Attachment

G – 1

Attachment G-1

Sediment Monitoring Results and Discussion of Sediment Quality

Introduction

Sediment monitoring studies have been conducted annually, consistent with the terms of the existing 301(h) permit since 1999, as well as in 1986, 1987 and the period 1990 through 1998 under a different set of sampling stations. The historic seven stations located in approximately 60-80 m (200-260 ft) deep were sampled in August as are the new stations beginning in 1998. The fifteen new stations shown in (Figure G-1-1) range in depth from approximately 20 to 100 (67 -333 ft). Five stations were located on each of three transects along isobaths of approximately 20 m (Transect C), 50 m (Transect D), and 100 m (Transect E). Each transect included two stations near the diffuser at or inshore of the boundary of the zone of mixing (ZOM) and three stations beyond the diffuser at distances of approximately 2.4 to 2.7 km east, 4.4 to 4.9 km west, and 5.9 to 6.5 km west of the center of the diffuser. The eleven benthic surveys at the Sand Island outfall prior to 1999 were based on seven stations located on one transect (herein called Transect B in subsequent Benthic Reports) at 58 to 77 m, the approximate depth of the outfall diffuser. In addition, during two of the five years in the present permit,, a Regional Monitoring Program is undertaken. The latest one was conducted in 2001.as part of the EPA sponsored EMAP effort which included other stations around Oahu and other parts of Hawaii. The CCH designated these forty sampling stations 60 through 100 in the reporting of results for sediment chemistry contained in the 2001 AAR (CCH, 2002). Unlike the core monitoring benthic sampling program methods (see description below and detailed in Attachment G-3), no replicate samples are collected during the regional monitoring effort, thus variability within a station cannot be determined and statistical analyses are not robust.

Locations of the forty regional monitoring stations are shown in Figure G-1-2.

Sediment monitoring is done to determine if high rates of organic accumulation in sediments can be detected by elevated sediment concentrations of silt-clay content, total organic carbon (TOC), total Kjeldahl nitrogen (TKN),, reduced oxygen-reduction potential (redox) and changes in sediment grain size. In addition, concentrations of toxicants were measured annually under the core program except when regional monitoring is performed. Sediment chemistry analysis included total metals, volatile organics, semivolatile organics, chlorinated pesticides and PCBs, organophosphorus pesticides and dioxin, cyanide, TOC, nitrogen (all forms) and acid volatile sulfide.

The CCH's ocean monitoring program requires regular assessments of sediment quality, including the distribution and concentration of chemical contaminants in bottom sediments within the Mamala Bay study area. The objectives of these assessments are ~~to determine the spatial extent and magnitude of wastewater-related changes to~~ sediment quality (four ZOM stations) and their possible relation to the health of biological communities, and to validate predictions regarding the effects of improved wastewater treatment on reducing the extent of impacts to bottom conditions. For the regional monitoring, the objectives are to collect information on the relative quality of sediments and changes in this quality over time.

Changes over time in the amounts of chemical contaminants in wastewaters (related either to concentrations or to volumes) discharged to the ocean, as well as the proportions of wastewater particles that settle and accumulate on the sea floor, may be reflected in the physical and chemical characteristics of sediments near the outfall. Improvements in the quality of the effluent can be expected to theoretically result in lower contaminant concentrations in bottom sediments. Periodic measurements of sediments are made to determine if any trends are observable. To date, the infrequent sampling combined with extremely low levels of contaminants makes such an assessment challenging in the interpretation of results. These monitoring studies are important for determining the extent of alterations in the physical and chemical characteristics of sediments, which in turn, are used to help evaluate the health of associated biological communities of infaunal and epibenthic fish and invertebrates.

Chemical characteristics included concentrations of organic matter, as measured by total organic carbon (TOC) and acid volatile sulfides (AVS), metals, chlorinated pesticides, polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs). The list of analytes was generally similar to that used for the National Status and Trends (NS&T) program (NOAA 1993) and the list Besides measuring chemical characteristics of sediments, physical measures (grain size distributions) were also determined, as these are useful in evaluating both chemical and biological community distributions. Results from sediment quality measurements performed during 1998 through 2002 are presented in this Attachment. Additionally, results from more localized outfall monitoring program are compared to regional conditions from the August 2001 regional monitoring programs, because this provides a broader context for evaluating the magnitude of any changes to sediment quality associated with the Sand Island discharge. In addition, other available studies and data have been presented in an effort to provide some perspective on what is known about Mamala Bay sediment quality. One large influencing factor is the fact that dredge disposal has been conducted for almost 50 years at sites off the edge of the shelf. Whether all of the sediment made it to the designated sites is a good question given some of the data. This material has covered a wide are of the bay offshore of the outfall and its distribution over the sea floor is something of interest that must be noted.

Each of the measured parameters is discussed below with regard to the findings during the past permit period and also in historical perspective. What is important is if there are any trends in long-term accumulations or changes which could adversely impact marine biota. Before the discussion, the methods used are summarized. The details are contained in the NPDES permit (Appendix J) and in the individual Benthic Monitoring Reports (See Attachment G-3 for the latest).

Station Positioning

The positioning of each station was established using the Garmin differential global positioning system. General station locations are shown in Figure G-1-1. Positions for each replicate grab sample at each station are reported in the Benthic Monitoring Reports each year along with the depths for each replicate.

Sampling Methods

The sampling methodology used in the benthic surveys generally followed the recommendations of Swartz (1978) and U.S. EPA guidelines (U.S. EPA 1987a, 1987b), hereafter referred to as EPA procedures. A 0.16-m2 modified van Veen grab sampler deployed from a stern-mounted A-frame on the research vessel *Noi I Kai* (CCH ocean monitoring vessel) was used to obtain bottom samples at all fifteen stations for the core program and 40 stations for the regional program.

Sampling dates were in August of each year. Penetration of the sampler must be adequate for all replicates or they are repeated. The minimum penetration depth for all grabs is generally 7 cm and the maximum as high as 15 cm . Three van Veen grab samples were taken at each station. A subsample 7.6 cm in diameter by 5 cm deep was taken from each grab sample for infaunal analysis and a subsample 4.8 cm in diameter by 5 cm deep for mollusk analysis. Subsampling was necessary because the epifauna and infauna in the m-ea are known to be both small and abundant (Nelson 1986; Russo et al. 1988) and processing of the entire sample would be impractical. Replicated grab samples taken at each station, rather than replicated subsamples from one grab sample, were used to provide information on intrastation variability. All three nonmollusk subcores were processed on a 0.5-mm screen.

Samples for geochemical analyses (total organic carbon [TOC], oxidation-reduction potential [ORP], total Kjeldahl nitrogen [TKN], and grain size) were obtained from the grabs from which the biological subcores were taken. Each replicate van Veen grab contained more than enough sediment for both purposes.

Sediment Grain Size

EPA's 1998 published review of the CCH's sediment data from the historical seven stations sampled during 1990-93 indicated sediments were over 90% sand. The silt-clay content of the sediments from these stations was relatively low. The average at any station in any given year ranged from 1.5% at Station B3 in 1992 to 7.3% at Station B6 in 1993. The grain size characteristics were generally similar among stations, except for Station B1 (control station) which had a relatively higher content of fine and very fine sand and lower content of coarse and medium sand. The silt-clay content was generally lower in the vicinity of the diffuser, and highest at stations located farthest from the outfall (EPA, 1998). EPA noted that this was the opposite of what would be expected if sediments were being deposited in the vicinity of the outfall and that there was no apparent trend in the silt-clay content of the sediments in the vicinity of the Sand Isand outfall diffuser. The data for silt-clay content of sediments sampled in 1986 and 1987 generally displayed the same pattern among stations as observed in 1990-93.

Results collected since 1999 at the 15 new monitoring stations continue to show that sediments at all stations were composed of less than 17% silt and clay with high variability both within and between sites because of the depth variation between stations. Transect C stations are characterized by medium sand and coarser sediments (>50%) and a very low silt and clay fraction (<3.3%). Transect D stations were predominantly fine sand (39-71%) with the most variable grain size occurring among Transect E stations where fine sand dominated at Stations E1 and E6 (>70%) and to a lesser extent at Station E5 (56%). Stations E2 and E3 had medium sand and course sediment (>50%). Statistical differences be stations (reported in the AAR) showed that while there were differences between stations, they were not associated with finer grained particles (silt-clay fraction) which might be indicative or outfall-derived organic accumulation.

Sediment samples from 40 stations sampled for the SI Regional Monitoring Program were processed using grain size categories (Folk 1968) as follows: course sediment retained on a + 1-phi sieve; medium sand, passed through a + 1-phi sieve but retained on a +2-phi sieve; fine sand, passed through a +2 phi sieve but retained on a +4 phi sieve; and silt and clay, passed through a +4 phi sieve

There were differences among stations in sediment grain-size distribution The silt and clay fraction was the least variable (range 1.4 to 8.0 percent, except for 14.1% at Station 25 (CCH designated Station 85)(Note the sediment contractor labeled stations numbered 1 through 40 while the City designated them 61 though 100 to avoid confusion with historically numbered stations). Much greater ranges were recorded for the fine sand fraction (0.3 to 79.6 percent), medium sand fraction (1.4 to 92.6 percent), and the course sediment fraction (0.6 to 97.8 percent). Qualitative remarks in the survey log reflect the diversity of sediment conditions: e.g., "lots of rocks" at Station 7 (67), "minimal sand" at Station 18 (78), "hard substrate" at Station 35 (95), and "extensive sea grass" at Station 12 (72). The logs also indicate that the planned locations of some stations had to be changed due to the absence of sediment that could be sampled. This was especially true for the deeper stations where divers could not do the sampling and when the designated sample sites were on reef or in active surf areas. In areas with hard bottom, which are common in Mamala Bay, divers were often able to quickly find and sample sand pockets while in deeper waters finding sediment to sample was often tedious. Overall, the grain sized varied with depth with finer sediments in the deeper stations, as one would expect given the nearshore conditions of wave action and coral rubble.

Overall, the results show that grain size is highly variable and not uniform. From a pollution ecology perspective, the traditional models of metal and organics being associated with the fine sediments and accumulating does not apply to an environment like Mamala Bay. This is a nondepositional area and the open bay sandy sediments are moved about by prevailing currents.

Organic Materials Accumulation in Sediments

TOC and AVS were measured as indicators of sediment organic content which is important because it can affect the distribution and biological availability of sediment contaminants, as well as the composition of benthic infauna. Measurements of sediment TOC and VOC have been used widely for a variety of national and regional monitoring programs.

Total Organic Carbon

The concentrations of TOC measured at the seven historic stations in any given year indicated that the organic content of the sediments was relatively low, much less than 1% (EPA, 1998). As reported in the annual reports, dry weight concentrations were most variable over time and space, and showed no discernible patterns. It was noted by EPA that reported values for 1995, however, were 3 to 30 times lower than in previous years and CCH suggested that the lower values were the result of changing analytical laboratories over the permit term.

More recent sampling at the new stations has shown that sediment TOC values ranged from 0.24% to 2.08% with the mean slightly higher for Transect D than for Transects C and E.(Swartz et al. 2001). The higher TOC values on Transect D were found in samples obtained at beyond-diffuser stations D1 and D5. Mean TOC was higher for Transect D in the year 2000 (1.06%) than in 1999 (0.38%) and was (??? Describe August 2002). Statistical analysis showed no significant differences in mean TOC between beyond-diffuser stations and near-diffuser stations in 2000 (or 2002??) and no evidence that the Sand Island discharge has caused sediment organic enrichment near the outfall (Swartz et al., 2001).

Regional monitoring samples showed that TOC values were all less than 1% ranging from 0.21 –0.76 mg/kg. These are in the same range as the values observed in the past in the vicinity of the Sand Island outfall diffuser Data are reported in the 2001 AAR, in Chapter 6 (CCH, 2002).

Acid Volatile Sulfides

AVS are defined as the solid phase sediment sulfides that are soluble in cold acid (DiToro et al. 1990). Measurements of AVS are performed with the intent of providing information that can be used to to evaluate the bioavailability of cationic metals in sediments. Sediment sulfides are also important for the ocean monitoring program because they relate to a specific receiving water criterion of the CCH's permit.

