Chapter 3. Microbiology

INTRODUCTION

The City of San Diego performs shoreline and water column bacterial monitoring in the region surrounding the Point Loma Ocean Outfall (PLOO). This program is designed to assess general water quality conditions, evaluate the movement and dispersal of the wastewater plume, and monitor compliance with the 2001 California Ocean Plan (SWRCB 2001). Bacteriological densities (total coliforms, fecal coliforms, enterococcus), together with oceanographic data (see Chapter 2), provide information about the direction the wastewater plume is traveling in relation to ocean currents and large scale events (see Pickard and Emery 1990). Analyses of these data may also implicate point or non-point sources other than the outfall as contributing to bacterial contamination events in the region. The data from the bacteriological sampling and individual station compliance are regularly submitted to the San Diego Regional Water Quality Control Board in monthly receiving waters monitoring reports. This chapter summarizes and interprets patterns in bacterial concentrations collected for the Point Loma region during 2006, as well as historical data from 1991–2006.

MATERIALS AND METHODS

Field Sampling

Water samples for bacteriological analyses were collected at fixed shore and offshore sampling sites throughout the year (**Figure 3.1A**). Weekly sampling was performed at 8 shore stations

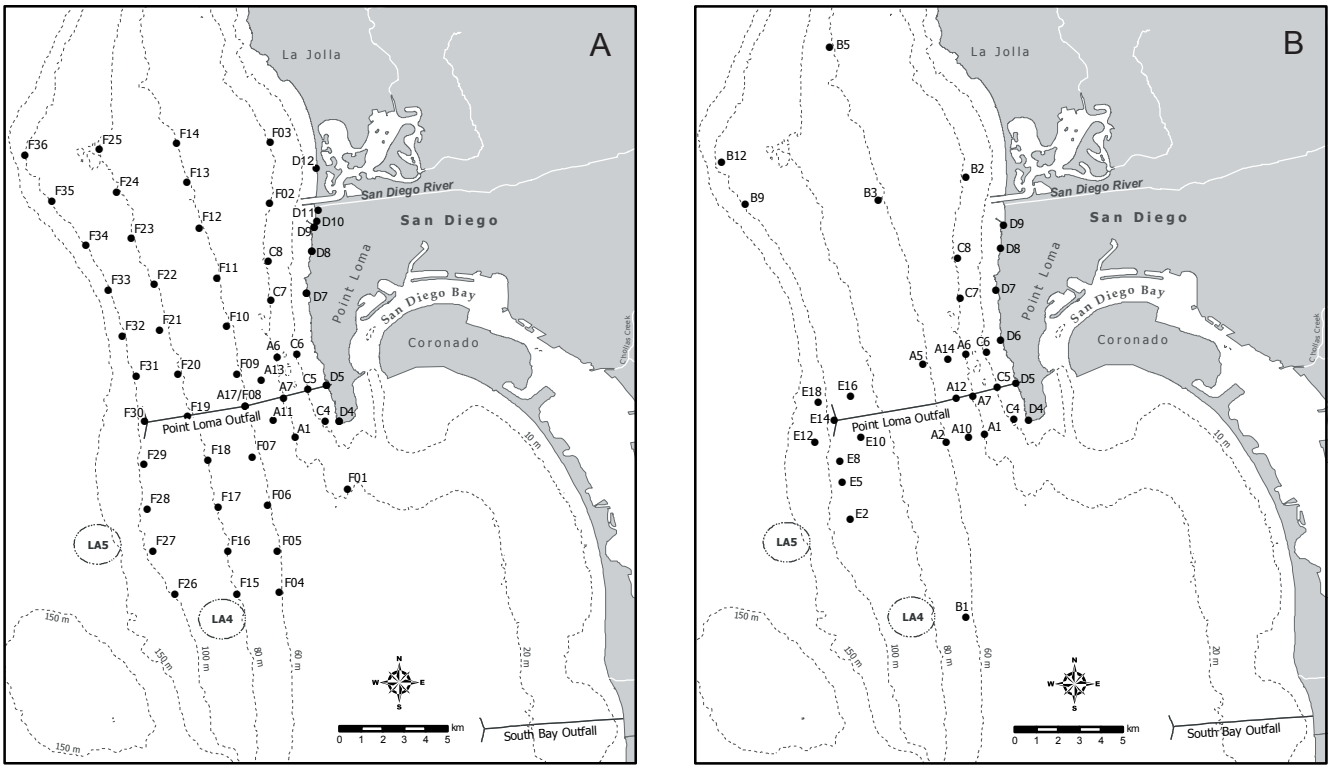

Figure 3.1
Water quality monitoring stations where bacteriological samples were collected, Point Loma Ocean Outfall Monitoring Program. (A) Current stations sampled in 2006. (B) Stations sampled from 1991–2003. Monthly offshore stations were sampled through July 2003. Shore station D6 was discontinued after July 31, 2003.

Table 3.1

Depths at which bacteriological samples are collected at the PLOO kelp and quarterly offshore stations.

	Sample depth (m)								
Station transect	1	3	9	12	18	25	60	80	98
9-m Kelp bed	x	x	x						
18-m Kelp bed	x			x	x				
18-m Offshore	x			x	x				
60-m Offshore	x					x	x		
80-m Offshore	x					x	x	x	
98-m Offshore	x					x	x	x	x

(D4, D5, D7–D12) to monitor bacterial levels along public beaches. Eight stations located in the Point Loma kelp bed were also monitored to assess water quality conditions in areas used for water contact sports (e.g., SCUBA, surfing, fishing, kayaking). These stations include 3 sites (stations C4, C5, C6) located near the inner edge of the kelp bed along the 9-m depth contour, and 5 sites (stations A1, A6, A7, C7, C8) located near the outer edge of the kelp bed along the 18-m depth contour. Samples were taken at 3 fixed depths for each kelp station (**Table 3.1**). The kelp stations were sampled weekly, such that each day of the week was represented over a 2 month period.

