Chapter 3. Microbiology

INTRODUCTION

The City of San Diego monitors water quality along the shoreline and in offshore ocean waters for the region surrounding the South Bay Ocean Outfall (SBOO). This aspect of the City's ocean monitoring program is designed to assess general oceanographic conditions, evaluate patterns in movement and dispersal of the SBOO wastewater plume, and monitor compliance with water contact standards defined in the 2001 California Ocean Plan (COP) as according to NPDES permit specifications (see Chapter 1). Results of all sampling and analyses, including COP compliance summaries, are submitted to the San Diego Regional Water Quality Control Board in the form of monthly receiving waters monitoring reports. Densities of fecal indicator bacteria (FIB), including total coliforms, fecal coliforms, and enterococcus, are measured and evaluated along with oceanographic data (see Chapter 2) to provide information about the movement and dispersion of wastewater discharged to the Pacific Ocean through the outfall. Analyses of these data may also help identify other point or non-point sources of bacterial contamination (e.g., outflows from rivers or bays, surface runoff from local watersheds). This chapter summarizes and interprets patterns in seawater FIB concentrations collected for the South Bay region during 2008.

Materials and Methods

Field Sampling

Seawater samples for bacteriological analyses were collected at a total of 39 NPDES-mandated shore, kelp bed, or other offshore monitoring sites during 2008 (Figure 3.1). Sampling was performed weekly at 11 shore stations to monitor FIB concentrations in waters adjacent to public beaches. Eight of these stations (S4, S5, S6, S8, S9, S10, S11, S12), located between the USA/Mexico border and Coronado, southern California, are subject to COP water contact standards (see Box 3.1). The other three shore stations (S0, S2, S3) are located in Mexican waters off northern Baja California and are not subject to COP requirements. In addition, 28 other stations were sampled in offshore waters to monitor FIB levels. These sites comprise a grid surrounding the SBOO along the 9, 19, 28, 38, and 55-m depth contours. Three of these sites (stations I25, I26, I39) are considered kelp bed stations because of their proximity to the Imperial Beach kelp bed. These three stations are subject to the COP water contact standards and are each sampled five times per month. The remaining 25 offshore stations are sampled once a month, which usually requires sampling over a 3-day period.

Seawater samples for the shore stations were collected from the surf zone in sterile 250-mL

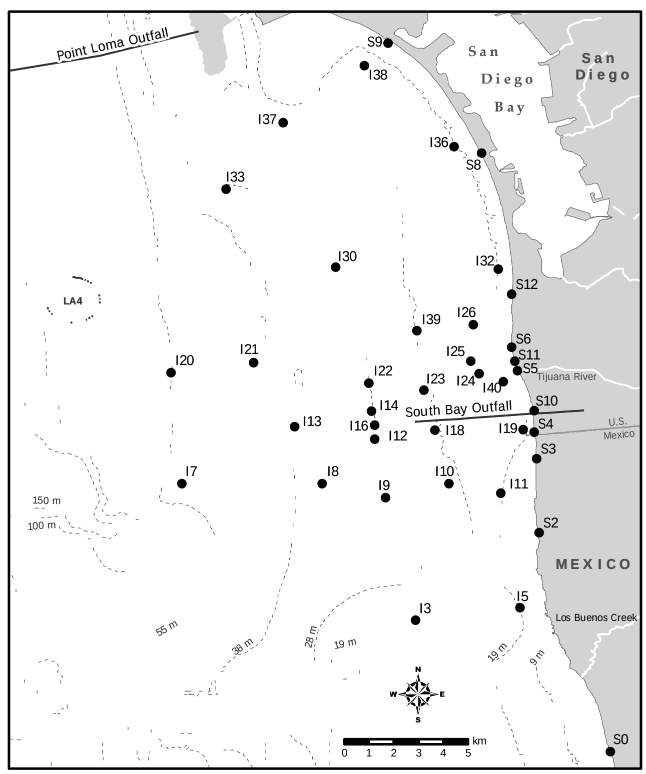

Figure 3.1
Water quality monitoring stations for the South Bay Ocean Outfall Monitoring Program.

Box 3.1

Bacteriological compliance standards for water contact areas, 2001 California Ocean Plan (SWRCB 2001). CFU=colony forming units.

(a) *30-day Total Coliform Standard* — no more than 20% of the samples at a given station in any 30-day period may exceed a concentration of 1000 CFU per 100 mL.

