Chapter 2. Ocean Conditions

INTRODUCTION

The City of San Diego monitors oceanographic conditions in the region surrounding the Point Loma Ocean Outfall (PLOO) to assess possible impacts from outfall discharge on the environment. Changes in current patterns, temperature, salinity, and density can affect the fate of the wastewater plume. They can also affect the distribution of turbidity plumes produced by non-point sources such as tidal exchange and runoff from San Diego Bay, Mission Bay, and the San Diego and Tijuana Rivers. These factors can either individually or synergistically affect water quality within the Point Loma region.

The fate of PLOO wastewater discharged into deep offshore waters is determined by oceanographic conditions and other events that impact horizontal and vertical mixing. Consequently, physical and chemical parameters such as water temperature, salinity, and density determine water column mixing potential, and are thus important components of ocean monitoring programs (Bowden 1975). Analysis of the spatial and temporal variability of above parameters as well as transmissivity, dissolved oxygen, pH, and chlorophyll may also elucidate patterns of water mass movement. Taken together, analyses of such measurements for the receiving waters surrounding the PLOO can help: (1) describe deviations from expected patterns, (2) reveal the impact of the wastewater plume relative to other inputs, (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; Ocean Imaging 2006, 2007a, b; also see Chapter 3). Thus, the City of San Diego combines measurements of physical oceanographic parameters with assessments of bacterial concentrations 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 2006, 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

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

(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 2001 California Ocean Plan (COP) water contact standards (SWRCB 2001). These stations include 3 sites (stations C4, C5, C6) located along the inshore edge of the kelp bed paralleling the 9-m depth contour, and 5 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 8 kelp bed stations was conducted 5 times per month.

Oceanographic measurements of temperature, pH, transmissivity (water clarity), conductivity, chlorophyll *a*, and dissolved oxygen were collected by lowering a SeaBird (SBE 25) conductivity, temperature, and depth (CTD) instrument through the water column. Conductivity measurements were translated into salinity (ppt), and density was calculated from temperature, conductivity, and depth. Profiles of each parameter were constructed for each station by batch process averaging of the data values recorded over 1-m depth intervals. This ensured that physical measurements used in subsequent data analyses corresponded with bacterial sampling depths. Visual observations of water color and clarity, surf height, human or animal activity, and weather conditions were also recorded during each CTD sampling event.

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 2006 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 4 channels were configured to a specific wavelength (color) combination which maximizes the detection of the PLOO plume's turbidity signature by differentiating between the wastewater plume and coastal turbidity. The depth penetration of the sensor varies between 8 and 15 meters, depending on overall water clarity. The spatial resolution of the data is dependent upon aircraft altitude, but is typically maintained at 2 meters. Sixteen overflights were done in 2006, which consisted of 2 overflights per month during the winter when the outfall plume had the greatest surfacing potential (see below) and one per month during spring and summer.

Three stations located closest to the outfall (F29, F30, F31) were selected for historical analysis of CTD parameters for the period 1995–2006 during which CTD measurements are comparable for all years. Mean data were determined for surface depths (≤2 m), sub-surface depths (10–20 m), bottom depths (≥88 m), and all depths combined for these stations. A time series of historical differences (anomalies) between monthly means for each year (1995–2006) and the monthly means for 2006 only were calculated for all depths for each CTD parameter. Means and standard deviations for surface, sub-surface, and bottom depths were calculated separately. Additionally, CTD profiles consisting of means ±1 SD at 5 m increments for 1995–2005 were compared with the 2006 mean profile data for temperature and salinity for these same 3 stations.

RESULTS AND DISCUSSION

Expected Seasonal Patterns of Physical and Chemical Parameters

Southern California weather can be classified into basically wet (winter) and dry (spring through fall) seasons (NOAA/NWS 2007), and changes in oceanographic conditions often track these seasons. Water properties in the Southern California Bight (SCB) show the most variability in the upper 100 m as the seasons change (Jackson 1986). A high degree

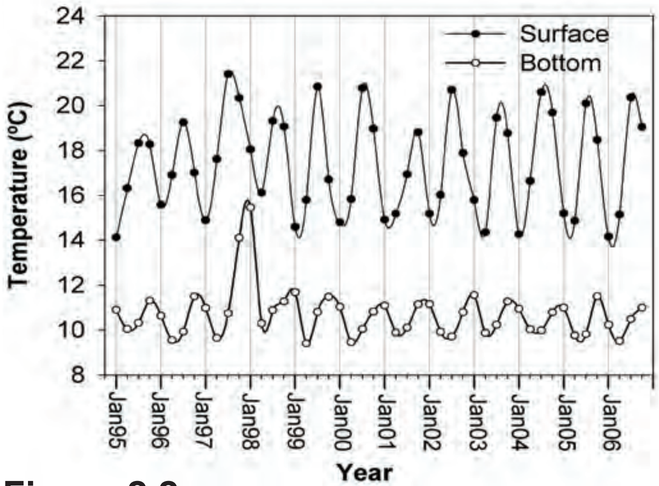

Figure 2.2
Mean quarterly surface and bottom temperatures (°C) for PLOO offshore stations from 1995–2006.

of homogeneity within the water column is the normal signature for all physical parameters from December through February (**Figure 2.2**). Storm water runoff however, may intermittently influence density profiles during these times by causing a low salinity lens within nearshore surface waters. The chance that the wastewater plume from the PLOO may surface is highest during these winter months when there is little, if any, stratification of the water column. These conditions will often extend into March, as the frequency of winter storms decreases and the seasons transition from wet to dry.

In late March or April, the increasing elevation of the sun and lengthening days begin to warm surface waters and re-establish the seasonal thermocline and pycnocline. Once water column stratification becomes established by late spring, minimal mixing conditions tend to remain throughout the summer and early fall months. In October or November, cooler temperatures, reduced solar input, and increased stormy weather begin to cause the return of the well-mixed, homogeneous water column characteristic of winter months.