Thirty-six offshore stations (F01–F36) were sampled quarterly (January, April, July, October) to estimate the spatial extent of the wastewater plume at these times. Sampling at these sites usually takes place over a 3 day period. Three of these stations (F01–F03) are located along the 18-m depth contour, while 33 sites (11 per transect) are located along the 60-m (stations F04–F14), the 80-m (stations F15–F25), and the 98-m (stations F26–F36) contours. The number of samples collected at each station was depth-dependent and ranged from 3 to 5 fixed depths (Table 3.1).

Seawater samples were collected from the surf zone at each station and stored in sterile 250-mL 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 sample collection. The seawater samples were then transported on ice to the City's Marine Microbiology Laboratory and analyzed to determine concentrations of total coliform, fecal coliform, and enterococcus bacteria.

Seawater samples from the kelp bed and quarterly offshore stations were collected using either a series of Van Dorn bottles or a rosette sampler fitted with Niskin bottles. Aliquots for each analysis were drawn into appropriate sample containers. The samples were refrigerated aboard ship and then transported to the City's Marine Microbiology Laboratory for analysis of total coliforms, fecal coliforms, and enterococcus bacteria. Visual observations of weather, sea state, and human or animal activity in the area were also recorded for each sampling event.

Monitoring of the San Diego area and neighboring coastline also included aerial and satellite image analysis performed by Ocean Imaging Corporation (OI). All usable images captured during 2006 by the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite were downloaded, and several quality Landsat Thematic Mapper (TM) images were purchased. Aerial images were collected with OI's DMSC-MKII digital multispectral sensor (DMSC). Its 4 channels were configured to a specific wavelength (color) combination which, according to OI's previous research, maximizes the detection of the SBOO plume's turbidity signature by differentiating between the wastewater plume and coastal turbidity. The depth penetration of the radiance detected by this sensor varies between 8 and 15 m, depending on overall water clarity. The spatial resolution of the data is dependent upon aircraft altitude, but is typically maintained at 2 m. Sixteen overflights were

Box 3.1

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

(1) *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.

(2) *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.

(3) *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.

(4) *geometric mean* — 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 5 samples.

done in 2006, which consisted of 2 overflights per month during the winter when the outfall plume had the greatest surfacing potential and one per month during spring and summer.

Laboratory Analyses and Data Treatment

All bacterial analyses were performed within 8 hours of sample collection and conformed to the standard membrane filtration techniques (see APHA 1992). The Marine Microbiology Laboratory follows guidelines issued by the EPA Water Quality Office, Water Hygiene Division and the California State Department of Health Services (CDHS) Environmental Laboratory Accreditation Program with respect to sampling and analytical procedures (Bordner et al. 1978, APHA 1992).

Colony counting, calculation of results, data verification, and reporting all follow EPA guidelines (see Bordner et al. 1978). Plates with bacterial 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 the calculation of compliance with 2001 California Ocean Plan (COP) water contact standards and statistical analyses in this report.

Shore and kelp bed station compliance with 2001 COP standards (see **Box 3.1**) were summarized according to the number of days that each station was out of compliance. Bacteriological data for offshore stations are not subject to COP standards, but were used to examine spatio-temporal patterns in the dispersion of the waste field. Such patterns were determined from mean densities of total coliform, fecal coliform, and enterococcus bacteria. Mean densities (±standard error) were calculated by month or quarter, station, depth, and time period (pre-outfall extension discharge and post-outfall extension discharge). Monthly sampling at the offshore stations (see Figure 3.1B) ended after July 2003 when a quarterly schedule at a new suite of stations began. Bacteriological data from February 2, 1992 through April 8, 1992 was not used because of the extremely high values that resulted from the outfall pipe break, which would have skewed the results.

Bacterial data were evaluated relative to monthly rainfall data (Lindbergh Field, San Diego, CA), oceanographic conditions (see Chapter 2), as well as other events (e.g., storm water flows, nearshore and surface water circulation patterns) identified through remote sensing data. Normality was determined graphically and homogeneity of variances was tested using the F-test. Bacteriological, oil and grease, and suspended solid data were log(x+1) transformed

to improve conformity to normality for use in parametric statistical analyses.

COP and AB 411 (CDHS 2000) bacteriological benchmarks were used as reference points to distinguish elevated bacteriological values in receiving water samples discussed in this report. These are >1000 CFU/100 mL for total coliforms, >400 CFU/100 mL for fecal coliforms, and >104 CFU/100 mL for enterococcus bacteria. Furthermore, contaminated water samples were identified as those with total coliform concentrations ≥1000 CFU/ 100 mL and a fecal:total (F:T) ratio ≥0.1 (see CDHS 2000). Samples from quarterly water quality stations that met these criteria were used as indicators of the PLOO waste field.

Quality assurance tests were performed routinely on water samples to ensure that sampling variability did not exceed acceptable limits. Duplicate and split field samples were collected and processed according to method requirements to measure intra-sample and inter-analyst variability, respectively. Results of these procedures were reported in the Quality Assurance Report (City of San Diego 2007).

The distribution of the PLOO waste field was estimated from maps of total coliform densities collected at the offshore stations. These maps were generated using the Spatial Analyst extension for ArcGIS 9.1. The Inverse Distance Weighting algorithm was used with the power set to 3, a neighborhood of 5, and default values for all other parameters. Bacterial densities from samples shallower than 60 m were not used because contaminated water was detected in only 1 such sample: the 12 m depth sample collected at station F01 on April 14. Interpolations of deep water total coliform concentrations are meant for simplified data visualization purposes only and are not statistically significant.

RESULTS AND DISCUSSION

Compliance with California Ocean Plan Standards

Compliance with COP bacterial standards for the shore and kelp stations was very high in 2006 (**Appendices A.1, A.2**). Shore station D11 was the only station to fall below 100% compliance. The few exceedances of the 30-day total coliform standard occurred at station D11 during March, the wettest month of the year. All kelp stations were 100% compliant with each COP bacterial standard.

Spatial and Temporal Trends

Shore stations

In 2006, a total of 2496 samples were collected for bacteriological analyses, including 495 from the shoreline stations, 1437 at the kelp stations, and 564 at the quarterly offshore stations. Of these, only 49 had total coliform concentrations greater than or equal to the 1000 CFU/100 mL benchmark. Five of these samples were collected at the shore stations and 44 at the offshore stations, while none were collected at the kelp stations. Forty of these 44 offshore samples also had F:T ratios ≥0.1 and were used as possible indicators of plume movement.

