Chapter 2. Oceanographic Conditions

Introduction

The City of San Diego monitors oceanographic conditions in the region surrounding the Point Loma Ocean Outfall (PLOO) to assist in evaluating possible impacts of wastewater discharge on the local marine environment. Measurements of water temperature, salinity, density, light transmittance (transmissivity), dissolved oxygen, pH, and 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 affect 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 coastal waters such as the Point Loma monitoring region, oceanographic conditions are strongly influenced by seasonal changes (Bowden 1975, Skirrow 1975, Pickard and Emery 1990). In southern California for example, differences between the typical wet, winter months (e.g., December–February) and dry, summer months (e.g., July–September) can affect water column mixing (horizontal and vertical), degree and depth of stratification, and current patterns. Consequently, events such as strong winter storms often bring higher winds, rain and waves, which in turn contribute to the formation of a well-mixed, and relatively homogenous (non-stratified) water column (Jackson 1986). Additionally, changes in ocean currents and the movement of water masses in and out of a study area can affect mixing conditions. The chance that wastewater plumes from sources such as the PLOO may surface is highest when the water column is well mixed and there is little, if any, stratification. In contrast, the likelihood of the plume surfacing decreases as the water column becomes more stratified such as during late spring through early fall.

Understanding changes in oceanographic conditions due to natural processes like seasonal patterns and shifting current regimes is important since they can affect the transport and distribution of wastewater, storm water and other types of sediment or contaminant plumes. In the Point Loma region such processes include tidal exchange from local bays, outflows from major rivers, lagoons and estuaries, discharges from storm drains or other point sources, surface water runoff from local watersheds, seasonal upwelling and changing ocean currents or eddies. 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 turbidity plumes in nearshore waters, sediment deposition, and bacterial contamination (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 main oceanographic conditions present in the Point Loma region during 2010 and compares these patterns to historical data. 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 2011). 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 PLOO discharge site.

In addition to the above, a multi-phase project is currently underway to examine the dynamics and strength of the thermocline and ocean currents off Point Loma, as well as the dispersion behavior of the PLOO wastewater plume using a combination of current meters (ADCPs), thermistor strings, and automated underwater vehicles (AUVs) (see Storms et al. 2006, Dayton et al. 2009, Parnell and Rasmussen 2010). Some initial results from this project are incorporated herein (e.g., ADCP current measurements and thermistor data from 2010), while others will be included in future reports as they become available. Finally, the oceanographic results reported in this chapter are also referred to in Chapters 3–7 to help explain patterns in the distribution of indicator bacteria in the coastal waters off Point Loma, as well as other changes in the local marine environment.

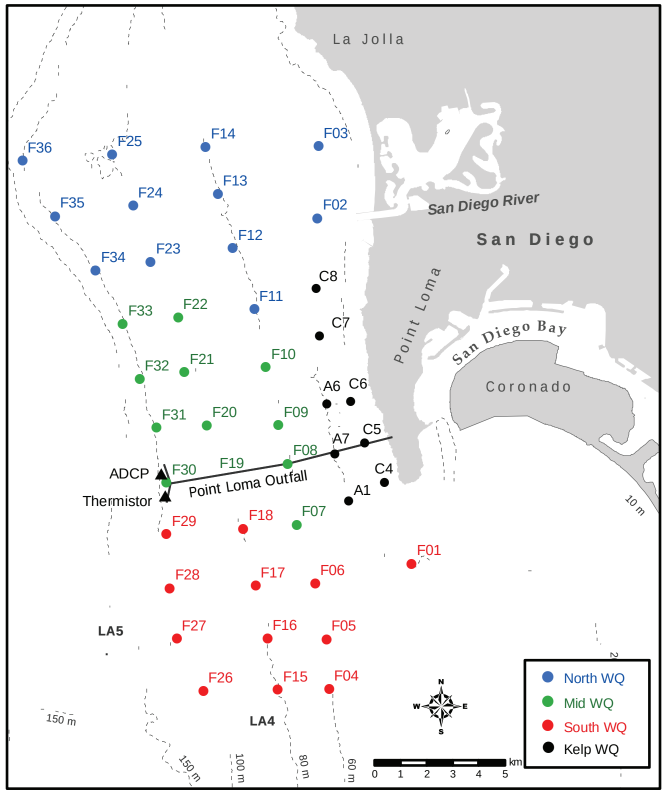

Figure 2.1
Locations of moored instruments (i.e., ADCP, thermistor) and water quality monitoring stations where CTD casts are taken, Point Loma Ocean Outfall Monitoring Program.

Materials and Methods

Field Sampling

Oceanographic measurements were taken at a total of 44 stations encompassing an area of ~146 km^2 surrounding the PLOO (Figure 2.1). This includes 36 offshore stations (F01–F36) located between ~1.7–10.2 km offshore of Point Loma along or adjacent to the 18, 60, 80 and 98-m depth contours, and eight kelp bed stations (A1, A6, A7, C4–C8) distributed along the inner (9 m) and outer (18 m) edges of the Point Loma kelp forest as described in Chapter 3. Monitoring at the offshore stations occurs quarterly, typically during the months of February, May, August and November in order to correspond to similar sampling for the Central Bight Regional Water Quality Monitoring Program conducted off Orange County, Los Angeles County, and Ventura County. However, sampling during the first quarter of 2010 was postponed until March to accommodate another Bight'08 related water quality project.

For sampling and analysis purposes, the above quarterly water quality monitoring sites are organized into northern (North WQ), mid-region (Mid-WQ), and southern (South WQ) groups, with each group composed of 12 stations: (a) North WQ = stations F02, F03, F11–F14, F23–F25, and F34–F36; (b) Mid-WQ = stations F07–F10, F19–F22, and F30–F33; (c) South WQ = stations F01, F04–F06, F15–F18, and F26–F29. All stations within each of these three groups are sampled on a single day during each quarterly survey. In addition, sampling at the eight kelp bed (Kelp WQ) stations is conducted five times per month to meet monitoring requirements for fecal indicator bacteria (see Chapter 3); however, only Kelp WQ data collected within about 1–2 days of the above quarterly stations are analyzed in this chapter.

In order to minimize differences between oceanographic parameters reflecting large-scale changes in water masses, the above four station groups are sampled as close together as possible, which typically occurs over 4–5 days. However, due to poor weather conditions, the March 2010 survey spanned a 12-day period, with one week occurring between the Mid-WQ station group survey and those of the other three groups (see

Table 2.1). Consequently, data for the March survey should be interpreted with caution as differences in oceanographic parameters may be due to temporal changes in water masses rather than spatial differences between sites.

Data for the various oceanographic parameters were collected using a SeaBird CTD (conductivity, temperature, and depth) instrument. The CTD was lowered through the water column at each station at a continuous rate to collect 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 averaging ensured that physical measurements used in subsequent analyses would correspond to discrete sampling depths for fecal indicator bacteria (see Chapter 3). Visual observations of weather and water conditions were recorded just prior to each CTD cast.

Moored Instruments

Moored instruments, including current meters (ADCPs: Acoustic Doppler Current Profilers) and vertical arrays of temperature sensors (thermistors) were deployed at two primary locations off Point Loma in order to provide continuous measurements of ocean currents and water temperatures for the area. These included one site near the present PLOO discharge site at a depth of about 100 m, and one site located south of the outfall along the 60-m depth contour.

Ocean current data were collected using one ADCP moored at each of the above sites throughout 2010. The ADCP data were collected every five minutes and then averaged into 25 depth bins of 4 m each. The depth bins used for this analysis ranged from 5 to 93 m. Additional details for processing and analyzing the ADCP data are presented below under "Data Treatment and Analysis". Only data from the 100-m contour were used in the initial analysis included herein.

Temperature data were collected every 10 minutes throughout 2010 from thermistor strings located at the 100-m and 60-m mooring sites. The individual thermistors (Onset Tidbit temperature loggers) were deployed on mooring lines at each site starting at 2 m off the seafloor and extending in series every 4 m to within 6 m of the surface. Occasional gaps exist in the time series where individual thermistors were lost at sea or failed to record data properly. As with the ADCP data, only thermistor data from the 100-m contour site were analyzed for this report. Further details on specific methodology are available in Storms et al. (2006).

