Chapter 2. Oceanographic Conditions

INTRODUCTION

The City of San Diego monitors oceanographic conditions in the region surrounding the South Bay Ocean Outfall (SBOO) to assist in evaluating possible impacts of wastewater discharge on the marine environment. Measurements of water temperature, salinity, density, light transmittance (transmissivity), dissolved oxygen and pH, in conjunction with biological indicators such as chlorophyll concentrations, are important indicators of biological and physical oceanographic processes (Skirrow 1975) that can impact marine life within a region (Mann 1982, Mann and Lazier 1991). In addition, because the fate of wastewater discharged into marine waters is determined not only by the geometry of an ocean outfall's diffuser structure and the rate of discharge, but also by oceanographic factors that govern water mass movement (e.g., horizontal and vertical mixing of the water column, current patterns), evaluations of physical parameters that influence the mixing potential of the water column are important components of ocean monitoring programs (Bowden 1975, Pickard and Emery 1990). For example, the degree of vertical mixing or stratification, and the depth at which the water column is stratified, indicates the likelihood and depth of wastewater plume trapping.

In relatively nearshore waters such as the SBOO monitoring region, oceanographic conditions are strongly influenced by seasonal changes (Bowden 1975, Skirrow 1975, Pickard and Emery 1990). Southern California weather can generally be classified into a wet, winter season (typically December through February) and a dry, summer season (typically July through September) (NOAA/NWS 2010), and differences between these seasons affect oceanographic conditions such as water column stratification and current patterns. For example, storm activity during southern California winters brings higher winds, rain, and waves which often contribute to the formation of a well-mixed, relatively homogenous or non-stratified water column (Jackson 1986). The chance that wastewater plumes from sources such as the SBOO may surface is highest during such times when the water column is well mixed and there is little, if any, stratification. These conditions often extend into spring as the frequency of storms decreases and the transition from wet to dry conditions begins. In late spring the increasing elevation of the sun and longer days begin to warm surface waters resulting in increased surface evaporation (Jackson 1986). Mixing conditions also 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 the fall, cooler temperatures, along with increases in stormy weather, begin to cause the return of well-mixed water column conditions.

Understanding changes in oceanographic conditions due to natural processes like the seasonal patterns described above is important since they can affect the transport and distribution of wastewater, storm water and other types of turbidity (e.g., sediment, contaminant) plumes. In the South Bay outfall region these include plumes associated with tidal exchange from San Diego Bay, outflows from the Tijuana River in U.S. waters and Los Buenos Creek in northern Baja California, storm water discharges, and runoff from local watersheds. For example, flows from San Diego Bay and the Tijuana River are fed by 1075 km^2 and 4483 km^2 of watershed, respectively, and can contribute significantly to nearshore turbidity, sediment deposition, and bacterial contamination (see Largier et al. 2004, Terrill et al. 2009). Overall, these different sources can affect water quality conditions both individually and synergistically.

This chapter describes the oceanographic conditions that occurred in the South Bay region during 2009. The main objectives are to: (1) describe deviations from expected oceanographic patterns, (2) assess possible influence of the SBOO wastewater discharge relative to other input sources, (3) determine the extent to which water mass movement or water column 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 results of remote sensing observations (e.g., aerial and satellite imagery) may also provide useful information on the horizontal transport of surface waters (Pickard and Emery 1990, Svejkovsky 2010). Thus, this chapter combines measurements of physical oceanographic parameters with assessments of remote sensing data to provide further insight into the transport potential in coastal waters surrounding the SBOO discharge site. The results reported herein are also referred to in subsequent chapters to explain patterns of indicator bacteria distributions (see Chapter 3) or other changes in the local marine environment (see Chapters 4–7).

Materials and Methods

Field Sampling

Oceanographic measurements were collected at fixed sampling sites located in a grid pattern encompassing an area of ~450 km^2 surrounding the SBOO (Figure 2.1). These forty offshore stations (designated I1–I40) are located between 3.4–14.6 km offshore along or adjacent to the 9, 19, 28, 38 and 55-m depth contours. The stations were sampled monthly, usually over a 3-day period. This included 11 stations sampled on the day designated "North WQ" (stations I28–I38), 15 stations sampled on the day designated "Mid WQ" (stations I12, I14–I19, I22–I27, I39, I40), and 14 stations sampled on the day designated "South WQ" (stations I1–I11, I13, I20, I21). See Appendix A.1 for the actual dates samples were collected during 2009.

Data for the various oceanographic parameters were collected using a SeaBird conductivity, temperature, and depth instrument (CTD). The CTD was lowered through the water column at each station to collect continuous measurements of water temperature, salinity, density, pH, transmissivity (a proxy for water clarity), chlorophyll *a* (a proxy for the presence of phytoplankton), and dissolved oxygen (DO). Profiles of each parameter were then constructed for each station by averaging the data values recorded over 1-m depth intervals. This data reduction ensured that physical measurements used in subsequent 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

Coastal monitoring of the SBOO region during 2009 also included aerial and satellite image analysis performed by Ocean Imaging of Solana Beach, CA (see Svejkovsky 2010). All usable images for the study area captured during the year by the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite were downloaded from Ocean Imaging's website (Ocean Imaging 2010) for each month, as well as 19 high clarity Landsat Thematic Mapper (TM) images. High resolution aerial images

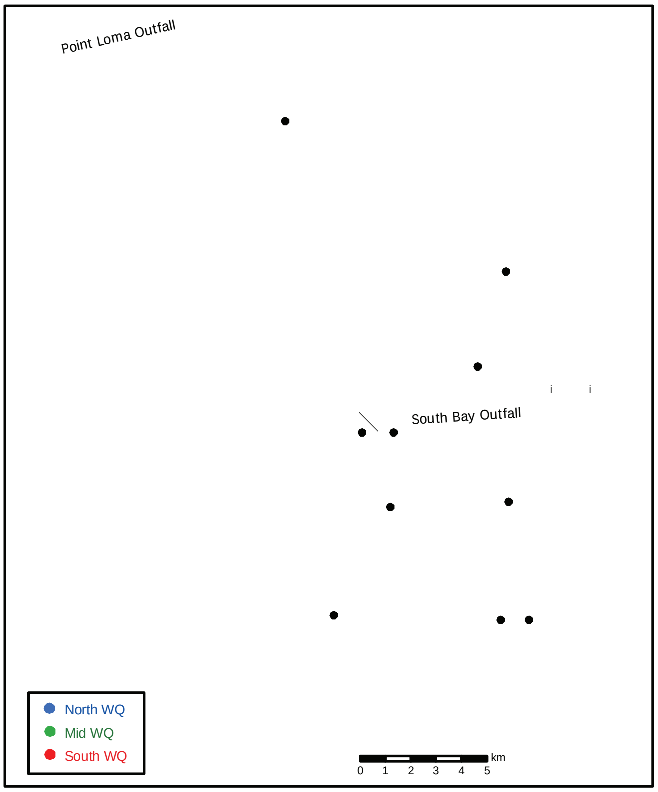

Figure 2.1
Water quality monitoring stations where CTD casts are taken, South Bay Ocean Outfall Monitoring Program.

were collected using Ocean Imaging's DMSC-MKII digital multispectral sensor and from a Jenoptik thermal imager integrated into the system. The DMSC's four channels were configured to a specific wavelength (color) combination designed to maximize detection of the SBOO wastewater signature by differentiating between the wastefield and coastal turbidity plumes. Depth of penetration for this sensor varies between 7–15 m depending on water clarity. The spatial resolution of the data is dependent upon aircraft altitude, but is typically maintained at 2 m. Fifteen DMSC overflights were conducted in 2009, which consisted of one to three flights per month during winter when the plume surfacing potential was greatest and when rainfall was typically highest. In contrast, only three surveys were flown during the spring and late summer months.

