Chapter 2. Oceanographic Conditions

INTRODUCTION

The fate of wastewater discharged into deep offshore waters is strongly determined by oceanographic conditions and other events that suppress or facilitate horizontal and vertical mixing. Consequently, measurements of physical and chemical parameters such as water temperature, salinity, and density are important components of ocean monitoring programs because these properties determine water column mixing potential (Bowden 1975). Analysis of the spatial and temporal variability of these parameters as well as transmissivity, dissolved oxygen, pH, and chlorophyll may also elucidate patterns of water mass movement. Taken together, analysis of such measurements for the receiving waters surrounding the discharge areas help: (1) describe deviations from expected patterns, (2) reveal the influence of wastewater plumes relative to other inputs such as from bays and rivers, (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. In addition, combining measurements of physical oceanographic parameters with assessments of bacterial concentrations can provide further insight into the transport potential surrounding a discharge site over time.

The City of San Diego regularly monitors oceanographic conditions in the region surrounding the Point Loma Ocean Outfall (PLOO) in order to assess the influence of a variety of sources. For example, although water quality in the region is naturally variable, it is also subject to several natural and anthropogenic sources of contamination. These include inputs from San Diego Bay, Mission Bay, and the San Diego River, as well as discharged wastewater through the PLOO. This chapter describes the oceanographic conditions that occurred off Point Loma during 2004, and is referred to in subsequent chapters to explain patterns of bacteriological occurrence (see Chapter 3) or other effects of the PLOO discharge on the marine environment (see Chapters 4–7). In addition, in the absence of information on deep water currents, bacterial concentrations provide the best indication of horizontal transport of discharged waters (Picard and Emery 1990; see Chapter 3).

MATERIALS AND METHODS

Oceanographic measurements were collected at fixed sampling sites located in a grid pattern surrounding the PLOO (**Figure 2.1**). Thirty-six offshore stations (designated F01-F36 in Figure 2.1) were sampled quarterly in January, April, July, and October, usually over a 3-day period. Three of these stations (F01–F03) are located along the 18-m depth contour, while 11 sites are located along each of the following depth contours: 60-m contour (stations F04–F14); 80-m contour (stations F15–F25); 98-m contour (stations F26–F36). Eight additional stations are located in the Point Loma kelp bed and subject to the 2001 California Ocean Plan (COP) water contact standards. These stations include three sites (stations C4, C5, C6) located along the inshore edge of the kelp bed paralleling the 9-m depth contour, and five sites (stations A1, A6, A7, C7, C8) located along the 18-m depth contour near the offshore edge of the kelp bed. To meet the COP sampling frequency requirements for kelp bed areas, sampling at the eight kelp bed stations was conducted five times per month.

Oceanographic measurements were collected by lowering a SeaBird conductivity, temperature,

Figure 2.1
Locations of water quality monitoring stations where CTD casts are taken for the Point Loma Ocean Outfall Monitoring Program.

and depth (CTD) instrument through the water column. Profiles of temperature, salinity, density, pH, transmissivity (water clarity), chlorophyll *a*, and dissolved oxygen were constructed for each station by averaging the values recorded over 1-m depth intervals during processing. Further details regarding the CTD data processing are provided in the City's Quality Assurance Plan (City of San Diego in prep). Visual observations of water color and clarity, surf height, human or animal activity, and weather conditions were also recorded prior to each CTD sampling event.

Monitoring of the San Diego and neighboring coastline also included satellite and aerial remote sensing performed by Ocean Imaging Corporation of Solana Beach, California (OI). Satellite imagery included data collected from both Moderate Resolution Imaging Spectroradiometer (MODIS) and Landsat Thematic Mapper (TM) instrumentation. The aerial imaging was done using OI's DMSC-MKII digital multispectral sensor (DMSC). Its four channels were configured to a specific wavelength (color) combination, determined by OI's previous research, which maximizes the detection of the PLOO plume's turbidity signature, while also allowing separation between the outfall plume and coastal discharges and turbidity. The depth penetration of the imaging varies between 8 and 15 meters, depending on general water clarity. The spatial resolution of the data is usually 2 meters. Several aerial overflights were performed each month during the rainy season, while fewer flights were conducted during the dry season.

