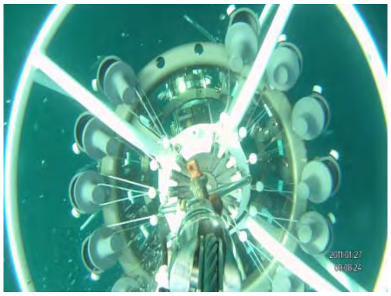
Chapter 3

# COASTAL OCEANOGRAPHY AND WATER QUALITY



Chapter 3
# COASTAL OCEANOGRAPHY AND WATER QUALITY

## INTRODUCTION

The Orange County Sanitation District (District) measures physical, chemical, and biological water quality indicators to determine the location and characteristics of its treated effluent after discharge to the ocean. The goals are to assess discharge-related changes to water quality and compare them to criteria contained in the California Ocean Plan (COP) and the District's NPDES discharge permit to determine compliance (see box) to evaluate potential impacts to the marine environment and public health. This chapter describes results from the July 2010 to June 2011 monitoring year. Chapter 2 (Compliance) has specific compliance evaluation details.

The District's monitoring region extends from Seal Beach down to Crystal Cove State Beach, from the shoreline to approximately 12 km offshore and to a water depth of 550 m. The entire sampling area covers approximately 340 $km^2$ (Figure 3-1). While not part of the Core monitoring program, the District is a member of a regional cooperative sampling effort with the City of Oxnard, City of Los Angeles, the Los Angeles County Sanitation District, and the City of San Diego known as the Central Bight Regional Water Quality Monitoring Program (Central Bight). When combined with the District's program, this additional sampling effectively extends the District's monitoring area north to Ventura County and south to Crystal Cove State Beach (Figure 3-2). The Central Bight monitoring provides regional data that enhances the evaluation of water quality changes due to natural or other anthropogenic discharges (e.g., stormwater) and provides a regional context for comparisons with the District's monitoring results.

Regional and local changes in ocean conditions strongly influence the District's study area on daily, seasonal, and yearly timescales. Large-scale and long-term climatic events, such as the Pacific Decadal Oscillation (PDO) and El Niño/Southern Oscillation (ENSO), also alter local conditions on decadal and multi-year timescales (Linacre 2010, OCSD 2004). These events are notable for producing changes in near coastal water surface temperature and rainfall/runoff in the monitoring area (OCSD 2004). One of the primary differences between PDO and ENSO is that PDO events have cycles of 5–20 years, but may persist for up to 70 years (MacDonald and Case 2005), while a typical ENSO event occurs, on average, every 5 years and may last 6–18 months (Chao et al. 2000, Mantua 2000). Upwelling can also strongly influence water quality and productivity in coastal areas by providing a source of additional nutrients to the coastal environment (Fischer et al. 1979, Sverdrup et al. 1963, Valiela 1995). These natural events modify anthropogenic effects, such as wastewater discharges, dredged material disposal, atmospheric deposition, and runoff from adjacent watersheds. Recent findings on the impact of climate change to the coastal ocean have the potential to exacerbate human influences to coastal receiving waters by altering water temperature and chemistry (e.g., salinity and pH), precipitation and associated runoff, and ocean circulation (Howarth et al. 2011, Scavia et al. 2002, Tynan and Opdyke 2011). These changes have the potential to affect where or if a particular species may occur and in what numbers.

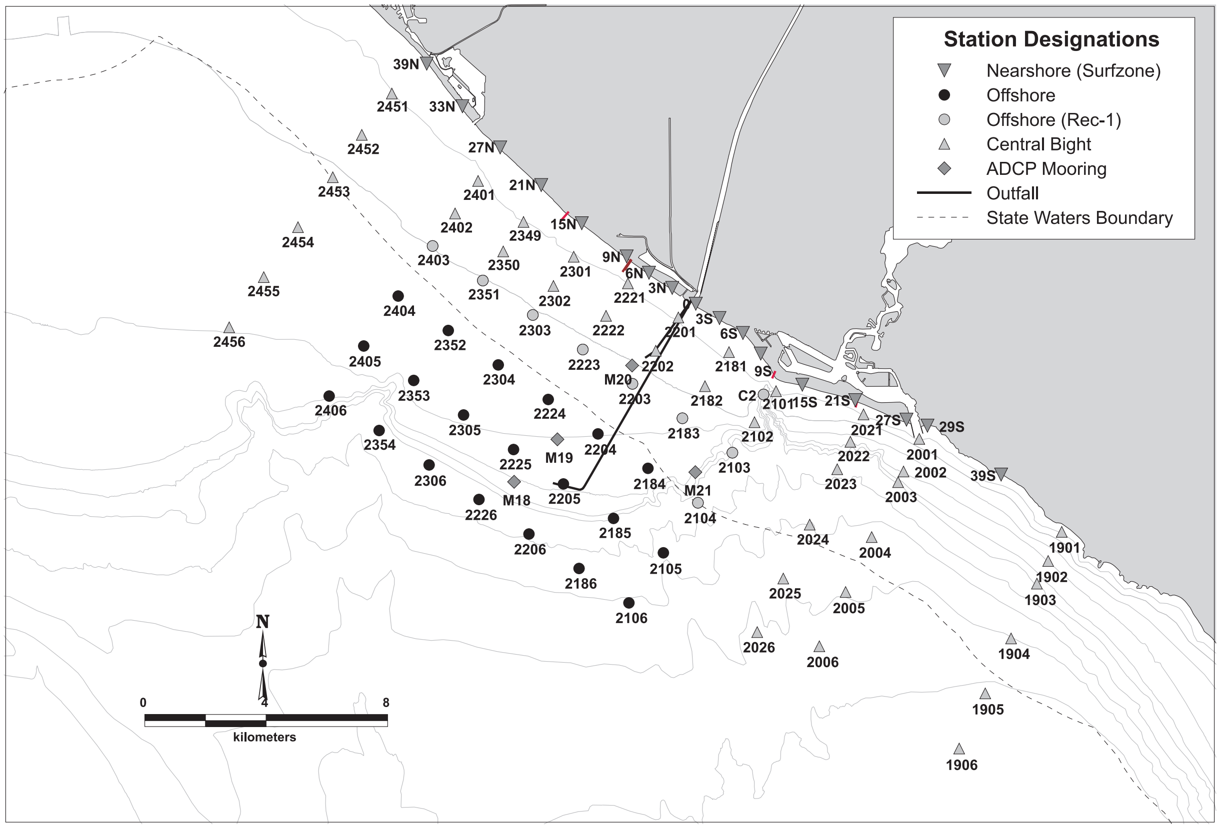



**Figure 3-1.** Water quality monitoring and current meter stations for 2010-11.

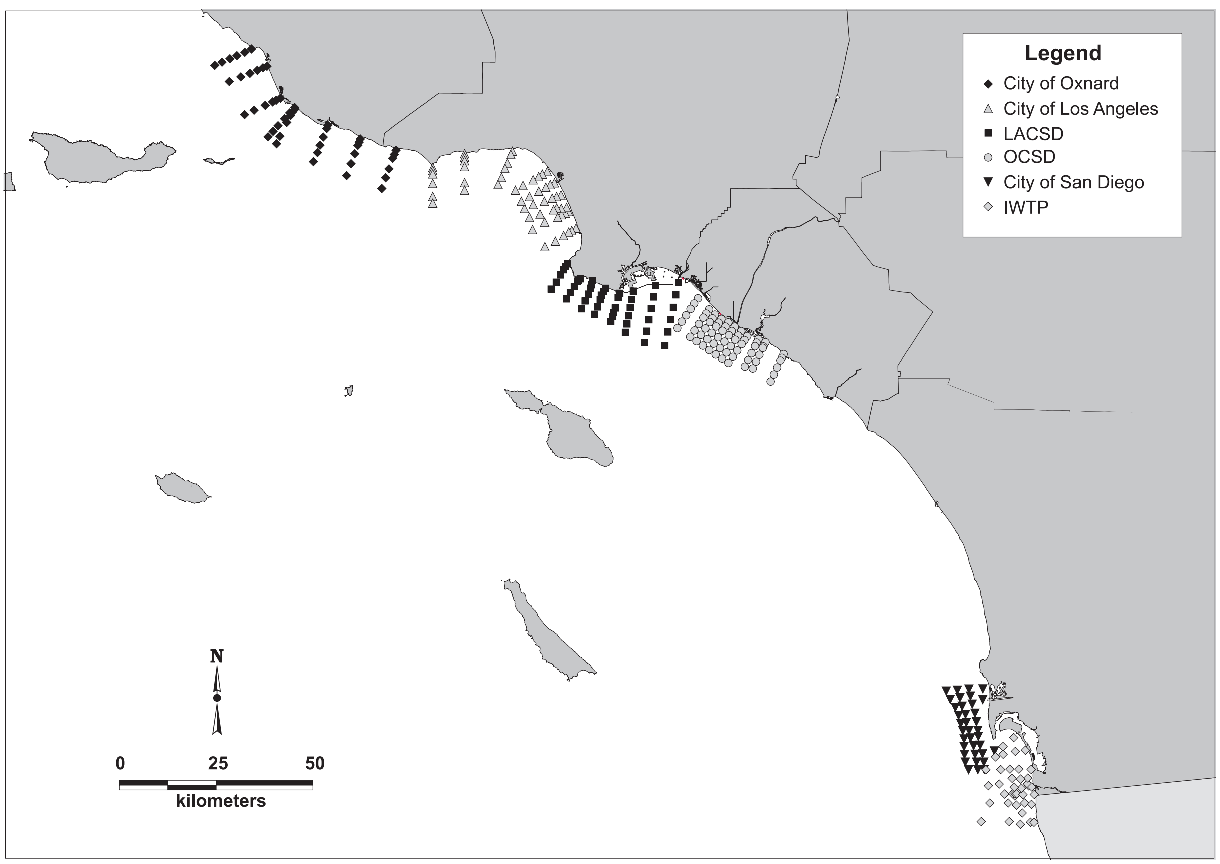



**Figure 3-2.** Sampling locations for the Central Bight Regional Water Quality Monitoring Program.

Orange County Sanitation District, California.

| **Compliance Criteria Pertaining to Water Quality Contained in the District's NPDES Ocean Discharge Permit (Order No. R8-2004-0062, Permit No. CAO110604).** | | |
|---|---|---|
| Criteria | | Description |
| C.2.a.1 | Total coliform (water contact) | Samples of water from each sampling station shall have a density of total coliform organisms less than 1,000 per 100 ml (10 per ml); provided that not more than 20 percent of the samples at any sampling station, in any 30-day period, may exceed 1,000 per 100 ml (10 per ml), and provided further that no single sample when verified by a repeat sample taken within 48 hours shall exceed 10,000 per 100 ml (100 per ml). |
| C.2.a.2 | Fecal coliform (water contact) | The fecal coliform density based on a minimum of not less than five samples for any 30-day period, shall not exceed a geometric mean of 200 per 100 ml nor shall more than 10 percent of the total samples during any 60-day period exceed 400 per 100 ml. |
| C.2.b | Shellfish harvesting standards | Within the Nearshore Zone, the following bacterial objectives shall be maintained throughout the water column: The median total coliform density shall not exceed 70 per 100 ml, and not more than 10 percent of the samples shall exceed 230 per 100 ml. |
| C.3.a | Floating particulates, oils and grease | Floating particulates, grease, and oil shall not be visible. |
| C.3.b | Water clarity and discoloration | The discharge of waste shall not cause aesthetically undesirable discoloration of the ocean surface. |
| C.3.c | Light transmittance | Natural light shall not be significantly reduced at any point outside the initial dilution zone as a result of the discharge of waste. |
| C.4.a | Dissolved oxygen | The dissolved oxygen concentration shall not at any time be depressed more than 10 percent from that which occurs naturally, as the result of the discharge of oxygen demanding waste materials. |
| C.4.b | Acidity (pH) | The pH shall not be changed at any time more than 0.2 units from that which occurs naturally. |
| C.4.f | Nutrients | Nutrient materials shall not cause objectionable aquatic growths or degrade indigenous biota. |

Wastewater discharges from the District's outfall dilute quickly by being "jetted" out through 503 discharge portholes located in the last 1.6 km of the outfall pipe. This initial dilution greatly reduces observable differences between the discharged less saline or "fresh" wastewater and seawater. Predicted changes to receiving water quality from the discharge are proportional to the ratio of wastewater mixed with seawater. The initial dilution ratio used in the District's NPDES permit is 180:1 and represents the lower 10$^{th}$ percentile; the mean was 352:1 (Tetra Tech 2008). Using the minimum centerline dilution of 124:1, predicted changes to receiving waters were small (Table 3-1) and fall within typical natural ranges and thereby represent low potential risks to the environment or human health.

**Table 3-1. Summary of selected final effluent and receiving water parameters and expected changes compared to natural seawater at 31-45 m depths from the wastewater discharge at a minimum centerline dilution of 124:1.**

Orange County Sanitation District, California.

| Parameter | Final Effluent Mean | Approx. Natural Mean | Expected Change (%) | COP/AB411 Objectives |
|---|---|---|---|---|
| Temperature (°C) | 25.10 | 11.39 | Increase up to 0.11 | Not Applicable |
| Salinity (psu) | 2.25 | 33.46 | Decrease up to 0.25 | Not Applicable |
| Dissolved Oxygen (mg/L) | 1.52 | 5.26 | Decrease up to 0.03 | <10% decrease |
| pH | 7.20 | 7.91 | Decrease up to 0.01 | <0.2 units |
| Ammonium (mg/L) | 30 | 0.2 | Increase up to 0.24 | Not Applicable |
| Total Coliform (MPN/100 mL) | 50,365 | 0 | Increase up to 403 | 10,000 single sample<br>1,000 geomean |
| Fecal Coliform (MPN/100 mL) | 7,280 | 0 | Increase up to 58 | 400 single sample<br>200 geomean |
| Enterococcus (MPN/100 mL) | 2,003 | 0 | Increase up to 16 | 104 single sample<br>35 geomean |

Two other factors limit potential discharge effects besides initial dilution. Dynamic mixing with the ocean water and transportation away from the diffuser by prevailing ocean currents further diluted the effluent. These currents include both large-scale ocean currents (e.g., Southern California Eddy) as well as smaller-scale local currents (Dailey et al. 1993, Noble and Xu 2004, Noble et al. 2009, OCSD 2010, SCCWRP 1973, SWRCB 1965). Additionally, natural water layering or stratification restricts the upward movement of the wastewater plume toward the surface; stratification off southern California is principally due to temperature (SWRCB 1965). Stratification restricts observable discharge-related changes to below 30–40 m depths during most surveys and plume rise into the upper 10 m of the water column is limited to less than 2 percent of the time (Tetra Tech 2002, 2008). These results were similar to other discharges studied by Petrenko et al. (1998) and Wu et al. (1994). Previous reports provide detailed analysis of currents (OCSD 1994; SAIC 2009, 2011), comparisons of water quality data with long-term historical trends (OCSD 1992, 1993, 1996a, b, 2004), and summaries of natural seasonal and human-related factors that affect dilution and movement of the wastewater discharge (OCSD 2004).

# METHODS

## Field Surveys

### Core Nearshore

Collection of nearshore water samples for analysis of fecal indicator bacteria (FIB)—total and fecal coliform and enterococci—were taken at the surfzone in ankle deep water, 3–5 days per week at 17 surfzone stations (Table A-1, Figure 3-1). The occurrence and size of any grease particles at the high tide line was recorded twice a week.

### Core Offshore

Each quarter (summer, fall, winter, and spring) three surveys were completed at 29 offshore stations (Table A-1, Figure 3-1). Three additional days of sampling were done at a subset of nine stations within 30 days of two of the full-scale grid sampling dates for calculating compliance with water contact (Rec-1) bacterial standards (Table A-2). During most surveys, additional bacteriological samples were collected at outfall Station 2205 and two nearfield locations, Stations 1 and 9 (Table A-1).

A Seabird© electronic sensor package (aka CTD) measured conductivity (used to calculate salinity), temperature, and depth (using pressure). Additional sensors on the package included dissolved oxygen (DO), pH, water clarity (transmissivity), chlorophyll-*a*, colored dissolved organic matter (CDOM), and photosynthetically active radiation (PAR). Data was collected 24 times/second using Seasoft (2010a) data collection software on both the downcast and upcast from 1 m below the surface ("surface" sample) to 2 m above the bottom or to a maximum depth of 75 m. Discrete samples were collected at specified depths at a subset of stations, nine for FIB and 20 for ammonia (NH3-N) (Table A-1). For 2010-11, three additional outfall and near-outfall stations were sampled for bacteria in order to better define an outfall gradient. Visual observations of water clarity (measured as Secchi-disc depth), water color, and floatable materials were also obtained at each station.

Both PAR and Secchi depth provide measures of natural light penetration through the water column. Use of a Secchi disk dates back to the mid-1800s and still represents a low cost method of studying water clarity. Even though Secchi depth methodology is standardized, data quality issues remain due to the inherent problem of seeing the disk under varying lighting conditions, different readings obtained by different technicians, and the imprecision of measuring depth manually using a marked line. PAR measurements obtained using a CTD offer several advantages over Secchi disks, including the ability to obtain continuous light penetration values throughout the water column as well as standardized measures not subject to human variability (i.e., differences in eyesight).

<u>Central Bight</u>

Each quarter, the five participating Central Bight agencies sampled an expanded station grid (Table A-1, Figures 3-1 and 3-2) using similarly equipped CTDs and comparable field sampling methods. The primary differences between sampling efforts lies in the maximum depth sampled and the number of days each survey took to complete. The District samples to a maximum of 75 m, while some of the other agencies sample up to 100 m. The District did not collect discrete water samples at the Central Bight stations.

<u>Currents</u>

Ocean currents were obtained using Teledyne RD Instruments acoustic Doppler current profilers (ADCP) (Table A-3, Figure 3-1). Set on the ocean bottom, three ADCPs (Stations M20, M19, and M18) were located along a line parallel to the outfall and approximately perpendicular to the local bathymetry at about 20 m, 40 m, and 60 m, respectively. The fourth ADCP (Station M21) was located at 55 m water depth downcoast from the main mooring line and adjacent to the shelf break on the western flank of the Newport Canyon. Current speed and direction were taken every 6 minutes at 1 m intervals throughout the water column along with bottom water temperatures. Instrument set up was done using WinSC (2003). After recovery, data was exported using WinADCP (2003).

### Data Processing and Analysis

Seasonal and annual tabular and graphic depictions of nearshore and offshore water quality data were compiled using IGODS (2010), Excel (2010), Deltagraph (2009), Surfer (2004), and/or SYSTAT (2007). ADCP data was processed using MATLAB (2007) routines. Offshore water quality data was grouped into five 15-meter bins for statistical analysis. Consistent with the method used to calculate 30-day geometric means for bacteria, non-detect values for FIBs below detection replaced with either 75% or 125% of the respective lower and upper detection limits (Appendix A); non-detect NH3-N values were handled in the same manner.

Appendix A contains more information on the methods used for collection and analysis of the water quality data. Compliance determinations with water quality criteria are discussed in Chapter 2 (Compliance).

## RESULTS AND DISCUSSION

### Regional Water Quality Conditions

This section focuses on summarizing large-scale oceanographic conditions and provides quarterly comparisons for selected parameters from the regional Central Bight program.

Several ocean ecosystem indices, such as the PDO, ENSO, and Upwelling Index are indicators of ocean conditions for the California Current system. As these indices change so too do the regional ocean conditions (Figure 3-3). During 2010-11, the warm PDO conditions (red) of the previous year changed back to the cool phase (blue), indicating a return to a cooler oceanographic regime that began in the fall of 2007 and continued through and 2009. The PDO mirrored the ENSO Index, which denoted the end of an El Niño in June 2010 and the development of a moderate to strong La Niña that persisted into the spring of 2011. Compared to previous years, the Upwelling Anomaly Index for 2010-11 was more variable and smaller in magnitude. The low values of this index, which represents potential productivity along the coast, indicated that 2010-11 was a weak upwelling year.

Temperature stratification was present at the Central Bight stations throughout the year, with surface to bottom temperature differences ranging from 4–10.5 °C (Table 3-2, Figure 3-4). Overall, summer waters were the warmest, and had the largest temperature range. Cooler surface waters were evident off Ventura with several areas of much warmer water located in Santa Monica Bay, off the Palos Verdes Peninsula, and inshore on the San Pedro Shelf. Fall surface temperatures were more uniform, with warmer average temperatures throughout the water column. The water column cooled significantly in winter. Surface waters dropped ~3 °C with uniformly cooler temperature distributions north to south. However, surface waters in the inner portion of Santa Monica Bay, off the San Pedro Shelf, and south to Crystal Cove State Beach warmed in the spring. There was also evidence of upwelling along the Ventura coast and off the Palos Verdes Peninsula (see light blue surface water in Figure 3-4).

Salinity patterns changed with season and depth (Figure 3-5). A notable region-wide feature in the summer and fall was a subsurface lower (bluer) salinity layer across the Central Bight. This subarctic water is transported into the area by the California Current at water depths (30–45 m) coinciding with where wastewater plumes stabilize after mixing with receiving waters; prior to regional sampling, this layer was often misinterpreted as plume-affected water. Other local features include fresh water inputs from the Los Angeles/Long Beach Harbors throughout the year, but most notably in the summer when there was no rainfall; these were the lowest salinity values measured for the entire year (Table 3-2). The lower surface water salinity in the fall and winter was most likely due to runoff from in October and December 2010 (see Figure 1-4). There was deep mixing of the low salinity surface waters off the San Pedro Shelf in winter and, the higher, subsurface salinity values (red to brown) throughout the study area during each season. Off Ventura, higher salinities, reached the surface in both the summer and spring.

Regionally DO values ranged from almost 14 mg/L at the surface in the spring to just over 2.5 mg/L at depth in the summer (Table 3-2, Figure 3-6). All DO values were above levels considered stressful (OCSD 1995) or hypoxic (USGS 2006). Strong gradients were present throughout the water column each season. Throughout the region, each season had DO values >10 mg/L with both the lowest (subsurface) and highest (surface) DO values occurring in the spring. High spring DO values are often associated with seasonal upwelling and higher productivity as evidenced by chlorophyll-*a*. However, for 2010-11 the lowest subsurface DO values (minimum and average) occurred in the summer quarter and the spatial and temporal patterns for DO and chlorophyll-a differed (see section below).

Chlorophyll-*a*, used as a surrogate for phytoplankton biomass, varied widely, both seasonally and regionally (Figure 3-7). Typically, both the maximum values and widest range occur in the spring. In 2010-11, both summer and spring had comparable chlorophyll-*a* concentrations (Table 3-2). Summer 2010 values were almost twice that of the previous summer. Highest concentrations were in surface waters off Ventura and on the inshore portion of the San Pedro Shelf. Subsurface maximums were evident throughout the region in all quarters.

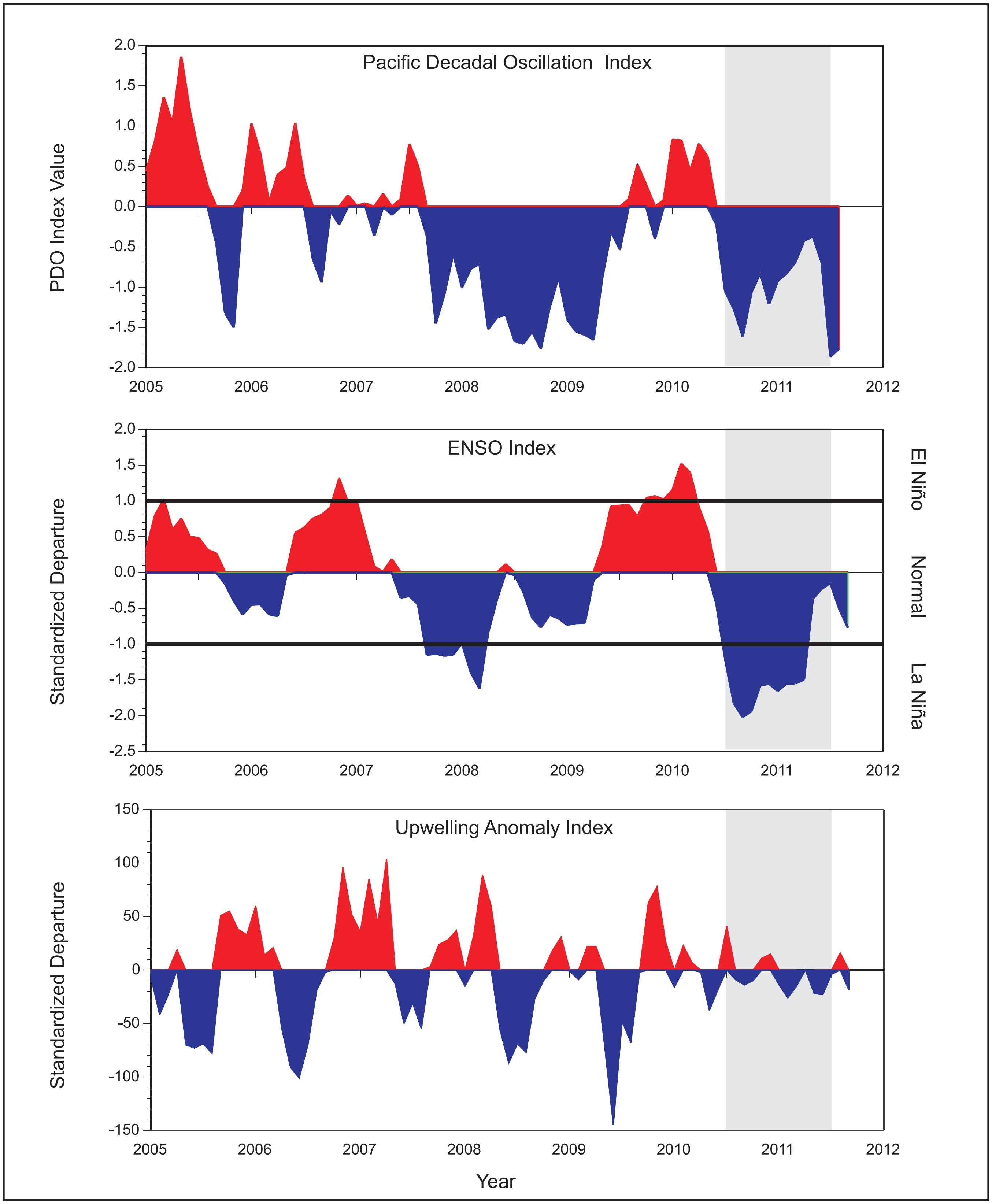



**Figure 3-3. Standardized values for the Pacific Decadal Oscillation (PDO), El Niño Southern Oscillation (ENSO), and Upwelling Anomaly indices, 2005–2011.**
**Current program year denoted in gray.**

PDO: http://jisao.washington.edu/pdo/PDO.latest
ENSO: http://www.cdc.noaa.gov/people/klaus.wolter/MEI/mei.htm
Upwelling: ftp://orpheus.pfeg.noaa.gov/outgoing/upwell/monthly/upanoms.mon

Orange County Sanitation District, California.