Remote Sensing – Aerial and Satellite Imagery

Coastal monitoring of the PLOO region during 2010 included remote imaging analyses performed by Ocean Imaging (OI) of Solana Beach, CA. All satellite and aerial imaging data collected during the year are made available for review and download from OI's website (Ocean Imaging 2011), while a separate annual report to summarize these data is also produced (Svejkovsky 2011). This chapter includes examples of Rapid Eye satellite imagery. Examples of multispectral color imagery from OI's DMSC-MKII aerial sensor and thermal infrared (IR) imagery from a Jenoptik thermal imager integrated into the system are also included. These technologies differ in terms of their resolution, frequency of collection, depth of penetration, and detection capabilities as described in the "Technology Overview" section of Svejkovsky (2011).

Data Treatment and Analysis

Data for the various oceanographic parameters measured off Point Loma in 2010 were analyzed in several different ways, including: (a) calculation of basic descriptive metrics by depth; (b) spatial analysis using Interactive Geographical Ocean Data System (IGODS) software; (c) comparison of long-term anomalies for each parameter since pre-discharge monitoring began in 1991. Each of the water column parameters measured in 2010 were summarized as monthly means of both surface waters (top 2 m) and bottom waters (bottom 2 m)

Table 2.1
Sample dates for quarterly oceanographic surveys conducted off Point Loma during 2010. Each survey was conducted over four days, with all stations in each station group sampled on a single day (see text and Figure 2.1 for list of stations and station locations). Survey Span = number of days between first and last day of sampling for each survey.

	2010 Quarterly Survey Dates			
Station Group	**March**	**May**	**August**	**November**
North WQ	2 Mar 10	5 May 10	9 Aug 10	2 Nov 10
Mid-WQ	12 Mar 10	6 May 10	12 Aug 10	3 Nov 10
South WQ	1 Mar 10	4 May 10	11 Aug 10	4 Nov 10
Kelp WQ	5 Mar 10	7 May 10	13 Aug 10	6 Nov 10
Survey Span	*12 days*	*4 days*	*5 days*	*5 days*

over all stations located along the 9, 18, 60, 80, and 98-m depth contours to provide an overview of trends across depth throughout the region. For spatial analysis, 3-dimensional graphical views were created using IGODS software, which uses a linear interpolation between stations and with depth at each site. Additional analysis included vertical profiles using the 1-m binned data for each parameter plotted using IGODS, but limited to a subset of seven of the 98-m stations (i.e., F27–F33). 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 off Point Loma between 1991 and 2010. These anomalies were calculated by subtracting the monthly means for each year from the mean of all 20 years combined. These values were calculated using data from all stations located along the 98-m depth contour with all depths combined.

Because ocean currents often vary by season, the ADCP-derived current data were divided into four seasons prior to conducting subsequent analyses, including: (a) winter (December, January, February); (b) spring (March, April, May); (c) summer (June, July, August); (d) fall (September, October, November). Although the winter period includes non-continuous months (i.e., January–February vs. December), preliminary analysis suggested that the current regimes for these three months were similar enough to justify pooling them together for this year's analysis. Since tidal currents are predictable and not likely to result in a net flow of water in a particular direction, tides were filtered prior to any data visualization or analysis using the PL33 filter developed by C. Flagg and R. Beardsley (Alessi et al. 1984). In order to visualize raw current data with tides removed on a seasonal basis (tide-removed data), current data were averaged by hour and plotted for four representative depth bins on compass plots; these mid-bin depths were 11 m, 35 m, 63 m and 91 m. In order to examine modes of currents that were present each season, an empirical orthogonal function (EOF) analysis was completed by singular value decomposition in MATLAB. Each current mode was plotted on compass plots for the same depth bins as tide-removed data. Although dominant physical processes are likely to be present in the first few EOFs, there is not always exact correspondence between EOFs and physical modes. Consequently, visualization of tide-removed data was used to assist in EOF interpretation. In all seasons, the first two EOFs described >97% of the total variability.

Results

Oceanographic Conditions in 2010

Water temperature and density

Seawater density is determined by temperature, salinity and pressure. In the shallower coastal waters of southern California and elsewhere, density is

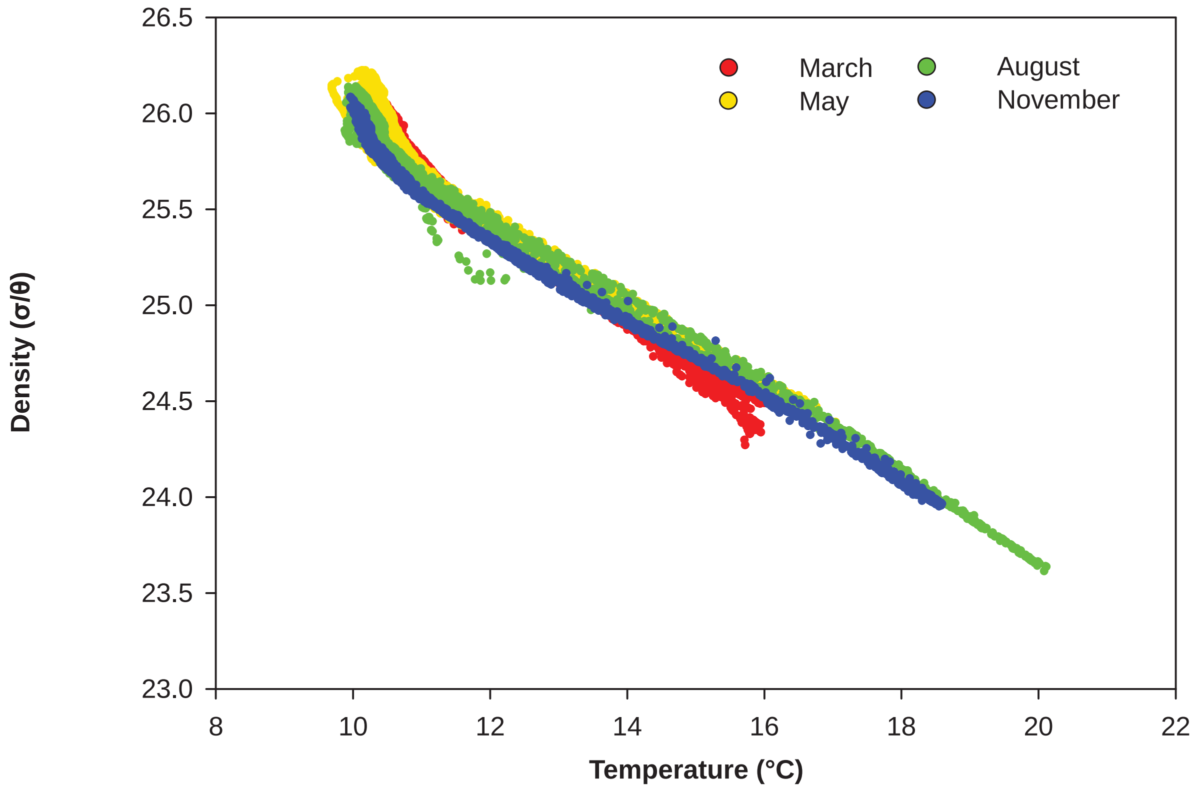

Figure 2.2
Scatterplot of temperature and density for PLOO stations sampled in 2010. Pearson correlation coefficient $r(11,619) = 0.98$, $p < 0.001$.

influenced primarily by temperature differences since salinity is relatively uniform (Bowden 1975, Jackson 1986, Pickard and Emery 1990). Because of such a strong correlation between temperature and density off Point Loma in 2010 (Figure 2.2), the results discussed below for temperature can be assumed to also apply to density with the exception of the following slight deviations in March and August. Based on temperature data for example, seawater was less dense than expected in surface waters during March (Appendix A.1), which may be due to freshwater runoff associated with rainfall that occurred during the previous month. In addition, temperatures were lower than expected in August at mid- and bottom-depths of a few offshore stations, although the reason for this pattern is unknown.

