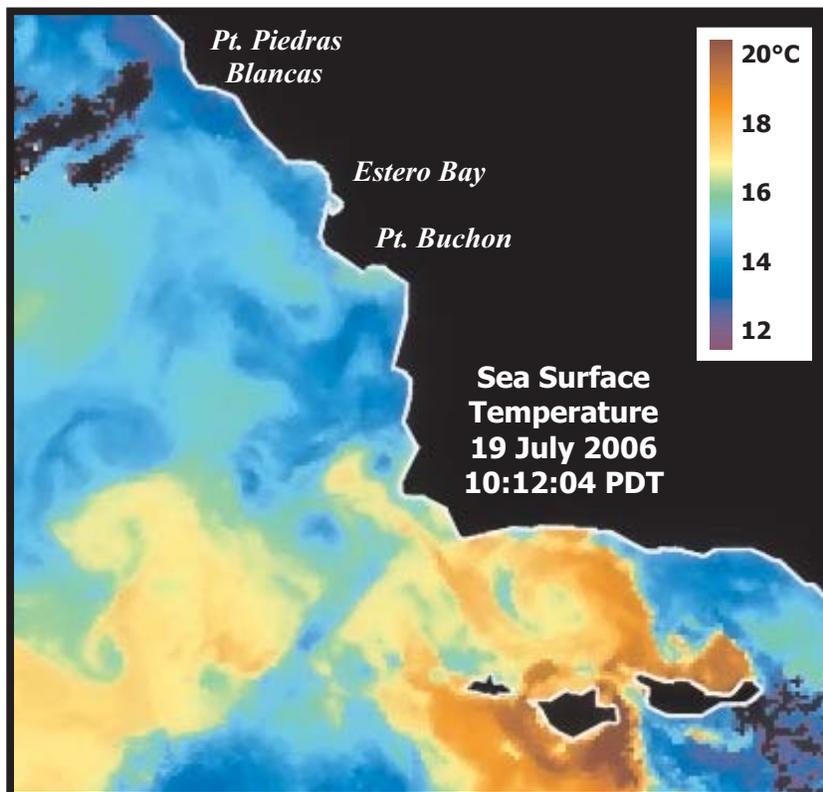


**City of Morro Bay and  
Cayucos Sanitary District**

## **OFFSHORE MONITORING AND REPORTING PROGRAM**

### **QUARTERLY REPORT**

### **WATER-COLUMN SAMPLING JULY 2006 SURVEY**



**Marine Research Specialists**

**3140 Telegraph Rd., Suite A  
Ventura, California 93003**

**Report to**

**City of Morro Bay and  
Cayucos Sanitary District**

**955 Shasta Avenue  
Morro Bay, California 93442  
(805) 772-6272**

**OFFSHORE MONITORING  
AND  
REPORTING PROGRAM**

**QUARTERLY REPORT**

**WATER-COLUMN SAMPLING  
JULY 2006**

**Prepared by**

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**August 2006**

# marine research specialists

3140 Telegraph Road, Suite A · Ventura, CA 93003 · (805) 644-1180

Mr. Bruce Keogh  
Wastewater Division Manager  
City of Morro Bay  
955 Shasta Avenue  
Morro Bay, CA 93442

25 August 2006

**Reference: Quarterly Receiving-Water Report – July 2006**

Dear Mr. Keogh:

Enclosed is the Quarterly Report for the Water-Quality Survey conducted on 19 July 2006. This third-quarter survey assessed the effectiveness of effluent dispersion during summer oceanographic conditions. Based on quantitative analyses of continuous instrumental measurements and qualitative visual observations, the wastewater discharge was found to be in compliance with the receiving-water limitations specified in the NPDES discharge permit, and with the objectives of the California Ocean Plan.

High-precision measurements clearly delineated discharge-related perturbations in all six seawater properties at two of the sixteen sampling stations. One of these stations was located close to the diffuser structure where seawater perturbations were generated by the presence of effluent constituents. The other station was located beyond the zone of initial dilution where seawater perturbations were generated by the upward displacement of ambient seawater entrained within the effluent plume. In both cases, dilution levels determined from salinity anomalies within the discharge plume significantly exceeded those anticipated by modeling and outfall design criteria. All of the measurements were indicative of low contaminant concentrations within the discharged wastewater, and of an outfall operating as designed.

Please contact the undersigned if you have any questions regarding the attached report.

Sincerely,

Douglas A. Coats, Ph.D.  
Program Manager

Enclosure (Five Report Copies)

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

---

Mr. Bruce Ambo  
City of Morro Bay

Date \_\_\_\_\_

## TABLE OF CONTENTS

|   |    |
|---|----|
| LIST OF FIGURES .....                         | i  |
| LIST OF TABLES .....                          | ii |
| INTRODUCTION .....                            | 1  |
| STATION LOCATIONS .....                       | 2  |
| METHODS .....                                 | 9  |
| <i>Ancillary Measurements</i> .....           | 9  |
| <i>Instrumental Measurements</i> .....        | 10 |
| <i>Temporal Trends in the pH Sensor</i> ..... | 12 |
| RESULTS.....                                  | 13 |
| <i>Beneficial Use</i> .....                   | 13 |
| <i>Ambient Seawater Properties</i> .....      | 14 |
| <i>Lateral Variability</i> .....              | 15 |
| <i>Discharge-Related Perturbations</i> .....  | 17 |
| <i>Initial Dilution Computations</i> .....    | 18 |
| DISCUSSION .....                              | 20 |
| <i>Outfall Performance</i> .....              | 21 |
| <i>NPDES Permit Limits</i> .....              | 21 |
| <i>Light Transmittance</i> .....              | 21 |
| <i>Dissolved Oxygen</i> .....                 | 22 |
| <i>pH</i> .....                               | 22 |
| <i>Temperature and Salinity</i> .....         | 22 |
| <i>Conclusions</i> .....                      | 23 |
| REFERENCES .....                              | 24 |

### APPENDICES

- A. Water-Quality Profiles and Vertical Sections
- B. Tables of Profile Data and Standard Observations

## LIST OF FIGURES

|  |   |
|--|---|
| <b>Figure 1.</b> Regional Setting of Receiving-Water Sampling Stations within Estero Bay ..... | 3 |
| <b>Figure 2.</b> Offshore Water Sampling Locations on 19 July 2006.....                        | 5 |
| <b>Figure 3.</b> Estero Bay Tidal Level during the Field Survey of 19 July 2006.....           | 8 |

**LIST OF TABLES**

**Table 1.** Description of Receiving-Water Monitoring Stations ..... 4  
**Table 2.** Average Coordinates of Vertical Profiles during the July 2006 Survey ..... 8  
**Table 3.** Instrumental Specifications for CTD Profiler..... 11  
**Table 4.** Discharge-Related Water-Property Anomalies ..... 18

## INTRODUCTION

The City of Morro Bay and the Cayucos Sanitary District (MBCSD) jointly own the wastewater treatment plant operated by the City of Morro Bay. A National Pollutant Discharge Elimination System (NPDES) permit, modifying secondary treatment requirements, was issued to the City of Morro Bay and the Cayucos Sanitary District in December 1998 (Permit No. CA0047881). This current permit was issued by Region 9 of the Environmental Protection Agency (EPA) and the Central Coast California Regional Water Quality Control Board (RWQCB-EPA 1998a). The previous permit expired in early 1998. An administrative extension was granted through 11 December 1998 to allow time for review and issuance of the current discharge permit (RWQCB 1998).

As part of the current permit provisions, the previous monitoring program was modified to better evaluate short- and long-term effects of the discharge on receiving waters, benthic sediments, and infaunal communities (RWQCB-EPA 1998b). The program continued to include a requirement for receiving-water-quality monitoring performed on a seasonal basis. Four quarterly surveys were intended to record ambient water properties that approximate winter, spring, summer, and fall conditions. In keeping with seasonal synopses, this quarterly report summarizes the results of water-quality sampling conducted on 19 July 2006. Specifically, this third-quarter survey was conducted to capture ambient oceanographic conditions along the central California coast during the summer season.

The water-quality surveys also provide timely assessments of the performance of the diffuser structure in dispersing wastewater within stratified receiving waters. Any significant, recent damage to the diffuser structure would be revealed by a decline in the level of wastewater dispersion measured in this survey compared to that of prior surveys, and compared to design specifications. As described in this report, no such decline was observed in the July 2006 field survey.

Both monitoring objectives were achieved through an evaluation of the water-column profiles and vertical sections of water-property distributions that are presented in Appendix A. Appendix B tabulates instrumental measurements and standard field observations. These data were used to assess compliance with the objectives of the California Ocean Plan (COP) as specified in the NPDES discharge permit.

The July 2006 field survey was the thirty-first receiving-water survey to be conducted under the monitoring provisions of the current permit. Compared to the previous permit, the number of stations increased from 11 to 16, and the stations were relocated closer ( $\leq 100$  m) to the diffuser structure. Sampling at these more closely spaced stations could only be achieved because of the availability of increased navigational accuracy that resulted from implementation of the differential global positioning satellite (DGPS) system. This system was commissioned during the March 1998 survey (MRS 1998a) and was subsequently employed in the precise determination of the open section of the diffuser structure during a diver survey on 29 September 1998 (MRS 1998bc).

The current sampling design also allowed surveying to be conducted more rapidly than previous surveys by eliminating the requirement for the time-consuming collection of discrete water samples using Niskin bottles. Continuous deployment of the CTD<sup>1</sup> instrument package between stations now provides a more synoptic snapshot of the water properties immediately surrounding the diffuser structure. Consequently,

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<sup>1</sup> Conductivity, Temperature, and Depth (CTD) were the original measurements recorded by this standard oceanographic instrument package, but the moniker now connotes an electronic instrument package with a broader suite of probes and sensors capable of *in situ* measurement of dissolved oxygen, transmissivity, and pH.

the extent of the effluent plume and the amplitude of its associated water-property anomalies can be more precisely determined. The sensitive sensors in the CTD instrument package are capable of detecting minute changes in water properties. These sensors are described in the Methods section below.

Surveys conducted prior to 1999 rarely detected the effluent plume because sampling stations were too widely separated to resolve the dilute wastewater signature that is highly localized around the outfall diffuser. With the implementation of the current sampling design in 1999, the presence of well-mixed effluent near the diffuser structure was found in all 31 of the subsequent water-quality surveys (MRS 2000, 2001, 2002, 2003, 2004, 2005, 2006), including the one described in this report. Moreover, improved navigation in concert with the denser sampling pattern more precisely delineated the location of the discharge-related perturbations in seawater properties.

Precision navigation is important for assessing compliance because most receiving-water limitations apply only beyond the narrow zone of initial dilution that surrounds the outfall. Additionally, the amplitudes of the effluent-related perturbations can be better determined by the denser sampling pattern. The amplitudes of discharge-related salinity anomalies reveal the details of dilution as the effluent plume disperses within receiving waters. Measured dilution factors lend insight into the current operational performance of the outfall and diffuser structure. As described in this report, the presence of dilute effluent undergoing turbulent mixing close to the diffuser structure was clearly delineated by the data collected during the July 2006 survey.

## **STATION LOCATIONS**

The water-sampling stations surround the area where effluent is discharged within Estero Bay (Figure 1). The 1,450 m long outfall pipe, which carries the effluent from the onshore treatment plant, terminates at the diffuser structure, which lies on the seafloor approximately 827 m from the shoreline<sup>2</sup>. The diffuser structure itself extends an additional 52 m toward the northwest from the outfall terminus.

Twenty-eight of the 34 available ports discharge effluent along a 42 m section of the diffuser structure. The other six diffuser ports remain closed to improve dispersion by increasing the ejection velocity from the remaining ports. For a given flow rate, the diffuser ports were hydraulically designed to create an turbulent ejection jet, which serves to rapidly mix effluent with receiving seawater immediately upon discharge. Additional turbulent mixing occurs as the buoyant plume of dilute effluent rises through the water column. Most of this buoyancy-induced mixing occurs within a zone of initial dilution (ZID), whose lateral extent is somewhat arbitrarily defined to be approximately 15 m from the centerline of the diffuser structure.

Beyond the ZID, the energetic waves, tides, and coastal currents within Estero Bay further disperse the discharge plume within the open-ocean receiving waters. Areas of special concern, such as sanctuaries and estuaries, are too distant to be affected by the effluent discharge. For example, the southern boundary of the Monterey Bay National Marine Sanctuary is located 38 km to the north, near Cambria Rock.

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<sup>2</sup> This distance was determined from a navigational survey conducted on 6 July 2005 to benchmark the locations of the current surfzone sampling stations along the shoreline adjacent to the diffuser structure. The beginning of the section of the diffuser structure containing open diffuser ports lies directly offshore surfzone Station C (Figure 1). This closest-approach shoreline position was determined at the water's edge when the tidal level was +2.7 ft, referenced to mean lower low water (MLLW).



**Figure 1.** Regional Setting of Receiving-Water Sampling Stations within Estero Bay

Similarly, the entrance to the Morro Bay National Estuary lies 2.8 km south of the discharge. As described in this and previous water-quality monitoring reports, wastewater is diluted beyond recognition within a distance that is 100-times smaller than the distance between the discharge and the Morro Bay harbor mouth. Moreover, direct seawater exchange between the discharge point and the Bay is restricted by the southerly orientation of the mouth of the Bay, and by the presence of Morro Rock. Morro Rock is the largest physiographic feature of the adjacent coastline and extends into Estero Bay approximately 2 km south of the point of discharge (Figure 1). Its presence interrupts the nearshore flow within the littoral cell along Atascadero Beach, and obstructs transport to the mouth of the Bay.

Near the diffuser, prevailing currents generally follow bathymetric contours, which parallel the north-south trend of the adjacent coastline. Because of rapid initial mixing achieved within 15 m of the diffuser structure, impingement of unmixed effluent onto the adjacent coastline 827 m away is highly unlikely. Nevertheless, water samples are regularly collected along the shoreline at the surfzone sampling stations shown in Figure 1. These surfzone samples are analyzed for total and fecal coliform levels. Results of these analyses are reported in monthly operational summaries and in annual reports. The occasional instances of elevated beach coliform levels result from onshore non-point sources rather than the discharge of disinfected wastewater from the MBCSD outfall (MRS 2000, 2001, 2002, 2003, 2004, 2005, 2006).

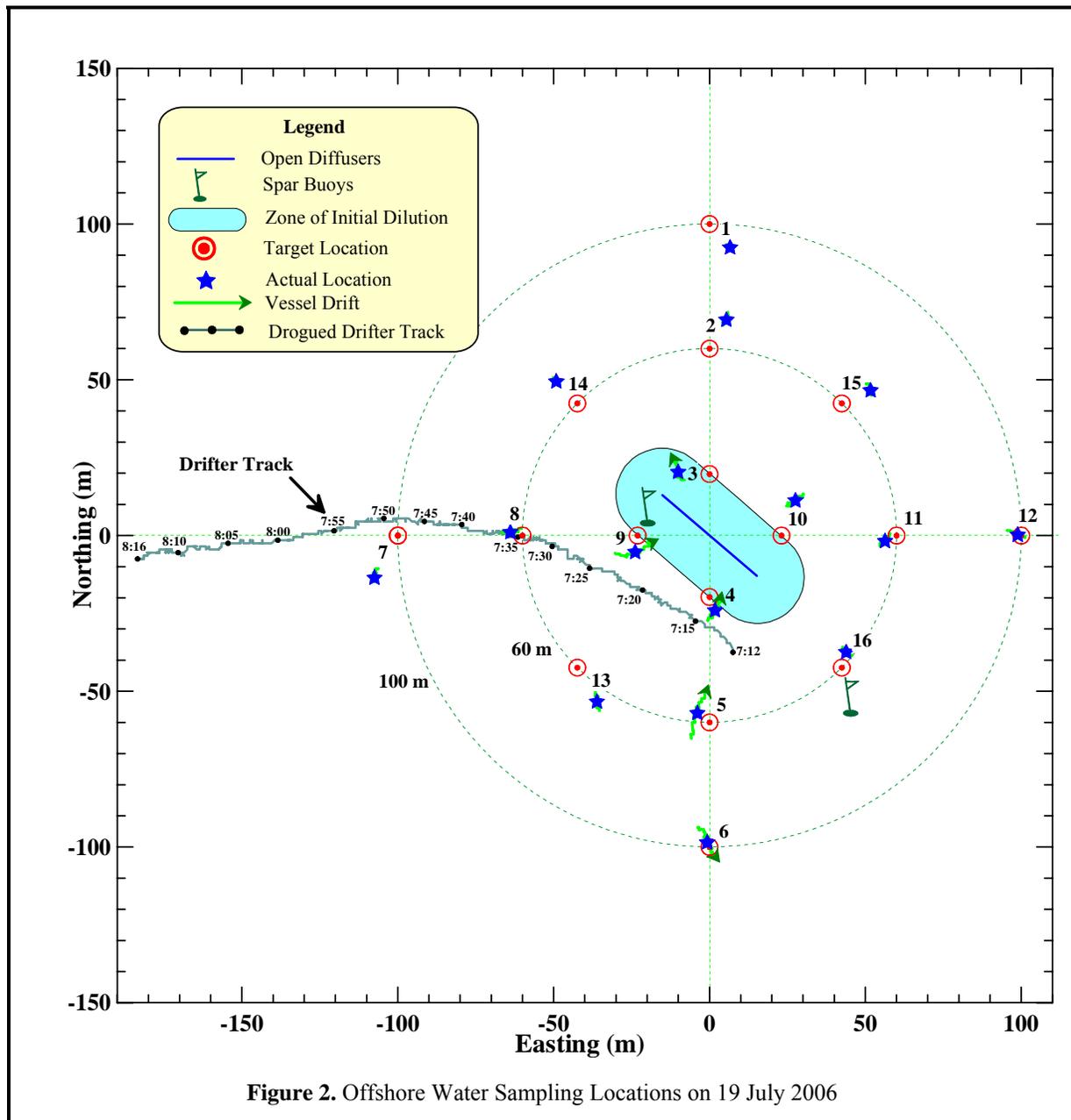
As shown in Figure 2, the water-sampling design consists of 16 fixed offshore stations located within 100 m of the outfall diffuser structure. The target locations of the 16 offshore sampling stations are indicated by the red ⊙ symbols in the Figure. Stations are situated at three distances relative to the center of the diffuser structure to capture any discharge-related trends in water properties. Six of the stations lie along a north-south axis at the same water depth (15.2 m) as the center of the diffuser. Stations 3 and 4 are positioned at the upcoast and downcoast boundaries of the ZID, at a distance of 15 m from the closest diffuser ports (Table 1). Stations 2 and 5 are located at nearfield distances (60 m) from the diffuser centroid. Stations 1 and 6 represent reference stations and are situated 100 m upcoast and downcoast of the centroid. Depending on the direction of the local oceanic currents at the time of sampling, one or more of these near and midfield stations could conceivably be influenced by the discharge. Under those circumstances, the midfield station on the opposite side of the diffuser can act as a reference station. Comparisons of water properties at these antipodal stations quantify departures from ambient seawater properties so that compliance with the NPDES discharge permit can be evaluated.