Data Treatment

The various water column parameters measured in 2009 were summarized as monthly means over all stations located along each of the 9, 19, 28, 38 and 55-m depth contours to provide an overview of trends throughout the entire year. For spatial analysis, 3-dimensional graphical views were created using Interactive Geographical Ocean Data System software (IGODS), which uses a linear interpolation between stations and with depth at each site. Data for these analyses were limited to four monthly surveys representative of the winter (February), spring (May), summer (August), and fall (November) seasons. These surveys were selected because they correspond to the quarterly water quality surveys conducted as part of the Point Loma Ocean Outfall monitoring program and the Central Bight Regional monitoring program. Additional spatial analysis included vertical profiles using the 1-m binned data for each parameter from the same surveys listed above, but limited to station I12 located closest to the wye's southern end, station I22 located just north of the outfall, and station I9 located just south of the outfall. These profiles were created to provide a more detailed view of data depicted in the IGODS graphics. Finally, a time series of anomalies for each parameter was created to evaluate significant oceanographic events in the region. Anomalies were calculated by subtracting the monthly means for each year between 1995–2009 from the mean of all 15 years combined. Means were calculated using data for the three stations described above, with all depths combined.

Results and Discussion

Oceanographic Conditions in 2009

Water Temperature

In 2009, mean surface temperatures across the entire SBOO region ranged from 13.5°C in March to 21.3°C in September, while bottom temperatures averaged from 10.4°C in May to 16.8°C in October (Table 2.1). Water temperatures varied as expected by depth, with the lowest temperatures of the year occurring at the bottom during the spring (Figure 2.2, Figure 2.3). Temperatures also varied as expected by season, with the water column ranging from well-mixed in the winter, to highly stratified in summer, to weakly stratified in fall. Since temperature is the main contributor to water column stratification in southern California (Dailey et al. 1993, Largier et al. 2004), differences between surface and bottom temperatures were important to limiting the surfacing potential of the wastewater plume during certain times of the year. Results from remote sensing observations and discrete bacteriological samples indicated that the plume surfaced during the winter when the water column was well-mixed, but was never detected in surface waters during the summer when the water column was highly stratified (e.g., Figure 2.4).

Ocean conditions were fairly consistent throughout the region during each season with two possible exceptions. First, slightly warmer surface waters occurred at the north end of the station grid in May (Figure 2.2B), possibly because these stations were sampled four days after those in the middle of the survey area and conditions changed during that short amount of time. Second, slightly different conditions were present in the water column near the outfall during February, May, and August (Figure 2.3). During these months, the water

Table 2.1

Summary of temperature, salinity, dissolved oxygen, pH, transmissivity, and chlorophyll *a* for surface and bottom waters in the SBOO region during 2009. Values are expressed as means for each month pooled over all stations along each depth contour.

Depth Contour		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature (°C)													
9-m	Surface	13.9	14.5	13.5	16.4	17.5	17.1	16.1	19.7	19.3	17.6	16.0	15.0
	Bottom	13.7	14.1	12.1	14.9	16.5	13.0	13.0	14.0	15.4	16.8	14.9	15.0
19-m	Surface	13.9	14.5	13.6	16.1	17.3	16.9	16.5	19.8	19.5	17.3	16.0	15.3
	Bottom	13.6	13.5	11.5	11.9	13.6	11.9	11.8	12.4	13.9	15.4	14.4	14.9
28-m	Surface	14.0	14.4	14.0	15.9	17.4	17.0	15.9	18.9	19.8	17.1	16.0	15.3
	Bottom	13.3	12.9	11.2	11.4	11.9	11.5	11.5	12.1	13.1	14.6	14.0	14.5
38-m	Surface	14.5	14.5	14.3	16.2	17.6	17.8	18.0	19.0	20.5	17.8	16.2	15.5
	Bottom	12.7	12.4	10.9	11.1	10.9	11.4	11.4	11.5	12.6	14.1	13.2	14.5
55-m	Surface	14.3	14.5	14.2	16.0	17.4	17.8	18.6	18.5	21.3	18.2	16.2	15.6
	Bottom	12.0	11.7	10.8	10.6	10.4	11.0	11.0	11.0	11.8	13.1	12.7	13.0
Salinity (ppt)													
9-m	Surface	33.30	33.42	33.40	33.53	33.62	33.69	33.48	33.49	33.41	33.32	33.45	33.44
	Bottom	33.34	33.44	33.53	33.55	33.65	33.68	33.52	33.40	33.34	33.31	33.27	33.34
19-m	Surface	33.33	33.44	33.42	33.52	33.60	33.66	33.46	33.45	33.44	33.29	33.32	33.49
	Bottom	33.38	33.44	33.62	33.59	33.69	33.69	33.51	33.34	33.30	33.26	33.26	33.37
28-m	Surface	33.35	33.43	33.38	33.50	33.61	33.59	33.44	33.47	33.49	33.30	33.32	33.42
	Bottom	33.43	33.45	33.70	33.61	33.73	33.69	33.53	33.34	33.28	33.23	33.26	33.35
38-m	Surface	33.38	33.43	33.35	33.49	33.59	33.57	33.51	33.47	33.54	33.36	33.48	33.47
	Bottom	33.49	33.47	33.76	33.64	33.75	33.67	33.54	33.42	33.29	33.20	33.27	33.35
55-m	Surface	33.37	33.43	33.33	33.48	33.57	33.54	33.53	33.48	33.56	33.42	33.41	33.49
	Bottom	33.57	33.58	33.76	33.75	33.81	33.65	33.60	33.53	33.39	33.24	33.30	33.32
Dissolved Oxygen (mg/L)													
9-m	Surface	8.2	8.5	7.3	8.0	8.4	8.4	8.6	7.8	7.9	7.5	7.6	7.3
	Bottom	7.9	7.7	5.3	7.1	8.2	6.4	7.1	7.5	7.8	7.3	6.8	7.0
19-m	Surface	8.2	8.4	7.5	8.2	8.5	8.5	9.0	8.3	7.6	7.6	7.8	7.2
	Bottom	7.1	6.3	4.3	4.4	6.4	5.1	5.9	6.5	7.5	7.4	7.2	6.9
28-m	Surface	8.3	8.5	7.9	8.1	8.3	7.9	8.7	8.1	7.2	7.5	7.9	7.2
	Bottom	6.6	5.8	4.0	4.4	5.2	4.7	5.0	6.5	7.0	7.6	7.1	6.7
38-m	Surface	8.4	8.4	8.2	8.0	8.1	7.4	8.0	8.0	7.0	7.3	7.8	7.3
	Bottom	6.1	5.6	3.6	4.2	3.7	4.7	4.9	5.6	6.7	7.5	6.7	6.8
55-m	Surface	8.4	8.1	8.3	7.9	8.0	7.5	7.8	8.0	6.9	7.1	7.7	7.3
	Bottom	5.5	4.9	3.7	4.0	3.3	4.6	4.4	4.9	5.6	6.9	6.3	6.2