Observed Seasonal Patterns of Physical and Chemical Parameters

The drought conditions present in late 2005 continued into January and February of 2006

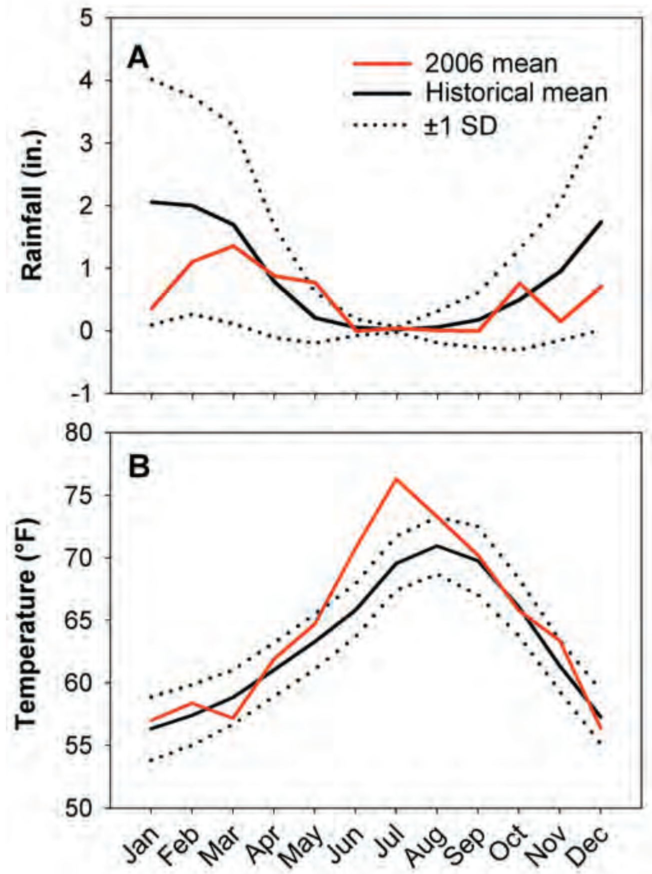

Figure 2.3
Total monthly rainfall (A) and monthly mean air temperature (B) at Lindbergh Field (San Diego, CA) for 2006 compared to monthly mean rainfall and air temperature (±1 SD) for the historical period of 1914 through 2005.

when there was only 0.36 and 1.11 inches of rain, respectively (**Figure 2.3A**) (NOAA/NWS 2007). Rainfall for these months typically averages about 2.0 inches. Precipitation returned to normal levels in March and April, and was above average in May. Thereafter, only 1.62 inches of rain fell from September through December. The total rainfall for 2006 was 6.15 inches, 40% below the annual average of 10.26 inches (NOAA/NWS 2007). Average air temperature for March approached the lowest recorded value for 91 years of historical weather data, while near record warm air temperatures occurred in June–August (Figure 2.3B). Annual ocean surface temperatures peaked during these same months. Despite these variations in air and ocean temperatures, thermal stratification of the water column followed normal seasonal patterns.

Mean surface temperatures at the offshore water quality stations ranged from a low of 14.1 °C in April to a high of 20.8 °C in July (**Table 2.1**). In contrast, sub-surface and bottom waters were less variable, and ranged from 11.5–15.0 °C, and 9.5–11.0 °C, respectively. January surface and sub-surface temperatures were 1.3 °C and 2.0 °C lower than comparative values for 2005 (City of San Diego 2006a).

Overall average surface temperatures for the 3 historical stations nearest the PLOO (F29, F30, F31) during January and April of 2006 were 0.9 °C and 1.2 °C below the historical average, respectively. April temperatures were outside the standard deviation of the historical mean (**Table 2.2**). In contrast, surface temperatures for July and October were more similar to the historical average, and well within the standard deviation. Bottom waters ranged from 9.5 to 11.0 °C, and were close to average temperatures during April, July, and October, but below average during January (**Figure 2.4**). However, during January and April temperatures at most depths were colder than the historical means, and salinity was well above average at lower depths. These deviations from the norm indicate the intrusion of cold upwelled water into the region (see below).

Monthly water temperatures at the nearshore kelp stations followed a similar pattern (**Table 2.3, Figure 2.5**). Mean surface temperatures in the kelp beds from January through April of 2006 ranged from 13.1 to 14.7 °C, which were cooler than previous year means of 15.0 to 16.0 °C over the same period (City of San Diego 2006a). A decline in surface and bottom temperatures in March coupled with an increase in salinity from March–June is supportive of the intrusion of cold upwelled water mentioned above. The seasonal warming of the nearshore waters began in May, and mean surface waters ranged between 17.3 and 21.1 °C from May through August. Mean surface temperatures declined between September and December from 18.1 °C to 15.9 °C. Bottom waters at the kelp stations ranged from 11.3 to 16.4 °C during the year. Relative to 2005, bottom water temperatures in 2006 were over 1 °C cooler from January through March, but 1.4–3.1 °C warmer the rest of the year (City of San Diego 2006a).

Table 2.1

Quarterly average values of temperature (Temp, °C), salinity (ppt), density (δ/θ), dissolved oxygen (DO, mg/ L), pH, transmissivity (XMS, %), and chlorophyll *a* (Chl *a*, µg/L), for top (≤2 m), sub-surface (10– 20 m), and bottom (≥88 m) waters at all quarterly PLOO stations during 2006.

