Chapter 2. Ocean Conditions

INTRODUCTION

The City of San Diego monitors oceanographic conditions in the region surrounding the Point Loma Ocean Outfall (PLOO) to assist in evaluating possible impacts of the outfall on the marine environment. Treated wastewater is discharged to the Pacific Ocean via the PLOO at depths of ~94–98 m and at a distance of approximately 7.2 km west of the Point Loma peninsula. During 2007, average daily flow through the outfall was 161 mgd. Changes in current patterns, water temperatures, salinity, and density can affect the fate of the wastewater plume. These types of changes can also affect the distribution of turbidity (or contaminant) plumes that originate from various point and non-point sources. In the Point Loma region these include tidal exchange from San Diego Bay and Mission Bay, outflows from the San Diego River, the Tijuana River and northern San Diego County lagoons and estuaries, storm drains or other water discharges, and surface water runoff from local watersheds. For example, flows from San Diego Bay and the Tijuana River are fed by 1,075 km^2 and 4,483 km^2 of watershed, respectively, and can contribute significantly to nearshore turbidity, sedimentation, and bacterial contamination (see Largier et al. 2004). Overall, these different factors can affect water quality conditions either individually or synergistically.

The fate of PLOO wastewater discharged into deep offshore waters at the edge of the continental shelf is determined by oceanographic conditions and other events that impact horizontal and vertical mixing. Consequently, oceanographic parameters such as water temperature, salinity, and density that determine the mixing potential of the water column are important components of ocean monitoring programs (Bowden 1975). Analysis of the spatial and temporal variability of these and other parameters (e.g., transmissivity or water clarity, dissolved oxygen, pH, and chlorophyll) may also elucidate patterns of water mass movement. Monitoring patterns of change in these parameters for the receiving waters surrounding the PLOO can help: (1) describe deviations from expected oceanographic patterns (2) assess the impact of the wastewater plume relative to other input sources, (3) determine the extent to which water mass movement or mixing affects the dispersion/dilution potential for discharged materials, and (4) demonstrate the influence of natural events such as storms or El Niño/La Niña oscillations.

Remote sensing observations from aerial and satellite imagery, and evaluation of bacterial distribution patterns may provide the best indication of the horizontal transport of discharged waters in the absence of information on deepwater currents (Pickard and Emery 1990; Svejkovsky 2006, 2007a, b; also see Chapter 3). Thus, the City of San Diego combines measurements of oceanographic parameters with assessments of indicator bacteria and remote sensing data to provide further insight into the transport potential in coastal waters surrounding the PLOO discharge site. This Chapter describes the oceanographic conditions that occurred off Point Loma during 2007, and is referred to in subsequent chapters to explain patterns of bacteriological occurrence (see Chapter 3) or other changes in the local marine environment (see Chapters 4–7).

Materials and Methods

Oceanographic measurements were collected at fixed sampling sites located in a grid pattern surrounding the PLOO (**Figure 2.1**). Thirty-six offshore stations (designated F01–F36) were sampled quarterly in January, April, July, and October, usually over a 3-day period. Three of these stations (F01–F03) are located along the 18-m depth contour, while 11 sites are located along each of the following depth contours: 60-m contour (stations F04–F14); 80-m contour (stations F15–F25); 98-m contour (stations F26–F36). Eight additional stations located in the Point Loma kelp bed are subject to the

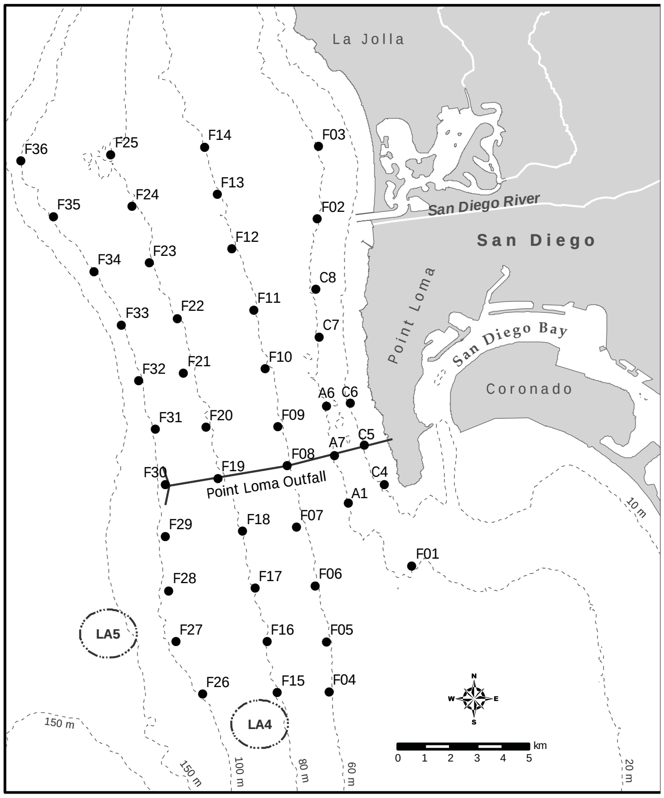

Figure 2.1
Water quality monitoring stations where CTD casts are taken, Point Loma Ocean Outfall Monitoring Program.