Table 2.1 *continued*

Depth Contour		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
pH													
9-m	Surface	8.1	8.1	8.1	8.2	8.3	8.2	8.2	8.2	8.3	8.3	8.2	8.2
	Bottom	8.1	8.1	8.0	8.1	8.3	8.0	8.0	8.0	8.2	8.2	8.1	8.2
19-m	Surface	8.1	8.2	8.1	8.2	8.3	8.2	8.2	8.2	8.3	8.3	8.2	8.2
	Bottom	8.0	8.0	7.9	7.8	8.1	7.8	7.9	8.0	8.2	8.2	8.2	8.2
28-m	Surface	8.1	8.2	8.2	8.2	8.3	8.1	8.2	8.2	8.2	8.2	8.2	8.2
	Bottom	8.0	7.9	7.8	7.8	7.9	7.8	7.8	8.0	8.1	8.2	8.1	8.2
38-m	Surface	8.1	8.2	8.2	8.1	8.3	8.2	8.2	8.2	8.3	8.2	8.2	8.2
	Bottom	7.9	7.9	7.8	7.8	7.8	7.8	7.8	7.9	8.1	8.2	8.1	8.1
55-m	Surface	8.1	8.1	8.2	8.1	8.3	8.1	8.2	8.1	8.2	8.2	8.1	8.2
	Bottom	7.9	7.9	7.8	7.7	7.7	7.8	7.8	7.8	8.0	8.1	8.1	8.1
Transmissivity (%)													
9-m	Surface	61	76	65	74	69	67	74	67	73	73	68	50
	Bottom	54	74	56	69	67	71	71	77	74	69	59	44
19-m	Surface	72	79	75	77	76	73	77	62	83	78	76	76
	Bottom	43	78	75	73	73	82	78	84	79	74	66	61
28-m	Surface	81	79	76	80	81	85	79	73	90	87	83	87
	Bottom	61	86	85	86	82	89	85	86	89	83	70	76
38-m	Surface	89	83	79	84	83	87	86	75	89	89	89	82
	Bottom	85	89	86	87	87	89	87	89	89	87	82	75
55-m	Surface	88	88	83	87	84	89	87	82	90	90	87	87
	Bottom	91	91	91	91	90	90	90	89	90	89	85	84
Chlorophyll *a* (µg/L)													
9-m	Surface	2.7	7.7	6.2	5.1	14.7	10.0	10.4	10.2	7.7	4.0	5.5	2.4
	Bottom	4.6	13.7	10.1	10.6	21.2	19.8	19.2	12.8	10.2	5.7	9.4	2.8
19-m	Surface	3.0	5.0	5.9	4.5	5.8	7.8	5.1	12.1	1.9	2.4	3.5	1.4
	Bottom	4.1	6.3	4.2	3.3	15.8	10.7	18.1	5.4	8.4	5.9	9.5	1.6
28-m	Surface	2.4	6.4	6.1	2.9	3.9	2.3	5.7	6.2	1.0	1.2	2.4	0.9
	Bottom	3.2	3.7	1.8	2.7	9.3	3.8	9.0	6.3	2.7	5.0	5.7	1.6
38-m	Surface	1.8	2.8	4.3	1.6	1.3	1.5	1.6	3.3	1.0	0.9	1.6	0.6
	Bottom	1.9	2.5	1.1	1.9	4.0	3.6	6.6	3.6	4.2	4.6	3.4	0.7
55-m	Surface	2.4	1.6	3.7	1.7	2.5	1.2	1.7	4.7	1.6	1.2	2.8	0.6
	Bottom	0.8	0.7	0.4	1.0	1.8	2.4	2.0	1.3	2.0	3.7	1.9	0.7