		Jan	Apr	Jul	Oct
Temp	*Surface*	14.1	15.2	20.8	18.7
	Sub-surface	13.3	11.5	14.2	15.0
	Bottom	10.4	9.5	10.4	11.0
Salinity	*Surface*	33.34	33.45	33.55	33.43
	Sub-surface	33.37	33.70	33.57	33.38
	Bottom	33.87	34.16	33.73	33.64
Density	*Surface*	24.9	24.7	23.4	23.9
	Sub-surface	25.1	25.7	25.0	24.7
	Bottom	26.0	26.4	25.9	25.7
DO	*Surface*	8.4	9.9	8.1	7.7
	Sub-surface	7.4	6.6	8.0	8.3
	Bottom	3.5	2.6	3.6	4.5
pH	*Surface*	8.1	8.3	8.2	8.2
	Sub-surface	8.1	8.0	8.1	8.2
	Bottom	7.8	7.7	7.8	7.9
XMS	*Surface*	84	83	84	88
	Sub-surface	87	87	82	89
	Bottom	90	91	90	90
Chl *a*	*Surface*	3.2	2.9	2.4	0.9
	Sub-surface	4.6	6.7	8.4	2.4
	Bottom	0.3	0.3	0.7	0.6

Thermal stratification in 2006 generally followed the typical annual pattern (Figures 2.2, 2.4, 2.5). A weak, shallow thermocline occurred between 10–20 m in January (City of San Diego 2006b). In contrast, the thermocline present during January 2005 was deeper (average depth of 35 m) as a result of colder bottom water (City of San Diego 2005a). Thermoclines of a 1 ºC change within 1 m depth were well developed at offshore stations in April, July and October. Differences between surface and bottom waters ranged from over 5.7 ºC to 10.4 ºC for these months (Table 2.2). April and

Table 2.2

Mean data for surface (≤2 m), sub-surface (≥10 and ≤27), and bottom depths (≥27 m) for 2006 compared to mean data (±1 SD) for 1995–2005 at stations F29, F30, and F31. Delta (Δ) is the difference between 2006 and 1995–2005 mean data. Data includes temperature (Temp °C), salinity (ppt), density (δ/θ), dissolved oxygen (DO, mg/L), pH, transmissivity (XMS %), and chlorophyll *a* (µg/L).

	Surface depths				Sub-surface depths				Bottom depths				All depths			
	Jan	Apr	Jul	Oct	Jan	Apr	Jul	Oct	Jan	Apr	Jul	Oct	Jan	Apr	Jul	Oct
Temperature																
2006	14.2	15.1	20.4	19.1	13.4	12.1	14.5	15.3	10.2	9.5	10.5	11.0	11.6	10.5	12.2	13.0
1995–2005	15.1	16.3	19.7	18.7	15.0	13.1	14.2	16.1	11.4	9.8	10.2	11.6	13.2	11.2	12.0	13.7
SD	1.0	1.0	1.4	1.2	1.2	1.5	2.0	1.9	1.3	0.3	0.4	1.1	1.9	1.9	2.6	2.6
Δ	-0.9	-1.2	0.7	0.4	-1.6	-1.0	0.3	-0.8	-1.2	-0.3	0.3	-0.6	-1.6	-0.7	0.2	-0.7
Salinity																
2006	33.33	33.48	33.54	33.45	33.36	33.66	33.57	33.39	33.89	34.18	33.72	33.60	33.56	33.94	33.61	33.47
1995–2005	33.39	33.42	33.60	33.50	33.48	33.68	33.55	33.44	33.70	33.99	33.86	33.61	33.55	33.78	33.66	33.49
SD	0.39	0.23	0.11	0.11	0.25	0.54	0.15	0.13	0.16	0.13	0.15	0.18	0.23	0.28	0.19	0.15
Δ	-0.06	0.06	-0.06	-0.05	-0.12	-0.02	0.02	-0.05	0.19	0.19	-0.14	-0.01	0.01	0.16	-0.05	-0.02
Density																
2006	24.88	24.73	23.44	23.90	25.05	25.53	24.96	24.67	26.05	26.39	25.87	25.69	25.54	26.03	25.44	25.19
1995–2005	24.65	24.49	23.69	23.93	24.76	25.36	24.96	24.47	25.65	26.19	26.03	25.56	25.18	25.78	25.50	25.03
SD	0.31	0.28	0.32	0.31	0.20	0.54	0.48	0.42	0.26	0.13	0.18	0.33	0.41	0.50	0.64	0.60
Δ	0.23	0.24	-0.25	-0.03	0.29	0.17	0.00	0.20	0.40	0.20	-0.16	0.13	0.36	0.25	-0.06	0.16
Dissolved Oxygen																
2006	8.5	9.6	8.1	7.6	7.6	7.6	8.0	8.4	3.5	2.6	3.6	4.6	5.4	4.4	5.3	6.4
1995–2005	8.0	8.4	8.1	7.6	7.9	8.1	8.7	8.3	4.7	3.4	4.2	5.0	6.5	5.2	6.2	6.8
SD	0.6	1.3	0.9	0.9	0.6	1.2	0.7	0.8	0.7	0.6	0.7	1.4	1.4	2.0	1.9	1.6
Δ	0.5	1.2	0.0	-0.0	-0.3	-0.5	-0.7	0.1	-1.2	-0.8	-0.6	-0.4	-1.1	-0.8	-0.9	-0.4
pH																
2006	8.2	8.3	8.2	8.2	8.1	8.1	8.1	8.2	7.8	7.7	7.8	7.9	7.9	7.9	7.9	8.0
1995–2005	8.1	8.2	8.1	8.2	8.1	8.0	8.0	8.1	7.8	7.7	7.6	7.8	8.0	7.8	7.8	8.0
SD	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2
Δ	0.1	0.1	0.0	0.0	-0.0	0.1	0.1	0.1	-0.0	0.0	0.2	0.1	-0.0	0.1	0.1	0.0
Transmissivity																
2006	84	84	85	89	88	85	84	89	91	91	89	88	90	90	88	90
1995–2005	84	81	85	88	86	84	88	88	86	88	87	88	87	88	88	89
SD	10	4	5	3	7	5	3	3	7	5	4	3	7	4	3	3
Δ	0	3	-0	1	2	1	-4	1	5	3	2	0	3	2	0	1
Chlorophyll a																
2006	5.0	2.2	2.0	0.9	5.2	8.3	6.0	2.1	0.3	0.3	0.8	0.6	1.9	2.1	3.0	2.2
1995–2005	3.3	3.0	3.5	2.8	4.2	7.8	3.7	4.4	1.9	1.3	1.7	1.5	3.1	3.1	3.3	2.9
SD	1.9	1.5	4.8	2.0	1.9	6.7	1.9	2.6	1.3	1.0	1.1	1.8	1.9	3.8	2.4	2.6
Δ	1.7	-0.8	-1.5	-2.0	1.0	0.5	2.3	-2.3	-1.6	-1.0	-0.9	-0.9	-1.2	-1.0	-0.3	-0.7