RESULTS AND DISCUSSION

Expected Seasonal Patterns of Physical and Chemical Parameters

The weather in southern California can be classified into two basic "seasons," wet (winter) and dry (spring through fall), and certain patterns in oceanographic conditions off Point Loma follow these "seasons." For instance, temperatures are typically similar at surface and mid-water depths during the winter months, but then diverge beginning in the spring with differences becoming greatest in mid- to late summer. In contrast, waters deeper than 40 m are typically cooler than surface and mid-level waters, and generally exhibit an opposite pattern of being warmest during winter and coldest throughout the spring and early summer.

The typical winter conditions present during January and February each year are characterized by cold water temperatures and a high degree of homogeneity throughout the water column for all physical and chemical parameters. Exceptions to these conditions occur when stormwater runoff due to heavy rainfall periodically influences the density profile and causes a freshwater lens within nearshore surface waters. With minimal stratification of the water column, the chance that the wastewater plume could surface is highest during these winter months.

Usually in March or April a decrease in the frequency of winter storms brings about the transition of seasons. During the spring and early summer months, surface waters begin to warm and cause the return of a seasonal thermocline and pycnocline to coastal and offshore waters. Once the water column becomes stratified, minimal mixing conditions tend to remain throughout the dry summer and fall months. In October or November, cooler weather, reduced solar input, and increased storm activity lead to the return of a well-mixed, homogeneous water column that is characteristic of winter months. Analyses of oceanographic data collected off Point Loma over the past 27 years support this pattern.

Observed Seasonal Patterns of Physical and Chemical Parameters

With the exception of greater than normal rainfall during February, drought conditions persisted from January through the first half of October in 2004 (**Figure 2.2**; NOAA/NWS 2005). Record rainfall occurred during late October followed by below normal rainfall in November and then record rainfall again in December. Despite these circumstances, oceanographic conditions during 2004 followed normal seasonal patterns (**Figure 2.3**). Mean surface water temperatures ranged from 14 to greater than 20°C, with the highest temperatures occurring in July and October (**Table 2.1**). Surface temperatures in winter and spring were approximately 1°C cooler than the previous year and 1–2°C warmer in summer and fall. Bottom waters were generally cooler than the previous year and remained cold throughout the year, with little seasonal variance. Mean bottom water temperatures ranged from 10.0 to 10.9°C in 2004 versus 9.8 to 11.5°C in 2003. The lowest temperatures were recorded in April and July and the warmest in January.

Thermal stratification in 2004 followed the typical annual pattern (Figure 2.3). Stratification was absent in January with surface and mid-level waters differing by less than 0.3°C (**Table 2.2**). However, seasonal stratification of the upper water column started to develop in April as surface water temperatures increased and mid-level and

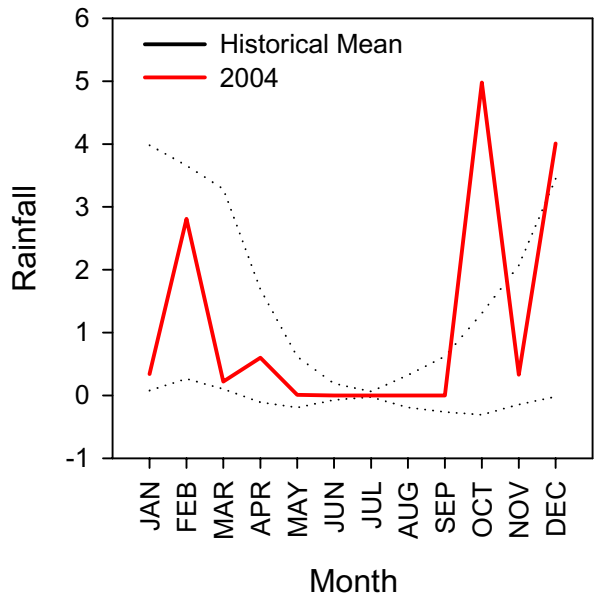

Figure 2.2
Total monthly rainfall (inches) at Lindbergh Field (San Diego, CA) for 2004 compared to monthly average rainfall (+/- 1 standard deviation) for 1914 through 2004.