**Table 1.** Description of Receiving-Water Monitoring Stations

| Station | Description         | Latitude      | Longitude      | Closest Approach Distance <sup>1</sup> (m) | Center Distance <sup>2</sup> (m) |
|---------|---------------------|---------------|----------------|--|----------------------------------|
| 1       | Upcoast Midfield    | 35° 23.253' N | 120° 52.504' W | 88.4                                       | 100                              |
| 2       | Upcoast Nearfield   | 35° 23.231' N | 120° 52.504' W | 49.4                                       | 60                               |
| 3       | Upcoast ZID         | 35° 23.210' N | 120° 52.504' W | 15.0                                       | 20                               |
| 4       | Downcoast ZID       | 35° 23.188' N | 120° 52.504' W | 15.0                                       | 20                               |
| 5       | Downcoast Nearfield | 35° 23.167' N | 120° 52.504' W | 49.4                                       | 60                               |
| 6       | Downcoast Midfield  | 35° 23.145' N | 120° 52.504' W | 88.4                                       | 100                              |
| 7       | Offshore Midfield   | 35° 23.199' N | 120° 52.570' W | 85.8                                       | 100                              |
| 8       | Offshore Nearfield  | 35° 23.199' N | 120° 52.544' W | 46.7                                       | 60                               |
| 9       | Offshore ZID        | 35° 23.199' N | 120° 52.519' W | 15.0                                       | 23                               |
| 10      | Shoreward ZID       | 35° 23.199' N | 120° 52.489' W | 15.0                                       | 23                               |
| 11      | Shoreward Nearfield | 35° 23.199' N | 120° 52.464' W | 46.7                                       | 60                               |
| 12      | Shoreward Midfield  | 35° 23.199' N | 120° 52.438' W | 85.8                                       | 100                              |
| 13      | Southwest Nearfield | 35° 23.176' N | 120° 52.532' W | 59.8                                       | 60                               |
| 14      | Northwest Nearfield | 35° 23.222' N | 120° 52.532' W | 40.2                                       | 60                               |
| 15      | Northeast Nearfield | 35° 23.222' N | 120° 52.476' W | 59.8                                       | 60                               |
| 16      | Southeast Nearfield | 35° 23.176' N | 120° 52.476' W | 40.2                                       | 60                               |

<sup>1</sup> Distance to the closest open diffuser port.

<sup>2</sup> Distance to the center of open diffuser section.



Six other stations (7 through 12) were aligned along a cross-shore transect in a pattern matching that of the along-shore transect. The four additional nearfield stations (13 through 16) measure the nearfield influence of effluent transported by ocean currents flowing at oblique angles to the bathymetry.

Although the discharge is considered a ‘point source,’ it does not occur at a point of infinitesimal size. Instead, the discharge is distributed along a 42 m section of the seafloor. This finite size is an important consideration when assessing wastewater dispersion close to the discharge. Because of the finite length of the discharge, the amount of wastewater dispersion at a given point in the water column is dictated by its distance to the closest diffuser port, rather than its distance to the center of the diffuser structure. Because

of the finite size of the source, this ‘*closest approach*’ distance is considerably less than the centerline distance normally cited in modeling studies (Table 1).

Station positioning within the compact sampling pattern specified in the current permit became feasible only after the advent of DGPS. The accuracy of traditional navigation systems such as LORAN or standard GPS is typically  $\pm 15$  m, a span equal to the total width of the ZID itself. Prior to 2 May 2000, standard commercial GPS receivers were not allowed to be perfectly accurate by law; and a built-in error system called Selective Availability (SA) was encoded into GPS transmissions. SA could introduce a misreading of up to 100 m, although it altered most measurements by less than 30 m. After May 2000, SA was turned off and the accuracy of standard GPS receivers improved substantially, with horizontal position errors of typically less than 10 m.

Nevertheless, extreme atmospheric conditions and physiographic obstructions cause satellite signals to bounce around, leading to errors in position beyond those that were previously introduced by SA. These other errors are greatly reduced with the Differential GPS (DGPS) system that was first implemented by the U.S. Coast Guard. DGPS incorporates a second signal from a nearby land-based beacon. Because the beacon is fixed at a known location, the position error in the reading from the GPS satellites can be precisely calculated at any given time. This correction is continuously transmitted to the DGPS receiver onboard the survey vessel and results in extremely stable and accurate offshore navigation, typically with position errors of less than 2 m.

At the beginning of 1998, the survey vessel F/V *Bonnie Marietta* was fitted with a Furuno™ GPS 30 and FBX2 differential beacon receiver. This navigational system was used on 29 July 1998 to precisely locate the position of the open section of the diffuser structure (MRS 1998b) and establish the new target locations for the receiving-water monitoring stations shown in Figure 2 and listed in Table 1.

DGPS allows precise determination of sampling locations during individual water-quality surveys. Knowledge of the precise location of the actual sampling sites relative to the diffuser position is crucial for accurate interpretation of the water-property fields. During any given survey, the actual sampling locations do not coincide with the exact target coordinates listed in Table 1. Winds, waves, and currents induce offsets during sampling. Using DGPS, these offsets can be resolved and the vessel location can be precisely tracked during sampling at each station. This is an important consideration because vertical profiling conducted at an individual station can cover a large horizontal distance relative to the ZID.

The magnitude of this horizontal drift during the July 2006 survey is apparent in Figure 2 from the length of the green tracklines that are apparent at a few of the stations, such as Stations 3, 4, 5, 6, and 9. These tracklines trace the horizontal location of the CTD instrument package as it was lowered to the seafloor. Their length reflects the station-keeping difficulty experienced during the July 2006 survey, which was unusually moderate compared to most prior surveys. The particularly mild drift of the CTD instrument package during the July-2006 survey was due to quiescent wind and current conditions. Quiescent metocean conditions are reflected by the low wind speeds reported in Table B-8 and the slow drifter movement shown by the drifter track in Figure 2. Nevertheless, the CTD tracklines at a few of the stations shown in Figure 2 reveal perceptible lateral drift. During the time it took the CTD to traverse the water column to the seafloor, which averaged 1m 12s, the instrument package moved an average of 6.5 m laterally.

At stations close to the diffuser structure, this horizontal drift in the position of the CTD complicates the assessment of compliance with discharge limitations. Receiving-water limitations specified in the COP only apply to measurements recorded beyond the ZID boundary. Within the ZID, rapid turbulent mixing

associated with the momentum of the effluent jet and the rise of the buoyant plume is expected, and the limitations apply to conditions after this initial mixing is complete. Specifically, the vertical casts at Stations 4 and 9 traversed the boundary of the ZID (Figure 2). Thus, strictly speaking, only a portion of the data recorded during those casts was subject to the receiving-water limitations specified in the NPDES discharge permit. Additionally, none of the measurements recorded at Station 3 were subject to the limitations because the CTD was well within the ZID boundary throughout the entire vertical cast at that station.

Compliance assessments notwithstanding, measurements recorded close to the diffuser structure within the ZID lend valuable insight into the outfall's effectiveness at dispersing wastewater during this particular survey. Damaged or broken diffuser ports would be reflected by low dilution rates and measurements of concentrated effluent throughout ZID. Without measurements recorded within the ZID, the discharge plume would probably go undetected. This was the case in nearly every water-quality survey conducted prior to 1999, before the denser sampling pattern now in use was instituted.

Surveys prior to 1999 also predated the advent of DGPS. Consequently, the 6.5 m average drift experienced during sampling at individual stations would not have been fully resolved with the navigation available at the time. In fact, before 1999 sampling was presumed to occur at a single, imprecisely determined, horizontal location near each station. For consistency with past surveys, a single reportable sampling location was also determined for each station during the July 2006 survey. These were based on the average location as shown by the blue stars in Figure 2. Average positions are also listed in Table 2, along with their distance from the diffuser structure. However, based on the foregoing discussion, the distance between the average station position and the ZID does not determine whether all the measurements at that station are subject to the receiving-water objectives in the discharge permit. For example, the 17.0 m and 19.4. m closest-approach distances specified for Stations 4 and 9 would suggest that all of the data at those stations were collected outside of the ZID. In reality, as shown by the green tracklines in Figure 2, deeper measurements were recorded within the ZID, where water-quality limitations do not apply.

The vessel drift indicated by the green tracklines in Figure 2 was dictated by the complex interaction between surface currents, wind forces, and residual vessel momentum remaining after station approach. As summarized in Table B-8, winds were light and variable, but were generally offshore throughout the survey. These winds, combined with oceanic currents directed toward the west, appeared to have little influence in the net drift over all the stations. Instead, the residual momentum of the vessel as it approached individual stations largely dictated the drift observed during the survey.

The moderate westward current flow that prevailed during the July 2006 survey was documented by the satellite-tracked drifter, whose path is shown by the grey line with black dots in Figure 2. The drifter is designed to track the subsurface current, with little influence from the wind. Each dot along the drifter trackline represents a time span of five minutes. The drogued drifter was deployed just southeast of the center of the diffuser structure at 07:12. The drifter was recovered an hour later, at 08:16 PDT. It had traveled 193 m toward the west (279°T) at an average speed of 5 cm/s or 0.1 knots. However, the direction of the drift changed slightly from a west by northwest trend to a more westerly trend around 07:35 PDT. This slight change in direction occurred shortly after the peak flood tide, which occurred at 07:26 PDT as documented in Table B-8 and Figure 3.

Table 2. Average Coordinates of Vertical Profiles during the July 2006 Survey

| Station | Time (PDT) |         | Latitude      | Longitude      | Closest Approach        |                           |
|---------|------------|---------|---------------|----------------|-------------------------|---------------------------|
|         | Downcast   | Upcast  |               |                | Range <sup>1</sup> (m)  | Bearing <sup>2</sup> (°T) |
| 1       | 7:50:06    | 7:51:07 | 35° 23.249' N | 120° 52.500' W | 82.7                    | 15                        |
| 2       | 7:45:54    | 7:47:12 | 35° 23.237' N | 120° 52.500' W | 60.1                    | 20                        |
| 3       | 7:40:21    | 7:41:33 | 35° 23.210' N | 120° 52.511' W | <b>9.2<sup>3</sup></b>  | 33                        |
| 4       | 7:37:10    | 7:38:23 | 35° 23.186' N | 120° 52.503' W | <b>17.0<sup>4</sup></b> | 221                       |
| 5       | 7:29:28    | 7:31:04 | 35° 23.168' N | 120° 52.507' W | 47.8                    | 203                       |
| 6       | 7:25:16    | 7:26:54 | 35° 23.146' N | 120° 52.505' W | 86.8                    | 191                       |
| 7       | 9:13:33    | 9:14:40 | 35° 23.192' N | 120° 52.575' W | 96.0                    | 254                       |
| 8       | 9:16:34    | 9:17:42 | 35° 23.200' N | 120° 52.546' W | 50.1                    | 257                       |
| 9       | 9:19:16    | 9:20:32 | 35° 23.196' N | 120° 52.520' W | <b>19.4<sup>4</sup></b> | 221                       |
| 10      | 9:24:29    | 9:25:33 | 35° 23.205' N | 120° 52.486' W | 26.7                    | 41                        |
| 11      | 9:27:47    | 9:28:52 | 35° 23.198' N | 120° 52.467' W | 42.7                    | 75                        |
| 12      | 9:30:38    | 9:31:42 | 35° 23.199' N | 120° 52.439' W | 84.8                    | 81                        |
| 13      | 9:38:52    | 9:40:00 | 35° 23.170' N | 120° 52.528' W | 63.8                    | 221                       |
| 14      | 7:58:54    | 8:00:08 | 35° 23.226' N | 120° 52.536' W | 50.1                    | 317                       |
| 15      | 7:54:22    | 7:55:32 | 35° 23.224' N | 120° 52.470' W | 69.2                    | 41                        |
| 16      | 9:34:46    | 9:35:53 | 35° 23.179' N | 120° 52.475' W | 37.6                    | 130                       |

<sup>1</sup> Distance from the closest open diffuser port. Observations collected within the ZID shown in bold

<sup>2</sup> Direction measured clockwise in degrees from true north from the closest diffuser port to the actual sampling location.

<sup>3</sup> All of the CTD cast was within the ZID boundary.

<sup>4</sup> Portions of the CTD (Conductivity-Temperature-Depth) cast were within the ZID boundary.

The westward flow that was measured by the drogued drifter is consistent with the ebb tide that prevailed during the survey (Figure 3). In the absence of external influences, an ebb tide normally induces a weak southwestward flow in the survey region. However, the flow is also often influenced by external processes, such as wind-generated upwelling. Strong upwelling conditions prevailed prior to, and during the survey, as is apparent in the satellite image on the cover of this report. The image was recorded during the survey and showed that skies were clear enough for sea-surface temperatures to be measured by

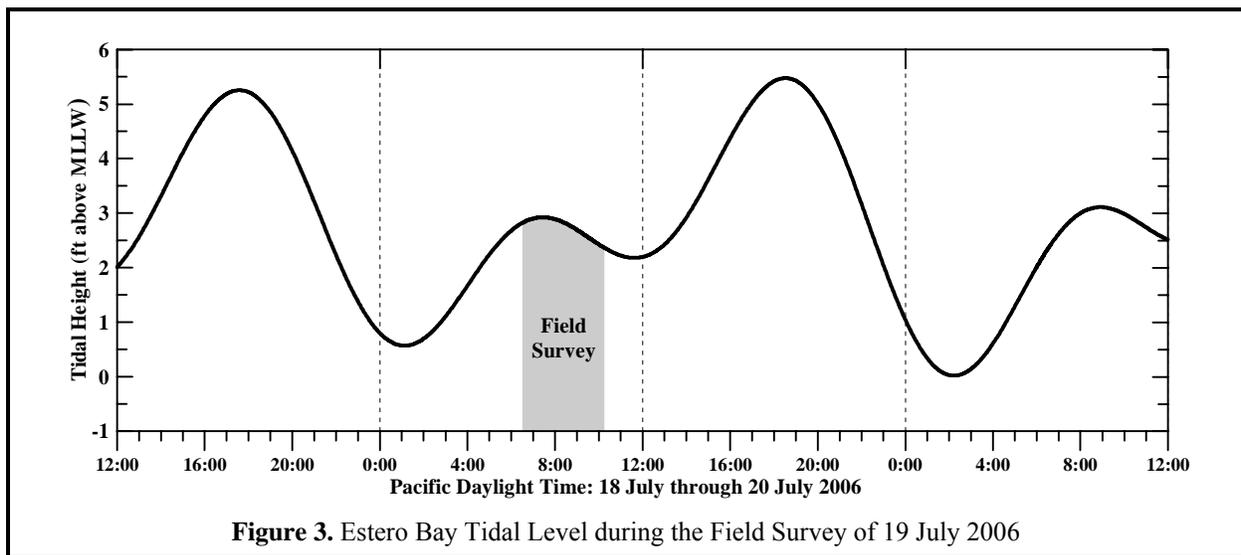


Figure 3. Estero Bay Tidal Level during the Field Survey of 19 July 2006

infrared sensors on NOAA's polar orbiting satellite. This is consistent with the visual observations of 0% cloud cover as the survey was underway (Table B-8).