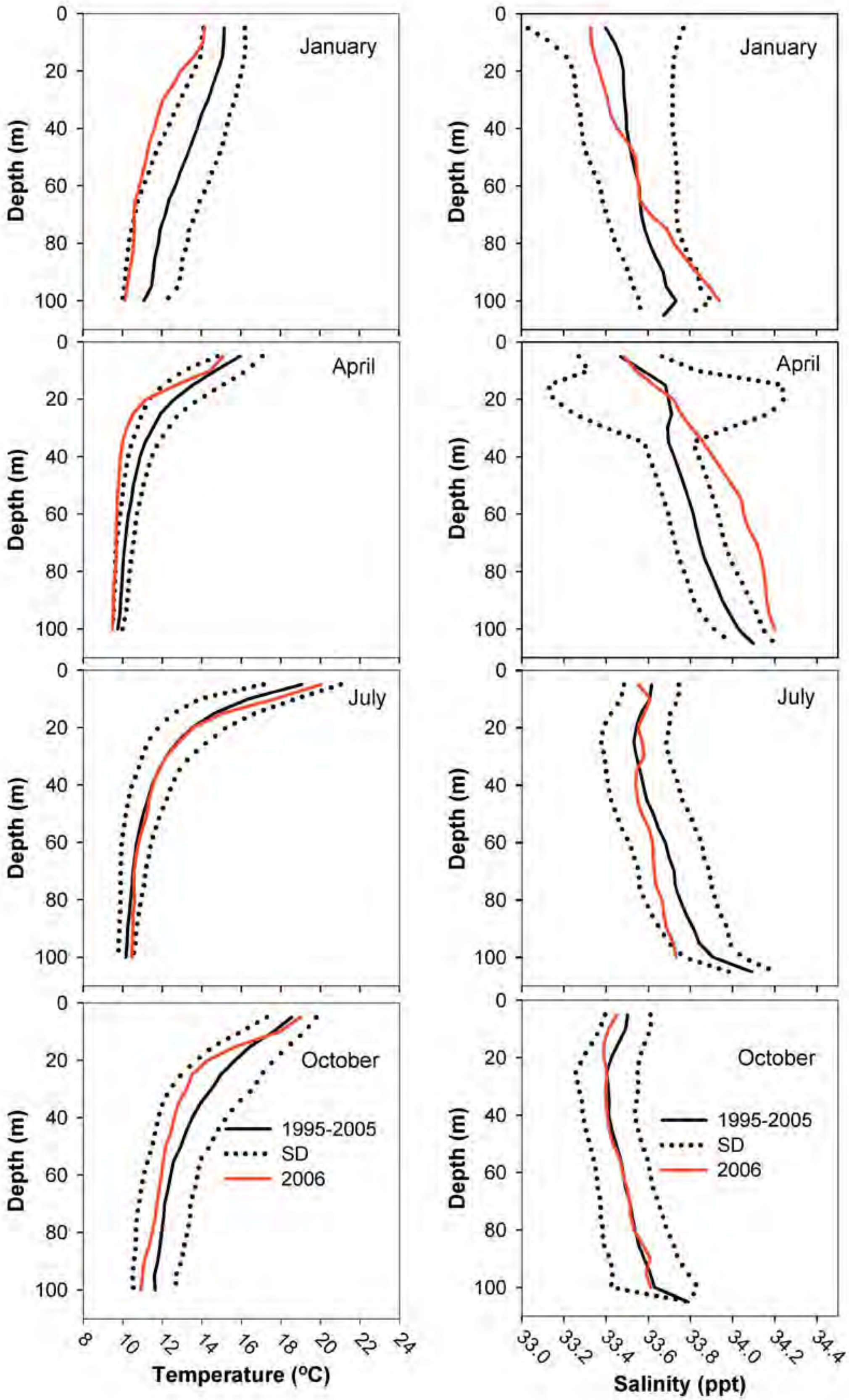

Figure 2.4
Mean temperature and salinity data for 2006 compared to mean temperature and salinity (±1 SD) for the historical period 1995 through 2005 at stations F29, F30, and F31 combined.