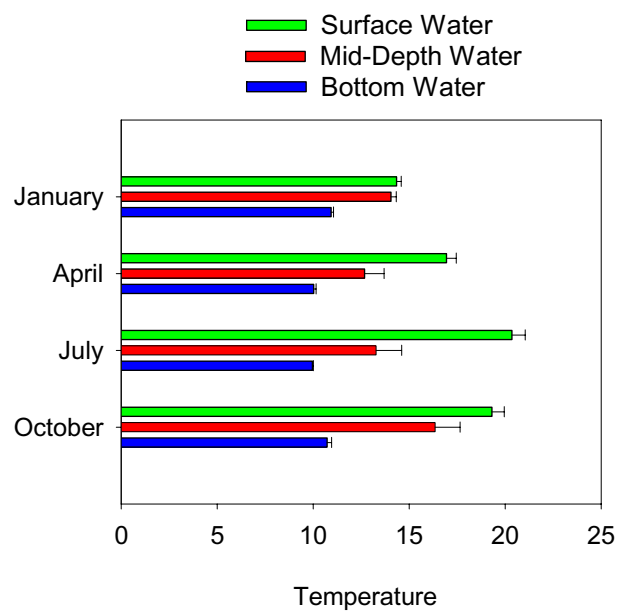

Figure 2.3
Average temperatures (°C) off Point Loma for surface (<2 m), mid-depth (10–20 m), and bottom (>88 m) waters during January, April, July, and October 2004.

Table 2.1

Quarterly mean values for top (≤2 m), mid-depth (10–20 m), and bottom (≥88 m) waters at all quarterly PLOO stations during 2004. Parameters measured are Temp=temperature (°C), salinity (ppt), density (δ/θ), DO=dissolved oxygen (mg/L), pH, XMS=transmissivity (%), and Chl *a*=chlorophyll *a* (µg/L).

		Jan	Apr	Jul	Oct
Temp	*Surface*	14.3	16.9	20.3	19.3
	Mid	14.0	12.7	13.3	16.3
	Bottom	10.9	10.0	10.0	10.7
Salinity	*Surface*	33.20	32.97	33.49	33.33
	Mid	33.20	33.41	33.43	33.25
	Bottom	33.51	33.73	33.79	33.42
Density	*Surface*	24.72	23.97	23.52	23.66
	Mid	24.79	25.22	25.12	24.31
	Bottom	25.63	25.96	26.02	25.60
DO	*Surface*	8.2	5.7	7.8	7.8
	Mid	8.2	7.2	8.1	8.6
	Bottom	4.8	4.3	3.8	5.1
pH	*Surface*	8.2	8.2	8.2	8.2
	Mid	8.1	8.0	8.1	8.2
	Bottom	7.8	7.8	7.7	7.8
XMS	*Surface*	87	79	85	91
	Mid	86	82	89	88
	Bottom	89	87	88	88
Chl *a*	*Surface*	3.2	2.8	2.6	1.2
	Mid	4.7	8.5	3.9	3.5
	Bottom	2.2	1.7	1.3	0.9

bottom water temperatures declined. By July, a highly stratified upper water column was clearly evident. Surface waters were over 20°C at this time and differed from mid-level and bottom waters by 7 and 10°C, respectively. This stratification began to breakdown in October as surface water temperatures fell and mid-level temperatures rose. Stratification at the shallower kelp stations showed a similar pattern (**Figure 2.4; Table 2.3**). In contrast, bottom waters were generally much cooler than surface or mid-level waters throughout the year. For example, bottom waters were at least 3.4°C colder than surface waters and 2.6°C cooler than mid-level waters over the four quarterly surveys. Since temperature is the main contributor to water

Table 2.2

Average temperature differences between surface waters (≤2 m), mid-depth waters (10–20 m) and bottom waters (≥88 m) surrounding the PLOO during 2004.