Oxidation-Reduction Potential (Redox)

Redox values less than zero were indicative of reducing conditions caused by the decomposition of deposited organic matter and the depletion of oxygen in the sediments. Under these conditions, sulfate was reduced to sulfide. Historical redox values ranged from 26 mV at Station B2 in 1991 to 160 mV at Station B4 in 1993 (EPA, 1998). The redox potential measured in 2000 ranged from 35 mV at Station E1 to 185 mV at Station C2A in individual samples with all samples positive indicating the presence of aerobic surficial sediments throughout the survey area (Swartz et al. 2001). It was noted that Mean ORP was significantly higher at Transect C stations (20m transect) than at stations on Transects D and E, but mean values at all transects exceeded 110 mV which is well above values that would be associated with reducing conditions. Statistical analysis showed that there were no statistical differences in sediment ORP values between near-diffuser stations and beyond-diffuser stations which indicate the effluent is not promoting anaerobic conditions in sediments near the outfall. (Swartz et al 2001, 2002 and 2003).

Regional monitoring results from the summer of 2001 show that ORP ranged from 15 mV (Station 85 , with a depth of 3.4 m) to 240 mV (Station 69 with a depth of 4.3 m). No statistical analysis was undertaken to evaluate this data set, but values were generally high with over half the samples exceeding 150 mV indicating aerobic sediments.

Total Kjeldahl Nitrogen

In its 1998 review of the data, EPA found that the concentrations of TKN at the historic seven stations were variable and consistent spatial or temporal patterns were not apparent (EPA, 1998).

Data collected since that time has shown variability with TKN values ranging from 126-338 mg/dry kg with extreme variability between replicates from the same station (i.e. 126-241mg/dry kg at Station D6 in August 2000). However, statistical analysis has shown that there were no significant differences in sediment TKN among transects or between beyond-diffuser stations and near-diffuser stations (Swartz, et. al., 2001). The values found is within the range of low organic content sediments and does not indicate a buildup of nitrogen in sediments near the ZOM.

Regional monitoring samples showed that TKN values were much higher tan those observed near the Sand Island outfall diffuser with a range of 59 mg./dry kg at station 96 to a high of 665 at station 76. Twelve out of the forty stations samples had values in excess of 400 mg/Dry kg. Data are reported in the 2001 AAR, in Chapter 6 (CCH, 2002).

Conclusion Regarding Sediment Indicators of Organic Accumulation

These sediment parameters associated with organic accumulation detailed above do not appear to show any outfall-related effects. All parameters measured are within the range of natural variability in other surveys and were not likely to have significant effects on benthic communities.

Sediment Contamination with Priority Pollutants

Numeric criteria for priority pollutant contamination in sediments currently does not exist. However, EPA draft sediment criteria for five non-ionic organic contaminants are available (U.S. EPA 1993b), and other marine reference levels (Long and Morgan 1990; Long and Morgan, 1995) can serve as guidelines for determining the potential adverse effects on benthic organisms. These criteria that are based on toxicity testing and correlation with identified effects from testing of sediments of known quality are described below. These marine reference levels have been used as a tool for screening to determine what may be identified as local "hot spots" where elevated levels of contaminants have been measured during the permit period. Also, the results of other available studies in Mamala Bay and its environs have been compiled for comparison and use in discussing the results obtained from the sampling done by CCH. Finally, there is discussion provided comparing the levels found near the Sand Island outfall with what is known about marine sediment quality from other locals and the possible sources of contamination other than treated wastewater effluent that may contribute to the observed concentrations of priority pollutants reported over the permit period.

Sediment Quality Guidelines (SQGs) developed for the National Oceans and Atmospheric Administration's (NOAA) National Status and Trends (NS&T) Program

Background and Intended Uses of the Guidelines

NOAA scientists developed the numerical sediment quality guidelines (SQGs) to serve as informal, interpretive tools for the NS&T Program (Long, 1998). Without national criteria or other widely-applicable numerical tools, NOAA scientists found it difficult to estimate the possible toxicological significance of chemical concentrations in sediments. The SQGs were not promulgated as regulatory criteria or standards, but as informal (non-regulatory) guidelines for use in interpreting chemical data from analyses of sediments. NOAA has used the guidelines to compare the degree of contamination among sub-regions, and to identify chemicals elevated in concentration above the guidelines that were also associated with measures of adverse effects. They were derived using existing national pooled data (including data from Pearl Harbor) and have been based on a weight of evidence approach for a wide range of constituents. SQGs had as a purpose the need to estimate the "safe" concentrations (i.e., concentrations below which effects were not likely) and values which when exceeded indicated that adverse effects were more likely. Therefore, two values were derived for each substance based on measured toxic effects on biota.

SQGs were derived initially using a database compiled from studies performed in both saltwater and freshwater and published in NOAA Technical Memorandum NOS OMA 52 (Long and Morgan 1990). A larger database compiled from many studies performed by numerous investigators in only saltwater was used to revise and update the SQGs (Long et al. 1995). Data from freshwater studies and/or of marginal quality used in 1990 were removed from the database in 1995, and a considerable amount of higher quality data was added to the database. Data from each study were arranged in order of ascending concentrations. Study endpoints in which adverse effects were reported were identified. From the ascending data tables, the 10th percentile and the 50th percentile (median) of the effects database were identified for each substance. The 10th percentile values were named the "Effects Range-Low" (ERL), indicative of concentrations below which adverse effects rarely occur. The 50th percentiles were named the "Effects Range-Median" (ERM) values, representative of concentrations above which effects frequently occur.

1995 Sediment Quality Guidelines

Based on the updated marine database assembled by Long et al. (1995), ERL and ERM values were calculated for 9 trace metals, 13 individual PAHs, 3 classes of PAHs, and 3 classes of chlorinated organic hydrocarbons (Tables G-1-1 and G-1-2). There were insufficient amounts of reliable data available to perform similar calculations for other substances, including a few previously reported by Long and Morgan (1990). The amount and quality of data used to derive the SQGs differed among the substances. Thus, to provide a measure of the reliability of the SQGs, the percentages of study endpoints indicating adverse effects were calculated for the chemical ranges defined by the ERLs and ERMs (Tables G-1-1 and G-1-2).

For all trace metals the percent of studies indicating adverse effects was less than 10% when concentrations were below the ERL values. For most organics, the incidence of effects was less than 25% when concentrations were below the ERLs. The incidence of effects increased to 20% to 30% for most trace metals and 40% to 60% for most organics when concentrations exceeded ERL values but were lower than the ERM values. When concentrations exceeded the ERM values, the incidence of adverse effects increased to 60% to 90% for most trace metals and 80% to 100% for most organics. However, the reliabilities of the ERMs for nickel, mercury, DDE, total DDTs, and total PCBs were much lower than those for other substances making predictions of effects less accurate than other chemicals.

The guidelines are commonly used by NOAA and others in North America both to rank and prioritize sites of concern and chemicals of concern. Using the SOGs, one can predict that samples or study areas in which many chemicals exceed the ERM values and exceed them by a large degree may be considered as more contaminated than those in which none of the SQGs are exceeded. Samples in which ERL concentrations are exceeded, but no ERM values are exceeded, might be given intermediate ranks. Similarly, chemicals at concentrations well above the ERM values might be given a higher priority than those at concentrations below the ERLs. Caution should be exercised when prioritizing sites or chemicals where chemicals where only the concentrations of nickel, mercury, DDE, total DDTs, or total PCBs are elevated.

SQGs can be used along with the results of toxicity tests to estimate the relative quality of sediments throughout a study area.

Field validation of predictive ability

To provide quantitative information on how well the SQGs correctly predict toxicity in actual field conditions, an analysis was conducted (Long et al. 1998a) with existing data compiled from many regional assessments conducted by NOAA and EPA (including data from Pearl Harbor). NOAA matched chemistry and toxicity data (acute amphipod survival tests) from 1,068 samples from the Atlantic, Gulf of Mexico, and Pacific coasts were compiled into a database which was used to perform statistical tests to evaluate the probablility of toxicity when certain levels were exceeded..

United States Geological Survey Dredge Disposal Studies

For more than a century, material dredged from Pearl and Honolulu Harbors has been dumped in Mamala Bay off Oahu, Hawaii. Other human activities in upland watershed and in nearshore waters added add other materials to the bay as well including contaminants such as lead, copper, tributyltin from antifouling paints, pesticides such as DDT, chlordane and dieldrin, and various hydrocarbons and synthetic organics. Until studies were initiated in the 1990's it was not known how the dredged material and these other contaminants are affecting the environment.

In 1991, the USGS began studying the dredged material in cooperation with the U.S. Army Corps of Engineers and the Environmental Protection Agency (EPA). Initial studies focused on mapping the material's distribution and thickness, determining its physical and chemical makeup, assessing its effect on sea floor life, and finding out whether it is being moved by currents. The project was subsequently expanded to look at the distribution and fate of all types of waste materials on the waters of Mamala Bay.

Mapping by sidescan sonar which creates images of the sea floor from reflected sound waves was used to determine the precise location of disposed dredge material offshore Honolulu. Samples of the dredged material were collected to determine their physical and chemical characteristics and how they might impact benthic biota.

Bottom photographs have revealed that bottom currents are of sufficient strength to move sand, mud and dredged material. Current meters were placed at a disposal site about 1.5 miles south of Honolulu Harbor to determine whether currents are moving the dredged material and whether it is being carried back toward the coast.

Mamala Bay Marine Disposal Sites

The South Oahu disposal site (OD0912) is the only active disposal site in Mamala Bay and services Pearl, Honolulu, and Barbers Point harbors. The site is defined by a skewed rectangle having the boundary coordinates 21° 15.97'N and 157° 57.33'W; 21° 15.4'N and 157° 55.97'W; 21°14.97'N and 157° 56.37'W; 21° 14.4'N and 157° 56.37'W. The site's center coordinates are 21° 15.16'N and 157° 56.83'W, and the site is located about 4.6 n mi (7.8 km) south of the entrance to Pearl Harbor (Figure G-1-3). Two other disposal sites are located in Mamala Bay, the Old Pearl Harbor and the Old Honolulu

Harbor disposal sites (Figure G-1-3). These later two sites have been inactive since 1980. The Mamala Bay sea floor and the disposal sites are described in detail in Torresan et al. (1995 a, 1995b, 1996, 1998, and 1999), Hampton et al. (1997), and EPA (1980).

The bathymetry and sea floor of Mamala Bay are highly varied. Water depths in the surveyed area vary from about 35 m on the shelf to over 600 m on the southeast corner of the area and exceed 1100 m in the southwest corner of the USGS survey area. The Bay's shelf is less than 50 m deep and extends a minimum distance of 600 m from shore off Diamond Head to a maximum of nearly 5,000 m east of Barber's Point. An extensive prominent step, the Mamala shelf occurs at the seaward edge of the insular shelf, at water depths to about 100 m. Profiles collected in 1993 and 1994 indicate that the step typically is a planar notch cut into the otherwise steeper slope (Hampton et al., 1997). Stearns (1978) observed a drowned reef on the Mamala shelf during submersible dives. A broad trough occurs seaward of the insular shelf with an average slope of about 1° in a south to southeast direction. Most of the disposal sites are contained within this trough. The head of the trough, from about 100 to 300 m water depth, is steep (~12°) with some local steps. The floor of the trough has slightly irregular topography generally of less than a few meters relief, although occasional outcrops of drowned reefs exceed heights of 100 m (Torresan and Gardner, 2000). The trough is bounded on the southwest by a southeast-trending platform that is underlain by a drowned reef that is dissected by a canyon. The platform extends seaward from the widest part of the shelf with the trough bounded on the northeast by the steep slope that leads up to Diamond Head. The entire region greater than about 200 to 300 m deep has been called the Lualualei shelf by Stearns (1961) and the 500-meter shelf by Kroenke and Wollard (1966). The shelf is thought to have been sculpted into basaltic basement rocks by wave action, then locally overgrown by reefs during subsidence to its present depth (Gregory and Kroenke, 1982).

The USGS studies showed that the extent of each dredged material deposit substantially exceeds the area of the three designated disposal sites. Bottom sampling shows that the dredged material is up to 40 cm thick, and comprises a poorly sorted cohesive gray mud mixed with sand-to cobble-size rubble and anthropogenic debris (Torresan et al, 1995a, 1995b, 1996; Hampton et al., 1997). Cores show that the natural, sediment is carbonate sand, composed of carbonate reef and microfauna debris with some volcanic grains (Hampton et al., 1997). Bottom video shows that the sea floor is littered with a variety of anthropogenic debris types including wire rope, 55 gallon drums, military ordnance, refuse, tires, bottles, cans, pottery, concrete blocks and other material (Torresan and Gardner, 2000)..