The intense upwelling that occurred around the time of the survey was largely responsible for the strong water-column stratification that was evident around the outfall in vertical profiles collected with the CTD (Figures A-1 through A-3 in Appendix A). Upwelling season normally begins sometime during late March and or early April when there is a "spring transition" to more persistent southward-directed winds along the Central California Coast. The spring transition is marked by the stabilization of a high atmospheric pressure field over the northeastern Pacific Ocean. Clockwise winds around this pressure field drive the prevailing northwesterly winds along the Central Coast. The prevailing winds move surface waters southward and offshore. To replace these coastal surface waters, deep, cool, nutrient-rich waters upwell near the coast as delineated in the cover image with blue (13°C) water along the shoreline. In particular, the satellite image shows that sea-surface temperatures were near 13°C within Estero Bay where the survey was conducted while sea surface temperatures farther offshore reached 17°C over much of the south-central coast. The lower Estero Bay temperatures represented in the satellite image were consistent with the near-surface temperatures measured by the CTD during the survey, which were at or below 13.89°C as recorded at Station 12 in Table B-1 in Appendix B.

The nutrient-rich seawater that is brought to the sea surface by upwelling enables phytoplanktonic blooms that are the foundation of the productive marine fishery found along the California coast. The cross-shore flow associated with persistent upwelling conditions also leads to vertical stratification of the water column. The resulting shallow (<10 m) thermocline is commonly maintained throughout the summer and into the fall. In contrast, winter oceanographic conditions are generally characterized by a vertically uniform water column that has been well mixed by intense winds generated by passing local storm fronts and large waves produced in distant Pacific storms.

## **METHODS**

The 38 ft F/V *Bonnie Marietta*, owned and operated by Captain Mark Tognazzini of Morro Bay, served as the survey vessel on 19 July 2006. Dr. Douglas Coats and Ms. Bonnie Luke of Marine Research Specialists (MRS) provided scientific support. Captain Mark Tognazzini supervised vessel operations, while Mr. Marc Tognazzini acted as marine technician. Secchi depth measurements and standard observations for weather, seas, water clarity/coloration, and the presence of any odors, floating debris, and oil and grease were recorded during the survey (Table B-8). Wind speeds and air temperatures were measured with a Kestrel<sup>®</sup> 2000 Thermo-Anemometer. These ancillary observations were collected during the rapid water-column profiling that was conducted at each station using a CTD instrument package.

### *Ancillary Measurements*

At all stations, a Secchi disk was lowered through the water column to determine its depth of disappearance (Table B-8). Secchi depths provide a visual measure of near-surface turbidity or water clarity. The depth of disappearance is inversely proportional to the average amount of organic and inorganic suspended material along a line of sight in the upper water column. As such, the Secchi depth measures natural light penetration, which can be limited by increased suspended particulate loads from plankton blooms, onshore runoff, seafloor resuspension, and wastewater discharge. It is also of biological significance because the depth of the euphotic zone, where most oceanic photosynthesis occurs, extends to approximately twice the Secchi depth. Secchi depths of between 3.5 m and 4.0 m that were observed during the July 2006 survey reflect a comparatively shallow euphotic zone that only reached to 7 m. This

restricted euphotic zone is typical of upwelling conditions when increased primary productivity, namely, increased plankton density, results in decreased light transmissivity within the upper water column.

Secchi depths are less precise than measurements recorded by the transmissometer mounted on the CTD instrument package. For example, the visibility of the disk, and hence its depth of disappearance, depends on the amount of natural light available at the time of the measurement. Thus, the Secchi depth reading can artificially change by as much as 0.5 m depending on whether the sample is taken on the sunny or shady side of the boat. Moreover, a temporal drift in the measurements can be introduced as the sun rises in the sky while the survey progresses. Nevertheless, Secchi depth measurements reflect general turbidity levels within the upper portion of the water column, including waters within a meter of the sea surface where, because of the physical size of the CTD package, the transmissometer cannot record turbidity.

During the July 2006 survey, a satellite-tracked drifter was deployed near the open section of the diffuser structure. The drifter was drogued at mid-depth (7 m) using the curtain-shade design of Davis et al (1982). In this configuration, the drifter's trajectory was largely dictated by the oceanic flow field rather than by surface winds. The time and precise position of the drifter deployment and recovery were recorded. The July 2006 survey was the seventh MBCSD survey to continuously record the drifter position throughout its deployment. In the past, the average ambient flow velocity during each survey was estimated solely from the deployment and recovery positions. However, during the July 2006 survey, the added satellite-tracking capability of the drifter revealed curvature in the path of the drifter as documented shown in Figure 2. Drifter data collected in most prior surveys lacked information on this and other short-term flow fluctuations that can occur within the duration of a survey.

### *Instrumental Measurements*

Vertical water-column profiling was conducted using an electronic instrument package equipped with a number of probes and sensors. A Sea Bird Electronics SBE-19 Seacat CTD package was used to collect profiles of conductivity, salinity, temperature, light transmittance, dissolved oxygen (DO), pH, density, and pressure at each station. A submersible pump on the CTD continuously flushed water through the conductivity cell and oxygen plenum at a constant rate, independent of the CTD's motion through the water column. After the October 2001 survey, the CTD was returned to the factory for full testing, repair, and calibration. Temporal drifts in the oxygen and alkalinity readings during the October 2001 survey indicated that the sensitivity of these probes had degraded because of an accumulation of marine growth. During the factory repair, the pH probe was replaced and the electrolyte in the oxygen sensor was refurbished. The entire CTD system was then recalibrated at the factory. Upon return of the instrument, the transmissivity, dissolved oxygen, and pH sensors were recalibrated at the MRS laboratory. Calibration coefficients determined at the factory and by MRS were nearly identical, and confirmed the accuracy and stability of the refurbished sensors.

The DO and pH sensors were again returned to the factory in May 2003 and in June 2006 for testing and recalibration. Because of increasing temporal drift associated with the aging DO probe, it was replaced on both occasions with a new DO probe. As is the case before all surveys, the CTD system was recalibrated at the MRS laboratory prior to the July 2006 survey. Calibration at upper-bound DO concentrations was established by immersing the CTD in an aerated, temperature-controlled calibration tank. In addition to oxygen readings at full saturation, a zero-oxygen calibration point was determined by filling the oxygen-sensor plenum with an 8% solution of sodium sulfite ( $\text{Na}_2\text{SO}_3$ ). Oxygen calibration coefficients were determined by regression analysis of sensor-membrane current and temperature, as recommended by the manufacturer (SBE 1993). As with prior factory calibrations, pre-cruise calibration coefficients determined by MRS closely corresponded to those determined by the factory.

Prolonged equilibration times of the pH sensor have been an ongoing challenge that have required removal of temporal trends in the pH data collected in most surveys, even those following the 2001 pH-sensor replacement. Laboratory tests conducted in conjunction with pre-cruise calibrations have demonstrated that the equilibration time is reduced if the sensor is immersed in water prior to deployment. This was accomplished during the July 2006 survey by attaching a water-filled hose to the sensor during transit to the survey area. Immediately prior to deployment, the hose was removed. Although this procedure did not entirely eliminate the temporal offsets, it markedly reduced their amplitude. The required pH adjustments were small, and did not exceed 0.046 pH units.

During the pre-cruise calibration, coefficients for the pH (alkalinity) sensor were determined from a linear regression of output voltage after immersion in three separate buffered solutions of known pH. Buffering solutions with a pH of  $4\pm 0.01$ ,  $7\pm 0.01$ ,  $8\pm 0.01$  and  $10\pm 0.02$  were used to bracket the range of in situ measurements. The SeaTech transmissometer was air calibrated by fitting the voltages recorded with and without blocking of the light transmission path in air, as recommended by the manufacturer (SBE 1989). Revised calibration coefficients determined prior to the survey were used in the algorithms that convert sensor voltage to engineering units when the field data were processed. Comparison with the factory calibration of the entire CTD package that was conducted in December 2001, and the more recent June 2006 replacement and calibration of the DO probe, confirmed the continued accuracy and stability of the temperature, pressure, and conductivity sensors, as well as the operational integrity of the oxygen and pH probes.

Six seawater properties were used to assess receiving-water quality in this report. They were derived from the continuously recorded output from the probes and sensors on the CTD. Pressure housing limitations on the combination oxygen/pH sensor confine the CTD to depths less than 200 m (Table 3), which is well beyond the maximum depth of the deepest station in the outfall survey. The precision and accuracy of the various probes, as reported in manufacturer's specifications, are also listed in the Table. Salinity (‰) was calculated from conductivity (Siemens/m) measurements. Density was derived from contemporaneous temperature (°C) and salinity data. It was expressed as 1000 times the specific gravity minus one, which is a unit of sigma-T ( $\sigma_t$ ).

All three of these physical parameters (salinity, temperature, and density) were used to determine the lateral extent of the effluent plume. Additionally, they define the layering (vertical stratification) of the receiving waters, which determines the behavior and dynamics of the wastewater as it mixes with

**Table 3. Instrumental Specifications for CTD Profiler**

| <b>Component</b>   | <b>Depth<sup>1</sup></b> | <b>Units</b> | <b>Range</b> | <b>Accuracy</b> | <b>Resolution</b> |
|--------------------|--------------------------|--------------|--------------|-----------------|-------------------|
| Housing            | 600                      | —            | —            | —               | —                 |
| Pump               | 3400                     | —            | —            | —               | —                 |
| Pressure           | 680                      | Psia         | 0 to 1000    | $\pm 5.0$       | $\pm 0.5$         |
| Depth              | —                        | Meters       | 0 to 690     | $\pm 3.0$       | $\pm 0.3$         |
| Conductivity       | 600                      | Siemens/m    | 0 to 6.5     | $\pm 0.001$     | $\pm 0.0001$      |
| Salinity           | 600                      | ‰            | 0 to 38      | $\pm 0.006$     | $\pm 0.0006$      |
| Temperature        | 600                      | °C           | -5 to 35     | $\pm 0.01$      | $\pm 0.001$       |
| Transmissivity     | 2000                     | %            | 0 to 100     | $\pm 0.1$       | $\pm 0.025$       |
| Dissolved Oxygen   | 200                      | mg/L         | 0 to 21.5    | $\pm 0.14$      | $\pm 0.014$       |
| Acidity/Alkalinity | 200                      | pH           | 0 to 14      | $\pm 0.1$       | $\pm 0.006$       |

<sup>1</sup> Maximum depth limit in meters

seawater within the ZID. Data on three remaining seawater properties, consisting of light transmittance

(water clarity), hydrogen-ion concentration (acidity/alkalinity – pH), and dissolved oxygen (DO), further characterize receiving waters, and were used to assess compliance with water-quality criteria. Light transmittance was measured as a percentage of the transmitted beam of light detected at the opposite end of a 0.25 m path. Increased transmittance indicates increased water clarity and decreased turbidity.

Before deployment at the initial station, the CTD was held below the sea surface for a ten-minute equilibration period. Subsequently, the CTD was raised to within 1.0 m of the sea surface and profiling commenced. The CTD was lowered at a continuous rate of speed to the seafloor. Measurements at multiple stations were collected during each of the two successful deployments by towing the CTD package below the water surface while transiting between adjacent stations. Upon retrieval of the CTD, the profile data were downloaded to a portable computer. In the second deployment, the CTD experienced a battery failure resulting in the recording of measurements at only one station (7). To maintain temporal consistency, that data was discarded, and the entire cross-shore transect was repeated after fresh batteries were placed in the CTD. However, this resulted in a longer-than-usual one-hour delay between when the along-shore and cross-shore data were collected.

### *Temporal Trends in the pH Sensor*

The pH sensor exhibited a slight temporal drift during the July 2006 survey. Perceptible drift in pH measurements has been consistently observed in prior water-quality surveys as the result of ongoing sensor equilibration during profiling. Prolonged exposure to the atmosphere between surveys results in the largest offsets and can also affect the dynamic range of the measurements. Smaller equilibration offsets have been observed when the CTD is redeployed after being brought onboard to download data during the middle of the survey. Previous attempts to mitigate sensor drift have included prolonging the soak time of the CTD after deployment below the sea surface prior to profiling. Soak times in excess of six minutes at the beginning of a survey were found to reduce but not entirely eliminate sensor drift. During the July 2006 survey, a tube filled with seawater was placed around the pH sensor to limit atmospheric exposure before the CTD was first deployed. This technique was successful at further ameliorating sensor drift.

Temporal drift in the pH sensor was responsible for slight, but perceptibly lower pH measurements at those stations occupied during the beginning of the CTD deployment, namely, Stations 6 through 3 as reflected in the earliest downcast times in Table 2. The pH measurements at the first two stations (6 and 5) averaged 0.046 pH units lower than the measurements recorded later in the deployments. Comparison with Table 3 shows that this artificial reduction in measured pH is smaller than the instrumental accuracy ( $\pm 0.1$  pH). However, it is larger than the instrumental resolution ( $\pm 0.006$  pH). As a result, slight artificial differences are embedded in the measurements reported at Stations 3, 4, 5, and 6 in Table B-7. However, the differences were not large enough to be statistically significant, which would be reflected in the Table by values listed in bold typeface and enclosed in a box, such as for some of the significant salinity anomalies shown in Table B-2. Nevertheless, removal of the artificial pH trend is important because they can mask very slight discharge-related anomalies that only become apparent when pH values at the same depth are compared at adjacent stations. Table B-6 listed the pH data after removal of the temporal trend. As a result of trend removal, slight discharge-related pH anomalies became apparent at Stations 3 and 9 as shown in the bottom frames of Figure A-5 and A-7. The absence of bolded and boxed entries in Table B-6 indicates that neither of these anomalies were statistically significant.

## RESULTS

The water-quality survey for the third quarter of 2006 began on Wednesday, 19 July 2006, at 07:12 PDT with the deployment of the drogued drifter. Subsequently, all water-column measurements were collected as required by the NPDES monitoring program (Table 2 and B-8). Sunrise was at 06:02 PDT and skies were clear but slightly hazy throughout the survey, which ended at 10:15 PDT when the vessel arrived back at port. Winds were light and variable throughout the survey. Average wind speeds, calculated over one-minute intervals, ranged from approximately 0.3 kt to 2.3 kt, with peak speeds ranging from 0.6 kt to 3.7 kt. Additionally, a 2 ft swell moved through the survey area from the west. Atmospheric visibility was greater than 2 nM along the ocean surface owing to the absence of low-lying fog. As a result, Morro Rock and the shoreline remained visible throughout the survey. Air temperatures remained between 15.3°C and 18.5°C during the survey. The surface seawater temperature (13.9°C) in the survey area were much lower than the average air temperature, but was consistent with coastal sea-surface temperatures within Estero Bay recorded by the satellite image shown on the cover of this report.

The discharge plume was not readily visible near the sea surface at any time during the survey. Throughout the survey, there was also no visual evidence of floating particulates, oil and grease, or seawater discoloration associated with the discharge.

### *Beneficial Use*

During the July 2006 survey, observations of beneficial use demonstrated that the coastal waters in the outfall vicinity continued to be utilized by wildlife and for recreation. Large numbers of California brown pelicans (*Pelecanus occidentalis californicus*), western gulls (*Larus occidentalis*), Heermann's gulls (*Larus heermanni*), Pelagic cormorants (*Phalacrocorax pelagicus*), and Brandt's cormorants (*Phalacrocorax penicillatus*) were observed transiting through or foraging near the survey area. Additionally, a pair of Caspian terns (*Sterna caspia*) was also observed in flight, while several Pigeon Guillemot (*Cepphus columba*) were observed in the waters closer to Morro Rock.

In addition to bird life, a juvenile southern sea otter (*Enhydra lutris*) and a juvenile California sea lion (*Zalophus californianus*) were observed on several occasions during the survey. Both animals were sighted approximately 100 m offshore of the survey area. The sea lion was seen making repeated dives to forage on fish. Its efforts were accompanied by those of several pelicans and a large number of cormorants. The sea otter was observed swimming through the area, but not foraging. Sea otters are a federally and state-protected species. Since the arrival of a raft of 30 to 40 sea otters just north of Port San Luis was observed in 1974 (Gotshall et al., 1984), they have become increasingly prevalent in the vicinity of Estero Bay (Gotshall et al., 1986). Sea otters feed almost entirely on macroinvertebrates (Ebert, 1968; Estes et al., 1981; Riedman and Estes, 1990) and the southward expansion of the sea otter is firmly correlated, chronologically and geographically, with the demise of the abalone fishery in the region (Morro Group, Inc. 1999).

Several other vessels were observed near the survey area during the course of the survey, including two sailboats. The party fishing vessel F/V Patriot out of Avila Beach transited approximately 1 km offshore of the survey area. The kelp cutter, M/V *Ocean Rose*, which is based in Morro Bay, followed the survey vessel out of the bay and toward the survey area during its transit to the kelp beds north of Estero Point. Dredging was occurring in the mouth of Morro Bay throughout the survey. The dredge spoils were deposited south of the bay entrance and did not affect the survey area. Multiple pedestrians were seen utilizing Atascadero Beach, and surfers were observed at the break located just north of Morro Rock. No other evidence of beneficial use of receiving waters was noted during the survey.