	Surface vs Mid	Surface vs Bot	Mid vs Bot
Jan	0.29	3.41	3.11
Apr	4.27	6.92	2.65
Jul	7.08	10.39	3.31
Oct	2.95	8.58	5.63

column stratification in southern California (Dailey et. al. 1993), these differences were important to limiting the surfacing potential of the waste field to depths below 40 m (see Chapter 3).

Surface water salinity was lower and more variable than in recent years and was strongly influenced by both unusually heavy rainfall and high summer temperatures. Surface salinity at the offshore stations averaged from 32.97 to 33.49 ppt in 2004 (Table 2.1). Storm runoff resulted in mean surface salinity below 33 ppt in April. In contrast, record air temperatures and the resulting seawater evaporation in July increased surface salinity during the summer months. The effects of the October rains are not reflected in the salinity values of Table 2.1 because quarterly sampling took place prior to the storms; however, a surface lens of freshened seawater (i.e., salinities <33 ppt) was recorded at the kelp stations during October, November, and December (see Table 2.3; City of San Diego 2004a, b, 2005). Seawater density, a function of temperature, salinity, and pressure, reflected the changes brought about by the increased storm activity and warmer than normal summer temperatures. In general, water density was lower throughout the water column when compared to the 2003 survey.

Data for the various other measured parameters (i.e., pH, transmissivity, chlorophyll *a*, dissolved oxygen) also varied in response to sporadic natural events, such as storm activity and increased primary productivity. Turbidity following rainfall events was readily visible in satellite and aerial imagery (see Ocean Imaging 2004a, b, 2005). Data from transmissivity measurements generally supported these aerial observations. For example,

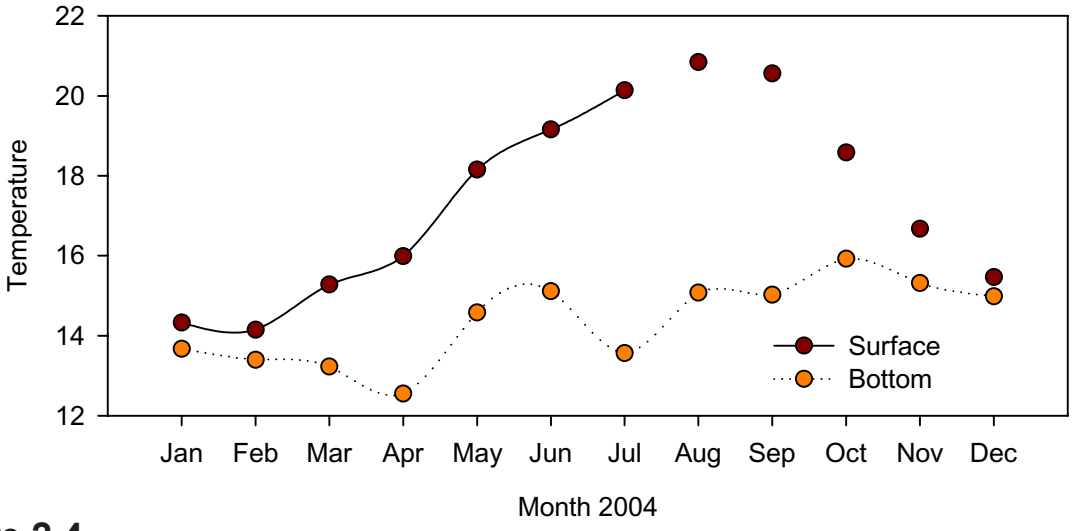

Figure 2.4

Average temperatures (°C) for surface (<2 m) and bottom waters for the Point Loma nearshore Kelp Bed stations sampled during 2004.

Table 2.3

Monthly average values for top (≤2 m) and bottom waters at all PLOO nearshore kelp bed stations sampled during 2004. Parameters measured are: Temp=temperature (°C), salinity (ppt), density (δ/θ), DO=dissolved oxygen (mg/L), pH, XMS=transmissivity (%), and Chl a=chlorophyll a (µg/L).

