of the 54 sediment samples collected during this program. As shown on Table 3-2 and in the Method 6010B table in Appendix C, silver was not found at any concentrations greater than the approximate detection limit of 0.031 mg/kg. As such, none of the samples collected from any of the areas contained concentrations of silver greater than the residential soil PRG of 390 mg/kg.

3.2.13 Vanadium

Vanadium was found in all of the 54 sediment samples collected during this program. As shown on Table 3-2 and in the Method 6010B table in Appendix C, the vanadium concentrations ranged from 0.12 to 194 mg/kg. Figure 3-12 shows the distribution frequency of the vanadium concentrations. This figure shows a split distribution configuration. Nearly half of the samples contained vanadium at concentrations of less than 25 mg/kg. The background samples contained concentrations of vanadium between 125 to 175 mg/kg. The muliwai samples contained concentrations consistent with the range of background concentrations.

None of the samples collected from any of the areas contained concentrations of vanadium greater than the residential soil PRG of 550 mg/kg. The U.S. EPA Generic vanadium SSL for protection of groundwater is 300 mg/kg. This level was not exceeded in any of the muliwai samples.

Figure 3-11
Selenium - 26 detects, 28 non-detects
Makua Muliwai Sampling May 2003

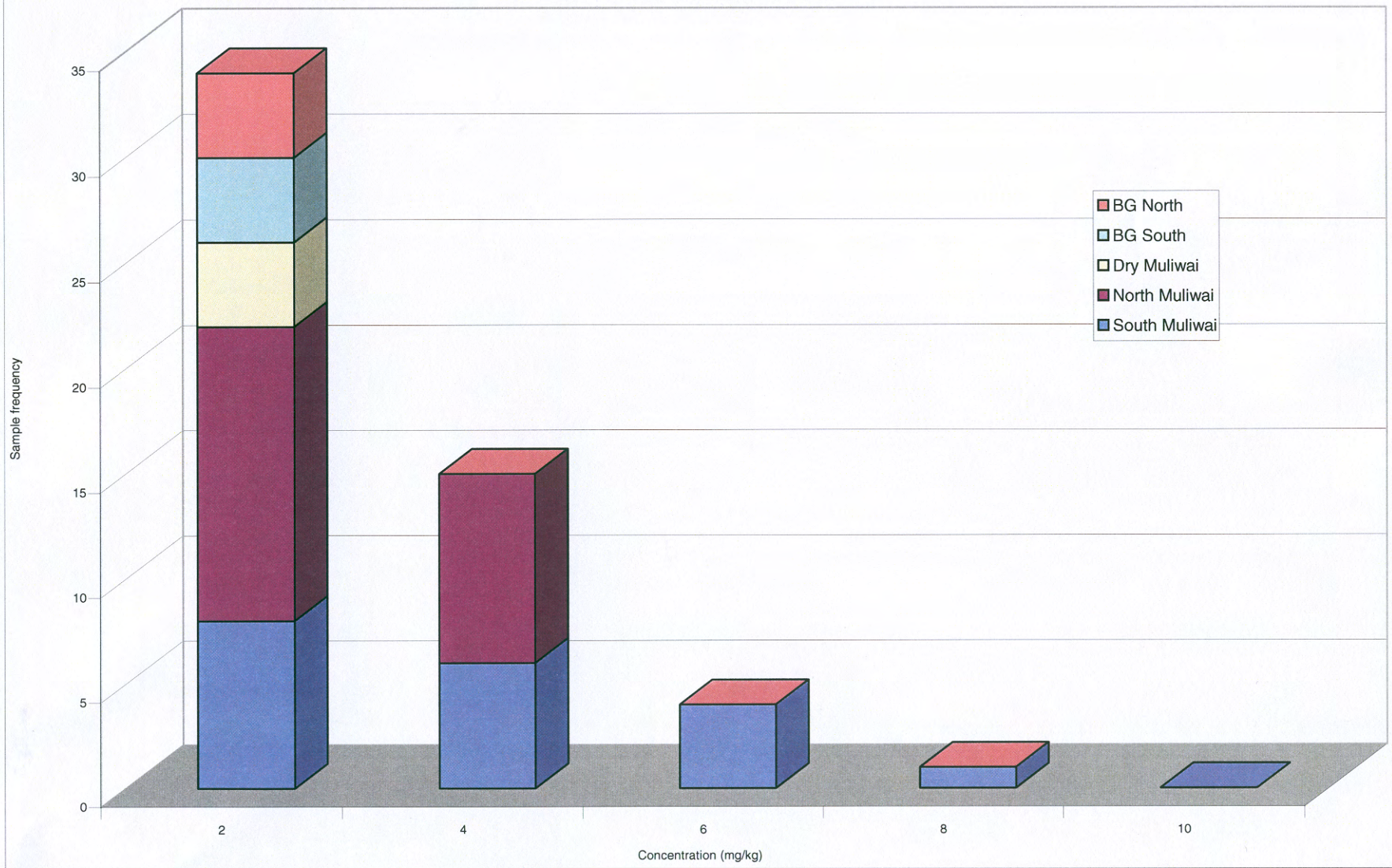
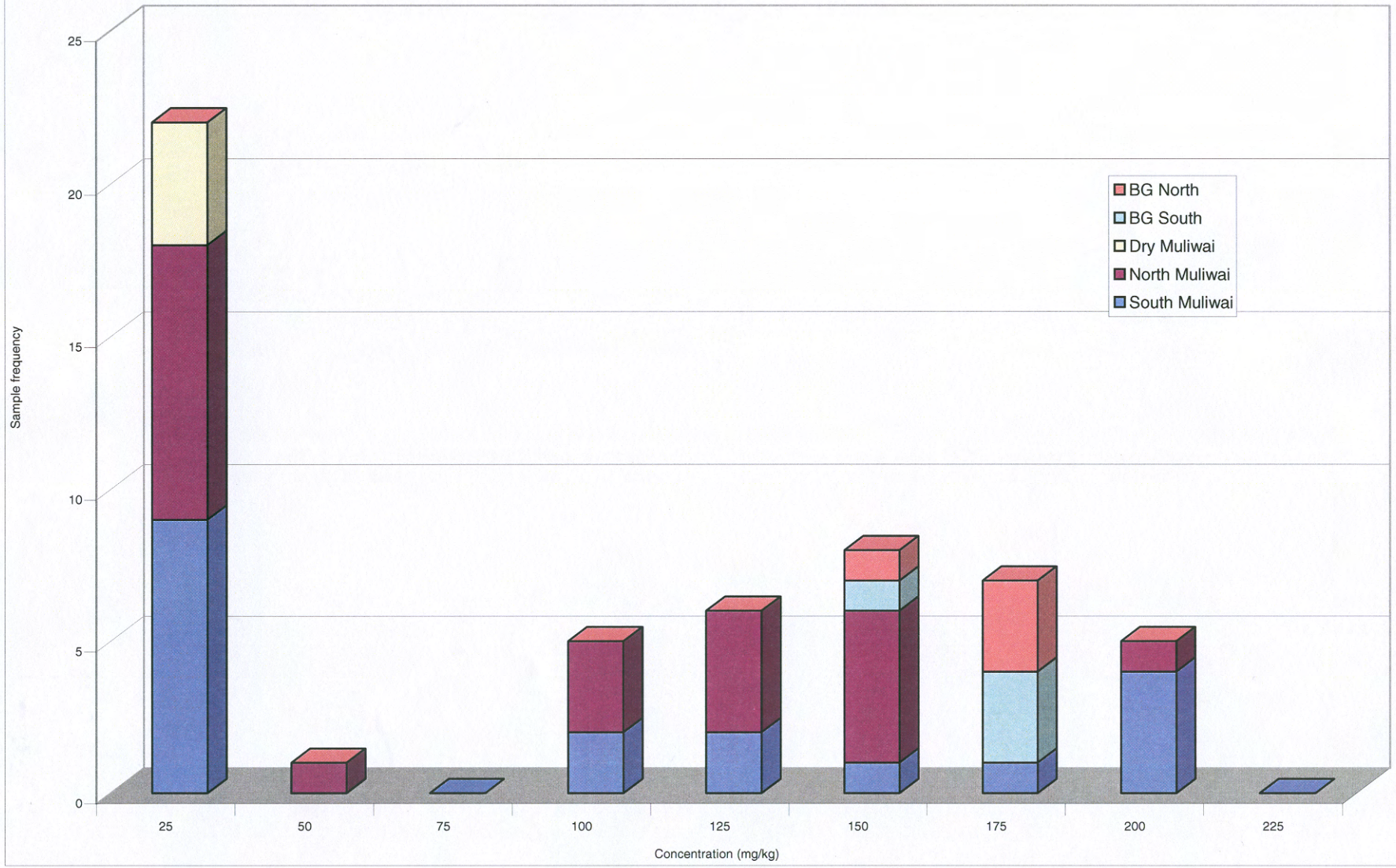


