Chapter 2. Oceanographic Conditions

INTRODUCTION

The City of San Diego regularly monitors oceanographic conditions of the water column to assess possible impacts from the outfall discharge as well as the effects of the local oceanic events on the fate of the discharge. The South Bay Ocean Outfall (SBOO) discharges treated wastewater approximately 5.6 km offshore at a depth of about 27 m. The average daily flow rate during 2006 was 24.5 mgd^{-1}. Water quality in the South Bay region is naturally variable, but is also subject to various anthropogenic sources of contamination, including discharge from the SBOO and outflows from sources such as San Diego Bay and the Tijuana River. These latter 2 non-point sources are fed by 415 and 1731 square miles of watershed, respectively, and contribute significantly to nearshore turbidity, sedimentation, and bacteriological densities (Largier et al. 2004).

The fate of SBOO wastewater discharged into 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 thus are important components of ocean monitoring programs (Bowden 1975). Analysis of the spatial and temporal variability of these 3 parameters in addition to transmissivity, dissolved oxygen, pH, and chlorophyll can elucidate patterns of water mass movement. Taken together, analyses of these measurements for the receiving waters surrounding the SBOO can help (1) describe deviations from expected patterns, (2) reveal the impact of the wastewater plume relative to other inputs such as from San Diego Bay and the Tijuana River, (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. The combination of physical parameter measurements, assessments of bacteriological concentrations and distributions (see Chapter 3), and remote sensing via satellite and aerial imagery provides further insight into the mass transport potential surrounding the SBOO throughout the year.

This chapter describes the oceanographic conditions that occurred during 2006 and is referenced in subsequent chapters to explain patterns of bacteriological occurrence (see Chapter 3) or other effects of the SBOO discharge on the marine environment (see Chapters 4–7).

MATERIALS AND METHODS

Field Sampling

Oceanographic measurements were collected at 40 fixed sampling stations located from 3.4 km to 14.6 km offshore (**Figure 2.1**). These stations form a grid encompassing an area of approximately 450 square kilometers and were situated along 9, 19, 28, 38, 55, and 60-m depth contours. Three of these stations (I25, I26, I39) are considered kelp bed stations, which are subject to 2001 California Ocean Plan (COP) water contact standards. The 3 kelp stations were selected for their proximity to suitable substrates for the Imperial Beach kelp bed; however, this kelp bed has been historically transient and inconsistent in terms of size and density (North 1991, North et al. 1993). Thus, these 3 stations are located in an area where kelp is only occasionally found.

Oceanographic measurements were collected at least once per month over a 3–5 day period. Data for temperature, salinity, density, pH, transmissivity (water clarity), chlorophyll *a*, and dissolved oxygen were recorded by lowering a SeaBird conductivity, temperature, and depth (CTD) instrument through the water column. Profiles of each parameter were constructed for each station by batch process

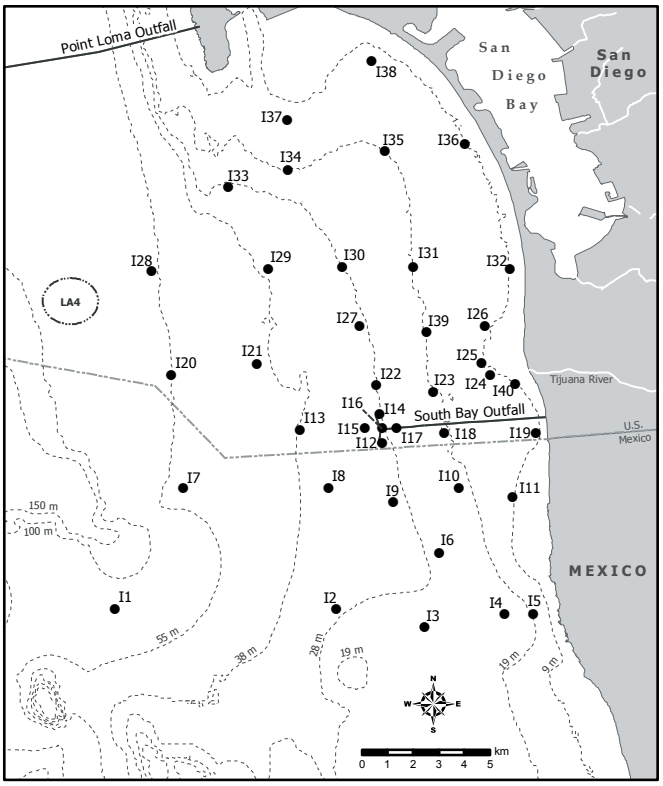

Figure 2.1
Water quality monitoring stations where CTD casts are taken, South Bay Ocean Outfall Monitoring Program.

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. To meet the COP sampling frequency requirements for kelp bed areas, CTD casts were conducted at the kelp stations an additional 4 times each month. Visual observations of weather and water conditions were recorded just prior to each CTD sampling event.

Remote Sensing

Monitoring of the SBOO area and neighboring coastline also included aerial and satellite image analyses 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 quality Landsat Thematic Mapper (TM) images were purchased. High resolution 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 maximizes the detection of the SBOO 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 and one per month during spring and summer.

Historical Data Analyses

Mean data were determined for surface depths (≤2 m), mid-depths (10–20 m), bottom depths (≥27 m), and all depths combined for stations I9, I12, I22, and I27. 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 11 years at all depths for each CTD parameter. Means and standard deviations for surface, mid, and bottom depths were calculated separately and are included in **Appendix A.1**. Additionally, CTD profile plots consisting of means ±1 SD at 5 m depth increments for 1995–2005 were compared with the 2006 mean profile data for temperature and salinity for these 4 stations.