### *Ambient Seawater Properties*

Data collected during the July-2006 survey reflect the classical, stratified conditions that are indicative of upwelling. Upwelling results in an influx of dense, cold, saline water at depth and often leads to a sharp thermocline, halocline, and pycnocline where temperature, salinity, and density change rapidly over short vertical distances. Under stratified conditions, isotherms crowd together to form a thermocline that restricts the vertical transport of the effluent plume and reduces its dispersion.

Strong upwelling-induced vertical gradients are plainly evident above the seafloor in the vertical profiles of Figures A-1 through A-3. During the first part of the survey, when data at Stations 1 through 6 were collected, the vertical gradients extended from the sea surface to a depth of approximately 12 m (Figure A-1). Within this stratified region, temperature (red lines) and pH (olive lines) steadily increased with depth at all stations except for Station 3. As discussed below, the presence of the discharge plume at Station 3 accounts for the different character of the vertical profiles observed there. However, at the other five stations, the shapes of the DO (dark blue lines), transmissivity (light blue lines), and density (black lines) were consistent among the stations.

The DO profiles exhibited a mid-depth maximum due to the intense primary productivity that was occurring because of upwelling. Slightly supersaturated DO concentrations occurred just below the sea surface due to the increased photosynthesis by phytoplankton, a process that produces oxygen. At the sea surface, rapid atmospheric exchange brought DO concentrations into equilibrium and resulted in slightly lower DO concentrations. Below the 7-m euphotic zone, DO concentrations rapidly declined because photosynthesis was limited, and biotic respiration and decomposition had slowly depleted oxygen levels in the deep watermass during the long period since its contact with the atmosphere. Upwelling brought this cold, dense, watermass from great depths offshore to replace the nearshore surface waters that were driven offshore by winds. Biotic respiration and decomposition also produced dissolved CO<sub>2</sub> (carbonic acid), which resulted in significantly lower pH (more acidic) levels within the deep watermass. Note also that the abundance of phytoplankton just below the sea surface also resulted in an increase in turbidity as reflected by the subsurface drop in turbidity that is evident in the vertical profile of transmissivity (light blue lines in Figure A-1). The upwelling-induced shallow subsurface maximum in DO, and the minimum in transmissivity are apparent as red areas in the cross-shore vertical sections shown in the middle and top frames of Figure A-5.

The shapes of the vertical profiles shown in Figure A-2 differ from those of Figure A-1 that are described above. Most show a much sharper thermocline where temperatures increase considerably over a more limited depth range. As described previously, measurements along the cross-shore transect at Stations 7 through 12 were recorded after a considerable lapse of time had occurred following the completion of the along-shore transect. During that time, a much colder, denser seafloor watermass with lower DO had begun moving into the survey area. This is apparent from a comparison of the deep portions of the vertical profiles shown in Figure A-2 with those of Figure A-1. The much sharper thermocline generates erroneous spikes in the salinity field that are apparent as zigzags in the salinity profiles shown by the green lines in Figure A-2. These salinity spikes are instrumental artifacts arising from the mismatch between conductivity and temperature measurements collected near strong thermal gradients. As described below, their presence complicates the interpretation of lateral anomalies in the salinity field, which can be misattributed to the discharge.

### *Lateral Variability*

The influence of the effluent discharge can be best identified from localized anomalies in seawater properties, particularly salinity. These discharge-related anomalies are evident at mid-depth at Station 3, in Figures A-4 and A-5, and near the sea surface at Station 9, in Figures A-6 and A-7. In contrast to the vertical profiles, discharge-related anomalies become especially apparent in the vertical sections when seawater properties from the same depth level are compared at adjacent stations. The vertical sections in Figure A-7 also show that the shallow discharge-related water-properties anomalies at Station 9 have the same characteristics as ambient seawater at depth. This contrasts with the deep anomalies at Station 3 in Figure A-5, which show no connection to seafloor properties.

Different processes generated these two discharge-related perturbations. The shallow anomalies at Station 9 became apparent because deep, naturally-occurring water properties had been entrained in the discharge plume and displaced upward into the water column where the surrounding seawater characteristics differed. In contrast, the anomalies at Station 3 could only have been caused by the characteristics of the effluent itself. Both of these perturbations become apparent only through a comparison of seawater properties measured at the same depth level at adjacent stations. Because of this, the analysis of lateral variability in seawater properties forms the basis for assessments of water-quality impacts.

In particular, the significance of each potential discharge-related anomaly was statistically evaluated by comparing its amplitude to the natural background variability. Each observation at a particular station was compared with the observations from other stations at the same depth level. Measurements recorded within 10 m of the sea surface were compared with other measurements at the same depth level below the sea surface. However, deeper measurements were compared with other measurements recorded at the same height above the sloping seafloor. This is done because deep seawater properties tend to parallel the sloping seafloor rather than the horizontal sea surface.

The statistical significance of departures from ambient seawater properties was computed from the raw CTD data listed in Tables B-1 through B-7. First, anomalies from mean conditions were computed by subtracting a particular measurement from the average of all other measurements at the same depth level, whether measured relative to the sea surface or the seafloor. Natural variability was estimated from the standard deviation of all measurements (excluding the one in question) for a given seawater parameter (e.g., salinity). Statistically significant anomalies were those that departed from mean conditions by more than the 95% confidence interval determined from the standard deviation and number of observations used to compute the average. Statistically significant departures from ambient conditions are highlighted in Tables B-1 through B-7, with bolded values enclosed in boxes.

Salinity (Table B-2) and transmissivity (Table B-5) were the only seawater properties that exhibited statistically significant anomalies in the July-2006 data. This contrasts with other surveys where significant anomalies in other water properties are occasionally found (MRS, 2006). The lack of statistical significance in other seawater anomalies during the July-2006 survey was not necessarily because the amplitudes of the anomalies were smaller than in other seasons. In fact, discharge-related thermal, pH, and DO anomalies are visually apparent at Stations 3 and 9 in the vertical sections of Figures A-4 through A-7. However, the amplitudes of these anomalies were not large relative to the variability in ambient water properties and consequently, they were not found to be statistically significant. Because the spatial variability in most seawater properties was large during the July-2006 survey, particularly in the vertical direction, the amplitude of the anomalies would need to be proportionally larger in order to be reliably resolved on a statistical basis. Thus, statistical significance is a function of the overall variability during a

given survey because it is more difficult to reliably discern small differences in a noisy field of measurements than in a uniform field.

Instrumental artifacts further complicate the analysis of lateral variability, namely, with respect to the salinity distribution. Except at Station 9, the statistical significance of all the salinity anomalies highlighted in Table B-2 was an artifact of salinity spiking that occurs when the CTD sensors cross a strong thermocline. Salinity is computed from the conductivity and temperature probes that do not measure the same water parcel because the sensors are physically separated on the CTD instrument package. In addition, the sensors do not have the same response times. Consequently, in regions of strong vertical temperature gradients, the mismatch between the conductivity and temperature measurements causes erroneous spikes in salinity. Salinity spiking is a common, unavoidable problem with CTD measurements collected within strong thermal gradients in the upper ocean. They are routinely observed in MBCSD surveys conducted when the water column is well stratified, as was the case during the second half of the July-2006 survey. Because the thermocline was weaker during the initial part of the survey when data from the Stations 1 through 6 and 14 and 15 were collected, no significant departures from ambient conditions were noted at those stations in Table B-2.

The presence of erroneous salinity spikes is evident from visual inspection of the high-resolution vertical profiles of temperature and salinity that were used to compute the depth-averaged data collated in the appendices. Salinity spikes are characterized by marked isolated changes in salinity that occur within strong thermoclines. They are generally less than 0.5 m thick in the high-vertical resolution profiles and appear as zigzag features in the lower-resolution salinity profiles shown as green lines in Figures A-1 through A-3. It is unlikely that the observed salinity reductions were caused by the presence of wastewater constituents, because the discharge plume is typically trapped beneath strong thermoclines, particularly one as strong as that observed during the latter half of the July-2006 survey.

The spike-induced salinity anomaly at Station 11 is particularly dramatic. This large-amplitude reduction in salinity spans a significant depth range. It is clearly apparent as the mid-depth region delineated in green and red in the top frame of Figure A-6. Despite its size and amplitude, it is probably unrelated to the discharge for two reasons. First, it does not coincide spatially with any anomalies in other water properties. This is apparent from a comparison of all the frames in Figures A-6 and A-7. The much weaker salinity anomaly at Station 9 coincides with discharge-related anomalies in most other water properties. Normally, a discharge-induced salinity anomaly as large as the one at Station 11 would also be expected to generate large anomalies in other water properties as well. The second reason that the anomaly was unrelated to effluent discharge is apparent from the position of Station 11. Figure 2 shows that Station 11 is located well to the east of the discharge structure while ambient flow was to the west. Not only was the anomaly located in opposite of the flow path, an intervening station (10) lies between Station 11 and the discharge point. It did not exhibit a consistent pattern of discharge related anomalies. In contrast, Station 9, located in the westward flow path, exhibited clear discharge-related anomalies.

Even without instrumental discrepancies, the presence of statistically significant anomalies that are unrelated to the discharge is expected. From the definition of a 95% confidence level, one ‘*significant*’ departure out of every 20 measurements should occur by chance alone. With 500 measurements examined for each of the six parameters, it would not be surprising if a few departed from the mean by an amount more than the 95% confidence interval. Moreover, when multiple hypotheses are being tested (*i.e.*, one for each observation), the error rate for each individual test should be adjusted to achieve the overall experimentwise error rate of 5% (95% confidence). By definition, this error rate is the probability that one or more of the hypothesis tests would incorrectly find a significant difference when none exists. Thus, without correcting for repeated hypothesis testing, the individual tests are conservative and “*significant*”

departures will be found more often than if a single test were being performed at the 95% confidence level.

In addition to the large number of significant localized reductions in salinity that are highlighted in Table B-2, there were six spike-related increases in salinity found. These localized positive salinity spikes could not have been generated by the discharge of effluent that is essentially devoid of salinity. Instead, as described above, they were instrumental artifacts related to salinity spiking or were random artifacts of the statistical test that was repeatedly applied to a large number of measurements. Similarly, the statistically significant transmissivity anomaly located at above the seafloor at Station 13 (Table B-5), is a positive anomaly where water clarity is higher than the surrounding waters at depth. Consequently, it could not have been generated by the presence of wastewater particulates. Instead, it was probably an artifact of natural variation in the distribution of ambient particulates associated with the resuspension of seafloor sediments.

### *Discharge-Related Perturbations*

During the July 2006 survey, two perturbations in seawater properties were unequivocally related to the discharge (Perturbations P1 and P2 in Table 4). A discharge-related perturbation is a group of anomalies in one or more seawater properties that are spatially contiguous at a particular station. The vertical distribution of seawater properties within and below the perturbations lends insight into which of two discharge processes were responsible for generating a particular anomaly. As indicated in Table 4, all of the anomalies within Perturbation P1 at Station 3 reflect the presence of dilute wastewater, while all the anomalies except salinity within Perturbation P2 at Station 9 were generated by entrainment of naturally turbid seawater within the rising effluent plume.

The anomalies associated with Perturbation P1 could not have been generated by the movement of ambient seawater alone. For example, the top frame of Figure A-4 shows that the anomalously low salinity observed at mid-depth at Station 3 was vertically isolated, and far lower than the ambient seawater at depth. Similarly, the temperature, transmissivity, DO and pH anomalies were vertically isolated, and supported concentrations that were beyond the range of properties within ambient seawater at depth.

Furthermore, the character of the anomalies in Perturbation P1 was consistent with the properties of effluent constituents. The temperature of the anomaly was 0.5°C higher than surrounding seawater and suggests the presence of warm dilute wastewater within the anomaly. Similarly, turbidity associated with effluent particulates would be expected to induce a localized reduction in transmissivity. Thus, the statistically significant 8% reduction in transmissivity probably resulted from an encounter with the effluent plume shortly after discharge. Such an encounter at Station 3 would be consistent with the location of the measurements, which were all collected within the ZID, and within approximately 10 m of the diffuser structure (Figure 2, Table 2). The increase in DO concentration associated with Perturbation P1 reflects the high dissolved oxygen content of the effluent plume that results from its recent contact with the atmosphere. Normally, reductions in DO due to the discharge of oxygen-demanding materials within wastewater are of greatest concern. However, the MBCSD treatment process efficiently removes nearly all of this organic material, and, as a result, dissolved oxygen levels within the effluent are actually higher than those of the ambient seawater at depth. Although all of the anomalies associated with Perturbation P1 were restricted to depths greater than 11 m, the salinity and density anomalies indicate that the very dilute effluent plume may have extended upward to within 2.5 m of the sea surface.

Table 4. Discharge-Related Water-Property Anomalies<sup>a</sup>

| Perturbation <sup>b</sup>   | Station | Depth Range    | Depth of Extremum | Property              | Magnitude         | Process     |
|-----------------------------|---------|----------------|-------------------|-----------------------|-------------------|-------------|
| P1<br>Dilution $\geq$ 603:1 | 3       | 9.0 to 11.0 m  | 10.0 m            | Salinity              | -0.056 ‰          | Effluent    |
|                             |         | 12.0 to 14.5 m | 13.0 m            | Temperature           | +0.50 °C          | Effluent    |
|                             |         | 10.0 to 14.5 m | 13.5 m            | Density               | -0.096 $\sigma_t$ | Effluent    |
|                             |         | 11.0 to 14.0 m | <b>12.5 m</b>     | <b>Transmissivity</b> | <b>-8.0 %</b>     | Effluent    |
|                             |         | 11.5 to 14.5 m | 13.5 m            | Dissolved Oxygen      | +1.7 mg/L         | Effluent    |
|                             |         | 13.0 to 16.5 m | 15.0 m            | pH                    | +0.12             | Effluent    |
|                             |         | 2.0 to 4.0 m   | 2.5 m             | Salinity              | -0.046 ‰          | Effluent    |
|                             |         | 2.0 to 4.0 m   | 2.5 m             | Density               | -0.069 $\sigma_t$ | Effluent    |
| P2<br>Dilution $\geq$ 355:1 | 9       | 0.0 to 4.0 m   | <b>3.5 m</b>      | <b>Salinity</b>       | <b>-0.095 ‰</b>   | Effluent    |
|                             |         | 0.0 to 6.5 m   | 2.0 m             | Temperature           | -0.50 °C          | Entrainment |
|                             |         | 1.5 to 6.5 m   | 2.0 m             | Density               | +0.068 $\sigma_t$ | Entrainment |
|                             |         | 2.0 to 6.5 m   | 4.0 m             | Transmissivity        | +4.6 %            | Entrainment |
|                             |         | 2.0 to 6.0 m   | 3.0 m             | Dissolved Oxygen      | -1.0 mg/L         | Entrainment |
|                             |         | 0.0 to 6.5 m   | 5.0 m             | pH                    | -0.08             | Entrainment |

<sup>a</sup> Anomalies shown in bold type were statistically significant

<sup>b</sup> Perturbations consist of a group of spatially consistent anomalies in different seawater properties

All of the anomalies except the salinity anomaly associated with Perturbation P2 at Station 9 were opposite of those of Perturbation P1. Accordingly, the lower temperature and reduced turbidity associated with Perturbation P2 are opposite of the anomalies that would be generated by the presence of wastewater constituents within warm turbid effluent. Instead, these and the other anomalies are consistent with the upward displacement of naturally occurring seawater rather than dilute effluent. This is an important distinction when assessing the discharge's compliance with the receiving-water objectives of the COP and the waste-discharge requirements of the NPDES permit.

### Initial Dilution Computations

The amplitude of negative salinity anomalies at Stations 3 and 9 lends insight into effectiveness of the outfall at dispersing effluent and, ultimately, compliance with the receiving-water objectives of the COP and NPDES discharge permit. The critical initial dilution applicable to the MBCSD outfall was conservatively estimated to be 133:1 (Tetra Tech 1992). This estimate was based on worst-case modeling using highly stratified conditions where the trapping of the plume below the thermocline limited the mixing achieved during the plume's buoyant rise through the water column. The dispersion modeling determined that, after initial mixing was complete, 133 parts of ambient water would have mixed with each part of wastewater. The modeling predicted that this dilution would be achieved after the plume rose only 9 m from the seafloor, whereupon it became trapped below a thermocline and spread laterally with no further substantive dilution. A 9-m rise translates into a trapping depth 6.4 m below the sea surface.

However, as described below, computation of dilution based on the salinity anomaly within the mid-depth perturbation at Station 3 demonstrate that the effluent plume actually achieved a far higher dilution at depths well below the predicted trapping depth. Moreover, the presence of a discharge-related salinity anomaly at 2.5 m at this same station indicates that the trapping depth was much shallower than the model predictions despite the highly stratified conditions that were present during the July 2006 survey. Both of these observations indicate that the modeling was conservative with regard to the dilutions that are actually achieved by the discharge.

The conservative nature of the dilution ratio determined from modeling is an important consideration because it was used to specify permit limitations on chemical concentrations in wastewater discharged from the treatment plant. These end-of-pipe effluent limitations were back-calculated from the receiving-water objectives listed in the COP (SWRCB 1997) using the 133:1 dilution ratio determined from the modeling. Use of a higher critical dilution ratio would relax the stringent end-of-pipe effluent limitations that are thought to be necessary in order to meet Ocean-Plan standards.