Figure 3-12
Vanadium - 54 detects, 0 non-detects
Makua Muliwai Sampling May 2003



3.2.14 Zinc

Zinc was found in all of the 54 sediment samples collected during this program. As shown on Table 3-2 and in the Method 6010B table in Appendix C, the zinc concentrations ranged from 0.79 to 188 mg/kg. Figure 3-13 shows the distribution of the zinc concentrations. Nearly half of the samples contained zinc at concentrations of less than 25mg/kg, with the remaining sample frequencies mostly distributed from 50 to 150 mg/kg and only one higher concentration of 188 mg/kg. All of the background samples contained concentrations of zinc in the central portion of the concentration range, between 75 to 125 mg/kg.

None of the samples collected from any of the areas contained concentrations of zinc greater than the residential soil PRG of 23,000 mg/kg. The U.S. EPA Generic zinc SSL for protection of groundwater is 620 mg/kg. This level was not exceeded in any of the muliwai samples. The Region 5 ESL is 121 mg/kg, which was exceeded in 4 of the samples, including one of the background muliwai samples. Zinc is a natural constituent of volcanic rocks. Background levels in Hawaiian soils are in the range of 120 to 130 mg/kg based on available literature from the Big Island. The 95 percent upper confidence level for concentrations of zinc in surface soil samples from the Makua installation was 146 mg/kg. Therefore, it is likely that the observed concentrations are due to natural sources.