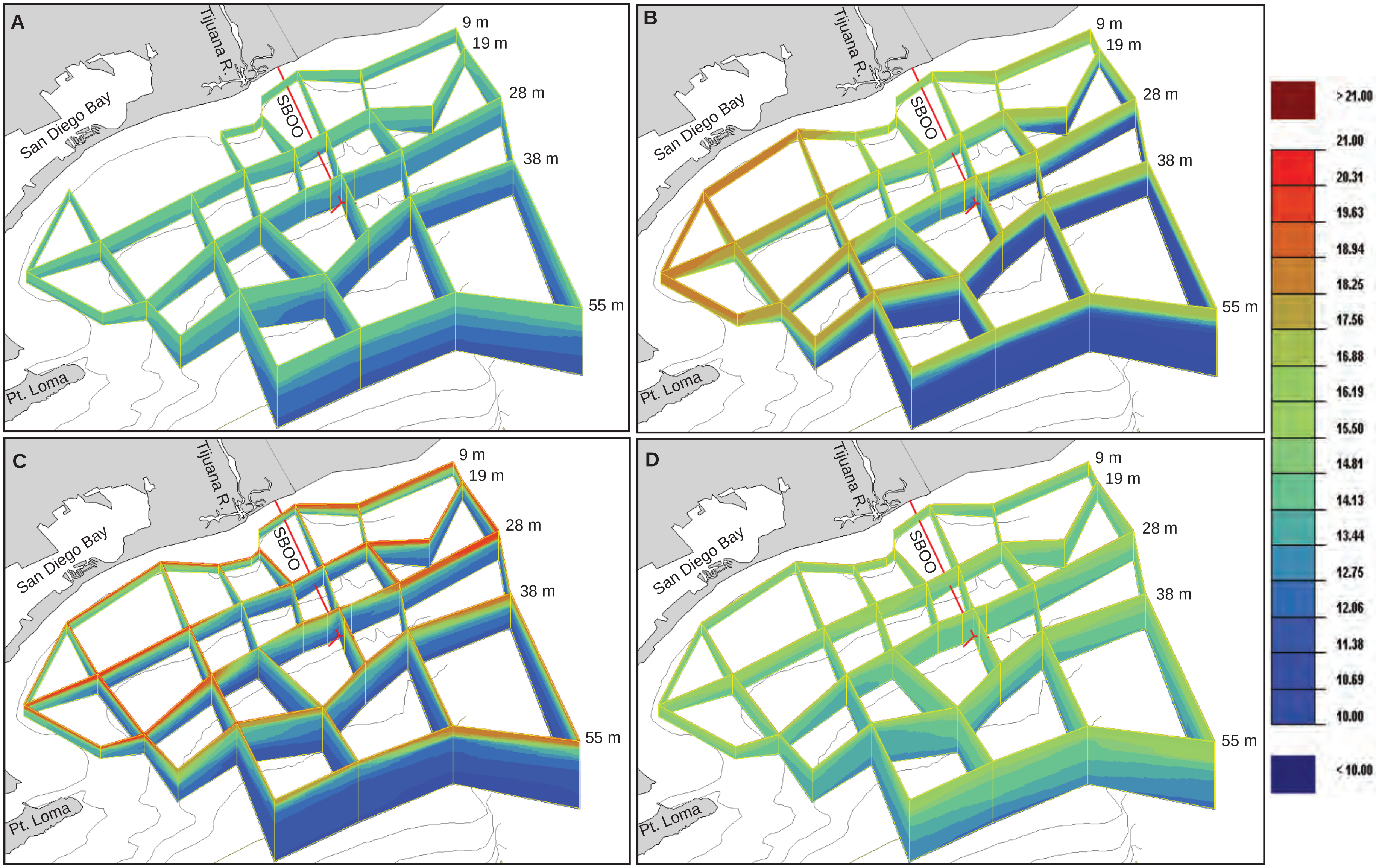

Figure 2.2

Ocean temperatures (°C) recorded in 2009 for the SBOO region during (A) February, (B) May, (C) August, and (D) November. Data are collected over three days during each of these monthly surveys; see Appendix A.1 for specific sample dates and stations sampled each day.

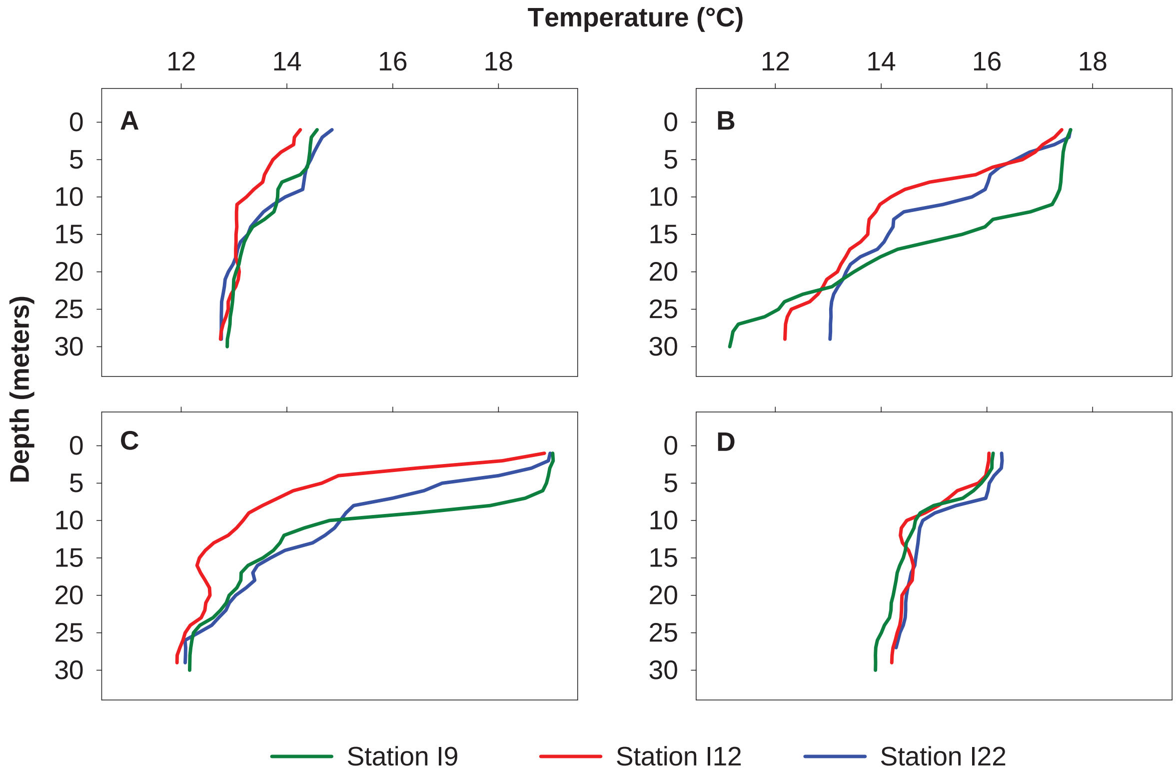

Figure 2.3
Vertical profiles of ocean temperature for SBOO stations I9, I12 and I22 during February (A), May (B), August (C), and November (D) 2009.

temperature at station I12 was colder than at nearby stations I9 and I22 at various depths. For example, temperatures in August at I12 differed by more than 1ºC from the other two stations at depths between about 3 and 17 m. This difference in temperature near the outfall may be due to the force of the effluent exiting the diffusers at depth pushing colder water from the bottom upwards into the water column (i.e., doming). However, it is clear from these analyses that temperature differences between stations at any particular depth were never greater than about 5ºC (Figure 2.3) and this condition was highly localized around the outfall (Figure 2.2).

Salinity

Average salinities for the SBOO outfall region ranged from a low of 33.29 ppt in October to a high of 33.69 ppt in June for surface waters, and from 33.20 ppt in October to 33.81 ppt in May at bottom depths (Table 2.1). High salinity values at bottom depths extended across the entire region in May (Figure 2.5B) and corresponded to the lower temperatures found at bottom depths as described above. Taken together, these factors are indicative of coastal upwelling that is typical for this time of year (Jackson 1986). There was some evidence of another region-wide phenomenon during the summer, when a thin layer of relatively low salinity values occurred at mid-water (i.e., sub-surface) depths between about 10 and 20 m (see Figure 2.5C). It seems unlikely that this sub-surface salinity minima (SSM) could be due to the SBOO discharge for several reasons. For example, corresponding changes indicative of the wastewater plume were not evident in any of the other oceanographic data (e.g., depressed transmissivity). Additionally, no evidence has ever been reported of the plume extending simultaneously throughout the region in so many directions. Instead, results from remote sensing observations (Svejkovsky 2010) and other oceanographic studies (e.g., Terrill et al. 2009) have clearly demonstrated the plume dispersing in specific directions at any one time (e.g., south, southeast, north). Furthermore, bacteriological