Bottom photographs of the area show winnowed dredged material and box cores show evidence of the post-disposal burial of dredged material by natural sediment (Torresan et al., 1996; Hampton et al., 1997). The data from current metering (episodic, near-bed velocities of 50 cm/sec) and sonar scans of large bedforms imply a westerly to northwesterly transport direction, along contours or up-slope, although there are a few areas of easterly indicators (Hampton et al., 1997). The bedforms show that bottom currents can be mechanism for transport of dredged materials and any associated contaminants.

The results of the 1998 multibeam survey provide abundant evidence that anthropogenic dredged-material deposits are present at six of the seven Hawaiian disposal sites. Studies show the dredged-material deposits in Mamala Bay cover more than 100 km^2 of sea floor and are more extensive than the area defined by the disposal site boundaries (Torresan and Gardner, 2000)..

EPA'S Previous Findings Regarding Metal Contaminants Near the Sand Island Outfall

EPA in its 1998 Tentative Decision found that median concentrations of 10 metals measured were relatively similar among stations. However, arsenic, chromium, lead, nickel, and zinc tended to be higher at Stations B1 and B6 (old permit Reference Stations), farthest from the discharge. Average nickel concentrations exceeded the Effects Range-Low (ERL) value of 30 ug/Kg (Long and Morgan 1990) at Reference Station B6 for all years monitored. Nickel concentrations at Reference Station B6 were significantly greater than at all other stations, in some cases, by an order of magnitude. Considerably higher concentrations of nickel and silver were measured at all stations in 1993, which suggest the possibility of systemic sample contamination or variable analytical procedures.

EPA concluded that there were no temporal trends in the data and no consistent outfall-related spatial trends. Reference Station B6 consistently showed higher concentrations of metals: arsenic, nickel, chromium, lead and possibly zinc. This did not appear to be outfall-related because stations nearer to, and on the same side of, the outfall, as Station B6, did not contain elevated amounts of these metals. The higher concentrations found at the Station B6 suggested that loadings of these metals were not derived from the Sand Island outfall.

EPA'S Previous Findings Regarding Organic Contaminants Near the Sand Island Outfall

In its 1998 Tentative Decision Document, EPA reported that between 1990 and 1995 approximately 40 organic sediment contaminants were detected in the vicinity of the Sand Island outfall. These included two volatile, 20 semi-volatile and 18 chlorinated organic compounds that were detected in at least one sample during this period. EPA noted that considerable variability was observed in the contaminant types detected both among the stations and measured concentrations. EPA found that because these chemicals were detected so infrequently, no statistical comparisons could be made.. However, EPA noted in its review of the maximum PAH and organochlorine pesticide concentrations that the predominant organic contaminant influences were at Stations B3, Z, and B6, particularly for PAH compounds. EPA noted that according to the CCH, ~~the reason for these differences was unclear. EPA noted that the wide variation in~~ detection limits obscured any other spatial or temporal trends.

EPA's Summary of the Effects Transport and Dispersion of Diluted Wastewater and Particulates

EPA found in its 1998 TDD that the information presented in the CCH's 1994 reapplication indicated that, following initial dilution, the wastewater and particulates were transported and dispersed in such a way that benthic sediments would not be adversely affected. Solids did not appear to accumulate around the outfall such that they adversely impact the benthos. Furthermore, it was consistent with data presented during the first 301(h) permit term that showed no consistent increases in sediment contaminant concentrations in the vicinity of the Sand Island outfall. While the data suggested certain spatial trends in some metals at Reference Station B6, and PAH and organochlorine compounds at Stations B3, Z and B6 (old monitoring stations), conclusive evidence was not collected. Statistical comparisons could not be made because contaminants were detected so infrequently.

Kimmerer and O'Connor (1996) provided similar conclusions as part of the Mamala Bay Study. EPA noted that as more data are collected through subsequent monitoring, it would be better able to evaluate the effect of the discharge and determine trends over time. EPA indicated that pollutant concentrations in the sediments are not expected to increase over time because the CCH's pretreatment program is designed and implemented to ensure that loadings of these pollutants are limited.

EPA concluded that the Sand Island discharge would not increase the concentrations of toxic substances in marine sediments to levels that will degrade marine biota. The long-term sediment monitoring program recommended by the Mamala Bay Study Commission (1996) was evaluated and there were major changes made in the monitoring program included in the 1998 301(h) modified permit to provide for collecting data over a much wider area of Mamala Bay to help assess the impacts from other sources.

Recent Sediment Trace Metals Monitoring Results (1998-2002)

Sediment trace metals monitoring from the outfall monitoring studies performed in compliance with the CCH's Sand Island WWTP NPDES permit were performed during three of the five years. Regional monitoring was to be performed during the other two years. Regional results are available for the year 2001. Average concentrations for all core monitoring stations are summarized for the three years (1999, 2000, and 2002) at the 15 monitoring stations in Table G-1-3. A summary of the minimum and maximum values measured at the core stations and the station at which the particular value was measured as presented in Table G-1-4. The average results are grouped according to the depth of the stations and summarized in Table G-1-5. Table G-1-6 shows the summary of results (minimum, maximum and average for the ZOM stations and compares these to SQG values (called criteria). Table G-1-7 presents the average results for individual ZOM stations. Table G-1-8 presents the range of results from the regional sampling at 40 stations, native sediment quality as measured by the USGS in comparison to the core and ZOM concentrations along with the SQG values (Long and Morgan, 1995).

Table G-1-9 presents a summary of results showing the range of values measured in sediments from the areas where dredge disposal has occurred and what the USGS has termed native sediments (background). As shown, it is apparent that dredge disposal activities results in a rough doubling of background levels of metals as a result of the placement of contaminated harbor sediments in offshore areas (USGS, 2000). The quality of the dredge disposal sediments for both operational areas of Pearl Harbor and general composite samples are presented in Tables G-1-10 and G1-11. Data from the deep water disposal sites are presented in Table G-1-12 based on the studies undertaken by the U.S. Geological Survey in 1994 and 1995 and posted on the internet and presented in published papers (Torresan et al, 1995; Torresan et al., 1996 and U.S. Geological Survey, 2003). These data are discussed further in the discussions of the individual metals which follows.

Aluminum

In Mamala Bay, aluminum in sediments has been found to be in the range of 106 to 3800 ppm over the region (based on EMAP regional monitoring study)(Table G-1-8). The highest level measured was 3800 ppm at Station 93 at a depth of 19 meters off Honolulu Harbor (Table G-1-8 and Figure G-1-2)(CCH, 2002). Concentrations in the 400-500 meter depths where dredge disposal has occurred were not measured by the USGS (Torresan et al, 1995; Torresan et al., 1996 and U.S. Geological Survey, 2003). Also, aluminum measurements were not made on Pearl Harbor sediments (Schroeder and Palermo, 2000).

At the Sand Island outfall ZOM, aluminum has ranged between 315 ppm (Station D3A) and 1080 (Station E3) averaging 776 ppm (Tables G-1-6 and G-1- 7). Overall, the range of concentrations in the core monitoring stations as been from 243 to 1880 ppm with the lowest concentration being found at Station C5A and the highest at Station D5 (Table G-1-3). Average concentrations over the shelf have ranged from 326 ppm for the 20 meter depth C stations (stations C1A, C2A, C3A, C5A and C6) 965 ppm for the 50 meter depth D stations and 1165 ppm for the 100-meter depth E Stations. Overall, the D and E stations average was higher than the average of the four ZOM stations which averaged 776 ppm (Tables G-1-5 and G-1-6).

There is no ER-L or ER-M value for aluminum (Table G-1-1) which ins not considered to be toxic to marine organisms at levels found in sediments.

Arsenic

Arsenic is a common semi-volatile trace element, well known for its toxic effects. It occurs naturally in seawater in various forms. In organisms, it is detoxified via production of organic forms of arsenic which are less toxic and more readily excreted. Hawaiian waters, including Mamala Bay, experience elevated levels of arsenic in the environment because of the volcanic activity which is known to contribute arsenic releases to the ocean. One well documented source in coastal waters which is a significant natural source of arsenic is the Punta Bunda submarine hot springs in Baja California (Lindstrom, 1995 in City of San Diego, 1995). These hot springs discharge water containing 420,500 ug/l (ppb) arsenic compared to 3 ppb in seawater and 1.8 to 2.9 ppb in the Point Loma wastewater effluent in San Diego.

Arsenic is of interest because it is known to be naturally high in sediments in the marine environment. While high arsenic levels can often be found, it is important to note that only the organic fractions of available arsenic are of health concern. The organic portion is often less than 20 percent of the total arsenic reported in analyses. Using total arsenic values can contribute to a high percentage of the risk of cancer when used in a standard human risk assessment model incorporating fish consumption (CCH, 2003 and CSDOC, 1993). Thus any modeling efforts must be adjusted to account for the organic fraction which requires a different analysis.

In Mamala Bay, arsenic in sediments has been found to be in the range of 0.7 to 16.2 ppm over the region (based on EMAP regional monitoring study)(Table G-1-8). The highest level measured was 16.2 ppm at Station 84 at a depth of 61 meters off the mouth of Pearl Harbor (Table G-1-8 and Figure C-1-2)(CCH, 2002). Concentrations in the 400-500 meter depths where dredge disposal has occurred were found to range from 1.8 to 51.6 ppm averaging 10.4 ppm (Tables G-1-9 and G-1-12)(Torresan et al, 1995; Torresan et al., 1996 and U.S. Geological Survey, 2003). Pearl Harbor has been shown to have maximum levels of 15.5 ppm in operational areas (piers, wharves, etc.) averaging between 10 ppm (Table G-1-10) (Schroeder and Palermo, 2000). In composites within the harbor areas of Pearl Harbor had concentrations ranging from 0.016 to 0.91 ppm averaging 0.285 ppm Table G-1-11 (Schroeder and Palermo, 2000).

At the Sand Island outfall ZOM, arsenic has ranged between 2.8 ppm (Station D3A) and 7.1 ppm (Station E2) averaging 5.0 (Tables G-1- 6 and G-1- 7). Overall, the range of concentrations in the core monitoring stations as been from 2.8 to 14.8 ppm with the lowest concentration being found at Station C3A and the highest at Station D5 (Table G-1- 4). Average concentrations over the shelf have ranged from 4.05 ppm for the 20 meter depth C stations (stations C1A, C2A, C3A, C5A and C6) 6.77 ppm for the 50 meter depth D stations and 6.2 ppm for the 100-meter depth E Stations. Overall, the D and E stations average was higher than the average of the four ZOM stations which averaged 5.0 ppm (Tables G-1-5 and G-1-6).

Overall, levels found near the outfall (2.8 - 14.8 ppm and averaging below 5 ppm) are below the ER-L level of 8.2 ppm and the ER-M value of 70 ppm (Tables G-1- 3 and G-1-4). This is indicative that there is little likelihood of adverse biological effects from the sediment concentrations found in Mamala Bay near the Sand Island outfall diffuser.

However, values in Pearl Harbor's operational areas and EMAP stations 94, 93 and 96 exceed the ER-L values and might be in a range to have biological effects (Table G-1-13)..

Arsenic is a widespread natural substance found in particularly high environmental levels near thermal vents and other volcanic activity where the release can cause widespread measurable increases in the water and tissues of marine organisms (City of San Diego, 1995 and 2000). This same phenonomenon appears to be the case in Mamala Bay where arsenic levels in sediments and fish muscle tissue are higher than what has been found in other areas.

Monitoring studies have shown that arsenic does accumulate through the food chain (Moore and Ramanoorthy, 1984; Mearns et.al. 1992). However, the high levels found are for total arsenic of which an estimated 90-95 percent may be in the non-toxic organic form (Washington Department of Ecology, 1995). See Appendix H for more discussion on bioaccumulation.

Beryllium

In Mamala Bay, beryllium in sediments has been found to be in the range of 0.02 to 0.17 ppm at the EMAP monitoring stations samples in 2001 (Table G-1-8). The highest concentration was measured at Station 93 with a sea floor depth of 19 meters off Honolulu Harbor (Table G-1-2)(CCH, 2002). No beryllium analyses were performed at the 400-500 meter depths where dredge disposal has occurred (Torresan et al, 1995; Torresan et al., 1996 and U.S. Geological Survey, 2003). Also, this metal was not measured in the various studies done of Pearl Harbor sediments, so there is no comparative data (Schroeder and Palermo, 2000).