**Table 3-2. Summary of quarterly water quality parameters for the Central Bight Regional Water Quality Monitoring Program by season during 2010-11.**

Orange County Sanitation District, California.

| | Parameter | Temperature (°C) | Density (kg/m3) | Salinity (psu) | pH (pH units) | Dissolved Oxygen (mg/L) | Oxygen Saturation (mg/L) | Oxygen Saturation (%) | Light Transmission (%) | Beam C (1/M) | Chlorophyll-a (µg/L) | CDOM (µg/L) | Ammonia (mg/L) | Total coliforms (MPN)* | Fecal coliforms (MPN) * | E. coli (MPN) * | Enterococcus (MPN) * |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Summer | Min | 9.63 | 22.61 | 32.36 | 7.60 | 2.56 | 7.56 | 28.24 | 44.47 | 0.33 | 0.11 | 0.00 | <0.02 | 2 | 2 | <10 | <2 |
| | Mean | 12.18 | 25.40 | 33.54 | 7.94 | 5.78 | 8.71 | 67.35 | 83.43 | 4.20 | 6.05 | 1.01 | 0.03 | 67 | 7 | 39 | 15 |
| | Max | 19.18 | 26.17 | 33.94 | 8.40 | 10.16 | 9.17 | 128.79 | 92.06 | 0.74 | 67.52 | 3.21 | 0.23 | 2,000 | 50 | 1100 | 480 |
| Fall | Min | 9.69 | 23.11 | 32.79 | 7.62 | 3.03 | 7.65 | 33.35 | 25.54 | 0.31 | 0.22 | 0.01 | <0.02 | <2 | <10 | <10 | <2 |
| | Mean | 13.37 | 25.07 | 33.42 | 7.96 | 6.25 | 8.51 | 74.45 | 84.87 | 6.24 | 4.40 | 0.70 | 0.03 | 44 | 7 | 24 | 12 |
| | Max | 18.89 | 26.05 | 33.83 | 8.37 | 9.43 | 9.17 | 119.24 | 92.62 | 0.67 | 39.19 | 3.00 | 0.22 | >2000 | 40 | 880 | 340 |
| Winter | Min | 9.45 | 24.12 | 32.73 | 7.67 | 2.91 | 8.16 | 31.59 | 22.78 | 0.39 | 0.02 | 0.43 | <0.02 | <2 | <2 | <10 | <2 |
| | Mean | 12.22 | 25.31 | 33.43 | 8.00 | 6.25 | 8.70 | 72.58 | 83.87 | 5.15 | 4.21 | 1.10 | 0.03 | 290 | 84 | 75 | 15 |
| | Max | 15.44 | 26.23 | 33.95 | 8.29 | 10.00 | 9.20 | 122.35 | 90.62 | 0.72 | 31.72 | 2.93 | 0.29 | 24196 | 5372 | 4884 | 340 |
| Spring | Min | 9.56 | 24.09 | 33.21 | 7.66 | 3.05 | 7.76 | 33.24 | 22.71 | 0.42 | 0.36 | 0.21 | <0.02 | 2 | 2 | <10 | <2 |
| | Mean | 11.85 | 25.48 | 33.56 | 7.92 | 5.41 | 8.77 | 62.64 | 82.68 | 0.78 | 6.31 | 0.89 | 0.03 | 110 | 6 | 45 | 13 |
| | Max | 17.87 | 26.20 | 33.94 | 8.41 | 11.28 | 9.19 | 136.03 | 89.94 | 5.93 | 65.76 | 3.09 | 0.24 | >2000 | 20 | 700 | 220 |
| Annual | Min | 9.45 | 22.61 | 32.36 | 7.60 | 2.56 | 7.56 | 28.24 | 22.71 | 0.31 | 0.02 | 0.02 | <0.02 | <2 | <2 | <10 | <2 |
| | Mean | 12.41 | 25.31 | 33.49 | 7.96 | 5.92 | 8.67 | 69.26 | 83.71 | 0.73 | 5.24 | 0.93 | 0.03 | 128 | 26 | 46 | 14 |
| | Max | 19.18 | 26.20 | 33.94 | 8.41 | 11.28 | 9.19 | 136.03 | 92.62 | 6.24 | 67.52 | 3.21 | 0.24 | 2000 | 84 | 1100 | 480 |

* Bacteria data from City of Oxnard, Hyperion, and OCSD
NS = not sampled

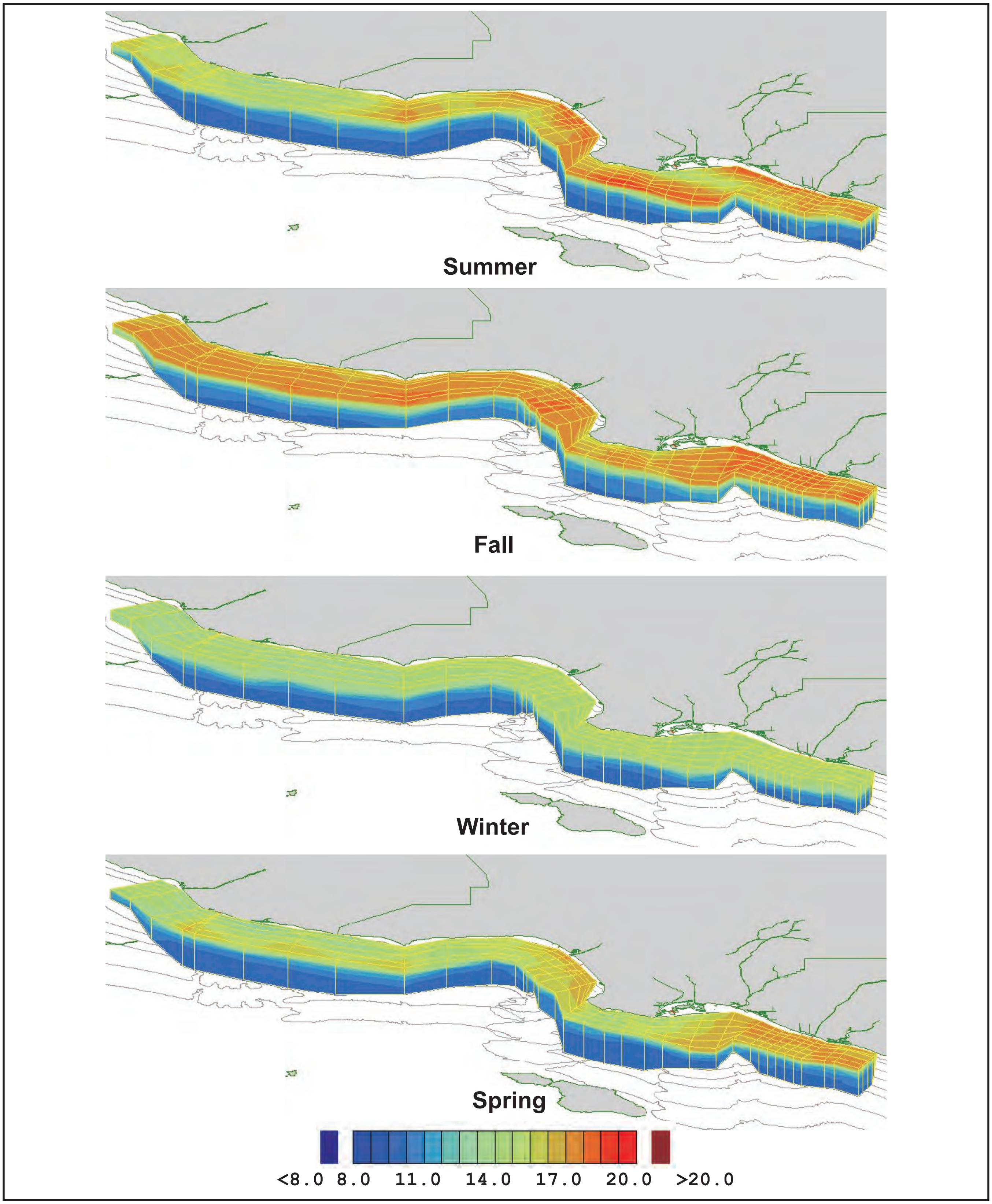



**Figure 3-4.** **Seasonal patterns of temperature (°C) for summer (August 2010), fall (November 2010), winter (February 2011), and spring (May 2011) for the Central Bight Regional Water Quality Monitoring Program grid.**

Orange County Sanitation District, California.

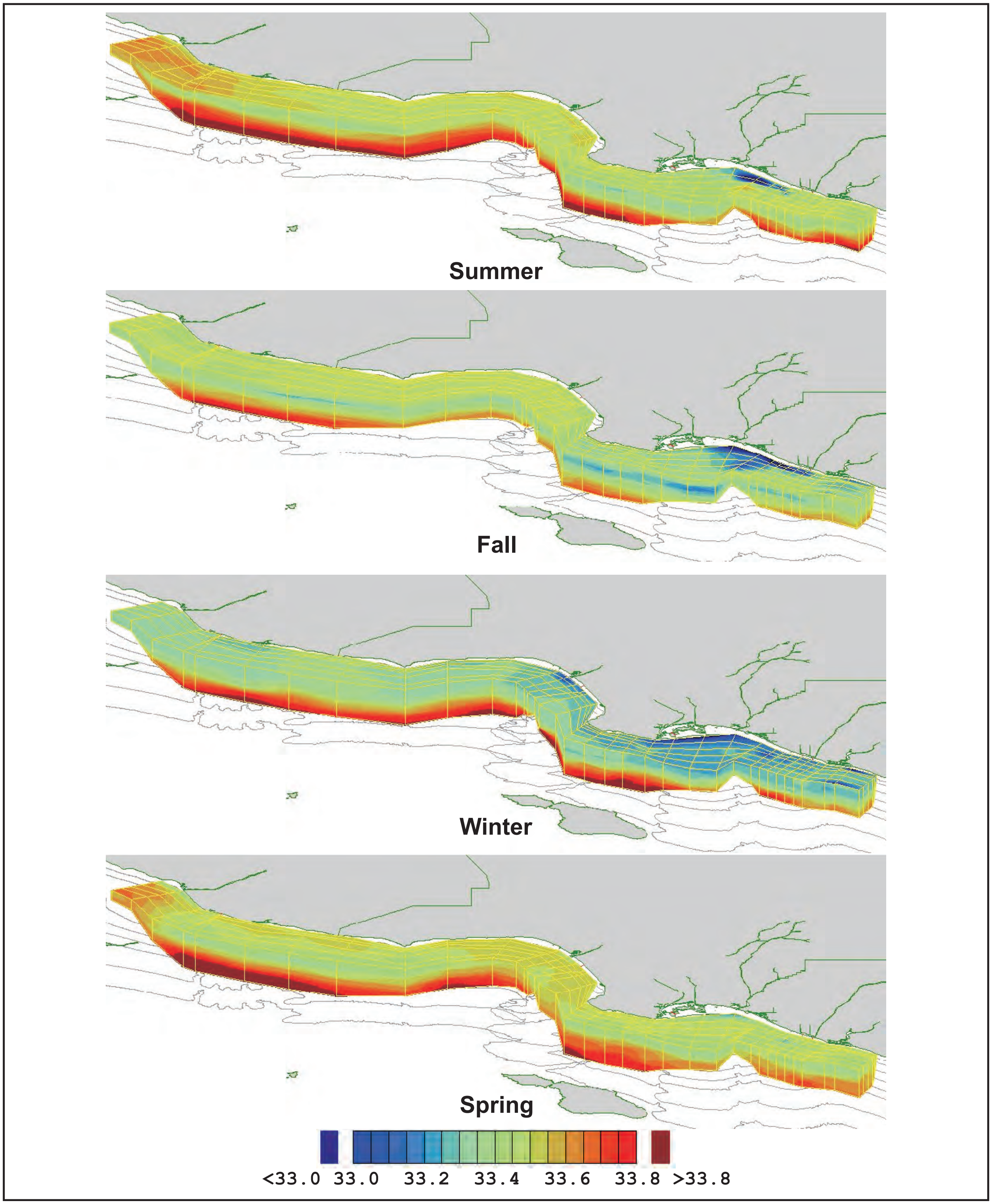



**Figure 3-5.** **Seasonal patterns of salinity (psu) for summer (August 2010), fall (November 2010), winter (February 2011), and spring (May 2011) for the Central Bight Regional Water Quality Monitoring Program grid.**

Orange County Sanitation District, California.

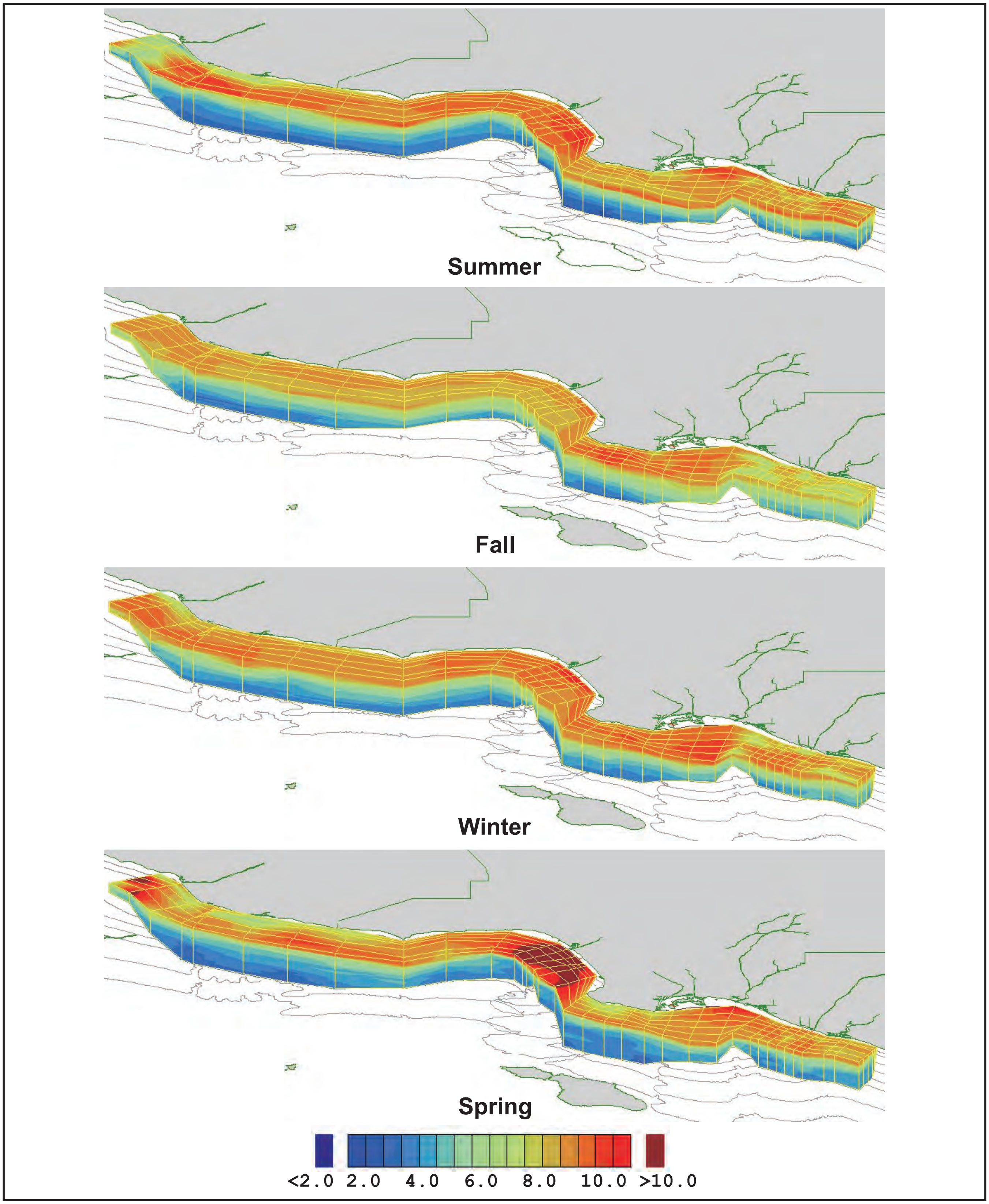



**Figure 3-6.** **Seasonal patterns of dissolved oxygen (mg/L) for summer (August 2010), fall (November 2010), winter (February 2011), and spring (May 2011) for the Central Bight Regional Water Quality Monitoring Program grid.**

Orange County Sanitation District, California.

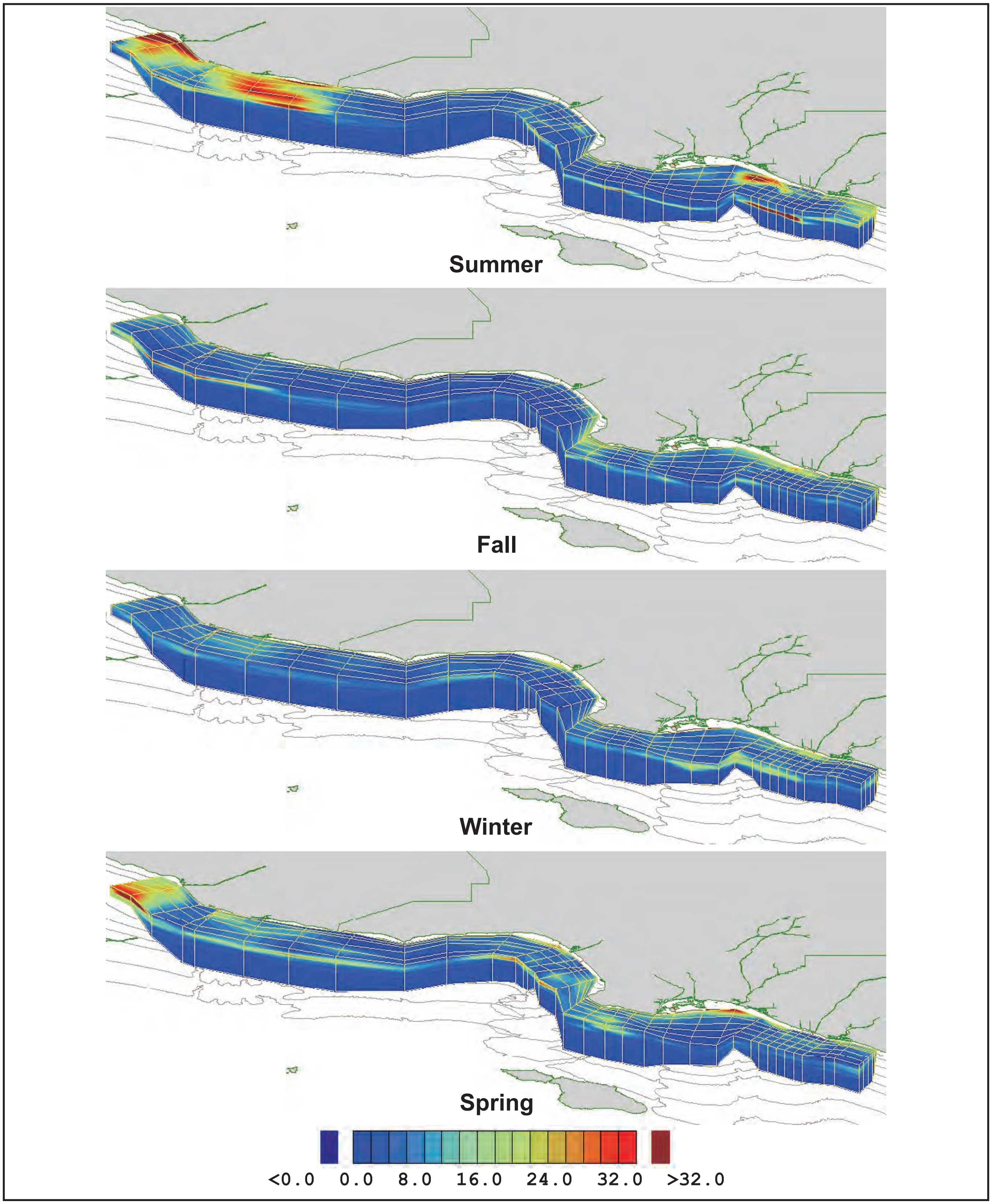



**Figure 3-7.** **Seasonal patterns of chlorophyll-*a* (µg/L) for summer (August 2010), fall (November 2010), winter (February 2011), and spring (May 2011) for the Central Bight Regional Water Quality Monitoring Program grid.**

Orange County Sanitation District, California.

## Local Water Quality Conditions

This section focuses on data collected for both the Nearshore (surfzone) and Offshore sampling programs, and includes seasonal comparisons and determinations of plume impacts.

Nearshore (Surfzone) Bacteria

Summer and spring mean values for total and fecal coliforms were at or just below the lower method detection limit while enterococci were mostly above (Table 3-3, Figure 3-8). Fall and winter mean and maximum values were, with few exceptions, higher at all stations. Elevated values for all three FIBs were associated with the Talbert Marsh (TM) and the Santa Ana River (SAR). Maximum summer values for total and fecal coliform bacteria were lowest north of Station 6N, and then became elevated and variable from the Talbert Marsh to Station 3S. Summer enterococci spatial patterns were similar to total and fecal coliforms, but were less variable. All three spiked at Station 21S (Balboa Pier parking lot) where an earlier investigation linked elevated coliform concentrations to an onshore source (OCSD 1998). Mean and maximum values for all three FIBS increased in the fall at all stations, most likely tied to rainfall in October 2010 (Chapter 1), with maximum values near or above their respective single sample limits. The TM and SAR sources were evident as was the Bolsa Chica outlet near Station 27N for enterococci. Elevated winter mean and maximum values occurred at the SAR with impacts tapering off to roughly 6N upcoast and 6S downcoast. Enterococci counts were again elevated at 27N.
.

Over the year, maximum counts of total and fecal coliform decreased from north to south with the SAR strongly influencing fecal coliform concentrations. Many of the enterococci values exceeded the upper detection limit preventing analysis of spatial patterns. However, mean values had a similar north to south decline, as did the two coliform bacteria. The spatial pattern of exceedances—a consistent peak at Stations 27N and a broader area of affect from Stations 15N to 9S with a peak at Station 3N—mirrored these results (Figure 2-1).

Currents and Bottom Temperatures

Current meter and bottom temperature data were not continuous for the monitoring year. There was coverage during each quarter, but for only 9 of the 12 full water quality surveys (Tables A-2 and A-3). The vast majority (91–97%) of current speeds for 2010-11 were less than 20 cm/s (or 0.45 mph) with the highest speeds (>40 cm/s) recorded at the M19 and M20 (Figures 3-9, 3-10, B-2 to B-7). The predominant flow at all stations at depths below about 10 m was alongshore and upcoast Surface currents tended to be equally distributed in direction, but still alongshore; the exception being the 20 m Station M20, which had predominantly downcoast surface currents There was also a deflection of deeper currents to the west (away from the coast). Results were consistent with last year, including a general bias of upcoast flow. While the alongshore flows were consistent with previous current meter results (OCSD 2004, SAIC 2009, SAIC 2011), the predominant upcoast flow differed from previous findings (e.g., SAIC 2009) where the likelihood of up- or downcoast transport at plume depth (waters below 30 m) was equal.

As expected, bottom water temperatures increased from the offshore stations, M18 and M21, to the inshore station, M20 (Figures 3-9 and 3-10, B-2 to B-7). The warmest temperatures occurred in the fall and winter. There was no temperature data for spring, but by June, they were beginning to increase. Pulses of warm water came onto the shelf around mid-July, early and mid-October, and late December.