Thermistor data from the 100-m mooring showed typical seasonal variations with a well-mixed water column during the winter (January–February, December) and a warmer surface layer with a shallower thermocline during the spring to fall months, punctuated by upwelling and cooling events (Figure 2.3). Using CTD data from all stations in 2010, mean surface temperatures across the entire Point Loma monitoring region ranged from 15.1°C in March to 19.7°C in August, while bottom temperatures ranged from 10.0°C in August to 16.0°C in November (Table 2.2). Although the offshore data are limited to only four surveys per year, ocean temperatures appeared to vary by season as expected, with no discernable patterns relative to wastewater discharge (Figures 2.4, 2.5). For example, the lowest temperatures of the year tended to occur during May and August at bottom depths, which probably reflect spring and summer upwelling in the region. Thermal stratification also followed expected seasonal patterns, with the greatest difference between surface and bottom waters (almost 10°C) occurring during the summer (i.e., August). 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

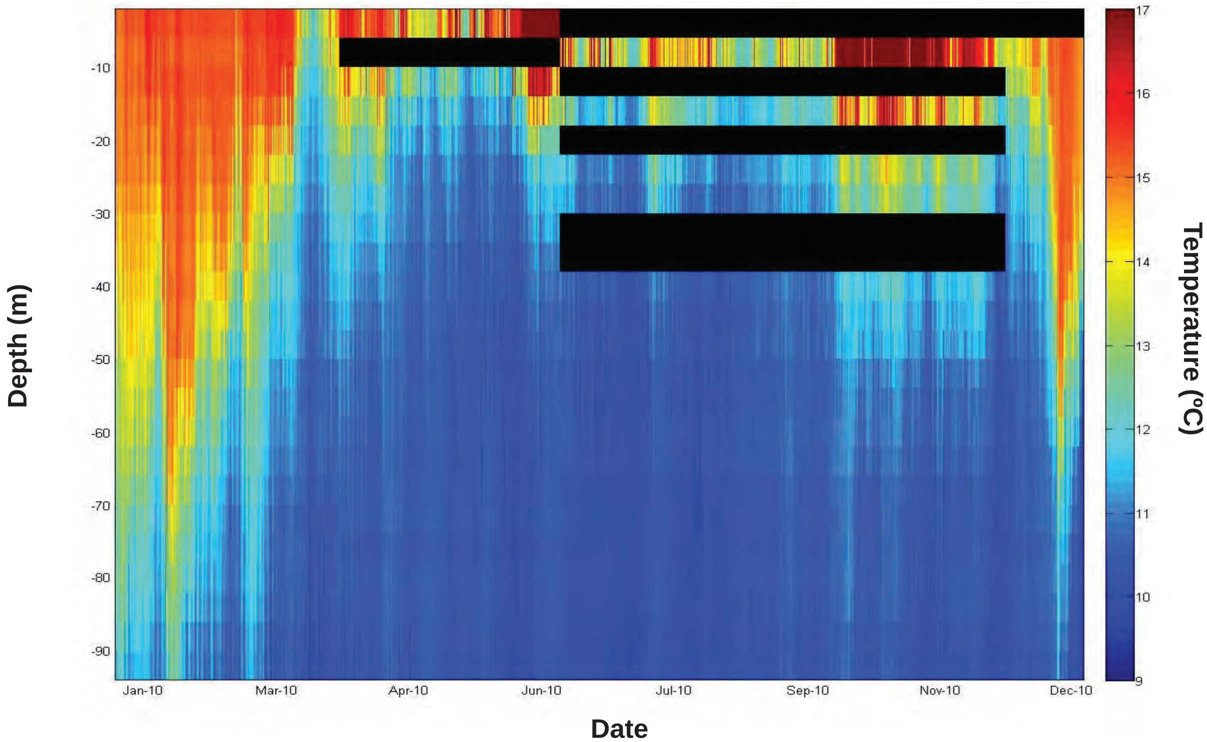

Figure 2.3

Temperature data collected at the 100-m thermistor site between January and December 2010. Data were collected every 10 minutes. Missing data are the result individual thermistors that were lost at sea or malfunctioning.

temperatures are important to limiting the surface potential of the wastefield throughout the year. Moreover, the wastewater plume from the PLOO was not visible in surface waters at any time during the year based on remote sensing observations (e.g., Figure 2.6; Svejkovsky 2011) or the results of discrete bacteriological samples (see Chapter 3).

In addition to region-wide phenomena such as upwelling seasonal changes in water column stratification, water temperatures varied among stations during each of the quarterly surveys conducted in 2010. For example, such differences were especially evident during the March survey, although this may have been because the four days of this survey were spread over 12 days instead of the usual 4–5 days due to poor weather (see Table 2.1). Consequently, differences between sampling sites in March were likely due to changes in oceanographic parameters associated with different water masses (Figures 2.4, 2.5).

Salinity

Average salinities for the region in 2010 ranged from a low of 33.2 psu in March to a high of 33.54 psu in May and August for surface waters, and from 33.29 psu in March to 34.07 psu in May at bottom depths (Table 2.2). As with ocean temperatures, salinity appeared to vary by season, with no discernable patterns relative to wastewater discharge (Figures 2.7, 2.8). The highest salinity values recorded during the year occurred at bottom depths during May and August and corresponded to the lower temperatures found in bottom waters as described above. Together these factors are indicative of coastal upwelling that is typical for spring and summer months (Jackson 1986). There was some evidence of another region-wide phenomenon that occurred during August and November (and in May to a lesser degree), when a layer of water with relatively low salinity values occurred at mid-water or “sub-surface” depths between about 10–40 m. It seems unlikely that this sub-surface salinity minimum (SSM) could be due to wastewater discharge from the PLOO for two reasons. First, seawater samples collected at the same depths and times did not contain elevated levels of indicator bacteria (see Chapter 3). Second, similar SSMs have been reported previously off San Diego and elsewhere

Table 2.2

Summary of temperature, salinity, dissolved oxygen, pH, transmissivity, and chlorophyll *a* for surface and bottom waters in the PLOO region during 2010. Values are expressed as means for each survey pooled over all stations along each depth contour.

		Mar	May	Aug	Nov
Temperature (^oC)					
9-m	Surface	15.1	16.6	17.5	17.2
	Bottom	14.2	14.4	12.0	16.0
18-m	Surface	15.6	15.8	17.5	17.5
	Bottom	13.3	11.5	11.3	13.0
60-m	Surface	15.4	15.4	17.8	18.1
	Bottom	11.0	10.5	10.4	10.6
80-m	Surface	15.5	15.7	18.9	18.3
	Bottom	10.8	10.3	10.2	10.3
98-m	Surface	15.5	15.6	19.7	18.4
	Bottom	10.5	10.2	10.0	10.1
Salinity (psu)					
9-m	Surface	33.22	33.54	33.54	33.42
	Bottom	33.29	33.53	33.47	33.40
18-m	Surface	33.20	33.48	33.52	33.41
	Bottom	33.40	33.60	33.42	33.38
60-m	Surface	33.22	33.47	33.53	33.43
	Bottom	33.68	33.94	33.77	33.54
80-m	Surface	33.32	33.46	33.52	33.44
	Bottom	33.77	34.02	33.88	33.66
98-m	Surface	33.35	33.43	33.53	33.46
	Bottom	33.84	34.07	33.93	33.77
Dissolved Oxygen (mg/L)					
9-m	Surface	7.8	9.7	8.9	8.3
	Bottom	7.0	7.2	5.4	6.8
18-m	Surface	8.3	10.1	9.0	7.9
	Bottom	6.1	4.8	5.3	5.8
60-m	Surface	8.2	10.0	9.2	8.1
	Bottom	4.2	2.6	3.4	4.8
80-m	Surface	8.0	10.0	8.8	8.0
	Bottom	3.9	2.6	3.1	4.2
98-m	Surface	8.0	9.3	8.3	7.8
	Bottom	3.8	2.4	3.0	3.9

		Mar	May	Aug	Nov
pH					
9-m	Surface	8.2	8.3	8.3	8.4
	Bottom	8.1	8.1	7.9	8.3
18-m	Surface	8.2	8.3	8.3	8.3
	Bottom	8.0	7.9	7.9	8.0
60-m	Surface	8.2	8.3	8.3	8.2
	Bottom	7.8	7.7	7.8	7.8
80-m	Surface	8.2	8.3	8.3	8.2
	Bottom	7.8	7.7	7.8	7.8
98-m	Surface	8.2	8.3	8.3	8.2
	Bottom	7.8	7.7	7.8	7.7
Transmissivity (%)					
9-m	Surface	61	72	79	77
	Bottom	61	77	82	67
18-m	Surface	68	71	78	80
	Bottom	67	82	79	78
60-m	Surface	78	78	79	88
	Bottom	73	76	84	80
80-m	Surface	84	78	82	89
	Bottom	78	85	86	84
98-m	Surface	87	83	84	89
	Bottom	86	89	88	89
Chlorophyll *a* (µg/L)					
9-m	Surface	4.0	12.5	7.4	3.9
	Bottom	2.6	3.3	5.3	5.9
18-m	Surface	5.5	17.3	9.0	3.7
	Bottom	2.7	7.6	17.1	3.5
60-m	Surface	2.8	9.3	6.9	2.0
	Bottom	0.8	6.2	2.6	1.1
80-m	Surface	1.8	7.7	2.8	1.7
	Bottom	0.4	3.0	1.0	0.6
98-m	Surface	1.6	4.2	2.0	1.6
	Bottom	0.4	0.6	0.8	0.5