Table 2.3

Mean values of temperature (Temp, °C), salinity (ppt), density (δ/θ),dissolved oxygen (DO, mg/L), pH, transmissivity (XMS, %), and chlorophyll *a* (Chl *a,* µg/L), for top (≤2 m) and bottom (10–20 m) waters at all nearshore PLOO kelp stations during 2006.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temp	*Surface*	13.9	14.3	13.1	14.7	17.3	19.0	21.1	19.0	18.1	18.1	17.6	15.9
	Bottom	13.2	12.9	11.3	11.3	12.9	13.7	15.2	14.2	14.7	16.4	16.2	15.5
Salinity	*Surface*	33.38	33.41	33.49	33.53	33.56	33.56	33.53	33.47	33.45	33.42	33.45	33.51
	Bottom	33.43	33.47	33.68	33.73	33.68	33.67	33.47	33.45	33.46	33.41	33.43	33.50
Density	*Surface*	24.95	24.90	25.19	24.90	24.34	23.90	23.33	23.83	24.05	24.04	24.18	24.62
	Bottom	25.13	25.22	25.69	25.72	25.37	25.21	24.73	24.92	24.84	24.43	24.50	24.71
DO	*Surface*	7.9	8.5	8.6	8.7	8.9	7.5	7.9	8.5	8.5	7.8	7.7	7.7
	Bottom	6.9	6.9	6.1	4.4	5.3	5.6	7.4	7.5	7.4	7.6	7.5	7.3
pH	*Surface*	8.2	8.2	8.2	8.2	8.3	8.3	8.2	8.2	8.2	8.1	8.1	8.2
	Bottom	8.1	8.1	8.0	7.9	8.0	8.0	8.1	8.1	8.1	8.1	8.1	8.1
XMS	*Surface*	79.17	82.80	76.24	75.75	75.33	76.84	80.65	82.93	81.94	85.06	80.94	77.50
	Bottom	78.86	84.90	83.44	83.26	83.01	82.27	85.72	83.10	83.62	86.58	84.07	77.74
Chl *a*	*Surface*	2.8	3.4	5.0	8.0	6.9	3.2	3.1	2.4	2.5	1.4	2.0	1.8
	Bottom	4.6	4.5	7.7	6.1	7.9	6.3	2.9	7.4	3.5	2.2	2.7	2.4

July thermoclines occurred at an average depth of ~9 m and increased to a depth of ~11 m in October (City of San Diego 2006c, d, e). Thermoclines with a difference of 1 ºC within 1 m depth at the kelp stations were few and near the bottom (17–18 m) in January and February (City of San Diego 2006b, c). From March to September the thermoclines became shallow (6–9 m) as surface temperatures increased (City of San Diego 2006d–j). Thermoclines persisted at sub-surface depths (13–14 m) in October and November, and were gone by December (City of San Diego 2006k–m). Since temperature is the main contributor to water column stratification in southern California (Dailey et. al. 1993), 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 2006, and the plume's signature was never detected in the remote sensing data, even in the satellite thermal bands, which have detected it occasionally in the past (see Ocean Imaging 2006, 2007a, b).

Surface and sub-surface water salinities were similar to previous years with a range of 33.34–33.70 at the quarterly offshore stations (Table 2.1), and 33.38–33.73 ppt for surface and bottom depths at kelp stations (Table 2.3). Salinity increased with depth at the quarterly offshore stations with the highest values occurring at bottom depths in April due to the intrusion of upwelled water (Table 2.2, Figure 2.4). There was little difference between surface and bottom salinity at the kelp stations from January to February and from July to December (Figure 2.5). The greatest differences occurred between March and June as a result of the intrusion of upwelled water.

Seawater density (a function of temperature, salinity, and pressure) inversely reflected the changes in thermal stratification. Consequently, the cooler, more saline water present in quarterly bottom and sub-surface waters in January and April had higher density values in 2006 relative to historical values (see Table 2.2) In contrast, average surface density was lowest in July at quarterly offshore and kelp stations when surface temperatures peaked (see Figure 2.5).