2001 California Ocean Plan (COP) water contact standards (SWRCB 2001). These stations include three sites (stations C4, C5, C6) located along the inshore edge of the kelp bed paralleling the 9-m depth contour, and five sites (stations A1, A6, A7, C7, C8) located along the 18-m depth contour near the offshore edge of the kelp bed. To meet 2001 COP sampling frequency requirements for kelp bed areas, sampling at the eight kelp bed stations was conducted five times per month.

Data for various water column parameters were collected using a SeaBird conductivity, temperature, and depth (CTD) instrument. The CTD was lowered through the water column at each station to collect continuous measurements of water temperature (°C), salinity (parts per thousand = ppt), density (δ/θ), pH, water clarity (% transmissivity), chlorophyll *a* (μg/L), and dissolved oxygen (mg/L). Profiles of each parameter were then constructed for each station by averaging the data values recorded over 1-m depth intervals. This ensured that physical measurements used in subsequent data analyses could correspond to discrete sampling depths for indicator bacteria (see Chapter 3). Visual observations of weather and water conditions were recorded just prior to each CTD cast.

Remote Sensing – Aerial and Satellite Imagery

Monitoring of the PLOO area and neighboring coastline also included aerial and satellite image analysis performed by Ocean Imaging (OI) of Solana Beach, CA. All usable images captured during 2007 by the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite were downloaded, and several high clarity Landsat Thematic Mapper (TM) images were purchased. High resolution aerial images were collected with OI's DMSC-MKII digital multispectral sensor (DMSC). The sensor's four channels were configured to a specific wavelength (color) combination designed to maximize detection of the PLOO discharge signature by differentiating between wastewater and coastal turbidity plumes. The depth penetration of the DMSC 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. Fifteen aerial surveys were flown in 2007, which consisted of two overflights per month during the winter when the outfall plume had the greatest surfacing potential (see below), and one flight per month during the spring and summer.

Data Treatment

The water column parameters measured in 2007 were summarized for each month by depth zone; profile data from the eight kelp stations were summarized for surface depths (≤2 m) and bottom depths (10–20 m), whereas profile data from the 36 offshore stations were summarized for surface depth (≤2 m), mid-depths (10–20 m), and bottom depths (≥ 88 m).

Mean temperature and salinity profile data from 2007 were compared with profile plots consisting of means ±1 standard deviation (SD) at 5 m depth increments for 1995–2007. The results from CTD casts conducted prior to 1995 were not comparable to later monitoring data due to changes in instrumentation. Data for the comparisons included herein were limited to the three stations located nearest the outfall discharge site along the 98-m depth contour. These include station F30 located immediately offshore of the center of the outfall wye, station F29 located 1.25 km south of the south diffuser, and station F31 located ~1.42 km north of the north diffuser. In addition, a time series of anomalies for each water column parameter was created to evaluate significant oceanographic events in the PLOO region. Anomalies were calculated by subtracting the monthly means for each year (1995–2007) from the mean of all 13 years combined. Means were calculated using the same three stations described above, all depths combined.

Results and Discussion

Climate Factors that Influence Oceanographic Conditions

Southern California weather can generally be classified into wet (winter) and dry (spring–fall) seasons (NOAA/NWS 2008a), and differences between these seasons affect certain oceanographic conditions (e.g., water column stratification, current patterns and direction). Understanding patterns of change in such conditions is important in that they can affect the transport and distribution of wastewater, storm water, or other types of turbidity plumes that may arise from various point or non-point sources (e.g., ocean outfalls, storm drains, outflows from rivers and bays, surface runoff from coastal watersheds). Winter conditions typically prevail in southern California from December through February during which time higher wind, rain and wave activity often contribute to the formation of a well-mixed or relatively homogenous (non-stratified) water column. The chance that the wastewater plume from the PLOO may surface is highest during such times when there is little, if any, stratification of the water column. These conditions often extend into March as the frequency of winter storms decreases and the seasons begin to transition from wet to dry. In late March or April the increasing elevation of the sun and lengthening days begin to warm surface waters, mixing conditions diminish with decreasing storm activity, and seasonal thermoclines and pycnoclines become re-established. Once the water column becomes stratified again by late spring, minimal mixing conditions typically remain throughout the summer and early fall months. In October or November, cooler temperatures associated with seasonal changes in isotherms, reduced solar input, along with increases in stormy weather, begin to cause the return of well-mixed or non-stratified water column conditions.