End-of-pipe limitations on contaminant concentrations within effluent were based on the definition of dilution (Fischer et al. 1979), where the concentration of a particular contaminant in effluent is given by:

$$C_e \equiv C_o + D(C_o - C_s) \quad \text{Equation 1}$$

where:  $C_e$  = the concentration of a constituent in the effluent,  
 $C_o$  = the concentration of the constituent in the ocean after dilution by  $D$  (i.e., the COP objective),  
 $D$  = the dilution ratio of the volume of seawater mixed with effluent, and  
 $C_s$  = the background concentration of the constituent in ambient seawater.

The actual dilution achieved by the outfall can also be computed from Equation 1 using measured seawater anomalies. This measured dilution can then be compared with the critical dilution factor determined from modeling. Salinity is an especially useful tracer because it directly reflects the magnitude of ongoing dilution. Specifically, the salinity concentration in effluent is negligible so  $C_e$  is eliminated in Equation 1 and the dilution ratio ( $D$ ) can be computed from the salinity anomaly ( $A = C_o - C_s$ ) as:

$$D = \frac{-C_o}{(C_o - C_s)} \equiv \frac{-C_o}{A} \quad \text{Equation 2}$$

where:  $D$  = the dilution ratio of the volume of seawater mixed with effluent,  
 $C_o$  = the salinity of the effluent-seawater mixture after dilution by  $D$ ,  
 $C_s$  = the background seawater salinity (approximately 32.9‰), and  
 $A = C_o - C_s$  = the salinity anomaly.

Computed dilutions during the heavily stratified conditions of the July 2006 survey demonstrate that the modeled dilution factors are far more conservative than those actually achieved by the discharge. Specifically, dilutions exceeding 600-fold were measured 10 m below the sea surface at Station 3. This is 3.6 m deeper than the 6.4 m trapping depth predicted by modeling. This high measured dilution was computed from Equation 2 using the salinity anomaly (−0.056‰) that was observed at Station 3 within Perturbation P1 (Table 4). The negative density anomaly that is also associated with this perturbation indicates that buoyancy equilibrium had yet to be reached, and that additional dilution would be expected to occur as the plume rises farther in the water column. Accordingly, the smaller salinity anomaly (−0.046‰) observed at 2.5 m reflects the increased dilution of 734-fold.

The dilutions computed for the salinity anomalies within Perturbation P1 are somewhat inconsistent with the lower dilution (355:1) found at a depth of 3.5 m within Perturbation P2 (Table 4). However, the larger-amplitude salinity anomaly (−0.095‰) observed within Perturbation P2 may have been artificially enhanced by salinity spiking. In any regard, even this dilution level is more than double the dilution predicted by conservative modeling. These dilution computations demonstrate that, during the July 2006 survey, the outfall was performing better than designed, and was rapidly diluting effluent more than 355-

fold beyond the ZID. Consequently, COP receiving-water objectives were easily met by the chemical concentration limits promulgated by the NPDES discharge permit issued to the MBCSD.

## **DISCUSSION**

Sampling during the July 2006 survey indicated that the wastewater discharge was in compliance with the receiving-water limitations specified in the NPDES permit, and with the water-quality objectives of the COP (SWRCB 1997) and the Central Coast Basin Plan (RWQCB 1994). Specifically, there were no particulates of sewage origin seen floating on the ocean surface at any of the stations sampled during the July 2006 water-quality survey, and the discharge complied with all other quantitative limits on seawater properties.

Although discharge-related changes in all six water properties were observed during the July 2006 survey, the changes were either not statistically significant, were measured well within the boundary of the ZID, or resulted from the displacement of ambient seawater rather than the presence of effluent constituents. Receiving-water limitations only apply to statistically significant changes caused by the presence of effluent constituents beyond the margin of the ZID. The limitations do not apply to measurements within the ZID because the discharged wastewater is thought to be undergoing rapid initial mixing with the surrounding seawater. This was certainly the case for the mid-depth anomalies associated with Perturbation P1. The negative density anomaly was indicative of a buoyant effluent plume that was continuing to mix as it rose through the water column.

Other than salinity, the transmissivity anomaly at Station 3 was the only discharge-related change in seawater properties that was found to be statistically significant. It was observed at depth close to the diffuser structure where turbidity increases resulting from the discharge of effluent particulates would be expected. Because of its 12.5-m depth, the increased turbidity of this anomaly would have little influence on the penetration of ambient light, which is largely restricted to the 7-m euphotic zone. Besides, the anomaly was observed well within the ZID where water-quality standards do not apply.

The discharge-related anomalies associated with Perturbation P2 were located beyond the ZID boundary. However, none of these anomalies other than salinity were statistically significant. Moreover, they were generated by the upward displacement of ambient seawater rather than the presence of effluent constituents. As such, discharge limitations, such as for DO concentrations do not apply because the changes were not induced by the discharge of oxygen-demanding materials. Although the discharge-related salinity anomaly at Station 9 was statistically significant, there are no restrictions on the alteration of this seawater property. In any regard, the amplitude of the observed salinity deviations were very small compared to the temporal variability in salinity that occurs within this coastal region.

### *Outfall Performance*

Small anomalies in salinity indicated the presence of dilute wastewater at Stations 3 and 9. These high-precision observations demonstrated that the diffuser structure was operating better than predicted by modeling, and that the discharged wastewater experienced high levels of dilution within and beyond the ZID. A dilution of 603:1 was determined from the salinity anomaly located close to the diffuser structure at Station 3. This is more than four times the minimum critical dilution of 133:1 specified in the NPDES permit. The statistically significant salinity anomaly at Station 9 was larger in amplitude, but may have been inflated by salinity spiking. Even so, it indicates dilution ratios exceeding 355-fold, which is still well above the 133:1 dilution used in the NPDES permit to establish end-of-pipe concentration limits on

effluent constituents. With the higher dilution ratio that was determined from actual measurements during the July-2006 survey, contaminant concentrations within the wastewater could have been more than 2.5-times the limits specified in the NPDES discharge permit, and the receiving-water objectives of the California Ocean Plan (COP) would still have been achieved.

#### *NPDES Permit Limits*

The seawater properties measured during the July 2006 survey were statistically evaluated for compliance with the pertinent receiving-water limitations promulgated by the NPDES discharge permit and the COP. Specifically, the permit and COP state that the discharge shall not cause the following events to occur.

1. *Natural light to be significantly reduced at any point outside the initial dilution zone as the result of the discharge of waste*
2. *The dissolved oxygen concentration outside the zone of initial dilution to fall below 5.0 mg/L or to be depressed more than 10 percent from that which occurs naturally*
3. *The pH outside the zone of initial dilution to be depressed below 7.0, raised above 8.3, or changed more than 0.2 units from that which occurs naturally*
4. *Temperature of the receiving water to adversely affect beneficial uses*

The COP (SWRCB 1997) further defines a ‘significant’ difference as ‘...a statistically significant difference in the means of two distributions of sampling results at the 95 percent confidence level.’ For each observation in Tables B-1 through B-7, the statistical significance of departures from mean conditions at a given depth level were determined with an analysis of variance that compares a single observation with the mean of a larger set of samples (Sokal and Rohlf 1997, p228; Ury 1976). Although 15 independent hypothesis tests were performed at each depth level, no Bonferroni adjustment to the error rate was included, so the tests are conservative. Specifically, Bonferroni adjustment indicates that the actual confidence level for the overall null hypothesis test for differences in properties is higher, around 99.7%, rather than the 95% level that applies to a single test. The standard deviation that was applied in the tests was determined from the entire data set to reflect the full range in ambient properties, including vertical variations.

#### *Light Transmittance*

Based on the statistical analysis, there was only one station where significant reductions in instrumentally recorded light transmittance were found. Table B-5 shows a significant transmissivity decrease of 8% 4-m above the seafloor at Station 3. However, this measurement was recorded close to the diffuser structure at a location well within the ZID where the COP limitation does not apply. Furthermore, the entire vertical extent of the entire discharge-related transmissivity anomaly was restricted to depths exceeding 11 m, where little natural light penetrates. The shallowest portion of the transmissivity anomaly was located 4 m below the euphotic zone, which is determined from twice the maximum Secchi depth of 4 m as listed in Table B-8. Thus, the presence of this “significant” transmissivity anomaly could not have caused a significant “...reduction in the transmittance of natural light...” The other statistically significant transmissivity anomaly was associated with an increase in transmissivity near the seafloor at Station 13. As such, it could not have been generated “...as the result of the discharge of waste” (SWRCB 1997). Similarly, the upward movement of ambient seawater, not the presence of wastewater particulates, generated the nonsignificant, positive transmissivity anomaly associated with Perturbation P2 at Station 9.

### *Dissolved Oxygen*

Although it is not explicitly stated in the NPDES discharge permit, the COP specifies that the DO limitation only applies to reductions that occur “...as a result of the discharge of oxygen demanding waste materials.” Clearly, then, the DO limitation does not apply to reductions in DO caused by the movement of ambient waters, regardless of whether or not they were induced by the physics of the discharge. None of the discharge-related DO anomalies was significant, and the only one associated with a DO reduction (Perturbation P2 at Station 9) was generated by the entrainment of ambient seawater. Therefore, it was not subject to the limitations. Even so, the amplitude of that DO anomaly was so small (-1 mg/L) that it did not constitute statistically significant deviations from the norm. This would have to be the case since the anomaly was created by the upward movement of ambient seawater that is naturally depleted in oxygen at depth. Regardless, all of the DO measurements complied with the numerical limits specified in the permit. Specifically, none of the DO measurements fell below the 5-mg/L minimum specified in the Basin Plan and the NPDES discharge permit. In fact, none of the 500 measurements collected during the July-2006 survey fell below 6.3 mg/L. In addition, the discharge-related reduction at Station 9 was too small to be considered “...to be depressed more than 10 percent from that which occurs naturally,” given that the measured concentration of 8.7 mg/L was much higher than the 7.2 mg/L average concentration of ambient seawater near the seafloor.

### *pH*

As with the DO anomalies, none of the discharge-related pH anomalies found in the July 2006 survey were statistically significant (Table B-6 and B-7). In addition, there were only two visually perceptible pH anomalies apparent in the vertical sections shown in the bottom frames of Figures A-5 and A-7. The amplitudes of these anomalies were less than 0.2 pH units, so they could not be considered changed by ‘...more than 0.2 pH units from that which occurs naturally.’ The range across the entire pH field remained between 7.87 and 8.16, and thus, all of the measurements also complied with the lower (7.0 pH) and upper (8.3 pH) bounds on discharge-induced pH changes.

### *Temperature and Salinity*

With amplitudes of 0.5°C, the discharge-related thermal anomalies were small compared to the 2.4°C range in temperature that occurred because of the naturally occurring vertical stratification during the survey. Accordingly, the anomalies were not found to be statistically significant. Even if these discharge-related thermal anomalies had been found to be statistically significant, they would be considered too small ‘...to adversely affect beneficial uses....’ For example, the observed amplitudes were much less than the large-scale spatial variability seen in the sea-surface temperatures shown in the satellite image on the cover of this report. Only the small, highly localized, discharge-induced increase in temperature at Station 3 resulted from the presence of warm, dilute wastewater. Nevertheless, the temperature of 12.35°C measured within the anomaly was still lower than the maximum temperature of 13.23°C that was measured in ambient seawater at the sea surface at that station (Table B-1).

Although salinity anomalies provide the best tracer of discharged effluent, their actual amplitude (<0.1‰) was small compared to seasonal and spatial differences in salinity that occur along the south-central California coast. For example, in 2005, the difference in average salinity between the April and July survey was six times higher (0.64‰). In any regard, the observed range in both the measured temperature (2.4°C) and salinity (0.3‰) across all data collected during the July 2006 survey was too small to be considered harmful to marine biota or deleterious to beneficial uses.

*Conclusions*

All of the measurements recorded during the July 2006 survey complied with the receiving-water limitations specified in the NPDES discharge permit. The discharge-related anomalies that were found close to the diffuser structure at Station 3 were caused by the presence of dilute effluent. However, despite the 600-fold dilution observed at that point, the plume was continuing to undergo additional rapid mixing. The dilution levels achieved beyond the ZID were more than 2.5-times the levels predicted by modeling. These measurements confirmed that the diffuser structure and the outfall were operating better than would be expected from the modeling.

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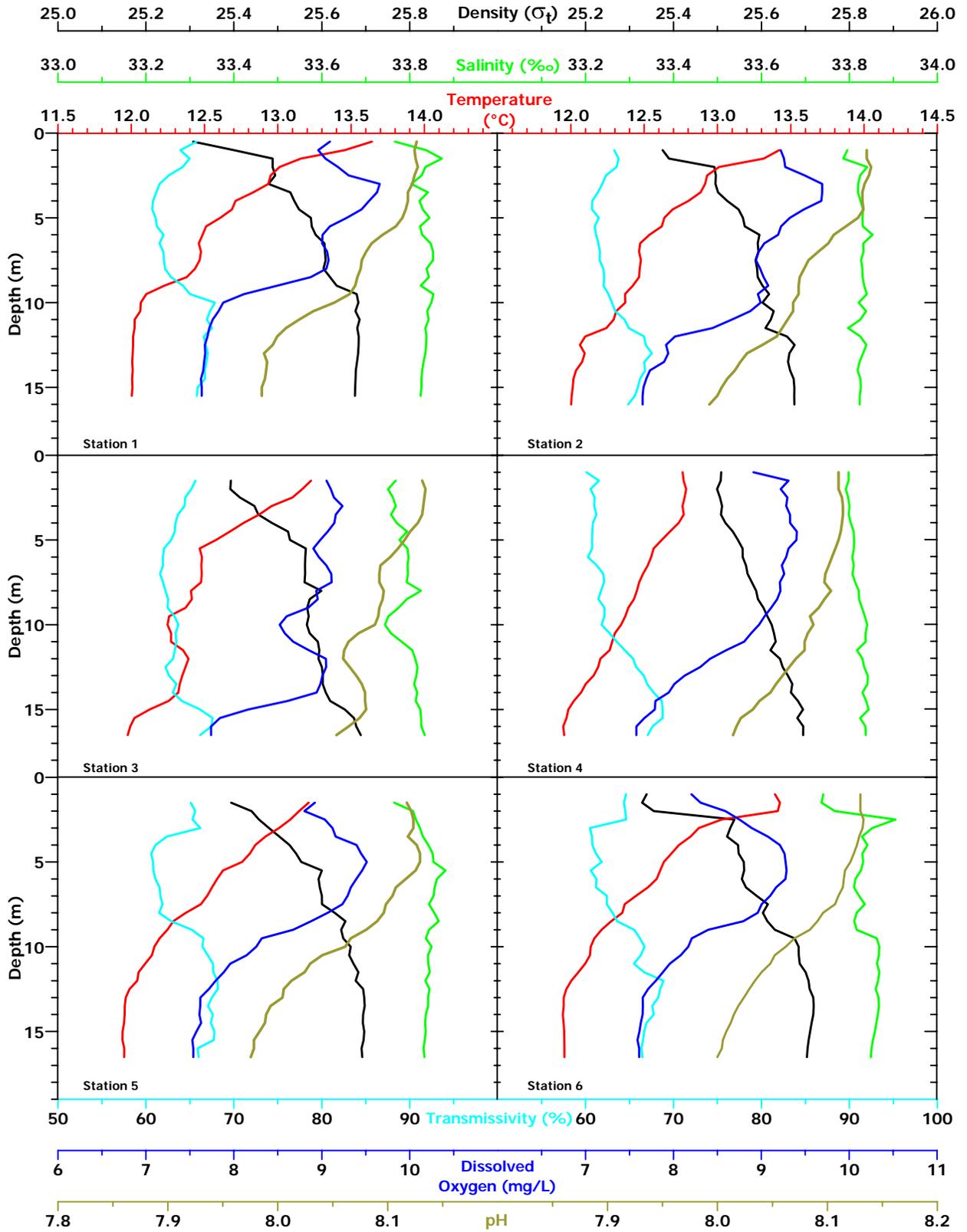
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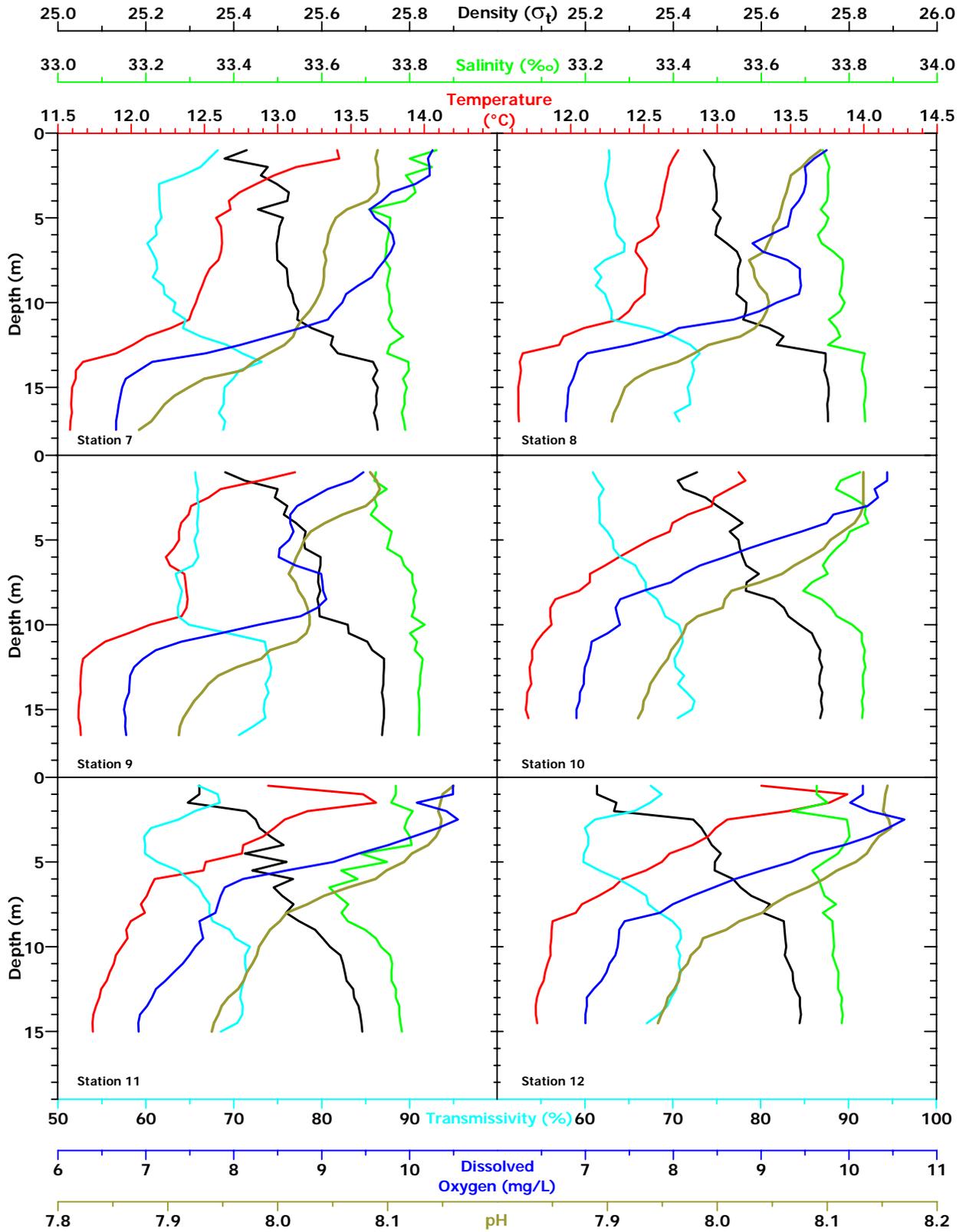
*APPENDIX A*

