# *Chapter 4. Sediment Characteristics*

## Introduction

Ocean sediment samples are collected and analyzed as part of the South Bay Ocean Outfall (SBOO) monitoring program to characterize the surrounding physical environment and assess general sediment quality. The analysis of parameters such as sediment grain size and the relative percentages of both coarse (e.g., sand) and fine (e.g., silt and clay) fractions can provide useful information about current velocity, amount of wave action, and overall habitat stability. Further, understanding particle size distributions facilitates interpretation of the interactions between benthic organisms and the environment. For example, differences in sediment composition (e.g., fine vs. coarse particles) and associated levels of organic loading at specific sites can affect the burrowing, tube building, and feeding abilities of infaunal invertebrates, thus affecting benthic community structure (Gray 1981, Snelgrove and Butman 1994). Also, many demersal fish species are associated with specific sediment types that reflect the habitats of their preferred invertebrate prey (Cross and Allen 1993). Consequently, understanding the differences in sediment conditions and quality over time and space is crucial to assessing coincident changes in benthic invertebrate and demersal fish populations (see Chapters 5 and 6, respectively).

Both natural and anthropogenic factors affect the composition, stability and distribution of seafloor sediments. Natural factors that affect sediment conditions on the continental shelf include inputs from rivers and bays (e.g., outflows, tidal exchange), beach erosion, runoff from other terrestrial sources, decomposition of calcareous organisms, strength and direction of bottom currents, wave action, and seafloor topography (e.g., Emery 1960). Geological history can also affect the chemical composition of local sediments. For example, erosion from coastal cliffs and shores, and flushing of terrestrial sediments and debris from bays, rivers and streams can contribute to the deposition and accumulation of metals or other contaminants and also affect the overall organic content of sediments. Additionally, primary productivity by marine phytoplankton is a major source of organics to these sediments (Mann 1982, Parsons et al. 1990).

Municipal wastewater outfalls are one of many anthropogenic factors that can directly influence the composition and distribution of sediments through the discharge of treated effluent and the subsequent deposition of a wide variety of organic and inorganic compounds. Some of the most commonly detected compounds discharged via ocean outfalls are trace metals, pesticides, and various organic compounds such as organic carbon, nitrogen, and sulfides (Anderson et al. 1993). Moreover, the presence of large outfall pipes and associated ballast materials (e.g., rock, sand) may alter the hydrodynamic regime in surrounding areas.

This chapter presents summaries and analyses of sediment particle size and chemistry data collected during 2009 at monitoring sites surrounding the SBOO. The primary goals are to: (1) assess possible effects of wastewater discharge on benthic habitats by analyzing spatial and temporal variability of various sediment parameters, (2) determine the presence or absence of sedimentary and chemical footprints near the discharge site, and (3) evaluate overall sediment quality in the region.

## Materials and Methods

### Field Sampling

Sediment samples were collected at 27 benthic stations in the SBOO region during January and July 2009 (Figure 4.1). These stations range in depth from 18 to 60 m and are distributed along or adjacent to four main depth contours. Each sediment sample was collected from one side of a chain-rigged double Van Veen grab with a 0.1-$m^2$ surface area; the other grab sample from the cast

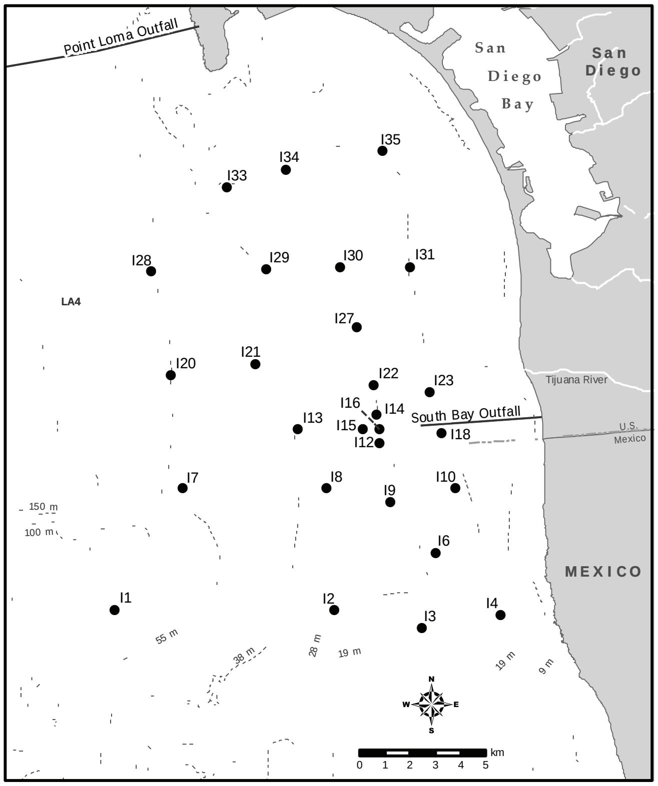


**Figure 4.1**
Benthic station locations sampled for the South Bay Ocean Outfall Monitoring Program.

was used for macrofaunal community analysis (see Chapter 5) and visual observations of sediment composition. Sub-samples for various analyses were taken from the top 2 cm of the sediment surface and handled according to EPA guidelines (U.S. EPA 1987).