Bacterial densities were generally low at the shore stations in 2006 (**Table 3.2**). Monthly total coliform densities during the year averaged from 2 to 1264 CFU/100 mL. Although rainfall was below average for the year, the highest mean densities occurred during the wet months (e.g., February through May; see Chapter 2). For example, total coliform densities were highest in February as a result of one sample collected from station D11 on February 21 following a rain event (NOAA/NWS 2007; **Table 3.3**). Of the 5 shore samples with total coliforms ≥1000 CFU/100 mL, 2 were collected in February and May during rain events, and one occurred in March when trace amounts of rain fell prior to sampling. Two samples from station D8 were not associated with rain events but did contain bacterial levels that exceeded the benchmark values for total and fecal coliforms and were indicative

Table 3.2

Shore station bacterial densities and rainfall data for the PLOO region during 2006. Mean total coliform, fecal coliform, and enterococcus bacteria densities are expressed as CFU/100 mL. Rain is measured at Lindbergh Field, San Diego, CA (see NOAA/NWS 2007). Sample size (n) for each station is given in parentheses.

Month	Rain (in.)		D4 (61)	D5 (62)	D7 (62)	D8 (62)	D9 (62)	D10 (62)	D11 (62)	D12 (61)	All stations
Jan	0.36	*Total*	5	4	5	274	96	132	141	22	85
		Fecal	6	2	3	140	6	15	14	3	24
		Entero	3	2	3	24	10	11	16	5	9
Feb	1.11	*Total*	57	6	59	61	8	77	1264	5	195
		Fecal	6	3	70	21	2	16	37	4	20
		Entero	3	5	7	8	2	6	17	2	6
Mar	1.36	*Total*	2	3	6	54	16	256	668	90	137
		Fecal	2	2	4	20	3	20	25	4	10
		Entero	3	2	2	16	4	12	10	6	7
Apr	0.88	*Total*	2	57	3	58	10	72	230	10	55
		Fecal	2	17	3	23	4	6	17	4	9
		Entero	2	6	2	6	2	3	4	3	4
May	0.77	*Total*	85	43	23	176	10	286	319	6	119
		Fecal	4	12	6	46	3	24	42	2	17
		Entero	3	9	7	94	2	29	54	3	25
Jun	0.00	*Total*	49	56	24	76	24	40	76	115	56
		Fecal	2	6	4	9	3	11	18	10	8
		Entero	2	2	5	4	2	7	7	38	8
Jul	0.04	*Total*	13	20	128	32	13	53	116	21	49
		Fecal	2	2	7	14	2	49	28	8	14
		Entero	2	2	4	2	2	9	31	2	7
Aug	0.01	*Total*	52	16	92	28	13	180	96	52	66
		Fecal	3	4	5	4	2	19	17	9	8
		Entero	2	2	2	2	2	12	29	7	8
Sep	0.00	*Total*	6	15	124	80	10	48	32	7	40
		Fecal	2	4	4	28	3	12	14	10	10
		Entero	2	6	8	9	2	3	4	2	5
Oct	0.76	*Total*	17	24	57	137	21	61	29	16	45
		Fecal	2	3	10	53	4	24	11	5	14
		Entero	4	2	18	22	2	15	6	7	10
Nov	0.15	*Total*	11	32	136	360	16	81	49	61	93
		Fecal	6	6	29	113	4	22	30	33	30
		Entero	9	6	10	84	8	7	7	39	21
Dec	0.71	*Total*	7	10	13	164	52	66	64	22	50
		Fecal	4	6	6	92	20	30	40	7	26
		Entero	2	30	2	287	18	38	142	14	67
Annual means		**Total**	**24**	**24**	**55**	**128**	**25**	**112**	**251**	**34**	
		Fecal	**3**	**5**	**12**	**48**	**5**	**21**	**24**	**8**	
		Entero	**3**	**6**	**6**	**46**	**5**	**13**	**27**	**11**	

Table 3.3

Elevated total coliform, fecal coliform, and enterococcus bacteria (Entero) densities (CFU/100 mL) at PLOO shore stations in 2006. Fecal to total coliform ratios (F:T) ≥0.1(see text) are bolded. Rain was measured at Lindbergh Field, San Diego, CA (see NOAA/NWS 2007).

Date	72-Hour rain (in.)	Station	Total	Fecal	Entero	F:T
January 18	0.00	D8	1200	740	38	**0.62**
February 21	0.19	D11	6200	100	48	0.02
March 5	0.05	D11	2600	78	28	0.03
May 22	0.77	D11	1000	120	220	**0.12**
November 18	0.00	D8	1000	420	220	**0.42**

of contaminated water (F:T ratio ≥0.1). However, high counts of indicator bacteria have also been present during dry periods at station D8 in previous years (City of San Diego 2005, 2006g) and the relationship between rainfall and monthly mean fecal coliform concentrations was not significant (Spearman correlation; n=12, p=0.32).

Other potential sources of contamination that may have contributed to elevated bacterial densities at shore stations D8 and D11 include kelp and seagrass beach wrack (see Martin and Gruber 2005) and shorebirds, all of which were present during the collection of many of the samples (City of San Diego 2006a–f). There is also a tidally influenced storm drain at station D8, which may accumulate organic debris (kelp and surfgrass) and amplify bacterial densities (Martin and Gruber 2005). In contrast, the beach around station D11 is a designated dog recreation area and has a population of transient people living along the San Diego River upstream of the sampling site. Contamination from both sources is suspected in the elevated bacterial counts at this station.

Kelp bed and offshore stations

Only 2% of the offshore station samples (n=40) collected in 2006 were indicative of contaminated waters (total coliform density ≥1000 CFU/100 mL and an F:T ratio ≥0.1; **Appendix A.3**). Total coliform densities in shallow depths (1–25 m) ranged from <2 to 1400 CFU/100 mL throughout the year, while densities of fecal coliforms ranged from <2 to 160 CFU/100 mL. Only one shallow water sample, station F01 in April, was indicative of contaminated water. The highest mean densities of indicator bacteria came from depths of 60 m and greater (**Figure 3.2A**), suggesting that the stratified water column restricted the plume to mid- and deep-water depths throughout the year (see Chapter 2).