RESULTS AND DISCUSSION

Expected Seasonal Patterns of Physical and Chemical Parameters

Southern California weather can be classified into 2 basic seasons: wet (winter) and dry (spring through fall) (NOAA/NWS 2007), and certain patterns in oceanographic conditions 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 of homogeneity within the water column is the normal signature for all physical parameters from December through February (**Figure 2.2**). Stormwater runoff however, may intermittently influence density profiles during these times by causing a low

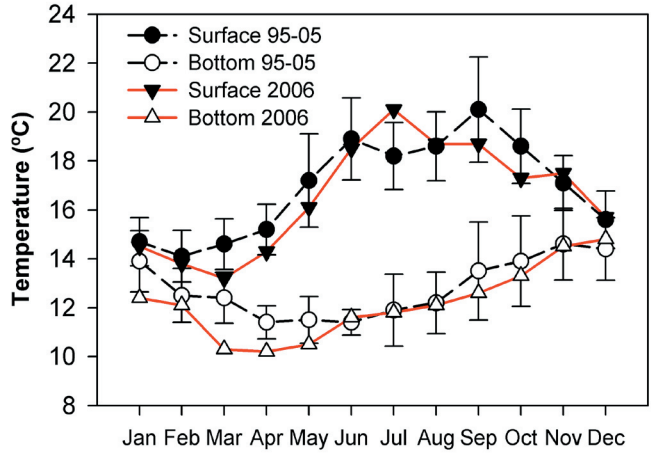

Figure 2.2
Mean monthly surface and bottom temperatures (°C) and standard deviations for 1995–2005 are compared to mean temperatures for 2006.

salinity lens within nearshore surface waters. The chance that the wastewater plume from the SBOO 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 when there was only 0.36 and 1.11 inches of rain, respectively (**Figure 2.3A**) (NOAA/NWS 2007). Rainfall has historically averaged 2.06 and 1.96 inches respectively for these months. Rainfall returned to normal levels in March, while above average rainfall occurred in May with 0.77 inches compared to the historical average of 0.21

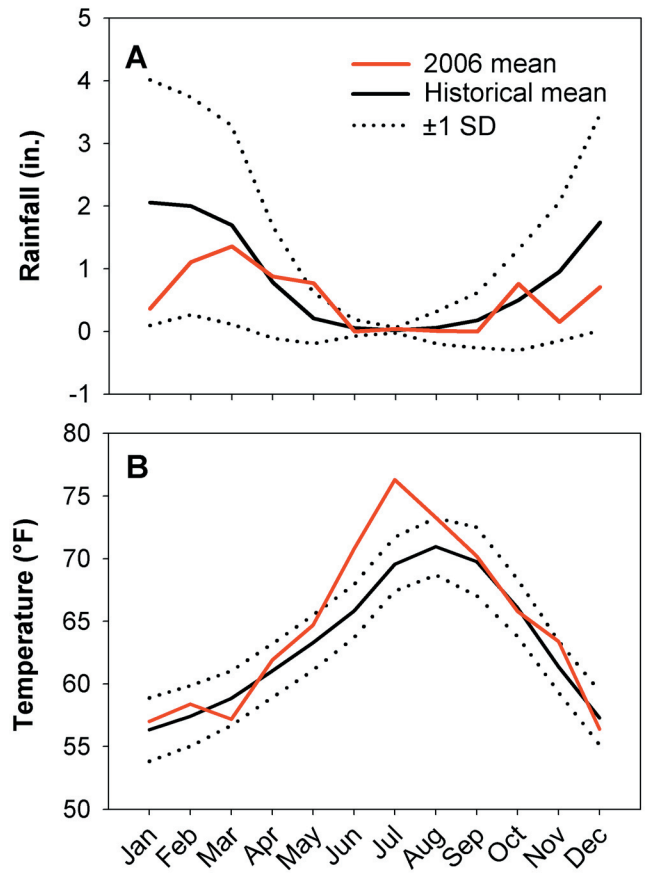

Figure 2.3
Total monthly rainfall (A) and monthly mean air temperature (B) at Lindbergh Field (San Diego, CA) for 2006 compared to monthly mean rainfall and air temperature (±1 SD) for the historical period 1914 through 2005.

inches. Thereafter, only 1.62 inches of rain fell from September through December, resulting in a total annual rainfall of 6.15 inches, well below the annual average of 10.26 inches. During March, average air temperature approached the lower confidence limit of the 91-year historical average limit, while near record warm air temperatures occurred in June–August (Figure 2.3B). Annual ocean surface temperatures peaked during these same months. Despite these circumstances, thermal stratification of the water column followed normal seasonal patterns at the nearshore and offshore sampling areas.

Temperature is the main factor affecting water density and stratification of southern California ocean waters (Dailey et al. 1993, Largier et al. 2004) and provides the best indication of the surfacing potential of the wastewater plume. This is

particularly true of the South Bay where waters are shallow and salinity is relatively constant. Average temperatures from all depths for stations I9, I12, I22, and I27 (28-m depth contour) for the period 1995–2005 were compared with mean data for 2006 (**Table 2.1**). Overall, water temperatures during the winter, summer, and fall months in 2006 were similar to historical values from 1995–2005. Monthly differences between these 2 periods ranged from -0.6 to 1.0 °C, well within their respective standard deviations. However, water column temperatures were colder than normal from March through May, when temperatures ranged between 11.6 and 12.0 °C, approximately 1.4–1.6 °C lower than historical values. These differences were also true for temperatures at surface, mid, and bottom depths over the same period (see Appendix A.1). January also had cooler bottom waters than normal with a difference of -1.5 °C from the historical mean, and mid-depth and surface waters were warmer than average in June and July, respectively. The peak in surface water temperature during July was coincident with the second highest recorded July air temperature since 1914.