### Laboratory Analyses

All sediment chemistry and particle size analyses were performed at the City of San Diego's Wastewater Chemistry Services Laboratory. Particle size analysis was performed using either a Horiba LA-920 laser scattering particle analyzer or a set of six nested sieves. Sieves were used when a sample contained substantial amounts of coarse material (e.g., coarse sand, gravel, shell hash) which would damage the Horiba analyzer and/or where the general distribution of sediment sizes in the sample would be poorly represented by laser analysis. The mesh sizes of the sieves are 2.0 mm, 1.0 mm, 0.5 mm, 0.25 mm, 0.125 mm, and 0.063 mm, and separate a seventh fraction of all particles finer than 0.063 mm. In 2009, three samples were processed by sieve analysis: I23 (January), I28 (July), and I34 (July). All other particle size analyses were performed on the Horiba analyzer, which measures particles ranging in size from 0.00049 mm to 2.0 mm (i.e., 11 to -1 phi). Prior to laser analysis, coarser sediments were removed by screening the samples through a 2.0-mm mesh sieve; these data are expressed herein as the "coarse" fraction of the total sample sieved. Results from sieve analysis and output from the Horiba were categorized into sand, silt, and clay fractions as follows: sand was defined as particles ranging between 2.0 and >0.0625 mm in diameter, silt as particles between 0.0625 and >0.0039 mm, and clay as particles between 0.0039 and >0.00049 mm. These data were standardized and combined with any sieved coarse fraction (i.e., particles >2.0 mm) to obtain a distribution of coarse, sand, silt, and clay fractions totaling 100%. These four size fractions were then used in the calculation of various particle size parameters, which were determined using a normal probability scale (see Folk 1968). These parameters were then summarized and expressed as overall mean particle size (mm), phi size (mean, standard deviation, skewness, kurtosis), and the proportion of coarse, sand, silt, and clay. Additionally, the proportion of fine particles (percent fines) was calculated as the sum of all silt and clay fractions for each sample.

Each sediment sample was analyzed for total organic carbon (TOC), total nitrogen (TN), total sulfides, trace metals, chlorinated pesticides (e.g., DDT), polychlorinated biphenyl compounds (PCBs), and polycyclic aromatic hydrocarbons (PAHs) on a dry weight basis (see Appendix C.1). TOC and TN were measured as percent weight (% wt) of the sediment sample; sulfides and metals were measured in units of mg/kg and are expressed in this report as parts per million (ppm); pesticides and PCBs were measured in units of ng/kg and expressed as parts per trillion (ppt); PAHs were measured in units of µg/kg and expressed as parts per billion (ppb). The data for each parameter reported herein were generally limited to values above method detection limits (MDL). However, concentrations below MDLs were included as estimated values if the presence of the specific constituent was verified by mass-spectrometry (i.e., spectral peaks confirmed). A detailed description of the analytical protocols is available in City of San Diego (2010).

### Data Analyses

Data summaries for particle size and chemistry parameters included detection rates (i.e., number of reported values/number of samples), annual means of detected values for all stations combined (areal mean), and minimum, median, and maximum values during the year. Total PAH, total DDT, and total PCB were calculated for each sample as the sum of all constituents with reported values; values for each individual constituent are listed in Appendix C.2. Statistical analyses included Spearman Rank correlation of all sediment chemistry parameters with percent fines. This non-parametric analysis accommodates non-detects (i.e., analytes measured below MDLs) without the use of value-substitutions (Helsel 2005). However, depending on the data distribution, the instability in ranked-based analyses may intensify with increased censoring (see Conover 1980). Therefore, a criterion of < 50% non-detects was used to screen eligible constituents for this analysis. Results from the correlation analyses were confirmed by graphical analyses.

In addition, data from the 2009 surveys were compared to the Effects Range Low (ERL) and Effects Range Median (ERM) sediment quality guidelines of Long et al. (1995) when available to assess contamination levels. The National Status and Trends Program of the National Oceanic and Atmospheric Administration (NOAA) originally calculated the ERLs and ERMs to provide a means for interpreting monitoring data. The ERLs are considered to represent chemical concentrations below which adverse biological effects are rarely observed. Values above the ERL but below the ERM represent values at which effects occasionally occur. Concentrations above the ERM indicate likely biological effects, although these are not always validated by toxicity testing (Schiff and Gossett 1998). Levels of contamination were further evaluated by comparing the current survey results with historical data, including comparisons between annual maximum values from 2009 to those from the pre-discharge period (1995–1998). In addition, data for percent fines and organic indicators from stations closest to the outfall (nearfield) were compared to all other stations (farfield) over the pre- and post-discharge periods. Stations considered "nearfield" (I12, I14, I15, I16) are located within 1000 m of the outfall wye.