There was little evidence that the wastewater plume reached nearshore waters in 2006. For example, none of the bacteriological samples collected from the kelp bed stations had elevated bacterial densities. Mean bacterial densities were highest at stations along the 80 and 98-m transects of quarterly offshore stations (Figure 3.2B). Thirty-five of the 40 samples indicative of contaminated water were collected from sites along these transects. The other 5 samples came from station F01 (18-m depth contour) and stations F05, F06, F09, and F10 (60-m depth contour). The relatively high bacterial densities in samples collected at station F01 may be related to the release of over 10 million gallons of sewage during 2005–2006 from Naval Base San Diego into San Diego Bay (US Navy 2006). Mean bacterial densities were generally highest at the 80 m stations in April, the 98 m stations in July, and the 80 m and 98 m stations in October (**Table 3.4**) The lowest densities were in January with elevated samples in only one sample (see Appendix A.3).

The spatial distribution of the wastefield varied by quarter in 2006 (**Figure 3.3**). Interpolation of the bacteriological data from 60 m and below indicates that there was a possible offshore movement in January, as evidenced by the lack of elevated bacterial densities around and inshore of the PLOO diffusers. The only January sample containing bacterial densities indicative of contaminated water occurred 5.6 km north of the PLOO at station F33 (60 m depth sample). MODIS imagery showed offshore flows of surface waters that occurred up to 1 week before the January quarterly sampling (Ocean Imaging 2007a).

In April, the wastefield was detected along the 80 and 60 m contours, mostly to the north and inshore of the outfall. Although the wastefield appeared to have moved eastward in April, it was not detected at special study stations A11 and A13 or at any of the kelp bed stations (City of San Diego 2006c). MODIS imagery indicated that surface waters were flowing north in early April, but had switched back to a southward flow right before the April quarterly sampling (Ocean Imaging 2007b). Elevated bacterial densities were found up to 7.5 km south of the PLOO along the 60 m contour in April and may have been due to discharge from the San Diego Bay and Tijuana River following several rain events. MODIS imagery revealed turbidity plumes from the San Diego Bay and Tijuana River in the sampling area before the April sampling (Ocean Imaging 2007b).

In July and October, contaminated water was detected up to 12.5 km (7.8 mi) north of the PLOO (stations F36 and F25) along the 80 m and 98 m contours. Data from an acoustic doppler current profiler (ADCP) also indicated that the dominant direction of current flow for bottom waters (42–98 m depths) around the PLOO diffusers in October was north with some movement east and west (City of San Diego, unpublished data).

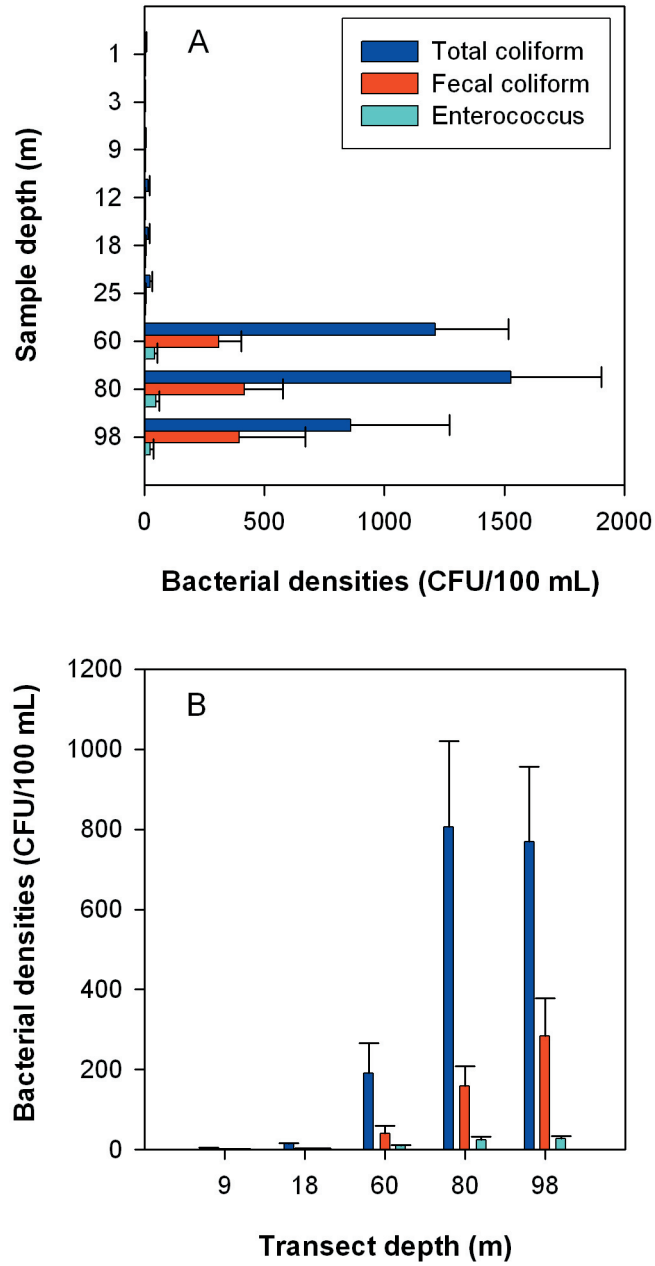

Figure 3.2
Kelp and quarterly offshore station bacterial densities for the PLOO region during 2006. Total coliform, fecal coliform, and enterococcus bacterial densities (mean±SD; CFU/100 mL) by (A) sample depth and (B) transect depth.