Although temperatures at kelp stations were below average early in the year, thermal stratification of the water column generally followed normal seasonal patterns (**Figures 2.4**, **Table 2.2)**. Below average bottom temperatures during January resulted in a stronger than normal stratification near the bottom of the water column (**Figure 2.5**). More typical seasonal stratification began to develop in March and April with temperature differences between surface and bottom waters of 2.9 °C and 4.1 °C, respectively (Table 2.2). In April, thermal stratification was relatively strong, and low temperatures were outside the confidence limits for the historical averages. Thermoclines of ~1 °C over less than 1 meter of depth developed between 5–13 m in March and April. Stratification was strongest in June and July with 7−8 °C differences between surface and bottom water temperatures. The thermoclines were observed at an average depth of 13 m in June and became much shallower in July with an average depth of 6 m. A weaker shallow thermocline persisted into November, but became undetectable by December.

Localized upwelling can transport colder deeper water and nutrients from below the thermocline to surface waters and may also cause onshore transport of wastewater plumes (Roughan et al. 2005). In the South Bay, topographic features such as the Point Loma headland create a divergence of the prevailing southerly flow as it encounters shallower isobaths (see Roughan et al. 2005). This creates a vorticity that transports deeper water to the surface where it is subsequently swept southward within the South Bay. Satellite imagery of the SBOO region using AVHRR thermal sensors and infrared TM sensors showed patterns that are consistent with this description on June 28 and July 14 (**Figure 2.6**). Colder upwelled water, light to dark blue in the AVHRR images and white features in the TM imagery, appears to flow south from the Point Loma headland. In August 2006, localized upwelling was apparent from a marked decline of water temperatures at kelp and monthly stations (Table 2.2, Figure 2.4).

Salinity values for stations I9, I12, I22, and I27 averaged from 33.34 to 33.64 ppt per month, with the lowest values occurring in January and the highest in March–May (Table 2.1). Mean mid-depth and bottom water salinities for the same period ranged from 33.68 to 33.82, respectively, and were near or slightly higher than the standard deviation (Appendix A.1b,c). These values were coincident with the occurrence of the coldest bottom temperatures of ~10 °C, the influx of which is normal for this period (Figures 2.4, 2.5). The unusual occurrence of heavy rainfall in May (i.e., 0.77 inches) did not cause a reduction in surface water salinities at kelp or monthly stations. Overall, the greatest differences between surface and bottom water salinity at all stations occurred from March through May during 2006.

Density, a product of temperature, salinity, and pressure, is influenced primarily by temperature in the South Bay region where depths are shallow and salinity profiles are relatively uniform. Therefore, changes in density typically mirror changes in

Table 2.1

Mean data at all depths for 2006 compared to historical mean data and standard deviations (±1 SD) for 1995–2005 at stations I9, I12, I22, and I27, and difference (Δ) between 2006 and 1995–2005 mean data. Data includes temperature (°C), salinity (ppt), density (δ/θ), dissolved oxygen (mg/L), pH, transmissivity (%), and chlorophyll *a* (µg/L).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature												
2006	14.3	13.3	12.0	11.6	11.9	15.0	15.1	13.9	16.0	14.9	16.4	14.9
1995–2005	14.4	13.4	13.4	13.1	13.5	14.1	14.1	14.0	15.6	15.5	15.5	14.9
SD	1.2	1.2	1.4	1.7	2.7	3.1	2.8	2.6	3.2	2.5	1.7	1.3
Δ	-0.1	-0.1	-1.4	-1.5	-1.7	0.9	1.0	-0.1	0.4	-0.6	0.9	-0.0
Salinity												
2006	33.34	33.41	33.51	33.64	33.61	33.61	33.53	33.43	33.44	33.38	33.39	33.48
1995–2005	33.48	33.52	33.50	33.61	33.63	33.66	33.61	33.55	33.50	33.44	33.42	33.46
SD	0.20	0.18	0.20	0.14	0.11	0.15	0.15	0.15	0.12	0.12	0.15	0.46
Δ	-0.14	-0.11	0.01	0.03	-0.02	-0.05	-0.07	-0.12	-0.06	-0.06	-0.03	0.02
Density												
2006	24.85	25.09	25.42	25.60	25.51	24.88	24.78	24.97	24.53	24.73	24.42	24.82
1995–2005	24.92	25.15	25.15	25.28	25.19	25.08	24.99	25.02	24.66	24.65	24.60	24.82
SD	0.27	0.28	0.38	0.41	0.60	0.70	0.65	0.57	0.75	0.55	0.39	0.46
Δ	-0.07	-0.06	0.27	0.32	0.32	-0.20	-0.21	-0.05	-0.13	0.08	-0.18	0.00
Dissolved oxygen												
2006	8.0	8.6	7.0	6.0	6.5	7.6	7.4	7.1	8.2	7.9	7.7	6.9
1995–2005	7.7	7.5	7.6	7.3	7.1	7.6	8.1	8.3	8.1	8.4	7.8	7.8
SD	0.7	1.0	1.4	1.7	1.8	1.7	1.5	1.5	1.4	1.5	0.8	0.7
Δ	0.3	1.1	-0.6	-1.3	-0.6	-0.0	-0.7	-1.2	0.2	-0.5	-0.1	-0.9
pH												
2006	8.1	8.2	8.0	8.0	8.0	8.1	8.1	8.1	8.1	8.1	8.1	8.1
1995–2005	8.0	8.0	8.0	7.9	8.0	8.0	8.0	8.0	8.1	8.1	8.1	8.1
SD	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
Δ	0.1	0.2	0.0	0.1	0.0	0.1	0.1	0.1	0.0	0.0	0.1	-0.0
Transmissivity												
2006	85	81	81	84	87	79	84	89	87	87	87	80
1995–2005	83	80	82	81	83	82	84	84	85	86	85	85
SD	7	12	10	8	5	7	6	5	5	6	4	6
Δ	2	1	-1	3	4	-3	-0	5	2	1	2	-5
Chlorophyll a												
2006	4.6	11.0	10.3	4.0	5.8	10.1	4.1	2.7	3.4	4.0	2.4	1.8
1995–2005	4.8	5.7	4.9	8.1	6.2	7.4	4.6	5.5	5.1	4.3	4.4	5.6
SD	2.2	4.4	2.1	6.2	3.9	6.5	3.6	3.9	3.6	3.5	2.9	3.3
Δ	-0.2	5.4	5.4	-4.1	-0.4	2.7	-0.5	-2.8	-1.7	-0.3	-2.0	-3.8

temperature. This relationship was true for 2006 as indicated by CTD data collected at the kelp and offshore water quality stations (Figure 2.4). Offshore surface water density was lowest in July when these waters were warmest. The difference between surface and bottom water densities was greatest from April through September, with the resulting pycnocline contributing to the stratification of the upper column at the time.