## Results and Discussion

### Particle Size Distribution

Ocean sediments were diverse at the benthic sites sampled around the SBOO in 2009. Percent sands were generally the largest fraction with values ranging from 20.5% to 98.6%, whereas percent fines (silt and clay) ranged from 0% to 79.5% (Table 4.1). However, there were no clear patterns in grain-size distribution relative to the outfall (Figure 4.2). The diversity of sediment types within the region appears to reflect the different geological origins of various materials as it has for many years. For example, visual observations of the grab samples collected during the year revealed the presence of several unique types of coarse sediments, including red relict sands, black sands, and shell hash (see Appendix C.3). Overall, sediment composition has been highly variable throughout the South Bay region since sampling first began in 1995 (see City of San Diego 2000).

In contrast to the regional diversity described above, there has not been any substantial increase in fine sediments at stations near the outfall or throughout the region since wastewater discharge began in 1999 (see Figure 4.3). Additionally, sediment composition remained fairly stable at most stations during 2009. For example, intra-station particle size composition varied by less than 10% at most sites between the winter and summer surveys (see Appendix C.3). This general continuity between seasons in terms of percent fines is evident in Figure 4.3. The main exceptions to this pattern occurred at stations I16, I18, I23, I28 and I29. For example, sediments collected from station I16 in January contained the highest proportion of fines (79.5%), which

## Table 4.1

Summary of particle size and sediment chemistry parameters at SBOO benthic stations during 2009. Data include the detection rate (DR), areal mean of detected values, and minimum (Min), median, and maximum (Max) values for the entire survey area. The maximum value from the pre-discharge period (i.e., 1995–1998) is also presented. ERL=effects range low threshold; ERM=effects range median threshold; na=not available; nd=not detected; SD=standard deviation; TN=total nitrogen; TOC=total organic carbon.

| | 2009 Summary* | | | | | Pre-discharge | | |
|---|---|---|---|---|---|---|---|---|
| **Parameter** | **DR (%)** | **Areal Mean** | **Min** | **Median** | **Max** | **Max** | **ERL** | **ERM** |
| *Particle Size* | | | | | | | | |
| Mean *(mm)* | ** | 0.26 | 0.02 | 0.13 | 0.66 | 0.76 | na | na |
| Mean *(phi)* | ** | 2.4 | 0.6 | 3.0 | 5.7 | 4.2 | na | na |
| SD *(phi)* | ** | 0.9 | 0.5 | 0.9 | 1.9 | 2.5 | na | na |
| Coarse *(%)* | ** | 4.0 | 0.0 | 0.0 | 27.1 | 52.5 | na | na |
| Sand *(%)* | ** | 83.8 | 20.5 | 88.6 | 98.6 | 100.0 | na | na |
| Fines *(%)* | ** | 12.2 | 0.0 | 9.6 | 79.5 | 47.2 | na | na |
| *Organic Indicators* | | | | | | | | |
| Sulfides *(ppm)* | 89 | 2.18 | nd | 0.81 | 25.30 | 222.00 | na | na |
| TN *(% weight)* | 98 | 0.024 | nd | 0.019 | 0.163 | 0.077 | na | na |
| TOC *(% weight)* | 100 | 0.346 | 0.030 | 0.183 | 5.460 | 0.638 | na | na |
| *Trace Metals (ppm)* | | | | | | | | |
| Aluminum | 100 | 4932 | 741 | 4355 | 30100 | 15800 | na | na |
| Antimony | 31 | 0.4 | nd | nd | 0.9 | 5.6 | na | na |
| Arsenic | 100 | 2.76 | 0.36 | 1.82 | 11.90 | 10.90 | 8.2 | 70 |
| Barium | 100 | 25.17 | 1.99 | 20.70 | 177.00 | 54.30 | na | na |
| Beryllium | 44 | 0.09 | nd | nd | 0.33 | 2.14 | na | na |
| Cadmium | 48 | 0.10 | nd | nd | 0.42 | 0.41 | 1.2 | 9.6 |
| Chromium | 100 | 10.0 | 3.2 | 9.3 | 33.2 | 33.8 | 81 | 370 |
| Copper | 96 | 3.6 | nd | 3.0 | 37.6 | 11.1 | 34 | 270 |
| Iron | 100 | 6480 | 1300 | 6100 | 29300 | 17100 | na | na |
| Lead | 96 | 2.36 | nd | 1.77 | 20.00 | 6.80 | 46.7 | 218 |
| Manganese | 100 | 51.4 | 5.7 | 48.3 | 291.0 | 162.0 | na | na |
| Mercury | 50 | 0.010 | nd | nd | 0.063 | 0.078 | 0.15 | 0.71 |
| Nickel | 100 | 3.4 | 0.7 | 2.6 | 22.8 | 13.6 | 20.9 | 51.6 |
| Selenium | 0 | — | nd | nd | nd | 0.62 | na | na |
| Silver | 22 | 0.41 | nd | nd | 0.63 | nd | 1 | 3.7 |
| Thallium | 0 | — | nd | nd | nd | 17 | na | na |
| Tin | 76 | 0.7 | nd | 0.4 | 4.5 | nd | na | na |
| Zinc | 100 | 17.1 | 2.3 | 13.2 | 126.0 | 46.9 | 150 | 410 |
| *Pesticides (ppt)* | | | | | | | | |
| Total DDT | 41 | 1084 | nd | nd | 9400 | 23380 | 1580 | 46100 |
| HCB | 24 | 261 | nd | nd | 700 | nd | na | na |
| *Total PCB (ppt)* | 44 | 523 | nd | nd | 970 | na | na | na |
| *Total PAH (ppb)* | 0 | — | nd | nd | nd | 636.5 | 4022 | 44792 |