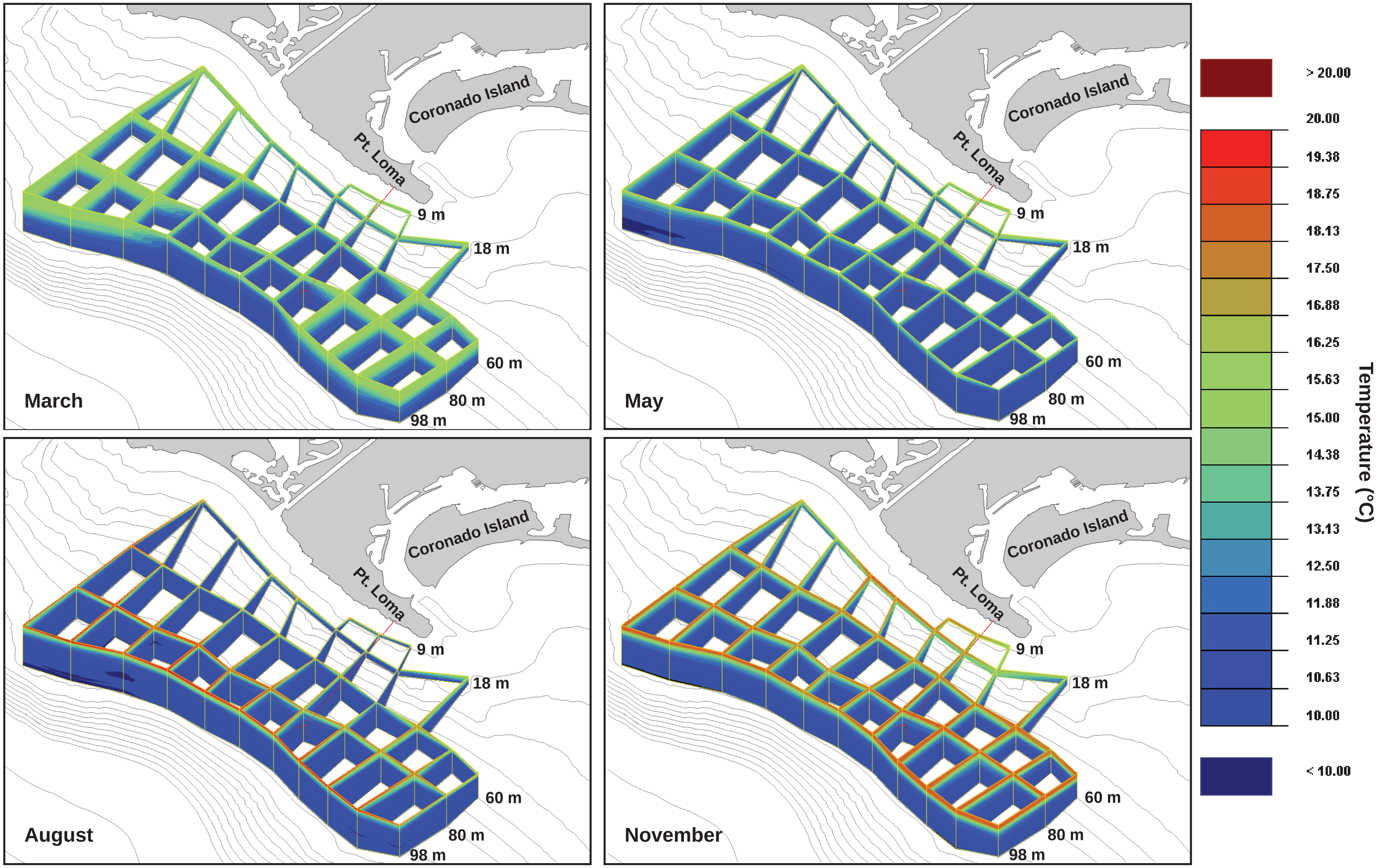

Figure 2.4
Ocean temperatures recorded in 2010 for the PLOO region. Data are collected over four days during each of these quarterly surveys; see Table 2.1 and text for specific sample dates and stations sampled each day.

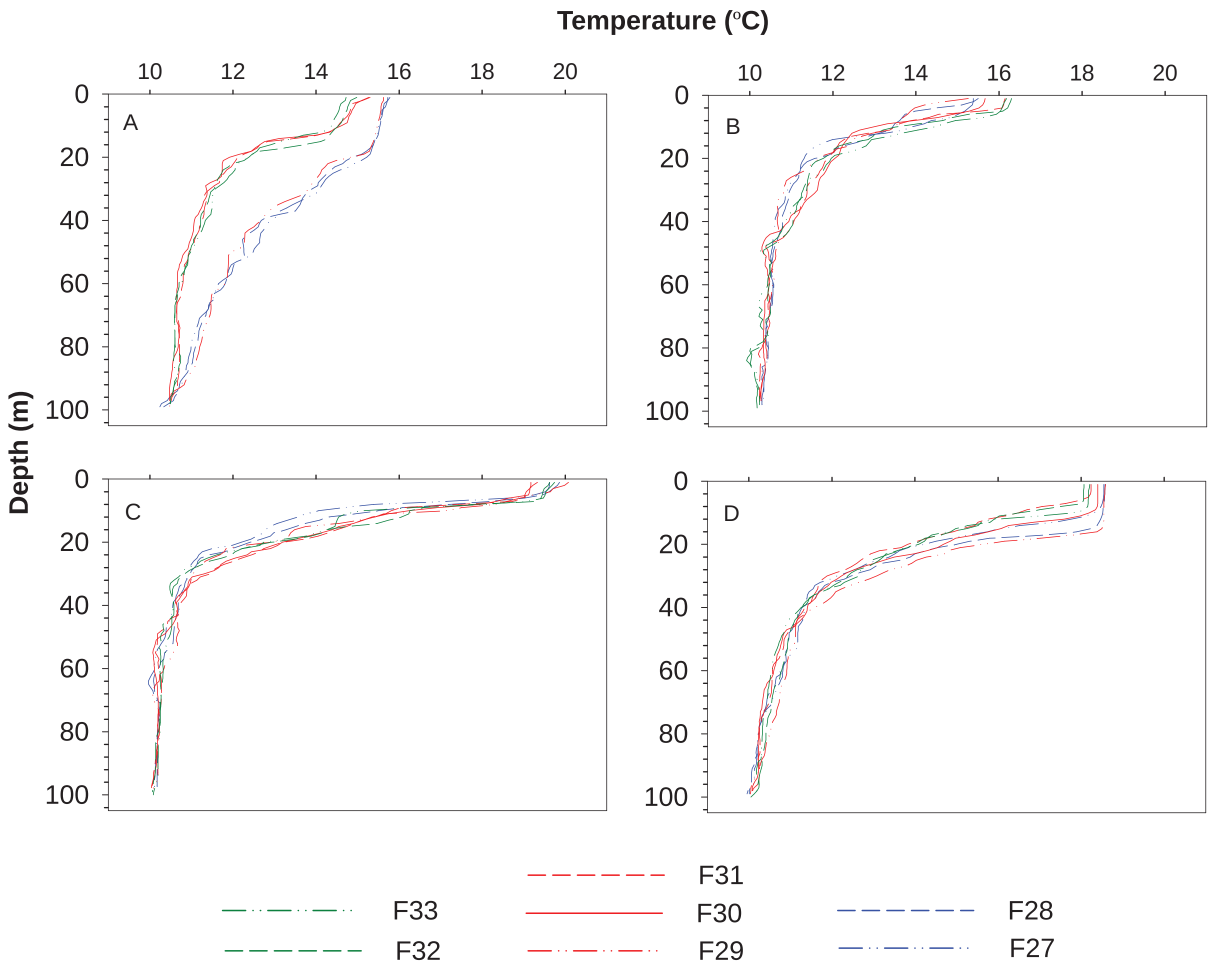

Figure 2.5
Vertical profiles of ocean temperature for PLOO stations F27–F33 during each 2010 quarterly survey.

in southern California, including: (a) the Point Loma monitoring region during the summer and fall of 2009 (City of San Diego 2010a); (b) the South Bay outfall monitoring region during 2009 and 2010 (City of San Diego 2010b, 2011); (c) coastal waters off Orange County, California for many years (e.g., OCSD 1999); (d) coastal waters extending as far north as Ventura, California (OCSD 2009). Further investigations are required to determine the possible source(s) of this phenomenon.