Temperature and Density

Water temperature varied with depth and season (Table 3-4, Figure 3-11). The upper 30 m, had the highest maximum temperatures, the biggest annual range and, except for winter, temperatures were twice as variable as those below 30 m. Winter temperatures were the least variable season indicating less water column stratification. While the warmest temperature and the largest range occurred in the summer, the highest average temperature at all depths was in the fall. Below 15 m, winter 2011 had warmer water than summer 2010 and had the warmest average water for the 31-45 m

**Table 3-3. Summary statistics for surfzone total coliform, fecal coliform, and enterococcus bacteria (MPN/100 mL) by station and seasons during 2010-11.**

Orange County Sanitation District, California.

| Station | Summer | | | | Fall | | | | Winter | | | | Spring | | | | Annual | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min | Mean | Max | Std Dev | Min | Mean | Max | Std Dev | Min | Mean | Max | Std Dev | Min | Mean | Max | Std Dev | Min | Mean | Max | Std Dev |
| **Total Coliform** | | | | | | | | | | | | | | | | | | | | |
| **39N** | 11.0 | 21.0 | 150 | 1.9 | 13.5 | 53.1 | 5,200 | 4.7 | 13.5 | 26.7 | 13,000 | 3.9 | 13.5 | 17.5 | 440 | 1.9 | 11.0 | 26.4 | 13,000 | 3.3 |
| **33N** | 13.5 | 19.0 | 91 | 1.7 | 13.5 | 62.9 | 8,000 | 5.5 | 13.5 | 31.2 | 2,600 | 3.4 | 13.5 | 17.9 | 350 | 1.8 | 13.5 | 28.1 | 8,000 | 3.4 |
| **27N** | 13.5 | 17.6 | 310 | 1.8 | 13.5 | 65.4 | 12,000 | 5.4 | 13.5 | 41.3 | 3,000 | 3.4 | 13.5 | 20.0 | 800 | 2.1 | 13.5 | 30.6 | 12,000 | 3.4 |
| **21N** | 13.5 | 17.9 | 220 | 1.7 | 13.5 | 70.4 | 18,750 | 7.2 | 13.5 | 32.9 | 3,600 | 3.4 | 13.5 | 25.0 | 860 | 2.9 | 13.5 | 31.4 | 18,750 | 4.0 |
| **15N** | 13.5 | 21.4 | 200 | 2.1 | 13.5 | 79.6 | 11,000 | 7.8 | 13.5 | 59.2 | 4,800 | 3.8 | 13.5 | 23.4 | 1,000 | 2.5 | 13.5 | 38.5 | 11,000 | 4.3 |
| **12N** | 13.5 | 21.4 | 220 | 2.1 | 13.5 | 74.8 | 8,000 | 7.0 | 13.5 | 43.7 | 4,000 | 3.6 | 13.5 | 23.7 | 640 | 2.3 | 13.5 | 35.3 | 8,000 | 3.9 |
| **9N** | 13.5 | 23.3 | 150 | 1.9 | 13.5 | 61.9 | 8,400 | 7.0 | 13.5 | 43.2 | 5,800 | 3.6 | 13.5 | 20.0 | 500 | 2.1 | 13.5 | 32.9 | 8,400 | 3.8 |
| **6N** | 13.5 | 26.1 | 560 | 2.6 | 13.5 | 64.2 | 7,000 | 5.8 | 13.5 | 60.5 | 7,800 | 3.9 | 13.5 | 24.2 | 420 | 2.4 | 13.5 | 39.1 | 7,800 | 3.8 |
| **3N** | 13.5 | 46.4 | 2,300 | 4.2 | 13.5 | 60.4 | 8,200 | 6.0 | 13.5 | 89.1 | 8,000 | 5.1 | 13.5 | 21.5 | 1,400 | 2.4 | 13.5 | 47.8 | 8,200 | 4.7 |
| **TM** | 13.5 | 22.0 | 200 | 2.0 | 13.5 | 148.7 | 25,000 | 8.0 | 13.5 | 128.0 | 15,000 | 4.8 | 13.5 | 33.2 | 11,000 | 3.9 | 13.5 | 59.1 | 25,000 | 5.5 |
| **0** | 13.5 | 24.6 | 1,300 | 2.5 | 13.5 | 80.6 | 5,600 | 6.1 | 13.5 | 175.6 | 12,000 | 7.5 | 13.5 | 26.4 | 1,400 | 2.7 | 13.5 | 54.3 | 12,000 | 5.5 |
| **SAR-N** | 13.5 | 28.7 | 720 | 2.6 | 13.5 | 54.5 | 21,000 | 5.2 | 13.5 | 670.2 | 20,000 | 8.0 | 13.5 | 43.5 | 1,800 | 4.7 | 13.5 | 78.8 | 21,000 | 7.4 |
| **SAR-S** | 13.5 | 26.9 | 290 | 2.6 | 13.5 | 62.8 | 17,000 | 5.3 | 13.5 | 657.4 | 21,250 | 7.8 | 13.5 | 43.9 | 2,000 | 4.8 | 13.5 | 79.6 | 21,250 | 7.4 |
| **3S** | 13.5 | 16.7 | 1,800 | 2.0 | 13.5 | 50.6 | 11,250 | 6.9 | 13.5 | 120.0 | 9,000 | 5.4 | 13.5 | 20.1 | 11,000 | 2.6 | 13.5 | 37.1 | 11,250 | 4.9 |
| **6S** | 13.5 | 15.9 | 73 | 1.5 | 13.5 | 45.2 | 5,400 | 5.0 | 13.5 | 73.6 | 6,000 | 4.0 | 13.5 | 19.3 | 5,000 | 3.0 | 13.5 | 31.3 | 6,000 | 3.8 |
| **9S** | 13.5 | 16.6 | 330 | 1.7 | 13.5 | 42.7 | 4,800 | 5.2 | 13.5 | 48.5 | 700 | 3.3 | 13.5 | 14.7 | 36 | 1.3 | 13.5 | 26.3 | 4,800 | 3.2 |
| **15S** | 13.5 | 15.3 | 150 | 1.6 | 13.5 | 42.8 | 6,800 | 4.8 | 13.5 | 30.5 | 520 | 2.8 | 13.5 | 14.9 | 160 | 1.4 | 13.5 | 23.1 | 6,800 | 2.9 |
| **21S** | 13.5 | 16.8 | 1,200 | 2.1 | 13.5 | 42.4 | 3,250 | 4.8 | 13.5 | 26.5 | 980 | 2.5 | 13.5 | 17.7 | 55 | 1.6 | 13.5 | 23.7 | 3,250 | 2.9 |
| **27S** | 13.5 | 15.3 | 150 | 1.5 | 13.5 | 29.9 | 1,800 | 4.2 | 13.5 | 22.1 | 180 | 2.1 | 13.5 | 15.1 | 55 | 1.3 | 13.5 | 19.6 | 1,800 | 2.4 |
| **29S** | 13.5 | 17.0 | 130 | 1.6 | 13.5 | 39.0 | 5,400 | 4.8 | 13.5 | 35.0 | 6,400 | 3.8 | 13.5 | 21.1 | 380 | 2.0 | 13.5 | 26.2 | 6,400 | 3.1 |
| **39S** | 13.5 | 16.5 | 1,400 | 1.9 | 13.5 | 37.0 | 4,000 | 4.7 | 13.5 | 25.2 | 820 | 2.9 | 13.5 | 17.3 | 130 | 1.6 | 13.5 | 22.5 | 4,000 | 2.9 |
| **All** | 11.0 | 20.4 | 2,300 | 2.2 | 13.5 | 56.8 | 25,000 | 5.8 | 13.5 | 60.9 | 21,250 | 5.4 | 13.5 | 21.7 | 11,000 | 2.6 | 11.0 | 34.6 | 25,000 | 4.2 |

**Table 3-3 continues.**

**Table 3-3 Continued.**

| Station | Summer | | | | Fall | | | | Winter | | | | Spring | | | | Annual | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min | Mean | Max | Std Dev | Min | Mean | Max | Std Dev | Min | Mean | Max | Std Dev | Min | Mean | Max | Std Dev | Min | Mean | Max | Std Dev |
| **Fecal Coliform** | | | | | | | | | | | | | | | | | | | | |
| **39N** | 13.5 | 18.3 | 130 | 1.7 | 13.5 | 27.3 | 3,200 | 3.3 | 13.5 | 15.4 | 240 | 1.5 | 13.5 | 15.0 | 36 | 1.3 | 13.5 | 18.3 | 3,200 | 2.1 |
| **33N** | 13.5 | 17.3 | 150 | 1.7 | 13.5 | 29.4 | 1,800 | 3.2 | 13.5 | 19.4 | 580 | 2.0 | 13.5 | 17.0 | 110 | 1.6 | 13.5 | 20.1 | 1,800 | 2.2 |
| **27N** | 13.5 | 16.3 | 220 | 1.7 | 13.5 | 31.1 | 2,400 | 3.6 | 13.5 | 22.1 | 400 | 2.1 | 13.5 | 15.1 | 240 | 1.5 | 13.5 | 20.1 | 2,400 | 2.3 |
| **21N** | 13.5 | 16.5 | 55 | 1.4 | 13.5 | 32.1 | 3,400 | 4.1 | 13.5 | 20.8 | 460 | 2.1 | 13.5 | 16.6 | 150 | 1.6 | 13.5 | 20.5 | 3,400 | 2.4 |
| **15N** | 13.5 | 18.2 | 220 | 1.7 | 13.5 | 37.6 | 2,400 | 4.2 | 13.5 | 26.6 | 720 | 2.5 | 13.5 | 18.8 | 250 | 1.9 | 13.5 | 24.0 | 2,400 | 2.7 |
| **12N** | 13.5 | 19.6 | 250 | 1.9 | 13.5 | 37.0 | 2,000 | 4.3 | 13.5 | 22.4 | 920 | 2.4 | 13.5 | 19.8 | 220 | 1.9 | 13.5 | 23.6 | 2,000 | 2.7 |
| **9N** | 13.5 | 22.2 | 180 | 2.1 | 13.5 | 29.8 | 2,000 | 3.8 | 13.5 | 22.1 | 1,000 | 2.2 | 13.5 | 16.0 | 73 | 1.4 | 13.5 | 21.9 | 2,000 | 2.4 |
| **6N** | 13.5 | 25.7 | 440 | 2.5 | 13.5 | 27.2 | 1,200 | 3.2 | 13.5 | 24.8 | 3,200 | 2.6 | 13.5 | 18.2 | 130 | 1.7 | 13.5 | 23.7 | 3,200 | 2.5 |
| **3N** | 13.5 | 38.2 | 2,200 | 4.1 | 13.5 | 30.2 | 5,400 | 4.0 | 13.5 | 31.0 | 1,100 | 2.9 | 13.5 | 15.8 | 36 | 1.3 | 13.5 | 27.4 | 5,400 | 3.2 |
| **TM** | 13.5 | 20.5 | 220 | 2.0 | 13.5 | 48.1 | 14,000 | 5.4 | 13.5 | 33.6 | 1,200 | 3.0 | 13.5 | 22.2 | 3,800 | 2.5 | 13.5 | 28.9 | 14,000 | 3.3 |
| **0** | 13.5 | 20.9 | 1,500 | 2.3 | 13.5 | 37.0 | 5,000 | 3.6 | 13.5 | 46.2 | 4,200 | 3.9 | 13.5 | 18.5 | 860 | 2.1 | 13.5 | 28.3 | 5,000 | 3.1 |
| **SAR-N** | 13.5 | 22.0 | 720 | 2.4 | 13.5 | 28.4 | 8,200 | 4.1 | 13.5 | 129.7 | 9,600 | 7.3 | 13.5 | 26.8 | 6,800 | 3.6 | 13.5 | 38.1 | 9,600 | 4.9 |
| **SAR-S** | 13.5 | 20.9 | 290 | 2.2 | 13.5 | 29.1 | 14,000 | 3.7 | 13.5 | 147.9 | 8,600 | 6.5 | 13.5 | 28.0 | 4,600 | 3.6 | 13.5 | 39.6 | 14,000 | 4.7 |
| **3S** | 13.5 | 15.9 | 820 | 1.9 | 13.5 | 29.0 | 2,600 | 3.6 | 13.5 | 35.1 | 3,000 | 3.3 | 13.5 | 16.3 | 660 | 1.9 | 13.5 | 22.5 | 3,000 | 2.8 |
| **6S** | 13.5 | 14.5 | 91 | 1.3 | 13.5 | 23.2 | 800 | 2.6 | 13.5 | 20.2 | 200 | 2.0 | 13.5 | 17.0 | 220 | 1.8 | 13.5 | 18.3 | 800 | 2.0 |
| **9S** | 13.5 | 14.2 | 250 | 1.4 | 13.5 | 24.5 | 620 | 2.8 | 13.5 | 18.1 | 180 | 1.8 | 13.5 | 13.9 | 36 | 1.1 | 13.5 | 17.1 | 620 | 1.9 |
| **15S** | 13.5 | 14.6 | 110 | 1.3 | 13.5 | 23.9 | 1,100 | 2.5 | 13.5 | 18.6 | 560 | 2.0 | 13.5 | 14.5 | 55 | 1.3 | 13.5 | 17.4 | 1,100 | 1.9 |
| **21S** | 13.5 | 17.2 | 900 | 2.1 | 13.5 | 23.6 | 1,000 | 2.7 | 13.5 | 17.7 | 73 | 1.6 | 13.5 | 15.1 | 110 | 1.5 | 13.5 | 18.0 | 1,000 | 2.0 |
| **27S** | 13.5 | 14.2 | 73 | 1.2 | 13.5 | 20.3 | 560 | 2.5 | 13.5 | 14.3 | 55 | 1.3 | 13.5 | 13.8 | 18 | 1.1 | 13.5 | 15.4 | 560 | 1.6 |
| **29S** | 13.5 | 15.5 | 55 | 1.4 | 13.5 | 24.2 | 1,000 | 3.0 | 13.5 | 19.9 | 5,000 | 2.6 | 13.5 | 18.0 | 160 | 1.7 | 13.5 | 19.0 | 5,000 | 2.2 |
| **39S** | 13.5 | 13.9 | 36 | 1.1 | 13.5 | 20.0 | 860 | 2.7 | 13.5 | 15.8 | 180 | 1.6 | 13.5 | 15.0 | 73 | 1.4 | 13.5 | 15.9 | 860 | 1.8 |
| **All** | 13.5 | 18.3 | 2,200 | 2.0 | 13.5 | 28.5 | 14,000 | 26.5 | 13.5 | 26.5 | 9,600 | 3.2 | 13.5 | 17.3 | 6,800 | 1.9 | 13.5 | 22.0 | 14,000 | 2.7 |

**Table 3-3 continues.**

**Table 3-3 Continued.**

| Station | Summer | | | | Fall | | | | Winter | | | | Spring | | | | Annual | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min | Mean | Max | Std Dev | Min | Mean | Max | Std Dev | Min | Mean | Max | Std Dev | Min | Mean | Max | Std Dev | Min | Mean | Max | Std Dev |
| **Enterococcus** | | | | | | | | | | | | | | | | | | | | |
| **39N** | 1.5 | 5.9 | 86 | 3.3 | 1.5 | 8.0 | 500 | 5.5 | 1.5 | 3.5 | 500 | 3.3 | 1.5 | 3.0 | 84 | 2.7 | 1.5 | 4.7 | 500 | 3.8 |
| **33N** | 1.5 | 6.4 | 114 | 3.0 | 1.5 | 19.2 | 500 | 4.7 | 1.5 | 9.2 | 500 | 3.7 | 1.5 | 5.0 | 250 | 4.1 | 1.5 | 8.5 | 500 | 4.2 |
| **27N** | 1.5 | 4.4 | 44 | 2.5 | 1.5 | 29.7 | 500 | 5.0 | 1.5 | 27.7 | 500 | 3.2 | 1.5 | 6.1 | 500 | 3.7 | 1.5 | 11.9 | 500 | 4.6 |
| **21N** | 1.5 | 5.2 | 56 | 2.7 | 1.5 | 18.9 | 500 | 5.3 | 1.5 | 16.1 | 500 | 3.6 | 1.5 | 4.1 | 150 | 2.9 | 1.5 | 8.8 | 500 | 4.2 |
| **15N** | 1.5 | 6.1 | 62 | 2.9 | 1.5 | 14.8 | 500 | 5.4 | 1.5 | 18.0 | 500 | 3.1 | 1.5 | 4.8 | 500 | 3.2 | 1.5 | 9.3 | 500 | 4.0 |
| **12N** | 1.5 | 5.3 | 58 | 3.2 | 1.5 | 13.9 | 500 | 5.6 | 1.5 | 12.6 | 500 | 3.8 | 1.5 | 5.0 | 180 | 3.1 | 1.5 | 8.2 | 500 | 4.1 |
| **9N** | 1.5 | 6.0 | 68 | 3.0 | 1.5 | 10.0 | 500 | 5.3 | 1.5 | 11.2 | 500 | 3.8 | 1.5 | 4.0 | 500 | 3.1 | 1.5 | 7.1 | 500 | 3.9 |
| **6N** | 1.5 | 7.3 | 316 | 3.8 | 1.5 | 12.9 | 500 | 4.9 | 1.5 | 14.2 | 500 | 3.8 | 1.5 | 4.6 | 40 | 2.9 | 1.5 | 8.8 | 500 | 4.1 |
| **3N** | 1.5 | 14.5 | 500 | 5.8 | 1.5 | 12.5 | 500 | 4.9 | 1.5 | 18.1 | 500 | 4.4 | 1.5 | 4.0 | 50 | 2.5 | 1.5 | 10.7 | 500 | 4.8 |
| **TM** | 1.5 | 5.2 | 372 | 3.2 | 1.5 | 15.7 | 500 | 5.6 | 1.5 | 17.3 | 500 | 4.3 | 1.5 | 3.7 | 500 | 2.7 | 1.5 | 8.4 | 500 | 4.5 |
| **0** | 1.5 | 4.7 | 366 | 3.2 | 1.5 | 13.9 | 500 | 5.6 | 1.5 | 34.5 | 500 | 5.1 | 1.5 | 4.4 | 68 | 3.0 | 1.5 | 9.8 | 500 | 5.3 |
| **SAR-N** | 1.5 | 3.8 | 98 | 2.8 | 1.5 | 8.5 | 500 | 6.2 | 2.0 | 89.6 | 500 | 4.6 | 1.5 | 6.4 | 356 | 4.9 | 1.5 | 11.5 | 500 | 6.9 |
| **SAR-S** | 1.5 | 5.3 | 114 | 3.0 | 1.5 | 12.9 | 500 | 5.8 | 4.0 | 100.8 | 500 | 4.2 | 1.5 | 9.4 | 272 | 4.5 | 1.5 | 15.7 | 500 | 6.3 |
| **3S** | 1.5 | 2.6 | 66 | 2.6 | 1.5 | 9.0 | 500 | 6.3 | 1.5 | 18.7 | 500 | 4.6 | 1.5 | 3.3 | 70 | 3.0 | 1.5 | 6.0 | 500 | 4.9 |
| **6S** | 1.5 | 2.1 | 18 | 1.8 | 1.5 | 9.7 | 626 | 5.3 | 1.5 | 10.7 | 500 | 3.4 | 1.5 | 2.7 | 20 | 2.3 | 1.5 | 4.8 | 626 | 3.9 |
| **9S** | 1.5 | 2.0 | 20 | 1.7 | 1.5 | 7.8 | 500 | 4.5 | 1.5 | 6.7 | 128 | 3.4 | 1.5 | 2.2 | 18 | 1.9 | 1.5 | 3.8 | 500 | 3.3 |
| **15S** | 1.5 | 2.4 | 500 | 2.9 | 1.5 | 6.9 | 500 | 4.8 | 1.5 | 5.8 | 500 | 4.2 | 1.5 | 2.9 | 34 | 2.4 | 1.5 | 4.0 | 500 | 3.8 |
| **21S** | 1.5 | 2.7 | 500 | 2.6 | 1.5 | 6.6 | 196 | 4.9 | 1.5 | 4.3 | 140 | 3.3 | 1.5 | 2.8 | 24 | 2.3 | 1.5 | 3.8 | 500 | 3.4 |
| **27S** | 1.5 | 2.2 | 14 | 1.8 | 1.5 | 4.5 | 224 | 4.3 | 1.5 | 2.9 | 38 | 2.3 | 1.5 | 2.0 | 18 | 1.8 | 1.5 | 2.7 | 224 | 2.7 |
| **29S** | 1.5 | 2.7 | 24 | 2.1 | 1.5 | 7.0 | 500 | 4.7 | 1.5 | 4.5 | 116 | 3.4 | 1.5 | 3.1 | 170 | 2.7 | 1.5 | 4.0 | 500 | 3.4 |
| **39S** | 1.5 | 1.8 | 10 | 1.5 | 1.5 | 5.5 | 500 | 6.7 | 1.5 | 3.6 | 238 | 3.4 | 1.5 | 2.5 | 28 | 2.2 | 1.5 | 3.0 | 500 | 3.5 |
| **All** | 1.5 | 4.1 | 500 | 3.2 | 1.5 | 10.6 | 626 | 5.6 | 1.5 | 12.3 | 500 | 5.1 | 1.5 | 3.8 | 500 | 3.1 | 1.5 | 6.6 | 626 | 4.6 |

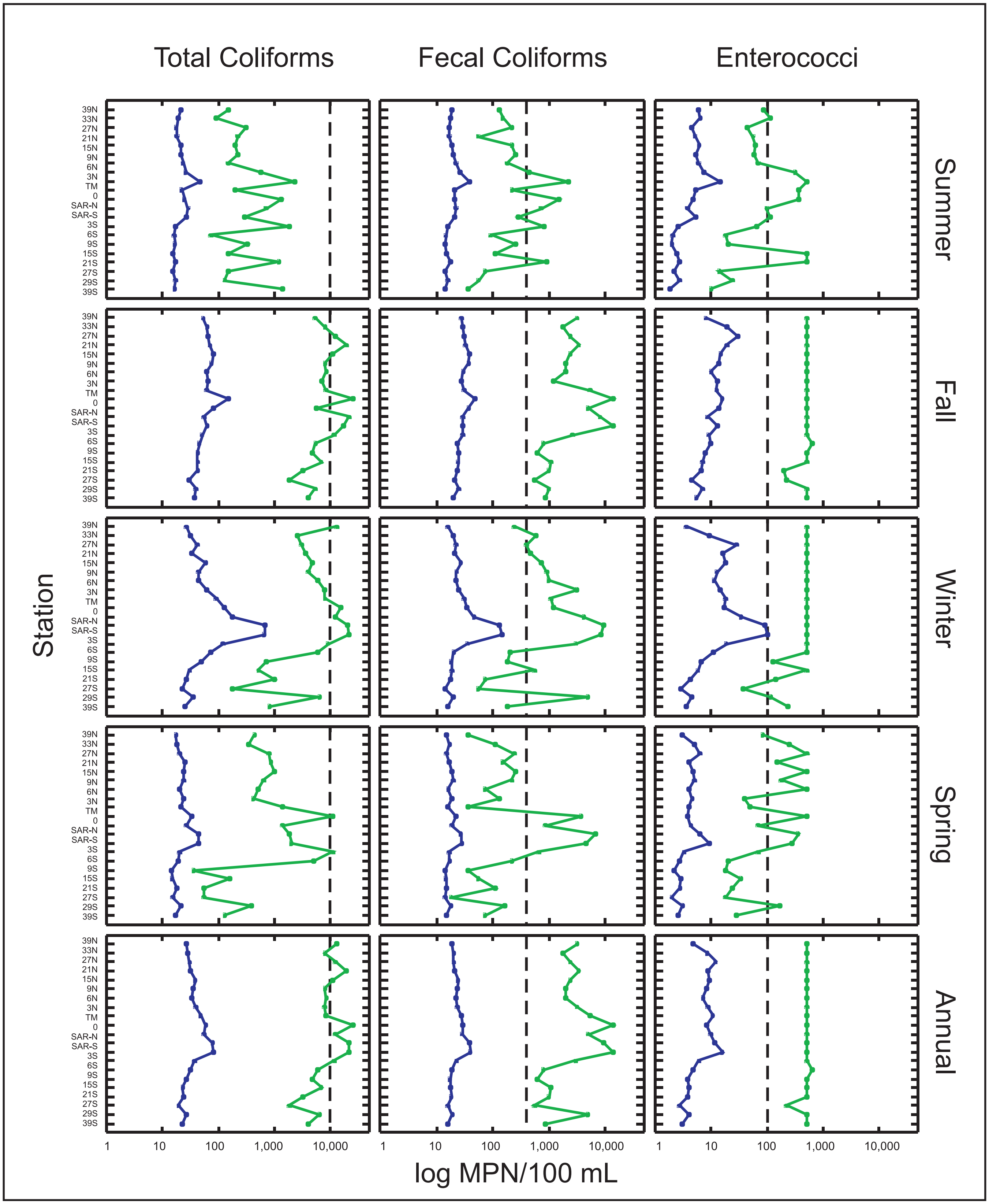



**Figure 3-8.** **Seasonal distribution of total coliform, fecal coliform, and enterococci bacteria at the District's nearshore (surfzone) water quality stations for July 1, 2010 to June 30, 2011.** **Blue line = geometric mean for the season, green line = maximum value during the season, dashed vertical line = single sample limit.**

Orange County Sanitation District, California.