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temp	Surface	14.3	14.1	15.3	16.0	18.2	19.2	20.1	20.8	20.6	18.6	16.7	15.5
	Bottom	13.7	13.4	13.2	12.5	14.6	15.1	13.6	15.1	15.0	15.9	15.3	15.0
Salinty	Surface	33.22	33.17	33.12	33.29	33.35	33.48	33.51	33.46	33.41	33.14	33.13	33.14
	Bottom	33.21	33.24	33.25	33.48	33.42	33.57	33.42	33.37	33.34	33.20	33.21	33.19
Density	Surface	24.74	24.74	24.46	24.43	23.97	23.82	23.58	23.36	23.39	23.70	24.15	24.44
	Bottom	24.87	24.95	24.98	25.29	24.82	24.81	25.04	24.68	24.65	24.36	24.52	24.58
DO	Surface	7.6	8.3	8.6	9.0	9.1	8.6	8.7	8.2	8.1	8.0	7.6	7.8
	Bottom	7.1	7.3	6.9	6.7	7.2	6.5	6.6	7.9	7.5	7.4	6.9	7.6
pH	Surface	8.1	8.1	8.1	8.1	8.2	8.2	8.2	8.1	8.2	8.1	8.1	8.1
	Bottom	8.0	8.0	7.9	7.9	8.1	8.0	8.0	8.1	8.1	8.1	8.1	8.1
XMS	Surface	81.5	78.2	79.0	75.3	77.9	75.8	79.6	84.4	80.9	77.5	76.7	76.2
	Bottom	83.2	82.3	84.0	79.9	79.9	79.9	85.0	85.0	83.9	84.6	81.3	77.4
Chl *a*	Surface	2.14	2.78	2.63	4.08	3.56	4.12	2.71	1.37	2.14	2.93	2.76	1.65
	Bottom	2.26	3.31	2.43	5.42	5.73	5.47	2.74	2.94	3.22	3.07	3.19	2.10