Dissolved oxygen and pH

Dissolved oxygen (DO) concentrations averaged from 7.8 to 10.1 mg/L in surface waters and from 2.4 to 7.2 mg/L in bottom waters across the Point Loma region in 2010, while mean pH values ranged from 8.2 to 8.4 in surface waters and from 7.7 to 8.3 in bottom waters (Table 2.2). 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 followed typical seasonal cycles for DO, with maximum differences between surface and bottom waters occurring in May (Table 2.2, Appendices A.2, A.3). Low DO concentrations at mid- and deeper depths during the spring and summer were likely related to cold, saline and oxygen poor waters moving inshore during periods of coastal upwelling as discussed previously for temperature and salinity. In contrast, very high DO values just below surface waters (i.e., at the thermocline) were likely associated with phytoplankton blooms as evident by high chlorophyll values at the same depths and surveys.

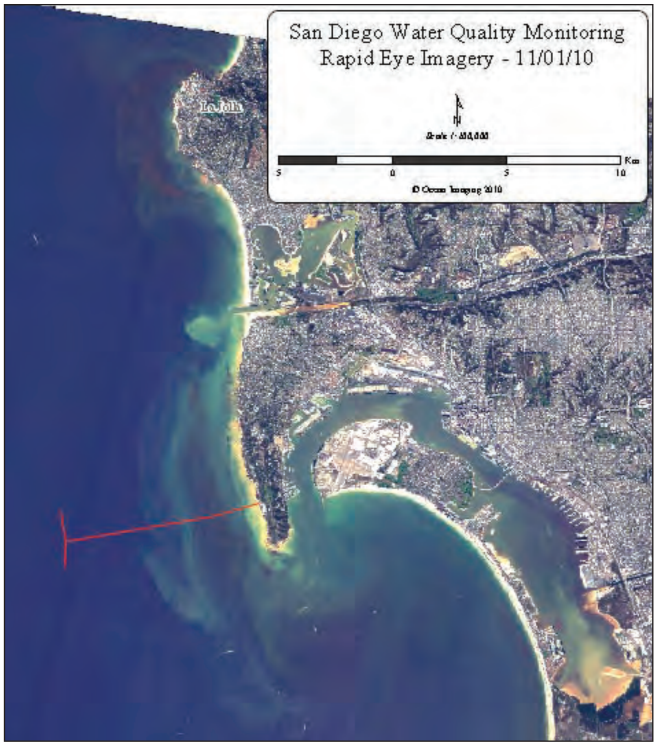

Figure 2.6
Rapid Eye satellite image of the Point Loma region acquired November 1, 2010 (Ocean Imaging 2011) showing typical clear water conditions over the PLOO with no visible evidence of the wastewater plume reaching surface waters.

Transmissivity
Water clarity appeared to vary within typical ranges for the PLOO region during 2010, with average transmissivity values between 61–89% in surface and bottom waters (Table 2.2). Transmissivity was consistently higher at the offshore sites than in inshore waters, by as much as 26% at the surface and 25% near the bottom. Reduced transmissivity at surface and mid-water depths tended to co-occur with peaks in chlorophyll concentrations associated with phytoplankton blooms (see Ocean Imaging 2011, Svejkovsky 2011, and Appendices A.4, A.5, A.6, A.7). Lower transmissivity during March and November at the stations located in inshore waters along the 9 and 18-m depth contours may also have been due to wave and storm activity and resultant increases in suspended sediment concentrations. In contrast, reductions in transmissivity that occurred offshore at depths >60 m were more likely associated with wastewater discharge from the PLOO. For example, reductions in water clarity at the three stations nearest the discharge site were most evident in March and May (Appendix A.5).

***Chlorophyll* a**
Mean chlorophyll concentrations across the PLOO region ranged from 0.4 µg/L near the bottom in March to 17.3 µg/L at the surface in May (Table 2.2). However, further analysis clearly showed that the highest chlorophyll values tended to occur at sub-surface depths (Appendices A.6, A.7). Although these results may reflect the presence of phytoplankton massing near the bottom of the thermocline where nutrient levels are high and light is not yet limiting, additional work is necessary to determine the thermocline boundaries off Point Loma in order to confirm this hypothesis. The highest concentrations of chlorophyll in 2010 were observed 10–20 m below the surface during May and August across much of the region, which corresponds to coastal upwelling indicated by the low water temperatures, high salinity, and low DO values at bottom depths as described previously. Additionally, high chlorophyll values in May corresponded to a phytoplankton bloom observed by remote sensing that extended across the entire region by the end of the month (Figure 2.9; also see Svejkovsky 2011). This relationship between coastal upwelling and plankton blooms has been well documented by remote sensing observations over the years (City of San Diego 2010b, 2011, Svejkovsky 2011).

Summary of Ocean Currents in 2010

Winter 2010
Tide-removed data plotted for winter 2010 show the highest magnitude ocean currents observed during 2010 (Figure 2.10A). The predominant current directions during January, February and December were north and south, but slightly skewed northwest and southeast in the 11, 35, and 91-m depth bins. The 91-m depth bin had its strongest currents in the north and south directions, but also had the lowest magnitude currents of all depth bins.

The first EOF explains 91.5% of the variability (Figure 2.11A). This EOF shows predominant