Mean chlorophyll *a* values in surface waters ranged from a low of 1.8 µg/L in November at the offshore

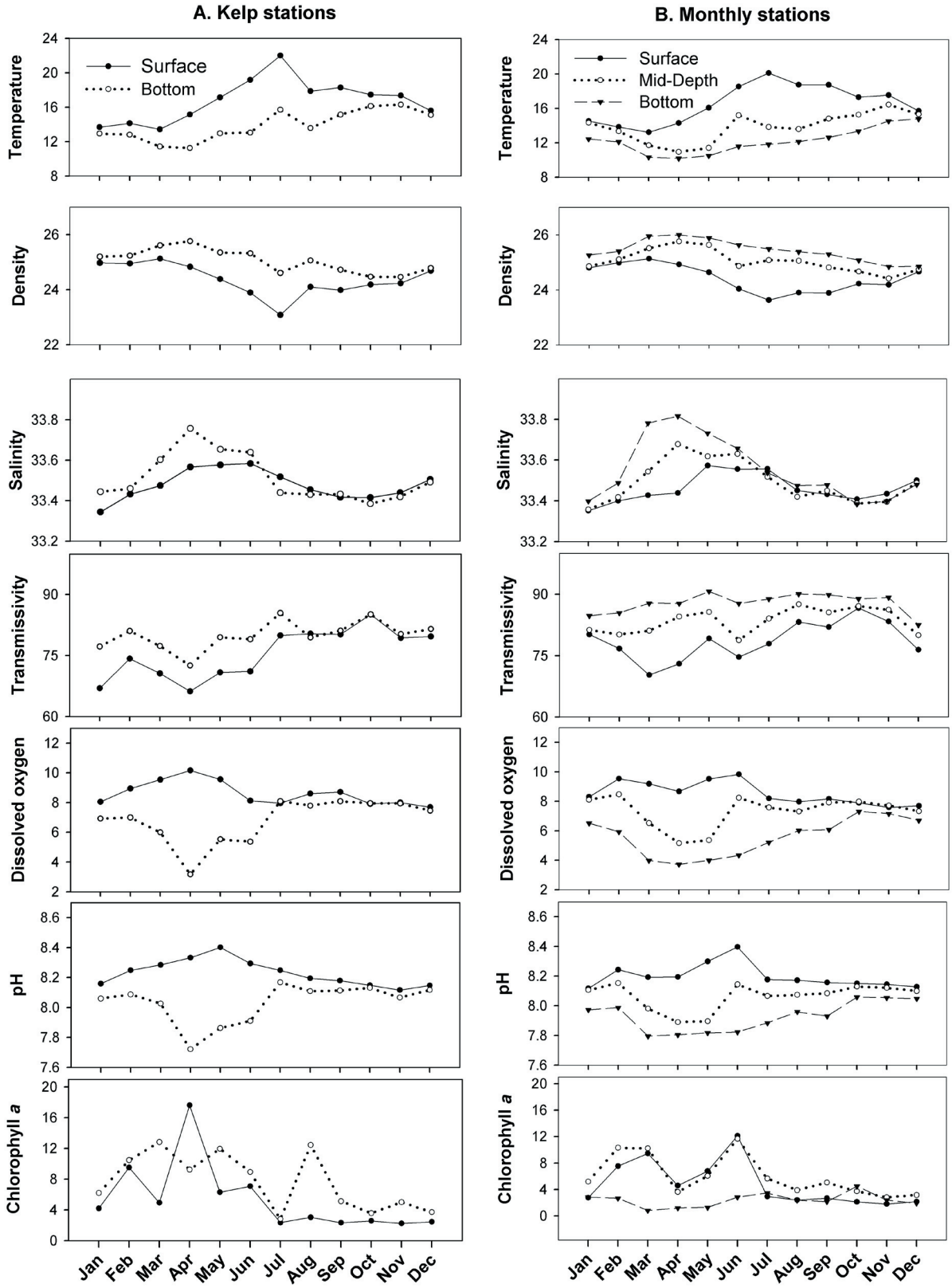

Figure 2.4

Monthly mean temperature (°C), density (δ/θ), salinity (ppt), transmissivity (%), dissolved oxygen (mg/L), pH, and chlorophyll *a* (µg/L) values for (A) surface (≤2m) and bottom (≥27m) waters at the kelp water quality stations and (B) surface (≤2m), mid-depth (10–20 m) and bottom (≥88m) waters at the monthly water quality stations during 2006.