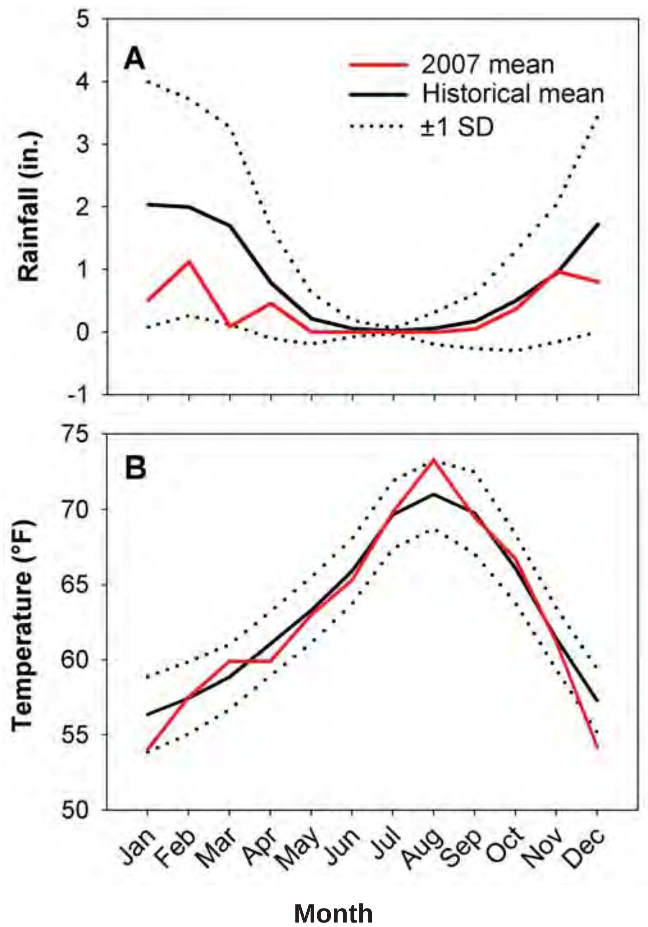

Figure 2.2
Total monthly rainfall (A) and monthly mean air temperature (B) at Lindbergh Field (San Diego, CA) for 2007 compared to monthly mean rainfall and air temperature (± one standard deviation) for the historical period 1914–2006.

Total rainfall was a little over 4 inches in the San Diego region during 2007, which was well below the historical average of more than 10 inches/year (NOAA/NWS 2008b). Although annual rainfall was less than normal for the year, the greatest and most frequent rains occurred during February similar to expected seasonal patterns (**Figure 2.2A**). In contrast, air temperatures were generally similar during the year to historical averages, although

Table 2.1

Summary of temperature (=temp; °C), salinity (ppt), density (δ/θ), dissolved oxygen (DO; mg/L), pH, chlorophyll *a* (Chl; µg/L), and transmissivity (XMS; %) for surface (≤2 m) and bottom (10-20 m) waters at all Point Loma kelp stations during 2007. Values are expressed as means for all stations combined.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temp	*Surface*	14.7	14.7	14.4	15.3	16.3	17.8	20.0	22.4	18.3	17.8	15.3	14.4
	Bottom	14.4	13.9	12.3	12.0	12.0	12.7	14.7	15.1	13.6	13.8	13.2	13.9
Density	*Surface*	24.95	24.92	25.05	24.91	24.71	24.40	23.81	23.21	24.14	24.23	24.75	24.92
	Bottom	25.00	25.10	25.54	25.64	25.65	25.52	25.02	24.91	25.16	25.10	25.17	25.02
Salinity	*Surface*	33.58	33.55	33.63	33.70	33.75	33.81	33.77	33.82	33.65	33.59	33.51	33.47
	Bottom	33.58	33.57	33.73	33.79	33.82	33.80	33.72	33.68	33.60	33.54	33.49	33.47
DO	*Surface*	7.9	7.8	8.4	8.5	9.4	9.4	8.3	8.1	8.3	8.0	7.8	7.8
	Bottom	7.6	6.9	5.8	5.0	5.0	5.6	7.6	7.6	7.4	7.1	6.7	7.2
pH	*Surface*	8.2	8.2	8.2	8.2	8.4	8.4	8.2	8.2	8.2	8.2	8.1	8.1
	Bottom	8.1	8.1	8.0	7.9	8.0	8.0	8.1	8.1	8.1	8.1	8.0	8.0
XMS	*Surface*	84	76	78	75	77	73	78	81	82	82	80	82
	Bottom	85	79	82	85	85	82	83	85	85	85	84	83
Chl	*Surface*	2.2	2.0	4.0	8.4	10.4	15.8	3.4	3.0	2.8	2.2	4.2	3.1
	Bottom	3.0	2.8	6.8	3.8	5.6	12.9	6.1	5.0	4.8	3.1	3.6	3.3

exceptions occurred in January, August and December (**Figure 2.2B**). The above normal air temperatures during the summer coincided with higher than normal surface water temperatures and salinity values for the PLOO region (see below). Aerial imagery indicated that current flow was predominantly southward in 2007, although with occasional northward flows occurred following storm events (Svejkovsky 2008). For example, increased outflows from the Tijuana River near Imperial Beach and Los Buenos Creek in northern Baja California during the wet season resulted in large northward-flowing turbidity plumes in San Diego coastal waters.