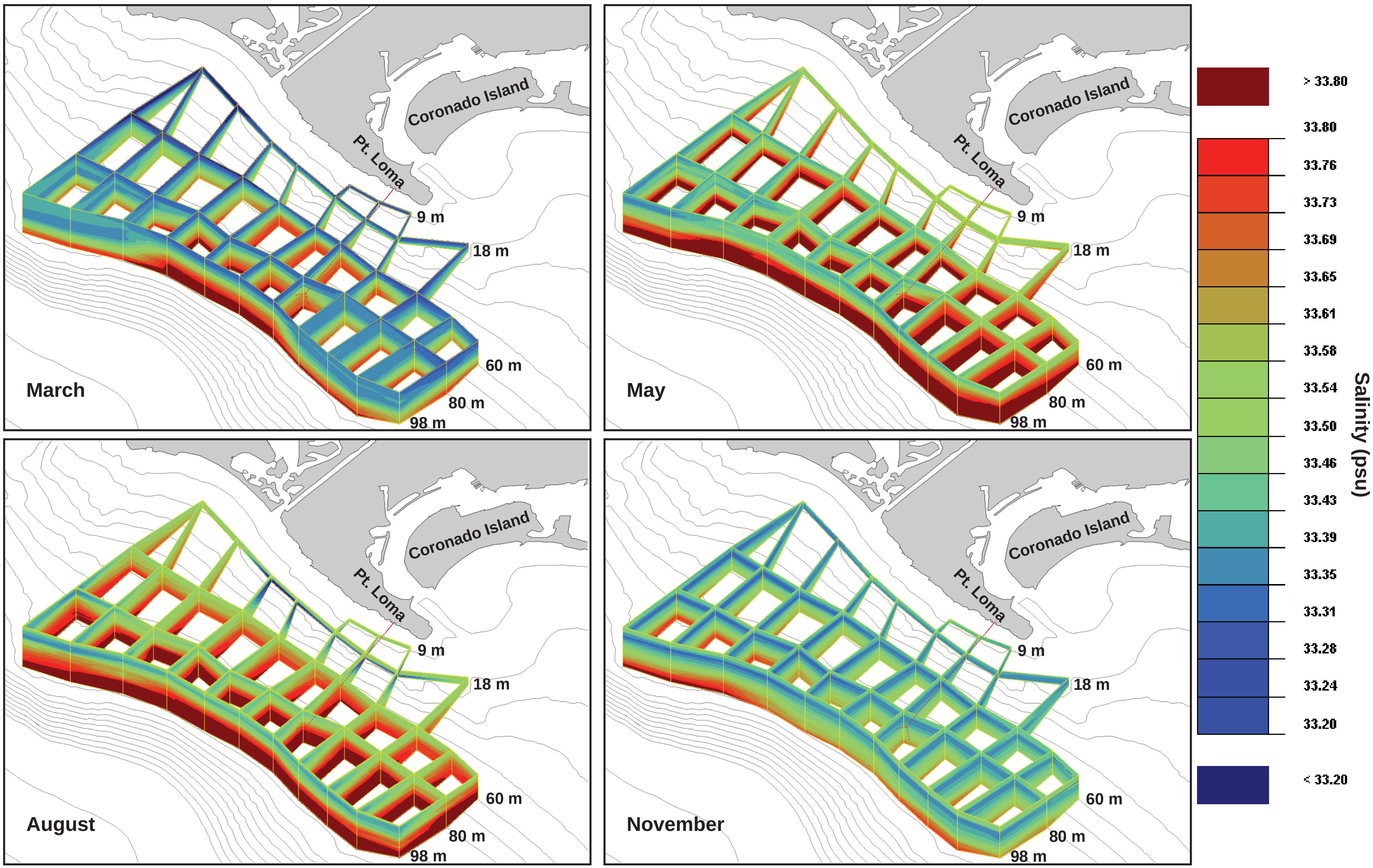

Figure 2.7
Levels of salinity recorded in 2010 for the PLOO region. Data are collected over four days during each of these quarterly surveys; see Table 2.1 and text for specific sample dates and stations sampled each day.

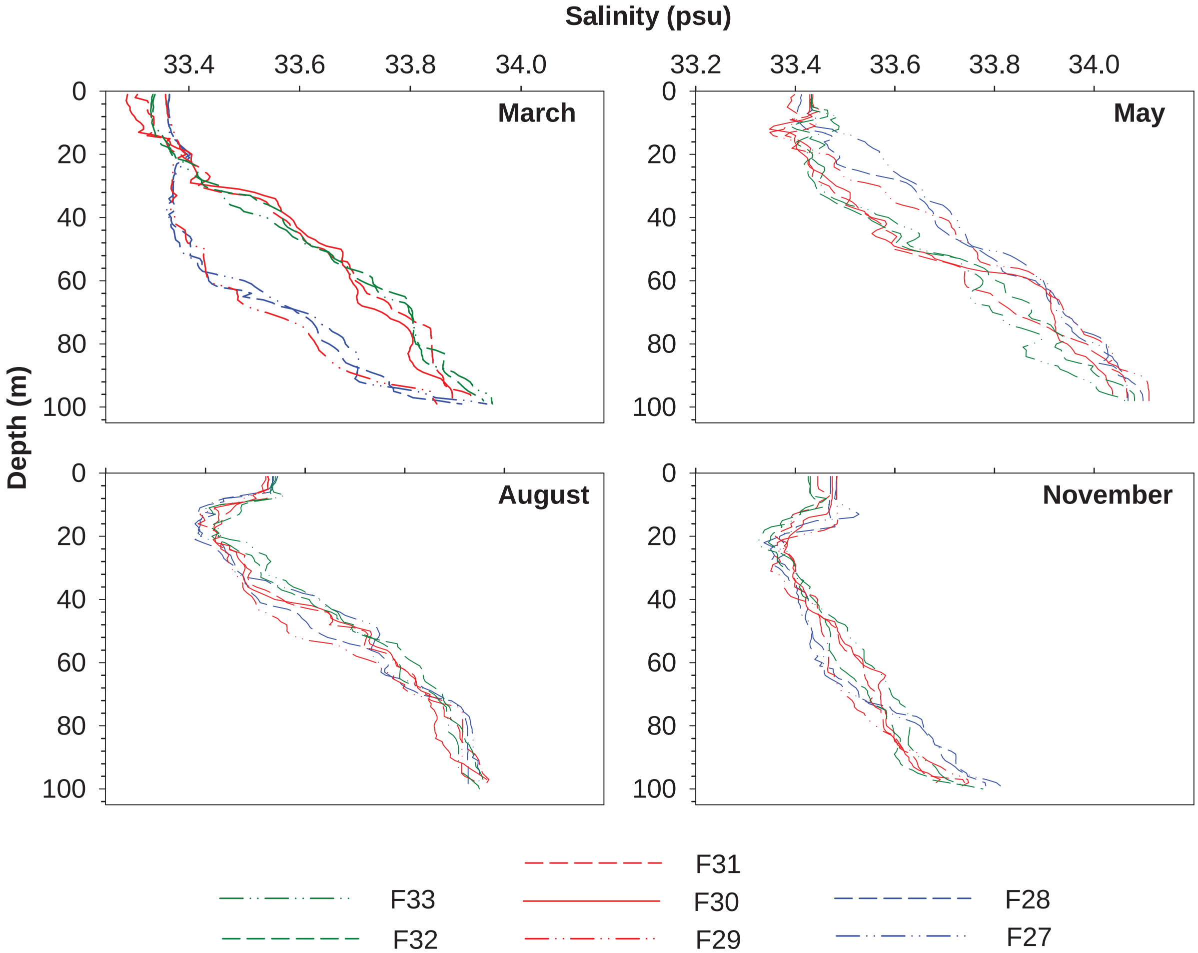

Figure 2.8
Vertical profiles of salinity for PLOO stations F27–F33 during each 2010 quarterly survey.

variability on the north-south axis for all depth bins, with the 11, 35, and 63-m depth bins skewed by a few degrees into the northwest-southeast axis. The 91-m depth bin shows most variability in the north-south axis with the lowest magnitude. The second EOF explains 6.4% of the variability (Appendix A.8A). Most variability is shown on the northwest-southeast axis for the 11, 35, and 68-m depth bins. Similar to the first EOF, the 91-m depth bin in the second EOF shows most variability along the north-south axis.

Spring 2010

Tide-removed data plotted for the spring months in 2010 showed high magnitude currents similar to that observed in winter (Figure 2.10B). The highest magnitude currents occurred in the 11 and 35-m depth bins in a southerly (slightly southeast) direction. However some north and northwest currents were also present in these two depth bins. The 63-m depth bin had lower magnitude currents compared to the 11 and 35-m depth bins, and these currents were in a northwest-southeast direction. The 91-m depth bin had low magnitude currents flowing in a north-south direction during the spring.

The first EOF explains 92.5% of the variability (Figure 2.11B) and shows predominant variability on the north-south axis for the 11, 35, and 63-m depth bins, and is slightly skewed to the northeast-southwest axis. The 91-m depth bin is low in magnitude along the north-south axis. The second EOF explains 6.1% of the variability

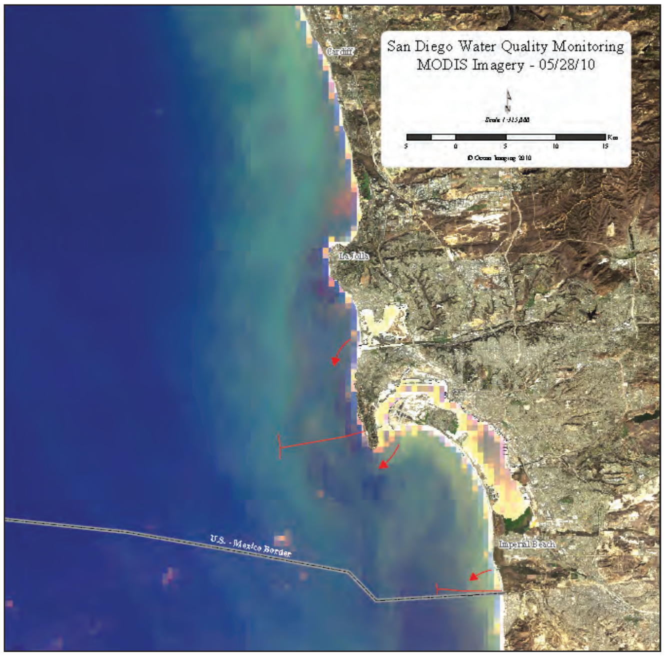

Figure 2.9

MODIS image of the PLOO and coastal region acquired on May 28, 2010, depicting extensive phytoplankton blooms in San Diego's nearshore waters (from Ocean Imaging 2011; see also Svejkovsky 2011).

(Appendix A.8B). Axes for the 11, 35, and 63-m depth bins are north-south, and slightly skewed northwest-southeast.