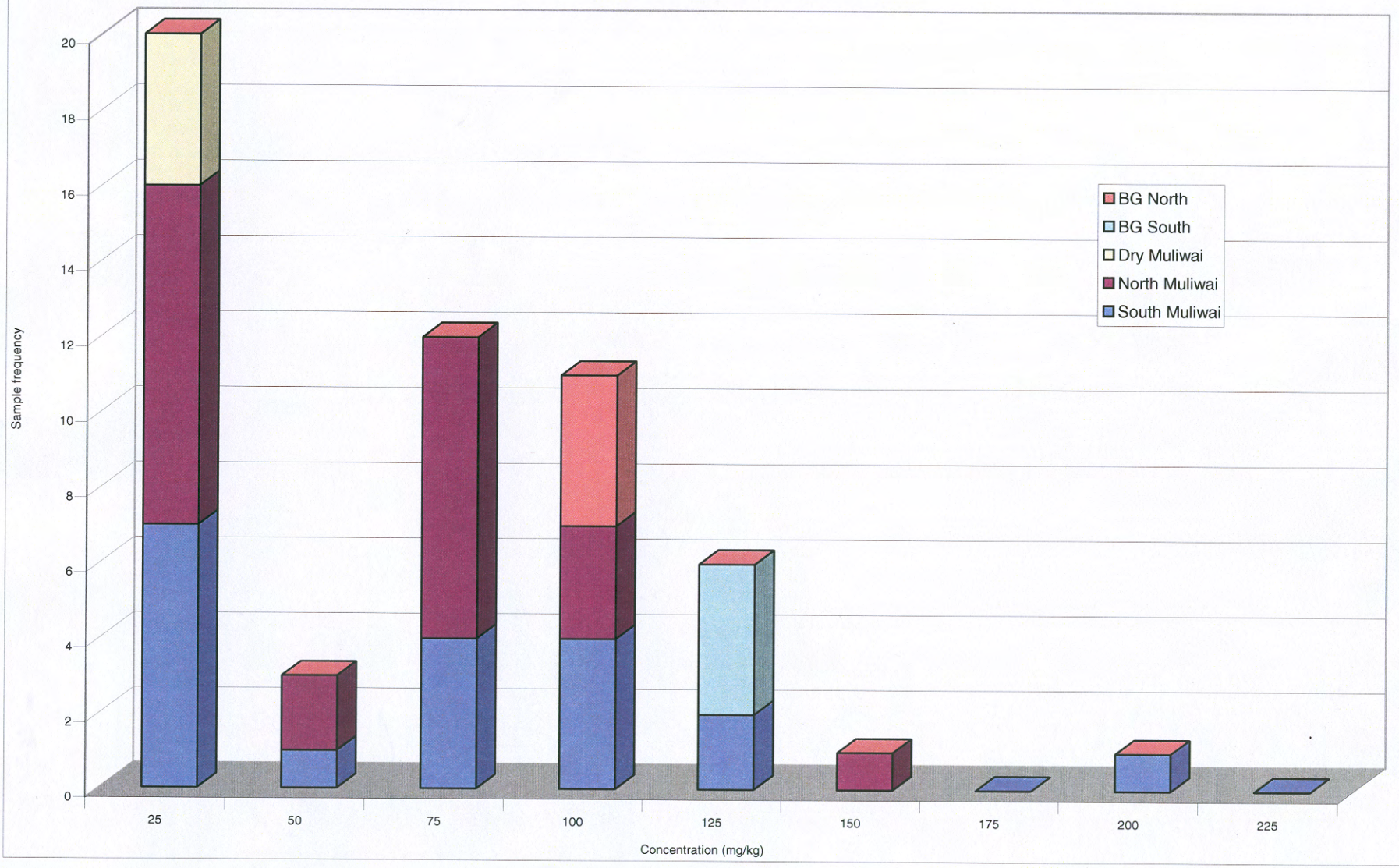
3.2.15 Metals Summary

With the exceptions of arsenic and chromium, none of the metals were found at concentrations greater than their respective USEPA Region IX residential soil PRGs. Multiple samples contained concentrations of arsenic greater than the residential and industrial cancer end-point PRGs; however, the concentrations in the muliwai samples appear to be consistent with the range of detected background concentrations. Four samples contained concentrations of chromium that exceeded the residential cancer end-point PRG; however, two of these samples were collected from background areas indicating that the range of observed chromium concentrations are due to natural conditions. Similarly, although some of the concentrations exceeded EPA Generic SSLs or Region 5 ESLs, the concentrations appear to be within normal ranges for Hawaiian soils.

3.3 ENERGETICS RESULTS (USEPA METHODS 314.0, 8330, AND 8332)

The energetic compounds analyzed by USEPA Methods 314.0, 8330, and 8332 included a full list of nitroaromatic and nitramine explosive compounds such as TNT, RDX and HMX, as well as relevant breakdown compounds. All of the 54 sediment samples collected for this program, including the background samples, were tested for these compounds. Also, the explosives nitroglycerin and perchlorate were analyzed in the twelve samples submitted for the extended suite of analyses. The results of these analyses are presented in the three tables in Appendix C by their respective method number and are also summarized in Table 3-1.

Figure 3-13
Zinc - 54 detects, 0 non-detects
Makua Muliwai Sampling May 2003



Only one energetic compound, RDX, was detected at a concentration greater than the laboratory detection limit. The RDX was found in a sample collected from the north muliwai at location NMM-06; this location was in a dry area near Mākua Stream (Figures 2-1 and 2-2). Nitroglycerin and perchlorate were not detected in any of the twelve sediment samples collected for these analyses.