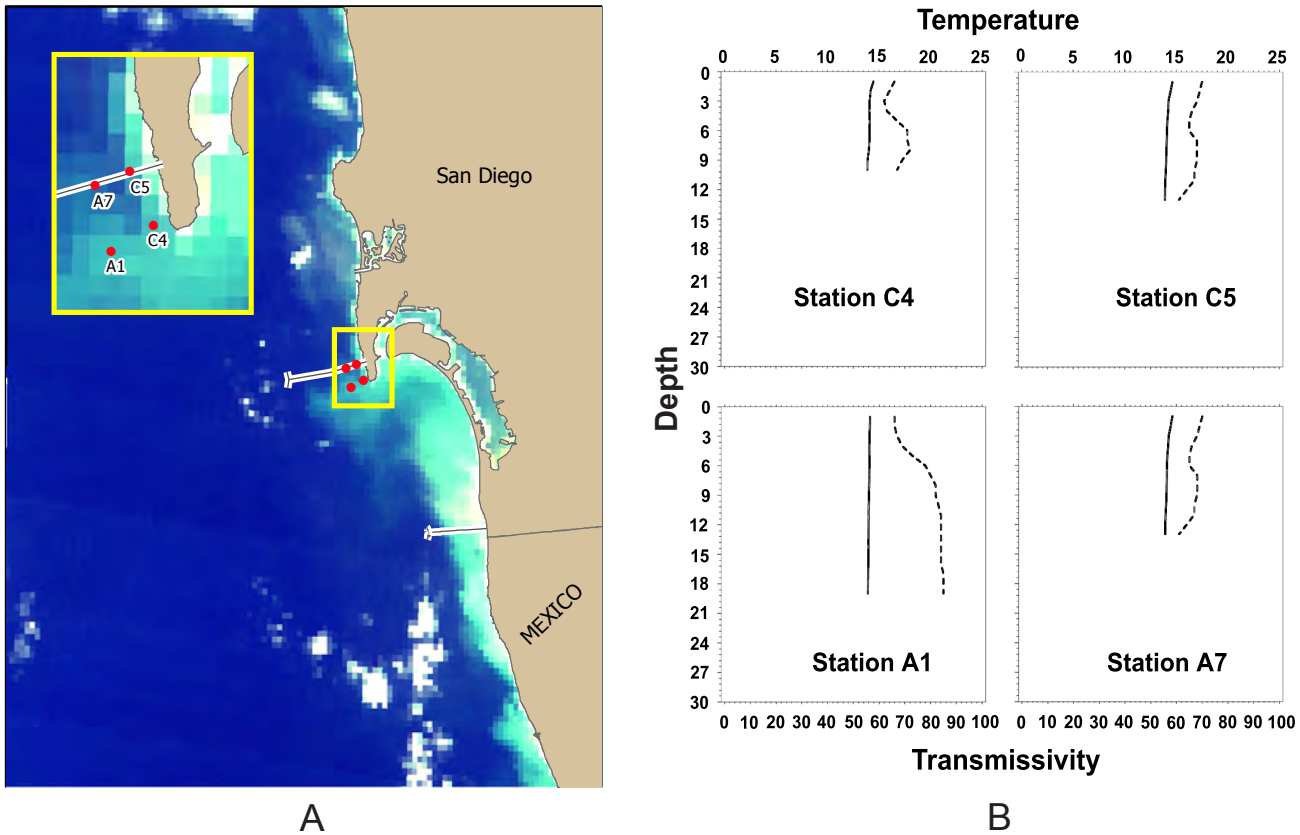

Figure 2.5

(A) MODIS satellite image showing the San Diego water quality monitoring region, captured on February 24, 2004 by Ocean Imaging and (B) CTD profiles of percent transmissivity (dotted lines) at stations A1, C4, A7, and C5 collected on February 25, 2004. White pixels in the MODIS image represent areas obscured by cloud cover offshore or "washout" or band saturation due to the histogram stretches used to enhance turbidity features in surface waters along the shoreline.

from February through April aerial images depict increased discharge of turbid waters from the San Diego Bay, Mission Bay, San Diego River, and more northward sources following the February storms (Ocean Imaging 2004a). The resultant discharge from San Diego Bay was apparent in lowered surface transmissivity at the two southernmost kelp stations (A1 and C4) on February 25, following a 2-day storm that dropped 1.4 inches of rain (**Figure 2.5**). In some cases, these storms gave rise to turbid water masses that extended to and beyond the PLOO outfall area (**Figure 2.6**). These conditions were apparent in lowered surface water transmissivity values (<80% light transmission) in April relative to values (≥ 85%) in January, July, and October (Table 2.1). In contrast, during June, July, August, and September the lack of rain and runoff helped the regional waters remain relatively clear through early October (Ocean Imaging 2004c, 2005). In mid-October and December however, the region was again subject to frequent terrestrial runoff from the winter storms. This caused great volumes of turbid runoff from San Diego Bay and Mission Bay that affected nearshore water conditions that also extended into the PLOO region (**Figure 2.7**). Transmissivity values for offshore stations were obtained prior to the record storms of mid-October and don't reflect these turbid conditions; however, data from the nearshore stations show a corresponding decrease in mean transmissivity values (Table 2.3).

Water clarity was also affected by a regional plankton bloom. Aerial imagery indicated the beginning of a plankton bloom in April (see Ocean Imaging 2004a) that corresponded to increased dissolved oxygen (DO) and chlorophyll *a* values. For example, relatively high mean DO