* Minimum, maximum, and median values were calculated based on all samples ($n=54$), whereas means were calculated on detected values only ($n\leq54$).

** Particle size parameters calculated for all samples.

greatly exceeded the historical maximum of 17% for this site, as well as the entire South Bay region (i.e., 50%). The high proportion of fine sediments at I16 during the winter appears to have been an anomaly as it did not persist into summer when the site was characterized by only 8% fines. The higher proportions of fines at stations I18 and I28 also did not persist into the summer.

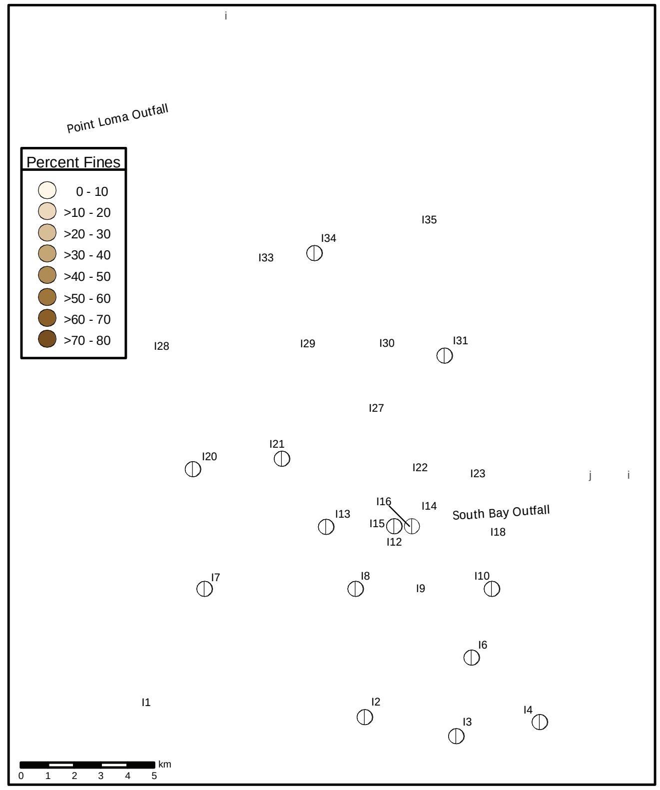


**Figure 4.2**
Distribution of fine sediments (percent fines) at SBOO benthic stations sampled during 2009. Split circles show results of January (left) and July (right) surveys.

The sorting coefficient reflects the range of particle sizes comprising sediments and is calculated as the standard deviation (SD) in phi size units (see Table 4.1). In general, areas composed of particles of similar size are considered to have well-sorted sediments (i.e., SD≤0.5 phi) and are indicative of areas subject to fast moving currents or large disturbances (e.g., storm surge, rapid suspension/deposition of materials). In contrast, poorly sorted sediments (i.e., SD≥1.0 phi) typically indicate areas of low disturbance that often result in highly variable or patchy grain size distributions (Folk 1968). Sediments collected throughout the South Bay region, including at stations located near the outfall, tended to be moderately well to poorly sorted, with average sorting coefficients ranging from 0.5 to 1.9. The highest sorting coefficients for 2009 (~1.9) occurred at stations I16, I18, and I28 in the January survey (Appendix C.3).

## Indicators of Organic Loading

Total organic carbon (TOC), total nitrogen (TN), and sulfides are quantified in sediments at stations surrounding the SBOO as measures of organic loading. Organic materials may be deposited in marine habitats via various pathways and originating from both anthropogenic (e.g., wastewater and stormwater discharges, urban runoff) and natural (e.g., primary productivity and breakdown of detrital materials) sources (Eganhouse and Venkatesan 1993). Consequently, organic enrichment is of concern because it may impair habitat quality for benthic marine organisms and thus disrupt ecological processes. For example, sulfides, which are the by-products of the anaerobic breakdown of organic matter, can be toxic to benthic species if the sediments become excessively enriched (Gray 1981). Additionally, nitrogen enrichment can lead to sudden phytoplankton "blooms" in coastal waters. After such blooms occur, a flux of organic material may again be deposited in the benthos as planktonic organisms die and settle to the seafloor.