The concentration of RDX in the sample NMM-06 was 230 μg/kg or 0.23 mg/kg. The residential cancer soil PRG for RDX is 4.4 mg/kg and the industrial cancer soil PRG for this compound is 16 mg/kg. Therefore, the sole detected concentration of RDX was substantially less than either of these soil PRGs. Because only one of the 54 samples collected during this program contained a detectable concentration of any energetic compound, it appears that energetics do not present a substantial risk to human health or the environment. It should be noted that there is no U.S. EPA Generic SSL, Hawai'i Tier I Action Level, or Region 5 ESL for RDX.

3.4 PETROLEUM HYDROCARBON RESULTS (USEPA METHOD 8021B)

The twelve samples included in the full suite of analyses list were tested by USEPA Method 8021B for the fuel constituents benzene, toluene, ethylbenzene, and xylenes (BTEX) (Table 2-1). The results of these analyses are presented in the table in Appendix C and are summarized in Table 3-1.

3.4.1 Benzene

Benzene was found in two of the twelve sediment samples analyzed by Method 8021B. These samples were collected from the north muliwai pond at sample locations NMM-12 and NMM-20 (Figure 2-2), and contained concentrations of benzene at 0.044 and 0.040 μg/kg, respectively. Benzene is a volatile constituent of gasoline. The source of the benzene could include MMR, highway runoff, or other public access areas.

The residential soil PRG for benzene is 600 μg/kg and the industrial soil PRG is 1,300 μg/kg. Therefore, the detected concentrations were well below USEPA soil PRGs for benzene.

3.4.2 Toluene

Toluene was found in 11 of the 12 sediment samples analyzed by Method 8021B. Six of these samples were collected from the north muliwai pond, at locations NMM-04, NMM-10, NMM-12, NMM-16 (and the duplicate sample from NMM-16), and NMM-20 (Figure 2-2). Four of these samples were collected from the south muliwai pond, at locations SMM-02, SMM-06, SMM-13, and SMM-14 (Figure 2-3). One of these samples was collected from the dry muliwai pond, at location DMM-01 (Figure 2-4). The concentrations of toluene in these samples ranged from 0.24 to 0.70 μg/kg, as shown in Table 3-1. Toluene, like benzene, is a constituent of fuels and may have originated from a variety of sources on and off the installation.

The residential and the industrial soil PRG for toluene is 520,000 μg/kg, many times higher than the trace concentrations detected in the samples.

3.4.3 Ethylbenzene

Ethylbenzene was found in 10 of the 12 sediment samples analyzed by Method 8021B, including four from the north muliwai, five from the south muliwai, and one from the dry muliwai (Figures 2-2, 2-3, and 2-4). Detection of ethylbenzene closely correlates with detection of toluene. The concentrations of ethylbenzene in these samples ranged from 0.3 to 2.0 μg/kg.

The residential soil PRG for ethylbenzene is 8,900 μg/kg and the industrial soil PRG is 20,000 μg/kg, both much higher than the trace concentrations detected in the samples.

3.4.4 Xylenes

Xylene isomers (i.e., o-xylene or m,p-xylenes) were found in 9 of the 12 sediment samples analyzed by Method 8021B, including four from the north muliwai, four from the south muliwai, and one from the dry muliwai (Figures 2-2, 2-3, and 2-4). The concentrations of xylene isomers in these samples ranged from 0.09 to 1.0 μg/kg (Table 3-1).

The residential soil PRG for total xylenes is 270,000 μg/kg, and the industrial soil PRG is 420,000 μg/kg, which are far higher than the trace concentrations detected in the samples.

3.4.5 Petroleum Hydrocarbon Summary

All twelve of the samples analyzed for petroleum hydrocarbon compounds contained trace concentrations of one or more of the BTEX chemicals. The detected concentrations are well below their respective USEPA Region IX residential and industrial soil PRGs. None of the samples exceeded the other agency criteria (US EPA Generic SSLs, Hawai'i Tier I Soil Action Levels, or Region 5 ESLs) used for comparison in this report

3.5 OC Pesticide Results (USEPA Method 8081A)

The twelve samples included in the full suite of analyses list were tested by USEPA Method 8081A for OC pesticides (Table 2-1). The results of these analyses are presented in the table in Appendix C and the results are summarized in Table 3-1.