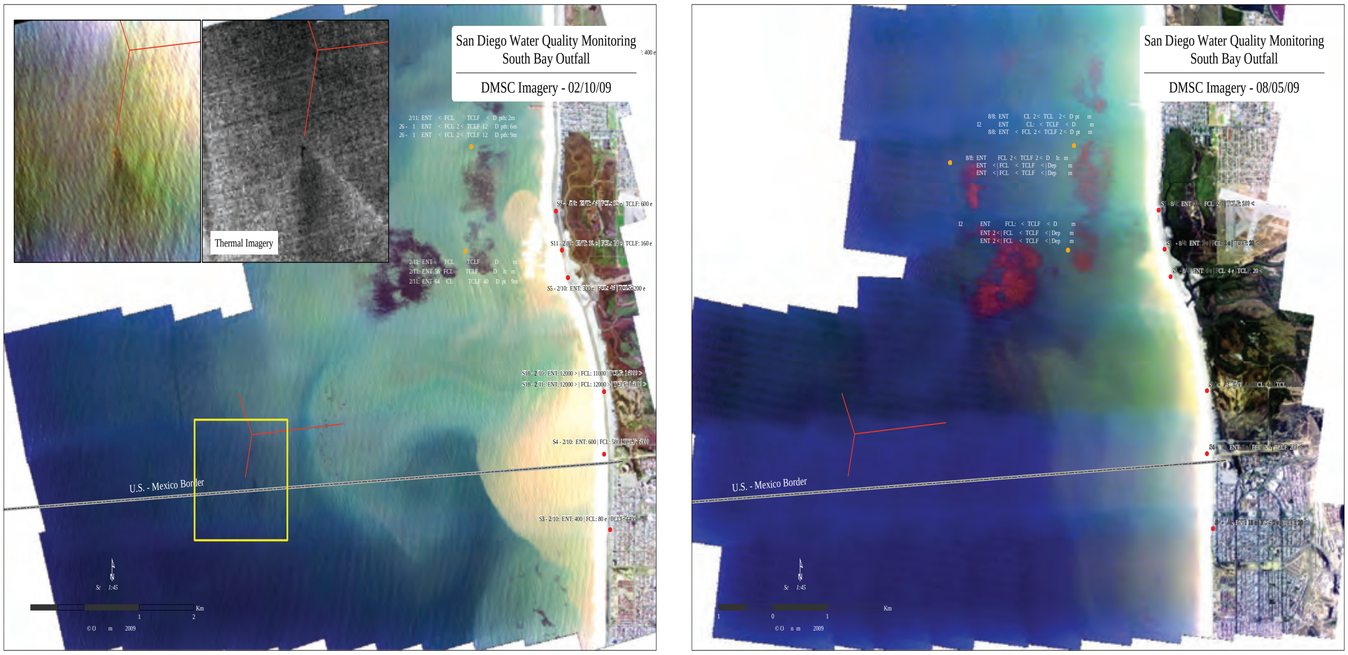

Figure 2.4
DMSC images of the SBOO outfall and coastal region acquired on February 10, 2009, demonstrating when the SBOO plume reaches the surface (left), and on August 5, 2009, demonstrating when the SBOO plume is submerged under the thermocline (right) (see text; images from Ocean Imaging 2010).

samples collected at the same depths and times did not contain elevated levels of indicator bacteria (see Chapter 3). Finally, similar SSMs have been reported previously off San Diego and elsewhere in southern California, including: (1) the Point Loma monitoring region during the summer and fall of 2009 (City of San Diego 2010); (2) coastal waters off Orange County, California for many years (e.g., Orange County Sanitation District 1999); (3) extending as far north as Ventura, California (Orange County Sanitation District 2009). Further investigations are required to determine the possible source (s) of this phenomenon.

In addition to the region-wide phenomena described above, salinity levels were slightly different at stations near the outfall during the year (Figure 2.5, Figure 2.6). Whereas temperatures tended to be relatively low at outfall station I12 during the winter, spring and summer months, salinity was relatively low at this station during the winter, summer and fall. The greatest difference occurred during February when the water column was well mixed; i.e., salinity values at outfall station I12 reached as low as 33.2 ppt, while values remained about 33.4 ppt throughout the water column at stations I9 and I22 to the north and the south (Figure 2.6A), as well as at stations located inshore and offshore of the outfall (Figure 2.5). During the fall, there was some indication of the plume reaching sub-surface waters at station I9 (Figure 2.5B, 2.6B), a pattern which corresponds to the prevailing current patterns for the area (e.g., see Terrill et al. 2009, Svejkovsky 2010). However, low salinity values that occurred in the middle of the water column at both I9 and I22 in August were more likely related to the thin SSM described above. Other stations within the region that had isolated, relatively low salinity levels at mid-depths included the southernmost offshore station (I1) in February and the northernmost offshore station (I28) in November (Figure 2.5A, D).

Density

Seawater density is a product of temperature, salinity and pressure, which in the shallower coastal waters of southern California is influenced primarily by temperature differences since salinity is relatively uniform (Bowden 1975, Jackson 1986, Pickard and Emery 1990). Therefore, changes in density typically mirror those in water temperatures. This relationship was true in the South Bay region during 2009. For example, differences between surface and bottom water densities resulted in a moderate pycnocline at depths between about 3–13 m in the spring, a strong pycnocline at depths between 3–7 m in the summer, and a weak pycnocline at depths between 7–10 m in the fall (Appendix A.2, A.3).

Dissolved Oxygen and pH

Dissolved oxygen (DO) concentrations averaged from 6.9 to 9.0 mg/L in surface waters and from 3.3 to 8.2 mg/L in bottom waters across the South Bay region in 2009, while mean pH values ranged from 8.1 to 8.3 in surface waters and from 7.7 to 8.3 in bottom waters (Table 2.1).

Changes in pH were closely linked to changes in DO since both parameters tend to reflect the loss or gain of carbon dioxide associated with biological activity in shallow waters (Skirrow 1975). Stratification of the water column also followed normal seasonal patterns for both parameters with the greatest variations and maximum stratification occurring during the spring and summer (Appendix A.4, A.5, A.6). For DO, low bottom water values during the spring across the survey area may be due to the cold, saline and oxygen poor ocean water that moves inshore during periods of coastal upwelling as suggested by temperature and salinity data (see above). In contrast, very high DO values just below the surface (i.e., at the pycnocline) during the spring were likely the result of phytoplankton blooms; these high DO values correspond with high chlorophyll values at these same depths during the same survey.

For both DO and pH, values at outfall station I12 differed from those at stations I9 and I22 (Appendix A.5). As with the variations in temperature and salinity described above, these differences were slight and highly localized (<1.7 mg/L for DO, <0.17 units for pH). The variations were so small, in fact, that they were not apparent in the 3-D graphics (see Appendix A.4, A.6). These changes in DO and pH near the outfall may also be due to doming caused by the force of the effluent pushing bottom waters upwards into the water column.