At the Sand Island outfall ZOM, beryllium has ranged from below detection limits (BDL) or not detected (ND) at stations D2 and D3A to 0.04 ppm (Station E3) averaging 0.03 ppm (Tables G-1-6 and G-1-7). Overall, the range of detectable concentrations in the core monitoring stations as been from 0.02 to 0.08 ppm with the lowest concentration being found at Stations D6 and D3A (ZOM station) and the highest at Station D5 (Table G-1- 4). Average concentrations over the shelf have been 0.04 ppm which is higher than the average of 0.03 ppm for the four ZOM stations (Tables G-1-3 and G-1-6).

Overall, levels found near the outfall (ND - 0.04 ppm and averaging below 0.03 ppm) cannot be compared to toxicity-inducing levels since there has been no ER-L or ER-M values developed (Table G-1-13). This is indicative that beryllium has little likelihood of adverse biological effects from the sediment concentrations found in most environments.

Cadmium

In Mamala Bay, cadmium in sediments has been found to be in the range of 0.08 to 0.23 ppm at the EMAP monitoring stations (based on the 2001 regional monitoring study) (Table G-1-8). The highest level being found at Station 82 at a depth of 74 m off Ewa Beach (Table G-1- 8 and Figure G-1-2)(CCH, 2002). Concentrations in the 400-500 meter depths where dredge disposal has occurred were found to range from 0.02 to 0.22 ppm and averaged 0.07 ppm (Tables G-1-9 and G-1-12)(Torresan et al, 1995; Torresan et al., 1996 and U.S. Geological Survey, 2003). Pearl Harbor has been shown to have maximum concentrations of 1 ppm in operational areas (piers, wharves, etc.) averaging 0.45 ppm (Table G-1-10). In composites within the harbor areas of Pearl Harbor, concentrations ranging from 0.3 to 1.5 ppm averaging 0.8 ppm (See Table G-1-11)(Schroeder and Palermo, 2000).

At the Sand Island outfall ZOM, cadmium has ranged between 0.06 ppm (Station E3) and 0.15 ppm (Station 3A) averaging 0.11 ppm (Tables G-1- 6 and G-1- 7). Overall, the range of concentrations in the core monitoring stations as been from 0.08 to 0.18 ppm with the lowest concentration being found at Stations D2 and D3A and the highest at Station E5 (Table G-1- 4). Average concentrations over the shelf have been 0.12 ppm which is slightly higher than the average of 0.11 for the four ZOM stations (Tables G-1-3 and G-1-6).

Overall, levels found near the outfall (0.02 - 0.08 ppm and averaging 0.11) are an order of magnitude below the ER-L level of 1.2 ppm and the ER-M value of 9.6 ppm (Tables G-1-3 and G-1-4). This is indicative that there is little likelihood of adverse biological effects from the sediment concentrations found near the Sand Island outfall diffuser.

Chromium, Total

Chromium levels in Mamala Bay sediments has been found to vary widely over the range of 3.1 to 25.9 ppm at the EMAP monitoring stations sampled in 2001(Table G-1-8). The highest level being found at Station 94 at a depth of 18 m near Honolulu Harbor Figure G-1-2)(CCH, 2002). Concentrations in the 400-500 meter depths where dredge disposal has occurred were found to range from 15.4 to 114 ppm and averaged 52 ppm (Tables G-1-9 and G-1-12)(Torresan et al, 1995; Torresan et al., 1996 and U.S. Geological Survey, 2003). Pearl Harbor has been shown to have maximum levels of 359 ppm in operational areas (piers, wharves, etc.) averaging 140 ppm (Table G-1-10). In composites within the harbor areas of Pearl Harbor had concentrations ranging from 7.4 to 35.5 ppm averaging 23.3 ppm (See Table G-1- 11(Schroeder and Palermo, 2000).

At the Sand Island outfall ZOM, chromium has ranged between 8.8 ppm (Station D3A) and 13.6 ppm (Station E2) averaging 11 ppm (Tables C-1-6 and C-1-7). Overall, the range of concentrations in the core monitoring stations as been from 7.8 to 22.7 with the lowest concentration being found at Station C5A and the highest at Station D5 (Table G-1-4). Average concentrations over the shelf have been 12.6 ppm which is higher than the average of 11 ppm at the four ZOM stations (Tables G-1-3 and G-1-4) indicating no outfall-related enrichment.

Overall, levels found near the outfall (7.8 - 22.7 ppm and averaging below 11 ppm) are significantly below the ER-L level of 81 ppm and the ER-M value of 370 ppm(Tables G-1-3 and G-1-4). This is indicative that there is little likelihood of adverse biological effects from the sediment concentrations found near the outfall diffuser. Pearl Harbor was found to have sediments that exceeded both the ER-L and ER-M values and efforts are underway to find alternatives to ocean disposal of sediments that exceed applicable disposal criteria (Schoeder and Palermo, 2000).

Copper

Copper concentrations In Mamala Bay sediment concentrations have been shown to range from 1.1 to 49.9 ppm over the EMAP regional monitoring study area (Table G-1-8 and Figure G-1-2). The highest level was measured at Station 94 at a depth of 18 m off Honolulu Harbor (Figure G-1-2)(CCH, 2002). Concentrations in the 400-500 meter depths where dredge disposal has occurred were found to range from 4.2 to 32.2 ppm (Tables G-1-9 and G-1-12)(Torresan et al, 1995; Torresan et al., 1996 and U.S. Geological Survey, 2003). Pearl Harbor has been shown to have maximum levels of 435 ppm in operational areas (piers, wharves, etc.) averaging 225 ppm (Table G-1-10). In composites within the harbor areas of Pearl Harbor concentrations ranging from 3.7 to 79.4 ppm and averaged 27.1 ppm in the open harbor areas (See Table G-1-11) (Schroeder and Palermo, 2000).

At the Sand Island outfall ZOM stations, copper has ranged from 1.16 (Station E2) to 4.2 ppm (Station E3)(Tables C-1-6 and C-1-7) averaging 2.2 ppm (Tables G-1-6 and G-1-7). Overall, the range of concentrations in the core monitoring stations has ranged from 0.56 to 4.5 ppm with the lowest concentration being measured at Station C6 and the highest at Station D1 (Table G-1-3 and Figure C-1-1). Average concentrations over the shelf have been 2.17 ppm which is about the same as the average for the ZOM stations which averaged 2.2 ppm (Tables G-1-3 and G-1-7) indicating no enrichment as a result of wastewater discharge.

Overall, levels found near the outfall (0.56 - 4.5 ppm and averaging below 2.2 ppm) are significant lower than the ER-L level of 34 ppm and the ER-M value of 270 ppm (Tables G-1-3 and G-1-6). This is indicative that there is little likelihood of adverse biological effects from the sediment concentrations found in Mamala Bay except for some locations in Pearl Harbor and at Station 96 of the regional monitoring program (Table G-1-13).

Iron

Iron is not a contaminant, but used along with aluminum as an index and normalizer for determining enrichment rations in contaminated sediments.

In Mamala Bay, iron in sediments has been found to be in the range of 130 to 10,200 ppm over the region (based on regional monitoring study)(Table G-1-8). The highest level being found at Station 93 off Honolulu Harbor(Figure G-1-2)(CCH, 2002). The USGS dredge disposal sediment survey did not analyze samples for iron (Torresan et al, 1995; Torresan et al., 1996 and U.S. Geological Survey, 2003). Pearl Harbor sediment iron levels have also not been reported as having been analyzed (Schroeder and Palermo, 2000).

In the Sand Island outfall ZOM, iron has ranged between 1090 ppm (Station D3A) and 2950 ppm (Station E3) averaging 1914 ppm (Tables G-1-6 and G-1-7). Overall, the range of concentrations in the core monitoring stations as been from 691 to 5700 ppm with the lowest concentration being found at Station C5A and the highest at Station D5 (Table G-1-3). Average concentrations over the shelf appear to have a depth gradient. The average for the 20 m C Stations was 1130 ppm, for the 50 m D Stations 2474 ppm, and for the 100 m E Stations 2706 ppm. Average concentrations over the shelf have been 2164 which is about the same as the four ZOM stations which averaged 1914 ppm (Tables G-1-3 and G-1-7).

There is no ER-L level or ER-M value for iron because is not a toxicant in marine sediments.

Lead

Lead in the environment has been derived from its historical use in paint, gasoline, storage batteries and various metal products. The phasing out of lead in gasoline has brought about a dramatic reduction in airborne lead which deposited on land where it was washed into local surface waters flowing to the ocean. Natural or background levels of lead are typically less than 10 mg/Kg dry weight (Moore and Ramanoorthy, 1984). Levels in excess of 10,000 mg/Kg have been reported as a result of contamination from mines and smelters.

Sediments in nearshore marine environments have been shown to have levels in the range of 1-76 mg/Kg in the U.S. (Moore and Ramanoorthy, 1984). In Mamala Bay, lead in sediments has been found to be in the range of 0.61 to 151 mg/Kg (ppm) with the highest level being found at Station 61 near Barbers Point as reported in the CCH AAR of 2001.

In the Sand Island outfall ZOM, lead has averaged between 1.49 mg/Kg (Station E2) and 3.03 mg/Kg (Station E3)(Table G-1-7), a relatively narrow range. Across the shelf, the core monitoring stations have ranged from 1.18 to 5.02 ppm, averaging 2.48 ppm (Tables G-1-3 and G-1-8). Sediments in Pearl Harbor have been found to have lead levels in the range of 8.6 to 55.3 mg/Kg with the mean of 12 composite samples being 31.1 mg/Kg dry wt. (Table G-1-11) In Pearl Harbor operational areas which are more contaminated, mean levels have ranged from 49.3 to 209 mg/Kg and averaging 150 ppm (Table G-1-10) with maximum levels of 509 ppm and in the range that is known to have toxic effects on marine invertebrates (Table G-1-13)(Long and Morgan, 1995).

At offshore dredge disposal sites, levels were much lower ranging from 0.45 to 35.6 ppm and averaging 7.5 ppm (Table G-1-12). It appears that such levels are typical of

Mamala Bay dredge sites which have been enriched by about 3 ppm compared to background (native sediments) levels (Table G-1-12).

Mercury

Mercury concentrations in Mamala Bay sediments monitored in 2001 as part of the regional EMAP program were found to be in the range of 0.02 to 3.45 ppm [based on a very limited number of samples (5) that had levels above the detection limits] (Table G-1- 8). The highest level being found at Station 93 at a depth of 19 m off Honolulu Harbor (Figure G-1-2)(CCH, 2002). Concentrations in the 400-500 meter depths where dredge disposal has occurred were found to range from 0.02 to 0.62 pp, ane averaging as high as 3.4 ppm at the South Oahu disposal site (Tables G-1-9 and Table G-1-12)(Torresan et al, 1995; Torresan et al., 1996 and U.S. Geological Survey, 2003). Pearl Harbor has been shown to have levels ranging up to 2.43 ppm in operational areas (piers, wharves, etc.) averaging 0.8 ppm (Table G-1-10). Composites within the harbor areas of Pearl Harbor had concentrations ranging from 0.082 to 0.49 ppm dry wt. averaging 01.9 ppm for various operational areas (See Table G-1-11(Schroeder and Palermo, 2000).

At the Sand Island outfall ZOM stations, mercury has ranged between <0.02 ppm (Station D2) and 0.06 ppm (Station E3)(Tables G-1-6 and G-1-7). Overall, the range of concentrations in the core monitoring stations as been from 0.02 to 0.08 ppm with the lowest concentration being found at Stations D2 and D3 and the highest at Station E1 (Table G-1-4). Average concentrations over the shelf have been 0.03 ppm (Table G-1-3) which is higher than the average of 0.02 ppm for the four ZOM stations (Table G-1-7)..

Overall, levels found near the outfall (<0.02-0.08 ppm averaging below 0.03 ppm) are well below the ER-L level of 0.15 ppm and the ER-M value of 0.7 ppm (Table G-1-8). This is indicative that there is little likelihood of adverse biological effects from the sediment concentrations found in Mamala Bay.
Muscle tissue levels of mercury in marine fish have been found to be relatively high in many popular edible species in the United States. Mercury is the primary trace metal for which consumption advisories have been issued by the U. S. Food and Drug Administration, EPA, and state health departments (U. S. EPA 2003 Fish Consumption Advisory Web site). The highest levels of mercury are found in the pelagic fish at the upper end of the food web such as tuna and swordfish. For more on mercury levels in fish see Appendix H.

