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 South Bay Ocean Outfall (SBOO) can help: (1) describe deviations from expected patterns, (2) reveal the impact of the wastewater plume relative to other inputs such as San Diego Bay and the Tijuana River, (3) determine the extent to which water mass movement or mixing affects the dispersion/dilution potential for discharged materials, and (4) demonstrate the influence of natural events such as storms or El Niño/La Niña oscillations. In addition, combining measurements of physical parameters with assessments of bacteriological concentrations (see Chapter 3) can provide further insight into the transport potential surrounding the SBOO throughout the year.

To assess possible impacts from the outfall discharge, the City of San Diego regularly monitors oceanographic conditions of the water column. Although, water quality in the South Bay region is naturally variable, it is also subject to various anthropogenic and natural sources of contamination such as discharge from the SBOO, San Diego Bay and the Tijuana River. This chapter describes the oceanographic conditions that occurred during 2004 and is referred to in subsequent chapters to explain patterns of bacteriological occurrence (see Chapter 3) or other effects of the SBOO discharge on the marine environment (see Chapters 4–7).

MATERIALS and METHODS

Field Sampling

Oceanographic measurements were collected at 40 fixed sampling sites located from 3.4 km to 14.6 km offshore (**Figure 2.1**). These stations form a grid encompassing an area of approximately 450 km^2 and were generally situated along 9, 19, 28, 38, and 55-m depth contours. Three of these stations (I25, I26, and I39) are considered kelp bed stations subject to the California Ocean Plan (COP) water contact standards. The three kelp stations were

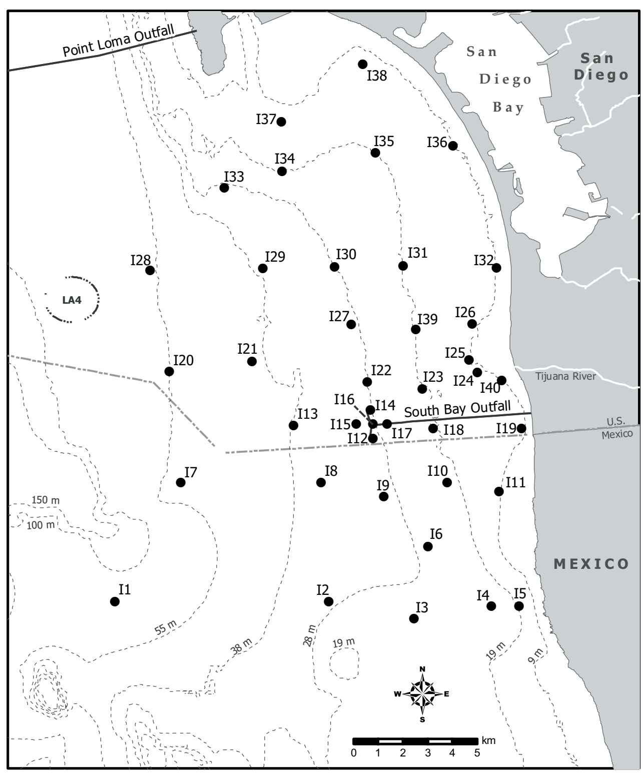

Figure 2.1
Water quality monitoring stations where CTD casts are taken, South Bay Ocean Outfall Monitoring Program.

selected for their proximity to suitable substrates for the Imperial Beach kelp bed; however, this kelp bed has been historically transient and inconsistent in terms of size and density (North 1991, North et al. 1993). Thus, these three stations are located in an area where kelp is only occasionally found.

Oceanographic measurements were collected at least once per month over a 3–5 day period. Values for temperature, salinity, density, pH, transmissivity (water clarity), chlorophyll *a*, and dissolved oxygen were recorded by lowering a SeaBird conductivity, temperature and depth (CTD) instrument through the water column. Profiles of each parameter were constructed for each station by averaging the values recorded over 1-m depth intervals during processing. This ensured that physical measurements used in subsequent data analyses corresponded with bacterial sampling depths. Further details regarding CTD data processing are provided in the City's Quality Assurance Plan (City of San Diego in prep.). To meet the COP sampling frequency requirements for kelp bed areas, CTD casts were conducted at the kelp stations an additional four times each month. Visual observations of weather and water conditions were recorded prior to each CTD sampling event.

Monitoring of the SBOO area and neighboring coastline also included satellite and aerial remote sensing performed by Ocean Imaging Corporation (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 SBOO 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 and a lesser number during the dry season.