Oceanographic Conditions in 2007

Water Temperature

Water temperature is the main factor affecting water density and stratification of southern California ocean waters (Dailey et al. 1993, Largier et al. 2004), and differences in surface and bottom temperatures can provide the best indication of the surfacing potential of wastewater plumes. Thermal stratification at the Point Loma kelp stations generally followed normal seasonal patterns in 2007 with the least stratification occurring during the winter months of January, February and December, and the greatest stratification in August (**Figure 2.3**). Surface temperatures at the kelp stations ranged from 14.4°C in March and December to 22.4°C in August , whereas bottom temperatures ranged from 12.0°C in April and May to 15.1°C in August (**Table 2.1**). Thermal stratification also appeared to follow typical seasonal patterns at the quarterly offshore sites (see **Figure 2.4**), with the water column ranging from slightly stratified in January to strongly stratified in July. Overall, offshore surface temperatures ranged from 14.7 to 20.9°C during the year, while bottom temperatures ranged from 9.9 to 11.4°C (**Table 2.2**). Since temperature is the main contributor to water column stratification

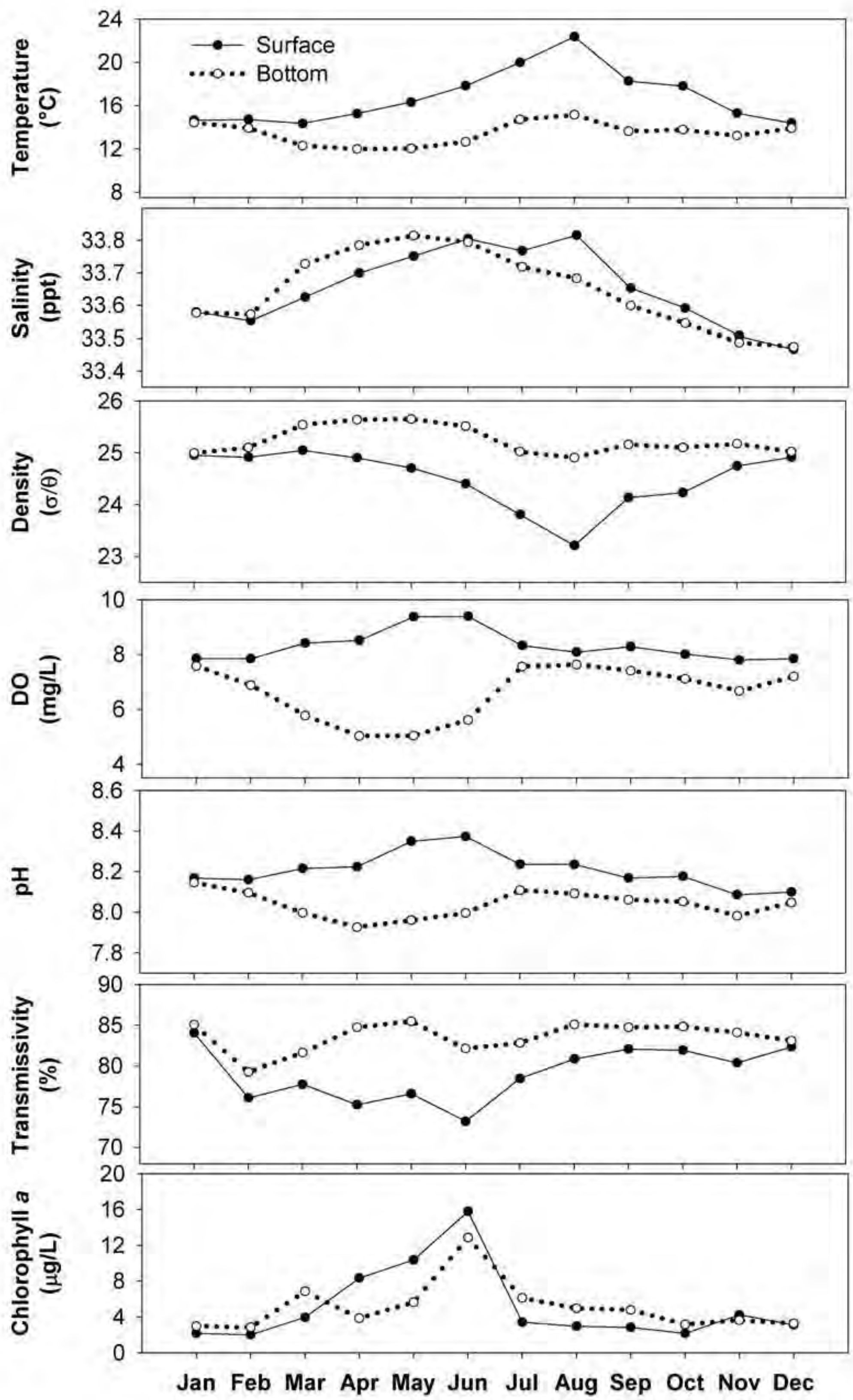

Figure 2.3
Monthly mean temperature, density, salinity, transmissivity, dissolved oxygen (DO), pH, and chlorophyll *a* values for surface (≤2m) and bottom (10-20 m) waters at the Point Loma kelp stations during 2007.