(b) *10,000 Total Coliform Standard* — no single sample, when verified by a repeat sample collected within 48 hrs, may exceed a concentration of 10,000 CFU per 100 mL.

(c) *60-day Fecal Coliform Standard* — no more than 10% of the samples at a given station in any 60-day period may exceed a concentration of 400 CFU per 100 mL.

(d) *30-day Fecal Geometric Mean Standard* — the geometric mean of the fecal coliform concentration at any given station in any 30-day period may not exceed 200 CFU per 100 mL, based on no fewer than five samples.

bottles. In addition, visual observations of water color and clarity, surf height, human or animal activity, and weather conditions were recorded at the time of collection. The samples were then transported on blue ice to the City of San Diego's Marine Microbiology Laboratory (CSDMML) and analyzed to determine concentrations of total coliform, fecal coliform, and enterococcus bacteria.

Seawater samples were collected at three discrete depths at each of the kelp bed and other offshore stations and analyzed for the above FIBs (i.e., total and fecal coliforms, enterococcus), total suspended solids (TSS), and oil and grease (O&G). These samples were collected using either an array of Van Dorn bottles or a rosette sampler fitted with Niskin bottles. Aliquots for each analysis were drawn into appropriate sample containers. All seawater samples were refrigerated on board ship and transported to the CSDMML for subsequent analysis. TSS and O&G samples were taken to the City's Wastewater Chemistry Laboratory for analysis. Visual observations of weather and sea conditions, and human or animal activity were also recorded at the time of sampling. Monitoring of the SBOO area and neighboring coastline also included aerial and satellite image analysis performed by Ocean Imaging of Solana Beach, California (e.g., Svejkovsky 2009; also see Chapter 2).

Laboratory Analyses and Data Treatment

All bacterial analyses were performed within 8 hours of sample collection and conformed to standard membrane filtration techniques (see APHA 1998). The CSDMML follows guidelines issued by the United States Environmental Protection Agency (EPA) Water Quality Office, Water Hygiene Division, and the California State Department of Health Services (CDHS) Environmental Laboratory Accreditation Program (ELAP) with respect to sampling and analytical procedures (Bordner et al. 1978, APHA 1998).

Procedures for counting colonies of indicator bacteria, calculation and interpretation of results, data verification and reporting all follow guidelines established by the EPA (Bordner et al. 1978) and APHA (1998). According to these guidelines, plates with FIB counts above or below the ideal counting range were given greater than (>), less than (<), or estimated (e) qualifiers. However, these qualifiers were dropped and the counts treated as discrete values during calculation of means and in determining compliance with COP standards.

Quality assurance tests were performed routinely on seawater samples to ensure that sampling variability did not exceed acceptable limits. Duplicate and split bacteriological samples were processed according to method requirements to measure intra-sample and inter-analyst variability, respectively. Results of these procedures were reported in City of San Diego (2009).

Bacteriological benchmarks defined in the 2001 COP and Assembly Bill 411 (AB 411) were used as reference points to distinguish elevated FIB values in receiving water samples discussed in this report. These benchmarks are: (a) >1000 CFU/100 mL for total coliforms; (b) >400 CFU/100 mL for fecal coliforms; (c) >104 CFU/100 mL for enterococcus. Data were summarized for analysis as counts of samples in which FIB concentrations exceed any of these benchmarks. Furthermore, any seawater sample with a total coliform concentration ≥1000 CFU/100 mL and a fecal:total (F:T) ratio ≥0.1 was considered representative of contaminated waters (see CDHS 2000). This condition is referred to as the fecal:total ratio (FTR) criteria herein.

Results and Discussion

Shore Stations

Concentrations of indicator bacteria were higher along the South Bay shoreline in 2008 than in 2007 (see City of San Diego 2008), which likely reflects the higher levels of rainfall that occurred during the year (i.e., 12 inches in 2008 vs. 4 inches in 2007). During 2008, monthly FIB densities averaged 7 to 16,000 CFU/100 mL for total coliforms, 2 to 8600 CFU/100 mL for fecal coliforms, and 2 to 7223 CFU/100 mL for enterococcus (Appendix B.1). As expected, the majority of samples with elevated FIBs (91 of 104 samples) and nearly all samples that exceeded the FTR criteria (53 of 54 samples) were collected during the wet season (Table 3.1), primarily during January, February, and December (Appendix B.2). In addition, a MODIS satellite image of the region taken on February 5, 2008 showed turbidity plumes from the Tijuana River and Los Buenos Creek (in Mexico) encompassing all of the SBOO shore stations, six of which had elevated total coliform concentrations >1000 CFU/100 mL on that day (Figure 3.2). These types of turbidity plumes have been observed repeatedly over the past several years following rain events (e.g., see Svejkovsky 2008, 2009).