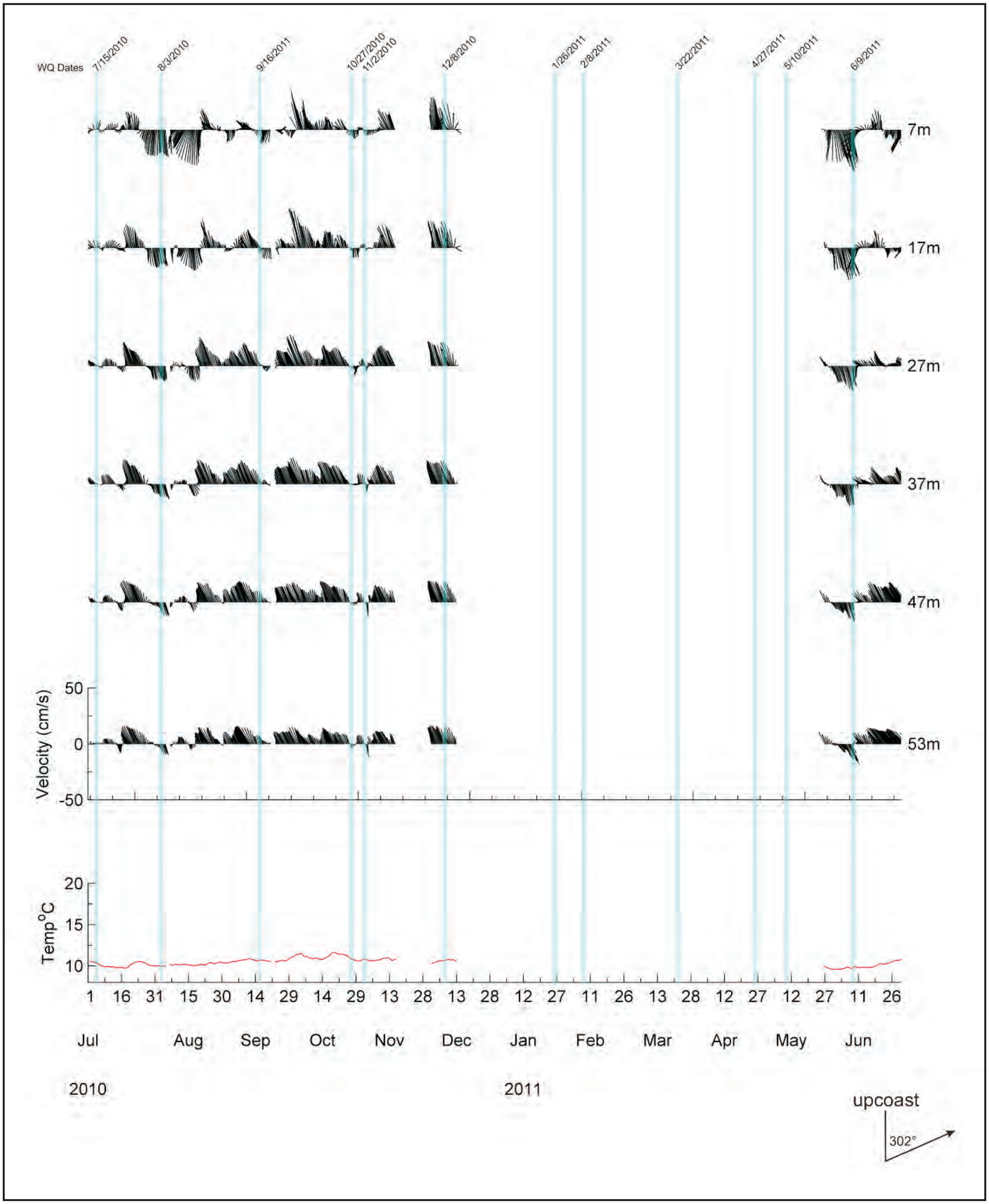



**Figure 3-9. Bottom temperature (°C) and current speed (cm/s) and direction by depth for mooring M-18, July 2010–June 2011.**
**Blue lines denote water quality sampling events.**

Orange County Sanitation District, California.

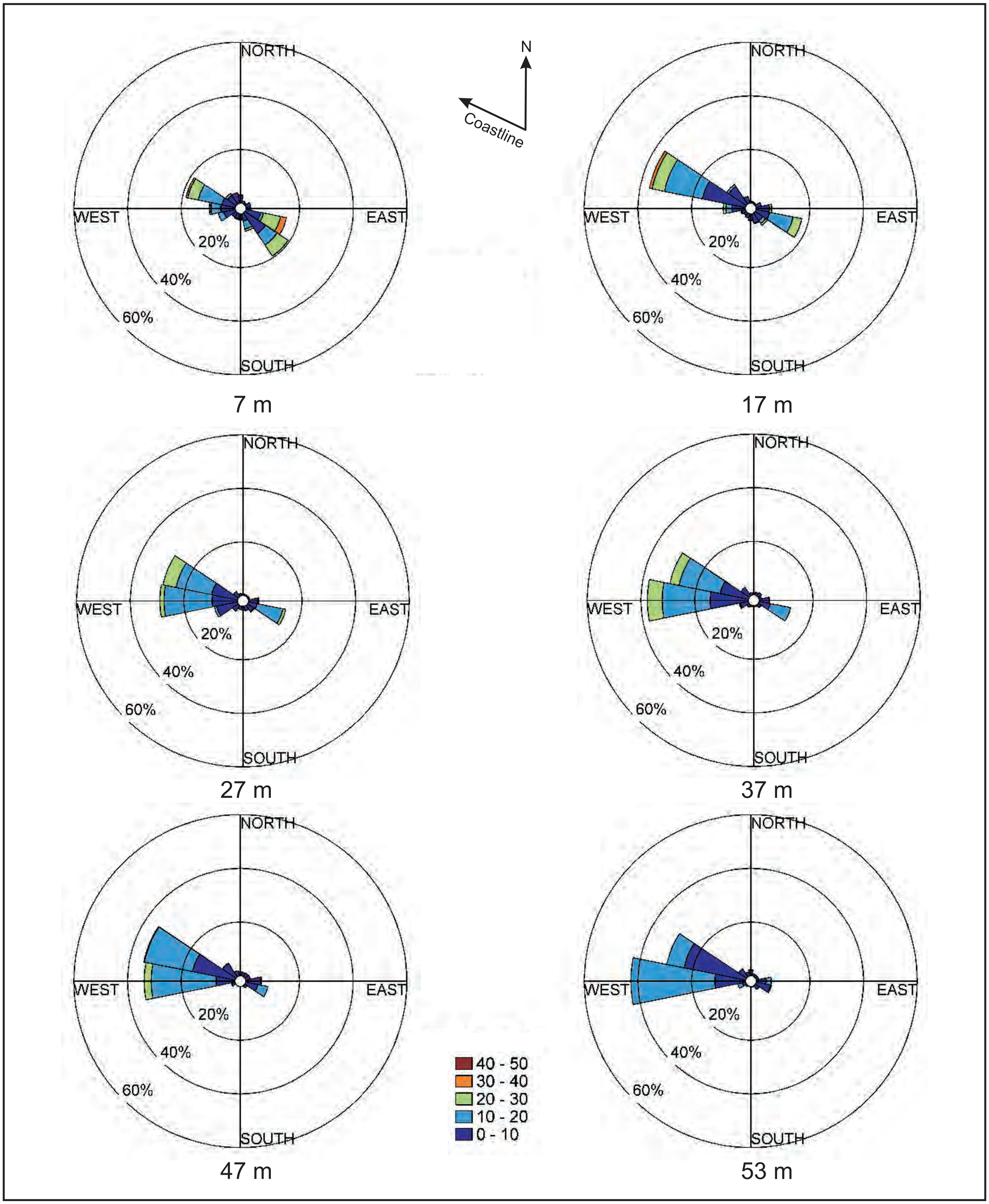



**Figure 3-10. Average current speed (cm/s) and direction by depth for mooring M-18, July 2010–June 2011.**

Orange County Sanitation District, California.

**Table 3-4. Summary of quarterly water quality parameters by depth strata and season during 2010-11.**

Orange County Sanitation District, California.

| Depth (m) | Summer 2010 | | | | Fall 2010 | | | | Winter 2011 | | | | Spring 2011 | | | | Annual | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min | Mean | Max | Std Dev | Min | Mean | Max | Std Dev | Min | Mean | Max | Std Dev | Min | Mean | Max | Std Dev | Min | Mean | Max | Std Dev |
| **Temperature (°C)** | | | | | | | | | | | | | | | | | | | | |
| **1-15** | 11.61 | 15.60 | 20.07 | 1.53 | 12.82 | 16.62 | 18.89 | 1.62 | 12.56 | 14.21 | 15.13 | 0.35 | 10.30 | 14.71 | 17.87 | 1.75 | 10.30 | 15.25 | 20.07 | 1.68 |
| **16-30** | 10.29 | 12.21 | 16.35 | 1.00 | 11.18 | 13.70 | 17.99 | 1.30 | 11.37 | 13.64 | 14.59 | 0.53 | 9.95 | 11.75 | 15.23 | 0.95 | 9.95 | 12.87 | 17.99 | 1.30 |
| **31-45** | 9.82 | 10.78 | 12.22 | 0.41 | 10.58 | 11.71 | 15.24 | 0.58 | 10.19 | 12.31 | 14.42 | 0.91 | 9.71 | 10.60 | 12.23 | 0.45 | 9.71 | 11.39 | 15.24 | 0.94 |
| **46-60** | 9.46 | 10.30 | 11.14 | 0.29 | 10.29 | 11.00 | 12.17 | 0.37 | 9.97 | 10.99 | 13.83 | 0.68 | 9.58 | 10.15 | 10.89 | 0.26 | 9.46 | 10.63 | 13.83 | 0.59 |
| **61-75** | 9.27 | 10.09 | 10.73 | 0.27 | 10.12 | 10.54 | 11.62 | 0.24 | 9.49 | 10.35 | 11.81 | 0.42 | 9.46 | 9.90 | 10.37 | 0.19 | 9.27 | 10.22 | 11.81 | 0.38 |
| **All** | 9.27 | 12.57 | 20.07 | 2.45 | 10.12 | 13.59 | 18.89 | 2.62 | 9.49 | 12.92 | 15.13 | 1.49 | 9.46 | 12.10 | 17.87 | 2.23 | 9.27 | 12.81 | 20.07 | 2.28 |
| **delta T (°C)** | | | | | | | | | | | | | | | | | | | | |
| **1-15** | -0.36 | 0.26 | 2.70 | 0.30 | -0.33 | 0.15 | 1.40 | 0.20 | -0.34 | 0.03 | 0.68 | 0.05 | -0.16 | 0.20 | 1.77 | 0.25 | -0.36 | 0.16 | 2.70 | 0.23 |
| **16-30** | -0.08 | 0.16 | 1.38 | 0.17 | -0.23 | 0.19 | 1.45 | 0.17 | -0.05 | 0.07 | 0.72 | 0.08 | -0.10 | 0.13 | 1.28 | 0.16 | -0.23 | 0.14 | 1.45 | 0.15 |
| **31-45** | -0.17 | 0.05 | 0.40 | 0.05 | -0.17 | 0.07 | 1.32 | 0.08 | -0.22 | 0.11 | 0.69 | 0.11 | -0.09 | 0.05 | 0.85 | 0.06 | -0.22 | 0.07 | 1.32 | 0.09 |
| **46-60** | -0.06 | 0.02 | 0.17 | 0.02 | -0.09 | 0.03 | 0.26 | 0.04 | -0.15 | 0.06 | 0.73 | 0.08 | -0.12 | 0.02 | 0.17 | 0.03 | -0.15 | 0.03 | 0.73 | 0.05 |
| **61-75** | -0.06 | 0.01 | 0.14 | 0.02 | -0.12 | 0.02 | 0.18 | 0.03 | -0.05 | 0.02 | 0.25 | 0.03 | -0.04 | 0.01 | 0.14 | 0.02 | -0.12 | 0.02 | 0.25 | 0.03 |
| **All** | -0.36 | 0.14 | 2.70 | 0.22 | -0.33 | 0.12 | 1.45 | 0.16 | -0.34 | 0.06 | 0.73 | 0.08 | -0.16 | 0.11 | 1.77 | 0.18 | -0.36 | 0.10 | 2.70 | 0.17 |
| **Density (kg/m$^3$)** | | | | | | | | | | | | | | | | | | | | |
| **1-15** | 22.43 | 24.65 | 25.56 | 0.35 | 23.11 | 24.34 | 25.19 | 0.39 | 23.81 | 24.80 | 25.21 | 0.12 | 24.09 | 24.83 | 25.85 | 0.37 | 22.43 | 24.66 | 25.85 | 0.37 |
| **16-30** | 24.47 | 25.36 | 25.81 | 0.21 | 24.12 | 24.99 | 25.49 | 0.26 | 24.63 | 24.96 | 25.42 | 0.13 | 24.72 | 25.46 | 26.02 | 0.22 | 24.12 | 25.18 | 26.02 | 0.30 |
| **31-45** | 25.33 | 25.67 | 26.03 | 0.11 | 24.67 | 25.38 | 25.67 | 0.12 | 24.80 | 25.25 | 25.83 | 0.20 | 25.35 | 25.75 | 26.15 | 0.14 | 24.67 | 25.50 | 26.15 | 0.25 |
| **46-60** | 25.58 | 25.85 | 26.13 | 0.10 | 25.30 | 25.57 | 25.77 | 0.10 | 24.95 | 25.59 | 25.97 | 0.21 | 25.67 | 25.90 | 26.17 | 0.11 | 24.95 | 25.72 | 26.17 | 0.20 |
| **61-75** | 25.74 | 25.97 | 26.18 | 0.09 | 25.42 | 25.72 | 25.87 | 0.08 | 25.32 | 25.82 | 26.17 | 0.17 | 25.78 | 26.00 | 26.22 | 0.11 | 25.32 | 25.88 | 26.22 | 0.16 |
| **All** | 22.43 | 25.32 | 26.18 | 0.55 | 23.11 | 25.01 | 25.87 | 0.58 | 23.81 | 25.12 | 26.17 | 0.38 | 24.09 | 25.42 | 26.22 | 0.51 | 22.43 | 25.21 | 26.22 | 0.53 |
| **Salinity (psu)** | | | | | | | | | | | | | | | | | | | | |
| **1-15** | 32.36 | 33.46 | 33.63 | 0.05 | 32.79 | 33.37 | 33.78 | 0.08 | 31.66 | 33.26 | 33.55 | 0.09 | 33.19 | 33.45 | 33.77 | 0.05 | 31.66 | 33.38 | 33.78 | 0.11 |
| **16-30** | 33.34 | 33.47 | 33.64 | 0.04 | 33.25 | 33.38 | 33.53 | 0.03 | 33.12 | 33.31 | 33.50 | 0.05 | 33.34 | 33.49 | 33.80 | 0.07 | 33.12 | 33.41 | 33.80 | 0.09 |
| **31-45** | 33.40 | 33.53 | 33.78 | 0.06 | 33.21 | 33.38 | 33.49 | 0.04 | 33.11 | 33.35 | 33.62 | 0.07 | 33.42 | 33.59 | 33.90 | 0.09 | 33.11 | 33.46 | 33.90 | 0.12 |
| **46-60** | 33.45 | 33.65 | 33.89 | 0.08 | 33.28 | 33.45 | 33.57 | 0.05 | 33.22 | 33.47 | 33.74 | 0.12 | 33.52 | 33.69 | 33.93 | 0.09 | 33.22 | 33.56 | 33.93 | 0.14 |
| **61-75** | 33.55 | 33.76 | 33.93 | 0.07 | 33.39 | 33.54 | 33.68 | 0.06 | 33.31 | 33.62 | 33.90 | 0.13 | 33.56 | 33.75 | 33.95 | 0.11 | 33.31 | 33.67 | 33.95 | 0.13 |
| **All** | 32.36 | 33.53 | 33.93 | 0.12 | 32.79 | 33.40 | 33.78 | 0.08 | 31.66 | 33.35 | 33.90 | 0.14 | 33.19 | 33.55 | 33.95 | 0.13 | 31.66 | 33.45 | 33.95 | 0.15 |

**Table 3-4 continues.**

**Table 3-4 continued.**

| Depth (m) | Summer 2010 | | | | Fall 2010 | | | | Winter 2011 | | | | Spring 2011 | | | | Annual | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min | Mean | Max | Std Dev | Min | Mean | Max | Std Dev | Min | Mean | Max | Std Dev | Min | Mean | Max | Std Dev | Min | Mean | Max | Std Dev |
| **Dissolved Oxygen (mg/L)** | | | | | | | | | | | | | | | | | | | | |
| **1-15** | 5.66 | 8.24 | 10.16 | 0.64 | 5.05 | 7.48 | 10.10 | 0.56 | 5.78 | 8.05 | 9.47 | 0.59 | 3.66 | 7.73 | 9.83 | 1.14 | 3.66 | 7.88 | 10.16 | 0.81 |
| **16-30** | 4.19 | 6.48 | 9.19 | 1.10 | 5.28 | 6.74 | 8.21 | 0.55 | 5.10 | 7.34 | 8.76 | 0.72 | 3.13 | 5.55 | 8.53 | 1.01 | 3.13 | 6.57 | 9.19 | 1.08 |
| **31-45** | 3.33 | 4.82 | 7.49 | 0.64 | 4.68 | 5.72 | 7.30 | 0.45 | 3.92 | 6.00 | 8.19 | 0.91 | 2.83 | 4.37 | 6.23 | 0.62 | 2.83 | 5.26 | 8.19 | 0.95 |
| **46-60** | 3.17 | 4.14 | 5.78 | 0.46 | 4.21 | 5.14 | 6.04 | 0.34 | 3.74 | 4.94 | 8.17 | 0.71 | 2.74 | 3.84 | 4.94 | 0.44 | 2.74 | 4.54 | 8.17 | 0.74 |
| **61-75** | 3.03 | 3.72 | 4.96 | 0.39 | 3.79 | 4.65 | 5.68 | 0.37 | 3.50 | 4.38 | 6.02 | 0.53 | 2.80 | 3.66 | 4.38 | 0.43 | 2.80 | 4.11 | 6.02 | 0.61 |
| **All** | 3.03 | 6.14 | 10.16 | 1.87 | 3.79 | 6.36 | 10.10 | 1.12 | 3.50 | 6.73 | 9.47 | 1.49 | 2.74 | 5.62 | 9.83 | 1.83 | 2.74 | 6.23 | 10.16 | 1.65 |
| **Dissolved Oxygen Saturation (%)** | | | | | | | | | | | | | | | | | | | | |
| **1-15** | 65.0 | 101.6 | 123.6 | 9.1 | 64.1 | 93.9 | 122.1 | 6.9 | 67.9 | 96.3 | 114.6 | 7.3 | 40.5 | 94.0 | 123.1 | 16.0 | 40.5 | 96.4 | 123.6 | 10.8 |
| **16-30** | 46.6 | 74.8 | 111.9 | 14.1 | 60.3 | 80.0 | 100.0 | 7.9 | 57.6 | 86.9 | 104.6 | 9.2 | 34.4 | 63.5 | 102.1 | 12.8 | 34.4 | 76.8 | 111.9 | 14.1 |
| **31-45** | 37.1 | 53.9 | 86.2 | 7.5 | 52.4 | 65.2 | 85.8 | 5.8 | 43.2 | 69.3 | 97.4 | 11.7 | 31.0 | 48.6 | 71.3 | 7.3 | 31.0 | 59.7 | 97.4 | 11.9 |
| **46-60** | 34.8 | 45.8 | 64.7 | 5.2 | 46.8 | 57.7 | 69.4 | 4.2 | 41.5 | 55.5 | 97.2 | 8.8 | 29.9 | 42.3 | 55.1 | 4.9 | 29.9 | 50.6 | 97.2 | 8.9 |
| **61-75** | 33.3 | 40.9 | 55.0 | 4.3 | 41.9 | 51.6 | 64.5 | 4.2 | 38.1 | 48.5 | 68.5 | 6.3 | 30.6 | 40.2 | 48.3 | 4.8 | 30.6 | 45.4 | 68.5 | 7.0 |
| **All** | 33.3 | 72.2 | 123.6 | 25.2 | 41.9 | 75.9 | 122.1 | 16.6 | 38.1 | 79.0 | 114.6 | 19.3 | 29.9 | 65.5 | 123.1 | 24.4 | 29.9 | 73.4 | 123.6 | 22.1 |
| **pH (pH units)** | | | | | | | | | | | | | | | | | | | | |
| **1-15** | 7.95 | 8.22 | 8.40 | 0.07 | 7.74 | 8.12 | 8.49 | 0.12 | 7.97 | 8.19 | 8.35 | 0.05 | 7.81 | 8.17 | 8.56 | 0.12 | 7.74 | 8.17 | 8.56 | 0.10 |
| **16-30** | 7.80 | 8.04 | 8.27 | 0.10 | 7.65 | 8.00 | 8.32 | 0.14 | 7.88 | 8.12 | 8.26 | 0.08 | 7.70 | 7.97 | 8.38 | 0.13 | 7.65 | 8.03 | 8.38 | 0.13 |
| **31-45** | 7.73 | 7.88 | 8.14 | 0.07 | 7.59 | 7.87 | 8.18 | 0.13 | 7.76 | 8.00 | 8.26 | 0.12 | 7.68 | 7.85 | 8.15 | 0.10 | 7.59 | 7.91 | 8.26 | 0.12 |
| **46-60** | 7.71 | 7.82 | 7.95 | 0.05 | 7.57 | 7.81 | 8.10 | 0.13 | 7.75 | 7.90 | 8.26 | 0.09 | 7.67 | 7.81 | 8.06 | 0.08 | 7.57 | 7.84 | 8.26 | 0.10 |
| **61-75** | 7.69 | 7.78 | 7.89 | 0.05 | 7.52 | 7.77 | 8.08 | 0.14 | 7.75 | 7.86 | 8.04 | 0.07 | 7.66 | 7.79 | 8.07 | 0.08 | 7.52 | 7.80 | 8.08 | 0.10 |
| **All** | 7.69 | 8.01 | 8.40 | 0.18 | 7.52 | 7.96 | 8.49 | 0.18 | 7.75 | 8.07 | 8.35 | 0.14 | 7.66 | 7.97 | 8.56 | 0.18 | 7.52 | 8.01 | 8.56 | 0.18 |
| **Chlorophyll-*a* (µg/L)** | | | | | | | | | | | | | | | | | | | | |
| **1-15** | 1.05 | 9.73 | 55.29 | 8.92 | 1.55 | 7.62 | 31.21 | 4.04 | 1.10 | 7.69 | 31.72 | 4.73 | 0.82 | 13.21 | 56.81 | 10.64 | 0.82 | 9.46 | 56.81 | 7.81 |
| **16-30** | 1.63 | 11.38 | 67.52 | 10.56 | 1.51 | 6.19 | 18.00 | 2.71 | 1.67 | 7.55 | 25.65 | 4.18 | 0.63 | 7.49 | 48.32 | 6.03 | 0.63 | 8.11 | 67.52 | 6.73 |
| **31-45** | 0.60 | 2.64 | 61.68 | 3.88 | 1.05 | 2.37 | 8.87 | 1.16 | 0.91 | 2.80 | 14.73 | 1.83 | 0.33 | 2.75 | 15.69 | 1.96 | 0.33 | 2.64 | 61.68 | 2.41 |
| **46-60** | 0.39 | 1.04 | 2.93 | 0.39 | 0.58 | 1.36 | 6.25 | 0.46 | 0.52 | 1.27 | 7.67 | 0.61 | 0.25 | 1.68 | 8.16 | 1.40 | 0.25 | 1.34 | 8.16 | 0.84 |
| **61-75** | 0.33 | 0.63 | 1.86 | 0.20 | 0.45 | 0.89 | 3.27 | 0.32 | 0.46 | 0.82 | 1.59 | 0.20 | 0.25 | 1.18 | 4.75 | 0.80 | 0.25 | 0.88 | 4.75 | 0.49 |
| **All** | 0.33 | 6.72 | 67.52 | 8.74 | 0.45 | 4.75 | 31.21 | 3.84 | 0.46 | 5.25 | 31.72 | 4.59 | 0.25 | 7.05 | 56.81 | 8.39 | 0.25 | 5.91 | 67.52 | 6.73 |