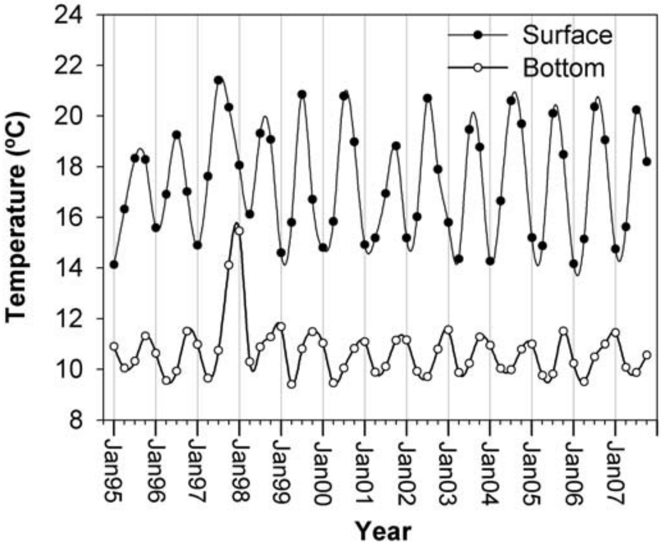

Figure 2.4
Mean surface and bottom water temperatures for PLOO offshore stations from 1995–2007.

in southern California, these differences between surface and bottom waters along with seasonal thermoclines were important to limiting the surfacing potential of the waste field throughout the year (see Chapter 3). Moreover, the wastewater plume was not detectable in aerial imagery during 2007 (Svejkovsky 2008).

Salinity
Salinities at the kelp stations ranged from 33.47 ppt in December to 33.82 ppt in August surface waters, and from 33.47 ppt in December to 33.82 ppt in May at bottom depths (Table 2.1). Salinity at these stations followed normal seasonal patterns; salinities increased at all depths from March through May, peaked in August at the surface, and then declined at both the surface and bottom (Figure 2.3). Surface salinities at the offshore stations ranged from 33.56 ppt in January to 33.76 ppt in July, while bottom salinities ranged from 33.73 in January to 33.99 in April (Table 2.2). Although data for the offshore stations are limited to only four times a year, salinities at these stations appeared to follow seasonal patterns similar to those that occurred at the kelp stations (i.e., peaked in summer, declined in the fall).

Density
Seawater density, a product of temperature, salinity, and pressure, is influenced primarily by temperature in coastal shelf waters where salinity profiles are relatively uniform (i.e., change little with depth). Therefore, changes in density typically mirror changes in temperature. This relationship was true for 2007 data, as indicated by water column data collected at the kelp and offshore stations (Tables 2.1, 2.2). The differences between surface and bottom water densities at the kelp stations resulted in a pycnocline from April through October with maximum stratification occurring in August (Figure 2.3). Similar patters were present at the offshore stations with the highest densities occurring where water temperatures were coldest. Surface seawater densities decreased between January, April and July, but were higher again in October. Bottom seawater densities increased between April and July and then decreased in October.

Dissolved Oxygen, pH and Transmissivity
Average dissolved oxygen (DO), pH and transmissivity values for 2007 are summarized in Tables 2.1 and 2.2. DO concentrations averaged 7.8 to 9.4 mg/L in surface waters and 5.0 to 7.6 mg/L in bottom waters for the kelp stations, while mean values for the quarterly offshore stations ranged between 7.8–8.4 mg/L at the surface and 2.9–4.4 mg/L near the bottom. Mean pH values ranged from 8.1 to 8.4 in surface waters and 7.9 to 8.1 in bottom waters at the kelp stations, and between 7.7 and 8.2 across all depths for the offshore stations. Transmissivity averaged 73–85% at the kelp stations and 81–90% for the offshore stations.

Chlorophyll a
Mean chlorophyll *a* concentrations in surface waters ranged from 2.0 μg/L in February to 15.8 μg/L in June at the kelp stations, and from 1.0 μg/L in October to 4.2 μg/L in April at the offshore stations (Tables 2.1 and 2.2). The high chlorophyll values reported for surface waters at the kelp stations beginning in March corresponded to phytoplankton blooms observed in MODIS satellite imagery (Svejkovsky 2008). Such spring blooms are likely the result of upwelling events that typically occur during this time of the year (Jackson 1986, Svejkovsky 2008). These blooms developed into a red tide surrounding the kelp

Table 2.2

Summary of temperature (=temp; °C), salinity (ppt), density (δ/θ), dissolved oxygen (DO; mg/L), pH, chlorophyll *a* (Chl; µg/L), and transmissivity (XMS; %) for surface (≤2 m), mid-depth (10-20 m) and bottom (≥88 m) waters at all PLOO offshore stations during 2007. Values are expressed as means for all stations combined.