Historical Analyses

The extension of the PLOO was designed to eliminate bacterial contamination in the Point Loma kelp bed and nearshore waters. To evaluate the effectiveness of the outfall extension, mean bacterial densities for pre-discharge (1/1/1991–11/23/1993) and post-discharge (11/24/1993–12/31/2006) periods were compared for shore, kelp, and offshore station surveys (see Materials and Methods). The results

Table 3.4

Mean bacterial densities (CFU/100 mL) for quarterly sampling events in 2006 at PLOO kelp bed and offshore stations. n=number of samples collected quarterly. Sample size for 9-m kelp bed stations in January=42.

Assay	Contour	n	January	April	July	October
Total	9-m kelp bed	45	3	2	3	4
	18-m kelp bed	75	10	13	3	11
	18-m offshore	9	8	184	109	2
	60-m offshore	33	109	584	34	37
	80-m offshore	44	123	1362	451	1284
	98-m offshore	55	150	6	1809	1110
Fecal	9-m kelp bed	45	2	2	2	2
	18-m kelp bed	75	3	3	2	2
	18-m offshore	9	3	27	28	3
	60-m offshore	33	20	127	9	4
	80-m offshore	44	23	331	91	193
	98-m offshore	55	35	3	754	345
Entero	9-m kelp bed	45	2	2	2	2
	18-m kelp bed	75	2	2	2	2
	18-m offshore	9	2	2	24	2
	60-m offshore	33	9	23	4	2
	80-m offshore	44	11	61	10	18
	98-m offshore	55	14	2	60	33

indicate that the PLOO extension has greatly reduced the flow of the wastewater plume into the Point Loma kelp bed such that it is rarely, if ever, detected along the shoreline or the kelp beds (see **Figures 3.4–3.5**). Mean total and fecal coliform densities from samples collected at the shore stations, and all 3 indicator bacteria at the kelp stations, were significantly lower once discharge through the extended outfall began (**Table 3.5**). Station D5, located along the shoreline where the outfall pipe meets the shore, had the largest decline in fecal coliform densities during the post-discharge period. The largest overall decrease at the kelp stations occurred in total coliform densities, while fecal coliform densities declined at all depths in the post-discharge period.

Mean densities of indicator bacteria at the offshore samples were also significantly lower and samples indicative of contaminated water have been restricted to deeper waters since discharge began through the extended outfall (**Figure 3.6**, Table 3.5). For example, the highest fecal coliform densities occurred in samples taken from 24 to 43 m during the pre-discharge period, but occurred in samples from 80 m during the post-discharge period (**Figure 3.7**). Similarly, fecal densities greater than 400 CFU/100 mL have not been found shallower than 12 m during the post-discharge period. Finally, total coliforms densities during the post-discharge period have fallen below 1000 CFU/100 mL at stations along the 60 m contour near the old outfall as well as those stations farther inshore, with densities >1000 CFU/100 mL limited to stations along the 80 m contour (Figure 3.7). Overall these results suggest that the extension of the outfall pipe has suppressed the surfacing potential and significantly reduced the onshore movement of the PLOO wastefield.

SUMMARY AND CONCLUSIONS

There was no evidence that the Point Loma Ocean Outfall (PLOO) wastewater plume reached the shoreline or recreational waters in 2006. Elevated