Table 2.2

Differences between the surface (≤2 m) and bottom (≥27 m) waters for mean values of temperature (Temp, °C), density (δ/θ), salinity (ppt), dissolved oxygen (DO, mg/L), pH, transmissivity (XMS, %), and chlorophyll *a* (Chl *a*, µg/L) at all monthly SBOO stations during 2006.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temp	*Surface*	14.5	13.8	13.2	14.3	16.1	18.5	20.1	18.7	18.7	17.3	17.5	15.7
	Bottom	12.4	12.1	10.3	10.2	10.5	11.6	11.8	12.1	12.6	13.3	14.5	14.8
	Δ	2.1	1.7	2.9	4.1	5.6	6.9	8.3	6.6	6.1	4.0	3.0	0.9
Density	*Surface*	24.80	24.99	25.13	24.92	24.64	24.04	23.63	23.90	23.89	24.22	24.19	24.66
	Bottom	25.26	25.40	25.95	26.00	25.88	25.63	25.49	25.38	25.29	25.07	24.84	24.85
	Δ	-0.46	-0.41	-0.82	-1.08	-1.24	-1.59	-1.86	-1.48	-1.40	-0.85	-0.65	-0.19
Salinity	*Surface*	33.35	33.40	33.43	33.44	33.57	33.56	33.56	33.45	33.43	33.41	33.43	33.50
	Bottom	33.40	33.49	33.78	33.82	33.73	33.66	33.54	33.48	33.48	33.38	33.40	33.48
	Δ	-0.05	-0.09	-0.35	-0.38	-0.16	-0.10	0.02	-0.03	-0.05	0.03	0.03	0.02
DO	*Surface*	8.3	9.5	9.2	8.7	9.5	9.8	8.2	8.0	8.2	7.9	7.6	7.7
	Bottom	6.5	5.9	4.0	3.7	4.0	4.3	5.2	6.0	6.1	7.3	7.2	6.7
	Δ	1.8	3.6	5.2	5.0	5.5	5.5	3.0	2.0	2.1	0.6	0.4	1.0
pH	*Surface*	8.1	8.2	8.2	8.2	8.3	8.4	8.2	8.2	8.2	8.2	8.1	8.1
	Bottom	8.0	8.0	7.8	7.8	7.8	7.8	7.9	8.0	7.9	8.1	8.1	8.0
	Δ	0.1	0.2	0.4	0.4	0.5	0.6	0.3	0.2	0.3	0.1	0.0	0.1
XMS	*Surface*	80	77	70	73	79	75	78	83	82	87	83	76
	Bottom	85	85	88	88	91	88	89	90	90	89	89	82
	Δ	-5	-9	-18	-15	-12	-13	-11	-7	-8	-2	-6	-6
Chl *a*	*Surface*	2.8	7.5	9.4	4.6	6.8	12.1	3.0	2.4	2.7	2.1	1.8	2.2
	Bottom	2.9	2.7	0.8	1.2	1.3	2.9	3.5	2.4	2.2	4.5	2.4	1.9
	Δ	-0.1	4.9	8.6	3.4	5.5	9.2	-0.5	0.0	0.5	-2.4	-0.6	0.3

stations to a high value of 17.6 µg/L in April at the kelp stations (Table 2.2, Appendix A.2). Generally, chlorophyll *a* was consistently elevated from February through June at surface and mid-depths at the offshore stations, and at surface and bottom depths at the kelp stations. Increases in plankton density, as estimated using chlorophyll *a*, likely influenced some of the declines in transmissivity and increases in oxygen and pH that occurred during these periods. Plankton blooms were also observed throughout the year in the aerial imagery (Ocean Imaging 2006, 2007a, b).

Historical Analyses of CTD Data

A review of historical oceanographic data for 4 stations surrounding the SBOO does not reveal a measurable impact from the wastewater discharge that began in 1999. Instead, these data were consistent with changes within the California Current System observed by CalCOFI (Peterson et al. 2006) (**Figure 2.7**). Three significant events have affected the California Current System during the last decade: (1) the 1997–1998 El Niño event; (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 in October 2002. Temperature and salinity data for the South Bay region are consistent with the first 2 events, although recent data show a trend of cooler water beginning in 2005. This trend varies from other surveys of the California Current System and 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 within the South Bay region were also below the mean from late 2002–2006. However, recent CalCOFI data showed an increase