Summer 2010

Tide-removed data plotted for summer 2010 (Figure 2.10C) showed predominant south and southeast currents in the 11-m depth bin, with some north, northeast and northwest currents. The 35-m depth bin had lower magnitude north-south currents with some east currents. The 63-m depth bin had primarily north and northwest currents. The 91-m depth bin had the lowest magnitude, and its currents were primarily north and northeast.

The first EOF explains 84.8% of the variability (Figure 2.11C). In the 11 and 35-m depth bins, the predominant axis of variability is north-south and slightly in the northwest-southeast axis. Both the 63 and 91-m depth bins are much lower in magnitude. The 63-m depth bin has a southwest-northeast axis, while the 91-m depth bin has a north-south axis. The second EOF explains 14.3% of the variability (Appendix A.8C) and shows predominant variability on or very close to the north-south axis for all depth bins.

Fall 2010

Fall ocean currents were overall the slowest currents in 2010 (Figure 2.10D). Tide-removed data plotted for this season in the 11, 35, and 63-m depth bins showed that all currents were mostly moving in a north-south direction and slightly skewed into the northwest-southeast axis, although there were some smaller magnitude currents in other directions. The 91-m depth bin had most currents flowing north and south with some east currents.

The first EOF explains 77.9% of the variability (Figure 2.11D) and shows the most variability along the north-south axis for the 11 and 35-m depth bins, northeast-southwest axis for the 63-m depth bin, and north-south axis for the 91-m depth bin. The smallest magnitude currents were in the 91-m depth bin. The second EOF explains 19.3% of the variability (Appendix A.8D) and has most variability on the north-south axis in the 11, 63 and 91-m depth bins. The 35-m depth bin is very small in magnitude and has a northwest-southeast axis.

Historical Assessment of Oceanographic Conditions

A review of 20 years (1991–2010) of oceanographic data collected at stations along the 98-m depth contour revealed no significant impacts that could be attributed to wastewater discharge using current methods (Figure 2.12). Although the change from monthly to quarterly sampling in late 2003 has reduced the number of data points for interpretation, results for the region are still consistent with described changes in large-scale patterns in the California Current System (CCS) (Peterson et al. 2006, McClatchie et al. 2008, 2009, Bjokstedt et al. 2010, NOAA 2011). For example, six major events have affected the CCS during the last decade: (1) the 1997–1998 El Niño event; (2) a shift to cold ocean conditions between 1999–2002; (3) a subtle but persistent return to warm ocean conditions beginning in October 2002 that lasted through 2006;

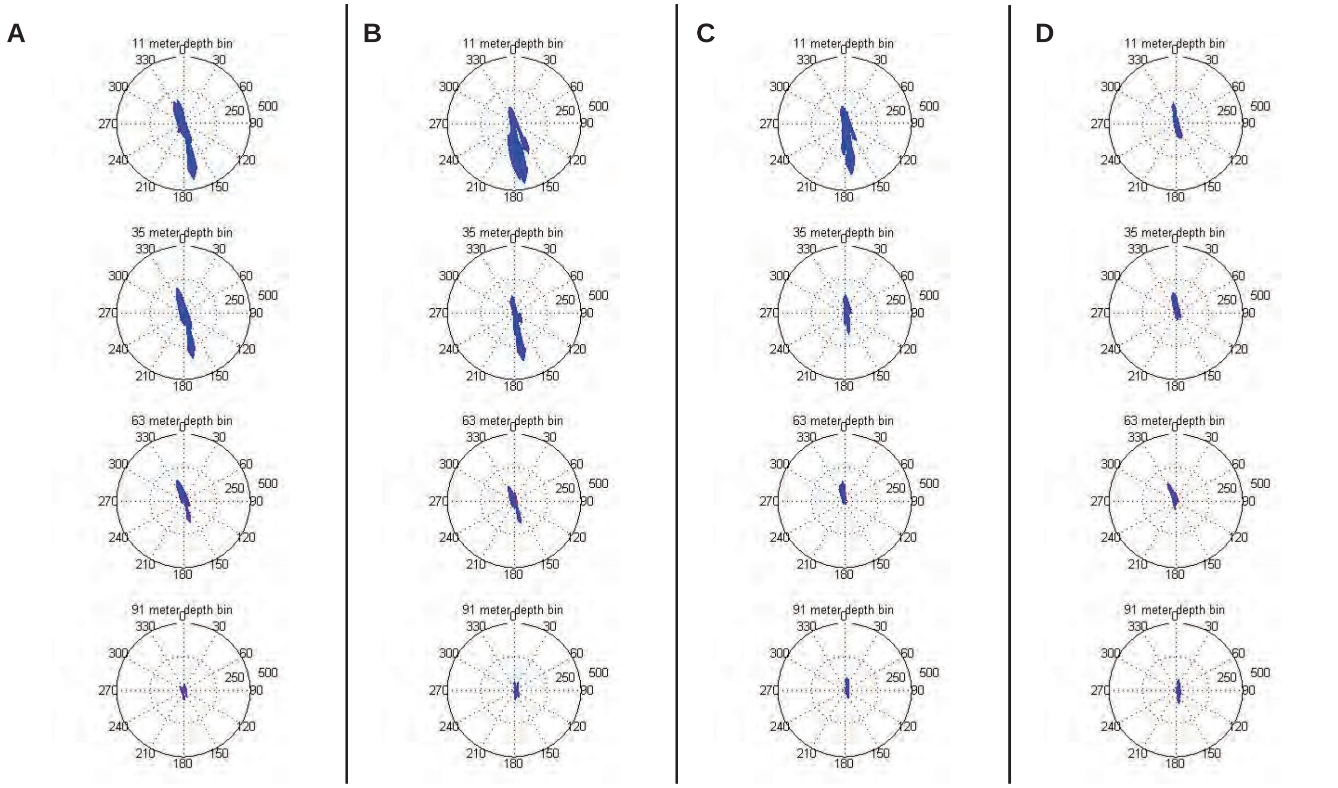

Figure 2.10

Hourly average currents for PLOO on tidally filtered data for (A) winter, (B) spring, (C) summer, and (D) fall during 2010. Arrow length indicates current magnitude (mm/s).

(4) intrusion of subarctic surface waters resulting in lower than normal salinities during 2002–2004; (5) development of a moderate to strong La Niña event in 2007 that coincided with a cooling of the Pacific Decadal Oscillation (PDO); (6) development of a second La Niña event starting in May 2010. Temperature and salinity data for the Point Loma region are consistent with all but the third of these CCS events; i.e., while the CCS was experiencing a warming trend that lasted through 2006, the PLOO region experienced cooler than normal conditions during 2005 and 2006. The conditions in 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, whereas 2010 saw the return of cold La Niña conditions.

Water clarity (transmissivity) around the outfall has tended to be higher than the historical average since about mid-1996 (Figure 2.12). This may be due in part to relatively low values that occurred in 1995 and early 1996, perhaps related to factors such as sediment plumes associated with offshore disposal of dredged materials from a large dredging project in San Diego Bay. Subsequent reductions in transmissivity during some winters (e.g., 1998 and 2000) appear to be the result of increased amounts of suspended sediments associated with strong storm activity (e.g., see NOAA/NWS 2010).

There have been no apparent large-scale historical trends in DO concentrations or pH values related to the PLOO discharge (Figure 2.12). 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 periods of strong upwelling.