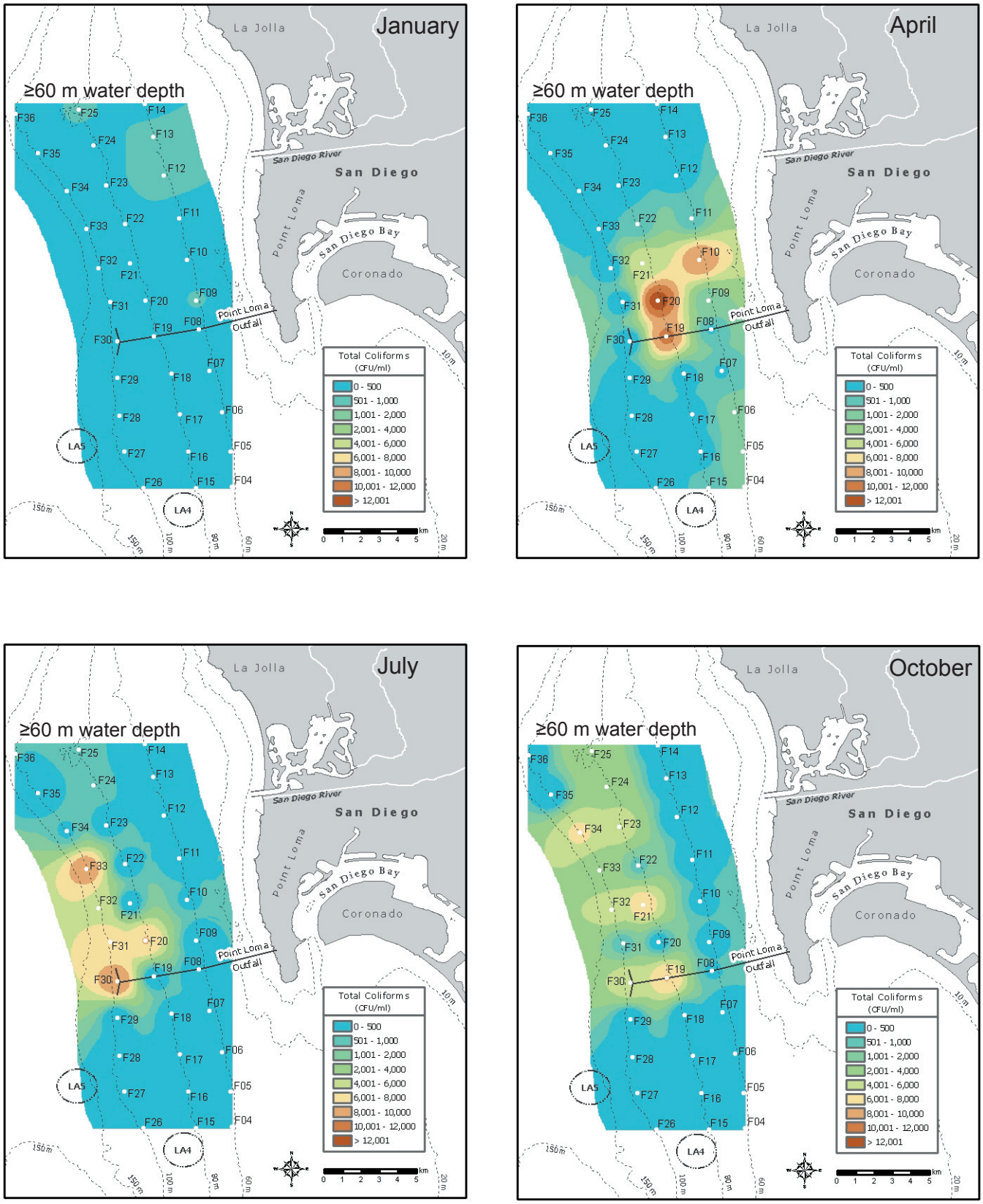

Figure 3.3
Distribution of mean total coliform counts from depths of 60 m and below collected during quarterly offshore surveys in 2006. Contaminated water (see text) was generally not detected in samples shallower than 60 m depth.

Table 3.5

Independent sample t-test results for pre-extension discharge versus post-extension discharge periods from PLOO shore, kelp, and monthly offshore stations. Data are log(x+1) transformed. The pre-extension discharge period is from January 1991 to November 1993, while post-extension data used in this analysis is from November 1993 to December 2006 (Shore and Kelp) and November 1993 to July 2003 (Offshore).

	Variable	t	df	P
Shore	Total coliform	-2.243	1319	0.025
	Fecal coliform	-3.967	1294	<0.001
	Enterococcus	-1.698	5786	0.089
Kelp	Total coliform	-68.360	13,356	<0.001
	Fecal coliform	-59.411	11,668	<0.001
	Enterococcus	-55.091	12,281	<0.001
Offshore	Total coliform	-28.937	6735	<0.001
	Fecal coliform	-27.340	6131	<0.001
	Enterococcus	-25.688	6430	<0.001

bacterial densities along the shore were limited to stations D8 and D11 where the source of contamination may have been heavy recreational use or decaying kelp and surfgrass wrack material. Despite a below average amount of rainfall in 2006, most of these elevated bacterial densities came during the wettest months of February through May. All of the kelp bed stations had low densities of all indicator bacteria. Furthermore, all 7 kelp bed stations and all but one shore station were 100% compliant with the 4 COP standards. Shore station D11, located near the mouth of the San Diego River, was 95% compliant with the 30-day total coliform standard and 100% compliant with the other 3 COP standards. All of the exceedances at station D11 occurred during March when rains were heaviest; however, an analysis of rainfall and shore station bacterial densities showed that there was no significant correlation between rain and fecal coliforms.

It is also unlikely that the PLOO wastewater ever reached surface waters in 2006. Bacteriological evidence of contaminated water at the offshore stations was predominantly limited to samples collected from depths of 60 m and deeper. The only shallow water sample indicative of contaminated water was taken from station F01 (12 m depth) in April, and may have been due to sewage discharge from Naval Base San Diego into the San Diego Bay.

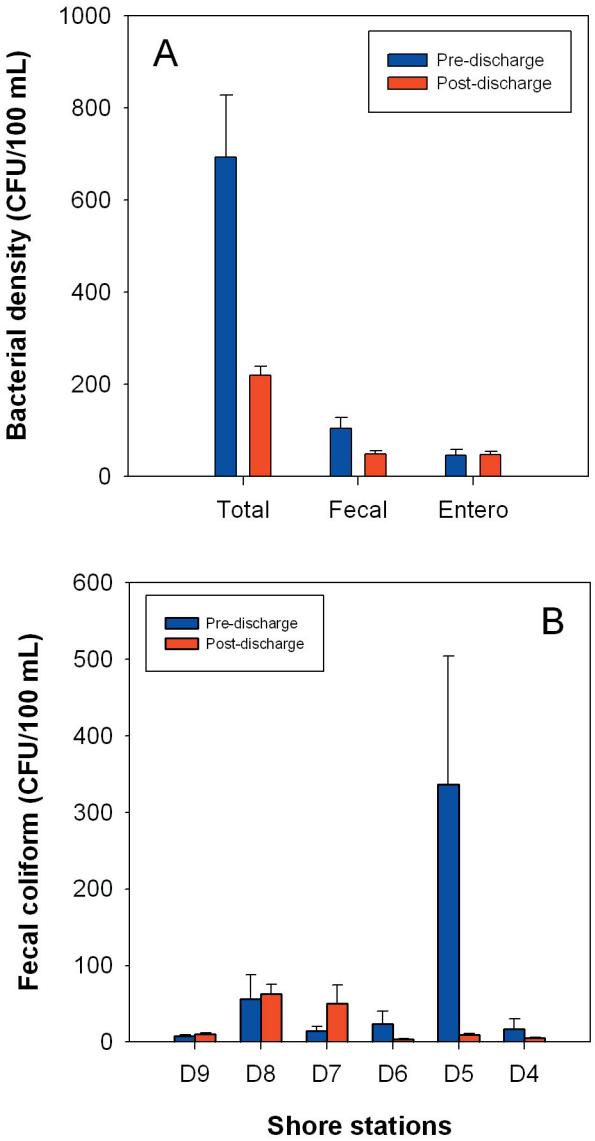

Figure 3.4

Mean bacterial densities (mean±SE) for PLOO shore stations from 1991–2006. The pre-extension period is from January 1991 to November 1993 while post-extension is from November 1993 to December 2006. Sample size indicated as Pre/Post. (A) Mean densities by parameter. Total=total coliform (n=1007/4768), Fecal=fecal coliform (n=1007/4781), Entero=enterococcus (n=1008/4780). (B) Mean fecal coliform densities by station (n=212–556). Stations are arranged from north to south on the x-axis.