		Jan	Apr	Jul	Oct
Temp	*Surface*	14.7	15.6	20.2	18.2
	Mid	14.6	13.2	15.2	15.4
	Bottom	11.4	10.1	9.9	10.6
Density	*Surface*	24.92	24.81	23.75	24.21
	Mid	24.95	25.32	24.89	24.71
	Bottom	25.71	26.15	26.13	25.91
Salinity	*Surface*	33.56	33.66	33.76	33.67
	Mid	33.56	33.67	33.67	33.50
	Bottom	33.73	33.99	33.92	33.78
DO	*Surface*	7.8	8.4	8.0	7.8
	Mid	7.7	7.1	9.1	8.1
	Bottom	3.8	2.9	3.6	4.4
pH	*Surface*	8.1	8.2	8.2	8.1
	Mid	8.1	8.1	8.2	8.1
	Bottom	7.8	7.7	7.7	7.8
XMS	*Surface*	85	81	86	87
	Mid	86	84	86	88
	Bottom	89	88	90	89
Chl	*Surface*	4.0	4.2	1.5	1.0
	Mid	4.8	6.1	3.6	2.9
	Bottom	0.2	0.3	0.5	0.4

stations during June and then declined thereafter. During March and from July through October, chlorophyll levels were higher at bottom depths at the kelp stations, which most likely reflected decaying phytoplankton sinking towards the bottom. Increases in dissolved oxygen levels and pH along with declines in water clarity (transmissivity) that occurred at the kelp stations in 2007 were likely influenced by increases in phytoplankton densities based on chlorophyll measurements (Figure 2.3). Chlorophyll concentrations were much lower at the offshore stations (Table 2.2).

Historical Assessment of Oceanographic Conditions

Profiles of mean temperature and salinity data for outfall stations F29, F30 and F31 during January and April of 2007 were similar to the historical profiles for 1995–2006 (**Figure 2.5**). Temperature and salinity were relatively high during July when values in the top 40 m approached the upper end of the historical range (i.e., means ± 1 SD). These higher values were most likely influenced by increased summer air temperatures (see Figure 2.2B). Low water temperatures and high salinities in October 2007, especially at depths below 40 m, are likely indicative of upwelling (see Figure 2.5). Salinity also decreased sharply at this time at depths between about 15 and 40 m depths, which most likely represents a mixture of less dense seawater and freshwater effluent discharge via the outfall that was pushed upward by the intrusion of denser upwelled seawater. The upward movement of wastewater creates a doming effect at these stations near the outfall that has also been observed in multispectral satellite imagery (see Svejkovsky 2008). However, remote sensing observations never revealed the plume reaching surface waters in 2007 (Svejkovsky 2008). The restriction of elevated densities of indicator bacteria to depths ≥60 m also indicates that the wastewater plume remained trapped in relatively deep waters during the year (see Chapter 3).

A review of historical oceanographic data between 1995 and 2007, using the same three PLOO stations (F29, F30, and F31), does not reveal any measurable impact that can be attributed to discharge (**Figure 2.6**). Although the change from monthly to quarterly sampling after July 2004 has decreased the number of data points for interpretation, the results are still notably consistent with the changes in large-scale patterns in the region as observed by CalCOFI (Peterson et al. 2006; Goericke et al. 2007). These authors describe four significant events that have affected the California Current System (CCS) during the last decade: (1) the 1997–1998 El Niño; (2) a dramatic shift to cold ocean conditions that lasted from 1999 through 2002; (3) a more subtle but persistent return to warm ocean conditions beginning