Table 3.1
The number of samples with elevated bacteria collected at SBOO shore stations during 2008. Elevated FIB=the total number of samples with elevated FIB densities; contaminated=the total number of samples that meet the fecal:total coliform ratio criteria indicative of contaminated seawater; Wet=January–March and November–December; Dry=April–October; n=total number of samples. Rain data are from Lindbergh Field, San Diego, CA. Stations are listed north to south from top to bottom.

Station		Season: Wet	Season: Dry	Total
S9	Elevated FIB	3	—	3
	Contaminated	1	—	1
S8	Elevated FIB	4	—	4
	Contaminated	2	—	2
S12	Elevated FIB	5	—	5
	Contaminated	3	—	3
S6	Elevated FIB	10	—	10
	Contaminated	6	—	6
S11	Elevated FIB	10	—	10
	Contaminated	7	—	7
S5	Elevated FIB	13	1	14
	Contaminated	11	—	11
S10	Elevated FIB	11	—	11
	Contaminated	5	—	5
S4	Elevated FIB	9	—	9
	Contaminated	4	—	4
S3	Elevated FIB	13	3	16
	Contaminated	4	1	5
S2	Elevated FIB	7	3	10
	Contaminated	6	—	6
S0	Elevated FIB	6	6	12
	Contaminated	4	—	4
Total counts	Rain (in)	10.7	1.4	12.1
	Elevated FIB	91	13	104
	Contaminated	53	1	54
	n	242	341	583

The general relationship between rainfall, elevated FIB concentrations, and the number of contaminated samples has remained consistent since monitoring began in 1995 (Figure 3.3). This is particularly evident along the shore near the

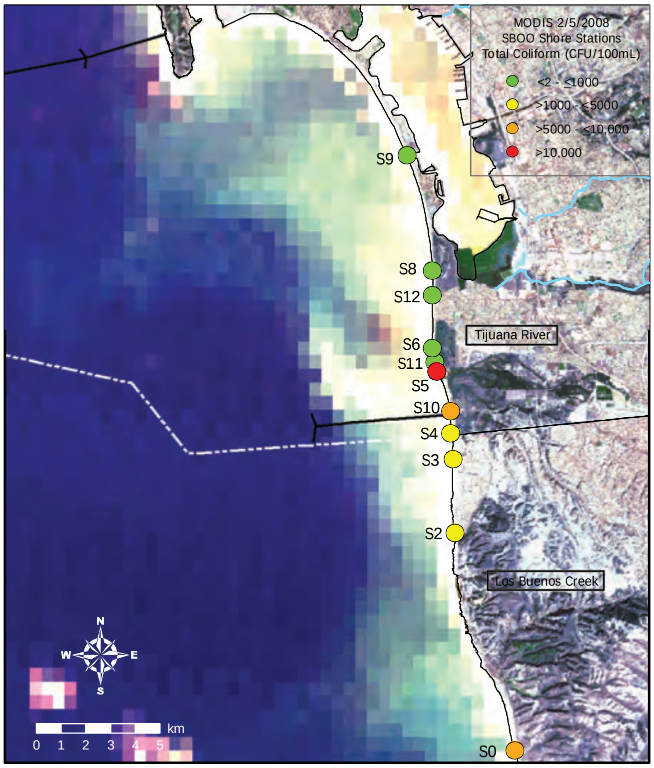

Figure 3.2
MODIS satellite image showing the SBOO monitoring region on February 5, 2008 (Svejkovsky 2009) combined with total coliform concentrations at shore stations sampled on the same day. Turbid waters from the Tijuana River and Los Buenos Creek can be seen moving northwest along the coastline, overlapping southern stations with higher levels of contamination. Waters are clear over the outfall discharge site.