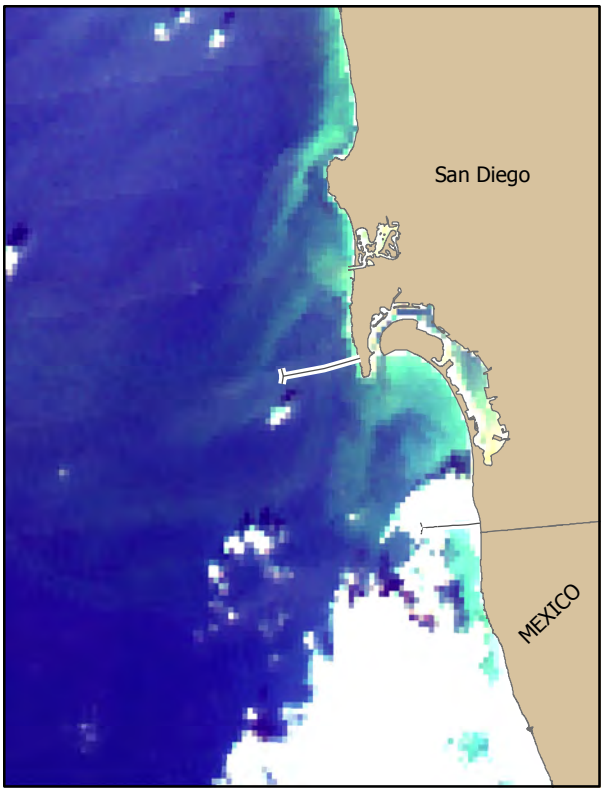

Figure 2.6
MODIS satellite image provided by Ocean Imaging showing the San Diego water quality monitoring region, captured on March 3, 2004. White pixels offshore represent areas obscured by cloud cover. White pixels along the shoreline are the result of "washout" or band saturation due to the histogram stretches used to enhance turbidity features in surface waters.

values (7.2 mg/L) in April mid-level waters corresponded to a very high chlorophyll *a* value (8.5 mg/L) (see Table 2.1). The kelp stations showed low transmissivity values that corresponded to the highest chlorophyll *a* and surface DO values from April through June (Appendix A.1). Relatively low DO values in bottom waters of these nearshore stations over the same period were concurrent with elevated chlorophyll values, suggesting that the low oxygen levels likely resulted from the biological degradation of plankton as it sank below the surface.

These storm and plankton-driven turbidity patterns in surface waters act as markers of water movement within the satellite imagery. From January through September 2004, with few exceptions, aerial imagery of turbidity patterns indicated that water movement was primarily southward (see Figure 2.6, and Ocean Imaging 2004a, b, c). For example, February rains and subsequent runoff from the San Diego River and along the shores of La Jolla and North County gave rise to sediment-laden waters that were advected southwestward over the Point Loma outfall. With the start of record storm activity in October, surface waters in the outfall region were subject to frequent northward currents. For instance, after heavy rainfall in October and December the outer edge of a very large, combined storm water plume from the Tijuana River and from San Diego Bay reached as far northward and seaward as the PLOO outfall wye (see Figure 2.7, and Ocean Imaging 2005). In addition, a storm-related sewage overflow at the Point Loma Facility on October 27 caused 2.2 MG of sewage to flow into the ocean, and this persistent northward flow likely helped flush the sewage effluent out of the kelp bed areas and disperse it offshore (see Chapter 3).

SUMMARY AND CONCLUSIONS

Drought conditions in San Diego continued from January through mid-October in 2004 with the exception of heavy rainfall during February. Then, during the latter half of October and again in December, record rainfall resulted in heavy runoff and turbid waters both inshore and offshore in the Point Loma region. Despite these circumstances, oceanographic conditions during 2004 generally followed normal seasonal patterns. Surface water temperatures were slightly colder during January, but warmer during April, July, and October when compared to 2003. Thermal stratification of the water column followed the typical cycle with maximum seasonal stratification apparent in summer and a mixed water column during late fall and winter.

Surface water salinity was lower and more variable than in recent years and was strongly influenced by both unusually heavy rainfall and high summer temperatures. Surface salinity values fell below