RESULTS and DISCUSSION

Expected Seasonal Patterns of Physical and Chemical Parameters

Southern California weather can be classified into two basic "seasons", wet (winter) and dry (spring through fall), and certain patterns in oceanographic conditions track these "seasons." In the winters, water temperatures are cold and the water column is well-mixed resulting in similar properties throughout the water column. In contrast, dry summer weather warms the surface waters and introduces thermally-sustained stratification. Despite a sampling schedule that limits oceanographers to snapshots in time spread out over several days during each month, analyses of oceanographic data collected from the South Bay region over the past nine years support this pattern.

Each year, typical winter conditions are present in January and February. A high degree of homogeneity within the water column is the normal winter signature for all physical parameters, although storm water runoff may intermittently influence density profiles by causing a freshwater lens within nearshore surface waters. The chance that the wastewater plume may surface is highest during these winter months when there is little, if any, stratification of the water column.

Winter conditions often extend into March, when a decrease in the frequency of winter storms brings about the transition of seasons. The increasing elevation of the sun and lengthening days begin to warm the surface waters and cause the return of a seasonal thermocline and pycnocline to coastal and offshore waters. Once stratification is established by late spring, minimal mixing conditions tend to remain throughout the summer and early fall. In October or November, cooler weather, reduced solar input, and increased stormy weather cause

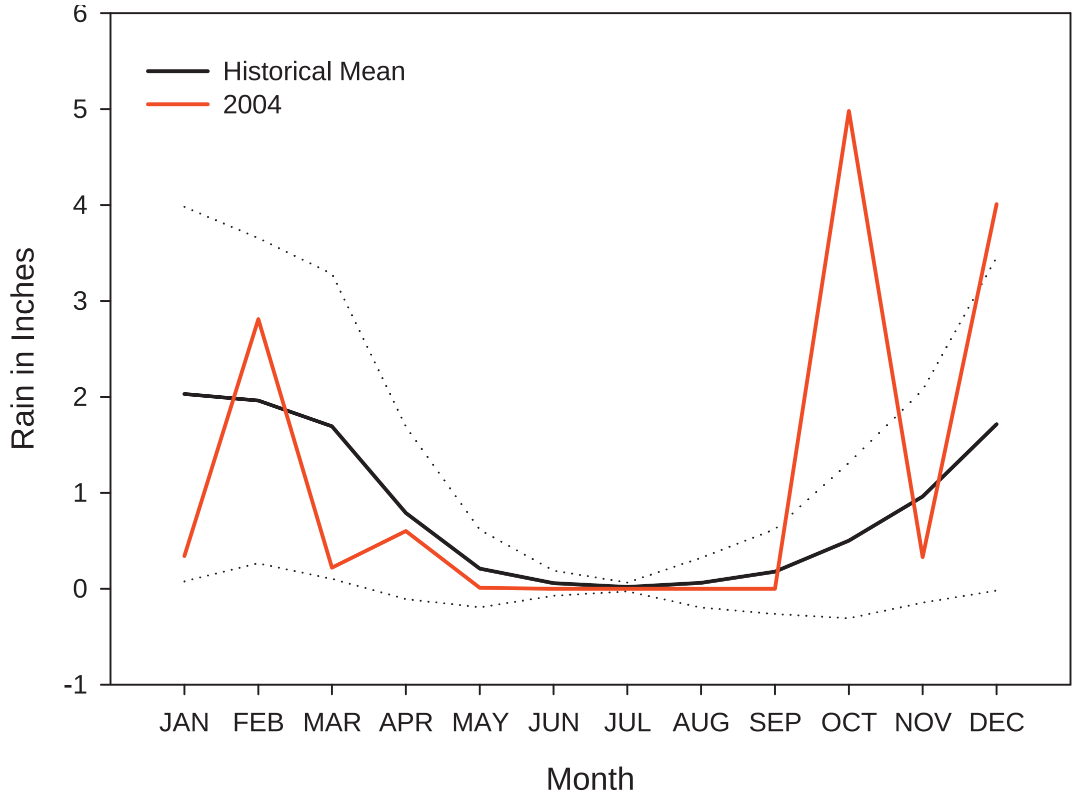

Figure 2.2
Total monthly rainfall at Lindbergh Field (San Diego, CA) for 2004 compared to monthly average rainfall (+/- 1 standard deviation) for the historical period 1914–2004.

the return of the well-mixed, homogeneous water column characteristic of winter months.

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 the second half of October followed by below normal rainfall in November and then record rainfall again in December. Despite these circumstances, thermal patterns of the water column followed normal seasonal trends at the nearshore and offshore sampling areas (**Figures 2.3, 2.4**).