Nickel

Nickel is abundant in the ocean being one of the components of the manganese nodules covering much of the sea floor. It has been estimated that up to 20% of the world production of nickel could come from deep-sea nodules (Moore and Ramanoorthy, 1984). Nickel is a common component in more than 3000 different alloys including stainless steel and alloy steels, ductile and cast irons, and many other common products used to convey water and wastewater. They are also used on common products for marine operations because of their corrosion resistance. Background levels of nickel in the Pacific ocean are somewhere in the range of 9-14 mg/Kg dry wt.. Sediments in nearshore marine environments have been shown to have levels in the range of 1-76 mg/Kg in the U.S. (Moore and Ramanoorthy, 1984).

It is appears that background level of nickel in Mamala Bay sediments are high. Nickel levels in sediments has been found to be in the range of 1.1 to 69.9 ppm at the EMAP monitoring stations sampled as part of the regional monitoring study completed in 2001 (Table G-1-8). The highest level being found at Station 94 at a depth of 18 m off Honolulu Harbor (Table G-1-8 and Figure G-1-2)(CCH, 2002). Concentrations in the 400-500 meter depths where dredge disposal has occurred were found to range from 13.3 to 56.2 ppm and average 31 ppm (Tables G-1-9 and G-1-12)(Torresan et al, 1995; Torresan et al., 1996 and U.S. Geological Survey, 2003). Pearl Harbor has been shown to have a maximum concentration of 218 ppm in operational areas (piers, wharves, etc.) averaging 95 ppm (Table G-1-10). In composites within the harbor areas of Pearl Harbor had concentrations ranging from 6.7 to 39.2 ppm averaging 28 ppm (See Table G-1-11 (Schroeder and Palermo, 2000).

Nickel levels at the Sand Island outfall ZOM stations has ranged between 2.0 ppm (Station D3A) and 15.1 ppm (Station E3) averaging 7 ppm (Tables G-1-6 and G-1-7). Overall, the range of concentrations in the core monitoring stations as been from 1.7 to 22.6 ppm with the lowest concentration being found at Station C3A (ZOM) and the highest at Station D5 (Tables G-1-3 and G-1-4). Average concentrations over the shelf have been 8.2 ppm which is slightly higher than the average of 7.0 ppm at the four ZOM stations (Table G-1-3 and G-1-6).

Overall, levels found near the outfall (1.7 - 15.1 ppm and averaging 7 ppm) are below the ER-L level of 20.9 ppm and the ER-M value of 51.6 ppm (Table G-1-_). This is indicative that there is little likelihood of adverse biological effects from the sediment concentrations near the outfall. The highest level measured (Station D-5) slightly exceeds the ER-L value indicating the potential for measuring a biological effect (amphipod bioassay). Nickel levels in Pearl Harbor and at the EMAP stations 84,94,96 and 98 exceeded the ER-L criterion and at Station 93, the ER-M value was exceeded by the 69.9 ppm level at this station. Given only a single sample was taken at one point in time, additional monitoring data is needed to put these values in perspective.

Nickel is not a significant or widespread contaminant in most marine sediments with levels in most industrial parts of the world in the range of 50-100 mg/Kg. Near smelters concentrations have been found to be as high as 500 mg/Kg or more (Moore and Ramanoorthy, 1984) where it was also found that nickel levels were high in the fish from nearby freshwater lakes and rivers.

Monitoring studies have shown that nickel does not accumulate through the food chain (Moore and Ramanoorthy, 1984; Mearns et al. 1992). Tissue levels of marine fish have been found to range from 0.5 mg/Kg to 7.2 mg/Kg wet wt. in the United Kingdom. For more discussion on levels in fish see Appendix H.

Silver

In Mamala Bay, silver concentrations in sediments has been found to be in the range of 0.03 to 0.11 ppm the region sampled as part of the EMAP regional monitoring study completed in 2001 (Table G-1-8). The highest level being found at Station 94 at a depth of 18 m. near Honolulu Harbor (Figure G-1-2)(CCH, 2002). Concentrations in the 400-500 meter depths where dredge disposal has occurred were found to range from 0.02 to 0.11 ppm (Tables G-1-9 and G-1-11(Torresan et al, 1995; Torresan et al., 1996 and U.S. Geological Survey, 2003). Pearl Harbor has been shown to have maximum levels of 2.1 ppm dry in operational areas (piers, wharves, etc.) averaging 1.25 ppm (Table G-1-10). In composites within the harbor areas of Pearl Harbor concentrations ranging from 0-0.4 to 3.7 ppm averaging 1.6 ppm (See Table G-1-11)(Schroeder and Palermo, 2000).

In the Sand Island outfall ZOM, silver has ranged between 0.04 ppm (Station E2) and 0.24 ppm (Station D2)(Tables G-1- 6 and G-1-7). Overall, the range of concentrations in the core monitoring stations has ranged between 0.021 and 0.24 ppm with the lowest concentration being found at Station D6 and the highest at Station D2 (Tables G-1-3 and G-1-4). Average concentrations over the shelf have been 0.07 ppm which is lower than the average of 0.10 for the four ZOM stations (Table G-1-3) indicating a slight enhancement within the ZOM as has been shown by most ocean outfall monitoring studies.

Overall, levels found near the outfall (0.021 - 0.24 ppm and averaging below 0.10 ppm) are well below the ER-L level of 1.0 ppm and the ER-M value of 3.7 ppm (Table G-1-_). Such low levels are indicative of a low potential for adverse biological effects from the sediment concentrations found in Mamala Bay or near the outfall diffuser.

Zinc

Zinc concentrations in the sediments of Mamala Bay sampled during the 2001 EMAP regional monitoring study were found to range from 0.8 to 42.8 ppm (Table G-1-8). The highest level being found at Station 94 at a depth of 18 m near Honolulu Harbor G-1-2)(CCH, 2002). Concentrations in the 400-500 meter depths where dredge disposal has occurred were found to range from 12.4 to 71.6 ppm and average 36 ppm (Tables G-1-9 and G-1-12)(Torresan et al, 1995; Torresan et al., 1996 and U.S. Geological Survey, 2003). Pearl Harbor has been shown to have maximum levels of 505 ppm in operational areas (piers, wharves, etc.) averaging 170 ppm (Table G-1-10). In composites within the harbor areas of Pearl Harbor, concentrations ranging from 23.8 to 107.3 ppm averaging 65 ppm (See Table G-1- 11)(Schroeder and Palermo, 2000).

In the Sand Island outfall ZOM, zinc has ranged between 2.8 ppm (Station D2) and 13.3 ppm (Station D3A) averaging 6.9 ppm (Tables G-1-6 and G-1-7). Overall, the

range of concentrations in the core monitoring stations has been between 1.4 and 16.3 with the lowest concentration being found at Station C5A and the highest at Station D1 (Tables G-1-3 and G-1-4). Average concentrations over the shelf have been 6.05 ppm which is lower than the average of 6.9 ppm for the four ZOM stations (Table G-1-3) indicating a slight enhancement within the ZOM, but still below the average for the 50 and 100 meter depth sampling stations (Table G-1-5). Zinc levels appear to be depth related since they increase as once moves across the shelf to deeper depths (Table C-1-5).
Overall, levels found near the outfall (2.8 - 13.3 ppm and averaging below 7 ppm) are and order of magnitude below the ER-L level of 150 ppm and the ER-M value of 410 ppm (Table G-1-13). This is indicative of no likelihood of adverse biological effects from the sediment concentrations of zinc found in the offshore areas of Mamala Bay and near the outfall. The only exception is in the operational areas of Pearl Harbor where values exceeded the ER-L and ER-M levels (Table G-1-13). As noted earlier, efforts are underway to find alternatives to the ocean disposal of dredge material from Pearl Harbor that exceeds criteria for ocean disposal (Schroeder and Palmero, 2000).

Conclusions Regarding Trace Metals Concentrations

Within the Mamala Bay area where sediment sampling has been performed it has been found that concentrations of the metals iron, aluminum, chromium, copper lead, and zinc, which have strong affinities for finer grained sediments and exhibited clear depth-related increases with negligible effects from the CCH's Sand Island wastewater discharge. Deeper areas are influenced by the disposal of dredged material which has been disposed of for years offshore in deeper water and carried shoreward and distributed across the shelf.

Differences in spatial patterns for the metals could be related to several factors including:

(1) different affinities for various sedimentary phases (such as aluminosilicates or organic coatings of particles);
(2) varying affinities of individual metals for different particle sizes; or
(3) differences in relative proportions of metals in the effluent versus those in bottom sediments

In evaluating the relative dominance of the various metals, a comparison of the relative concentrations of metals in different sectors of the environment provides some perspective.

For published information the concentrations of key trace metals in the earth's crust (Moore and Ramamoorthy, 1984) reported the following order of concentration of metals (highest to lowest):

Cr > Zn >Ni > Cr > Pb > As > Hg > Cd (they did not report on Al, Ag, Se, Th, Be, or An)

For the 14 trace metals measured in the Sand Island effluent the order of concentration is:

Zn > Cr > Al > Ni > Ag > Ag > Cr > Pb > Se > Th > As > An > Ce > Hg > Be

For the 12 trace metals measured in sediments [No thallium (Th) or selenium (Se)] the following order of concentrations was found for the Core and ZOM stations:

Core

Fe> Al > Cr > Ni > Zn > As > Pb > Cu > Cd > Ag > Be > Hg

ZOM

Fe> Al > Cr > Ni > Zn > As > Cu > Pb > Cd > Ag > Be > Hg

Note that the only difference between the core and ZOM stations is that copper is found at a slightly higher concentration in the ZOM.

For the dredge disposal sites in deeper water, the concentrations data shows that zinc and mercury concentrations are higher than the native sediments as shown by the order listed below:

Native sediments

Cr > Ni > Zn > As > Cu > Pb > Se > Cd > Ag > Hg

Dredge disposal sites

Cr > Zn > Ni > Cu > Pb > As > Hg > Ag > Cd > Se

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As summary of these various sediment data are presented in Table G-1-8. Also of interest is how these compare to sediment criteria used to screen to determine the potential for biological effects from high sediment concentrations of metals. A review and summary comparison of such a comparison is shown in Table G-1-13. As indicated, Pearl Harbor and some of the regional monitoring stations had higher levels of sediment metals. This has been recognized in Pearl Harbor and the Navy has been pursuing alternatives to dredge disposal at sea.

The traditional cadmium-silver distribution patterns in sediments around outfalls in the Southern California Bight (with fine-grained depositional sediment regimes) was not evident within the study area of Mamala Bay as were any other useful tracers for the wastewater discharge from Sand Island as it relates to sediment quality. Note that silver concentrations in tissues of marine bivalves (mussels) and in seawater have been used previously as a tracer for sewage in the marine environment (Martin et al. 1988; Sanudo-Wilhelmy and Flegal 1992).

The magnitude of metal concentrations in bottom sediments varied, based primarily on their abundances in source minerals. Concentrations of metals such as chromium, nickel and zinc which are relatively abundant in the earth's crust, are expected to be higher than those of mercury and silver, which typically are present at low levels in source materials.

Average metal concentrations in sediments from sampling stations along the 20, 50 and 100-m contours during the three years of core program monitoring are listed in Table G-1-5, along with corresponding concentrations averages for the depth as a whole.

Table G-1-9 compared core sediment data gathered by the USGS at various locations to assess the influence of dredge disposal activities on sediment quality. As is evident from the data, background levels or "native" sediment metals concentrations have been enhanced at least two-fold in areas where dredge disposal has occurred. This impact is much greater than any outfall impact that is discernible. In fact, it does not appear that there is any sediment enrichment to sediments as a result of the Sand Island discharge. Note that results for 2001 regional program are not shown because these samples were from different locations and were single samples, not replicates, thus are not statistically comparable to the core stations. Comparisons among years in average metal concentrations at the ZOM and other stations indicate that there is no consistent pattern.

As indicated in Table G-1-6, average sediment metal concentrations at the ZOM stations and all core monitoring stations during 1999-2002 were consistently below the corresponding ER-L and ER-M sediment quality criteria , which correspond, respectively, to bulk sediment concentrations below which effects to benthic organisms are rarely observed (ER-L) and levels above which effects are frequently observed or expected (ER-M). Of all of the sediment samples collected during the last permit period, only the maximum concentrations measured exceeded the ER-L values for some constituents. None of the ER-M values were exceeded. Sediments with metal concentrations that exceeded ER-L values were from Stations D1 (Pb), D5 (As), and D5 (Ni). None of these higher values were from ZOM stations. These occurrences of elevated metals (e.g., arsenic and nickel at Station D5) were probably due to natural sources and geochemical processes.