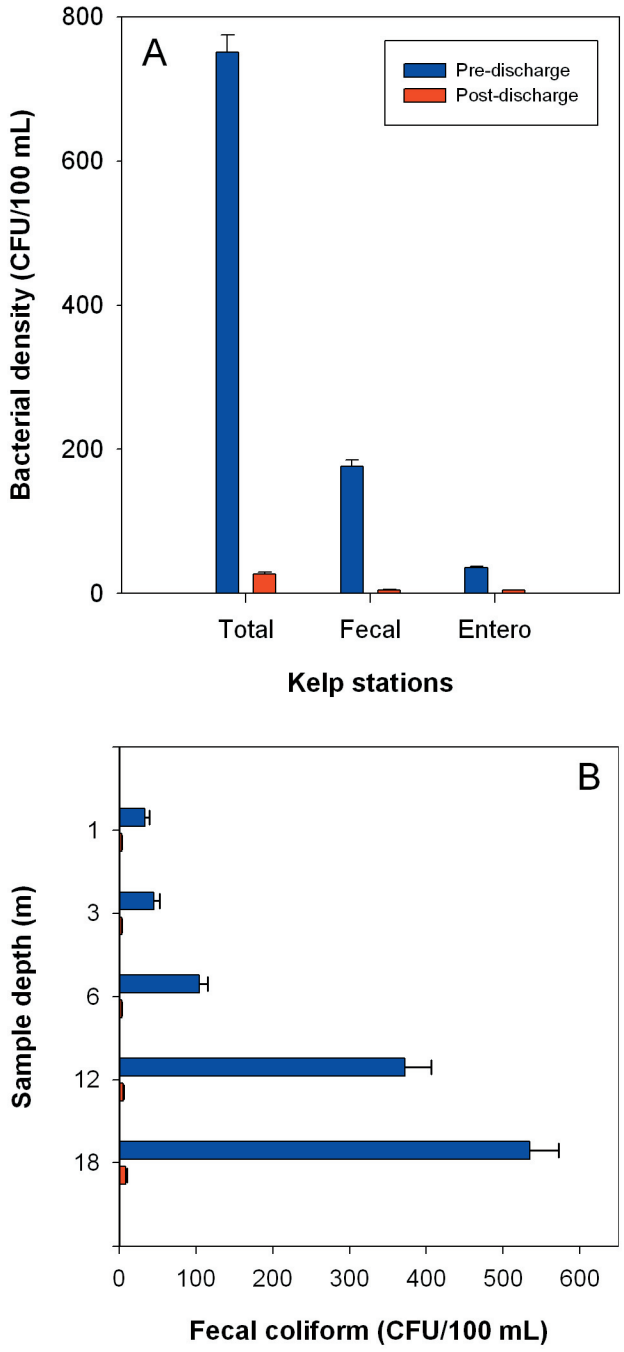

Figure 3.5
PLOO kelp station mean bacterial densities (mean±SE) collected by (A) parameter and (B) depth from 1991–2006. The pre-discharge period is from January 1991 to November 1993 while post-discharge is from November 1993 to December 2006. Sample size indicated as Pre/Post. Total=total coliform (n=10,550/17,883), Fecal=fecal coliform (n=10,540/17,925), Entero=enterococcus (n=10,531/17,924).

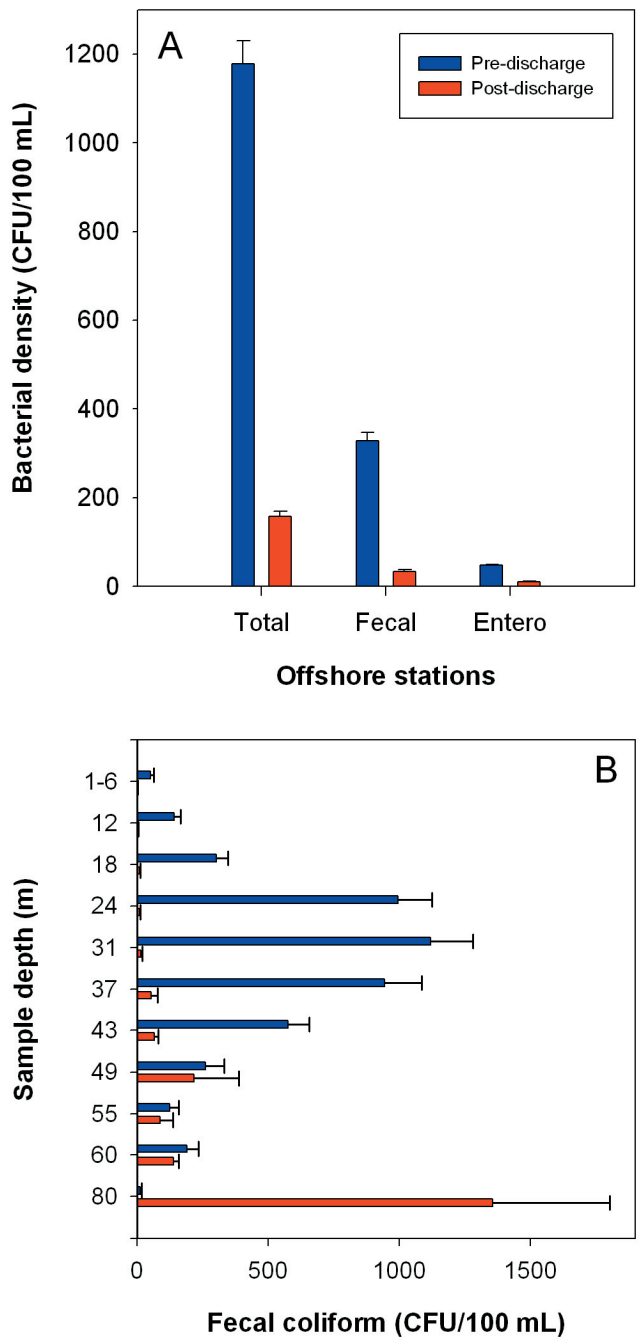

Figure 3.6
PLOO monthly offshore station mean bacterial densities (mean±SE) collected by (A) parameter and (B) depth from 1991–2006. The pre-discharge period is from January 1991 to November 1993 while post-discharge is from November 1993 to July 2003. Sample size indicated as Pre/Post. Total=total coliform (n=4444/6977), Fecal=fecal coliform (n=4477/6980), Entero=enterococcus (n=4476/6980).