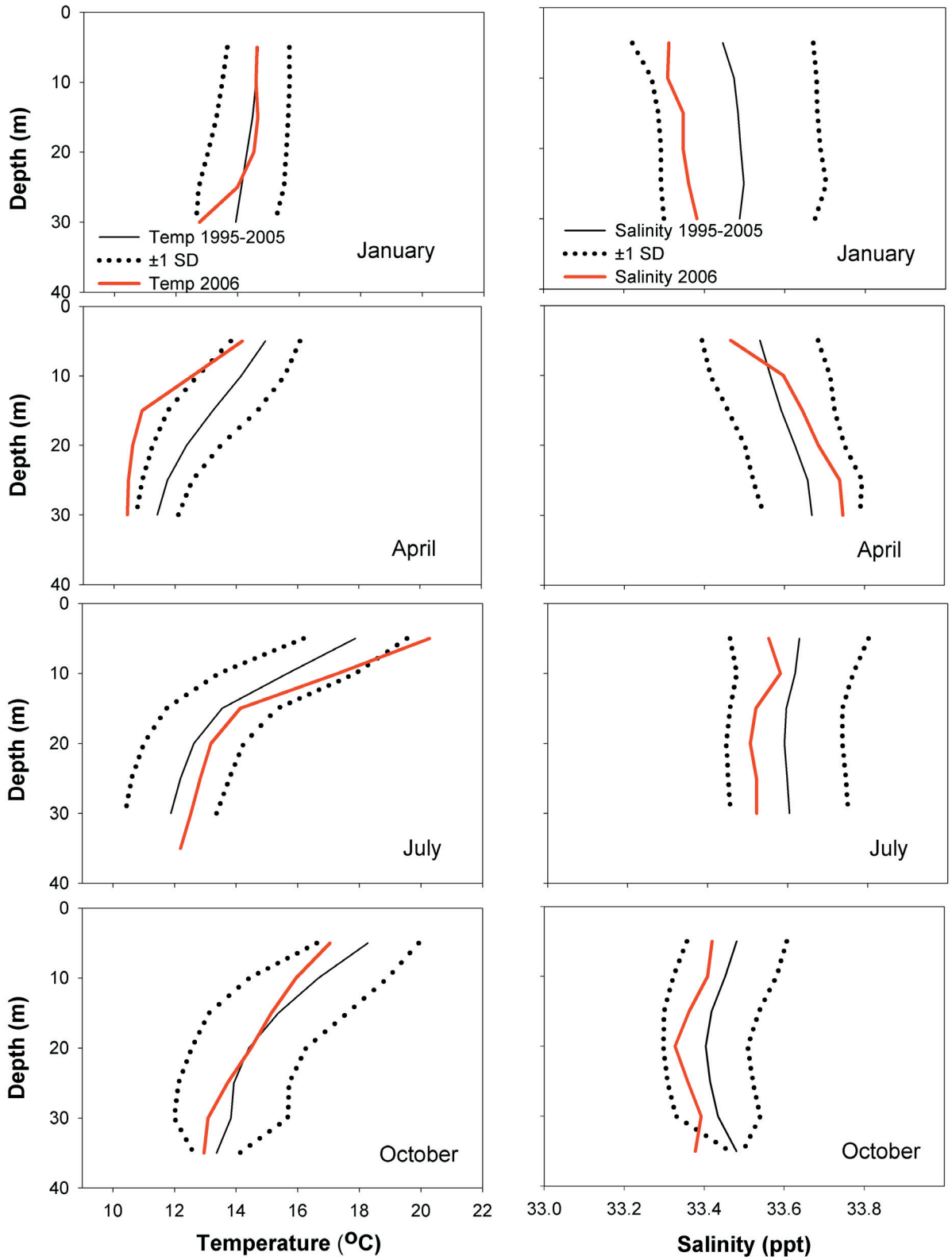

Figure 2.5
Mean quarterly temperature and salinity data for 2006 compared to mean temperature and salinity (±1 SD) for the historical period 1994 through 2005 at stations I9, I12, I22, and I27.

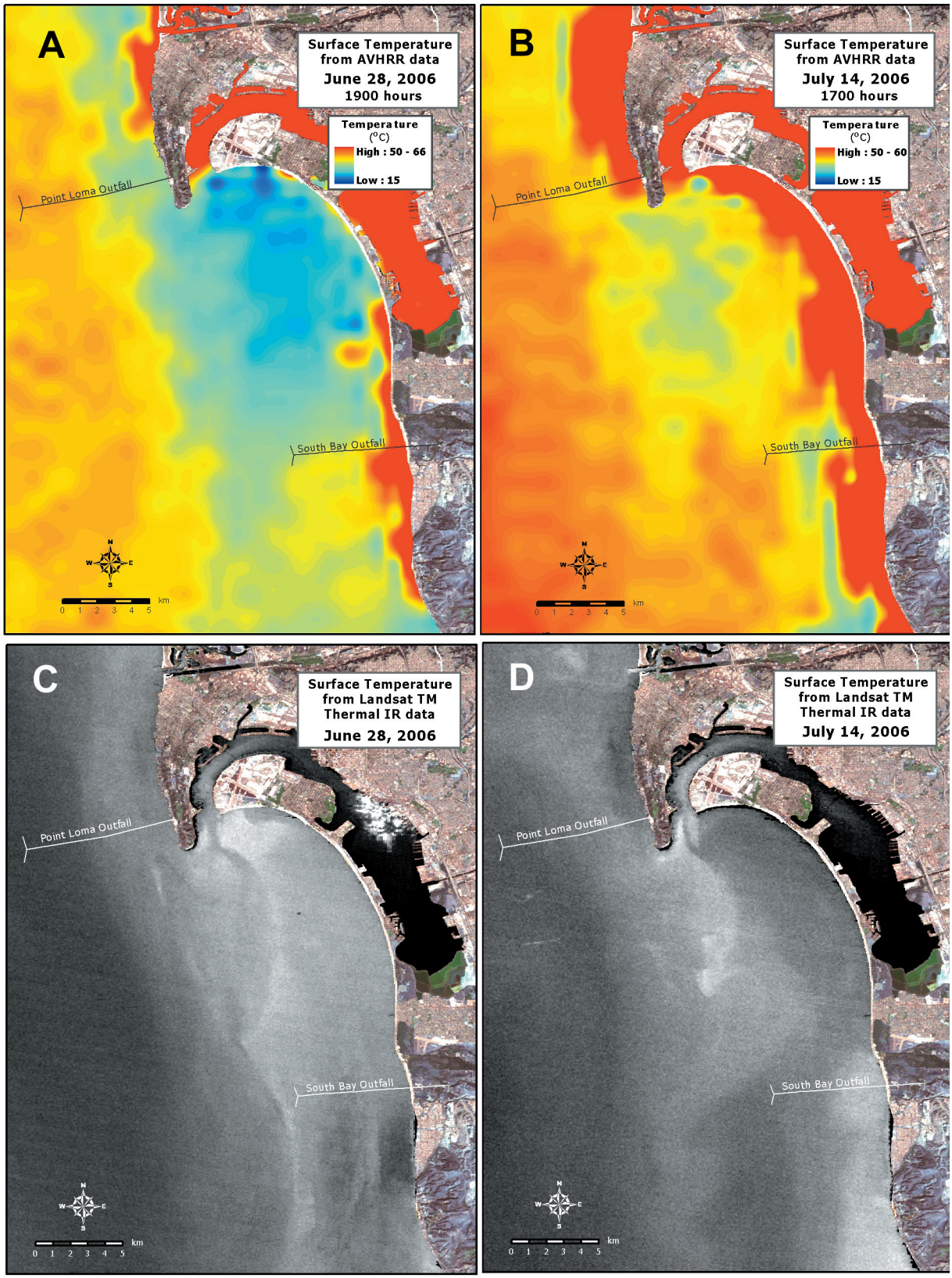

Figure 2.6

Satellite imagery showing the San Diego 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.