**Table 3-4 continues.**

**Table 3-4 continued.**

| Depth (m) | Summer 2010 | | | | Fall 2010 | | | | Winter 2011 | | | | Spring 2011 | | | | Annual | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min | Mean | Max | Std Dev | Min | Mean | Max | Std Dev | Min | Mean | Max | Std Dev | Min | Mean | Max | Std Dev | Min | Mean | Max | Std Dev |
| **Light Transmission (%)** | | | | | | | | | | | | | | | | | | | | |
| **1-15** | 52.44 | 77.36 | 87.48 | 5.86 | 57.53 | 81.33 | 86.74 | 4.47 | 43.63 | 79.03 | 87.18 | 6.25 | 37.19 | 77.27 | 88.35 | 5.70 | 37.19 | 78.78 | 88.35 | 5.86 |
| **16-30** | 61.50 | 82.15 | 88.61 | 4.26 | 63.55 | 84.46 | 88.90 | 3.09 | 46.15 | 81.95 | 88.61 | 5.63 | 45.94 | 83.25 | 88.87 | 4.42 | 45.94 | 82.93 | 88.90 | 4.60 |
| **31-45** | 70.62 | 85.82 | 89.21 | 3.00 | 67.42 | 86.27 | 89.43 | 2.74 | 46.34 | 84.57 | 88.97 | 6.12 | 62.44 | 85.20 | 89.03 | 4.35 | 46.34 | 85.44 | 89.43 | 4.38 |
| **46-60** | 65.30 | 86.62 | 89.46 | 3.32 | 66.28 | 86.61 | 89.62 | 3.27 | 39.78 | 85.07 | 89.55 | 7.16 | 46.38 | 84.57 | 89.27 | 5.68 | 39.78 | 85.71 | 89.62 | 5.25 |
| **61-75** | 82.34 | 87.59 | 89.62 | 1.67 | 81.94 | 88.02 | 89.77 | 1.55 | 78.56 | 87.27 | 89.66 | 2.13 | 75.75 | 85.76 | 89.37 | 2.61 | 75.75 | 87.16 | 89.77 | 2.20 |
| **All** | 52.44 | 82.44 | 89.62 | 5.90 | 57.53 | 84.43 | 89.77 | 4.20 | 39.78 | 82.37 | 89.66 | 6.57 | 37.19 | 82.09 | 89.37 | 6.00 | 37.19 | 82.83 | 89.77 | 5.83 |
| **Beam C (1/m)** | | | | | | | | | | | | | | | | | | | | |
| **1-15** | 0.54 | 1.04 | 3.45 | 0.32 | 0.57 | 0.83 | 2.21 | 0.23 | 0.55 | 0.96 | 3.32 | 0.35 | 0.50 | 1.04 | 3.96 | 0.32 | 0.50 | 0.97 | 3.96 | 0.32 |
| **16-30** | 0.48 | 0.79 | 1.95 | 0.21 | 0.47 | 0.68 | 1.81 | 0.16 | 0.48 | 0.81 | 3.09 | 0.31 | 0.47 | 0.74 | 3.11 | 0.23 | 0.47 | 0.76 | 3.11 | 0.24 |
| **31-45** | 0.46 | 0.61 | 1.39 | 0.15 | 0.45 | 0.59 | 1.58 | 0.13 | 0.47 | 0.68 | 3.08 | 0.34 | 0.47 | 0.65 | 1.88 | 0.22 | 0.45 | 0.64 | 3.08 | 0.23 |
| **46-60** | 0.45 | 0.58 | 1.71 | 0.16 | 0.44 | 0.58 | 1.65 | 0.16 | 0.44 | 0.66 | 3.69 | 0.41 | 0.45 | 0.68 | 3.08 | 0.30 | 0.44 | 0.63 | 3.69 | 0.29 |
| **61-75** | 0.44 | 0.53 | 0.78 | 0.08 | 0.43 | 0.51 | 0.80 | 0.07 | 0.44 | 0.55 | 0.97 | 0.10 | 0.45 | 0.62 | 1.11 | 0.12 | 0.43 | 0.55 | 1.11 | 0.10 |
| **All** | 0.44 | 0.78 | 3.45 | 0.30 | 0.43 | 0.68 | 2.21 | 0.21 | 0.44 | 0.79 | 3.69 | 0.36 | 0.45 | 0.80 | 3.96 | 0.31 | 0.43 | 0.76 | 3.96 | 0.31 |
| **CDOM (µg/L)** | | | | | | | | | | | | | | | | | | | | |
| **1-15** | 0.19 | 0.80 | 1.78 | 0.26 | -0.06 | 0.93 | 2.87 | 0.61 | 0.52 | 1.18 | 2.41 | 0.41 | 0.33 | 1.09 | 3.09 | 0.35 | -0.06 | 1.01 | 3.09 | 0.45 |
| **16-30** | 0.23 | 1.00 | 2.78 | 0.34 | 0.25 | 1.00 | 4.92 | 0.65 | 0.60 | 1.20 | 3.07 | 0.34 | 0.59 | 1.15 | 2.08 | 0.24 | 0.23 | 1.09 | 4.92 | 0.43 |
| **31-45** | 0.42 | 1.04 | 2.96 | 0.46 | 0.23 | 1.12 | 5.05 | 0.82 | 0.73 | 1.43 | 3.90 | 0.49 | 0.65 | 1.18 | 2.78 | 0.25 | 0.23 | 1.20 | 5.05 | 0.56 |
| **46-60** | 0.37 | 0.86 | 2.35 | 0.29 | 0.26 | 0.88 | 3.81 | 0.58 | 0.90 | 1.29 | 4.33 | 0.36 | 0.74 | 1.18 | 2.50 | 0.21 | 0.26 | 1.06 | 4.33 | 0.43 |
| **61-75** | 0.39 | 0.77 | 1.13 | 0.16 | 0.26 | 0.78 | 2.53 | 0.51 | 0.97 | 1.11 | 1.31 | 0.05 | 0.72 | 1.09 | 1.31 | 0.13 | 0.26 | 0.95 | 2.53 | 0.31 |
| **All** | 0.19 | 0.90 | 2.96 | 0.34 | -0.06 | 0.96 | 5.05 | 0.66 | 0.52 | 1.23 | 4.33 | 0.40 | 0.33 | 1.13 | 3.09 | 0.27 | -0.06 | 1.06 | 5.05 | 0.46 |
| **Normalized Irradiance (µE/(cm$^2$ ·sec))** | | | | | | | | | | | | | | | | | | | | |
| **1-15** | 0.8 | 19.5 | 100.0 | 19.0 | 0.2 | 10.1 | 100.0 | 12.6 | 0.1 | 10.6 | 100.0 | 16.1 | 0.2 | 9.8 | 78.7 | 11.9 | 0.1 | 12.4 | 100.0 | 15.7 |
| **16-30** | 0.1 | 1.8 | 9.0 | 1.5 | 0.0 | 1.1 | 7.2 | 1.1 | 0.0 | 0.9 | 4.6 | 0.8 | 0.0 | 0.8 | 6.5 | 0.9 | 0.0 | 1.1 | 9.0 | 1.1 |
| **31-45** | 0.0 | 0.3 | 1.8 | 0.3 | 0.0 | 0.2 | 1.6 | 0.2 | 0.0 | 0.2 | 1.1 | 0.2 | 0.0 | 0.2 | 1.7 | 0.2 | 0.0 | 0.2 | 1.8 | 0.2 |
| **46-60** | 0.0 | 0.1 | 0.6 | 0.1 | 0.0 | 0.1 | 0.7 | 0.1 | 0.0 | 0.1 | 0.5 | 0.1 | 0.0 | 0.1 | 0.7 | 0.1 | 0.0 | 0.1 | 0.7 | 0.1 |
| **61-75** | 0.0 | 0.1 | 0.5 | 0.1 | 0.0 | 0.1 | 0.4 | 0.1 | 0.0 | 0.1 | 0.4 | 0.1 | 0.0 | 0.1 | 0.6 | 0.1 | 0.0 | 0.1 | 0.6 | 0.1 |
| **All** | 0.0 | 6.9 | 100.0 | 14.0 | 0.0 | 3.6 | 100.0 | 8.5 | 0.0 | 3.8 | 100.0 | 10.5 | 0.0 | 3.5 | 78.7 | 8.1 | 0.0 | 4.4 | 100.0 | 10.6 |

**Table 3-4 continues.**

**Table 3-4 continued.**

| Depth (m) | Summer 2010 | | | | Fall 2010 | | | | Winter 2011 | | | | Spring 2011 | | | | Annual | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min | Mean | Max | Std Dev | Min | Mean | Max | Std Dev | Min | Mean | Max | Std Dev | Min | Mean | Max | Std Dev | Min | Mean | Max | Std Dev |
| **Ammonium (mg/L)** | | | | | | | | | | | | | | | | | | | | |
| **1-15** | <0.02 | <0.02 | 0.05 | 0.00 | <0.02 | <0.02 | 0.07 | 0.00 | <0.02 | <0.02 | 0.05 | 0.00 | <0.02 | <0.02 | 0.11 | 0.01 | <0.02 | <0.02 | 0.11 | 0.00 |
| **16-30** | <0.02 | 0.02 | 0.17 | 0.02 | <0.02 | 0.02 | 0.18 | 0.03 | <0.02 | 0.02 | 0.08 | 0.01 | <0.02 | 0.02 | 0.09 | 0.01 | <0.02 | 0.02 | 0.18 | 0.02 |
| **31-45** | <0.02 | 0.02 | 0.15 | 0.02 | <0.02 | 0.03 | 0.16 | 0.03 | <0.02 | 0.04 | 0.20 | 0.04 | <0.02 | 0.02 | 0.15 | 0.02 | <0.02 | 0.03 | 0.20 | 0.03 |
| **46-60** | <0.02 | <0.02 | 0.04 | 0.01 | <0.02 | <0.02 | 0.06 | 0.01 | <0.02 | 0.03 | 0.22 | 0.04 | <0.02 | 0.02 | 0.04 | 0.01 | <0.02 | 0.02 | 0.22 | 0.02 |
| **61-75** | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| **All** | <0.02 | <0.02 | 0.17 | 0.01 | <0.02 | <0.02 | 0.18 | 0.02 | <0.02 | 0.02 | 0.22 | 0.02 | <0.02 | <0.02 | 0.15 | 0.01 | <0.02 | <0.02 | 0.22 | 0.02 |
| **Total Coliform Bacteria (MPN/100 mL)** | | | | | | | | | | | | | | | | | | | | |
| **1-15** | <10 | <10 | 504 | 1 | <10 | <10 | 2909 | 2 | <10 | <10 | 52 | 1 | <10 | <10 | 31 | 1 | <10 | <10 | 2909 | 2 |
| **16-30** | <10 | 21 | 1376 | 5 | <10 | 13 | 1354 | 3 | <10 | 11 | 3448 | 3 | <10 | 11 | 74 | 2 | <10 | 13 | 3448 | 3 |
| **31-45** | <10 | 33 | 2755 | 6 | <10 | 17 | 1058 | 3 | <10 | 52 | >24196 | 14 | <10 | 11 | 134 | 2 | <10 | 25 | >24196 | 7 |
| **46-60** | <10 | 23 | 857 | 5 | <10 | 14 | 185 | 2 | <10 | 45 | >24196 | 12 | <10 | <10 | 52 | 2 | <10 | 21 | >24196 | 6 |
| **61-75** | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| **All** | <10 | 13 | 2755 | 3 | <10 | 12 | 2909 | 3 | <10 | 13 | >24196 | 5 | <10 | <10 | 134 | 2 | <10 | 12 | >24196 | 3 |
| **Fecal Coliform Bacteria (MPN/100 mL)** | | | | | | | | | | | | | | | | | | | | |
| **1-15** | <10 | <10 | 34 | 1 | <10 | <10 | 22 | 1 | <10 | <10 | 11 | 1 | <10 | <10 | 11 | 1 | <10 | <10 | 34 | 1 |
| **16-30** | <10 | 10 | 108 | 2 | <10 | <10 | 176 | 2 | <10 | <10 | 789 | 2 | <10 | <10 | 22 | 1 | <10 | <10 | 789 | 2 |
| **31-45** | <10 | 12 | 188 | 2 | <10 | <10 | 120 | 2 | <10 | 22 | 6744 | 8 | <10 | <10 | 45 | 1 | <10 | 13 | 6744 | 4 |
| **46-60** | <10 | <10 | 133 | 2 | <10 | <10 | 34 | 2 | <10 | 19 | 4260 | 6 | <10 | <10 | <10 | 1 | <10 | 11 | 4260 | 3 |
| **61-75** | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| **All** | <10 | <10 | 188 | 2 | <10 | <10 | 176 | 1 | <10 | <10 | 6744 | 3 | <10 | <10 | 45 | 1 | <10 | <10 | 6744 | 2 |
| **Enterococcus Bacteria (MPN/100 mL)** | | | | | | | | | | | | | | | | | | | | |
| **1-15** | <10 | <10 | 52 | 1 | <10 | <10 | 85 | 1 | <10 | <10 | 41 | 1 | <10 | <10 | 41 | 1 | <10 | <10 | 85 | 1 |
| **16-30** | <10 | <10 | 109 | 2 | <10 | <10 | 84 | 2 | <10 | <10 | 364 | 2 | <10 | <10 | 41 | 1 | <10 | <10 | 364 | 2 |
| **31-45** | <10 | <10 | 142 | 2 | <10 | <10 | 86 | 2 | <10 | 20 | 2359 | 5 | <10 | <10 | 98 | 1 | <10 | 12 | 2359 | 3 |
| **46-60** | <10 | 10 | 75 | 2 | <10 | <10 | 31 | 1 | <10 | 16 | 1376 | 4 | <10 | <10 | 20 | 1 | <10 | 11 | 1376 | 3 |
| **61-75** | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| **All** | <10 | <10 | 142 | 1 | <10 | <10 | 86 | 1 | <10 | 10 | 2359 | 2 | <10 | <10 | 98 | 1 | <10 | <10 | 2359 | 2 |

NS = No sample

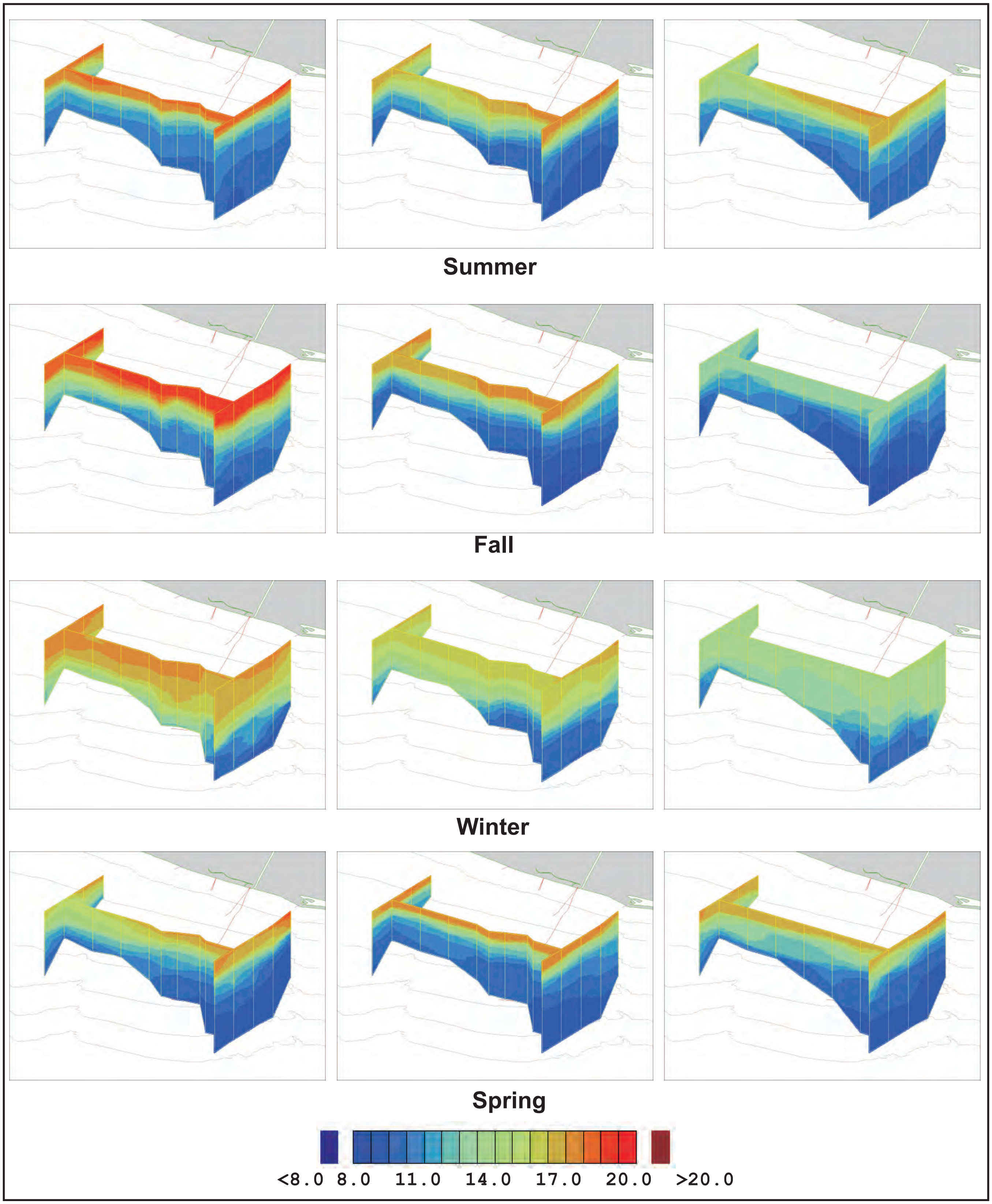



**Figure 3-11.** **Seasonal patterns of temperature (°C) for summer (July 15, August 3, September 16, 2010), fall (October 27, November 2, December 8, 2010), winter (January 26, February 8, March 22, 2011), and spring (April 27, May 10, June 9, 2011).**

Orange County Sanitation District, California.

depth bin for the entire year. While spring had the coldest average water temperatures for depths below 15 m, summer temperatures nearly matched those of spring and contained the coldest water measured during the year.

The water column was stratified into late fall (December 6 survey) when surface waters cooled and the thermocline weakened (Figures 3-11 and 3-12). Weak temperature stratification existed until late April when the thermocline reestablished itself. A narrow band of warm surface water along, with extensive cold subsurface waters, was present in the summer, fall, and spring. While winter surface temperatures were cooler, subsurface temperatures were warmer. Within seasons, changes include the cooling between the November and December cruises and in the 2 weeks between the January and February cruises.

Density was negatively correlated (r=-0.988) with temperature with comparable seasonal and depth related patterns (Table 3-4; Figure B-8). The greatest variability was in the upper 30 m with the exception of winter where the greatest variability was below 30 m. Overall, for temperature and density, the ranges, mean values, and spatial and temporal patterns for 2010-11 were typical of long-term OCSD observations (OCSD 1996b; 2004; SAIC 2009) and with regional observations (Table 3-2).

### *Plume Related Changes*

The predicted plume impact would be an increase in water temperature after mixing. This direct effect seems offset by the entrainment of colder, deeper water as the buoyant plume rises in the water column (Figure 3-11, October 27, 2010). Plume entrainment was less apparent in 2010-11 due to the pervasiveness of the cold water during most surveys. Additionally, temperature and density profiles for outfall Station 2205 all fell within measured values from stations not impacted by the discharge (Figures B-9 to B-11) and the calculated level of change (Table 3-1) was within natural variability.

## Salinity

For 2010-11, salinity values had a range of 2.3 psu. Variability depended on season and depth with the largest ranges at the surface, particularly in the winter (Table 3-4). Average salinity generally increased with depth with the exception of fall when average salinity values remained relatively stable from the surface to 45 m. Fall had the lowest average salinity at depths below 45 m, and the lowest variability. Low surface salinity values were most likely due to shore sources (see Figure 3-5). Spring had the highest average and maximum values for each depth category. The increase in salinity with depth and the low variability is consistent with previous southern California studies (SWRCB, 1965).

Generally, there was little within-season change in salinity over the year, but salinity did vary significantly between seasons (Figure 3-13). The lower subsurface salinity in summer was primarily due to the intrusion of subarctic water into the region (see Figure 3-5) with some contribution by the discharged wastewater (e.g., July 15$^{th}$). Deeper, more saline, waters came up onto the shelf in the summer, consistent with the colder subsurface waters discussed above. In the fall and winter, there were definitive subsurface plume and surface runoff impacts. By early February, the intrusion of more saline waters (red and orange colors southeast of the outfall) returned and remained through the spring. As was the case for temperature, the general patterns and ranges for salinity were consistent with long-term monitoring (e.g., summarized in OCSD 1996b, 2004) and Central Bight results (Table 3-2).

### *Plume Related Changes*

The plume is essentially a freshwater source discharged into saline waters, so a primary plume signature is the difference in salinity after initial dilution. Discharge-related decreases in salinity of about 0.2 psu were apparent each quarter below the pycnocline or at mid-depth with the exception of spring when the plume-related changes were not apparent (Figure B-12). The subsequent transport of the lower salinity plume water was consistent with measured currents (see Figure 3-9). For example, the area of low nearfield salinity during October and November reflects the very weak currents at that time. By the December survey, current speeds had increased and changed direction moving the plume upcoast.

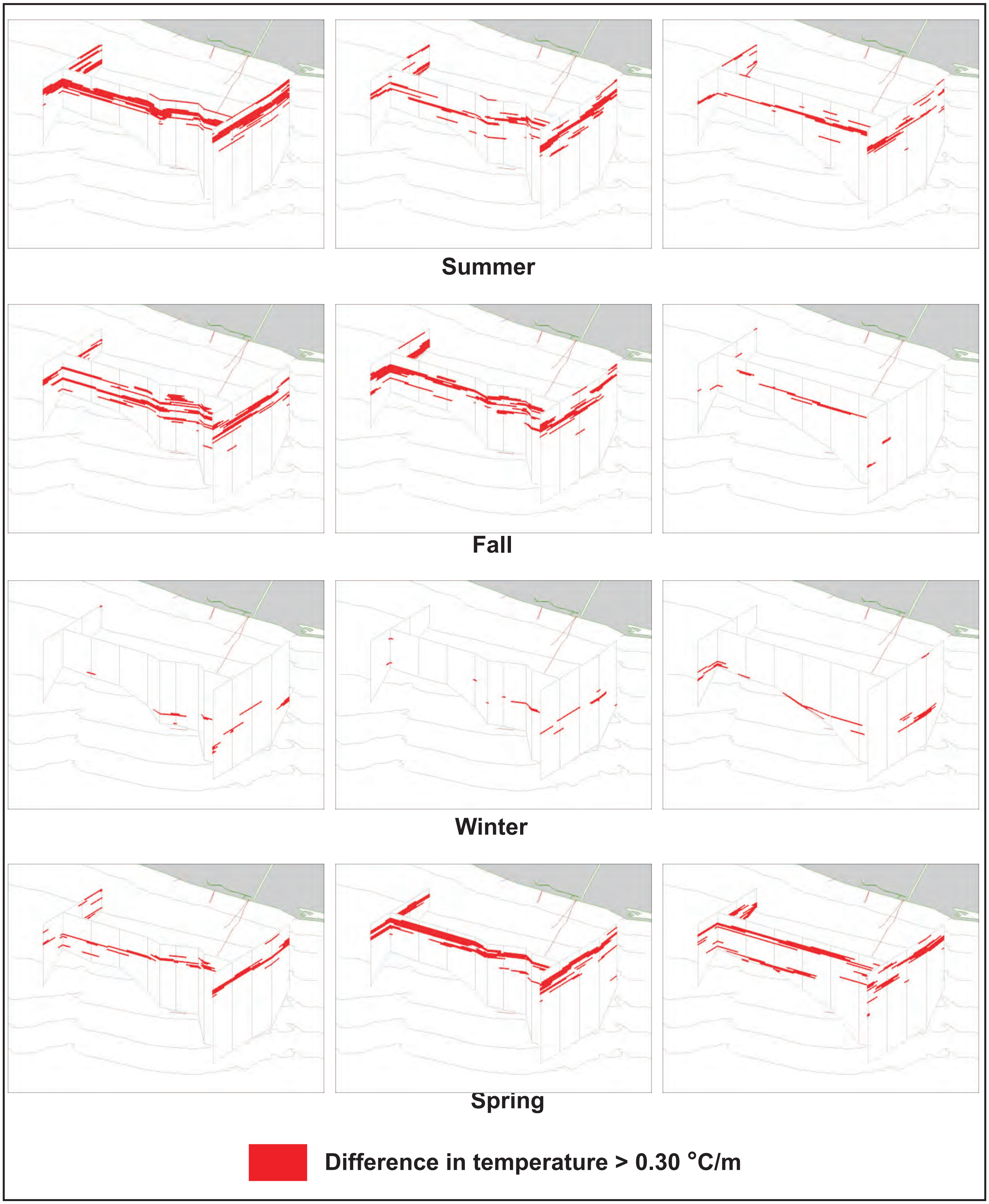



**Figure 3-12.** **Seasonal patterns of thermocline depth for summer (July 15, August 3, September 16, 2010), fall (October 27, November 2, December 8, 2010), winter (January 26, February 8, March 22, 2011), and spring (April 27, May 10, June 9, 2011).**
**The thermocline is defined as change in temperature >0.30 °C/m.**

Orange County Sanitation District, California.

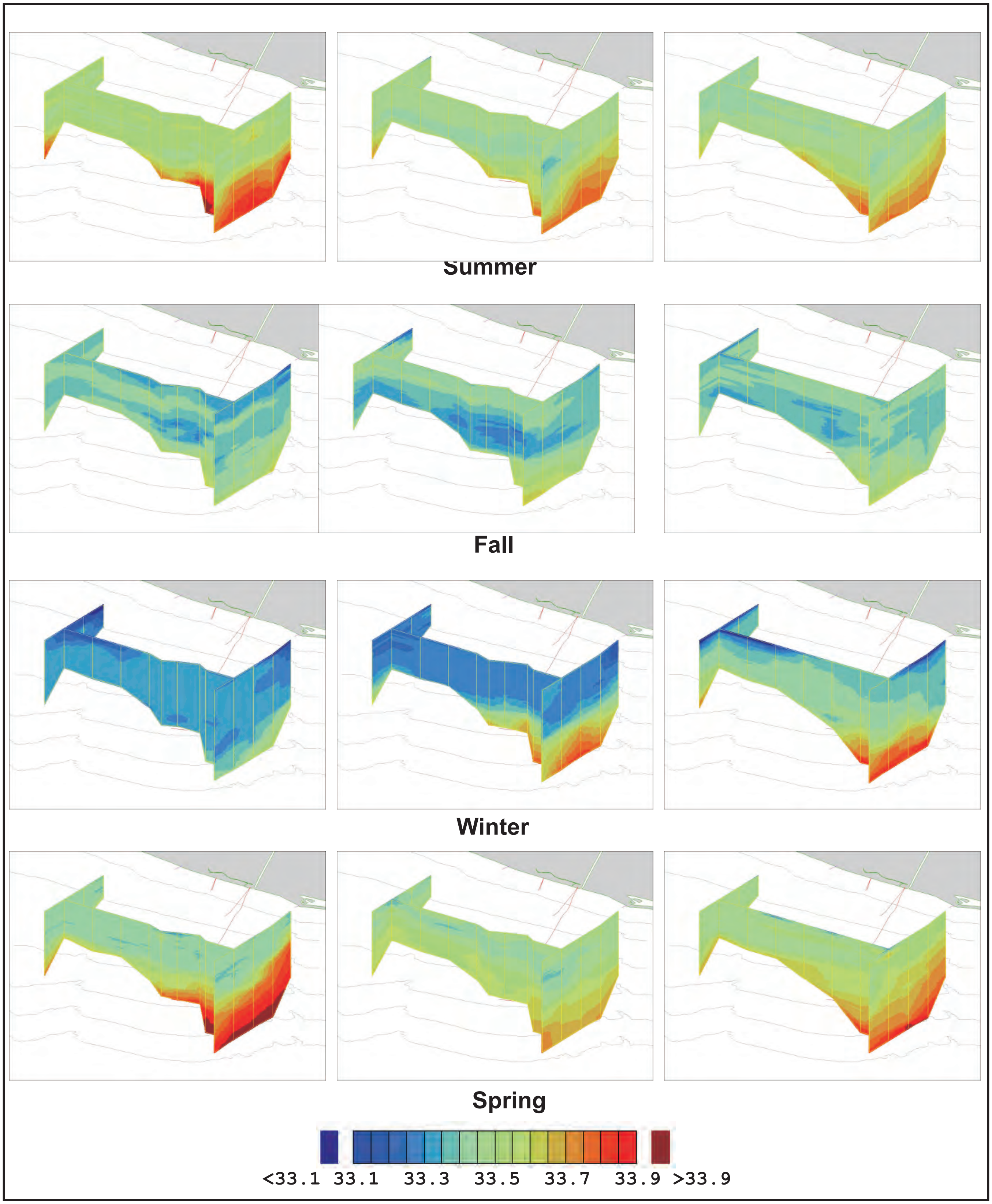



**Figure 3-13.** **Seasonal patterns of salinity (psu) for summer (July 15, August 3, September 16, 2010), fall (October 27, November 2, December 8, 2010), winter (January 26, February 8, March 22, 2011), and spring (April 27, May 10, June 9, 2011).**

Orange County Sanitation District, California.