Temperature is the main factor affecting stratification of southern California ocean waters (Dailey et. al. 1993) and provides the best indication of the surfacing potential of the wastewater plume. During 2004, surface water temperatures ranged from 13.8 to 14.2°C in January–March. Seasonal warming of the surface water began in April, progressed gradually, and peaked in September when mean surface temperatures reached 22.2°C (**Table 2.1**). This pattern of a steady, gradual rise in surface temperatures was much different than in 2003, when temperature was more variable and peaked in July rather than September (City of San Diego 2004a). A relatively rapid decline in surface temperatures then occurred from September to October (~5°C) and from November to December (~2.5°C). In contrast, bottom temperatures were less variable, ranging from 10.3 to 14.4°C. Bottom temperatures decreased from 12.8°C in January to 10.3°C in June, and then gradually increased to 14.4°C by December. This pattern was generally similar to the previous year, although compared to 2003, 2004 bottom temperatures were 1–2°C cooler in January and February and about 1°C warmer in November and December.

Surface and mid-level water temperatures dipped several times during the year (i.e., May, July,

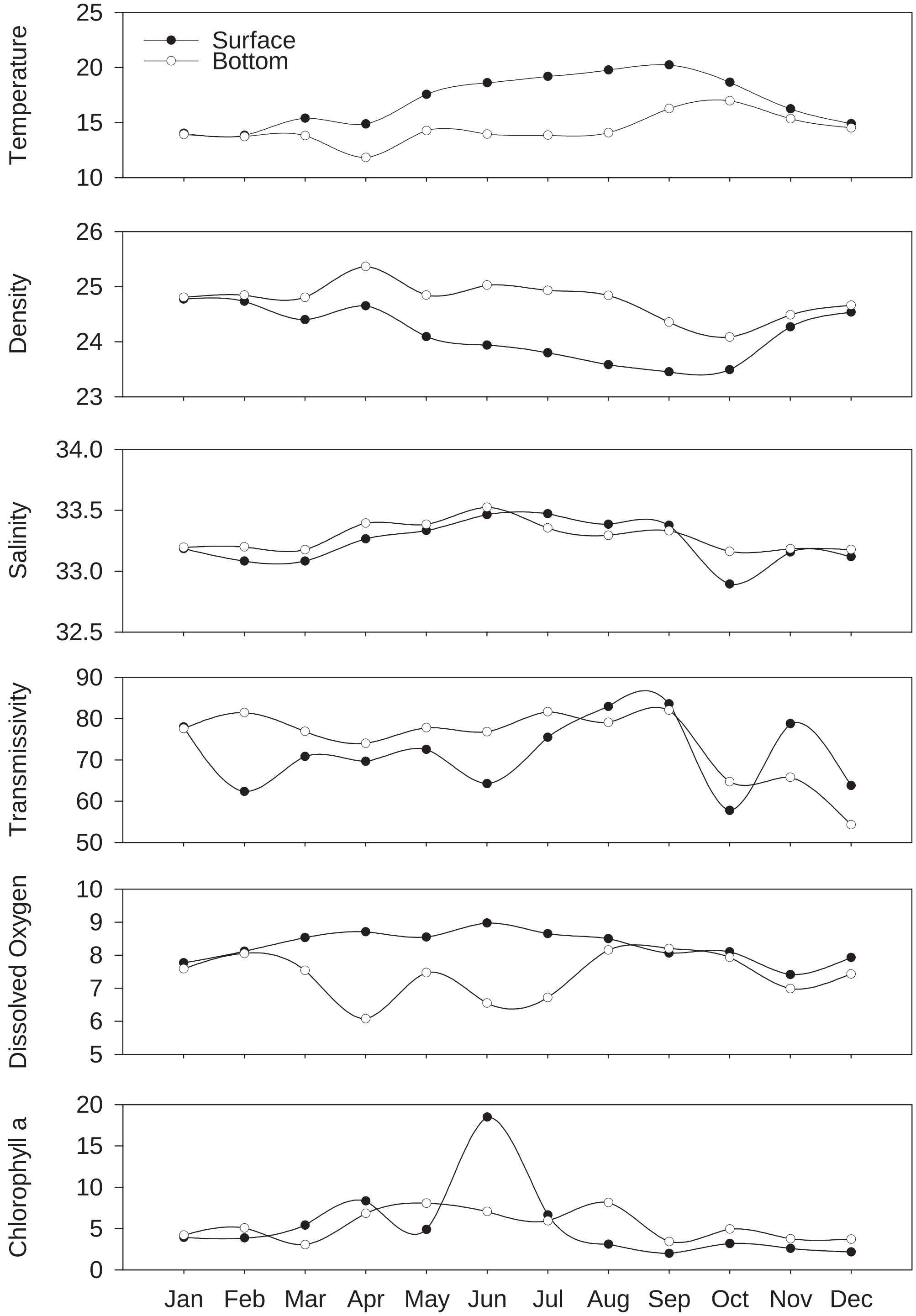

Figure 2.3

Monthly average temperature (°C), density (δ/θ), salinity (ppt), transmissivity (%), dissolved oxygen (mg/L), and chlorophyll *a* (µg/L) values for surface (≤ 2m) and bottom (≥ 18m) waters at the three kelp water quality stations during 2004.

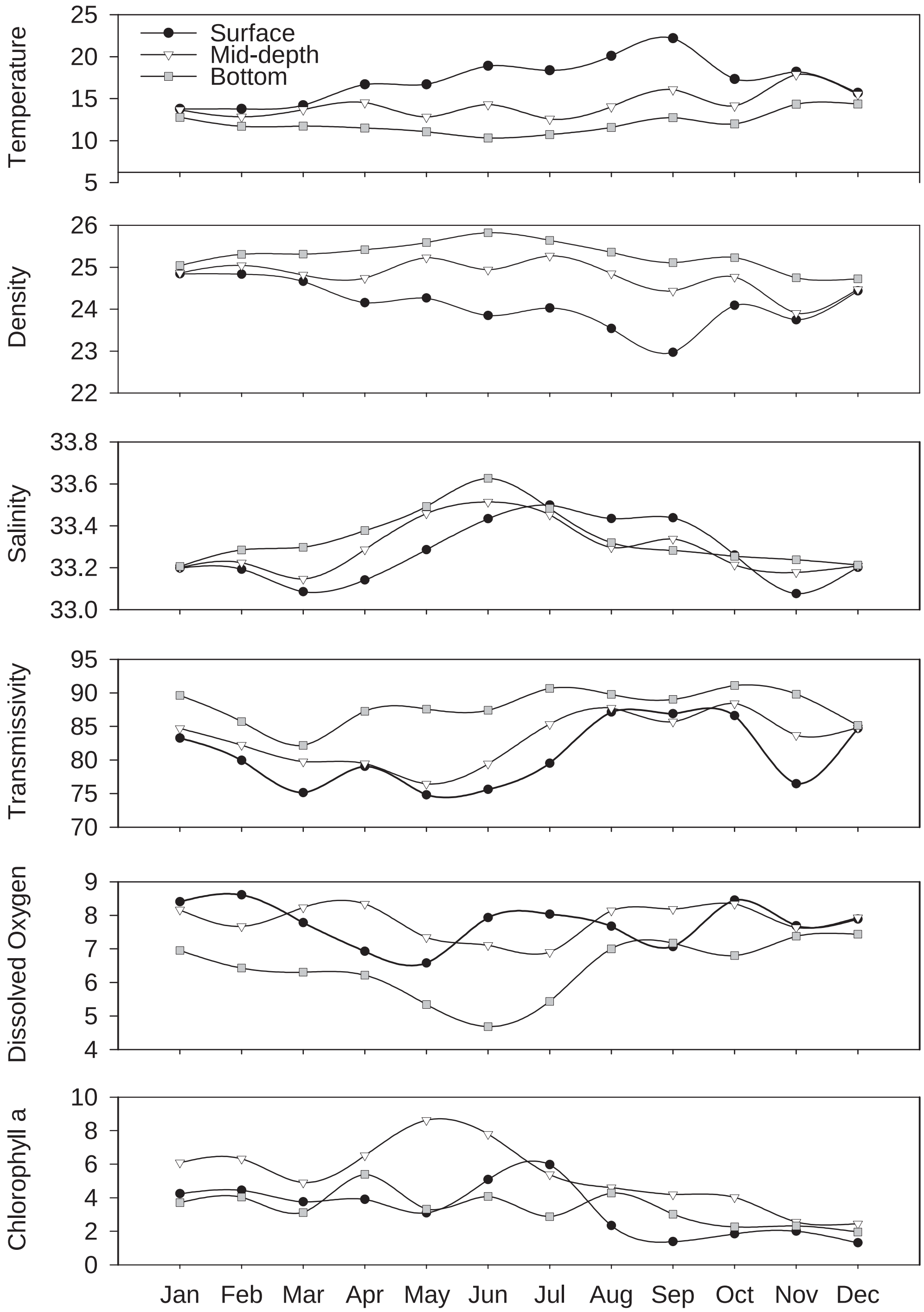

Figure 2.4

Monthly average temperature (°C), density (δ/θ), salinity (ppt), transmissivity (%), dissolved oxygen (mg/L), and chlorophyll *a* (µg/L) values for surface (≤ 2m), mid-depth (10–20m), and bottom (≥ 27m) waters at the monthly water quality stations during 2004.