Tijuana River (i.e., at stations S3–S6, S10–S11) and Los Buenos Creek (i.e. at stations S0, S2). These eight stations have historically had higher numbers of samples with elevated FIB densities than stations S8, S9, and S12 located further north (see City of San Diego 2007). Contaminated waters originating from the Tijuana River and Los Buenos Creek during periods of increased flows (e.g., during storms or extreme tidal exchanges) are likely sources of bacteria for nearby monitoring sites (see Largier et al. 2004, Terrill et al. 2009). Such contaminants may be from upstream sources, including sod farms, surface runoff not captured by the canyon collector system, the Tijuana estuary (e.g., decaying plant material), and partially treated effluent from the San Antonio de los Buenos Wastewater Treatment Plant (SABWTP) in Mexico that discharges into Los Buenos Creek.

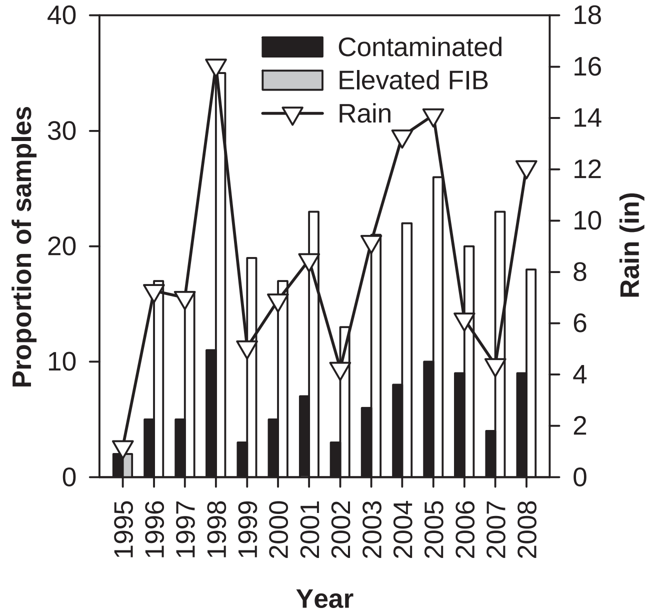

Figure 3.3
Comparison of annual rainfall to the proportion of samples with elevated FIB densities and the proportion of samples that met fecal:total coliform ratio criteria indicative of contaminated seawater (=contaminated) collected at SBOO shore stations between 1995 and 2008. Shoreline sampling began in October 1995. Rain for 1995 includes only October-December. Rain was measured at Lindbergh Field, San Diego, CA.

Shoreline bacterial contamination that occurred during periods of warmer, dry conditions between April–October tended to be limited to a few of the most southern stations (see Table 3.1). For example, 92% of the samples with elevated FIB densities that were not associated with rainfall occurred at stations S0, S2, and S3, all of which are located south of the international border. There are several potential sources of FIB contaminants near these stations, including low-flow Tijuana River water, uncontrolled residential and commercial discharge points in Mexico, and/or northward transport of SABWTP associated wastewater discharge to the ocean via Los Buenos Creek (Terrill et al. 2009).

Kelp Bed Stations

There was no evidence that the wastewater plume from the SBOO impacted any of the three kelp bed stations in 2008. Instead, elevated FIB densities at these sites corresponded to periods of heavy rainfall similar to the pattern seen along the shore. For example, all

Table 3.2

The number of samples with elevated bacteria collected at SBOO kelp stations during 2008. Elevated FIB=the total number of samples with elevated FIB densities; contaminated=the total number of samples that meet the fecal:total coliform ratio criteria indicative of contaminated seawater; Wet=January–March and November–December; Dry=April–October; n=total number of samples. Rain data are from Lindbergh Field, San Diego, CA.

Station			Season		
			Wet	Dry	Total
I25	2 m	Elevated FIB	6	—	6
		Contaminated	2	—	2
	6 m	Elevated FIB	7	—	7
		Contaminated	3	—	3
	9 m	Elevated FIB	6	—	6
		Contaminated	2	—	2
I26	2 m	Elevated FIB	4	—	4
		Contaminated	1	—	1
	6 m	Elevated FIB	5	—	5
		Contaminated	2	—	2
	9 m	Elevated FIB	4	—	4
		Contaminated	2	—	2
I39	2 m	Elevated FIB	2	—	2
		Contaminated	2	—	2
	12 m	Elevated FIB	1	—	1
		Contaminated	—	—	—
	18 m	Elevated FIB	1	—	1
		Contaminated	1	—	1
Total counts		Rain (in)	10.7	1.4	12.1
		Elevated FIB	36	—	36
		Contaminated	15	—	15
		n	180	252	432