## Dissolved Oxygen, and pH

Water temperature, salinity, depth, and the presence of oxygen producing phytoplankton all influence observed oxygen concentrations. Over 90% of the DO values were above 4 mg/L and no value indicated hypoxic conditions (<2 mg/L). The average DO values decreased with depth for all seasons (Table 3-4, Figure 3-14). Spring had the lowest average and minimum DO values overall and for each depth bin. Summer and fall DO values above 10 mg/L were lower than the maximum value (13.41 mg/L) of the previous year. Every survey had elevated subsurface DO at mid-depth as well as the presence of low oxygen bottom-water impinging on the shelf. The 2010-11 DO patterns and values were consistent with regional values and fell within the range of long-term monitoring results (summarized in OCSD 1996b, 2004).

Dissolved oxygen and pH were well correlated (r=0.864) both spatially and seasonally (Table 3-4, Figure 3-15). Values decreased from the surface to the bottom with highest average pH during winter. No values in 2010-11 were below 7.5, a level at which slight reductions in hatching and survival of juvenile copepods and euphausids have been measured (Peterson et al. 2010). These general patterns for pH were consistent with 2010-11 regional data as well as with past monitoring years (e.g., OCSD 1996a, b, 2004–2011).

### *Plume Related Changes*

The major DO and pH spatial patterns were not plume related, but did coincide with deeper water impinging onto the shelf or with elevated chlorophyll-*a*. Localized decreases in DO and pH were mostly due to the rising plume causing entrainment of deeper water with lower DO and pH (Figure 3-14, October 27th). Values at outfall Station 2205 fell within the range of values from non-outfall stations (B-13 to B-15). Overall there were few instances of >10% depression of DO values relative to background conditions and compliance with criterion C.4.a was above 95% (Chapter 2) while the pH criterion (C.4.b) was met 100% this year.

## Water Clarity and Color

### *Percent Transmissivity*

Water clarity varied with depth and season. The highest maximum and depth-averaged transmissivity (clearest water) occurred in the fall (Table 3-4). The lowest values occurred in winter and extended from the surface down to 60 m, most likely due to the significant rainfall (~9 in) that occurred in December. In addition to sediment loads brought in by river runoff, the effect of phytoplankton, plume entrainment, upwelling, and resuspension of sediments were apparent in the patterns of decreased transmissivity throughout the year (Figure 3-16). Generally, transmissivity data was comparable to regional values with two exceptions: lower average transmissivity in the Districts study area during the winter and higher minimum values in all seasons as compared to the Central Bight data (Table 3-2).

### *Colored Dissolved Organic Matter (CDOM)*

Despite the other potential sources of CDOM, such as rivers, zooplankton, and bacteria (Kowalczuk et al. 2003, Steinberg et al. 2004) the use of CDOM has proven to be a reliable plume tracer in southern California (Jones et al. 2011, Rogowski et al. 2011). Plume-related CDOM affects (orange and red areas) matched well with salinity, temperature, light transmittance (Figure 3-17). Changes were limited to depths below 15 m with the highest values in the fall at depths between 15–45 m (Table 3-4). Elevated CDOM values in the upper 15 m of water were co-located with elevated chlorophyll-*a* or associated with land-based sources, such as Newport Harbor (Figure 3-18).

### *Secchi and Water Color*

Spatial and temporal patterns in Secchi depth and water color data were generally consistent with the transmissivity results. The lowest water clarity (shallowest Secchi depth and highest Forel/Ule values) occurred at the nearshore stations and in the Newport Canyon (Station C2) with progressively clearer water with increasing distance offshore during most surveys (Figures 3-19 and 3-20). Waters were clearest in the fall and winter and the most turbid in the spring.

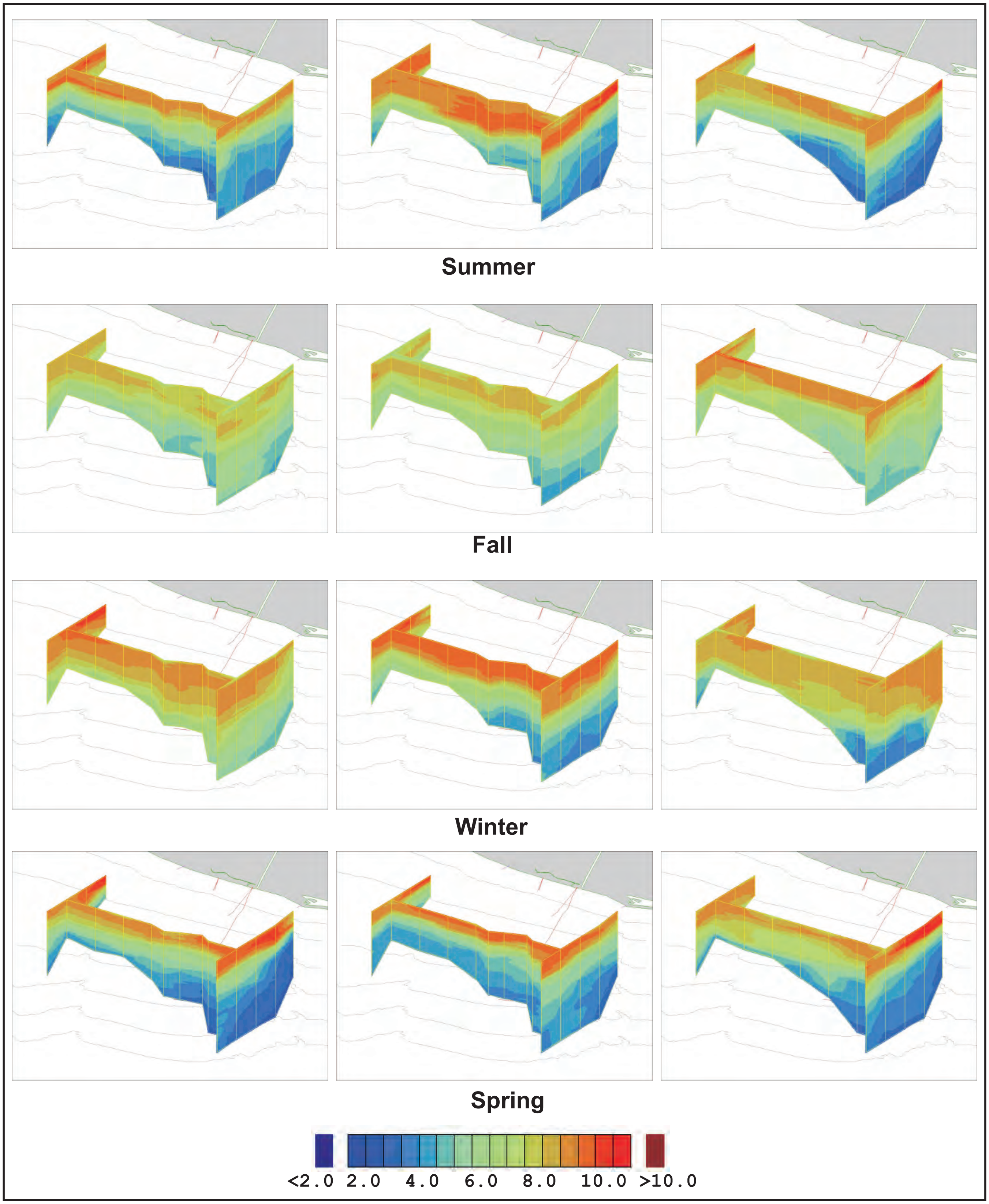



**Figure 3-14.** **Seasonal patterns of dissolved oxygen (mg/L) for summer (July 15, August 3, September 16, 2010), fall (October 27, November 2, December 8, 2010), winter (January 26, February 8, March 22, 2011), and spring (April 27, May 10, June 9, 2011).**

Orange County Sanitation District, California.

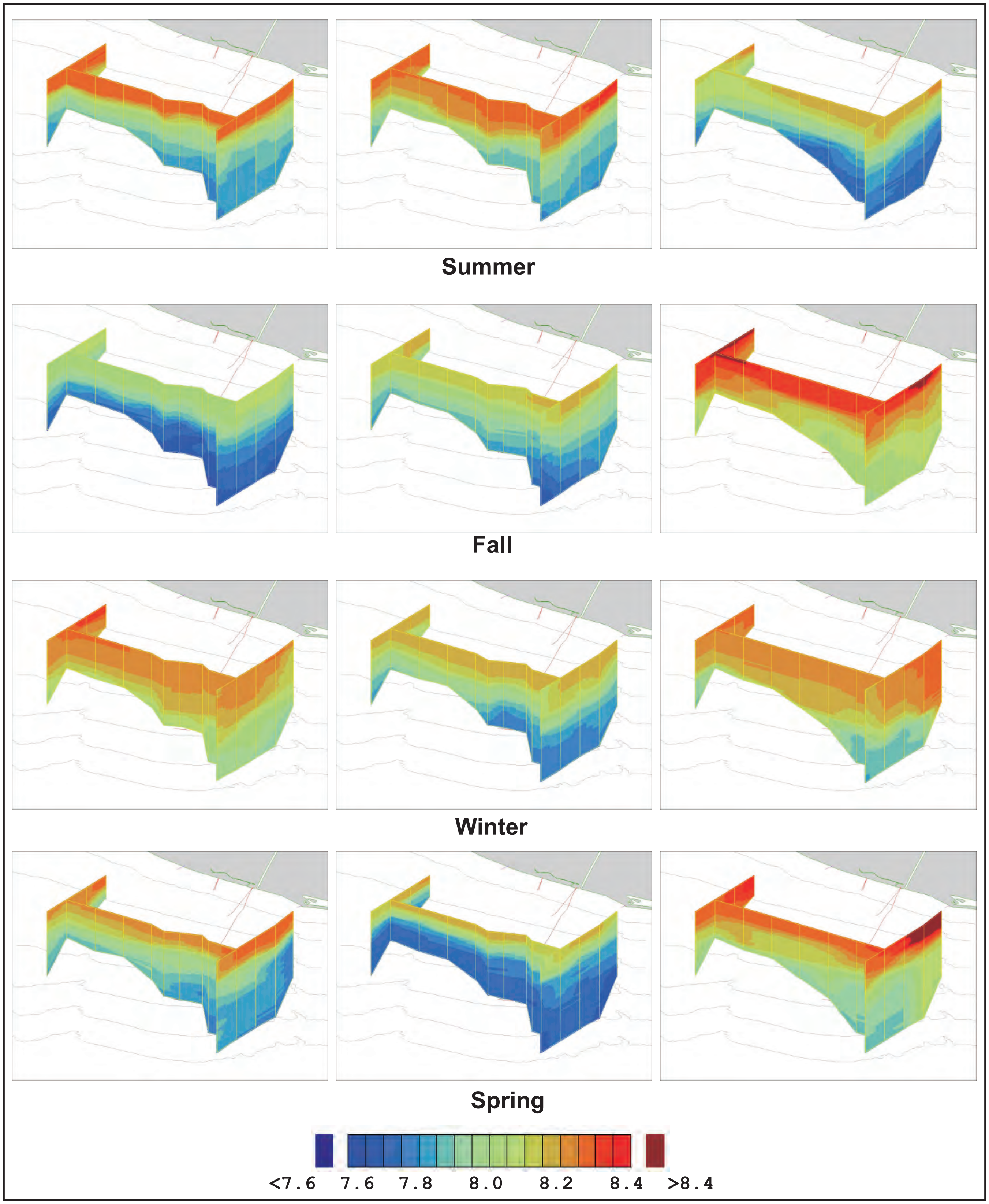



**Figure 3-15. Seasonal patterns of pH for summer (July 15, August 3, September 16, 2010), fall (October 27, November 2, December 8, 2010), winter (January 26, February 8, March 22, 2011), and spring (April 27, May 10, June 9, 2011).**

Orange County Sanitation District, California.

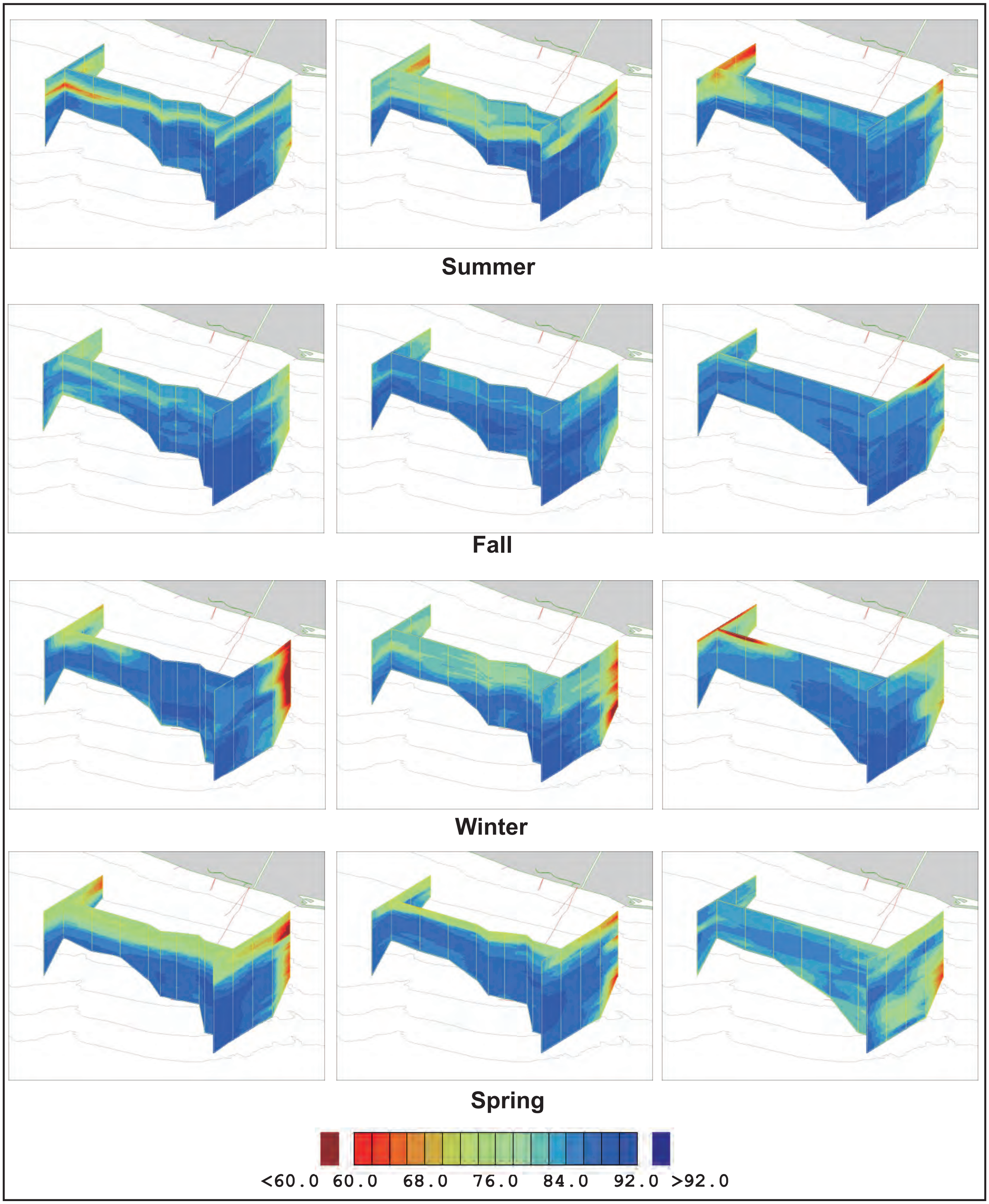



**Figure 3-16.** **Seasonal patterns of light transmission (%) for summer (July 15, August 3, September 16, 2010), fall (October 27, November 2, December 8, 2010), winter (January 26, February 8, March 22, 2011), and spring (April 27, May 10, June 9, 2011).**

Orange County Sanitation District, California.

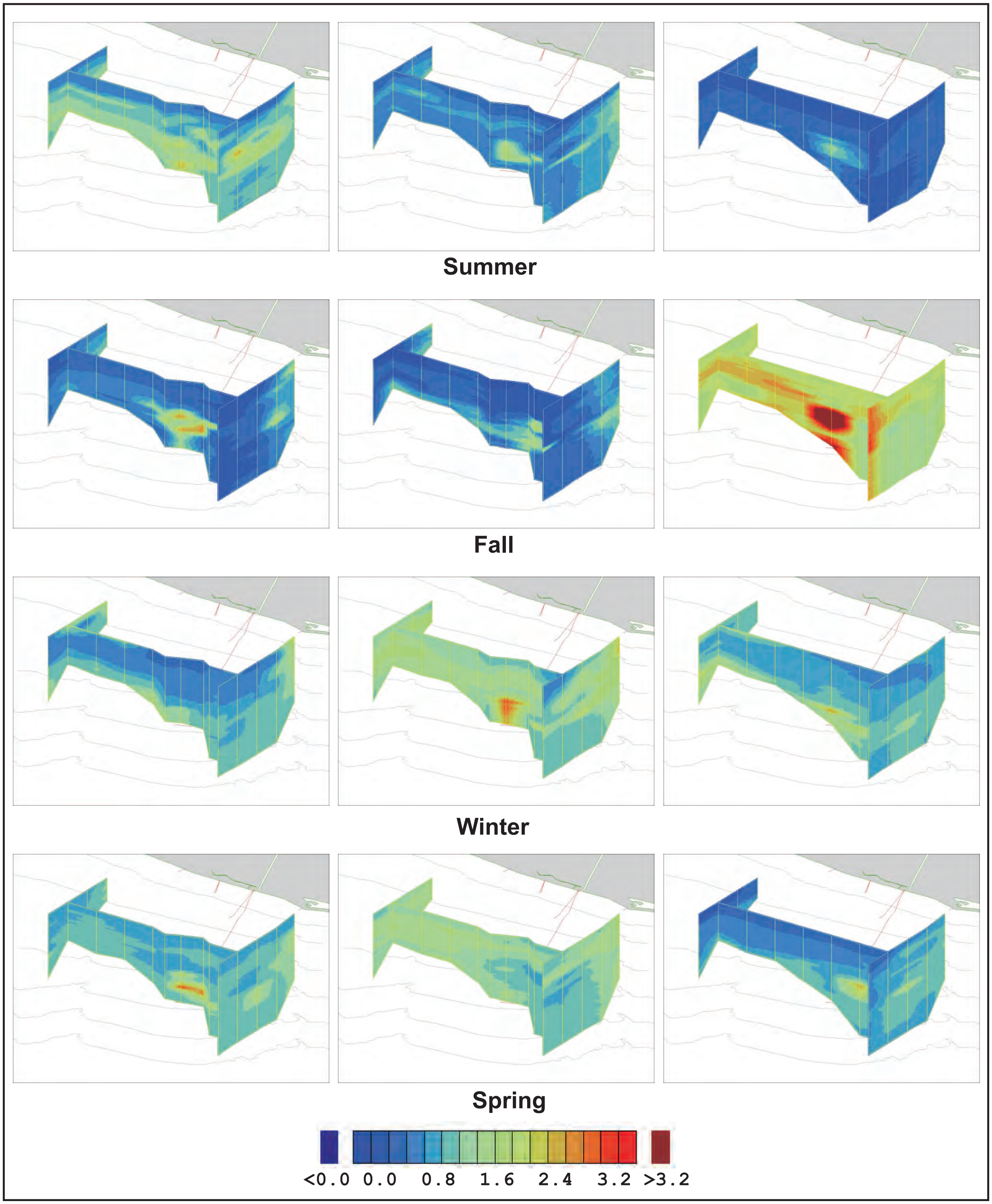



**Figure 3-17.** **Seasonal patterns of color dissolved organic matter (CDOM, µg/L) for summer (July 15, August 3, September 16, 2010), fall (October 27, November 2, December 8, 2010), winter (January 26, February 8, March 22, 2011), and spring (April 27, May 10, June 9, 2011).**

Orange County Sanitation District, California.

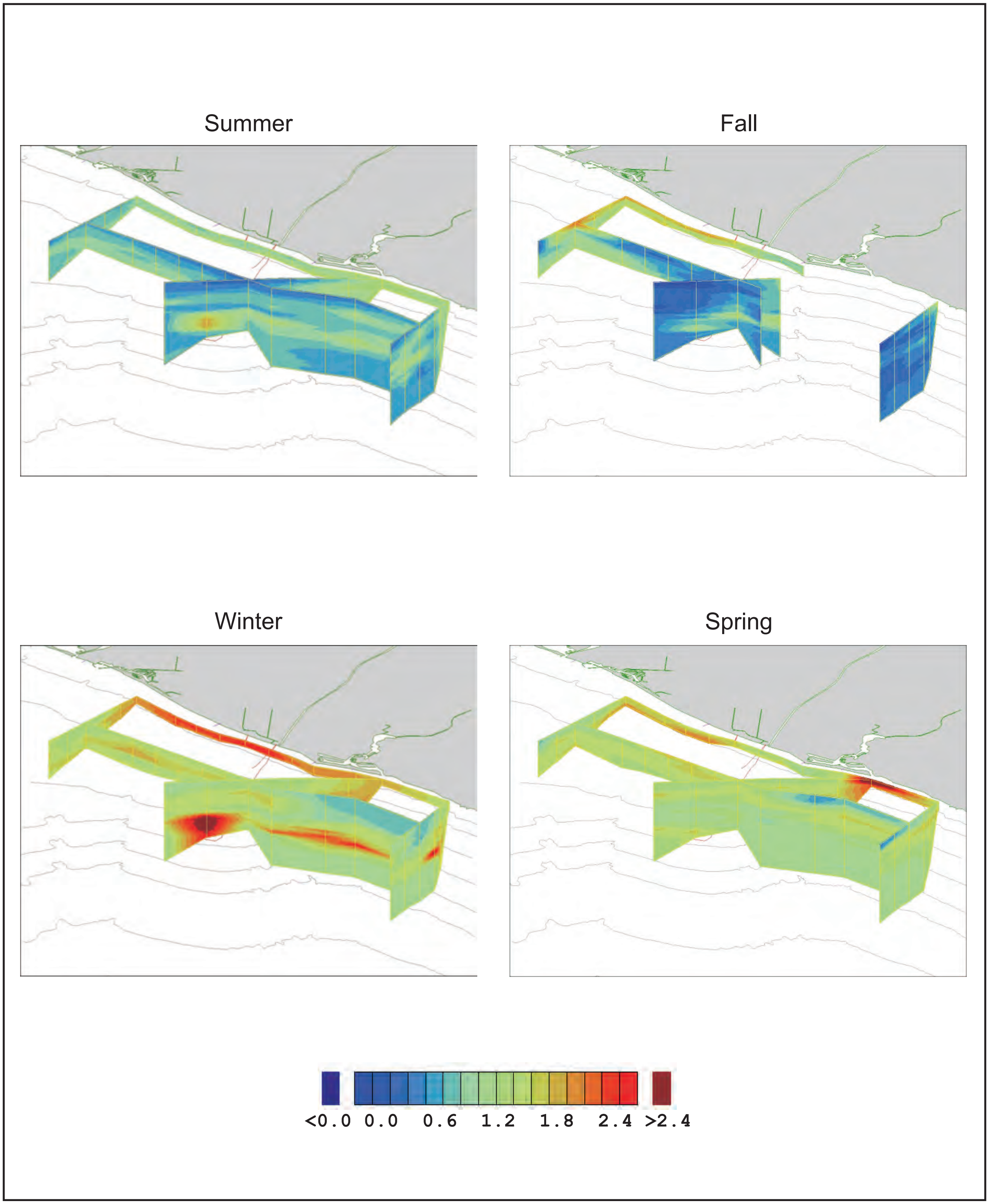



**Figure 3-18.** **Seasonal patterns of color dissolved organic matter (CDOM, µg/L) at OCSD regional stations for summer (August 2010), fall (November 2010), winter (February 2011), and spring (May 2011).**

Orange County Sanitation District, California.