Table 2.1

Differences between the top (≤2 m) and bottom (≥27 m) waters for mean values of temperature (°C), salinity (ppt), density (δ/θ), dissolved oxygen (mg/L), pH, chlorophyll *a* (µg/L), and transmissivity (%) at all SBOO stations during 2004. The greatest differences between top and bottom values are highlighted and in bold type.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature	*Surface*	13.8	13.8	14.2	16.7	16.7	18.9	18.4	20.1	22.2	17.4	18.2	15.7
	Bottom	12.8	11.7	11.7	11.5	11.1	10.3	10.7	11.6	12.7	12.0	14.3	14.4
	Difference	1.0	2.1	2.5	5.2	5.7	**8.6**	7.7	**8.5**	**9.5**	5.4	3.9	1.3
Density	*Surface*	24.84	24.83	24.66	24.16	24.26	23.85	24.03	23.54	22.97	24.09	23.75	24.44
	Bottom	25.04	25.31	25.32	25.42	25.59	25.83	25.64	25.36	25.11	25.23	24.75	24.72
	Difference	0.20	0.47	0.65	1.26	1.33	**1.98**	1.62	**1.82**	**2.14**	1.14	1.00	0.29
Salinity	*Surface*	33.20	33.19	33.09	33.14	33.29	33.43	33.50	33.44	33.44	33.26	33.08	33.20
	Bottom	33.21	33.28	33.30	33.38	33.49	33.63	33.48	33.32	33.28	33.25	33.24	33.21
	Difference	**-0.01**	-0.09	**-0.21**	**-0.24**	**-0.21**	-0.19	0.02	0.12	0.16	0.01	-0.16	-0.01
DO	*Surface*	8.4	8.6	7.8	6.9	6.6	7.9	8.0	7.7	7.1	8.5	7.7	7.9
	Bottom	7.0	6.4	6.3	6.2	5.3	4.7	5.4	7.0	7.2	6.8	7.4	7.4
	Difference	1.5	**2.2**	1.5	0.7	1.2	**3.3**	**2.6**	0.7	-0.1	1.7	0.3	0.5
pH	*Surface*	8.1	8.2	8.1	8.2	8.2	8.2	8.2	8.2	8.2	8.1	8.1	8.1
	Bottom	8.0	8.0	7.9	7.9	7.9	7.8	7.9	8.0	8.0	8.0	8.0	8.1
	Difference	0.1	0.2	0.2	**0.3**	**0.4**	**0.4**	0.3	0.2	0.2	0.2	0.1	0.0
XMS	*Surface*	83	80	75	79	75	76	80	87	87	87	76	85
	Bottom	90	86	82	87	88	87	91	90	89	91	90	85
	Difference	6	6	7	8	**13**	**12**	11	3	2	5	**13**	0
Chl a	*Surface*	4.2	4.4	3.7	3.9	3.1	5.1	6.0	2.3	1.4	1.8	2.0	1.3
	Bottom	3.7	4.0	3.1	5.4	3.3	4.1	2.9	4.3	3.0	2.3	2.3	2.0
	Difference	0.5	0.4	0.6	-1.5	-0.2	1.0	**3.1**	**-1.9**	**-1.6**	-0.4	-0.3	-0.6

October). These changes appeared to be the result of an influx of cold water as indicated by decreased temperatures and increased water density (Figures 2.2 and 2.3). Aerial imagery suggested several upwelling events occurred that corresponded to temperature declines in spring and summer (see Ocean Imaging 2004c, d). However, this imagery did not detect the presence of the wastewater plume in nearshore waters following these events. Similar events have occurred during the past two years and may be the result of inshore movement of water from the California Current (see City of San Diego 2004a).