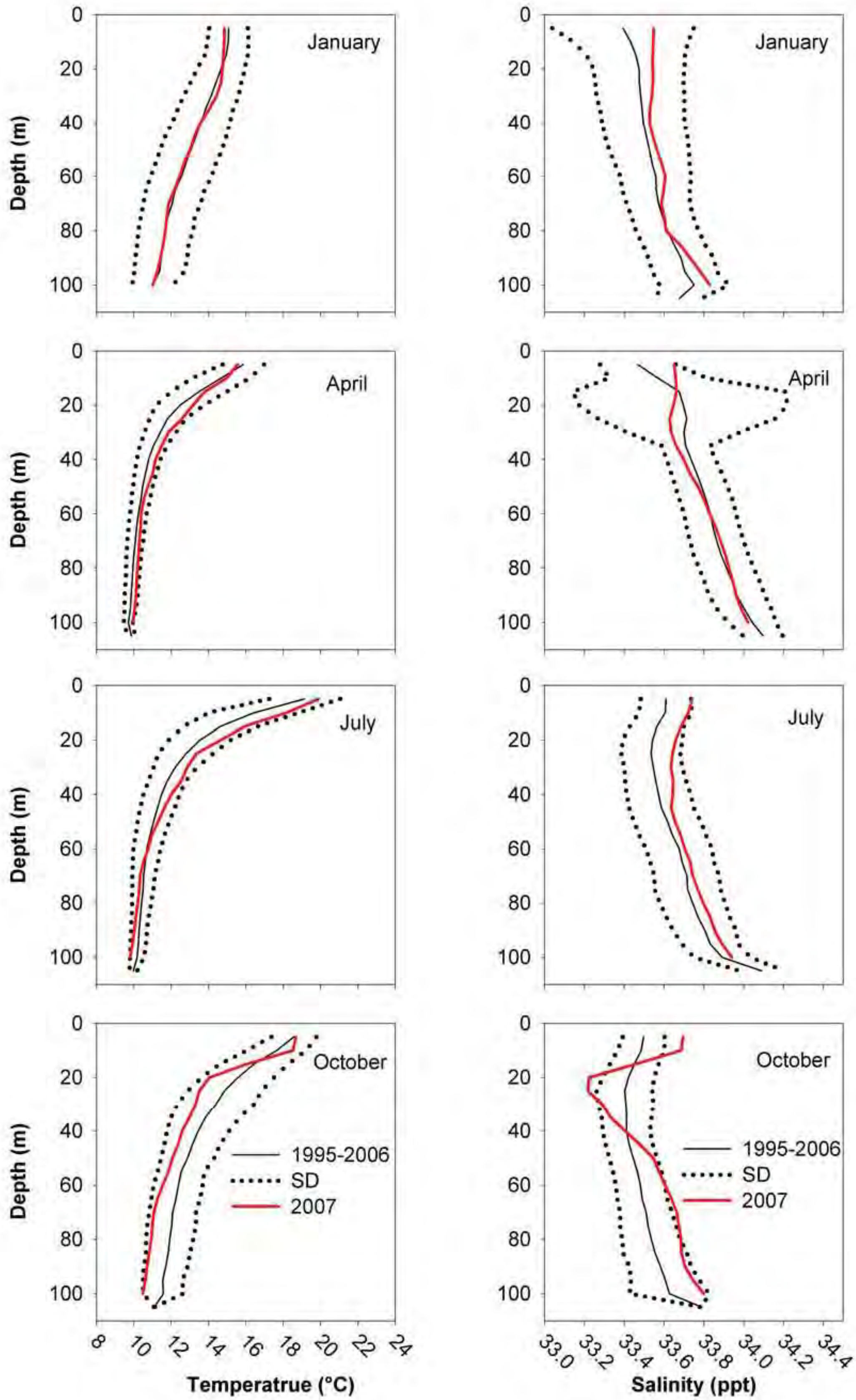

Figure 2.5
Comparison of temperature and salinity water column profiles for 2007 compared to historical data for 1995-2006 at select offshore stations located nearest the PLOO discharge site (F29, F30, and F31; see Figure 2.1). The historical data represent 12-year means ±1 standard deviation (SD) for each quarterly survey month.