ORGANICS, PESTICIDES AND OTHER PRIORITY POLLUTANTS

Many of the compounds analyzed as part of the priority pollutant scans and analyses done using the NOAA Status and Trends list of analytes are organic compounds and include pesticides, polychlorinated biphenyls (PCBs) and polyaromatic hydrocarbons (PAHs). Most are at very low levels below the detection limits of 1.5 to 10 ug/Kg (part per billion). All of the values reported as ND or not detected for the period 1999 through 2002 were eliminated from the data base used for this analysis. Only the detectable concentrations were reported. Results for all the detected constituents listed in alphabetical order are presented in Table G-1-14. The same data is presented by station in Table G-1-15.

Detectable concentrations of non-metallic priority pollutants in the sediments of core monitoring stations are infrequently measured and at very low concentrations (Table G-1-14). The most frequently detected are polyaromatic hydrocarbons (PAHs), and very low concentrations of the ubiquitous compound group of polychlorinated biphenyls (PCBs). The compounds found in sediments were, for the most part, not detectable in the Sand Island effluent.

Of the 87 detectable samples measured in sediments, only 18 of the samples were from ZOM stations. Given that sampling is done only once a year, not much can be said about the low inconsistent concentrations of organics and PCBs. These compounds are found in urban runoff and dredge spoils and the source can be from any of a number of sources given the extremely low concentrations. When compared to the sediment quality criteria for organics (Table G-1-2) it is clear that the concentrations measured in Mamala Bay sediments are at least an order of magnitude below levels that are associated with biological effects (Long and Morgan, 1995).

Pesticides

Only a single analysis was positive for a pesticide over the past four years of sediment monitoring at the core stations. This was 4,4'-DDT at Station E2 at a concentration only 1.8 ppb or 0.3 ppb above the limits of quantification (Table G-1-14). No measurements showed the presence of chlordane or dieldrin that exceeded stringent effluent limits imposed on the Sand Island discharge. It is clear that pesticides are not sediment contaminants on the main shelf areas of Mamala Bay.

PCBs

Some of the more unusual PCB congeners have been detected at very low concentrations in sediments in August 2000 at stations C3A and C6. These two stations are far apart but at the same depth. From spotty low frequency detections such as this, once can conclude that there is some background level of PCBs in shelf sediments that are occasionally detectable. Such low levels are almost ubiquitous in nature.

Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons (PAHs) are compounds of carbon and hydrogen that consist of two or more benzene rings fused in linear or cluster arrangements. These compounds are also referred to as polynuclear aromatics (PAHs), or polyaromatics. PAHs and the monocyclic (single-ring) aromatic hydrocarbons (MAHs), such as ~~benzene, are collectively known as aromatic hydrocarbons. The aromatic hydrocarbons~~ are only one of several groups of hydrocarbons found in fossil fuels (petroleum, coal) and their refined or combustion products. The other classes of hydrocarbons include aliphatic hydrocarbons (including alkanes, alkenes, and alkynes) and a wide variety of compounds that also contain sulfur, nitrogen and/or oxygen. Presence of these other hydrocarbons can help identify possible sources of associated PAHs.

Environmental concern about PAH levels in the is derived from the fact that many are potent carcinogens or mutagens. Of the EPA's 129 Priority Pollutants, 16 are PAHs. Reports of cancers in humans from occupationally related PAH exposure date back to 1775 when a London surgeon observed cancers in chimney sweeps (Mearns, et al. 1992). By the early 1900s, it was widely recognized that soot (from inefficient combustion of coal), coal tar (a distillate of coal), and coal pitch (the distillate residue) are all carcinogenic to humans (Dipple, 1985). Skin, respiratory, and gastrointestinal tumors have been associated with occupational exposure to PAHs (Dipple, 1985). Marine environmental concerns stem from the work done by Shimkin *et al.* (1951) who were able to induce skin tumors in mice with extracts of barnacles taken from the entrance to Newport Bay in southern California. These pioneering researchers isolated 2,3 benzopyrene from the barnacles and considered it the causative agent.

Many PAHs are ubiquitous in nature, while others are more indicative of fossil fuel combustion or petroleum discharges. Several PAHs from combustion (fluoranthene and pyrene) increased have been shown to be deposited in nearshore marine sediment layers deposited over 100 years ago (Mearns, et al 1991). In 1985, it was estimated that annual United States emissions of PAHs alone to be about 1000 tons with approximately 37 percent of this is from heat and power generation, 44 percent from open burning, 17 percent from coke production, and 2 percent from automobile emissions (Dipple, 1985). In contrast, lighter molecular-weight compounds, such as naphthalene and phenanthrene, are the major PAHs detected in water when crude or refined oils are released (Anderson *et al.,* 1974; Lee, 1977). It is known that both naphthalene and phenanthrene readily methylate in water and the resulting alkylated forms are usually more toxic to aquatic biota than the parent compounds. The ratio of naphthalenes and phenanthrenes to total PAH (tPAH) residue, the fossil fuel pollution index (FFPI), has been used as a guide to indicate the degree of PAH contamination by petroleum products versus other sources (Mearns et al 1991)..

PAHs are metabolized in higher organisms by oxidation of the parent compounds to reactive, water-soluble epoxides which can often be more toxic than parent compounds. These compounds can be rendered nontoxic by conjugation with glutathione, a naturally occurring peptide. However, reactive metabolites such as epoxides are also free to damage essential proteins and enzymes, as well as DNA.

In the marine environment, PAHs, especially higher molecular-weight compounds, have been shown to adsorb to particulates. Sediment and water-column microbes can degrade PAHs, but the higher molecular-weight compounds take much longer to degrade as evidenced by sediment core data in estuaries close to urban areas with combustion sources (Mearns et al.,1991). Mammals, fish, and invertebrates have varying capabilities to metabolize PAHs (Varanasi *et al.,* 1985)., with the higher molecular-weight PAHs having a greater tendency to be bioaccumulated in species that do not metabolize them (shellfish). Fish are known to rapidly metabolize most PAH compounds and excrete them in bile, thus PAHs are not usually detected in fish muscle. However, bivalve mollusks (mussels and oysters) do not rapidly metabolize PAHs, thus making them useful indicators of PAH contamination of the marine environment.

Documented sources of PAHs in the marine environment from readily measurable sources include treated sewage, stormwater run-off, and oil spills. Other sources include aerial fallout, petroleum refinery wastes, discharges of drilling fluids and produced waters, natural oil seeps, and hydrothermal seeps.

In southern California, where good monitoring data exists, there is evidence that suggests that the PAH input from stormwater run-off might now exceed that from treated wastewater (which as a predominant source twenty years ago) (Mearns et.al., 1991). PAHs are probably included as part of the "oil and grease" fraction routinely measured in wastewater effluents. Thus any reductions in the total annual inputs of oil and grease, such as has occurred in from the Sand Island discharge, are likely to reduce PAH mass emissions.

PAH compounds analyzed by the NS&T Program have included the following:.

LOW MOLECULAR WEIGHT
napthalene
2-methylnaphthalene
1-methylnaphthalene biphenyl
2,6-dimethylnaphthalene
acenaphthene
1 -methylphenanthrene

HIGH MOLECULAR WEIGHT
fluoranthene
pyrene benz(a)anthracene
chrysole
benzo(e)pyrene
benzo(a)pyrene
perylene
dibenz(a,h)anthracene

The overall non-normalized mean level of tPAH in sediment measured by NOAA's NS&T Program between 1984 and 1989 was 1341.9 ppb dw (median 312.67 ppb dw)

It is clear from the data reviewed above that PAHs are natural components of shelf sediments but not in the ranges experienced in San Diego Harbor and near Los Angeles. This appears to be true even near chronic petroleum seeps and sites of crude oil spills such as the heavily oiled Santa Barbara shelf. Thus, "background" concentrations of total or tPAHs are probably those measured in the cleaner areas, in the range of 1 to 100 ppb. However, higher concentrations can occur naturally elsewhere. Near hydrothermal vents in the Guaymas Basin, Gulf of California, for example, total concentrations of 26 PAHs (from high temperature pyrolysis of petroleum) were 578 and 824 ppb dw (Simoneit and Lonsdale, 1982). In cores from a Gulf of Mexico oil seep natural concentrations ranged from 177 to 6,800 ppb dw (Wade *et al.,* 1989).

Concentrations of tPAHs that have been associated with detrimental biological effects from sediment exposures have ranged from 0.0009 to 21,200,000 ppb dry weight (Long and Morgan, 1990). Total PAHs most often included the sum of 13 to 18 individual compounds, although some studies summed as few as 4 or as many as 21 compounds. The lower 10th percentile of concentrations associated with detrimental effects (ER-L) was determined to be 4022 ppb (Long and Morgan, 1995). The 50th percentile of concentrations with associated observed effects (ER-M) was 44,792 ppb tPAHs (Long and Morgan, 1995).

None of the concentrations of tPAH Mamala Bay have exceeded 50 ppb in sediment encountered in the core monitoring program conducted by CCH (Table G-1-14 and G-1-15). Compared to sediments from San Diego Harbor, Long Beach Harbor, Whites Point, Santa Monica Bay Hyperion outfall site, and the Orange County outfall site which have exceeded 4000 ppb tPAH at some time in the past, Mamala Bay levels are at "background".

Table G-1-1

ERL and ERM guideline values for trace metals (ppm, dry wt.) and percent incidence of biological effects in concentration ranges defined by the two values. ERL= Effects Range-Low; ERM= Effects Range-Median.

Chemical, ppm dry wt.	ERL	ERM	Guidelines Percent Incidence of Effects*		
			<ERL	ERL-ERM	>ERM
Arsenic	8.2	70	5.0	11.1	63.0
Cadmium	1.2	9.6	6.6	36.6	65.7
Chromium	81	370	2.9	21.1	95.0
Copper	34	270	9.4	29.1	83.7
Lead	46.7	218	8.0	35.8	90.2
Mercury	0.15	0.71	8.3	23.5	42.3
Nickel	20.9	51.6	1.9	16.7	16.9
Silver	1.0	3.7	2.6	32.3	92.8
Zinc	150	410	6.1	47.0	69.8

Source: Long et al., 1995

*Number of data entries within each concentration range in which biological effects were observed divided by the total number of entries within each range.

Table G-1-2

ERL and ERM guideline values for organic compounds (ppb, dry wt.) and percent incidence of biological effects in concentration ranges defined by the two values ERL= Effects Range-Low; ERM= Effects Range-Median.

Chemical ug/Kg dry wt	ERL	ERM	Guidelines Percent incidence of effects*		
			<ERL	ERL-ERM	>ERM
Acenaphthene	16	500	20	32.4	84.2
Acenaphthylene	44	640	14.3	17.9	100
Anthracene	85.3	1100	25	44.2	85.2
Fluorene	19	540	27.3	36.5	86.7
2-methyl naphthalene	70	670	12.5	73.3	100
Naphthalene	160	2100	16.0	41.00	88.9
Phenanthrene	240	1500	18.5	46.2	90.3
Sum LPAH	552	3160	13	48.1	1100
Benz(a)anthracene	261	1600	21.1	43.8	92.6
Benzo(a)pyrene	430	1600	10.3	63	80
Chrysene	384	2800	19	45	88.5
Dibenzo (a,h) anthracene	63.4	260	11.5	54.5	66.7
Fluoranthene	600	5100	20.6	63.6	92.3
Pyrene	665	2500	17.2	53.1	87.5
Sum HPAH	1700	9600	10.5	40.0	81.2
Sum of total PAH	4022	44792	14.3	36.1	85
p,p'-DDE	2.2	27	5.0	50.0	50.0
Sum total DDTs	1.58	46.1	20.0	75.0	53.6
Total PCBs	22.7	180	18.5	40.8	51.0

Source: Long et al., 1995

*Number of data entries within each concentration range in which biological effects were observed divided by the total number of entries within each range.