Transmissivity

Transmissivity appeared to be within normal ranges in the SBOO region during 2009 with average values of 50–90% on the surface and 43–91% in bottom waters (Table 2.1). Water clarity was consistently greater at the offshore monitoring sites than in inshore waters, by as much as 37% at the surface and 39% at the bottom. Reductions in water clarity that occurred at the surface and at mid-depths at stations along the 9, 18 and 28-m depth contours (including stations nearest the outfall) throughout the year tended to co-occur with peaks in chlorophyll concentrations associated with phytoplankton blooms (see Appendix A.7, A.8, A.9; see also Svejkovsky 2010). Lower transmissivity along the 9-m depth contour during the winter and fall months may also have been due to wave and storm activity. Changes in transmissivity levels relative to wastewater discharge were not discernible during the year.

***Chlorophyll* a**

Mean concentrations of chlorophyll *a* ranged from 0.4 µg/L in bottom waters at the offshore sites during March to 21.2 µg/L at inshore bottom depths in May (Table 2.1). However, further analysis clearly showed that the highest chlorophyll values tended to occur in the middle of the water column each season (Appendix A.9). These results reflect the fact that phytoplankton tend to mass at the bottom of the pycnocline where nutrient levels are greatest. The highest concentrations of chlorophyll for 2009 occurred during May at mid-depths across much of the region (see Appendix A.9B) and corresponded to the largest phytoplankton bloom observed by remote sensing for the year (Svejkovsky 2010), as well as the coastal upwelling event indicated by the very low temperatures, high salinity and low DO values at bottom depths described above. The relationship between coastal upwelling and subsequent plankton blooms has been well documented by remote sensing imagery over the years (e.g., Svejkovsky 2009, 2010).

In addition to these region-wide mid-depth plankton blooms, relatively high chlorophyll *a* concentrations were apparent at the surface during May and August at the nearshore stations (i.e., along the 9-m depth contour) centered on the mouth of the Tijuana River (Appendix A.9B, C). These higher surface concentrations may be related to a localized

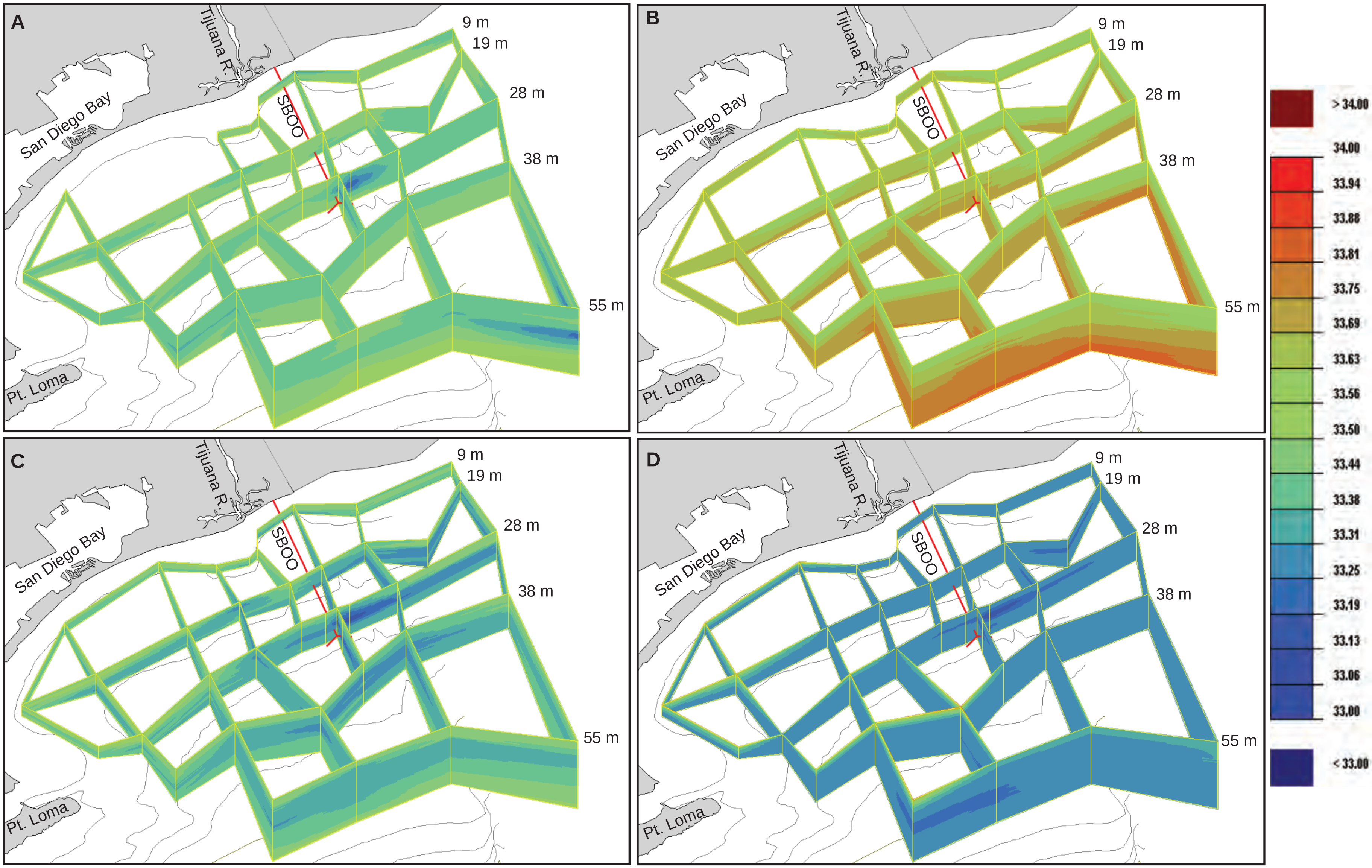

Figure 2.5

Levels of salinity (ppt) recorded in 2009 for the SBOO region during (A) February, (B) May, (C) August, and (D) November. Data are collected over three days during each of these monthly surveys; see Appendix A.1 for specific sample dates and stations sampled each day.