Like temperature, thermal stratification of the water column followed normal seasonal patterns. Stratification was minimal or absent from January through March with differences between average surface and bottom temperatures being only 1–2.5°C (Figure 2.3, Table 2.1). The absence of a stratified water column is the likely reason that plume-influenced waters were visually detected in near-surface waters during aerial overflights conducted from January through mid-March (Ocean Imaging 2004a, b). The seasonal thermocline began to develop in April at depths between 10–20m, and became shallower and stronger throughout the summer months. From July through September the thermocline was as shallow as 5 m with temperature differences between surface and bottom waters reaching 9.5°C in September. The shallow thermocline persisted into the first part of October, sinking to approximately 15m in November and disappearing in December. During the period of strongest thermoclines (April–September) no plume-influenced waters were visually detected in near-surface waters (Ocean Imaging 2004c, d). By December the thermocline was gone and a persistent, weak, near-surface signature of the plume was detected (Ocean Imaging 2005).

Density is a product of temperature, salinity and pressure (Pickard and Emery 1990). In the San Diego's South Bay area, temperature is the most important component in determining density because of the relatively shallow shelf depth and the relative uniformity of salinity. Therefore, changes in density typically mirror the changes in temperature, as they did in 2004. For example, surface water density was lowest (22.97 δ/θ) in September when surface waters were warmest (22.2°C) (see Table 2.1 and Figures 2.2, 2.3).

Surface water salinity was more variable than in recent years (see City of San Diego 2004a), but nevertheless displayed some seasonal patterns related to increasing air temperatures, rain runoff, and sporadic upwelling events. Surface salinity ranged from 33.08 to 33.50 ppt in 2004 (Table 2.1). During periods of substantial freshwater input from rain storms, near-surface salinity fell below 33 ppt at several shallow stations off the Tijuana River (City of San Diego 2004b, c). These conditions allowed for the development of salinity haloclines near the surface (1–5m) during the late winter and early spring (March–May) and again in late fall and winter (October–December) following rain events.

Increased turbidity of the coastal waters following rainfall events and plankton blooms was readily visible in satellite and aerial imagery. CTD profile data for transmissivity, chlorophyll *a*, and dissolved oxygen generally supported these aerial observations. Nearshore water clarity was significantly impacted by storms in February, October, and December (see Ocean Imaging 2004b, 2005). Transmissivity declined in February and March following storm activity due to increased flow from the Tijuana River (Figures 2.3, 2.4, **2.5A**). The area surrounding the mouth of the river remained contaminated through April (see Chapter 3). During the storms of October–December the outfall region was again subject to frequent terrestrial runoff, primarily from the Tijuana River. The October survey of monthly stations were obtained prior to the record storms of late October, consequently the resulting turbidity observed in aerial imagery is only apparent in transmissivity data from the nearshore stations (Figure 2.2). Recurring rain caused large volumes of turbid runoff along the coast from mid-October through December.