There was no evidence of organic enrichment that could be associated with wastewater discharge in South Bay sediments during 2009. Although detection rates for TOC, TN and sulfides were high (i.e., ≥89%; see Table 4.1), median concentrations of these organic indicators were similar to values found between 1995–1998 prior to the onset of discharge (Figure 4.3). Further, concentrations of these indicators co-varied with the proportion of fine sediments in each sample (Table 4.2) instead of proximity to the outfall. TN was found to be correlated the tighest with percent fines (Figure 4.4A), followed by TOC and then sulfides. Because of this relationship, values for each organic indicator varied widely across the region. TOC ranged from 0.03 to 5.46% wt, TN ranged from 0.008 to 0.163% wt, and sulfides ranged from 0.2 to 25.3 ppm (Table 4.1). The highest TN and sulfide concentrations occurred at station I16 in January, as did the second highest concentration of TOC (see Appendix C.4). In fact, this was the highest TN concentration reported since monitoring began in 1995. However, levels of all three indicators at the other outfall stations, as well as at I16 during the following July survey, were within the range of values reported elsewhere in the region.

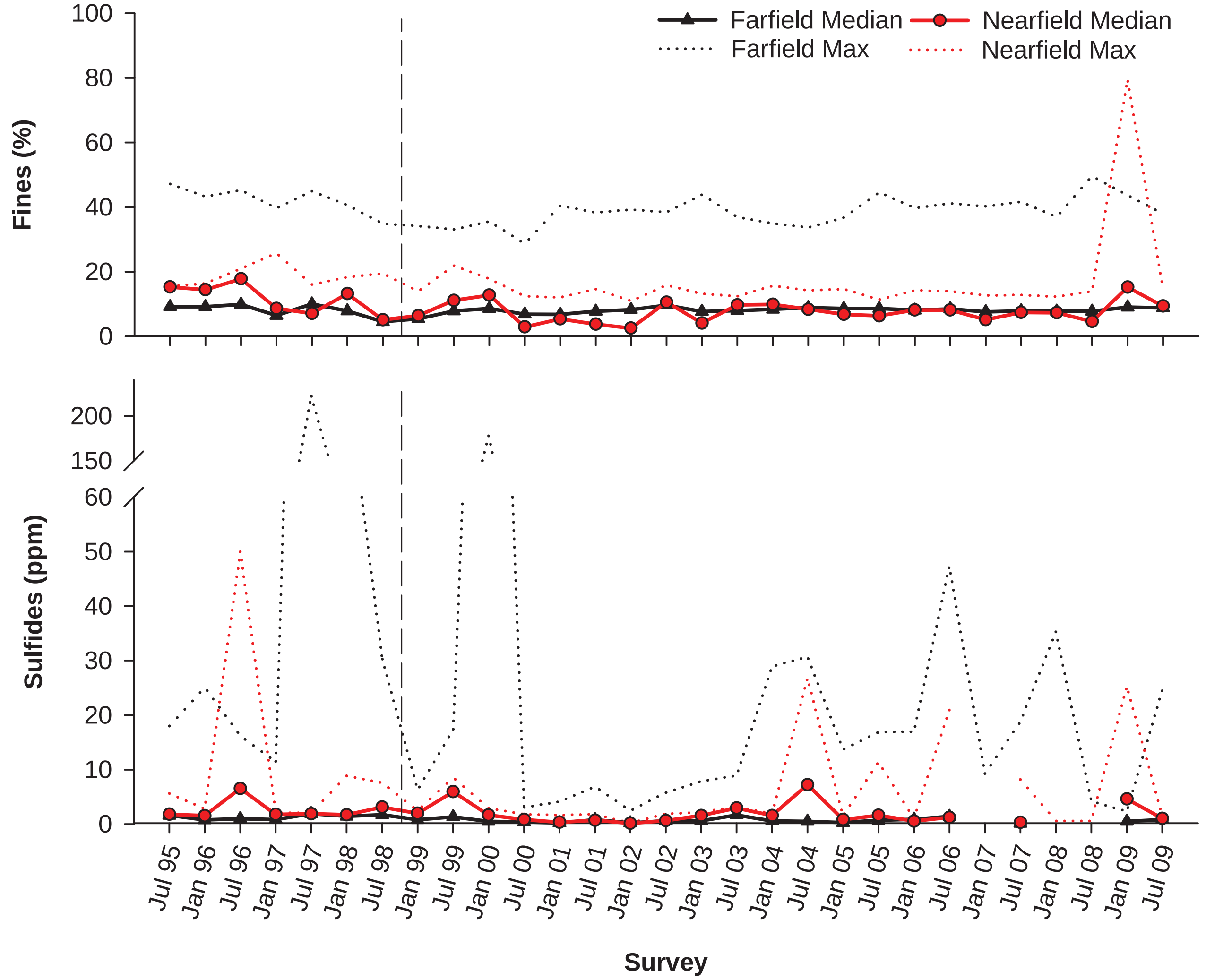


**Figure 4.3**

Summary of particle size and organic indicator data surrounding the SBOO from 1995 to 2009: Percent fines (Fines); Sulfides; Total Nitrogen (TN); Total Organic Carbon (TOC). Data are expressed as median and maximum values pooled over all farfield ($n=23$) and nearfield ($n=4$) stations. Breaks in data represent surveys where the median or maximum value was below detection limits. Dashed lines indicate onset of discharge from the SBOO.