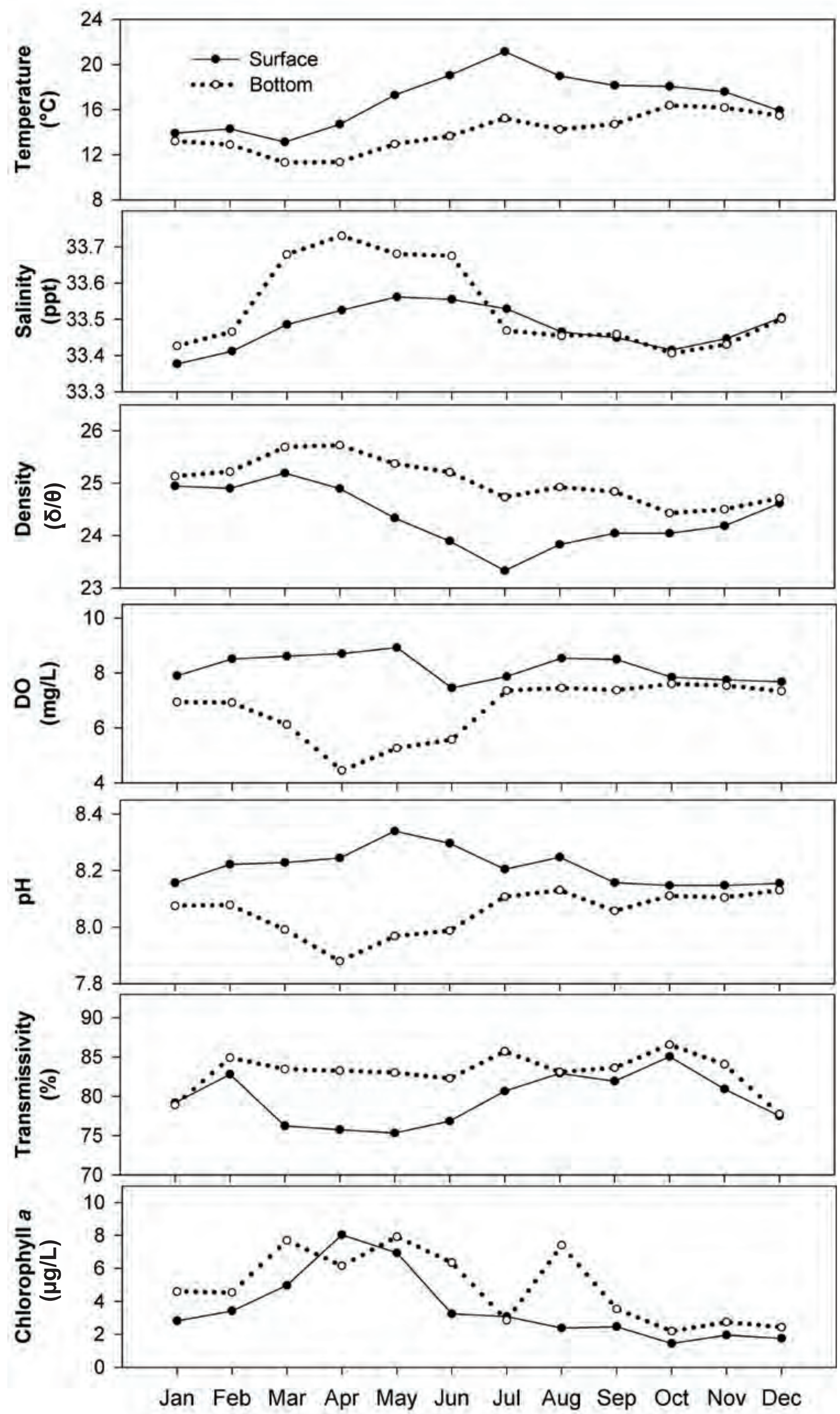

Figure 2.5
Monthly mean temperature (°C), salinity (ppt), density (δ/θ), dissolved oxygen (DO, mg/L), pH, transmissivity (%), and chlorophyll *a* (µg/L) values for surface (≤2m) and bottom (10–20 m) waters at the kelp water quality stations during 2006.

With the limited rainfall during 2006, variability in pH, transmissivity, chlorophyll *a*, and dissolved oxygen appeared mostly due to responses to plankton blooms. Plankton was observed primarily at inshore kelp stations from January through July as increased concentrations of chlorophyll *a* and dissolved oxygen, and decreased percent transmissivity (City of San Diego 2006b–h). Chlorophyll *a* spiked upwards at bottom depths in August, and was accompanied by a slight drop in water clarity, but returned to normal levels for the remainder of the year (Figure 2.5). Chlorophyll *a* concentrations at quarterly offshore stations during 2006 were low, indicating lower levels of phytoplankton in the offshore waters. The highest mean value (8.3 µg/L) occurred in July 2006 (City of San Diego 2006h), and contrasted greatly with that of July 2005 when the occurrence of a persistent red tide produced mean values above 75 µg/L (City of San Diego 2005c). DMSC and high resolution satellite imagery supported the presence of nearshore plankton blooms on several occasions during the summer, and indicated that offshore water surrounding the PLOO was relatively clear throughout the year (Ocean Imaging 2006, 2007a, b).

Remote sensing data provided several interesting observations regarding patterns of water movement in 2006. Satellite and aerial imagery indicated that surface waters generally flowed south for much of 2006, although northward flows did occasionally occur, they were often of short duration (Ocean Imaging 2006, 2007a, b). However, one such event caused a sedimentary plume from the Tijuana River following an April storm to spread northward towards Point Loma. The plume did not reach the shore or the kelp beds, although it may have affected water quality conditions at some southern stations (see Chapter 3). Thermal radiance imagery from TM and AVHRR satellites revealed a sharp thermal boundary that separated inner waters containing the kelp bed and nearshore open water from waters farther offshore (**Figure 2.6**; see Ocean Imaging 2007a). This boundary also corresponds to an ocean current shear zone, with the offshore currents being much stronger and generally southward directed relative to the inshore currents. A satellite image from November 9 also indicated an area of slightly cooler water over the outfall wye that has been observed previously, and is probably due to a doming or upwelling effect of slightly cooler subsurface water caused by displacement of underlying outfall discharge (Ocean Imaging 2006). However, the impact of these events on the physical and chemical properties of the water column in the area have not been fully characterized.

Historical Analyses of CTD Data

A review of historical oceanographic data for 3 stations surrounding the PLOO (1996–2006) did not reveal any measurable impact from wastewater discharge which began in November 1993 (**Figure 2.7**). Instead, these data were consistent with observed climate changes within the California Current System. Three significant climate events have affected the California Current System 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 initiated in October 2002 (Peterson et al. 2006). The long-term temperature and salinity data for Point Loma are consistent with the first 2 events, although recent data show a trend of cooler water beginning in 2005. This trend is more consistent with coastal data from northern Baja, Mexico where temperatures were below the decadal mean during 2005 and 2006 (Peterson et al. 2006). Salinity values were also mostly below the decadal mean from late 2002–2006, but increased in 2006 in the southern California and northern Baja California regions.

Water clarity (transmissivity) has generally increased in the Point Loma region since initiation of discharge through the extended outfall. However, several changes in water clarity unrelated to the outfall were also apparent in the historical data. Lower transmissivity values observed in 1995 and 1996 were likely related to a large San Diego Bay dredging project in which dredged sediments were disposed of at the LA-5 dredge disposal site, which left large, visible plumes of sediment throughout