The discharge depth (~98 m) may be the dominant factor that keeps the plume from reaching the surface. Wastewater is released into cold, dense seawater that does not appear to mix with the top 25 m of the water column. Physical parameters suggest that the water column was strongly

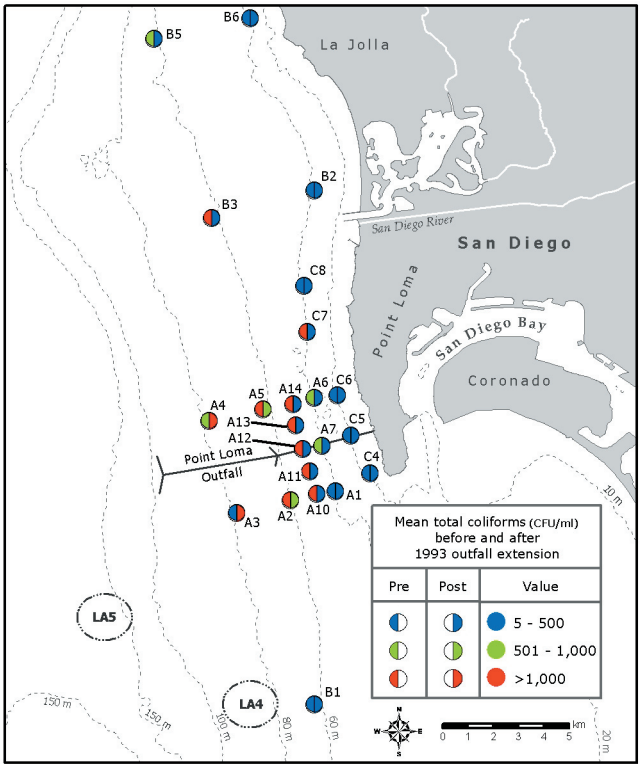

Figure 3.7
Comparison of pre- and post-discharge mean total coliform densities (CFU/100 mL) for PLOO water quality monitoring stations where monthly bacteriological samples were collected from 1991–2003.

stratified during the spring through fall months (see Chapter 2). However, the absence of evidence for bacteriological contamination in the surface waters in January, when the water column was well mixed, suggests that stratification may not be the only factor limiting the depth of the plume to 60 m and deeper.

The dominant direction of the PLOO waste field flow appeared to be northward in 2006. High bacterial densities were detected at the northern limits of the quarterly sampling grid during most quarters, and were detected at the southern limits only in April. There was also evidence that the plume moved inshore to the 60-m depth contour in April. It also appears that the plume may have dispersed farther offshore than most of the sampling stations in January, when contaminated water was only detected well north of the PLOO in the 60 m sample from station F33. There did not appear to be one consistent pattern for the distribution of the wastefield.

Analyses of historical data indicated that since the extension of the PLOO, the wastefield is no longer reaching the shoreline. Mean coliform densities at shore stations significantly decreased during the post-discharge period. Similarly, all kelp bed station indicator bacterial densities decreased significantly during the post-discharge period. The largest decreases were detected in the 12 and 18-m depth samples. There is no bacteriological evidence that the PLOO wastefield has reached the Point Loma kelp bed since the outfall extension went into operation. Similarly, all indicator bacterial densities from the monthly offshore stations significantly decreased during the post-discharge period. The highest mean fecal coliform densities shifted from 24–43 m depth samples during the pre-discharge period to 80 m samples during the post-discharge period. These results, combined with recent results from quarterly station samples, indicate that the wastewater plume is remaining below the thermocline and offshore of the Point Loma kelp bed.

LITERATURE CITED

[APHA] American Public Health Association (1992). Standard Methods for the Examination of Water and Wastewater, 18th edition. Greenberg A.E., L.S. Clesceri, and A.D. Eaton, eds. American Public Health Association, American Water Works Association, and Water Pollution Control Federation. 1391 p.

Bordner, R., J. Winter and P. Scarpino, eds. (1978). Microbiological Methods for Monitoring the Environment: Water and Wastes, EPA Research and Development, EPA-600/8-78-017. 337 p.

[CDHS] California State Department of Health Services. (2000). Regulations for Public Beaches and Ocean Water-Contact Sports Areas. Appendix A: Assembly Bill 411, Statutes of 1997, Chapter 765. http://www.dhs.ca.gov/ps/ddwem/beaches/ab411_regulations.htm.

City of San Diego. (2004). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2003. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2005). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2004. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2006a). Monthly Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, January 2006. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2006b). Monthly Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, February 2006. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2006c). Monthly Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, March 2006. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2006d). Monthly Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, April 2006. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2006e). Monthly Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, May 2006. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2006f). Monthly Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, November 2006. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2006g). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2005. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2007). EMTS Division Laboratory Quality Assurance Report, 2006. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Martin, A. and S. Gruber. 2005. Amplification of indicator bacteria in organic debris on southern California beaches. Technical paper 0507. Weston Solutions, Inc. Presented at StormCon 2005. Orlando, FL, USA. July 2005. 7 p.

NOAA/NWS. (2007). The National Oceanic and Atmospheric Association and the National Weather Service Archive of Local Climate Data for San Diego, CA. http://www.weather.gov/climate/index.php?wfo=sgx.

Ocean Imaging. (2007a). Satellite and Aerial Coastal Water Quality Monitoring in The San Diego/Tijuana Region: Monthly Report for January through March 2006. Solana Beach, CA. 41 p.

Ocean Imaging. (2007b). Satellite and Aerial Coastal Water Quality Monitoring in The San Diego/Tijuana Region: Monthly Report for April through September 2006. Solana Beach, CA. 37 p.

Pickard, D.L., and W.J. Emery. 1990. Descriptive Physical Oceanography. 5Th Ed. Pergamon Press, Oxford. 320 p.

[SWRCB] California State Water Resources Control Board. (2001). California Ocean Plan, Water Quality Control Plan, Ocean Waters of California. California Environmental Protection Agency. Sacramento, CA.

US Navy. 2006. Navy Discovers Sewage Discharge from a Naval Base San Diego Barracks. Press Release. November 17, 2006. Navy Region Southwest.