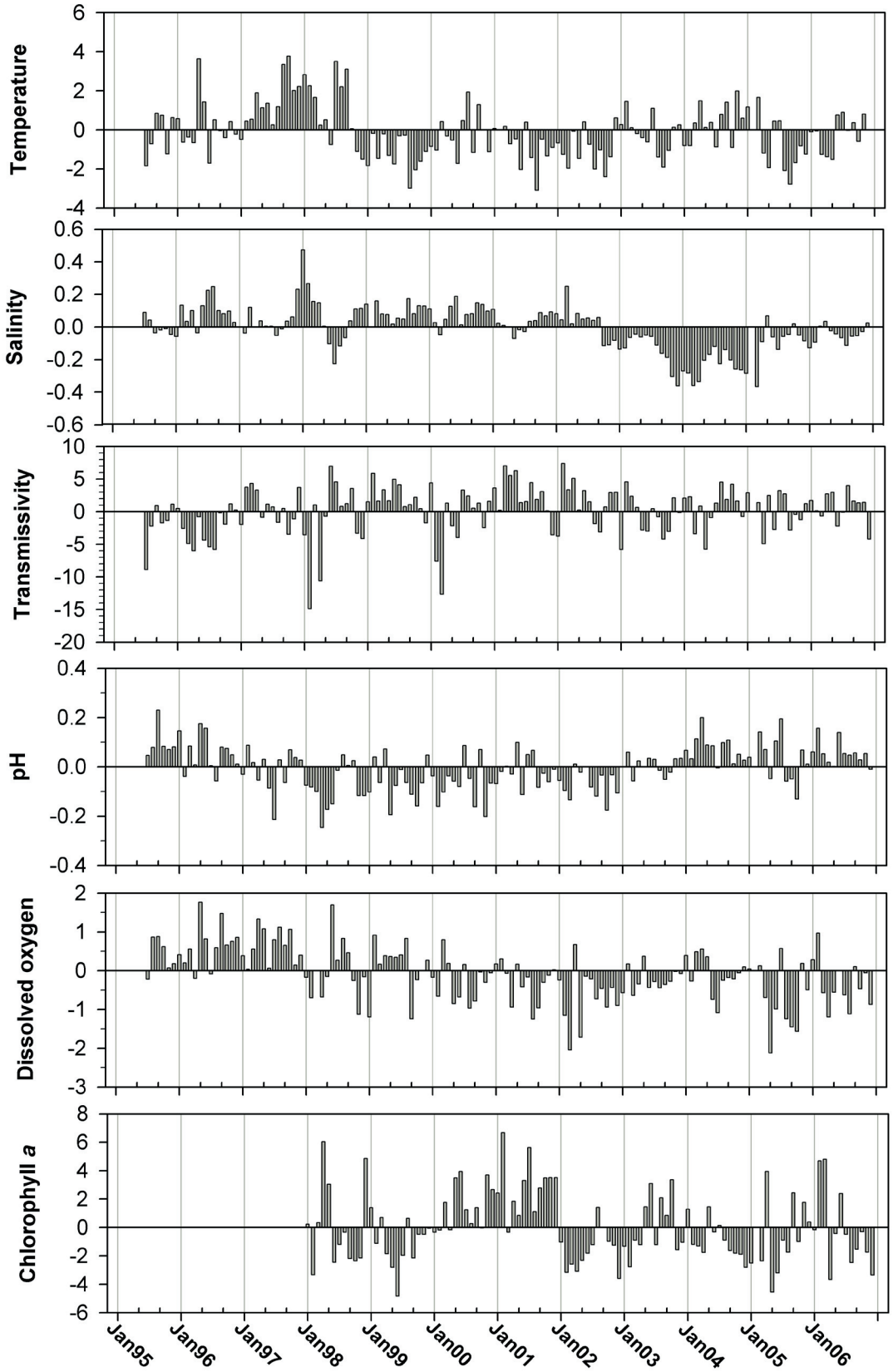

Figure 2.7
Time series of differences between means for each month and the historical monthly means for 1995–2006 for temperature (°C), salinity (ppt), transmissivity (%), pH, dissolved oxygen (mg/L), and chlorophyll a (µg/L).

in 2006 in portions of the Southern California and northern Baja California regions.

Overall water clarity (transmissivity) has generally increased in the South Bay since initiation of discharge in 1995, but several intermittent decreases in clarity were 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 at LA-5, leaving large, visible plumes of sediment throughout the region (see City of San Diego 2006). Several large decreases during winter periods such as those in 1998 and 2000 appear to be the result of increased amounts of suspended sediments caused by strong storm activity when monthly total rainfall ranged from one to nearly 8 inches (NOAA/NWS 2007). Smaller decreases in spring and early summer are probably related to plankton blooms such as those observed throughout the region in 2005 (City of San Diego 2006).

Although chlorophyll *a* concentrations have mostly increased in southern California during recent years (Peterson et al. 2006), the South Bay data are more consistent with those observed in northern Baja California where chlorophyll *a* mostly decreased. Occasional increases within the South Bay region occurred as a result of red tides blooms 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).

Trends in relation to the outfall were not apparent for pH and dissolved oxygen. 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 which make temporal changes difficult to evaluate.

Remote Sensing

Imagery from the remote sensing studies generally confirmed water column stratification that was apparent from CTD data. For example, DMSC aerial imagery detected the outfall plume's near-surface signature on several occasions when the water column was mixed including January through April and in December (**Figure 2.8**); however the size and intensity of the plume tended to be significantly less than in previous years (Ocean Imaging 2006, 2007a, b). Subsequent aerial imagery suggested that the outfall plume remained deeply submerged from May through November when the water column was stratified.