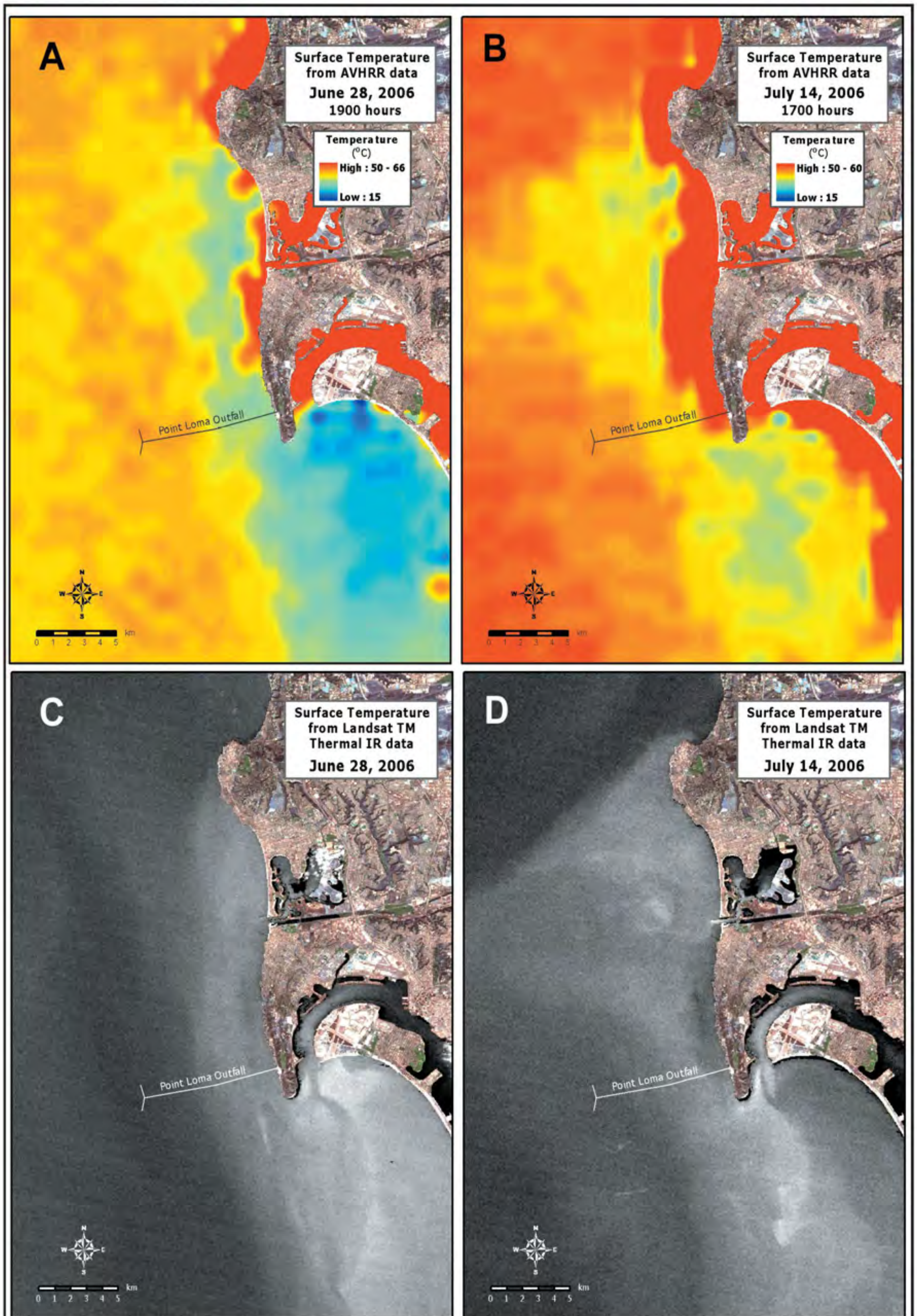

Figure 2.6

Satellite imagery showing the South Bay water quality monitoring region on June 28 and July 14, 2006 using AVHRR sensor data (A and B), and Landsat TM Infrared data (C and D). Cooler water resulting from upwelling events appears as shades of blue in AVHRR images and as lighter shades of gray in infrared images.