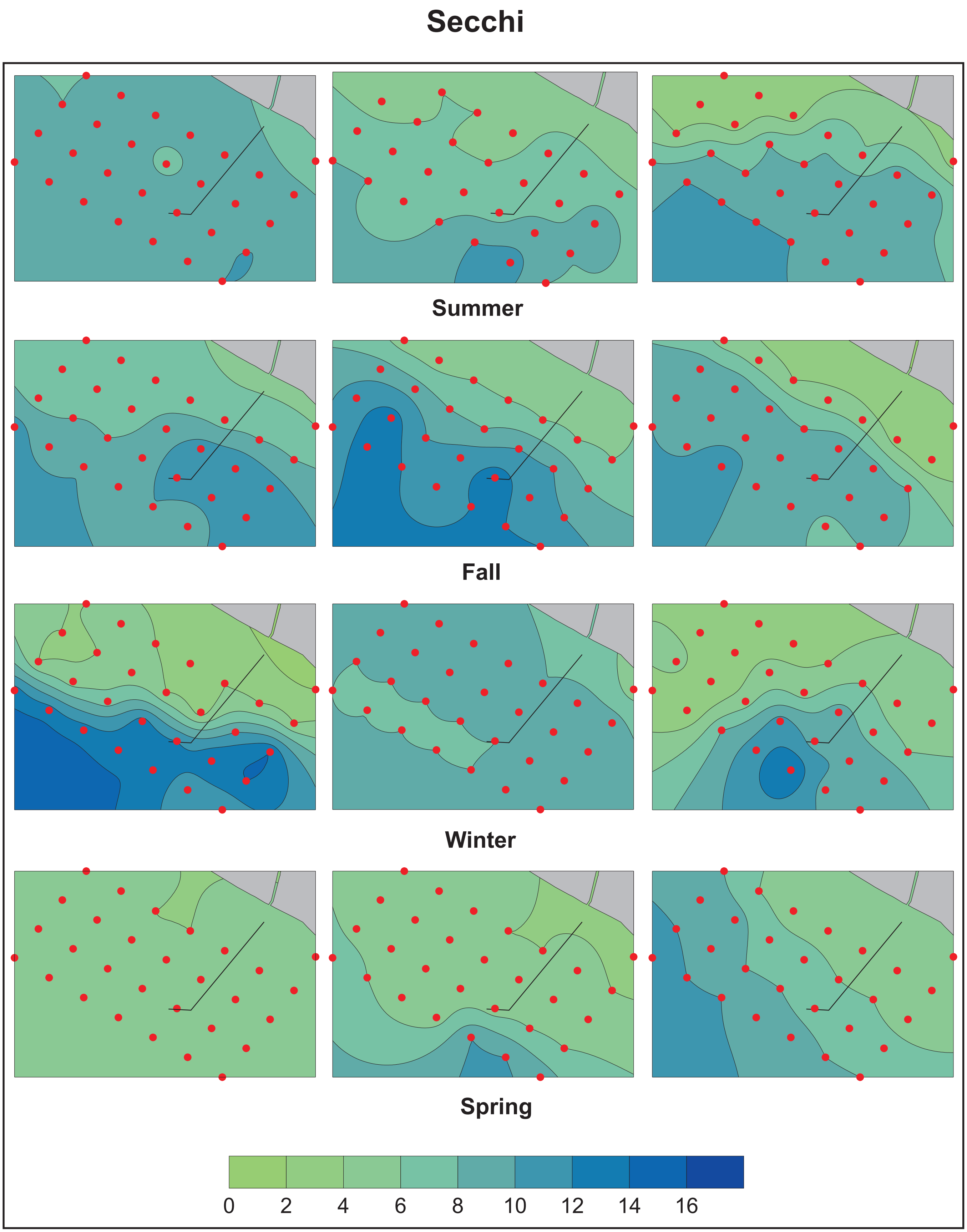



**Figure 3-19.** **Seasonal patterns of secchi depth (m) for summer (July 15, August 3, September 16, 2010), fall (October 27, November 2, December 8, 2010), winter (January 26, February 8, March 22, 2011), and spring (April 27, May 10, June 9, 2011).**
**Higher secchi values indicate clearer water.**

Orange County Sanitation District, California.

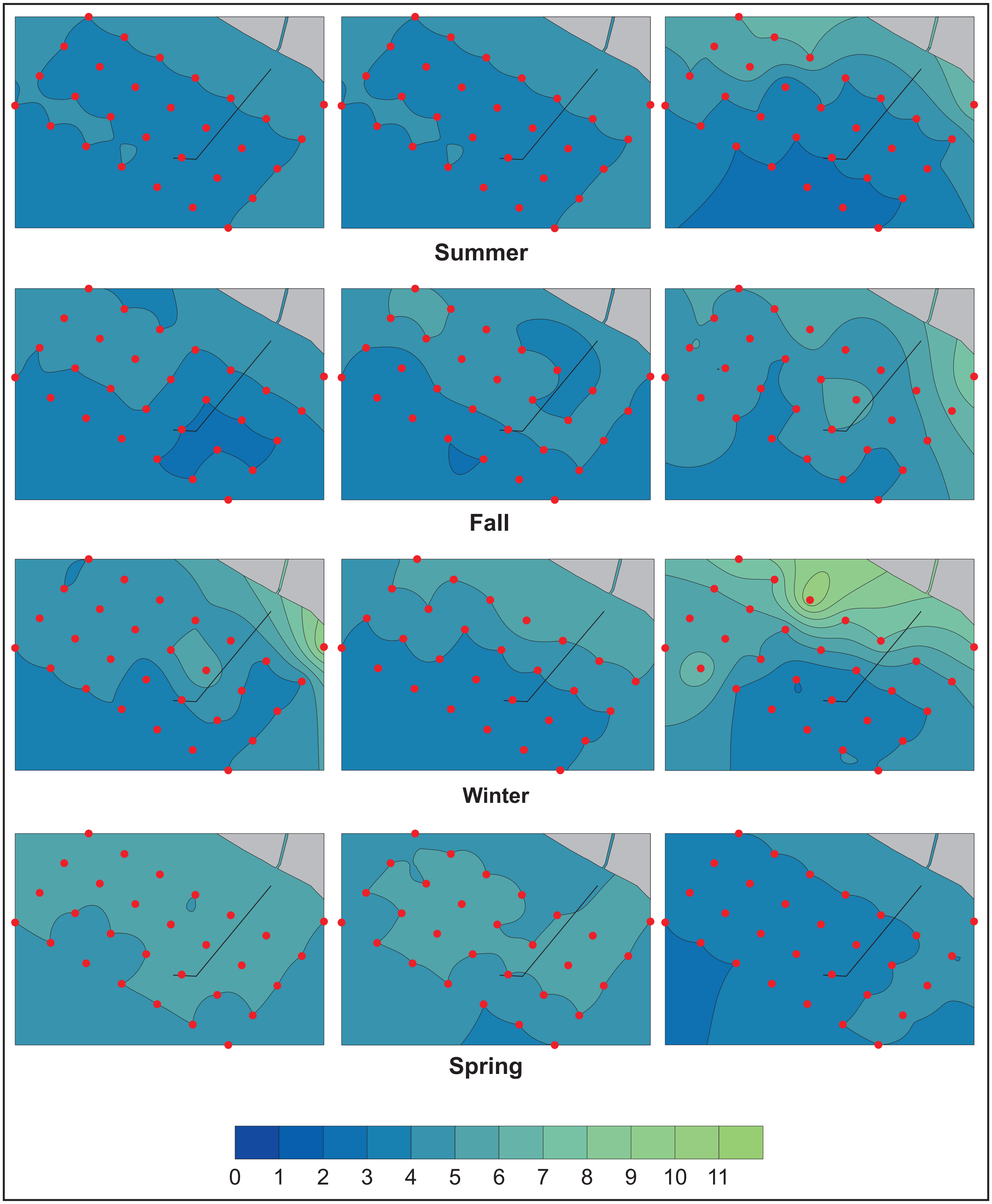



**Figure 3-20. Seasonal patterns of water color (Forel/Ule) for summer (July 15, August 3, September 16, 2010), fall (October 27, November 2, December 8, 2010), winter (January 26, February 8, March 22, 2011), and spring (April 27, May 10, June 9, 2011).**
**Lower water color values indicate clearer water.**

Orange County Sanitation District, California.

*Photosynthetically Active Radiation (PAR)*
Light levels rapidly decreased within the upper 10 m of the water column (Figure 3-21). The range of depths for the 10% light level was between 1–15 m (Table 3-4). The 1% light level (euphotic zone depth) was as deep as 45 m in all seasons, though, on average, it was limited to the upper 30 m of the water column. Summer had the clearest surface water and spring the least clear (maximum of 78.7%). Fall and winter PAR were comparable, perhaps due to the rainfall.

Both the 10% and 1% PAR light levels were significantly correlated to Secchi depth (r=0.19 and 0.63, respectively). However, there was a closer affinity in the spatial patterns between the 1% light levels and Secchi depth than to the 10% light levels (Figure 3-22). Intuitively, this makes sense since both the 1% PAR and Secchi depth measure a more comparable light extinction endpoint.

*Chlorophyll-a*
Measurements of chlorophyll-*a* fluorescence, used as a surrogate to collecting discrete samples for phytoplankton, are an indicator of phytoplankton abundance and biomass in coastal waters. While chlorophyll-*a* does not distinguish between the source of chlorophyll (terrestrial versus marine) or plankton species, high concentrations typically indicate high phytoplankton biomass and reflect a potential response to nutrient loads. For 2010-11, spring had the highest depth-averaged mean values, while fall had the lowest (Table 3-4). Elevated chlorophyll-*a* was measured subsurface (16–30 m) in the summer and from the surface down to 45 m in the winter and spring. Subsurface maxima were evident throughout the year, but muted in the fall (Figures 3-21 and 3-23).

For each quarter, the chlorophyll-*a* peak was below the 10% light level (Figure 3-19) and was significantly correlated to 1% PAR, 10% PAR, or Secchi (r=0..22, 0.53, and 0.55, respectively). While the 10% light level generally corresponds to minimum levels needed by phytoplankton for photosynthesis, the subsurface layering patterns also correspond to typical sinking depths for phytoplankton (Hardy 1993).

*Plume Related Changes*
There were no patterns relative to the outfall for chlorophyll-*a*, Secchi depth, water color, and PAR, therefore criteria C.3.b for water clarity and discoloration was met. Plume-related changes in transmissivity and CDOM occurred below the pycnocline or at mid-depth (Figures 3-16 and 3-17). A plume impact would include changes in water clarity that diminishes light as it penetrates water such that it would have an effect on phytoplankton by reducing photosynthesis and inhibiting growth. However, reductions in light levels due to the plume were small (<10% for light transmittance) and below the 10% light level as defined by PAR (Figure 3-21). With the exception of CDOM, water clarity measures at the outfall fell within the ranges of the monitoring area (Figures B-16 to B-20). The overall effect on the “natural” light penetration criterion (C.3.c) was, therefore, minimal and not ecologically significant (see Chapter 2).

## Nutrients, Bacteria, and Floatables

*Ammonia*
Ammonia concentrations (NH3-N) were below detection in nearly 84% of the samples collected in 2010-11. Of the 432 remaining samples with detectable ammonia, 314 (72%) occurred below 15 m. Elevated levels of NH3-N in the upper 30 m of water were restricted to winter and spring (Table 3-4). Mean and maximum values for 2010-11 were lower than the previous two years and were more consistent with results prior to 2008. While there were elevated NH3-N concentrations due to the discharge, these values were below the ocean surface and localized near the outfall (Figure 3-24). Spatial patterns and concentration ranges were similar to prior year’s results (OCSD 2004–2011). Local NH3-N values were lower in all seasons as compared to regional values (Table 3-2). Values above 30 m at outfall Station 2205 all fell within the range of non-outfall stations, while those below 30 m exceeded background values (Figure B-21). Taking into account the limited vertical and spatial distribution of NH3-N, lack of coincidence with chlorophyll-*a,* and low probability of toxicity, it was determined that compliance with the nutrient criterion (C.4.f) was met.

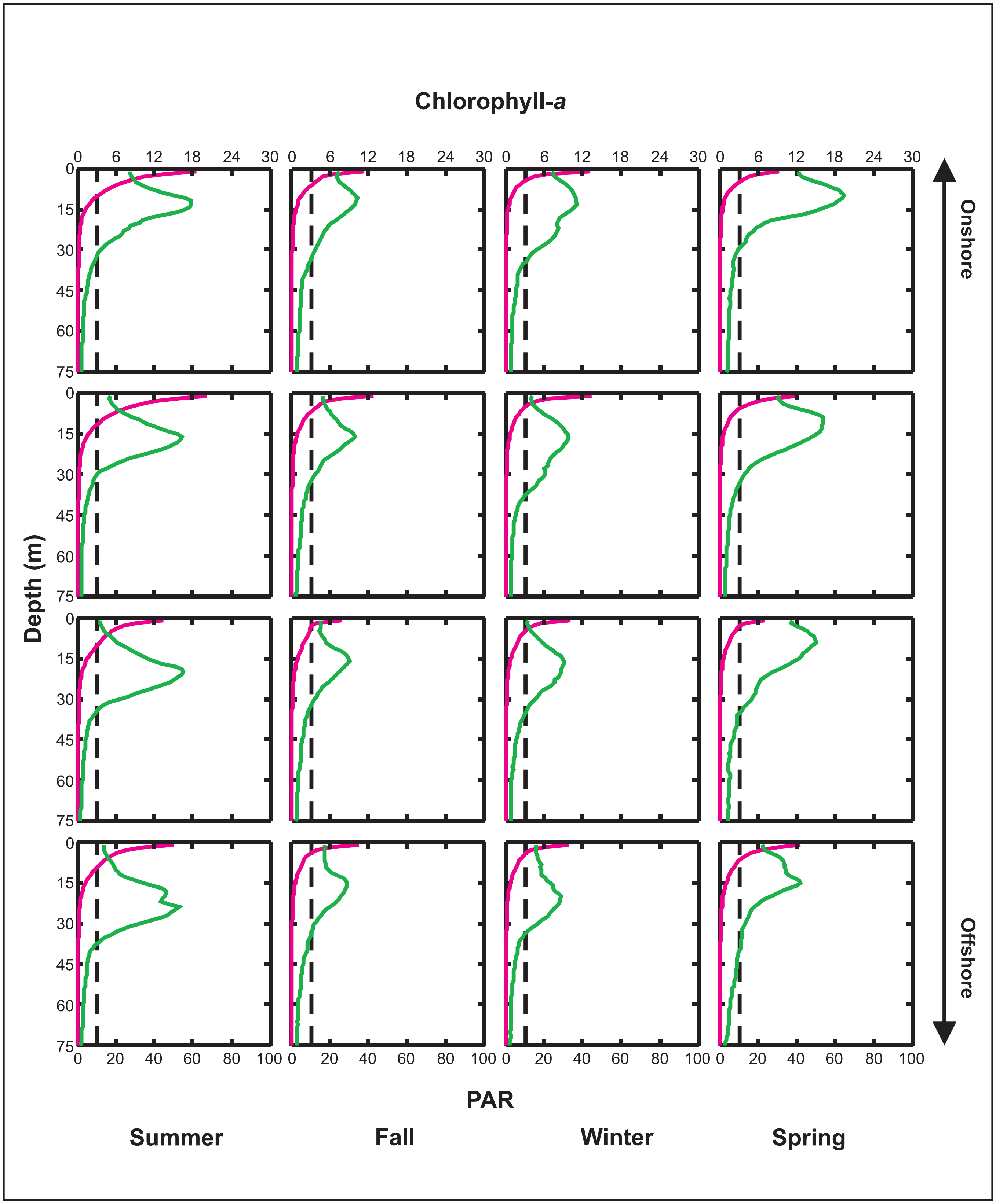



**Figure 3-21.** **Quarterly average chlorophyll-*a* fluorescence (µg/L; green line) and photosynthetically active radiation (PAR; µE/(cm$^2$·sec); red line) with depth for summer (August 2010), fall (November 2010), winter (February 2011), and spring (May 2011).**

**Black dashed line represents the 10% light penetration level.**

Orange County Sanitation District, California.

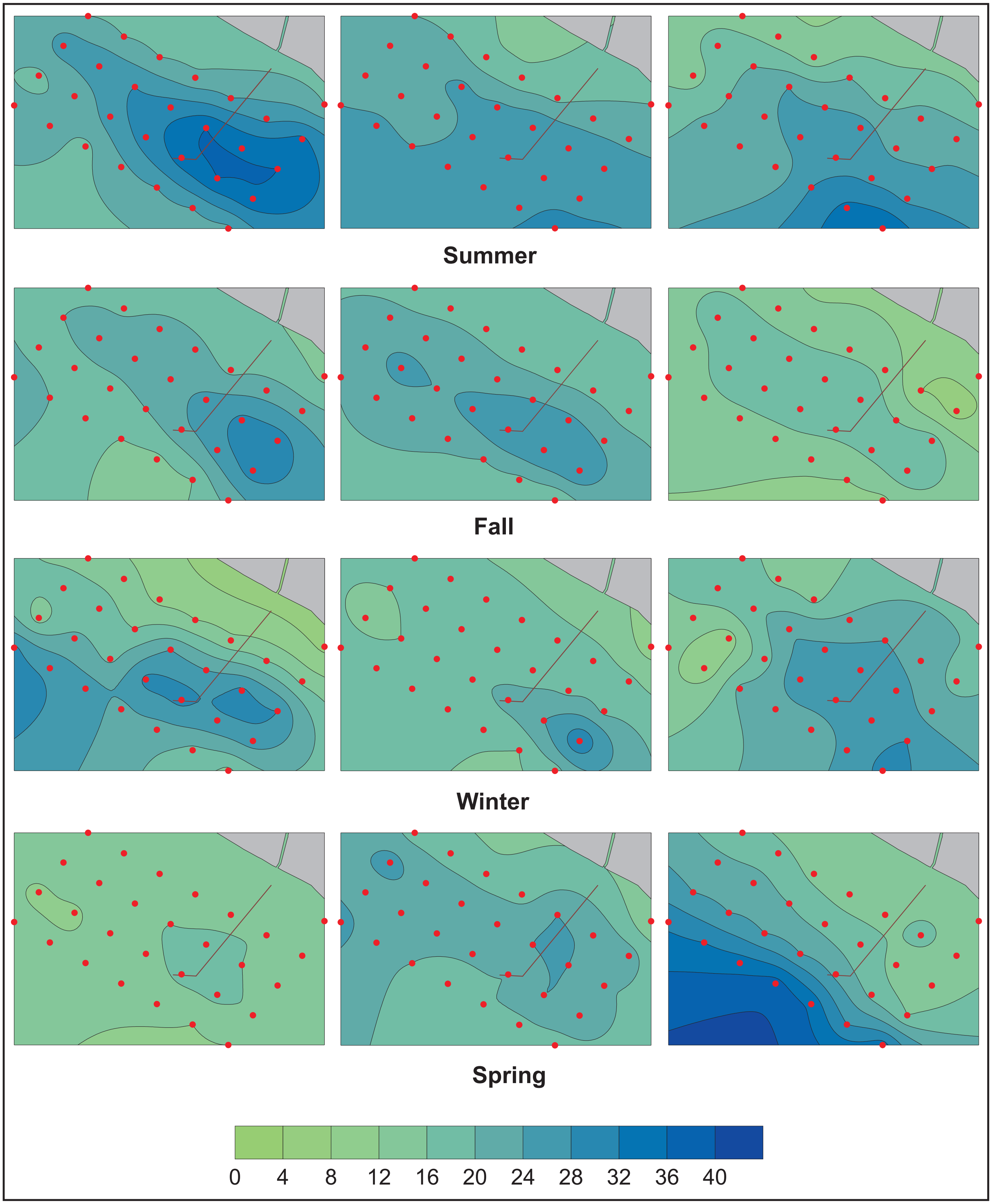



**Figure 3-22.** **Seasonal patterns of 1% PAR depth (m) for summer (July 15, August 3, September 16, 2010), fall (October 27, November 2, December 8, 2010), winter (January 26, February 8, March 22, 2011), and spring (April 27, May 10, June 9, 2011).**

Orange County Sanitation District, California.

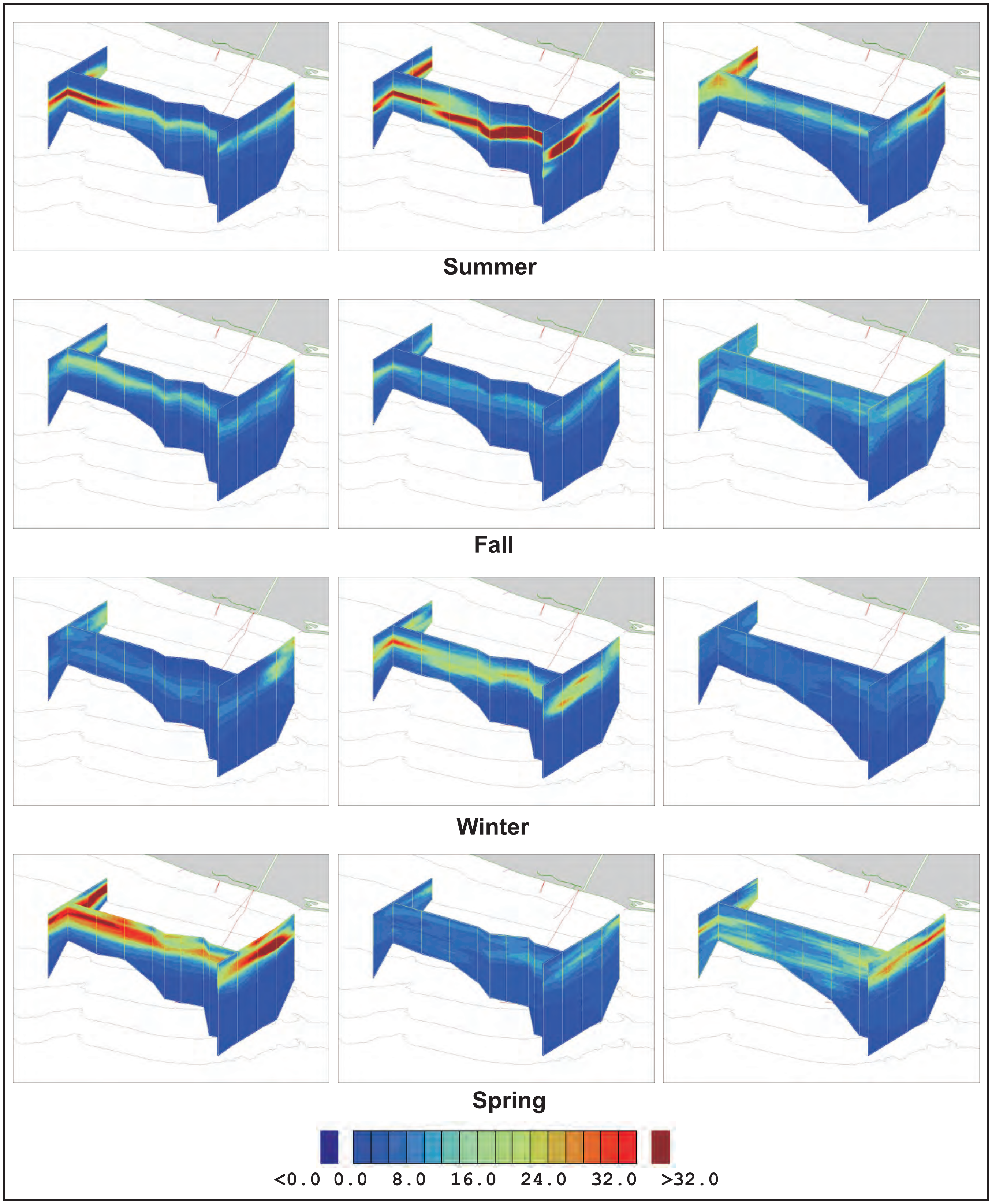



**Figure 3-23.** **Seasonal patterns of chlorophyll-*a* (µg/L) for summer (July 15, August 3, September 16, 2010), fall (October 27, November 2, December 8, 2010), winter (January 26, February 8, March 22, 2011), and spring (April 27, May 10, June 9, 2011).**

Orange County Sanitation District, California.