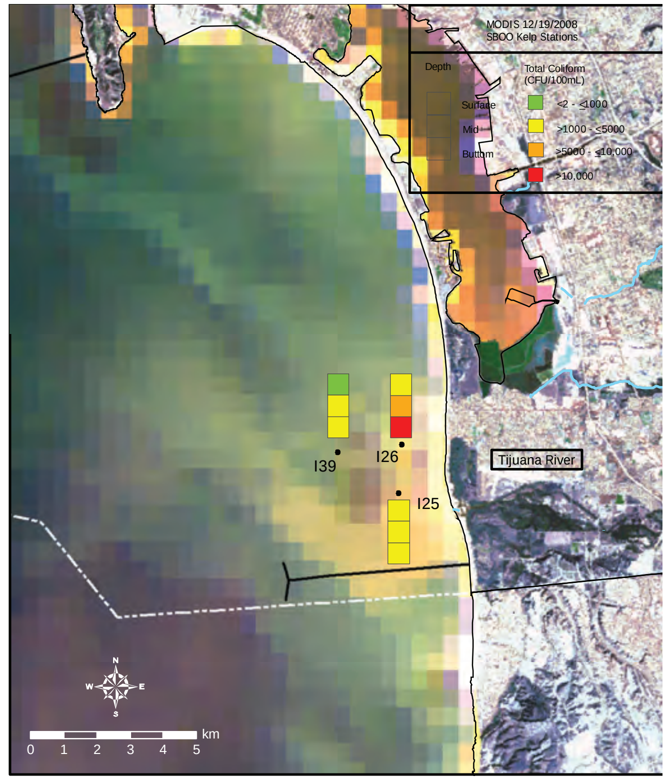

Figure 3.4

MODIS satellite image showing the SBOO monitoring region on December 19, 2008 (Svejkovsky 2009) combined with total coliform concentrations at kelp stations sampled on the same day at each depth. Turbid waters from the Tijuana River and Los Buenos Creek can be seen moving northwest along the coastline overlapping the kelp bed stations. Waters are relatively clear over the outfall discharge site.

samples with elevated FIBs and that met the FTR criteria at the kelp stations occurred during the wet season (Table 3.2). Furthermore, MODIS satellite imaging for December 19, 2009 indicated a rain-influenced turbidity plume moving northeast from the Tijuana River and encompassing all three of the kelp bed stations (Figure 3.4). Elevated total coliforms occurred in all but one of the seawater samples collected on this day at these three sites. Most of the elevated FIBs reported at the kelp bed stations comprised total coliform bacteria (i.e., 26 of 36 samples); 14 of these 26 samples also had elevated fecal coliforms (Appendix B.3). Less than half of the samples with elevated FIB concentrations exceeded the FTR criteria. Densities of enterococcus bacteria were elevated in 28 samples, 10 of which did not co-occur with elevated total or fecal coliforms.

Total suspended solids (TSS) and oil and grease (O&G) are also measured at the kelp bed stations as potential indicators of wastewater. However, previous analyses have demonstrated that these parameters have limited utility as indicators of the waste field (City of San Diego 2007). TSS varied considerably during 2008, ranging between 1.7 and 27.5 mg/L per sample (Table 3.3), while O&G was not detected in any samples. Of the 20 seawater samples with elevated TSS concentrations (≥8.0 mg/L), only two corresponded to samples with elevated FIBs. In contrast, nine of these high TSS samples occurred at bottom depths; these

Table 3.3

Summary of total suspended solid (TSS) concentrations in samples collected from kelp bed stations in 2008. The method detection limit is 1.6 mg/L for TSS; n=number of samples with detected concentrations.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Suspended Solids												
n	9	9	9	9	9	9	9	9	9	9	9	9
Min	3.2	4.2	3.5	5.1	4.5	3.1	4.2	3.8	4.3	3.3	3.4	1.7
Max	27.5	15.0	7.8	9.1	11.0	15.8	6.7	7.9	10.6	6.5	25.5	12.5
Mean	7.5	8.2	5.4	6.6	7.7	7.2	5.3	5.3	6.4	5.0	8.4	5.3

high counts were likely due to the re-suspension of bottom sediments when the CTD reached (touched) the sea floor. The remaining 11 high TSS values were found in surface-water and mid-water samples, and were most likely associated with phytoplankton blooms (see Chapter 2).