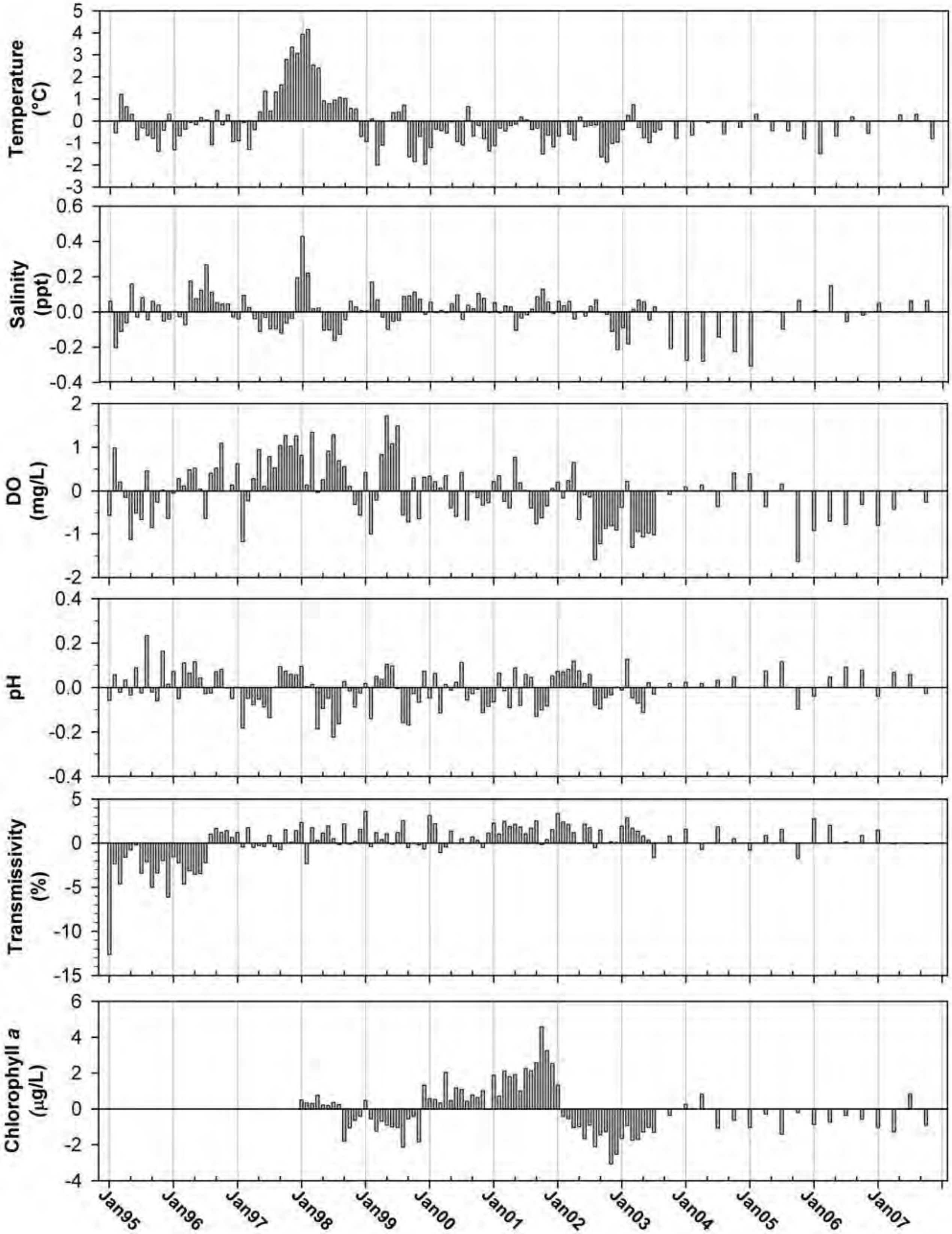

Figure 2.6
Time series of temperature, salinity, transmissivity, pH, dissolved oxygen (DO), and chlorophyll anomalies between 1995 and 2007. Anomalies were calculated by subtracting the monthly means for each year (1995–2007) from the mean of all 13 years combined; data were limited to stations F29, F30, and F31, all depths combined.

in October 2002; (4) the intrusion of subarctic surface waters that resulted in lower than normal salinities in southern California during 2002–2003 (Goericke et al. 2007). Temperature and salinity data for the Point Loma region are consistent with the first, second, and fourth CCS events.

Overall water clarity (transmissivity) around the outfall has tended to be higher than the historical mean since mid-1996. The lower transmissivity values in 1995 and 1996 may have been related to sediment plumes associated with the offshore disposal of dredged materials from a large dredging project in San Diego Bay. Decreases in transmissivity during winter periods such as in 1998 and 2000 appear to be the result of increased amounts of suspended sediments caused by strong storm activity (see NOAA/NWS 2008b). In addition, small decreases during the late spring and early summer were probably related to phytoplankton blooms such as those observed throughout the region in 2005 (see City of San Diego 2006). Anomalies in transmissivity values during 2006 and 2007 were mostly indicative of reduced turbidity due to the relatively low rainfall that occurred during these two years.

Chlorophyll *a* concentrations in the Point Loma region have been below average most of the time in recent years (Figure 2.6). These results are more consistent with those observed in northern Baja California, and are in contrast to the rest of southern California during recent years (Peterson et al. 2006). Occasional periods of higher than normal chlorophyll concentrations within the Point Loma region occurred as a result of red tides caused by the dinoflagellate *Lingulodinium polyedra*. This species persists in river mouths and responds with rapid population increases to optimal environmental conditions, such as significant amounts of nutrients from river runoff during rainy seasons (Gregorio and Pieper 2000). During 2007, chlorophyll levels were generally below historical mean values, with the exception of a positive spike in July that corresponded to the remnant of a phytoplankton bloom that peaked in June (see above).

There were no apparent trends in pH values or dissolved oxygen concentrations related to the PLOO. These parameters are complex, dependent on temperature and depth, and sensitive to physicochemical and biological processes (Skirrow 1975). Moreover, dissolved oxygen and pH are subject to diurnal and seasonal variations that make temporal changes difficult to evaluate. However, below normal concentrations for dissolved oxygen during 2005–2007 appear to be related to the low levels of chlorophyll *a* levels during these years.

Summary and Conclusions

There was no apparent relationship between the outfall and values of ocean temperature, salinity, pH, transmissivity, chlorophyll *a*, and dissolved oxygen during 2007. Instead, oceanographic conditions generally followed normal seasonal patterns. For example, differences between surface and bottom waters (i.e., stratification) first developed in spring, peaked in the summer and then declined thereafter. Since temperature is the main contributor to water column stratification in southern California, these differences between surface and bottom waters along with seasonal thermoclines were important to the prevention of the waste field surfacing throughout the year (see Chapter 3). The restriction of elevated densities of indicator bacteria to depths ≥60 m also indicates that the wastewater plume remained trapped in relatively deep waters during the year (see Chapter 3). Moreover, the wastewater plume was not detectable in aerial imagery during 2007 (Svejkovsky 2008).

Long-term analysis of water column data collected between 1995 and 2007 also did not reveal any changes in oceanographic parameters at stations around the PLOO that could be attributed to the discharge of wastewater. Instead, major changes in water temperatures and salinity for the Point Loma region corresponded to significant climate events that occurred within the California Current System between 1995 and 2005 (see previous discussion). During late 2006 and early 2007, no clear patterns were observed in the California Current System, and regional or local processes dominated observed patterns. Additionally, water clarity has increased in the PLOO region over the past several years, and changes in pH and dissolved oxygen levels have not exhibited any apparent trends related to wastewater discharge.

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