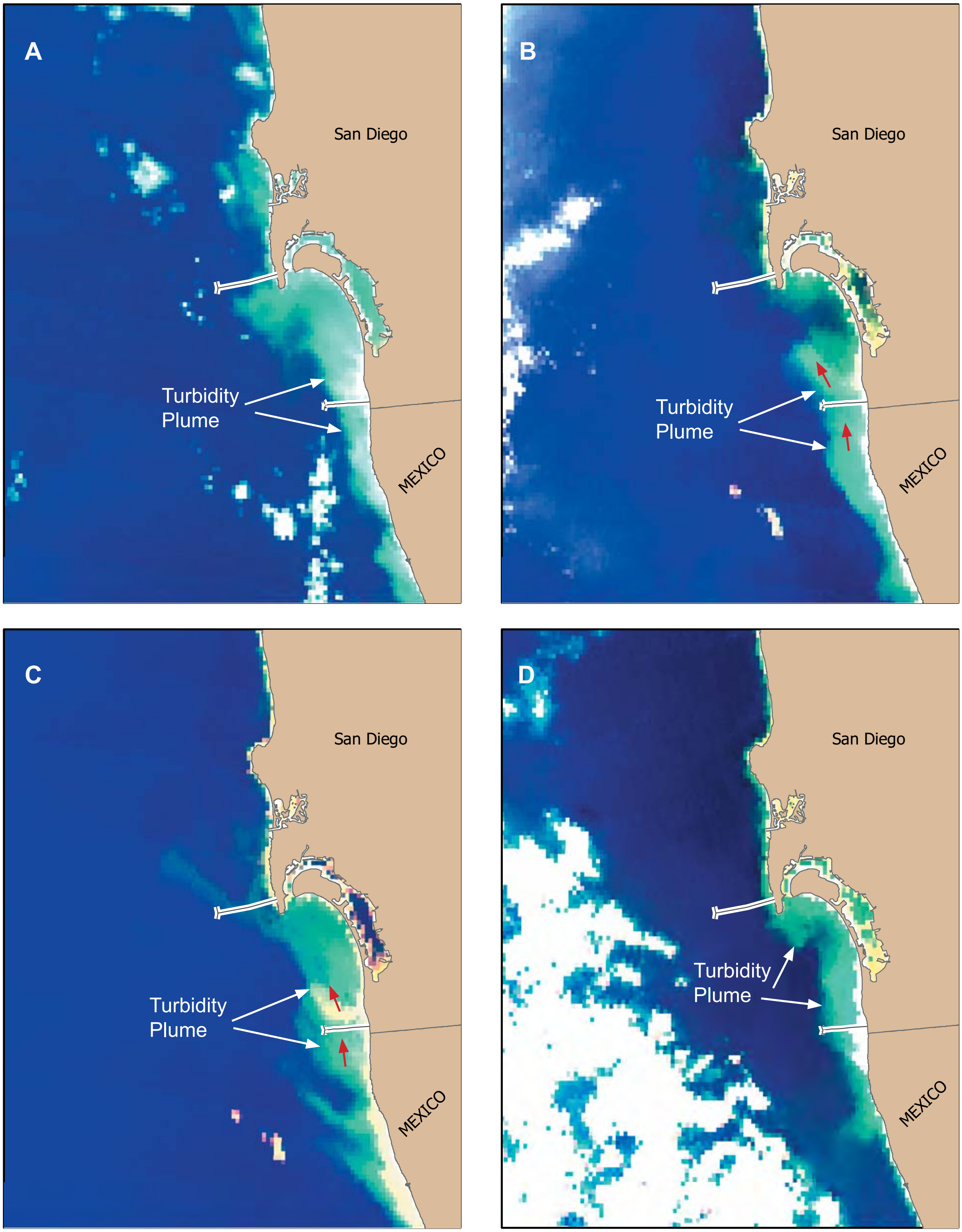

Figure 2.5
MODIS satellite image showing the San Diego water quality monitoring region, captured in 2004 on (A) February 24, (B) October 23, (C) October 30, and (D) December 27. White pixels offshore represent areas obscured by cloud cover. White pixels along the shoreline are the result of "washout" or band saturation due to the histogram stretches used to enhance turbidity features in surface waters.

Northward surface currents carried this very large Tijuana River runoff plume to within 300 m of the outfall wye (Figures 2.5B, C). Even after 20 days without rain DMSC aerial data on December 26 indicated the presence of lingering runoff effects near the outfall area (Figure 2.5D).

Transmissivity was also affected by a regional increase in plankton and wave-caused turbidity over the Tijuana River alluvial fan (Ocean Imaging 2004c, d). During May and June, for example, chlorophyll *a* concentrations increased in the surface waters of the kelp stations and at mid-depths of the offshore sites (Figures 2.3, 2.4). This was accompanied by smaller than expected increases in dissolved oxygen concentrations. Many factors can affect photosynthesis and oxygen production such as the species of plankton present, species succession, population size and position within the water column, nutrient levels, day length, cloud cover, and the time of sampling (Eppley and Holm-Hansen 1986). Water surveys were generally done in the early morning, and maximum levels of oxygen production may not have been achieved upon sampling. Additionally, the lower oxygen value at bottom depths present from May through July is likely due to increased depletion by biological and detrital oxidation (Pickard and Emery 1990). Increased stratification and decaying plankton contribute to this loss of oxygen.

These storm and plankton-driven turbidity patterns in surface waters act as markers of water movement visible in the satellite imagery. From January through September 2004, with few exceptions, aerial imagery of turbidity patterns indicated that water movement was primarily southward (Ocean Imaging 2004a, b, c, d). One exception included a predominantly northward flow that occurred after the first of two significant rain events in April, which caused significant runoff from the Tijuana River to travel as far north as Imperial Beach (Ocean Imaging 2004c). With the transition into fall and the start of record storm activity, surface waters in the outfall region were subject to frequent northward currents. For example, after a heavy storm on October 23 the turbid plume from the Tijuana River reached as far northward and seaward as the SBOO wye (Figure 2.5B). Moreover, during December the outer edge of a very large Tijuana River runoff plume reached to within 300 m of the wye (Ocean Imaging 2005). Despite these occurrences, aerial imagery indicated that the plume generally did not increase in extent after a storm, and riser discharge does not become more visible following early or late rain seasons (Ocean Imaging 2005).

SUMMARY and CONCLUSIONS

Oceanographic conditions during 2004 were generally within expected variability. Above average rainfall was recorded in February, while record rainfall occurred in October and December. The influx of freshwater during these months contributed to shallow haloclines as well as large plumes of turbid water along shore and occasionally near the outfall. Additionally, above average temperatures during the summer contributed to the development of a strong, shallow thermocline/pycnocline that lasted from June through September.