Offshore Stations

Elevated FIB concentrations were rare in samples collected from the 25 non-kelp bed offshore stations during 2008. Only 39 of 900 samples (~4.3%) collected at these sites had elevated FIBs and only 15 (~1.7%) met the FTR criteria for contaminated waters (Table 3.4, Appendix B.4). Most samples with elevated FIB levels were collected during the wet season at stations located along the 9 and 19-m depth contours (i.e., stations I11, I19, I23, I24, I32, I40). As with the shore and kelp bed stations, evidence from MODIS satellite imaging suggests that the nearshore region is being affected by contaminants (turbidity plumes) originating from the Tijuana River and Los Buenos Creek. For example, a MODIS image taken January 16, 2008 showed a turbidity plume associated with increased rainfall moving northwest and encompassing stations I19 and I40 (Figure 3.5). Samples collected that day at these two stations had elevated total coliform densities, whereas samples collected at stations located farther offshore (i.e., I12, I14, I16, I22, I23, I24) had low FIB levels. In contrast, only seven samples with elevated FIBs were collected during the dry season at non-outfall stations. These included one sample each from stations I9 and I10 located south of the outfall along the 28-m and 19-m depth contours, respectively, and five samples from station I5 located along the 19-m contour in Mexican waters. Elevated FIB levels at I5 during the current and previous years (e.g., see City of San Diego 2007) are likely related to contaminated outflows from the nearby Los Buenos Creek.

Only eight of the above samples with elevated FIB densities were collected adjacent to the SBOO diffusers (i.e., stations I12, I14, I16) during 2008 (Table 3.4), all of which were collected from a depth of 18 m. Most of these samples also met the FTR

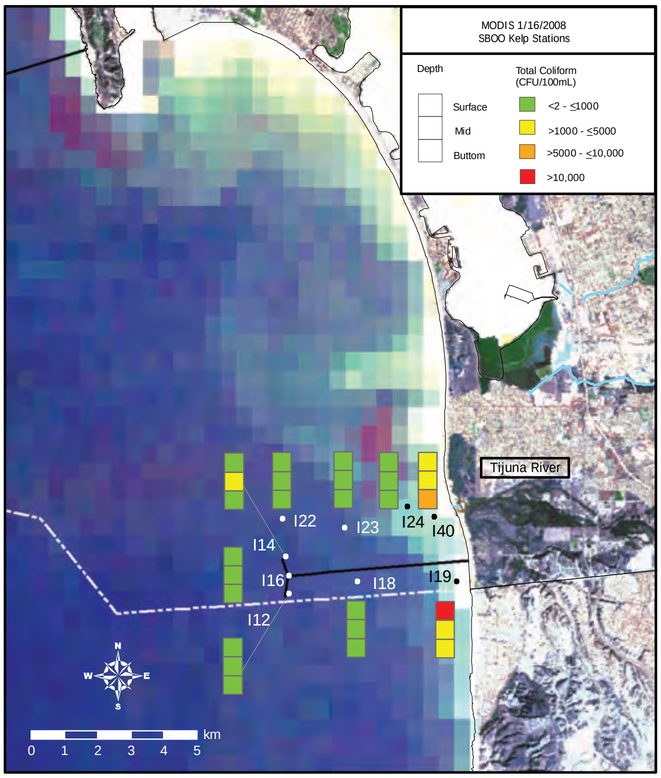

Figure 3.5

MODIS satellite image showing the San Diego monitoring region on January 16, 2008 (Svejkovsky 2009) combined with total coliform concentrations at offshore stations sampled on the same day. Turbid waters from the Tijuana River and Los Buenos Creek can be seen moving north along the coastline and overlapping stations where contamination was high nearshore. Waters are clear over the outfall discharge site.

Table 3.4

The number of samples with elevated bacteria collected at SBOO offshore stations during 2008. Elevated FIB=the total number of samples with elevated FIB densities; contaminated=the total number of samples that meet the fecal:total coliform ratio criteria indicative of contaminated seawater; Wet=January–March and November–December; Dry=April–October; n=total number of samples. Rain data are from Lindbergh Field, San Diego, CA. Offshore stations not listed had no samples with elevated FIB concentrations.