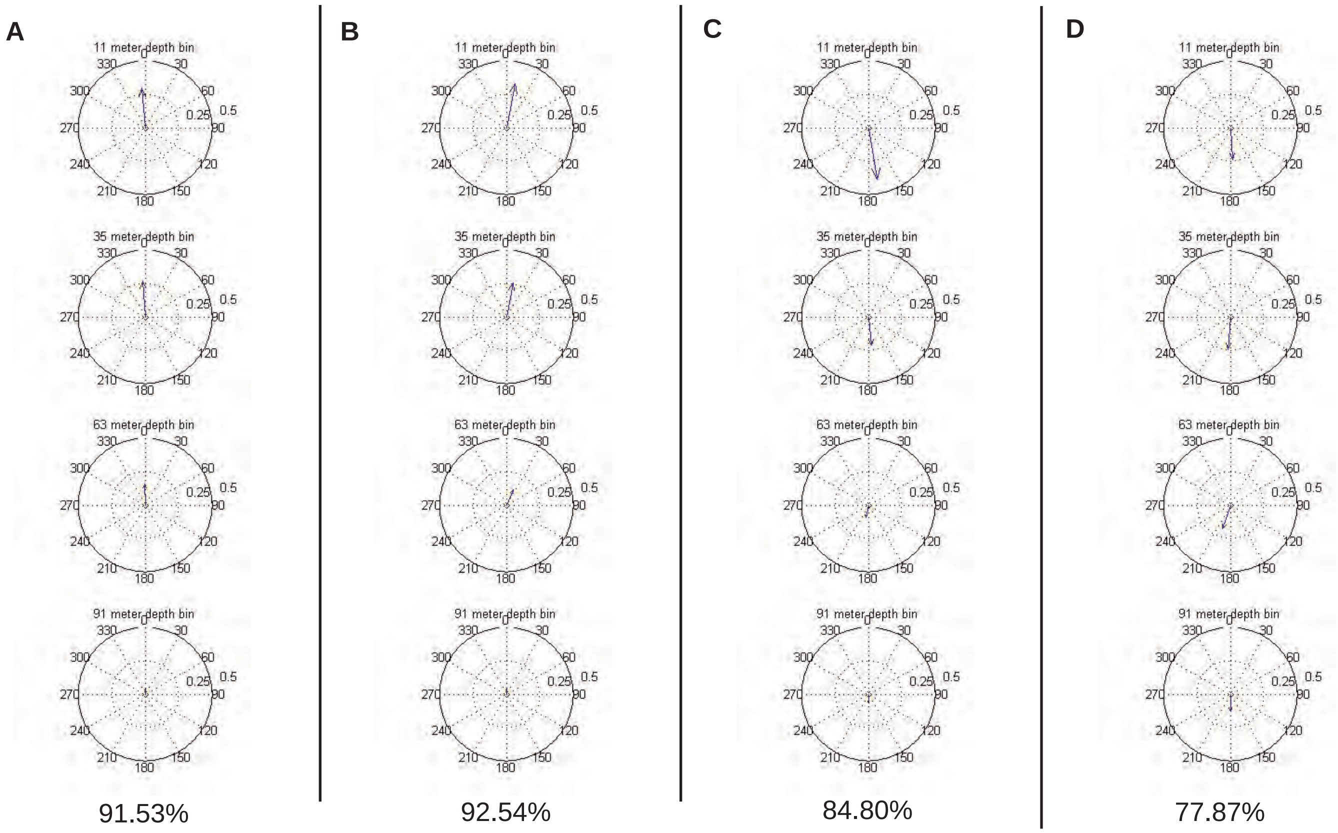

Figure 2.11
Empirical Orthogonal Function 1 (EOF) for (A) winter, (B) spring, (C) summer, and (D) fall in 2010. Percentages indicate fraction of the total variance accounted for by the EOF. Arrow length indicates relative current magnitude.

Discussion

Ocean conditions surrounding the Point Loma outfall in 2010 were generally typical for the region. This included local coastal upwelling and corresponding phytoplankton blooms that were strongest during the spring and summer months and which occurred across the entire region. Upwelling was indicated by relatively cold, dense, saline waters with low DO levels. Phytoplankton blooms were indicated by high chlorophyll concentrations and confirmed by remote sensing observations. Additionally, water column stratification followed patterns typical for San Diego coastal waters, with maximum stratification occurring in mid-summer. Further, oceanographic conditions for the region remained consistent with other well documented large-scale patterns (Peterson et al. 2006, Goericke et al. 2007, McClatchie et al. 2008, 2009, Bjokstedt et al. 2010, NOAA 2011). These observations suggest that other factors such as upwelling of deep ocean waters and large-scale climatic events such as El Niños and La Niñas continue to explain most of the temporal and spatial variability observed in oceanographic parameters off southern San Diego.

Satellite and aerial imagery observations conducted revealed no evidence of the wastewater plume reaching near-surface waters during 2010, even during the winter and fall months when the water column was only weakly stratified (Svejkovsky 2011). This is consistent with results from the bacteriological surveys conducted during the year (see Chapter 3), which also supports the conclusion that the wastefield did not reach surface waters in 2010. Additionally, ocean current measurements recorded in 2010 at sites near the outfall indicated that local currents flowed in northerly and southerly directions throughout most of the year, with some currents directed slightly northwest or southeast. The highest magnitude

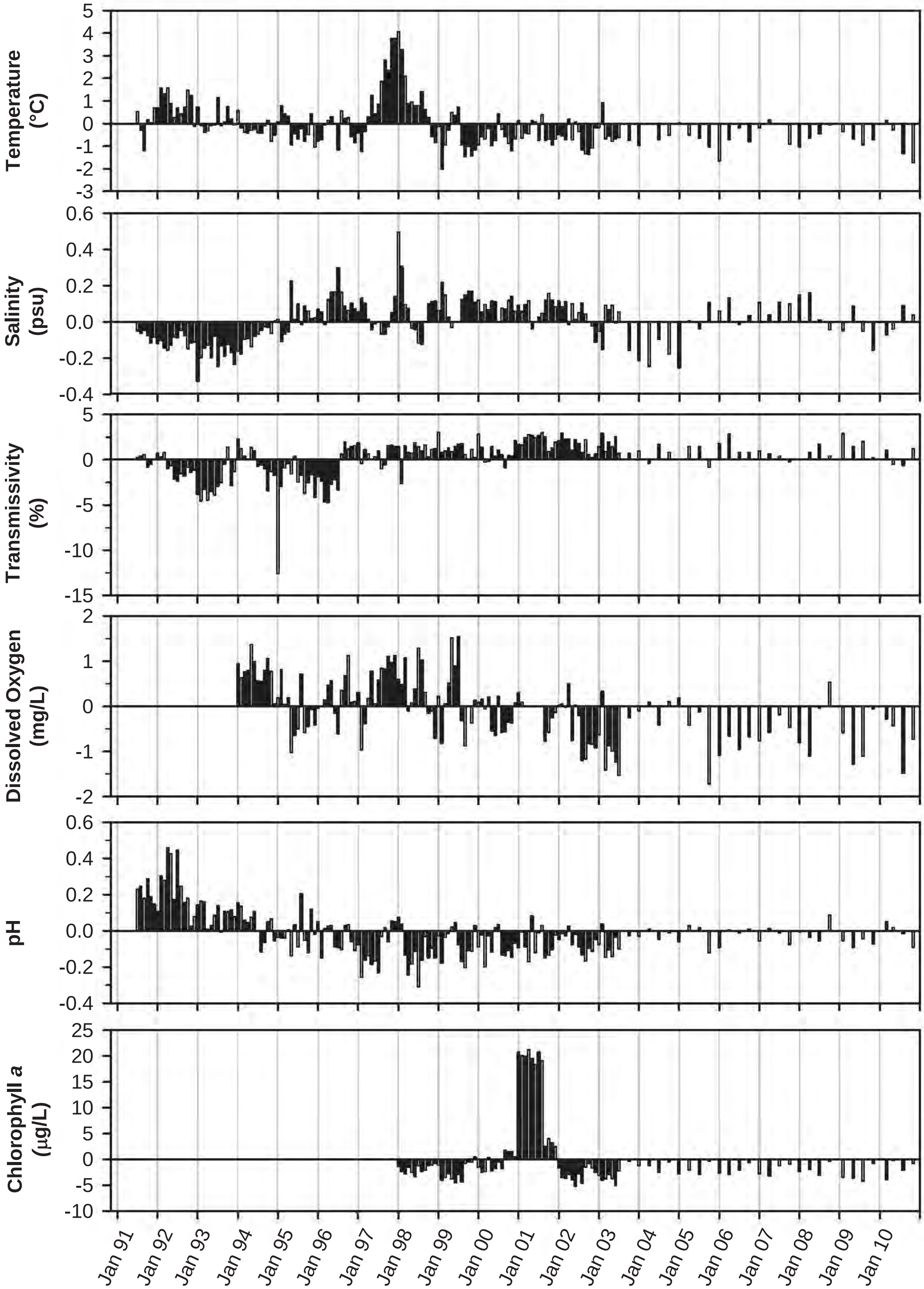

Figure 2.12

Time series of temperature, salinity, transmissivity, dissolved oxygen, pH, and chlorophyll anomalies between 1991 and 2010. Anomalies were calculated by subtracting monthly means for each year (1991–2010) from the mean of all 20 years combined; data were limited to all stations located along the 98-m depth contour, all depths combined.

currents during the year occurred in winter and spring, while the slowest currents occurred in the fall. Consequently, these results indicate that current conditions off Point Loma were not conducive to shoreward transport of the PLOO wastefield at any time during 2010.

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