Table G-1-3 Average Sediment Concentration of Trace Metals at Sand Island NPDES Core Monitoring Stations
1999 - 2002

Analyte, mg/Kg (ppm) dry	C1A	C2A	C3A	C5A	C6	D1	D2	D3A	D5	D6	E1	E2	E3	E5	E6	Overall
Aluminum, Total	375	306	335	288	382	1175	832	487	1613	930	1693	847	940	1413	1460	872
Arsenic, Total	5.85	3.77	3.05	3.53	3.42	7.33	4.42	3.40	12.85	6.43	7.37	6.43	5.77	7.63	3.80	5.67
Beryllium, Total	0.03	ND	ND	ND	ND	0.04	0.03	Nd	0.06	0.03	0.05	0.03	0.03	0.04	0.035	0.04
Cadmium, Total	0.14	0.15	0.13	0.13	0.12	0.12	0.11	0.11	0.11	0.09	0.13	0.12	0.09	0.12	ND	0.12
Chromium, Total	13.00	11.62	9.93	8.62	10.82	16.30	11.43	9.75	18.83	13.43	15.53	12.50	10.59	15.10	11.33	12.59
Copper, Total	1.49	1.39	1.42	1.36	1.25	3.19	2.18	1.83	2.48	2.14	3.72	1.94	2.69	2.79	2.72	2.17
Iron, Total	1700	1031	1024	765	1057	2858	1495	1185	4818	2398	3310	2363	2613	3173	2677	2164
Lead, Total	3.54	2.09	2.31	1.33	1.39	4.17	1.70	2.30	2.62	1.28	3.97	1.49	3.03	3.36	2.64	2.48
Mercury, Total	ND	ND	0.03	ND	ND	0.05	0.02	0.02	0.020	ND	0.06	ND	0.04	0.025	ND	0.03
Nickel, Total	9.43	2.45	2.48	2.28	5.10	8.18	3.83	2.63	18.52	14.45	9.17	9.47	12.23	10.83	11.87	8.19
Silver, Total	0.03	0.029	0.05	ND	ND	0.12	0.12	0.10	0.06	0.02	0.13	0.05	0.13	0.04	0.036	0.07
Zinc, Total	5.12	3.78	3.92	2.42	2.52	10.32	6.47	7.02	8.30	3.65	9.50	5.43	8.70	7.37	6.30	6.05

Station Depth, meters	19	19	19	21	49	53	53	50	50	50	100	100	84	101	101
Distance from:															
Mid-Point of Diffuser, km	2.71	1.30	1.46	4.87	4.04	2.50	0.72	0.76	4.67	6.13	2.41	0.74	0.69	4.45	5.89
Mid-Point of Diffuser, miles	1.68	0.81	0.91	3.03	6.50	1.55	0.45	0.47	2.90	3.81	1.50	0.46	0.43	2.76	3.66

Table G-1-4
Core Monitoring Station Statistics (min/max of detectable values)1999-2002

Analyte	**Concentration**		**Station with**	**Station with**	**Criteria**	
Metals, mg/Kg dry	**Minimum**	**Maximum**	**Minimum**	**Maximum**	**ER-L**	**ER-M**
Aluminum, Total	243	1880	C5A	D5	none	none
Arsenic, Total	2.8	14.8	C3A	D5	8.2	70
Beryllium, Total	0.02	0.08	D6,E2	D5	NV	NV
Cadmium, Total	0.08	0.18	D2,D3A	E5	1.2	9.6
Chromium, Total	7.8	22.7	C5A	D5	81	370
Copper, Total	0.56	4.5	C6	D1	34	270
Iron, Total	691	5700	C5A	D5	none	none
Lead, Total	1.18	5.02	D6	D1	4.67	218
Mercury, Total	0.02	0.08	D2,D3A	E1	0.15	0.7
Nickel, Total	1.7	22.6	C3A	D5	20.9	51.6
Silver, Total	0.021	0.24	D6	D2	1	3.7
Zinc, Total	1.4	16.3	C5A	D1	150	410

Table G-1-5
Average Sediment Metals Concentrations for Core Stations by Depth Contour
(1999,2000, and 2002)

Sand Island NPDES **Analyte, mg/Kg dry wt.**	**Station C1A**	**Station C2A**	**Station C3A**	**Station C5A**	**Station C6**	**20 meter Station Averages**
Aluminum, Total	375	306.17	334.67	287.83	382.00	**337.07**
Arsenic, Total	5.85	3.77	3.05	3.53	3.42	**3.92**
Beryllium, Total	0.03	ND	ND	ND	ND	**0.01**
Cadmium, Total	0.14	0.15	0.13	0.13	0.12	**0.13**
Chromium, Total	13.00	11.62	9.93	8.62	10.82	**10.80**
Copper, Total	1.49	1.39	1.42	1.36	1.25	**1.38**
Iron, Total	1700.00	1031.17	1023.83	765.17	1056.50	**1115.33**
Lead, Total	3.54	2.09	2.31	1.33	1.39	**2.13**
Mercury, Total	ND	ND	0.03	ND	ND	**0.01**
Nickel, Total	9.43	2.45	2.48	2.28	5.10	**4.35**
Silver, Total	0.03	0.029	0.05	ND	ND	**0.02**
Zinc, Total	5.12	3.78	3.92	2.42	2.52	**3.55**
Station Depth, meters	19	19	19	21	20	20

Sand Island NPDES **Analyte, mg/Kg dry wt.**	**Station D1**	**Station D2**	**Station D3A**	**Station D5**	**Station D6**	**50 meter Station Averages**
Aluminum, Total	1175.00	832.17	486.50	1613.33	930.00	**1007.40**
Arsenic, Total	7.33	4.42	3.40	12.85	6.43	**6.89**
Beryllium, Total	0.04	0.03	Nd	0.06	0.03	**0.03**
Cadmium, Total	0.12	0.11	0.11	0.11	0.09	**0.10**
Chromium, Total	16.30	11.43	9.75	18.83	13.43	**13.95**
Copper, Total	3.19	2.18	1.83	2.48	2.14	**2.36**
Iron, Total	2858.33	1495.00	1185.00	4818.33	2397.50	**2550.83**
Lead, Total	4.17	1.70	2.30	2.62	1.28	**2.41**
Mercury, Total	0.05	0.02	0.02	0.020	ND	**0.02**
Nickel, Total	8.18	3.83	2.63	18.52	14.45	**9.52**
Silver, Total	0.12	0.12	0.10	0.06	0.02	**0.08**

Zinc, Total	10.32	6.47	7.02	8.30	3.65	**7.15**
Station Depth, meters	53	53	50	50	50	51

Sand Island NPDES **Analyte, mg/Kg dry wt.**	**Station E1**	**Station E2**	**Station E3**	**Station E5**	**Station E6**	**100 meter Station Averages**
Aluminum, Total						
Arsenic, Total	1693.33	847.00	939.67	1413.33	1460.00	**1270.67**
Beryllium, Total	7.37	6.43	5.77	7.63	3.80	**6.20**
Cadmium, Total	0.05	0.03	0.03	0.04	0.035	**0.04**
Chromium, Total	0.13	0.12	0.09	0.12	ND	**0.09**
Copper, Total	15.53	12.50	10.59	15.10	11.33	**13.01**
Iron, Total	3.72	1.94	2.69	2.79	2.72	**2.77**
Lead, Total	3310.00	2363.33	2613.33	3173.33	2676.67	**2827.33**
Mercury, Total	3.97	1.49	3.03	3.36	2.64	**2.90**
Nickel, Total	0.06	ND	0.04	0.025	ND	**0.02**
Silver, Total	9.17	9.47	12.23	10.83	11.87	**10.71**
Zinc, Total	0.13	0.05	0.13	0.04	0.036	**0.08**
	9.50	5.43	8.70	7.37	6.30	**7.46**
Station Depth, meters	100	100	84	101	101	**97.00**

SUMMARY AVERAGES BY DEPTH

Average by Depth Contour	**20 meter Station Averages**	**50 meter Station Averages**	**100 meter Station Averages**
Sand Island NPDES **Analyte, mg/Kg dry wt.**			
Aluminum, Total	**337.07**	**1007.40**	**1270.67**
Arsenic, Total	**3.92**	**6.89**	**6.20**
Beryllium, Total	**0.01**	**0.03**	**0.04**
Cadmium, Total	**0.13**	**0.10**	**0.09**
Chromium, Total	**10.80**	**13.95**	**13.01**
Copper, Total	**1.38**	**2.36**	**2.77**
Iron, Total	**1115.33**	**2550.83**	**2827.33**
Lead, Total	**2.13**	**2.41**	**2.90**
Mercury, Total	**0.01**	**0.02**	**0.02**
Nickel, Total	**4.35**	**9.52**	**10.71**
Silver, Total	**0.02**	**0.08**	**0.08**
Zinc, Total	**3.55**	**7.15**	**7.46**

Table G-1-6
Summary of Zone of Mixing (ZOM) Sediment Metals Concentrations

Analyte	Concentration			Station with	Station with	Criteria	
Metals, mg/Kg dry	Minimum	Maximum	Average	Minimum	Maximum	ER-L	ER-M
Aluminum, Total	315	1080	776	D3A	E3	none	none
Arsenic, Total	2.8	7.1	5	D3A	E2	8.2	70
Beryllium, Total	ND	0.04	0.03	D2,D3A	E3	NV	NV
Cadmium, Total	0.06	0.15	0.11	E3	D3A	1.2	9.6
Chromium, Total	8.8	13.6	11	D3A	E2	81	370
Copper, Total	1.16	4.2	2.2	E2	E3	34	270
Iron, Total	1090	2950	914	D3A	E2	none	none
Lead, Total	1.27	3.41	2.13	D2,D3A	E3	4.67	218
Mercury, Total	<0.02	0.06	0.02	D2	E3	0.15	0.7
Nickel, Total	2	15.1	7	D3A	E3	20.9	51.6
Silver, Total	0.04	0.24	0.1	E2	D2	1	3.7
Zinc, Total	2.8	13.3	6.9	D2	D3A	150	410

Table G-1-7
Average ZOM Sediment Metals Concentration by Station

Average,mg/Kg dry (1999,2001, and 2002)	Station D2	Station D3A	Station E2	Station E3	ZOM
Analyte	**Average**	**Average**	**Average**	**Average**	**Average**
Aluminum, Total	832.17	486.50	847.00	939.67	**776.33**
Arsenic, Total	4.42	3.40	6.43	5.77	**5.00**
Beryllium, Total	0.03	ND	0.03	0.03	**0.03**
Cadmium, Total	0.11	0.11	0.12	0.09	**0.11**
Chromium, Total	11.43	9.75	12.50	10.59	**11.07**
Copper, Total	2.18	1.83	1.94	2.69	**2.16**
Iron, Total	1495.00	1185.00	2363.33	2613.33	**1914.17**
Lead, Total	1.70	2.30	1.49	3.03	**2.13**
Mercury, Total	0.02	0.02	ND	0.04	**0.02**
Nickel, Total	3.83	2.63	9.47	12.23	**7.04**
Silver, Total	0.12	0.10	0.05	0.13	**0.10**
Zinc, Total	6.47	7.02	5.43	8.70	**6.90**

Table G-1-8
Summary Comparison of Native, Regional, Core and ZOM Station Sediment Metals Concentrations

Analyte Metals, mg/Kg dry	USGS Native	Regional Stations		NPDES Stations		ZOM Stations		Criteria	
	Average	Min	Max	Min	Max	Min	Max	ER-L	ER-M
Aluminum, Total		106	3800	243	1800	315	1080		
Arsenic, Total	10.2	0.7	16.2	2.8	14.8	2.8	7.1	8.2	70
Beryllium, Total		0.02	0.17	0.02	0.08	ND	0.04		
Cadmium, Total	0.056	0.08	0.23	0.02	0.08	0.06	0.15	1.2	9.6
Chromium, Total	39.6	3.1	25.9	7.8	22.7	8.8	13.6	81	370
Copper, Total	8.3	1.1	49.9	0.56	4.5	1.16	4.2	34	270
Iron, Total		130	10,200	691	5700	1090	2950		
Lead, Total	4.6	0.61	151	1.18	5.02	1.27	3.41	4.67	218
Mercury, Total	0.026	0.02	3.45	0.02	0.08	<0.02	0.06	0.15	0.7
Nickel, Total	20.5	1.1	69.9	1.7	22.6	2	15.1	20.9	51.6
Silver, Total	0.027	0.03	0.11	0.021	0.24	0.04	0.24	1	3.7
Zinc, Total	18.7	0.8	4.28	1.4	16.3	2.8	13.3	150	410

Table G-1-9
Summary Comparison of Average Sediment Metals Concentrations in Sediments for Native and Dredge Disposal Sites