Station		Season		
		Wet	Dry	Total
9-m Depth Contour				
I19	Elevated FIB	7	—	7
	Contaminated	2	—	2
I11	Elevated FIB	1	—	1
	Contaminated	1	—	1
I24	Elevated FIB	4	—	4
	Contaminated	—	—	—
I32	Elevated FIB	2	—	2
	Contaminated	—	—	0
I40	Elevated FIB	6	—	6
	Contaminated	4	—	4
19-m Depth Contour				
I5	Elevated FIB	—	5	5
	Contaminated	—	—	—
I10	Elevated FIB	—	1	1
	Contaminated	—	—	—
I23	Elevated FIB	3	—	3
	Contaminated	2	—	2
28-m Depth Contour				
I22	Elevated FIB	1	—	1
	Contaminated	—	—	—
I12	Elevated FIB	1	2	3
	Contaminated	—	2	2
I14	Elevated FIB	1	1	2
	Contaminated	—	1	1
I16	Elevated FIB	1	2	3
	Contaminated	1	2	3
I9	Elevated FIB	—	1	1
	Contaminated	—	—	—
	Rain (in)	10.7	1.4	12.1
Total counts	Elevated FIB	27	12	39
	Contaminated	10	5	15
	n	375	525	900

criteria for contaminated waters (Appendix B.4). Consequently, it appears likely that these FIB densities were associated with wastewater discharge from the outfall. No samples with elevated bacteria were collected in surface or near-surface waters during the year, despite the fact that aerial imagery results indicated that the wastewater plume reached near-surface waters above the discharge site on several occasions between January–April and November–December (see Svejkovsky 2009). The low incidence of contaminated waters during winter at the surface and at depth may be due to chlorination of IWTP effluent, which typically occurs between November and April each year. The lack of elevated bacteria levels in surface waters during the summer is expected, as those are the months when the water column is well stratified and the waste field remains trapped beneath the thermocline.

California Ocean Plan Compliance

Compliance with the 2001 COP water contact standards for samples collected from January through December 2008 at the SBOO shore stations located north of the USA/Mexico border and at the three offshore kelp bed stations is summarized in Appendix B.5. Overall, compliance was a little lower this year than during 2007 (see City of San Diego 2008), which was likely related to the higher rainfall during 2008 and subsequent trends in FIB concentrations. During 2008, compliance along the shore ranged from 61 to 97% for the 30-day total coliform standard, 55 to 96% for the 60-day fecal coliform standard, and 79 to 100% for the 30-day fecal geometric mean standard. In addition, the shore station samples were out of compliance with the 10,000 total coliform standard 20 times during the year. Differences in compliance rates during the year generally reflected trends in elevated bacteria; i.e., compliance was lowest between January–March and November–December when rainfall was greatest, especially at stations closest to the Tijuana River (i.e., S5, S6, S11) and to the south (i.e., SD4, SD10) (see previous discussion).

Compliance rates for samples collected at the three kelp bed stations tended to be higher than