The only OC pesticide detected by this method was 4,4-DDT, which was found in the sample from location NMM-12 in the north muliwai (Figure 2-2). The concentration of 4,4-DDT in the NMM-12 sample was 0.1 μg/kg. The residential soil PRG for DDT is 1,700 μg/kg and the industrial soil PRG is 7,000 μg/kg. The Region 5 ESL for DDT is 4.16 ug/kg, which is well above the detected concentration.

3.6 Chlorinated Herbicide Results (USEPA Method 8151A)

The twelve samples included in the full-suite of analyses list were analyzed by USEPA Method 8151A for chlorinated herbicides. The results of these analyses are presented in Appendix C and are summarized in Table 3-1.

Only the herbicides bentazon, pentachlorophenol, and picloram were detected. These compounds were detected in three of the twelve sediment samples, including SMM-13 (pentachlorophenol and picloram) and SMM-14 (bentazon) in the south muliwai, and at DMM-01 (pentachlorophenol) in the dry muliwai.

The detected concentration of herbicides were far lower than the respective residential and industrial soil PRGs. The concentration of bentazon was 46 μg/kg, compared to the residential and industrial soil PRGs of 1,800,000 μg/kg and 18,000,000 μg/kg, respectively. The concentrations of pentachlorophenol were 0.823 and 2 μg/kg, compared to the residential and industrial soil PRGs of 3,000 μg/kg and 9,000 μg/kg, respectively. Lastly, the concentration of picloram was 0.4 μg/kg, compared to the residential and industrial soil PRGs of 4,300,000 μg/kg and 43,000,000 μg/kg, respectively. Region 5 ESLs have been identified for only a few of the chlorinated herbicides, and of these, only pentachlorophenol was detected, at a much lower concentration. The US EPA Generic SSL for pentachlorophenol is 1.0 ug/kg. One sample contained a concentration of 2 ug/kg. However, the SSL is based on groundwater protection, and therefore has little or no applicability to the muliwai sediment located adjacent to the ocean, where the shallow groundwater is brackish and would not be used as a source of drinking water.

3.7 SEMIVOLATILE ORGANIC COMPOUND RESULTS (USEPA METHOD 8270C)

The SVOCs that can be detected by USEPA Method 8270C include a wide range of compounds. The twelve samples included in the full suite of analyses list were tested by this method (Table 2-1). The results of these analyses are presented in the table in Appendix C and are summarized in Table 3-1. Only three compounds, bis (2-ethylhexyl)-phthalate, pentachlorophenol, and pyrene, were detected. These compounds were detected in two of the twelve sediment samples, including the sample from location NMM-20 (bis (2-ethylhexyl)-phthalate) in the north muliwai, and at location SMM-14 (pentachlorophenol and pyrene) in the south muliwai.

The detected concentrations of these three SVOCs were far below their respective USEPA Region IX soil PRGs. The concentration of bis (2-ethylhexyl)-phthalate, a plasticizer, was 22 μg/kg. The residential and industrial soil PRGs are 35,000 μg/kg and 120,000 μg/kg, respectively. The concentration of pentachlorophenol, a wood preservative and chlorinated herbicide constituent, was 230 μg/kg. The residential and industrial soil PRGs are 3,000 μg/kg and 9,000 μg/kg, respectively. This analyte is also detectable by Method 8151A (see Section 3.6), however, it was not detected by Method 8151A in the sample from location SMM-14. In addition, while pentachlorophenol was detected in sample SMM-13 by Method 8151A, it was not found in this sample by Method 8270C. Such analytical discrepancies suggest possible heterogeneity within the samples at these trace concentrations. Lastly, the concentration of pyrene was 77 μg/kg, and its residential and industrial soil PRGs are 2,300,000 μg/kg and 29,000,000 μg/kg, respectively.