### Trace Metals

Aluminum, arsenic, barium, chromium, iron, manganese, nickel and zinc were detected in all sediment samples collected in the SBOO region during 2009 (Table 4.1). Antimony, beryllium, cadmium, copper, lead, mercury, silver and tin were detected less frequently at rates of 22–96%, while selenium and thallium were not detected at all. Concentrations were highly variable for each of the 16 trace metals detected, with no discernable patterns evident relative to the outfall (see Appendix C.5). Instead, the concentrations for several metals were correlated with the proportion of fine particles in the samples (Table 4.2). For example, manganese was found to have the highest correlation with percent fines (Figure 4.4B), followed next by aluminum, nickel, barium and zinc. Each of these five metals had correlation coefficients >0.85. Overall, most samples collected during 2009 had metal concentrations that were within the range of values reported prior to discharge. Exceptions that occurred throughout the region included samples from stations I16, I18, I21, I29 and I33. For example, the winter sample from station I16, which was characterized by unusually fine sediments (see discussion above), had the highest concentrations of aluminum, barium, iron, lead, nickel and tin ever reported, including the period prior to discharge. Other metals in this sample that were

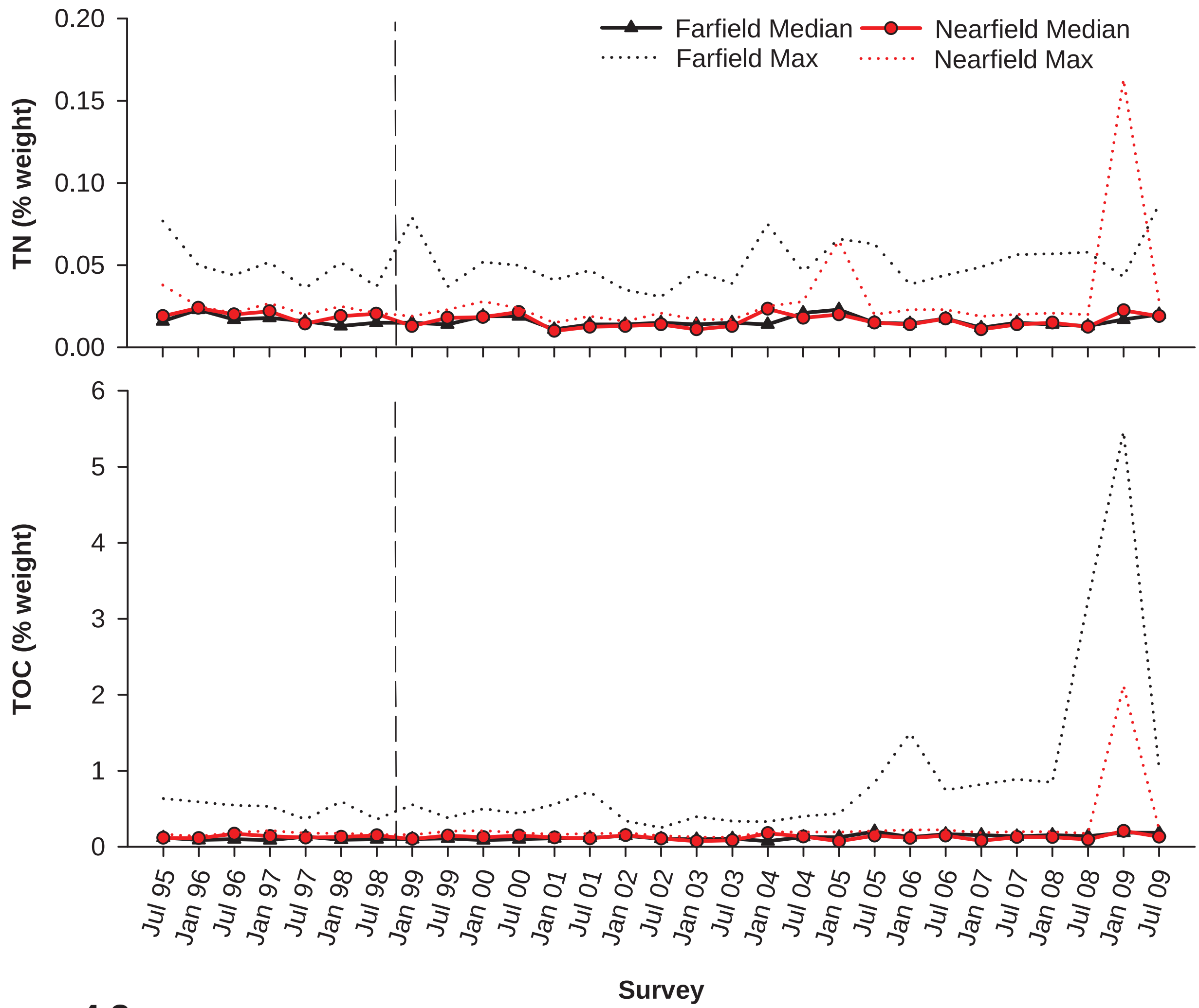


**Figure 4.3** *continued*

detected at levels higher than pre-discharge values included arsenic, cadmium, copper, manganese and zinc. The summer sample from station I29 also had relatively high percent fines, as well as levels of aluminum, barium, copper, iron, manganese and zinc that were higher than pre-discharge concentrations. In contrast, the sediment samples from stations I18, I21 and I33 each contained only a single metal that exceeded concentrations reported before discharge began (i.e., barium at I18, arsenic at I21, nickel at I33). Despite these relatively high values, only three metals exceeded environmental threshold values during the year. These included the ERL for arsenic from station I21 located northwest of the discharge site during both January and July, and the ERLs for copper and nickel in the station I16 January sample as described above. No samples collected during 2009 had metal concentrations that exceeded ERM thresholds.