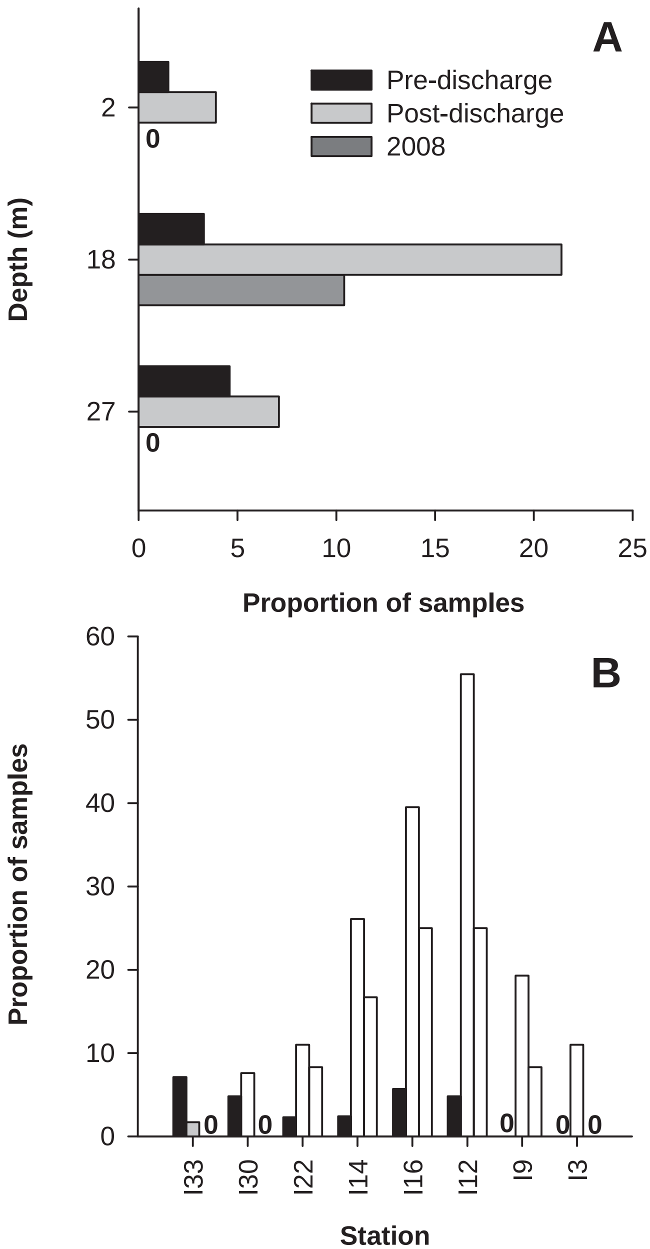

Figure 3.6
Summary of the proportion of samples with elevated FIB densities at SBOO offshore stations along the 28-m depth contour sampled in 2008 (n=288) versus pre-discharge (1995–1998; n=981) and post-discharge periods (1999–2007; n=2856) by depth (A) and by station (B) at the 18-m sample depth.

at the shore stations, which reflects the lower levels of FIBs found in these samples. Compliance at these sites during 2008 ranged from 88 to 100% for the 30-day total coliform standard, 79 to 100% for the 60-day fecal coliform standard, and 100% for the 30-day fecal geometric mean standard. In addition, the kelp bed stations were never out of compliance with the 10,000 total coliform standard. As with the shore stations, the lowest compliance rates tended to occur during months with the most rain (e.g., winter, spring) at station I25 located nearest the Tijuana River.

Summary and Conclusions

There was no evidence that contaminated waters associated with the wastewater discharged to the ocean via the SBOO reached the shoreline or near-shore recreational waters in 2008. Although elevated FIB densities were detected along the shore, and occasionally at the kelp bed or other nearshore stations throughout the year, these data do not represent shoreward transport of the SBOO wastewater plume. Instead, analysis of FIB distributions and the results of satellite imagery data indicate that other sources such as outflows from the Tijuana River and Los Buenos Creek, as well as surface runoff associated with rainfall events are more likely to impact water quality along and near the shore in the South Bay region. For example, the shore stations located near the Tijuana River and Los Buenos Creek have historically had higher numbers of contaminated samples than stations located farther to the north. Further, long-term analyses of various water quality parameters have demonstrated that the general relationship between rainfall and elevated FIB levels has remained consistent since ocean monitoring began in 1995, including the period prior to wastewater discharge (e.g., see City of San Diego 2000).

During 2008, the majority of elevated FIB densities not associated with rainfall events occurred at several offshore monitoring sites located within 1000 m of the SBOO diffuser and at a depth of 18 m. Additionally, no elevated FIBs were collected near or at the surface during the year, although remote sensing observations did detect the signature of the wastewater plume in near-surface waters over the discharge site on several occasions during the winter months. As discussed in the previous section, the lack of coincident contaminated waters at these times was most likely due to chlorination of

Table 3.5

Summary of oil and grease (O&G) and total suspended solid (TSS) concentrations in samples collected from offshore stations in 2008. The method detection limits are 1.4 mg/L for O&G and 1.6 mg/L for TSS; n=number of samples with detected concentrations.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Oil & Grease												
n	0	0	2	0	0	1	0	0	0	0	0	2
Min	—	—	1.8	—	—	2.5	—	—	—	—	—	1.6
Max	—	—	5.0	—	—	2.5	—	—	—	—	—	1.7
Mean	—	—	3.4	—	—	2.5	—	—	—	—	—	1.7
Total Suspended Soilds												
n	78	82	84	83	83	83	84	81	84	81	83	59
Min	1.7	1.8	1.8	1.8	1.7	1.7	1.7	1.8	2.3	1.7	1.7	1.6
Max	31.5	14.3	17.6	15.0	14.7	18.1	16.0	15.1	19.1	17.6	14.4	36.6
Mean	4.4	4.9	5.3	5.4	6.3	5.8	5.4	5.2	6.1	4.7	6.0	4.0

IWTP effluent that occurs during the winter. In contrast, the lack of contaminated surface waters during the summer is expected due to waste field entrapment beneath the thermocline.

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