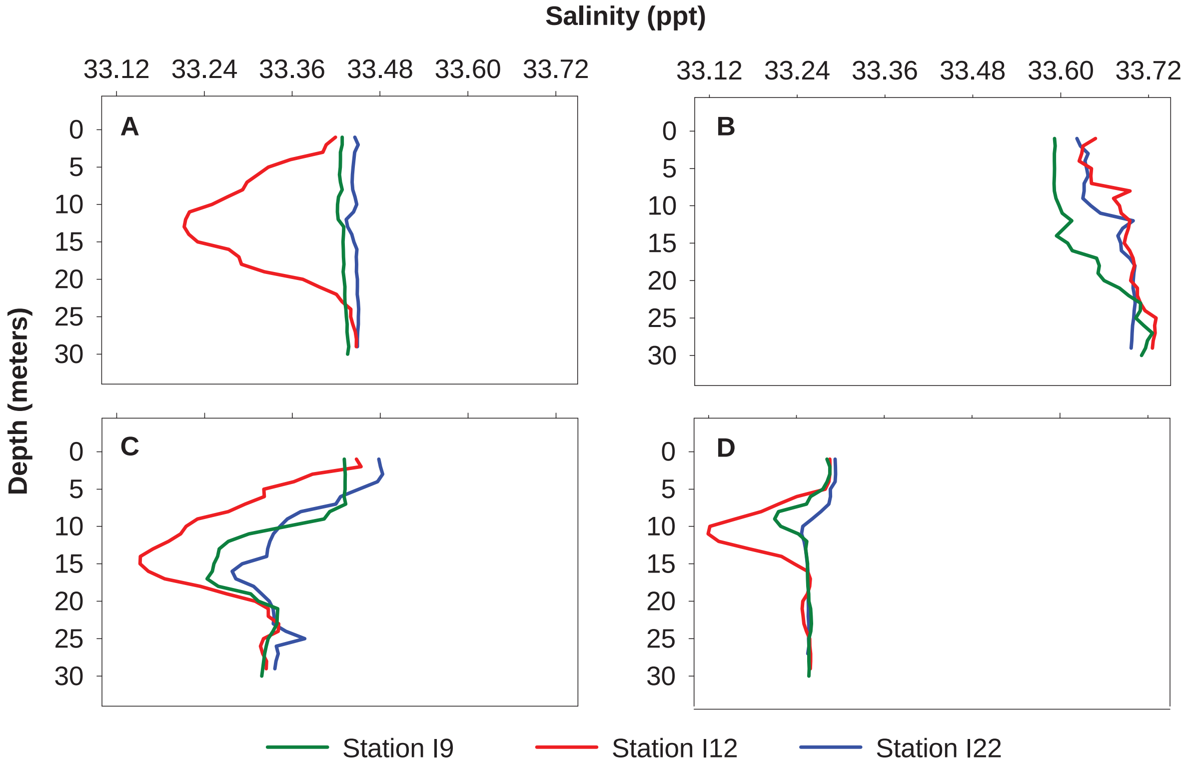

Figure 2.6
Vertical profiles of salinity for SBOO stations I9, I12 and I22 during February (A), May (B), August (C), and November (D) 2009.

phytoplankton bloom in that area depicted in a Landsat TM5 image taken in September (Figure 2.7); a water sample collected on September 16 at station I19 showed a mix of the dinoflagellates *Ceratium* sp and *Lingulodinium polyedrum*. Localized blooms like this are less likely related to nutrient rich waters brought into the area by upwelling, but instead are more likely influenced by the outflow of nutrients with river water that can also stimulate phytoplankton growth (see Gregorio and Pieper 2000).

Historical Assessment of Oceanographic Conditions

A review of oceanographic data between 1995 and 2009 using three representative stations along the 28-m depth contour (i.e., I9, I12, I22) did not reveal any measurable impact that could be attributed to the beginning of wastewater discharge via the SBOO (Figure 2.8). Instead, these data tend to track changes in large scale patterns in the California Current System (CCS) observed by CalCOFI (see Peterson et al. 2006, McClatchie et al. 2008, 2009). For example, five major events have affected the CCS during the last decade: (1) the 1997–1998 El Niño; (2) a shift to cold ocean conditions between 1999–2002; (3) a more subtle but persistent return to warm ocean conditions beginning in October 2002; (4) intrusion of subarctic surface waters resulting in lower than normal salinities during 2002–2004; (5) development of a moderate to strong La Niña in 2007 in conjunction with a cooling of the Pacific Decadal Oscillation (PDO). Temperature and salinity data for the South Bay region are consistent with all but the third of these CCS events; i.e., while the CCS was experiencing a warming trend starting in 2002, the SBOO region experienced cooler than normal conditions during 2005 and 2006. The conditions in southern San Diego waters during these two years were more consistent with observations from northern Baja California (Mexico) where water temperatures were well below the decadal mean (Peterson et al. 2006). During 2008 and 2009, temperatures remained cool, but closer to the overall average.

Water clarity (transmissivity) has generally increased in the South Bay region since 1999, although there have been several intermittent

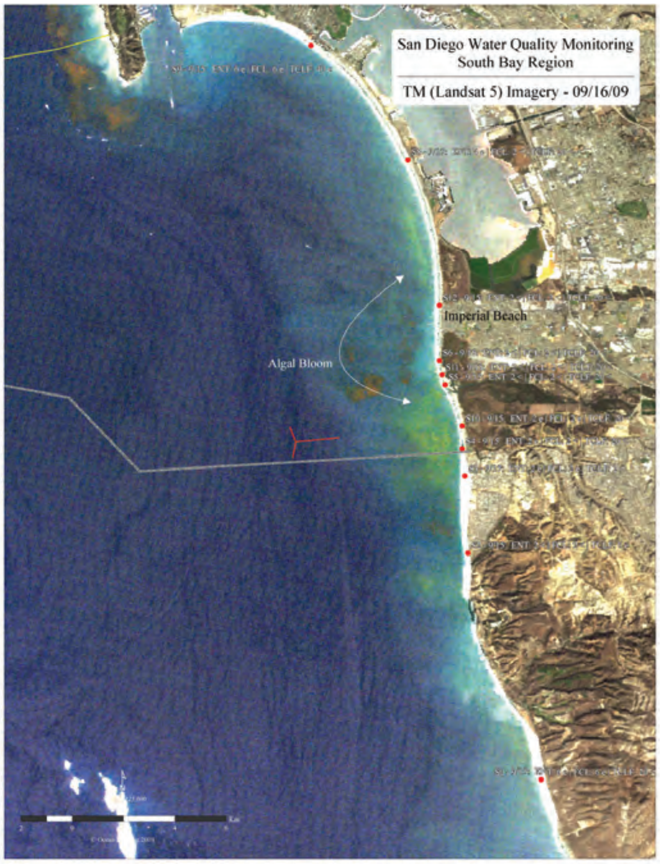

Figure 2.7
Landsat TM5 image of the SBOO outfall and coastal region acquired on September 16, 2009, depicting a localized phytoplankton bloom near the mouth of the Tijuana River (from Ocean Imaging 2010).

periods when clarity was below normal (Figure 2.8). Transmissivity was much lower than normal during the winter months of several years (e.g., 1998, 2000); these periods of low transmissivity are likely due to increased suspension of sediments caused by strong storm activity (see NOAA/NWS 2010). In addition, below average water clarity events that occur in the spring and early summer months are probably related to plankton blooms such as those observed throughout the region in 2005, 2008 and 2009 (see City of San Diego 2006, 2009, and the discussion in the previous section). In contrast, water clarity during 2006 and 2007 was mostly above the historical average. These latter results are indicative of reduced turbidity due to decreased storm activity and lower rainfall totals of less than 11 inches for these two years.