3.8 DIOXIN AND FURAN RESULTS (USEPA METHOD 8280A)

USEPA Method 8280A is a high resolution gas chromatography, and low resolution mass spectrometry method used to quantify 17 of the 75 individual polychlorinated dibenzo-p-dioxins (PCDDs) and 135 individual polychlorinated dibenzofurans (PCDFs). The method is used to detect these PCDDs/PCDFs at part-per-trillion concentrations. The sum of the concentrations of the congeners is also reported. The term congener refers to the groupings of isomers by number of chlorine atoms in the dioxin molecule. Thus, an isomer with four chlorine atoms is a tetrachlorinated dibenzo-p-dioxin (TCDD), an isomer with five chlorines is a pentachlorinated dibenzo-p-dioxin (PeCDD), and so on up to eight chlorines (octachlorinated dibenzo-p-dioxin, or OCDD).

Toxicity studies have shown that dioxin and furan isomers differ in their effects on human health. The most toxic isomer is 2,3,7,8-TCDD. Rather than develop health standards for each isomer, which would be extremely cumbersome, a system has been devised to relate the toxicities of each of the PCDD and PCDF isomers to the toxicity of the 2,3,7,8-TCDD isomer. The detected concentration of the isomer multiplied by its toxicity factor yields the toxicity equivalent (TEQ) of the isomer with respect to 2,3,7,8-TCDD. The sum of all of the TEQs for a given sample yields the total toxicity equivalent for the sample. This value can then be compared to the USEPA Region IX soil PRGs for the 2,3,7,8-TCDD isomer; the residential soil PRG is 0.0039 μg/kg, while the industrial soil PRG is 0.016 μg/kg.

The twelve samples included in the full suite of analyses list were tested for dioxins and furans (Table 2-1). No PCDFs were detected in any of the samples. One dioxin isomer was detected in each of two samples. Sample NMM-12-FL-3, which was collected at a depth of approximately 19 to 33 inches in the north muliwai, contained 0.15 μg/kg of the eight-chlorine isomer 1,2,3,4,6,7,8,9-OCDD. The TEQ of this concentration is 0.00015 μg/kg, which is well below the residential soil PRG. Sample SMM-13-FL-3-D, which was collected from a depth of approximately 37 to 40 inches in the south muliwai, contained 0.03 μg/kg of the four-chlorine isomer 2,3,7,8-TCDD. Since this is the isomer to which the toxicities of all of the isomers are compared, the TEQ is equal to the concentration. The concentration of 2,3,7,8-TCDD in this samples is about ten-times greater than the corresponding residential soil PRG, and about two times higher than the industrial soil PRG.

There is a Region 5 SSL of 0.0004 ug/kg for the 2,3,7,8-TCDD isomer. This was exceeded in the one sample in which the TCDD isomer was reported. However, since the sample was in a duplicate (co-located) sample, and since TCDD was not detected in the other sample of this pair of samples, the reported concentration is suspect.

Dioxins and furans are created in small quantities by combustion of materials containing chlorine (for example, some plastics). Soot containing dioxins and furans may be dispersed by winds and hence, low concentrations of these compounds are ubiquitous in the environment. Low concentrations (usually sub-microgram) of dioxins and furans were found in soil samples collected for the *Hydrogeologic Investigation of Mākua Military*

Reservation (ERDC 2004), including "background" samples collected at locations outside Mākua Valley. Based on these observations, and the fact that only two samples from the muliwai contained detectable amounts of dioxins, it is likely that any dioxins in the area result from regional atmospheric deposition rather than from a local source.

3.9 OTHER ANALYTICAL RESULTS (USEPA METHODS 335.2, 354.1, AND SM4500)

The twelve samples included in the full suite of analyses list were also analyzed by USEPA Methods 335.2 and 354.1 for cyanide and nitrite, respectively, as well as by SM4500D for nitrate. The results of these analyses are presented in the table in Appendix C and are summarized in Table 3-1.

Cyanide and nitrite were not detected in any of the twelve sediment samples collected from the three muliwai. However, all twelve sediment samples contained detectable concentrations of nitrate. The concentrations ranged from 3.9 to 19.5 mg/kg, with both of these minimum and maximum concentrations found in samples collected from the north muliwai pond. No USEPA Region IX PRGs have been established for nitrate in soils.