## Pesticides

Chlorinated pesticides were detected in up to 41% of the South Bay sediment samples collected in 2009 (Table 4.1, Appendix C.6). Total DDT (primarily p,p-DDE) was the most prevalent pesticide, occurring in sediments from 14 of 27 stations at concentrations ranging between 95–9400 ppt. The ERL for this pesticide was exceeded in only three samples in 2009, including one sample from station I16 (January) and two samples from station I29 (January and July). However, all DDT concentrations were lower than maximum values reported during the pre-discharge period. Another pesticide, hexachlorobenzene (HCB), was detected in 24% of samples, at a total of 12 stations, with values ranging from 77 to 700 ppt. As with the various trace metals, pesticide concentrations showed no patterns relative to wastewater discharge.

## Table 4.2

Results of Spearman Rank correlation analyses of percent fines and all other sediment chemistry parameters from samples collected in the SBOO region in 2009. Shown are analytes which had correlation coefficients ($r_s$) ≥ 0.60. For all analyses, $p < 0.001$. The strongest correlations with organic indicators and trace metals are illustrated graphically in Figure 4.4 below.

| Analyte | $r_s$ |
|---|---|
| *Organic Indicators* | |
| Sulfides *(ppm)* | 0.68 |
| Total Nitrogen *(% weight)* | 0.89 |
| Total Organic Carbon *(% weight)* | 0.81 |
| *Trace Metals (ppm)* | |
| Aluminum | 0.90 |
| Barium | 0.88 |
| Chromium | 0.63 |
| Copper | 0.81 |
| Iron | 0.65 |
| Manganese | 0.91 |
| Nickel | 0.89 |
| Zinc | 0.86 |

### PAHs and PCBs

PAHs were not detected in sediment samples collected during 2009. In contrast, 44% of the samples collected in 2009 had detectable levels of PCBs (compared to 9% in 2008), with concentrations ranging from 33 to 970 ppt (Table 4.1). PCBs were found in sediments from most SBOO stations in January 2009, but at only a single station in July (Appendix C.6). Total PCB concentrations at nearfield stations I12, I14, I15, I16 fell well within those reported elsewhere in the region (i.e., 360–840 ppt versus 330–970 ppt). The highest PCB concentration of the year was detected in January in sediment from I10, located south of the United States/Mexico border.

## Summary and Conclusions

Sediment composition in the South Bay outfall region was diverse in 2009, with grain size