Aerial and satellite imagery detected upwelling events during the summer months that were supported by CTD data in May and June. In addition to upwelled waters, it is likely that cooler, less saline water from the California Current may have been pushed inshore during October leading to a breakdown in stratification between surface and mid-depth waters.

Thermal stratification was strongest from April through mid-October. During summer months (July–September), when water clarity was very high, the wastewater plume was not visible due to the strong thermocline/pycnocline. The thermal stratification that existed throughout most of the year limited detection of the wastewater plume in surface waters. Remote sensing detected the plume at the surface in January and February and in sub-surface shallow waters in March and December. These conditions are supported by patterns of bacterial concentrations discussed in the following chapter.

Reduced water clarity during 2004 was primarily associated with record rainfall and from runoff that resulted in turbid plumes from the Tijuana River and, to a lesser extent, from San Diego Bay. Turbidity associated with the outfall plume did not appear to increase during these events and therefore did not significantly affect regional water clarity. In fact, the observed plume often appeared to move northward and away from the sampling area during periods of greatest storm activity. Chlorophyll concentrations, slight increases in dissolve oxygen levels, and total suspended solids concentrations (see Chapter 3) indicated that plankton blooms contributed to decreased water clarity during May and June. Finally, aerial imagery indicated that runoff from the Tijuana River appeared to be a significant factor in increased turbidity while the plume from the outfall tended to have a less significant effect. In general, the aerial imagery and data for the region's water column properties revealed little evidence of impact from the SBOO.

LITERATURE CITED

Bowden, K.F., 1975. Oceanic and Estuarine Mixing Processes. In: Ed., J.P. Riley and G. Skirrow (eds.) Chemical Oceanography, Vol. 1. Academic Press, San Francisco, p. 1–41.

City of San Diego. (2004a). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (2003). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2004b). Monthly Receiving Waters Monitoring Report for the International Boundary and Water Commission International Wastewater Treatment Plant Discharge to the Pacific Ocean through the South Bay Ocean Outfall, March 2004. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2004c). Monthly Receiving Waters Monitoring Report for the International Boundary and Water Commission International Wastewater Treatment Plant Discharge to the Pacific Ocean through the South Bay Ocean Outfall, October 2004. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (in prep.). EMTS Division Laboratory Quality Assurance Project Plan. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Dailey, M.D., Reish, D.J. and Anderson, J.W. (eds.) (1993). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA. 926 pp.

Eppley. R. W, and O. Holm-Hansen. 1986. Primary Production in the Southern California Bight. In: R. W. Eppley, ed. Lecture Notes on Coastal and Estuarine Studies, Vol.15. Springer-Verlag, New York. pp. 176–215.

NOAA/NWS. (2005). The National Oceanic and Atmospheric Association and the National Weather Service Archive of Local Climate Data for San Diego, CA. http://www.wrh.noaa.gov/sandiego/climate/lcdsan-archive.htm.

North, W.J. (1991). The Kelp Beds of San Diego and Orange Counties. 270 pp.

North, W.J., D.E. James, and L.G. Jones. (1993). History of kelp beds (Macrocystis) in Orange and San Diego Counties, California. Hydrobiologia, 260/261: 277–283.

Ocean Imaging. (2004a). Satellite and Aerial Coastal Water Quality Monitoring in The San Diego/Tijuana Region: Monthly Report for December 2003 & January 2004. Solana Beach, CA.

Ocean Imaging. (2004b). Satellite and Aerial Coastal Water Quality Monitoring in The San Diego/Tijuana Region: Monthly Report for February and March 2004. Solana Beach, CA.

Ocean Imaging. (2004c). Satellite and Aerial Coastal Water Quality Monitoring in The San Diego/Tijuana Region: Monthly Report for April and May 2004. Solana Beach, CA.

Ocean Imaging. (2004d). Satellite and Aerial Coastal Water Quality Monitoring in The San Diego/Tijuana Region: Monthly Report for June, July, August and September 2004. Solana Beach, CA.

Ocean Imaging. (2005). Satellite and Aerial Coastal Water Quality Monitoring in The San Diego/Tijuana Region: Monthly Report for October, November and December 2004. Solana Beach, CA.

Pickard, D.L, and W. J. Emery. 1990. Descriptive Physical Oceanorgraphy. 5th Ed. Pergamon Press, Oxford. 320 pp.

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