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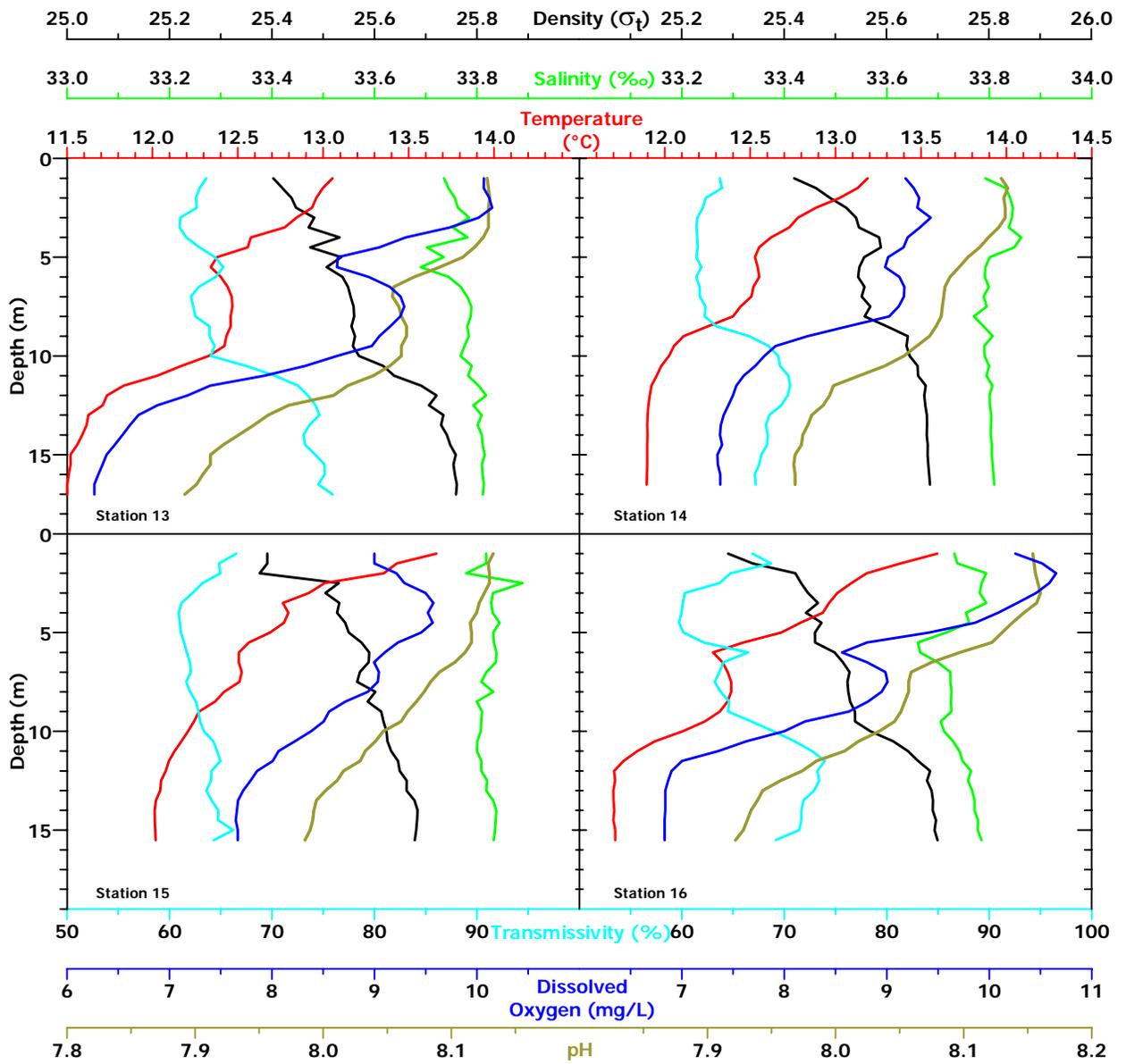
*Water Quality Profiles and Vertical Sections*



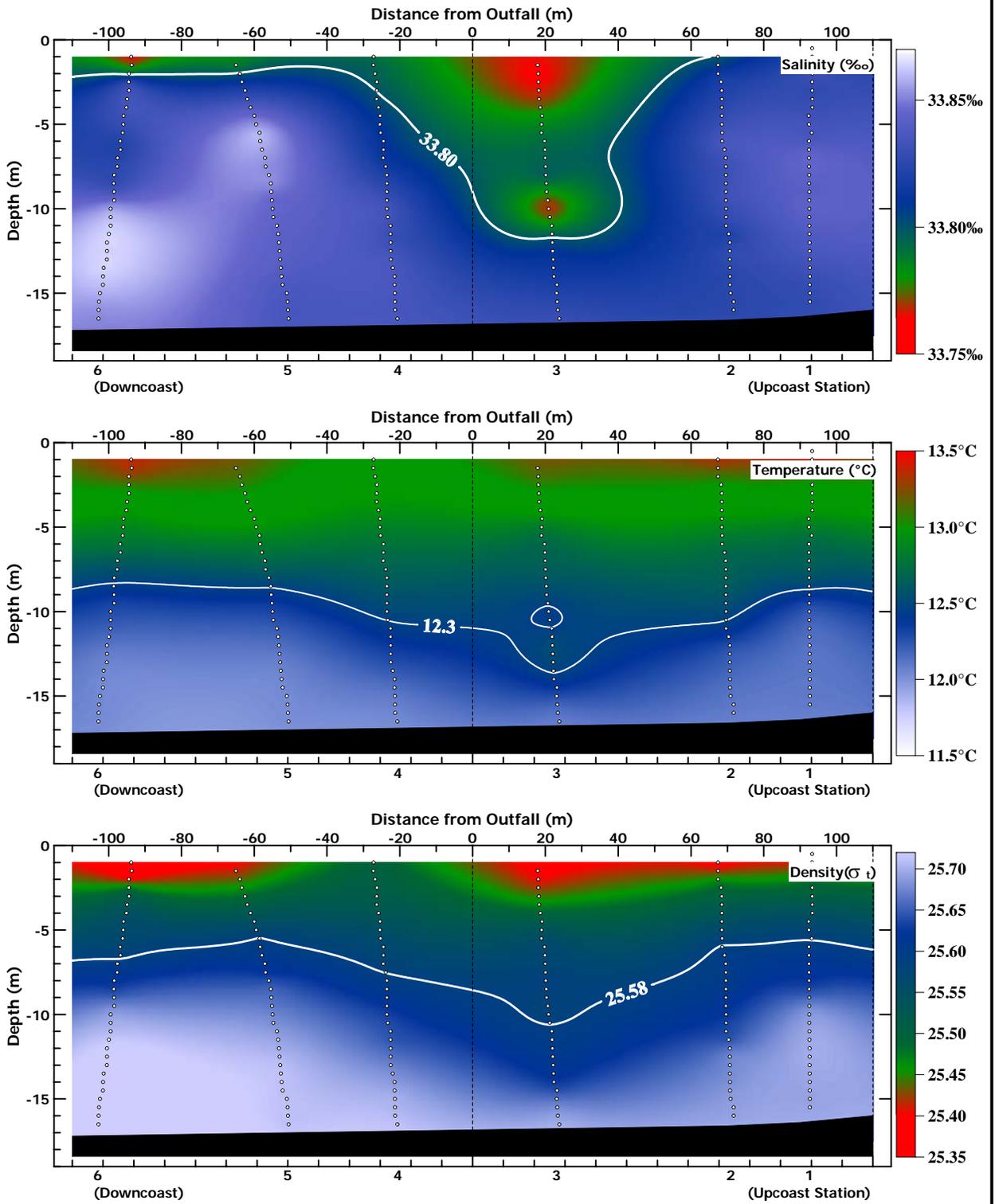
**Figure A-1.** Vertical Profiles of Water-Quality Parameters for Stations 1 through 6 measured on 19 July 2006



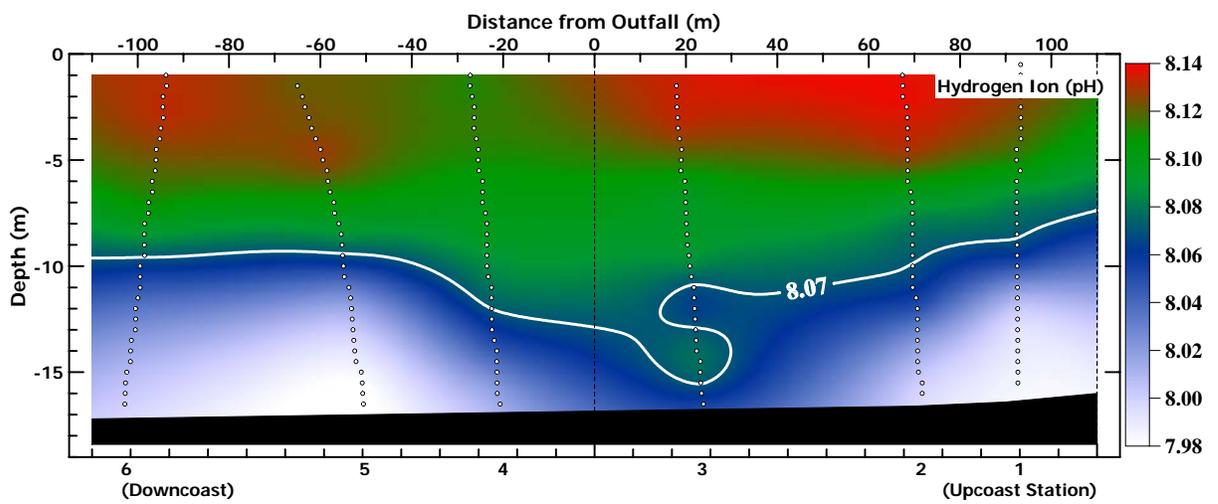
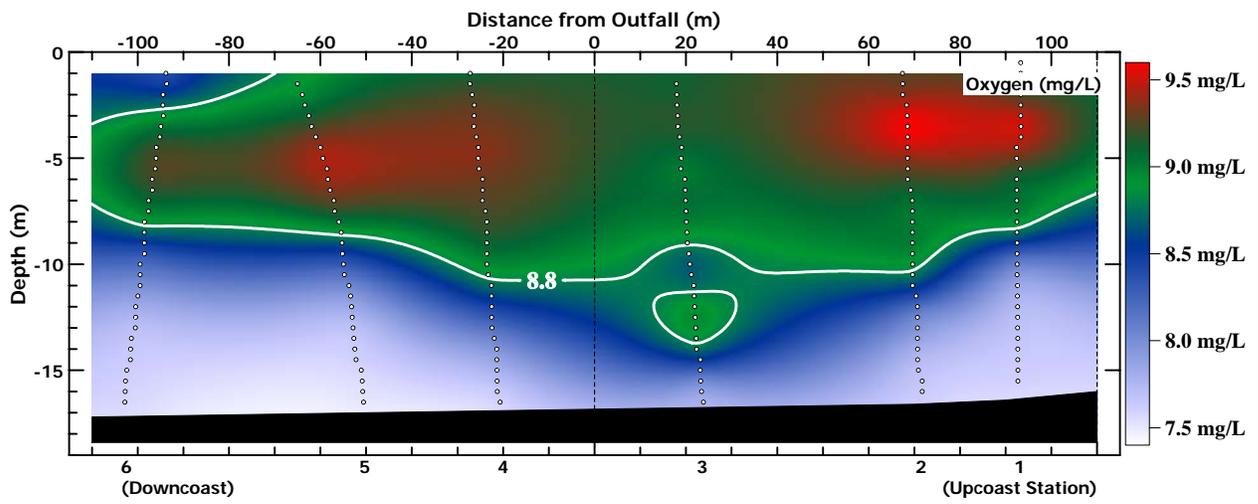
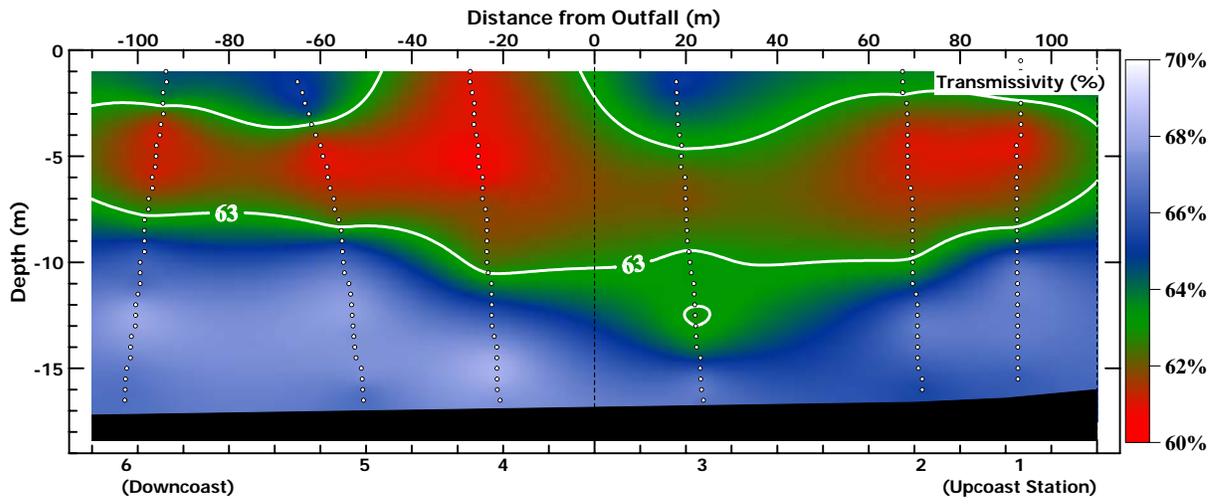
**Figure A-2.** Vertical Profiles of Water-Quality Parameters for Stations 7 through 12 measured on 19 July 2006