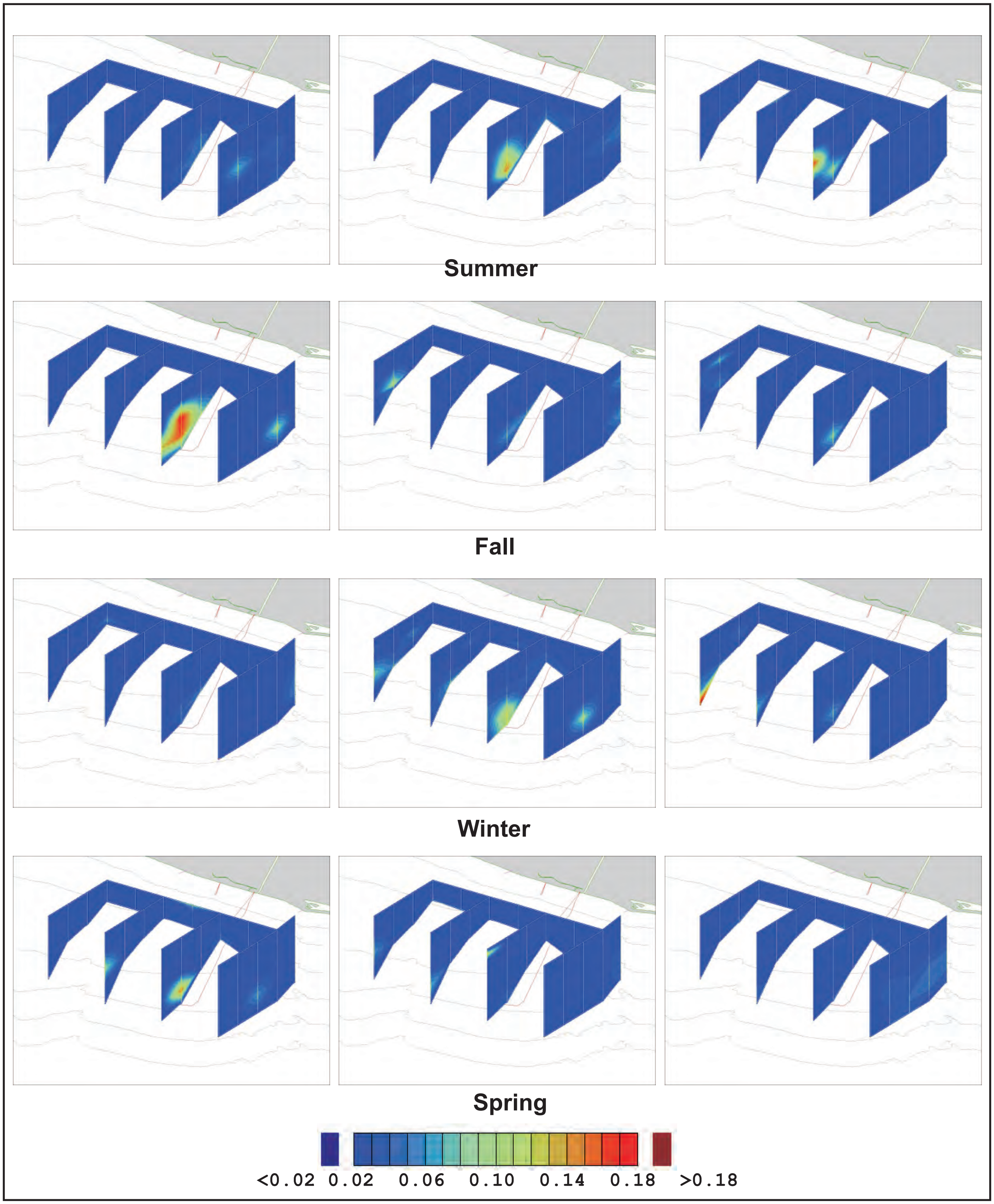



**Figure 3-24.** **Seasonal patterns of ammonia (mg/L) for summer (July 15, August 3, September 16, 2010), fall (October 27, November 2, December 8, 2010), winter (January 26, February 8, March 22, 2011), and spring (April 27, May 10, June 9, 2011).**

Orange County Sanitation District, California.

*Bacteria*

Prior to beginning disinfection in August 2002, the District used FIBs as a conservative plume tracer. Subsequent to disinfection, most samples have counts below the method detection of 20 MPN/100 mL. All three FIBs were correlated (r values ranged from 0.835 to 0.972) so total coliform bacteria, which had the highest counts, was used as a “worse-case” analysis of the impact of bacteria to the receiving water. Elevated total coliform bacteria typically occurred below 15 m, with elevated surface values associated with rainfall runoff (Table 3-4, Figures B-22 to B-24). Spatially, FIBs occurred primarily near the outfall with no evidence of impact at the Rec-1 stations along the 20 m isobath (Figures 3-25, B-25, and B-26). Most total coliform samples (73%) were below the detection limit of 10 MPN/100 mL with less than 1% greater than the upper detection limit 24,192/100 mL; high counts (>10,000) all occurred offshore at Stations 2205, 9, and 2104 after the final effluent disinfection levels were reduced in December 2010 (see Chapter 1). All offshore criteria for bacteria (C.2.a.1 and C.2.a.2) were met.

*Floatables*

Observations of grease and floatables address the potential effects from the wastewater discharge to beaches and offshore surface waters. No beach station had any observable grease during 2010-11 (Table B-10). There were also no offshore observations of floatable material related to the discharge or that affected water clarity (Tables B-11 and B-12). These results demonstrated compliance with criterion C.3.a and were consistent with findings from previous years (OCSD 2004–2011).

## CONCLUSIONS

Results from the District’s 2010-11 water quality monitoring program detected only minor changes in measured water quality parameters related to the discharge of wastewater to the coastal ocean, which is consistent with previously reported results (e.g., OCSD 2011). Plume-related changes in temperature, salinity, DO, pH, and transmissivity were measurable beyond the initial mixing zone during some surveys, but usually extended only into the nearfield stations, typically <2 km away from the outfall. None of these changes were determined to be environmentally significant since they fell within natural ranges to which marine organisms are exposed (Allen et al. 2005; Chavez et al. 2002; Hsieh et al. 2005; Jarvis et al. 2004; OCSD 1996a and 2004; Wilber and Clarke 2001) and compliance with COP criteria remained high (Chapter 2, 95–100%)

Prevailing ocean currents and stratification were two of the primary factors in determining the location of the discharged wastewater plume. Current flows for 2010-11 were oriented along the coast (parallel to the depth contours) and had weak, short-lived shoreward flows. Currents were more uniform than in previous years, with a predominant upcoast flow, but transport directions were consistent with long-term patterns (Noble et al. 2009, SAIC 2009).

The spatial extent of the wastewater plume was apparent in patterns of salinity and CDOM with changes occurring near the outfall during all surveys, but primarily below 15 m water depth. In contrast, values and patterns in dissolved oxygen and pH primarily responded to natural processes. One exception was apparent reduced oxygen concentration near the outfall due to the secondary entrainment of deeper lower oxygen water caused by the rising effluent plume. These results were consistent with predicted changes in DO and pH levels listed in Table 3-1 using a minimum centerline dilution value of 124:1 from Tetra Tech (2008). . Although subsurface (below 45 m) DO dipped to as low as 2.7 mg/L, average DO levels at depth exceeded 3.6 mg/L, and these lower values were attributed to naturally occurring upwelling.

Light transmissivity was more variable than other measured parameters (e.g., salinity) as it measures particles from multiple sources, such as the disturbance of near-bottom sediments due to waves and currents (resuspension), phytoplankton blooms, rainfall runoff, and the discharge plume. During 2010-11, strong decreases in light transmittance (almost 30%) were associated with the Newport Canyon, while much smaller changes (less than 10%) were associated with the discharge plume.

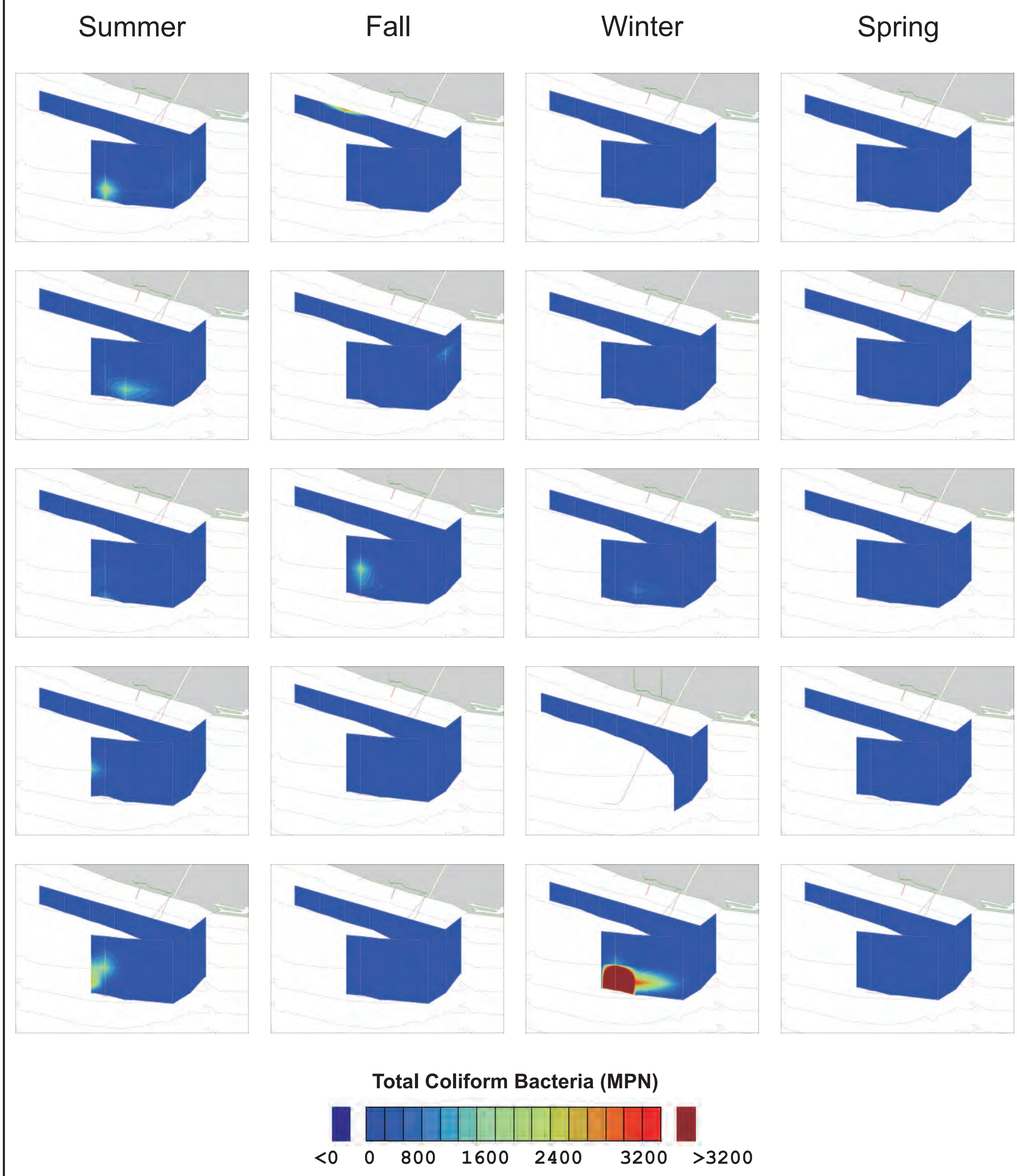



**Figure 3-25.** **Seasonal patterns of total coliforms (MPN/100mL) for summer (July 15, August 3, 10, 11, 12, 2010), fall (October 21, 26, 27, November 2, 4, 2010), winter (January 26, 27, February 1, 2, 8, 2011), and spring (April 26, 27, May 3, 4, 10, 2011).**

Orange County Sanitation District, California.

Light transmittance was most strongly affected by phytoplankton (chlorophyll-*a* r= -0.58). In all surveys, chlorophyll-*a* and, putatively, the resuspension of bottom sediments within the Newport Canyon had the greatest impacts on water clarity. While there were similar spatial patterns of reduced water clarity nearshore compared to offshore waters for Secchi depth and the 1% PAR, 10% PAR had a better relationship with the subsurface chlorophyll-*a* maxima.

Direct measures of the wastewater plume were nutrients (NH3-N) and bacteria. Maximum NH3-N concentrations were 20 times less than COP objective for chronic toxicity to marine organisms (4 mg/L; SWRCB 2005). Average values at all depths and for all seasons were several hundred times lower than this objective. Only 16% of the ammonium samples collected were above the detection limit of 0.02 mg/L and the vast majority of these (72%) were below 15 m, typically below the 10% PAR and maximum chlorophyll-a depths. This subsurface distribution was limited primarily to within 2 km of the outfall. The low levels and limited distribution of ammonium along with the lack of association with chlorophyll-*a* suggests that these concentrations were not environmentally significant.

Prior to disinfection, FIB levels were the primary plume tracer of the discharged wastewater plume. Since disinfection began in August 2002, offshore bacterial concentrations have remained low and predominately below measurement detection. This was the case for 2010-11 where 73–89% of the samples fell below the lower MDL of 10 MPN/100 mL. What was notable this year was the effect of reducing final effluent disinfection levels in December 2010. Prior to this change, no FIB value at the outfall exceeded its respective single sample maximum; after, counts for all FIBs exceeded their limits by an order of magnitude. However, the geometric means by depth and season did not change as dramatically.

Overall, the measured environmental and public health effects to the receiving water continue to be relatively small, with values that remain within the ranges of natural variability for the study area and reflected seasonal and yearly changes of large-scale regional influences. The limited observable plume effects occurred primarily at depth, even during the winter when stratification was weakest. In summary, results from 2010-11 water quality monitoring support the conclusion that the discharge is not greatly affecting the receiving water environment and that beneficial uses were maintained.

## REFERENCES


Allen, M.J., R.W. Smith, E.T. Jarvis, V. Raco-Rands, B.B. Bernstein, and K.T. Herbinson. 2005. Temporal trends in southern California coastal fish populations relative to 30-year trends in oceanic conditions. Pages 264–285. In: Weisberg, S.B. (ed.) Southern California Coastal Water Research Project Annual Report 2003-04. SCCWRP, Westminster, CA.

Chavez, F.P., J.T. Pennington, C.G. Castro, J.P. Ryan, R.P. Michisaki, B. Schlining, P. Walz, K.R. Buck, A. McFadyen, and C.A. Collins. 2002. Biological and chemical consequences of the 1997-1998 El Niño in central California waters. Prog.in Ocean. 54: 205–232.

Chao, Y., M. Ghil, and J.C. McWilliams (2000), Pacific interdecadal variability in this century's sea surface temperatures, *Geophys. Res. Lett.*, 27(15), 2261–2264.

Dailey, M.D., D.J. Reish, and J.W. Anderson, Eds. 1993. Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press. Los Angeles. 926 pages.

DELTAGRAPH. 2009. Deltagraph Version 5.6.5 [software]. SPSS, Inc. and Red Rock Software, Inc. Chicago, IL.

EXCEL. 2010. MS Excel Version 14 [software]. Microsoft Corporation. Redmond, WA.

Fischer, H.B., E.J. List, R.C.Y. Koh, J. Imberger, and N.H. Brooks. 1979. Mixing in Inland and Coastal Waters. San Diego. Academic Press. 483 pages.

Hardy, J.T. 1993. Phytoplankton. Chapter 5, In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.) Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA.

Howarth, R., F. Chan, D.J. Conley, J. Garnier, S.C. Doney, R. Marino, and G. Billen. 2011. Coupled biogeochemical cycles: eutrophication and hypoxia in temperate estuaries and coastal marine ecosystems. Front. Ecol. Environ. Vol. 9(1): 18-26.

Hsieh, C., C. Reiss, W. Watson, M.J. Allen, J.R. Hunter, R.N. Lea, R.H. Rosenblatt, P.E. Smith, and G. Sigihara. 2005. A comparison of long-term trends and variability in populations of larvae of exploited and unexploited fishes in the southern California region: A community approach. Prog. in Ocean. 67: 160–185.
JISAO (Joint Institute for the Study of the Atmosphere and Ocean). 2009. PDO Monthly Index Values 1900 to present. http://jisao.washington.edu/pdo/PDO.latest (December 30, 2009).

IGODS. 2010. IGODS (Interactive Graphical Ocean Database System) Version 3 Beta 3.4. [software]. Ocean Software and Environmental Consulting.

Jarvis, E.T., M.J. Allen, and R.W. Smith. 2004. Comparison of recreational fish catch trends to environment-species relationships and fishery-independent data in the Southern California Bight, 1980–2000. CalCOFI Rep. Vol. 45.

Jones, B.H., M.D. Noble, and G.L. Robertson. 2011. Huntington Beach: An In-Depth Study of Sources of Coastal Contamination Pathways and Newer Approaches to Effluent Plume to Dispersion. Proceedings of the International Symposium on Outfall Systems, May15-18, 2011. 8 pages

Kowalczuk, P., W.J. Cooper, R.F. Whitehead, M.J. Durako, and W. Sheldon. 2003. Characterization of CDOM in an organic rich river and surrounding costal ocean in the South Atlantic Bight. Aqiat. Sco. Vol. 65: 381-398

Linacre, L.R. Durazo, J.M. Herández-Ayón, F. Delgadilo-Hinojosa, G. Cervantes-Diaź, J.R. Lara-Lara, V. Camacho-Ibar, A. Siqueiros-Valencia, and C. Bazán-Guzmán. 2010. Temporal variability of the physical and chemical water characteristics at a coastal monitoring observatory: Station ENSENADA. Continental Shelf Research. Vol. 30, Issue 16: 1730-1742.

MacDonald, G.M. and R.A. Case. 2005. Variations in the Pacific Decadal Oscillation over the past millennium. Geophysical Research Letters. Vol. 32: L08703. 4 pages.

Mantua, Nate. 2000. The Pacific Decadal Oscillation (PDO). Joint Institute for the Study of the Atmosphere and Ocean. http://jisao.washington.edu/pdo/ (February 7, 2011)

MATLAB. 2007. MATLAB Version 7.4 [software]. The Mathworks Inc. Natick. MA

Noble, M. and J. Xu, eds., 2004, Huntington Beach Shoreline Contamination Investigation, Phase III, Final Report: Coastal Circulation and Transport Patterns: The Likelihood of OCSD's Plume Impacting Huntington Beach Shoreline: U.S. Geological Survey Open-File Report 2004–1019. http://pubs.usgs.gov/of/2004/1019/ (February 7, 2011).

Noble, M. A., K.J. Rosenberger, P. Hamilton, and J.P Xu. 2009. Coastal ocean transport patterns in the central Southern California Bight. In Lee, H.J. and W.R. Normark, editors. Earth Science in the Urban Ocean: The Southern California Continental Borderland. Special Paper 454. Boulder. The Geological Society. Pages 193–226.

OCSD (Orange County Sanitation District). 1986. Annual Report, July 1984–June 1985. Marine Monitoring, Vol. 4. Fountain Valley, CA.

OCSD. 1987. *Annual Report, July 1985–June 1986*. Marine Monitoring, Vol. 4. Fountain Valley, CA.

OCSD. 1988. *Annual Report, July 1986–June 1987*. Marine Monitoring. Fountain Valley, CA.

OCSD. 1989. *Annual Report, July 1987–June 1988*. Marine Monitoring, Vol. 4. Fountain Valley, CA.

OCSD. 1990. *Annual Report, July 1988–June 1989*. Marine Monitoring, Vol. 3. Fountain Valley, CA.

OCSD. 1991. *Annual Report, 5-Year Perspective, 1985–1990*. Marine Monitoring, Vol. 3 and Appendices. Fountain Valley, CA.

OCSD. 1992. *Annual Report, July 1990–June 1991*. Marine Monitoring, Vol. 3 and Appendices. Fountain Valley, CA.

OCSD. 1993. *Annual Report, July 1991–June 1992*. Marine Monitoring. Fountain Valley, CA.

OCSD. 1994. *Annual Report, July 1992–June 1993*. Marine Monitoring. Fountain Valley, CA.

OCSD. 1995. *Annual Report, July 1993–June 1994*. Marine Monitoring. Fountain Valley, CA.

OCSD. 1996a. *Science Report and Compliance Report, Ten Year Synthesis, 1985–1995*. Marine Monitoring. Fountain Valley, CA.

OCSD. 1996b. *Water Quality Atlas. Ten-Year Synthesis, 1985–1995*. Marine Monitoring. Fountain Valley, CA.

OCSD. 1998. *Special Project Report: Investigation of the Source of Occasional Elevated Coliform Concentrations at Station 21 South and 15 South.* Assessment Report #1, July 12, 1998)

OCSD. 2004 *Annual Report, Science Report, July 2002–June 2003*. Marine Monitoring, Fountain Valley, CA.

OCSD. 2005. *Annual Report, July 2003–June 2004*. Marine Monitoring, Fountain Valley, CA.

OCSD. 2006. *Annual Report, July 2004–June 2005*. Marine Monitoring, Fountain Valley, CA.

OCSD. 2007. *Annual Report, July 2005-June 2006*. Marine Monitoring, Fountain Valley, CA.

OCSD. 2008. *Annual Report, July 2006-June 2007*. Marine Monitoring, Fountain Valley, CA.

OCSD. 2009. *Annual Report, July 2007-June 2008*. Marine Monitoring, Fountain Valley, CA.

OCSD. 2010. *Annual Report, July 2008-June 2009*. Marine Monitoring, Fountain Valley, CA.

OCSD. 2011. *Annual Report, July 2009-June 2010*. Marine Monitoring, Fountain Valley, CA.

Peterson, B., J. Peterson, M. Pros, M. Precht, and L. Feinberg. 2010. Hypoxia and reduced pH in the Oregon upwelling zone: spatial and temporal variations in oxygen concentrations, effects of low oxygen on egg hatching and naupliar development of *Calanus marshallae* and effects of low pH on early larval development in *Calanus marshallae* and *Euphausia pacifica.* CalCOFI Conference. December 6-8, 2010. Scripps Institution of Oceanography, La Jolla, CA. Page 15. S-5.

Petrenko, A., B. Jones, and T. Dickey. 1998. Shape and initial dilution of San Island, Hawaii sewage plume. Journal of Hydraulic Engineering 124:565–571.

Rogowski, P., E. Terrill, M. Otero, L. Hazard, and B. Middleton. 2011. Mapping Ocean Outfall Plumes and their Mixing using Autonomous Underwater Vehicles. Proceedings of the International Symposium on Outfall Systems, May15-18, 2011. 8 pages.

SAIC (Science Applications International Corporation). 2009. Orange County Sanitation District Ocean Current Studies: Analyses of Inter- and Intra-Annual Variability in Coastal Currents. Final Report prepared for the Orange County Sanitation District. October 2009. 62 pages.

SAIC. 2011. Statistical Analysis of Multi-Year Currents at Inshore Locations in San Pedro Bay. Final Report prepared for the Orange County Sanitation District. October 2011. 36 pages.

Scavia, D., J.C. Field, D.F. Boesch, R.W. Buddemeier, V. Burkett, D.R. Cayan, M. Fogarty, M.A. Harwell, R.W. Howarth, C. Mason, D.J. Reed, T.C. Rover, A.H. Sallenger, and J.G. Titus. 2002. Climate Change Impacts on U.S. Coastal and Marine Ecosystems. Estuaries. Vol. 25: 149-165.

SCCWRP (Southern California Coastal Water Research Project). 1973. The Ecology of the Southern California Bight: Implications for Water Quality Management. El Segundo, California. 531 pages.

SEASOFT. 2010a. Seasoft CTD Data Acquisition Software, Version 7.21 [software]. Seabird Electronics, Inc. Bellevue, WA

SEASOFT. 2010b. Seasoft CTD Data Processing Software, Version 7.21 [software]. Seabird Electronics, Inc. Bellevue, WA

SURFER. 2004. Surfer Surface Mapping System Version 8.05 [software]. Golden Software Inc. Golden, Colorado.

Steinberg, D.K., N.B. Nelson, C.A. Carlson, and A.C. Prusak. 2004. Production of chromophoric dissolved organic matter (CDOM) in the open ocean by zooplankton and the colonial cyanobacterium *Thichodesmium* spp. Mar. Ecol. Prog. Ser. Vol. 267:45-56.

Sverdrup, H.U., M.W. Johnson, and R.H. Fleming. 1963. The Oceans: Their Physics, Chemistry and General Biology. Englewood Cliffs, NJ. Prentice-Hall, Inc. 1060 pages, plus maps.

SWRCB (State Water Resources Control Board). 1965. An Oceanographic and Biological Survey of the Southern California Mainland Shelf. Publication No. 27. 301 pages.

SWRCB. 2005. California Ocean Plan. Water Quality Control Plan, Ocean Waters Of California. Sacramento, CA. February 14, 2006. 57 pages.

SYSTAT. 2007. SYSTAT for Windows, Version 12 [software]. SYSTAT Software Inc., San Jose, California.

Tetra Tech, Inc. 2002. Nearfield and Farfield Modeling of an Ocean Outfall Wastewater Discharge. Final Report in Support for Preparation of NPDES Permit Application submitted to the Orange County Sanitation District, Fountain Valley, CA. November 2002.

Tetra Tech, Inc. 2008. Analysis of Initial Dilution for OCSD Discharge Flows with Diversions to the Groundwater Replenishment System (GWRS). Final Report Prepared for the Orange County Sanitation District, Fountain Valley, CA. December 23, 2008.

Tynan, S. and B. N. Opdyke. 2011. Effects of lower surface ocean pH upon the stability of shallow water carbonate sediments. Sci. Tot. Environ. Vol. 406, Issue 6:1082-1086.

USGS (United States Geological Survey). 2006. Hypoxia. Toxic Substances Hydrology Program. http://toxics.usgs.gov/definitions/hypoxia.html (February 10, 2009)

Valiela, I. 1995 Marine Ecological Processes. New York. Springer. 686 pages.

Wilber, D.H. and D.G. Clarke. 2001. Biological effects of suspended sediments: A review of suspended sediment impacts on fish and shellfish with relation to dredging activities in estuaries. *No. Am. J. of Fish. Mgmt*. 21: 855–875.

WINADCP. 2003. WinADCP Version 1.13 [software]. Teledyne/RD Instruments. San Diego, CA.

WINSC. 2003. WinSC Version 1.29 [software]. Teledyne/RD Instruments. San Diego, CA.

Wu, Y, L. Washburn, and B. Jones. 1994. Buoyant plume dispersion in a coastal environment – Evolving plume structure and dynamics. Continental Shelf Research 14:1001–1023.