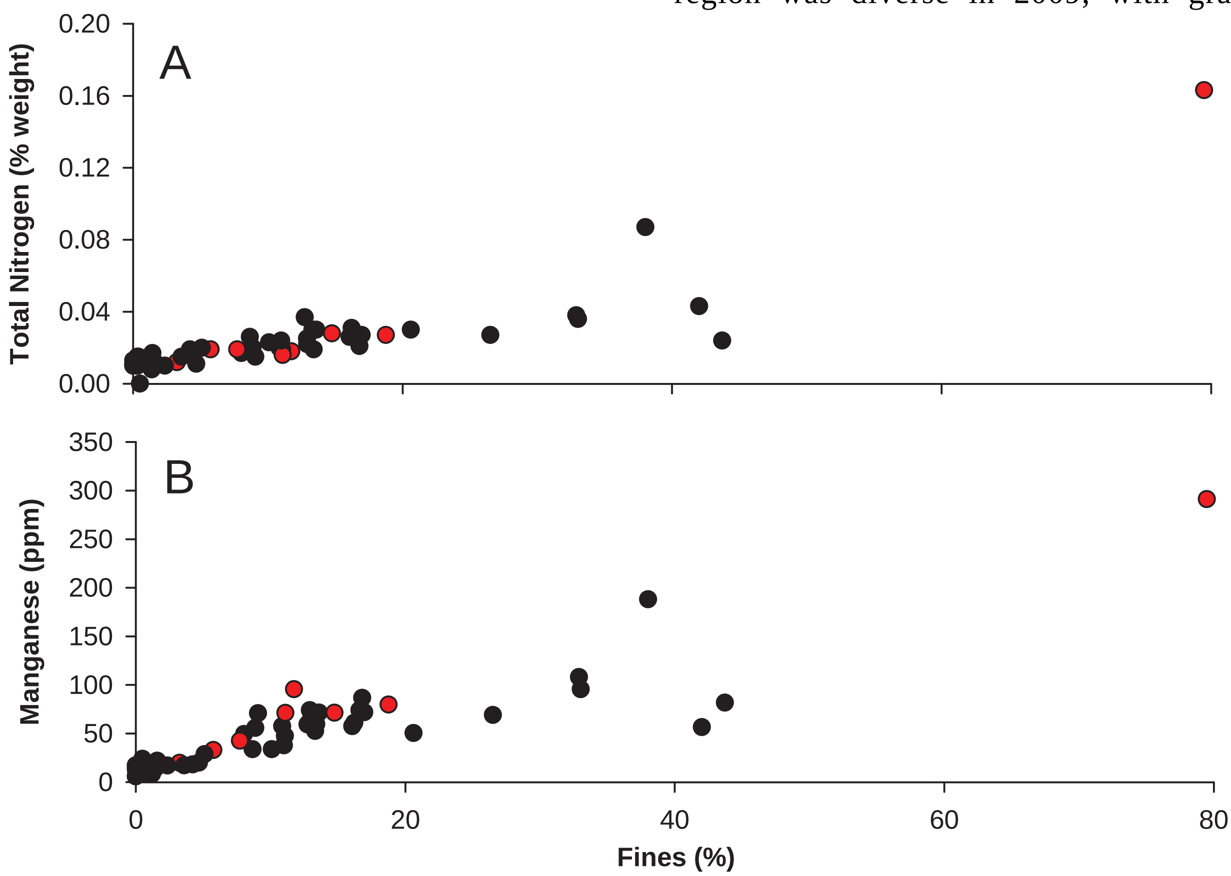


**Figure 4.4**

Scatterplot of percent fines and concentration of total nitrogen (A) and manganese (B) in SBOO sediments in 2009. Samples collected from nearfield stations are indicated in red.

distributions ranging from very fine to very coarse particles. The diversity of sediment types may be partially attributed to the multiple geological origins of red relict sands, shell hash, coarse sands, and other detrital materials that occur in the offshore area surrounding the SBOO (Emery 1960). In addition, sediment deposition associated with the transport of materials originating from the Tijuana River, and to a lesser extent from San Diego Bay, may contribute to the higher silt content at some stations located near the outfall, as well as to the north (see City of San Diego 1988). For example, in late December 2008 there was evidence of a large influx of fine sediments from coastal rivers (particularly the Tijuana River) with heavy winter rains, and subsequent re-suspension of these sediments by wave and surge action (J. Warrick, pers. comm., City of San Diego 2009). This may have contributed to the spikes in fine particles at several stations, particularly I16, I18, and I28 in January 2009, although it is unclear why the pattern was not more widespread throughout the region. Regardless, the high sorting coefficients of sediments in these samples, the lack of similar sediment conditions at nearby stations, or at I16, I18, and I28 during the following July survey, suggested these conditions occurred over a relatively small spatial (and possibly temporal) scale. There was no evident relationship between sediment grain size composition and proximity to the outfall discharge site.

Various trace metals, indicators of organic loading, chlorinated pesticides, and PCBs were detected in sediment samples collected from SBOO benthic stations during 2009. Concentrations of these contaminants were highly variable, and several were detected at relatively high levels for the region (i.e., higher than pre-discharge values) particularly in the January sample from station I16. Despite these relatively high values, concentrations remained relatively low compared to many other coastal areas off southern California such as Los Angeles (see Schiff and Gossett 1998, Noblet et al. 2003, Schiff et al. 2006, Maruya and Schiff 2009) and only three metals (arsenic, copper, nickel) and the pesticide DDT exceeded biological threshold values for southern California.

Overall, sediments in the South Bay region were similar in 2009 to years past (see City of San Diego 2007, 2008, 2009) and there was no evidence of contamination by the discharge of wastewater from the SBOO. Although there were some samples where constituent concentrations exceeded pre-discharge maximums, most samples had contaminant concentrations that were not substantially different from those detected before discharge began in early 1999 (see City of San Diego 2000). In addition, the samples that did exceed pre-discharge values and/or biological thresholds were collected from stations widely distributed throughout the region and showed no patterns that could be attributed to wastewater discharge. Instead, concentrations of TOC, TN, sulfides, and several metals tended to be higher at sites characterized by finer sediments. This pattern is consistent with that found in other studies, in which the accumulation of fine particles has been shown to greatly influence the organic and metal content of sediments (e.g., Eganhouse and Venkatesan 1993).

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