**Figure A-3.** Vertical Profiles of Water-Quality Parameters for Stations 13 through 16 measured on 19 July 2006



**Figure A-4.** Along-Shore Transects of Salinity, Temperature, and Density on 19 July 2006



**Figure A-5.** Along-Shore Transects of Transmissivity, Oxygen, and pH on 19 July 2006

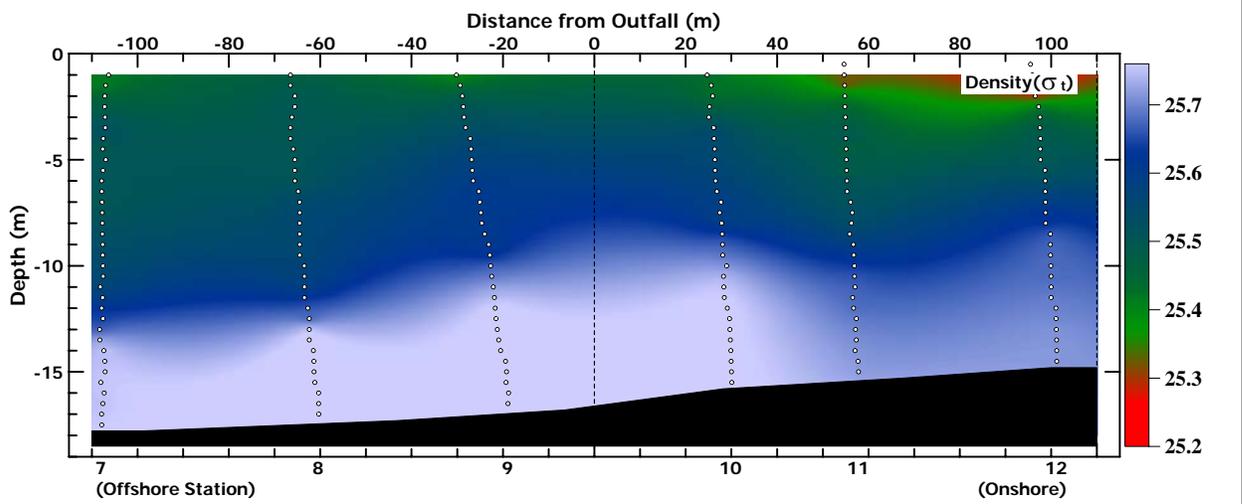
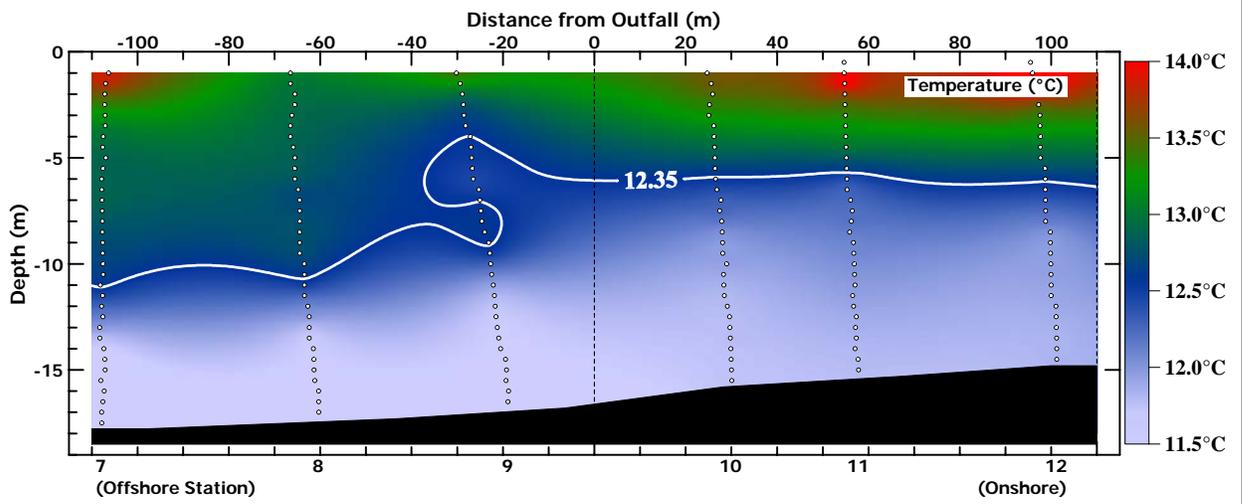
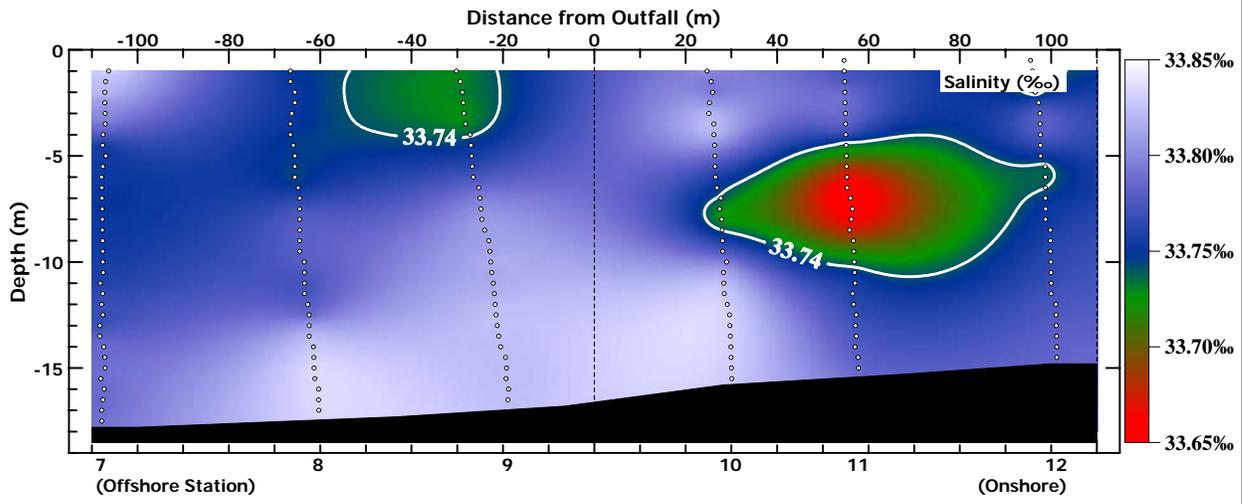


Figure A-6. Cross-Shore Transects of Salinity, Temperature, and Density on 19 July 2006

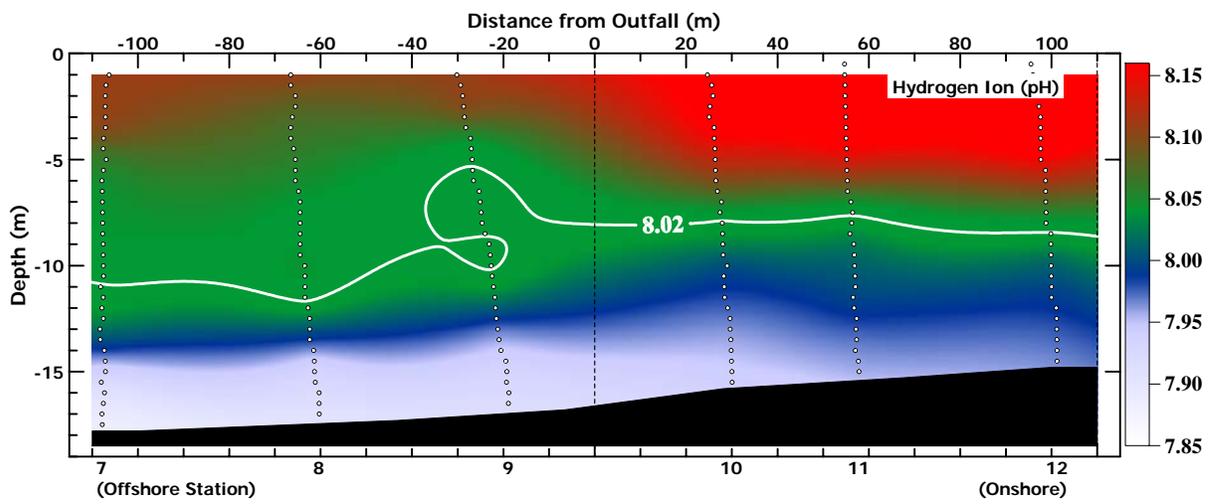
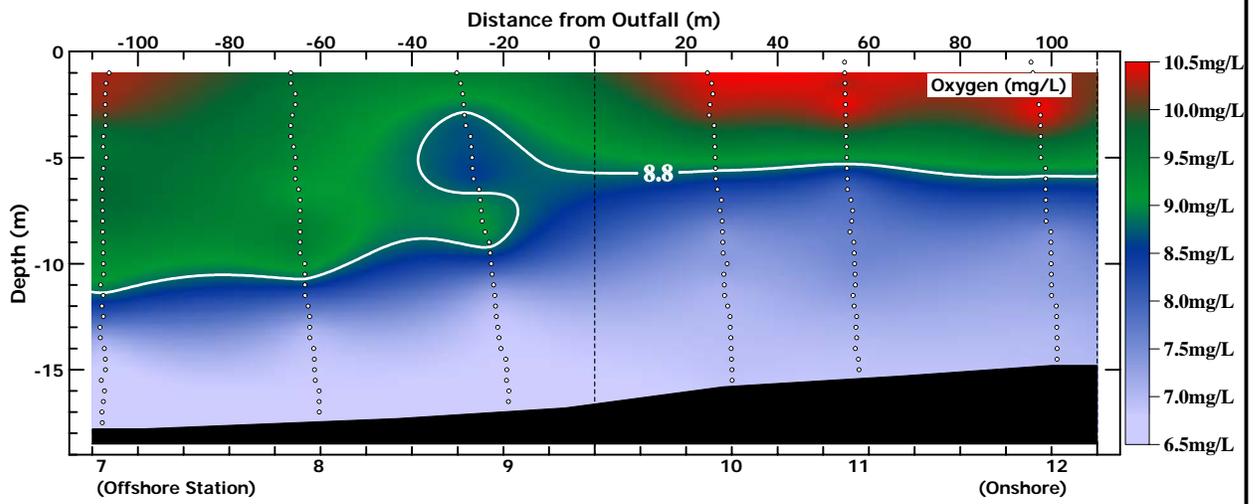
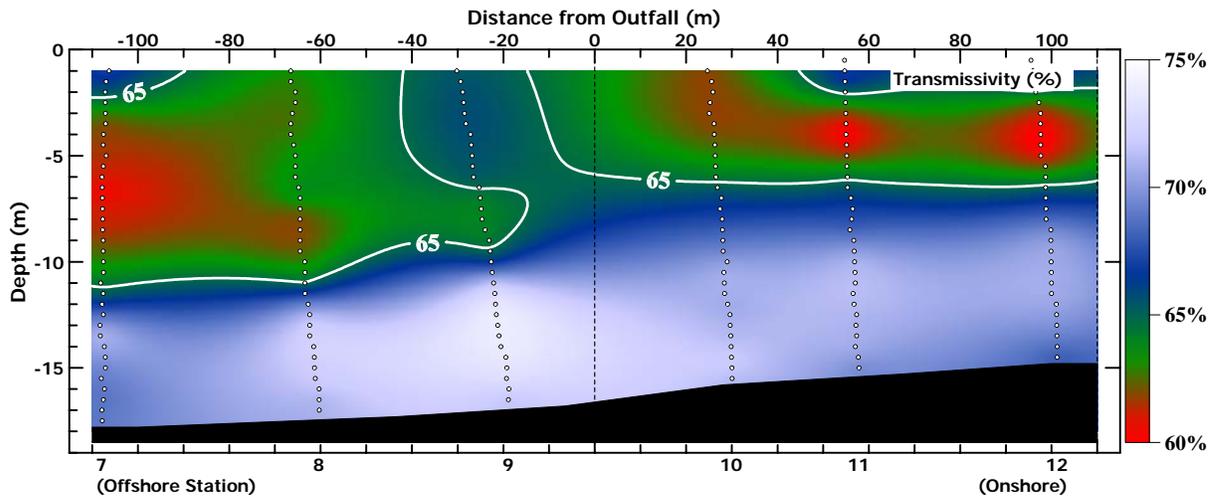


Figure A-7. Cross-Shore Transects of Transmissivity, Oxygen, and pH on 19 July 2006

***APPENDIX B***

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***Tables of Profile Data and Standard Observations***



Table B-2. Salinity<sup>1</sup> on 19 July 2006

| Depth (m) | Salinity (‰) |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
|-----------|--------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
|           | 1            | 2      | 3      | 4      | 5      | 6      | 7      | 8      | 9      | 10     | 11     | 12     | 13     | 14     | 15     | 16     |
| 0.5       | 33.767       |        |        |        |        |        |        |        |        |        | 33.769 | 33.726 |        |        |        |        |
| 1.0       | 33.837       | 33.795 |        | 33.798 |        | 33.741 | 33.861 | 33.740 | 33.724 | 33.825 | 33.769 | 33.726 | 33.736 | 33.792 | 33.818 | 33.732 |
| 1.5       | 33.873       | 33.786 | 33.768 | 33.798 | 33.765 | 33.736 | 33.800 | 33.748 | 33.720 | 33.781 | 33.758 | 33.751 | 33.744 | 33.832 | 33.818 | 33.738 |
| 2.0       | 33.836       | 33.841 | 33.751 | 33.792 | 33.808 | 33.767 | 33.851 | 33.755 | 33.748 | 33.770 | 33.808 | 33.669 | 33.757 | 33.840 | 33.779 | 33.794 |
| 2.5       | 33.827       | 33.825 | 33.762 | 33.798 | 33.814 | 33.905 | 33.792 | 33.751 | 33.719 | 33.807 | 33.795 | 33.794 | 33.763 | 33.846 | 33.889 | 33.785 |
| 3.0       | 33.804       | 33.820 | 33.768 | 33.800 | 33.823 | 33.852 | 33.807 | 33.752 | 33.726 | 33.838 | 33.788 | 33.798 | 33.785 | 33.844 | 33.832 | 33.781 |
| 3.5       | 33.841       | 33.819 | 33.758 | 33.799 | 33.830 | 33.829 | 33.813 | 33.752 | 33.711 | 33.836 | 33.801 | 33.801 | 33.753 | 33.838 | 33.828 | 33.794 |
| 4.0       | 33.822       | 33.826 | 33.770 | 33.803 | 33.842 | 33.841 | 33.791 | 33.749 | 33.735 | 33.844 | 33.805 | 33.788 | 33.782 | 33.862 | 33.831 | 33.754 |
| 4.5       | 33.830       | 33.831 | 33.794 | 33.810 | 33.852 | 33.830 | 33.708 | 33.736 | 33.759 | 33.802 | 33.689 | 33.775 | 33.702 | 33.849 | 33.844 | 33.760 |
| 5.0       | 33.845       | 33.830 | 33.776 | 33.811 | 33.854 | 33.832 | 33.756 | 33.753 | 33.755 | 33.793 | 33.749 | 33.744 | 33.736 | 33.801 | 33.832 | 33.715 |
| 5.5       | 33.823       | 33.831 | 33.795 | 33.811 | 33.881 | 33.826 | 33.755 | 33.745 | 33.749 | 33.771 | 33.645 | 33.716 | 33.690 | 33.793 | 33.833 | 33.661 |
| 6.0       | 33.829       | 33.853 | 33.797 | 33.807 | 33.862 | 33.814 | 33.752 | 33.729 | 33.781 | 33.753 | 33.682 | 33.731 | 33.745 | 33.791 | 33.838 | 33.665 |
| 6.5       | 33.848       | 33.832 | 33.795 | 33.810 | 33.857 | 33.811 | 33.748 | 33.737 | 33.788 | 33.740 | 33.618 | 33.737 | 33.768 | 33.799 | 33.837 | 33.700 |
| 7.0       | 33.853       | 33.832 | 33.796 | 33.807 | 33.855 | 33.822 | 33.747 | 33.764 | 33.806 | 33.751 | 33.637 | 33.744 | 33.781 | 33.789 | 33.819 | 33.724 |
| 7.5       | 33.853       | 33.827 | 33.793 | 33.813 | 33.844 | 33.835 | 33.743 | 33.786 | 33.807 | 33.715 | 33.660 | 33.770 | 33.789 | 33.795 | 33.809 | 33.724 |
| 8.0       | 33.838       | 33.829 | 33.826 | 33.821 | 33.856 | 33.817 | 33.756 | 33.786 | 33.815 | 33.695 | 33.645 | 33.740 | 33.788 | 33.770 | 33.832 | 33.726 |
| 8.5       | 33.844       | 33.830 | 33.793 | 33.822 | 33.866 | 33.811 | 33.751 | 33.783 | 33.809 | 33.737 | 33.660 | 33.762 | 33.781 | 33.789 | 33.800 | 33.725 |
| 9.0       | 33.825       | 33.834 | 33.775 | 33.829 | 33.844 | 33.817 | 33.748 | 33.783 | 33.812 | 33.759 | 33.699 | 33.763 | 33.784 | 33.807 | 33.810 | 33.726 |
| 9.5       | 33.854       | 33.840 | 33.752 | 33.835 | 33.837 | 33.862 | 33.754 | 33.778 | 33.805 | 33.772 | 33.724 | 33.764 | 33.776 | 33.790 | 33.808 | 33.705 |
| 10.0      | 33.849       | 33.821 | 33.744 | 33.841 | 33.850 | 33.868 | 33.754 | 33.790 | 33.834 | 33.807 | 33.735 | 33.766 | 33.768 | 33.791 | 33.807 | 33.712 |
| 10.5      | 33.840       | 33.838 | 33.758 | 33.837 | 33.841 | 33.867 | 33.760 | 33.780 | 33.801 | 33.829 | 33.756 | 33.762 | 33.790 | 33.800 | 33.801 | 33.729 |
| 11.0      | 33.843       | 33.825 | 33.781 | 33.837 | 33.842 | 33.863 | 33.752 | 33.754 | 33.817 | 33.829 | 33.760 | 33.769 | 33.783 | 33.794 | 33.800 | 33.742 |
| 11.5      | 33.836       | 33.797 | 33.806 | 33.817 | 33.846 | 33.868 | 33.763 | 33.771 | 33.812 | 33.836 | 33.759 | 33.776 | 33.803 | 33.806 | 33.809 | 33.748 |
| 12.0      | 33.838       | 33.825 | 33.813 | 33.830 | 33.836 | 33.865 | 33.785 | 33.780 | 33.830 | 33.833 | 33.759 | 33.775 | 33.818 | 33.800 | 33.809 | 33.764 |
| 12.5      | 33.838       | 33.839 | 33.818 | 33.834 | 33.845 | 33.860 | 33.756 | 33.752 | 33.827 | 33.837 | 33.769 | 33.775 | 33.793 | 33.801 | 33.820 | 33.758 |
| 13.0      | 33.836       | 33.831 | 33.816 | 33.842 | 33.842 | 33.866 | 33.749 | 33.835 | 33.825 | 33.831 | 33.769 | 33.784 | 33.809 | 33.804 | 33.818 | 33.767 |
| 13.5      | 33.831       | 33.823 | 33.810 | 33.841 | 33.842 | 33.868 | 33.797 | 33.831 | 33.824 | 33.831 | 33.776 | 33.782 | 33.801 | 33.804 | 33.832 | 33.771 |
| 14.0      | 33.829       | 33.819 | 33.817 | 33.830 | 33.837 | 33.865 | 33.798 | 33.829 | 33.820 | 33.834 | 33.777 | 33.785 | 33.810 | 33.803 | 33.838 | 33.771 |
| 14.5      | 33.827       | 33.825 | 33.814 | 33.838 | 33.835 | 33.861 | 33.785 | 33.835 | 33.822 | 33.829 | 33.779 | 33.783 | 33.811 | 33.805 | 33.837 | 33.778 |
| 15.0      | 33.827       | 33.826 | 33.824 | 33.844 | 33.836 | 33.858 | 33.794 | 33.838 | 33.822 | 33.832 | 33.783 |        | 33.816 | 33.805 | 33.835 | 33.778 |
| 15.5      | 33.825       | 33.824 | 33.826 | 33.824 | 33.835 | 33.854 | 33.788 | 33.837 | 33.822 | 33.829 |        |        | 33.810 | 33.807 | 33.833 | 33.785 |
| 16.0      |              | 33.823 | 33.826 | 33.836 | 33.831 | 33.851 | 33.789 | 33.834 | 33.822 |        |        |        | 33.811 | 33.808 |        |        |
| 16.5      |              |        | 33.834 | 33.838 | 33.833 | 33.849 | 33.783 | 33.835 | 33.821 |        |        |        | 33.814 | 33.810 |        |        |
| 17.0      |              |        |        |        |        |        | 33.787 | 33.836 |        |        |        |        | 33.812 |        |        |        |
| 17.5      |              |        |        |        |        |        | 33.790 |        |        |        |        |        |        |        |        |        |