There were no apparent trends in DO concentrations or pH values related to the SBOO discharge (Figure 2.8). These parameters are complex, dependent on water temperature and depth, and sensitive to physico-chemical and biological processes (Skirrow 1975). Moreover, DO and pH are subject to diurnal and seasonal variations that make temporal changes difficult to evaluate. However, DO values below the historical average appear to be related to low levels of chlorophyll or strong upwelling periods.

Summary and Conclusions

The South Bay outfall region was characterized by relatively normal oceanographic conditions in 2009, which included coastal upwelling and corresponding phytoplankton blooms that were strongest during the spring and occurred across the entire region. Upwelling was indicated by relatively cold, dense, saline waters with low DO levels. Plankton blooms were indicated by high chlorophyll concentrations and confirmed by remote sensing observations (i.e., aerial and satellite imagery). Additionally, water column stratification followed typical patterns for the San Diego region, with maximum stratification occurring in mid-summer and reduced stratification during the winter. Further, oceanographic conditions for the region remained notably consistent with changes in large scale patterns observed by CalCOFI (e.g., Peterson et al. 2006, Goericke et al. 2007, McClatchie et al. 2008, 2009), or they were consistent with data from northern Baja California (e.g., Peterson et al. 2006). These observations suggest that other factors such as upwelling of deep offshore waters and large-scale oceanographic events (e.g., El Niño, La Niña) continue to explain most of the temporal and spatial variability observed in water quality parameters off southern San Diego.

As expected, satellite and aerial imagery detected the signature of the SBOO wastewater plume in near-surface waters above the discharge site on several occasions between January–March and November–December when the water column was well mixed (Svejkovsky 2010). In contrast, the plume appeared to remain deeply submerged between April–October when the water column was stratified. Results from

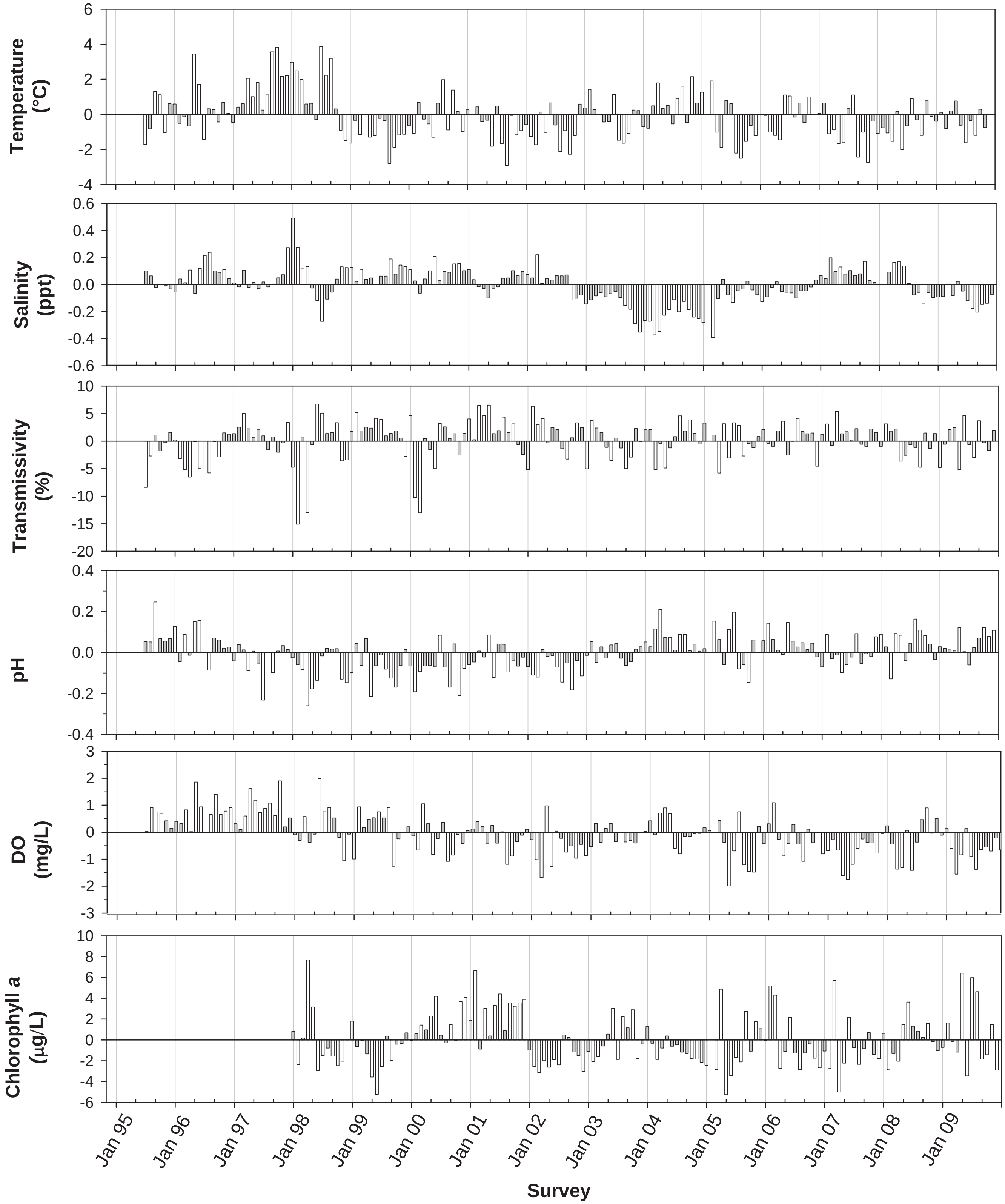

Figure 2.8
Time series of temperature, salinity, transmissivity, pH, dissolved oxygen (DO), and chlorophyll anomalies between 1995 and 2009. Anomalies were calculated by subtracting the monthly means for each year (1995–2009) from the mean of all years combined; data were limited to stations I9, I12, and I22, all depths combined.

bacteriological surveys further support the conclusion that the plume reached surface or near-surface waters only during the winter months when the water column was well-mixed (see Chapter 3). In addition, historical analysis of remote sensing observations made between 2003 and 2009 suggest that the wastewater plume from the SBOO has never reached the shoreline (Svejkovsky 2010). These findings were supported this past year by the application of new IGODS analytical techniques to the oceanographic data collected by the City's ocean monitoring program. While small differences were observed at stations close to the outfall discharge site, it was clear from these analyses that any variations among stations at any particular depth were very slight and highly localized.

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