3.10 ANALYTICAL RESULTS SUMMARY

All of the 54 sediment samples collected during this program were analyzed for metals. All of the metals detected in these samples appeared to be naturally occurring and within the range of background concentration. Only arsenic and chromium were found at concentrations greater than respective USEPA Region IX residential soil PRGs; however, these levels were all within the ranges of their background concentrations.

All of the 54 sediment samples collected during this program were analyzed for energetic compounds. Only one energetic compound, RDX, was detected and it was observed in only one of the 54 samples at a trace concentration, well below the residential soil PRG. This explosive is likely the result of activities at MMR, but was found at a low concentration that does not appear to be of an environmental or health-based concern. Also, since only one of the sediment samples contained an explosive chemical, off-site migration of explosives from MMR does not appear to be widespread.

Twelve of the 54 sediment samples were analyzed by a variety of methods for a wide range of potential contaminants of concern. Three semi-volatile compounds were detected at trace concentrations in two samples. Similarly, OC pesticides and chlorinated herbicides were detected in a few samples at trace concentrations. Fuel constituents (BTEX) were detected at trace concentrations in all twelve samples analyzed, suggesting that these compounds are widespread at very low concentrations. None of the BTEX concentrations approached their USEPA Region IX residential soil PRGs.

The results were also compared to the U.S. EPA Generic SSLs for groundwater protection, the Hawai'i Tier I soil Action Levels, and the EPA Region 5 ESLs. Some of the results, for the metals chromium, copper, cobalt, and selenium, exceeded thresholds for these metals that are lower than the residential or industrial soil PRGs. However, the metals concentrations are within the normal range for Hawaiian soils, and therefore

do not indicate a need for further action. Only a few sporadic concentrations above these alternative action levels were detected among the organic compounds, and do not suggest a consistent pattern of contamination.

The Hawai'i Tier I Soil Action Levels are intended for use at underground storage tank remediation sites, to help determine whether groundwater may be impacted by chemicals typically associated with leaking underground fuel tanks. These standards are not readily applicable to the muliwai sediments because the muliwai are located adjacent to the ocean, where the shallow groundwater is brackish and is not likely ever to be used as a potable source. Similarly, the EPA SSLs are designed to protect potable groundwater quality. The Region 5 ESLs were developed in an entirely different context (to protect species found within Region 5, which includes the land-locked center of the mainland United States), and cannot be assumed to be appropriate for use in the very different ecological context of Hawai'i.

SECTION 4
CONCLUSIONS

Based on all of the field observations and the analytical results of the muliwai sediment sampling program, the following conclusions were made:

- A wide range of sediment types, in terms of grain size and TOC content, were encountered in the three muliwai and two background areas. No correlation was observed between the grain size, the locations or depths of the samples, and the TOC or nitrate concentrations.
- Concentrations of metals detected in the muliwai were within the ranges found in the background samples.
- Arsenic and chromium were detected at concentrations above USEPA Region IX residential soil PRGs, but within background concentration ranges.
- All of the twelve samples that were analyzed for BTEX contained one or more of these compounds at trace concentrations. However, all of the concentrations of the BTEX chemicals in these samples were far lower than respective USEPA Region IX residential soil PRGs.
- Six of twelve sediment samples analyzed for the full suite of organic compounds contained one or more of the chemicals of concern, (with the exception of BTEX, which was detected more frequently). One sample contained one of the explosive compounds, and one sample contained one OC pesticide compound. Three chlorinated herbicides and three SVOCs were found in four samples. The detected concentrations were far below USEPA Region IX soil PRGs.
- Trace concentrations of two dioxin isomers were detected in two of the twelve muliwai sediment samples analyzed for dioxins and furans. The 2,3,7,8-TCDD isomer was detected at a concentration above the USEPA Region IX industrial soil PRG in one sample from the south muliwai, collected at a depth of approximately 37 to 40 inches. The TEQ of the

OCDD isomer found in the other sample, from the north muliwai, did not exceed the USEPA Region IX residential soil PRG.

SECTION 5
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