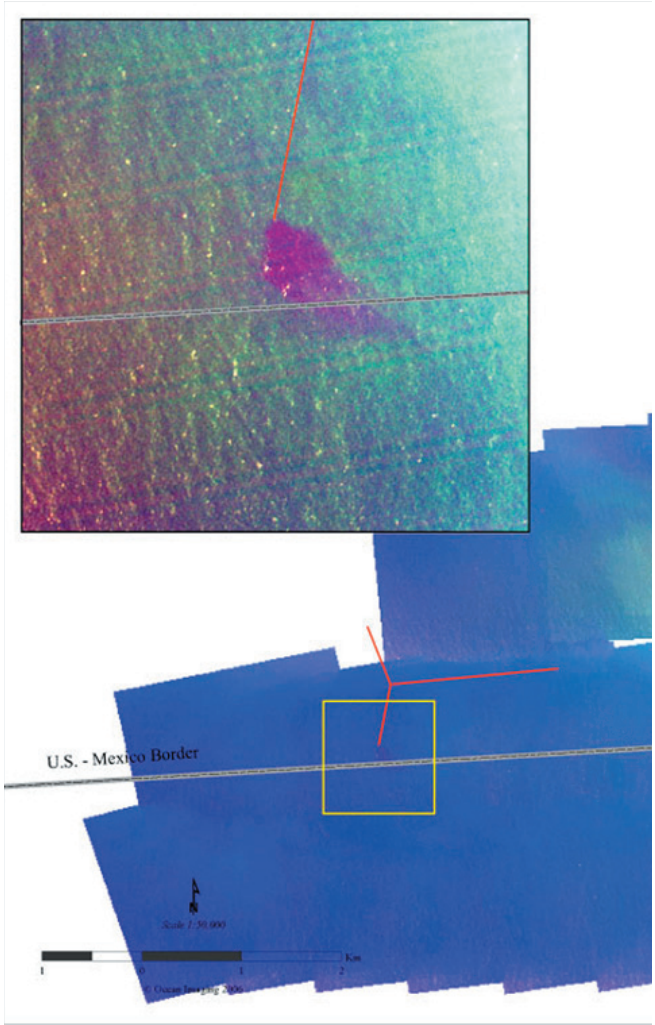

Figure 2.8
DMSC image composite of the SBOO outfall and coastal region acquired on January 31, 2006. Effluent from the south riser indicates a southerly flow.

The relatively few storms during 2006 resulted in decreased runoff and smaller than normal sedimentary plumes from the Tijuana River during winter thereby reducing coastal contamination during the first 3 months (Ocean Imaging 2006).

Generally, runoff plumes from the river remained within 3–4 km of the coastline and did not extend over the SBOO outfall wye region as observed in previous years (City of San Diego 2006). Northward flows during the first 3 months of 2006 resulted in 3 Coronado beach closures as discharge from the Tijuana River moved north past the Imperial Beach pier. In April a northward flow of effluent from Los Buenos Creek crossed into the South Bay. During the late spring, summer, and early fall dominant southward currents generally limited beach contamination to areas south of the river mouth. Additionally, MODIS imagery indicated the presence of shoreline turbidity throughout the period from wave and longshore current activity.

SUMMARY AND CONCLUSIONS

Oceanographic conditions in 2006 were generally within expected seasonal variability. Water temperatures at all depths were below average from March through May, but returned to normal during the remainder of the year. Maximum surface temperatures were above historical means in July, coincident with record monthly air temperatures. Although the seasonal transition for water temperatures occurred in early summer (June and July) rather than late summer (August and September) as seen in prior years, thermal stratification of the water column followed typical patterns.

Water column stratification began to develop in March and persisted through November, and remote sensing data generally confirmed this pattern. A weak outfall plume signature was detected near the surface by aerial imagery on several occasions during the winter months when the water column was mixed. Otherwise, remote sensing observations suggested that the outfall plume remained deeply submerged from May through November (Ocean Imaging 2006, 2007a, b).

With the exception of a slight decline in August temperatures, upwelling appeared to occur rarely in 2006 based on CDT data. A few South Bay upwelling events in June and July were visible in infrared satellite imagery. Aerial and satellite remote sensors also detected the presence of plankton blooms for much of 2006 that were confirmed as increases in chlorophyll *a* concentrations in CTD data. Plankton blooms in South Bay are complex, stimulated by localized upwelling, and occasionally influenced by large red tides created when the river is flowing and nutrients are more readily available.

Long-term analysis of CTD data for 1995–2006 did not reveal changes in water parameters relative to the discharge of wastewater that began in 1999. However, temperature and salinity data for South Bay did correspond to 2 of 3 significant climate events that occurred within the California Current System during this period: 1) the 1997–1998 El Niño event, and 2) 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 beginning in October 2002, was not observed. Instead, ocean conditions during that time were more consistent with coastal survey data from 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 SBOO region since initiation of wastewater discharge from the SBOO. Chlorophyll *a* levels in the South Bay have mostly decreased through time a trend consistent with water conditions in northern Baja California. Changes in pH and dissolved oxygen did not exhibit any apparent trends related to wastewater discharge. Changes in these parameters are complex, dependent on temperature and depth, and are sensitive to physicochemical and biological processes including carbon cycling. Moreover, both parameters are subject to diurnal and seasonal variations making it difficult to decipher temporal trends.

Rainfall was well below average during 2006 and drought conditions existed during January and February. Consequently there was a reduction in ocean contamination during the winter

months as a result of the decreased precipitation and absence of large runoff plumes as seen in previous years.

Aerial imagery indicated that current flow was primarily directed south during 2006. However, northward flow of effluent from Los Buenos Creek into the sampling region was observed once in aerial imagery. Finally, data from the region's water column, together with remote sensing data, revealed no evidence of impact from the SBOO along the coastline in 2006.

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