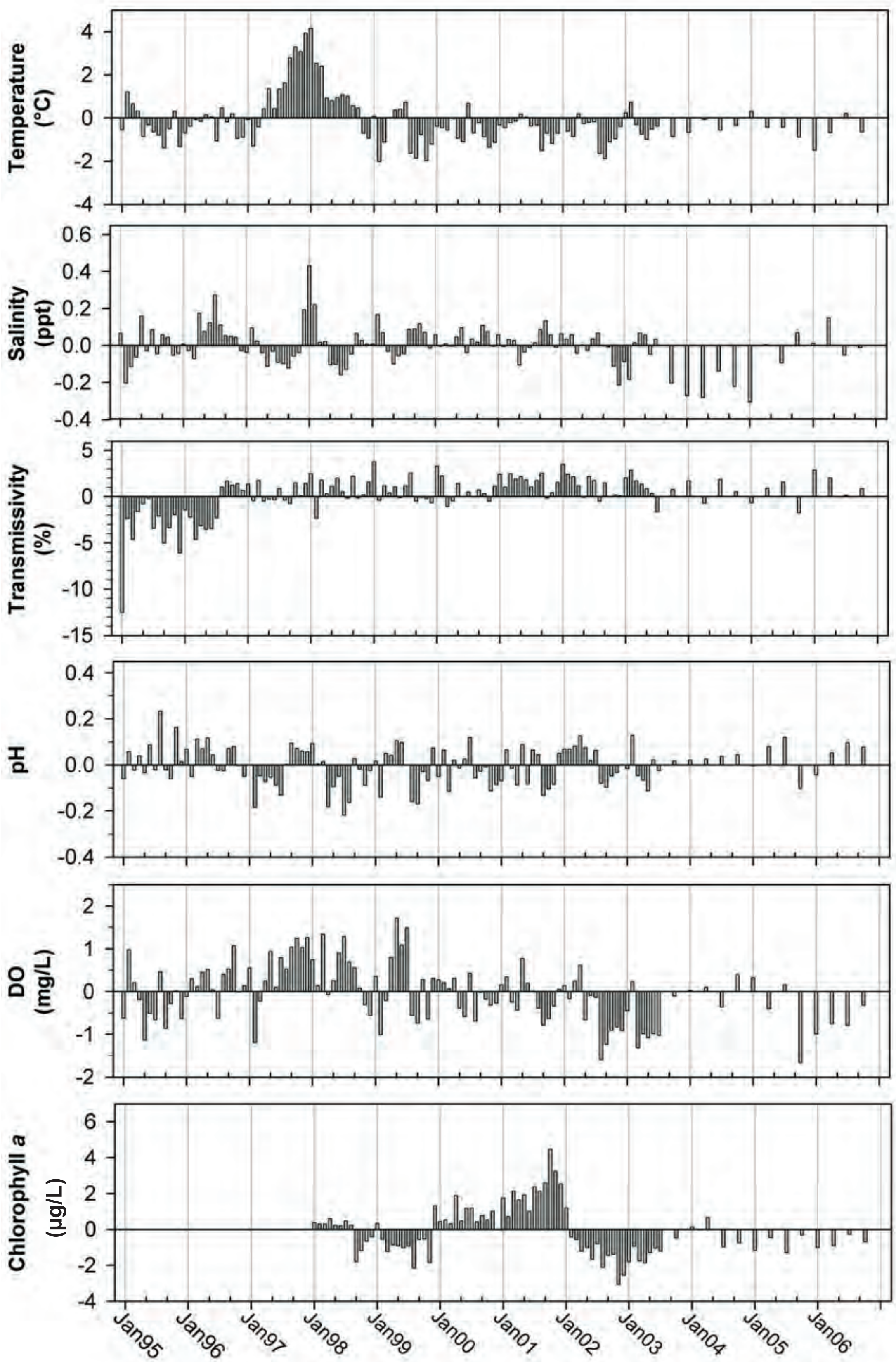

Figure 2.7

Time series of differences between means for each month and historical means for 1995–2006 for temperature (°C), salinity (ppt), transmissivity (%), pH, dissolved oxygen (DO, mg/L), and chlorophyll *a* (µg/L).

the region (see City of San Diego 2006a). Other smaller decreases in transmissivity values such as those seen at the beginning of 1998 and 2000 were likely a result of the increased amounts of suspended sediments caused by strong storm activity, whereas other such events appear to be related to plankton blooms.

Although chlorophyll *a* levels in most of southern California have increased during recent years as a result of general intensification within the California Current (Peterson et al. 2006), the Point Loma data are more consistent with the lower levels observed off northern Baja California, Mexico. For example, Figure 2.7 shows that chlorophyll *a* has decreased since 2001. However, red tides caused by blooms of the dinoflagellate *Lingulodinium polyedra* (formally *Gonyaulax polyedra*) have occurred on several occasions in the region, such as in 2001 and 2005. 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). The large plankton bloom of 2005 is not apparent in data from the 3 stations included in the historical analysis (see City of San Diego 2005c), and therefore is also not reflected in Figure 2.7.

Trends in relation to wastewater discharge from the PLOO were not apparent from pH and dissolved oxygen data. These 2 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 with temporal changes often being difficult to decipher. For example, during daylight hours photosynthesis decreases dissolved CO_2 concentrations to a late afternoon minimum, which causes pH and dissolved oxygen to rise and peak in the afternoon. Thus, changes in pH and dissolved oxygen are more closely related to changes in phytoplankton populations as reflected by chlorophyll *a* concentrations as well as changes in temperature and the carbonate cycle.

SUMMARY AND CONCLUSIONS

Drought conditions in November and December 2005 continued into 2006, resulting in greatly reduced runoff and few sediment plumes relative to the 2005 rain season. As a result, ocean waters around the PLOO were relatively clear throughout 2006 compared to 2005 ocean conditions. Meanwhile, air temperatures were near a record low in March and approached high records during June–August when surface water temperatures also peaked. Despite these circumstances, oceanographic conditions during 2006 generally followed normal seasonal patterns with some exceptions. Water temperatures for all depths at the kelp and offshore stations were much cooler during January–April than in previous years, and surface temperatures were warmest during June–August. This varies from past years when surface water temperatures around the PLOO were warmest between July and September, and bottom temperatures were coldest during April through July. Additionally, salinity values were much higher at sub-surface to bottom depths, especially at bottom depths in January and below 30 m in April during 2006. These cooler temperatures and high salinity values suggest an intrusion of upwelled water during these months.

Water column stratification generally followed the typical annual pattern, despite the slight variations in temperature and salinity. Thermal stratification first developed in spring, after which stratification peaked in July and then declined thereafter. At the kelp stations, thermoclines persisted at sub-surface depths in October and November, and were gone by December.

During 2006, there was no apparent relationship between the outfall and values of pH, transmissivity, chlorophyll *a*, and dissolved oxygen. Changes in these parameters have historically been associated primarily with storm activity and plankton blooms. However, with the relatively low rainfall in 2006, variability of these parameters was mostly associated with nearshore plankton blooms measured as chlorophyll *a* concentrations. DMSC and high resolution satellite imagery supported the presence of nearshore plankton blooms on several occasions during the summer, and indicated that offshore waters surrounding the PLOO were mostly clear throughout the year.

Satellite and aerial imagery indicated that surface waters generally flowed south during 2006. Infrared and thermal satellite data also revealed the presence of a sharp thermal boundary separating the inner waters containing the kelp bed from offshore waters surrounding the PLOO outfall with offshore ocean currents being stronger.

Historical CTD data for 1995–2006 did not reveal changes in water parameters as a result of the wastewater discharge from the outfall. However, historical temperature and salinity data for Point Loma recorded 2 of 3 significant climate events that affected the California Current System: the 1997–1998 El Niño, and a dramatic shift to cold ocean conditions that lasted from 1999 through 2002. The third event, a subtle but persistent return to warm ocean conditions initiated in October 2002, was not observed. Instead, ocean conditions during that time were more consistent with data from coastal waters off northern Baja, Mexico where a condition of colder than normal temperatures occurred during 2005 and 2006.

Water clarity measured as transmissivity has increased in the Point Loma region since initiation of wastewater discharge through the extended PLOO outfall. Reduced transmissivity values observed during 1995 and 1996 were most likely related to the disposal of dredged material from San Diego Bay at LA-5. Plankton blooms in the region are complex, stimulated by localized upwelling, and occasionally influenced by large red tides created when the rivers are flowing and nutrients are more readily available. However, chlorophyll *a* levels around the PLOO have generally decreased through time and were more consistent with those of northern Baja California, whereas levels within most of southern California mostly increased. Changes in pH and dissolved oxygen did not exhibit any apparent trends related to wastewater discharge.

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