Analyte Metals, mg/Kg dry	USGS Native	Old Honolulu	South Oahu	New Oahu	Criteria	
	Average	Average	Average	Average	ER-L	ER-M
Aluminum, Total						
Arsenic, Total	10.2	2.2	4.9	10.4	8.2	70
Beryllium, Total						
Cadmium, Total	0.056	0.039	0.051	0.07	1.2	9.6
Chromium, Total	39.6	77.2	71.6	52	81	370
Copper, Total	8.3	31.1	25	16.4	34	270
Iron, Total						
Lead, Total	4.6	5.5	11	7.5	4.67	218
Mercury, Total	0.026	0.079	3.4	0.08	0.15	0.7
Nickel, Total	20.5	46.9	39.6	31	20.9	51.6
Silver, Total	0.027	0.038	0.062	0.06	1	3.7
Zinc, Total	18.7	42.5	45.4	36.02	150	410

Table G-1-10
Sediment Metals Concentrations in Pearl Harbor Operational Areas (Piers and Wharves)

Analyte	Concentration			Criteria	
Metals, mg/Kg dry	**Minimum**	**Maximum**	**Average**	**ER-L**	**ER-M**
Aluminum, Total					
Arsenic, Total		15.5	10	8.2	70
Beryllium, Total					
Cadmium, Total		1	0.45	1.2	9.6
Chromium, Total		359	140	81	370
Copper, Total		435	225	34	270
Iron, Total					
Lead, Total		509	150	4.67	218
Mercury, Total		2.42	0.8	0.15	0.7
Nickel, Total		218	95	20.9	51.6
Silver, Total		2.1	1.25	1	3.7
Zinc, Total		505	170	150	410

Table G-1-11
Sediment Concentrations in Pearl Harbor Composite Samples (12 samples)

Analyte	Concentration			Criteria	
Metals, mg/Kg dry	**Minimum**	**Maximum**	**Average**	**ER-L**	**ER-M**
Aluminum, Total	n/a	n/a	n/a	none	none
Arsenic, Total	0.016	0.91	0.285	8.2	70
Beryllium, Total	n/a	n/a	n/a	NV	NV
Cadmium, Total	0.3	1.5	0.8	1.2	9.6
Chromium, Total	7.4	35.5	23.3	81	370
Copper, Total	3.7	79.4	27.1	34	270
Iron, Total	n/a	n/a	n/a	none	none
Lead, Total	8.6	55.3	31.1	4.67	218
Mercury, Total	0.082	0.49	0.19	0.15	0.7
Nickel, Total	6.7	39.2	28	20.9	51.6
Silver, Total	0.4	3.7	1.6	1	3.7
Zinc, Total	23.8	107.3	65.2	150	410

Source: Schroeder and Palermo, 2000

Table G-1-12
Sediment Metals in Deep Water Cores from Dredge Disposal Sites (Collected in 1994-95 by the U. S. Geological Survey)

Analyte	Concentration			Criteria	
Metals, mg/Kg dry	Minimum	Maximum	Average	ER-L	ER-M
Aluminum, Total	n/a	n/a	n/a	none	none
Arsenic, Total	1.8	51.6	10.4	8.2	70
Beryllium, Total	n/a	n/a	n/a	NV	NV
Cadmium, Total	0.02	0.22	0.07	1.2	9.6
Chromium, Total	15.4	114	52	81	370
Copper, Total	4.3	32.2	16.4	34	270
Iron, Total	n/a	n/a	n/a	none	none
Lead, Total	0.45	35.6	7.5	4.67	218
Mercury, Total	0.02	0.62	0.08	0.15	0.7
Nickel, Total	13.3	56.2	31	20.9	51.6
Silver, Total	0.02	0.11	0.06	1	3.7
Zinc, Total	12.4	71.6	36.02	150	410

Table G-1-13
Summary of Sediment Quality Criteria Exceedences by Monitoring Program

Analyte	Pearl Harbor			NPDES Stations		Criteria	
Metals, mg/Kg dry	Operational	Composites	Core	ZOM	Regional (Station #)	ER-L	ER-M
Aluminum, Total						none	none
Arsenic, Total	ER-M				ER-L (84,93,96)	8.2	70
Beryllium, Total						NV	NV
Cadmium, Total						1.2	9.6
Chromium, Total	ER-M	ER-M				81	370
Copper, Total	ER-M	ER-L			ER-L (96)	34	270
Iron, Total						none	none
Lead, Total	ER-M	ER-L				4.67	218
Mercury, Total	ER-M	ER-L				0.15	0.7
Nickel, Total	ER-M	ER-L			ER-M (93) ER-L (94,96,98)	20.9	51.6
Silver, Total						1	3.7
Zinc, Total	ER-M					150	410

Table G-1-14
Detected Non-Metals Priority Pollutants in Sediments Sorted Alphabetically by Constitutent

Sand Island NPDES Permit Sediment Sampling 1999, 2000, 2002.

Analyte	Station	Sampling Date	Result 1	Result 2	Average	Unit	PQL
4,4'-DDT	E2	August 29, 2002			1.8	ug/Kg dry	1.5
Acenaphthylene	C1A	August 10, 2000	23	ND	23.00	ug/Kg dry	5
Benz(a)anthracene	D1				8.50	ug/Kg dry	5
Benz(a)anthracene	D3A	October 6, 1999			13.00	ug/Kg dry	5
Benz(a)anthracene	E1				7.0	ug/Kg dry	5
Benzo(a)pyrene	D1				10.25	ug/Kg dry	5
Benzo(a)pyrene	D3A	October 6, 1999			13.50	ug/Kg dry	5
Benzo(a)pyrene	E1				13.0	ug/Kg dry	5
Benzo(a)pyrene	E3	August 11, 2000			5	ug/Kg dry	5
Benzo(a)pyrene	E5	August 10, 2000			6	ug/Kg dry	5
Benzo(b)fluoranthene	D1				12.00	ug/Kg dry	5
Benzo(b)fluoranthene	D3A	October 6, 1999			12.00	ug/Kg dry	5
Benzo(b)fluoranthene	E1				9.0	ug/Kg dry	5
Benzo(e)pyrene	D1				12.50	ug/Kg dry	5
Benzo(e)pyrene	D3A	October 6, 1999			15.00	ug/Kg dry	5
Benzo(e)pyrene	E1				9.5	ug/Kg dry	5
Benzo(e)pyrene	E6				12	ug/Kg dry	5-7.9
Benzo(g,h,i)perylene	C1A	August 10, 2000	14	ND	14.00	ug/Kg dry	5
Benzo(g,h,i)perylene	D1				14.75	ug/Kg dry	5
Benzo(g,h,i)perylene	D3A	October 6, 1999			15.50	ug/Kg dry	5
Benzo(g,h,i)perylene	D5	August 9, 2000	5	ND	5.00	ug/Kg dry	5
Benzo(g,h,i)perylene	E1				11.5	ug/Kg dry	5-7.8
Benzo(g,h,i)perylene	E5	August 10, 2000			5	ug/Kg dry	5
Benzo(g,h,i)perylene	E6				11	ug/Kg dry	5-7.9
Benzo(k)fluoranthene	D1				10.25	ug/Kg dry	5
Benzo(k)fluoranthene	D3A	October 6, 1999			13.50	ug/Kg dry	5
Benzo(k)fluoranthene	E1				9.0	ug/Kg dry	5
Benzo(k)fluoranthene	E6				17	ug/Kg dry	5-7.9
Chrysene	D1				9.25	ug/Kg dry	5
Chrysene	D3A	October 6, 1999			20.00	ug/Kg dry	5
Chrysene	E1				10.0	ug/Kg dry	5
Chrysene	E6				20	ug/Kg dry	5-7.9
Fluoranthene	C1A	August 10, 2000	8	12	10.00	ug/Kg dry	5
Fluoranthene	D1				11.07	ug/Kg dry	5
Fluoranthene	D3A	October 6, 1999			27.00	ug/Kg dry	5
Fluoranthene	D5	August 9, 2000	7	ND	7.00	ug/Kg dry	5
Fluoranthene	D6	August 9, 2000	ND	6	6.00	ug/Kg dry	5
Fluoranthene	E1				14.2	ug/Kg dry	5-7.8
Fluoranthene	E2	August 11, 2000			9	ug/Kg dry	5
Fluoranthene	E3	August 11, 2000			15	ug/Kg dry	5
Fluoranthene	E5	August 10, 2000			10	ug/Kg dry	5
Fluoranthene	E6				42	ug/Kg dry	5-7.9
Indeno(1,2,3-cd)pyrene	D1				11.50	ug/Kg dry	5
Indeno(1,2,3-cd)pyrene	D3A	October 6, 1999			12.50	ug/Kg dry	5
Indeno(1,2,3-cd)pyrene	E1				10.6	ug/Kg dry	5-7.8
Indeno(1,2,3-cd)pyrene	E6				14	ug/Kg dry	5-7.9
Naphthalene	C1A	August 10, 2000	36	11	23.50	ug/Kg dry	5
PCB 101	C3A	August 9, 2000	ND	1.1	0.55	ug/Kg dry	0.5
PCB 101	C6	August 9, 2000	0.70	ND	0.70	ug/Kg dry	0.5

Table G-1-14

Detected Non-Metals Priority Pollutants in Sediments Sorted Alphabetically by Constitutent (continue)

Analyte	Station	Sampling Date	Result 1	Result 2	Average	Unit	PQL
PCB 105	C3A	August 9, 2000	ND	1.2	0.60	ug/Kg dry	0.5
PCB 105	C6	August 9, 2000	0.74	ND	0.37	ug/Kg dry	0.5
PCB 118	C3A	August 9, 2000	ND	1.4	0.70	ug/Kg dry	0.5
PCB 118	C6	August 9, 2000	0.95	ND	0.48	ug/Kg dry	0.5
PCB 118	E2	August 29, 2002			1.1	ug/Kg dry	0.73
PCB 138	C3A	August 9, 2000	ND	2.1	1.05	ug/Kg dry	0.5
PCB 138	C6	August 9, 2000	1.3	ND	0.65	ug/Kg dry	0.5
PCB 138	E2	August 29, 2002			1.3	ug/Kg dry	0.73
PCB 149	C3A	August 9, 2000	ND	0.93	0.47	ug/Kg dry	0.5
PCB 149	C6	August 9, 2000	0.51	ND	0.51	ug/Kg dry	0.5
PCB 153	C3A	August 9, 2000	ND	1.3	0.65	ug/Kg dry	0.5
PCB 153	C6	August 9, 2000	0.86	ND	0.86	ug/Kg dry	0.5
PCB 153	E2	August 29, 2002			0.98	ug/Kg dry	0.73
PCB 81	C3A	August 9, 2000	ND	2.3	1.15	ug/Kg dry	0.5
PCB 81	C6	August 9, 2000	1.2	ND	1.2	ug/Kg dry	0.5
PCB 87	C3A	August 9, 2000	ND	0.63	0.32	ug/Kg dry	0.5
PCB 99	C3A	August 9, 2000	ND	0.57	0.29	ug/Kg dry	0.5
PCB 99	C6	August 9, 2000	0.51	ND	0.51	ug/Kg dry	0.5
Perylene	D1				5.00	ug/Kg dry	5
Perylene	D3A	October 6, 1999			6.00	ug/Kg dry	5
Perylene	E6				6	ug/Kg dry	5
Phenanthrene	C1A	August 10, 2000	14	7	10.50	ug/Kg dry	5
Phenanthrene	D1				7.00	ug/Kg dry	5
Phenanthrene	D3A	October 6, 1999			6.00	ug/Kg dry	5
Phenanthrene	E1				8.0	ug/Kg dry	5
Phenanthrene	E2	August 11, 2000			7	ug/Kg dry	5
Phenanthrene	E3	August 11, 2000			7	ug/Kg dry	5
Phenanthrene	E6				42	ug/Kg dry	5
Pyrene	C1A	August 10, 2000	6	8	7.00	ug/Kg dry	5
Pyrene	D1				12.87	ug/Kg dry	5
Pyrene	D3A	October 6, 1999			20.50	ug/Kg dry	5
Pyrene	D5	August 9, 2000	11	ND	11.00	ug/Kg dry	5
Pyrene	D6	August 9, 2000	ND	6	6.00	ug/Kg dry	5
Pyrene	E1				17.7	ug/Kg dry	5-7.8
Pyrene	E2	August 11, 2000			8	ug/Kg dry	5
Pyrene	E3	August 11, 2000			12	ug/Kg dry	5
Pyrene	E5	August 10, 2000			10	ug/Kg dry	5
Pyrene	E6				34	ug/Kg dry	5-7.9

FIGURE II.C.3
1970-2002
OAHU AND STATE TOTALS