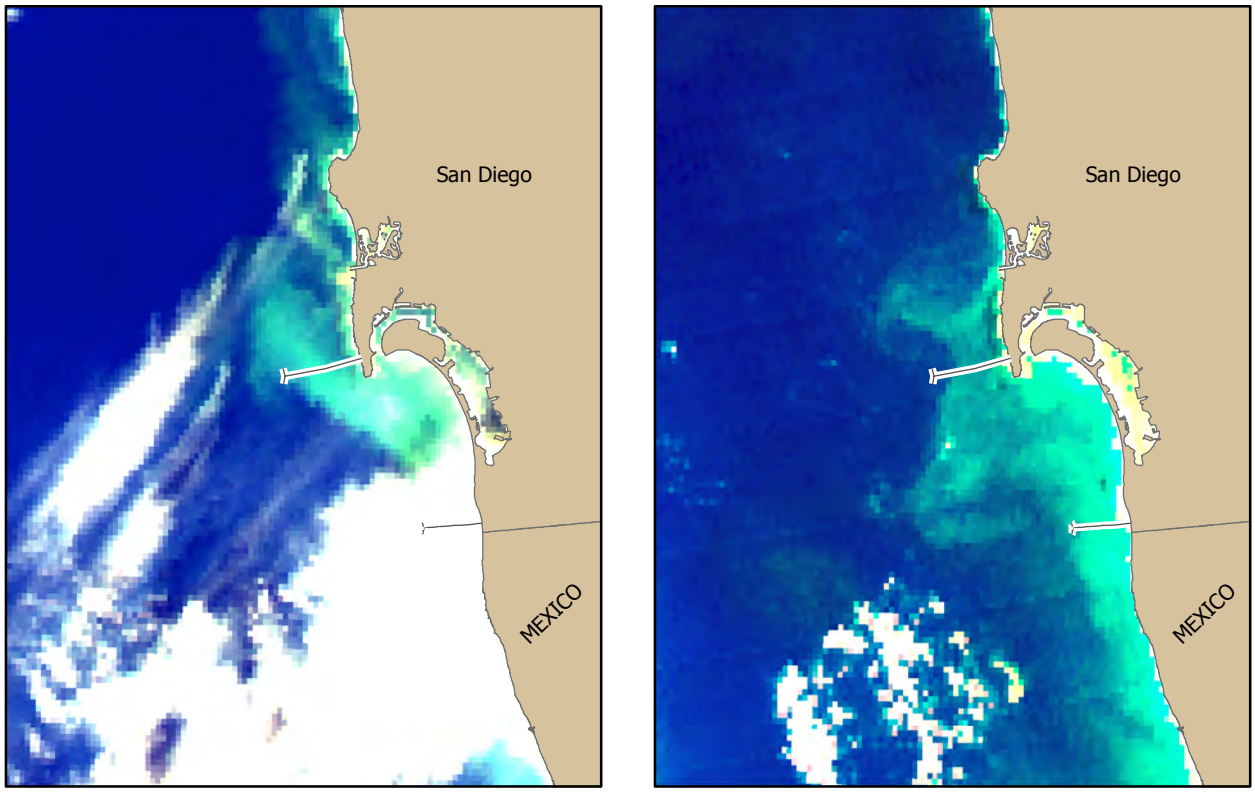

Figure 2.7
MODIS satellite image showing the San Diego water quality monitoring region, captured by Ocean Imaging on (A) October 29, 2004, and (B) December 9, 2004. White pixels offshore represent areas obscured by cloud cover. White pixels along the shoreline are the result of "washout" or band saturation due to the histogram stretches used to enhance turbidity features in surface waters.

33 ppt as a result of river and bay discharge following various storms. Warmer temperatures and lower salinities resulted in lower than normal densities throughout the water column during April and July.

Aerial and satellite imagery indicated that water clarity was frequently compromised by sediment resuspension and embayment flushing events following February, October, and December storms. Transmissivity values at the kelp bed stations reflected this nearshore turbidity, primarily from the Point Loma beaches or near the mouths of San Diego Bay and Mission Bay. In contrast, transmissivity was generally high during January, July and the first part of October.

Analysis of the physical water column properties as well as aerial and satellite imagery off Point Loma in 2004 provided no evidence that wastewater discharged via the PLOO reached either inshore sites or surface waters. Even during the winter months when water column stratification was weakest, there was no indication that the wastewater plume reached depths shallower than 40–60 m. These physical conditions will be important in the analysis of spatial patterns of bacterial concentrations to be discussed in the following chapter.

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