<sup>1</sup> Values enclosed in boxes were significantly lower than the mean of other salinity measurements at the same distance below the sea surface.





Table B-5. Light Transmittance<sup>1</sup> across a 0.25-m path on 19 July 2006

| Depth (m) | Light Transmittance (%) |       |              |       |       |       |       |       |       |       |       |       |              |       |       |       |
|-----------|-------------------------|-------|--------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------------|-------|-------|-------|
|           | 1                       | 2     | 3            | 4     | 5     | 6     | 7     | 8     | 9     | 10    | 11    | 12    | 13           | 14    | 15    | 16    |
| 0.5       | 65.76                   |       |              |       |       |       |       |       |       |       | 65.98 | 67.48 |              |       |       |       |
| 1.0       | 63.91                   | 63.26 |              | 60.10 |       | 64.60 | 68.18 | 62.73 | 65.61 | 60.91 | 68.18 | 68.74 | 63.59        | 63.70 | 66.52 | 66.88 |
| 1.5       | 64.98                   | 63.74 | 65.65        | 61.53 | 65.10 | 64.36 | 67.18 | 62.79 | 65.72 | 61.44 | 68.41 | 67.42 | 62.94        | 63.91 | 64.81 | 68.71 |
| 2.0       | 64.16                   | 63.52 | 65.16        | 60.56 | 65.61 | 64.51 | 66.23 | 62.67 | 65.92 | 62.14 | 65.57 | 65.64 | 62.57        | 62.33 | 64.97 | 64.77 |
| 2.5       | 62.59                   | 62.31 | 64.47        | 61.03 | 65.31 | 64.61 | 64.20 | 62.58 | 65.84 | 61.59 | 63.73 | 61.14 | 62.65        | 62.04 | 63.23 | 63.68 |
| 3.0       | 61.56                   | 61.89 | 64.40        | 60.98 | 66.19 | 60.48 | 61.49 | 62.30 | 66.00 | 61.65 | 60.58 | 60.00 | 61.04        | 61.52 | 62.24 | 60.28 |
| 3.5       | 61.18                   | 61.40 | 63.65        | 61.22 | 62.38 | 60.72 | 61.50 | 62.48 | 65.92 | 61.69 | 59.82 | 60.38 | 60.98        | 61.43 | 61.17 | 60.10 |
| 4.0       | 60.81                   | 60.77 | 63.37        | 60.83 | 61.09 | 60.78 | 61.56 | 62.69 | 65.83 | 61.68 | 59.91 | 60.36 | 61.63        | 61.52 | 60.87 | 59.96 |
| 4.5       | 60.73                   | 60.74 | 63.28        | 60.78 | 60.60 | 61.19 | 61.60 | 63.10 | 65.91 | 62.56 | 59.89 | 59.89 | 62.93        | 61.55 | 61.02 | 59.71 |
| 5.0       | 61.10                   | 61.52 | 62.88        | 60.73 | 60.82 | 61.82 | 61.78 | 63.41 | 65.52 | 63.17 | 61.31 | 59.83 | 64.42        | 61.41 | 61.11 | 60.15 |
| 5.5       | 61.24                   | 61.05 | 62.07        | 60.75 | 60.84 | 60.57 | 61.13 | 63.37 | 65.75 | 63.25 | 63.65 | 61.65 | 65.25        | 61.90 | 61.43 | 62.14 |
| 6.0       | 61.99                   | 61.19 | 61.92        | 60.26 | 61.08 | 61.23 | 61.23 | 63.65 | 65.98 | 64.01 | 64.88 | 63.80 | 64.51        | 61.40 | 61.67 | 66.45 |
| 6.5       | 61.54                   | 61.46 | 61.95        | 61.28 | 61.57 | 61.18 | 60.16 | 64.52 | 65.35 | 65.76 | 66.04 | 65.49 | 62.86        | 61.74 | 61.99 | 64.04 |
| 7.0       | 61.97                   | 61.62 | 61.61        | 62.02 | 61.64 | 62.42 | 60.69 | 64.46 | 63.40 | 66.22 | 66.54 | 66.99 | 62.10        | 61.77 | 62.09 | 63.66 |
| 7.5       | 62.06                   | 61.60 | 61.95        | 62.11 | 61.90 | 62.41 | 61.18 | 62.25 | 63.68 | 66.90 | 67.25 | 67.20 | 62.31        | 62.29 | 61.62 | 63.19 |
| 8.0       | 62.19                   | 62.02 | 62.23        | 61.75 | 61.49 | 63.06 | 61.30 | 61.10 | 64.12 | 66.95 | 67.23 | 68.48 | 62.52        | 62.23 | 62.02 | 63.78 |
| 8.5       | 62.84                   | 62.13 | 62.53        | 61.46 | 62.86 | 63.58 | 60.79 | 61.87 | 63.89 | 68.21 | 67.60 | 69.95 | 63.90        | 63.36 | 62.57 | 64.62 |
| 9.0       | 64.22                   | 62.04 | 62.47        | 62.15 | 65.22 | 65.53 | 62.00 | 61.24 | 63.63 | 68.72 | 69.56 | 70.83 | 63.91        | 66.58 | 62.83 | 64.51 |
| 9.5       | 65.00                   | 62.60 | 63.24        | 62.14 | 66.54 | 66.17 | 62.13 | 62.29 | 63.68 | 69.11 | 70.16 | 70.94 | 64.39        | 68.46 | 62.97 | 66.79 |
| 10.0      | 67.85                   | 63.00 | 63.69        | 61.82 | 66.43 | 66.72 | 63.35 | 62.64 | 64.90 | 70.70 | 71.84 | 70.42 | 64.02        | 69.40 | 63.37 | 68.94 |
| 10.5      | 67.30                   | 63.38 | 63.38        | 62.72 | 67.04 | 66.28 | 63.11 | 63.03 | 69.36 | 71.01 | 71.32 | 70.83 | 67.50        | 69.58 | 64.28 | 71.00 |
| 11.0      | 66.93                   | 64.43 | 63.46        | 63.55 | 67.63 | 65.50 | 64.53 | 63.02 | 73.54 | 71.14 | 71.27 | 70.67 | 70.29        | 70.40 | 64.63 | 72.69 |
| 11.5      | 67.51                   | 64.91 | 63.29        | 64.46 | 67.66 | 66.64 | 64.21 | 67.27 | 73.73 | 70.72 | 71.45 | 70.92 | 72.55        | 70.55 | 64.95 | 73.94 |
| 12.0      | 66.58                   | 66.65 | 63.08        | 65.41 | 68.15 | 68.87 | 66.25 | 70.05 | 73.99 | 70.19 | 71.14 | 70.57 | 73.51        | 70.33 | 64.09 | 73.23 |
| 12.5      | 66.81                   | 66.83 | <b>62.23</b> | 65.75 | 68.17 | 68.48 | 69.23 | 72.03 | 74.25 | 70.32 | 70.90 | 70.37 | 74.27        | 69.70 | 64.04 | 73.42 |
| 13.0      | 67.04                   | 67.54 | 62.63        | 66.63 | 67.50 | 68.26 | 70.96 | 73.07 | 74.14 | 71.29 | 70.73 | 69.81 | 74.62        | 68.54 | 63.60 | 72.89 |
| 13.5      | 66.89                   | 66.69 | 63.47        | 67.00 | 67.06 | 67.57 | 73.18 | 72.17 | 73.63 | 70.58 | 71.03 | 69.37 | 73.67        | 68.20 | 64.11 | 71.86 |
| 14.0      | 66.69                   | 66.77 | 63.06        | 67.73 | 67.62 | 67.75 | 70.62 | 72.43 | 73.96 | 71.61 | 70.98 | 68.42 | 73.07        | 68.36 | 64.76 | 71.66 |
| 14.5      | 66.73                   | 66.19 | 64.08        | 68.66 | 67.40 | 66.91 | 69.93 | 72.15 | 73.51 | 72.48 | 70.41 | 67.05 | 73.22        | 68.31 | 64.73 | 71.67 |
| 15.0      | 65.90                   | 65.94 | 66.16        | 68.76 | 67.79 | 66.66 | 68.94 | 71.69 | 73.41 | 72.20 | 68.55 |       | 74.22        | 67.77 | 66.21 | 71.45 |
| 15.5      | 65.80                   | 65.61 | 67.57        | 68.76 | 67.72 | 66.52 | 68.88 | 71.89 | 73.59 | 70.57 |       |       | 75.13        | 67.53 | 64.31 | 69.18 |
| 16.0      |                         | 64.84 | 67.45        | 67.62 | 65.87 | 66.37 | 68.84 | 72.00 | 72.22 |       |       |       | 75.14        | 67.12 |       |       |
| 16.5      |                         |       | 66.18        | 67.06 | 65.99 | 66.47 | 68.32 | 70.20 | 70.61 |       |       |       | 74.53        | 67.20 |       |       |
| 17.0      |                         |       |              |       |       |       | 69.02 | 70.75 |       |       |       |       | <b>75.91</b> |       |       |       |
| 17.5      |                         |       |              |       |       |       | 68.82 |       |       |       |       |       |              |       |       |       |

<sup>1</sup> Values enclosed in boxes were significantly different than the mean of other transmissivity measurements at the same distance above the seafloor.

**Table B-6. Detrended<sup>1</sup> pH on 19 July 2006**

| Depth (m)   | Hydrogen Ion Concentration (pH) |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|-------------|---------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|             | 1                               | 2     | 3     | 4     | 5     | 6     | 7     | 8     | 9     | 10    | 11    | 12    | 13    | 14    | 15    | 16    |
| <b>0.5</b>  | 8.126                           |       |       |       |       |       |       |       |       |       | 8.160 | 8.155 |       |       |       |       |
| <b>1.0</b>  | 8.124                           | 8.136 |       | 8.110 |       | 8.130 | 8.091 | 8.094 | 8.084 | 8.133 | 8.150 | 8.153 | 8.128 | 8.129 | 8.133 | 8.154 |
| <b>1.5</b>  | 8.125                           | 8.136 | 8.131 | 8.110 | 8.117 | 8.130 | 8.089 | 8.084 | 8.090 | 8.133 | 8.148 | 8.152 | 8.129 | 8.134 | 8.129 | 8.155 |
| <b>2.0</b>  | 8.127                           | 8.140 | 8.134 | 8.110 | 8.121 | 8.130 | 8.091 | 8.077 | 8.093 | 8.133 | 8.146 | 8.151 | 8.130 | 8.131 | 8.130 | 8.156 |
| <b>2.5</b>  | 8.124                           | 8.138 | 8.133 | 8.113 | 8.123 | 8.133 | 8.091 | 8.067 | 8.089 | 8.133 | 8.149 | 8.156 | 8.129 | 8.132 | 8.130 | 8.158 |
| <b>3.0</b>  | 8.122                           | 8.134 | 8.132 | 8.114 | 8.123 | 8.132 | 8.092 | 8.065 | 8.080 | 8.133 | 8.148 | 8.158 | 8.129 | 8.132 | 8.126 | 8.160 |
| <b>3.5</b>  | 8.118                           | 8.132 | 8.131 | 8.114 | 8.118 | 8.129 | 8.090 | 8.063 | 8.059 | 8.130 | 8.144 | 8.147 | 8.129 | 8.127 | 8.122 | 8.157 |
| <b>4.0</b>  | 8.118                           | 8.132 | 8.127 | 8.113 | 8.126 | 8.127 | 8.082 | 8.060 | 8.043 | 8.125 | 8.137 | 8.141 | 8.125 | 8.119 | 8.120 | 8.147 |
| <b>4.5</b>  | 8.116                           | 8.133 | 8.120 | 8.112 | 8.129 | 8.124 | 8.063 | 8.058 | 8.030 | 8.114 | 8.122 | 8.136 | 8.118 | 8.112 | 8.115 | 8.138 |
| <b>5.0</b>  | 8.113                           | 8.128 | 8.115 | 8.110 | 8.129 | 8.121 | 8.053 | 8.056 | 8.024 | 8.103 | 8.115 | 8.126 | 8.109 | 8.103 | 8.116 | 8.130 |
| <b>5.5</b>  | 8.107                           | 8.117 | 8.109 | 8.107 | 8.125 | 8.116 | 8.049 | 8.051 | 8.021 | 8.097 | 8.099 | 8.109 | 8.091 | 8.096 | 8.116 | 8.122 |
| <b>6.0</b>  | 8.095                           | 8.106 | 8.102 | 8.104 | 8.116 | 8.115 | 8.046 | 8.050 | 8.017 | 8.084 | 8.089 | 8.097 | 8.071 | 8.089 | 8.111 | 8.097 |
| <b>6.5</b>  | 8.085                           | 8.101 | 8.093 | 8.101 | 8.107 | 8.114 | 8.045 | 8.046 | 8.014 | 8.070 | 8.064 | 8.082 | 8.055 | 8.085 | 8.103 | 8.075 |
| <b>7.0</b>  | 8.080                           | 8.092 | 8.092 | 8.098 | 8.104 | 8.110 | 8.042 | 8.043 | 8.010 | 8.059 | 8.042 | 8.064 | 8.054 | 8.084 | 8.091 | 8.059 |
| <b>7.5</b>  | 8.076                           | 8.083 | 8.092 | 8.097 | 8.098 | 8.107 | 8.044 | 8.029 | 8.016 | 8.039 | 8.027 | 8.051 | 8.059 | 8.083 | 8.084 | 8.057 |
| <b>8.0</b>  | 8.075                           | 8.079 | 8.096 | 8.103 | 8.096 | 8.096 | 8.042 | 8.033 | 8.019 | 8.013 | 8.008 | 8.041 | 8.061 | 8.082 | 8.079 | 8.057 |
| <b>8.5</b>  | 8.072                           | 8.075 | 8.095 | 8.097 | 8.090 | 8.091 | 8.042 | 8.034 | 8.024 | 8.007 | 8.002 | 8.020 | 8.065 | 8.078 | 8.073 | 8.054 |
| <b>9.0</b>  | 8.070                           | 8.074 | 8.092 | 8.092 | 8.080 | 8.084 | 8.041 | 8.038 | 8.027 | 8.005 | 7.993 | 8.008 | 8.065 | 8.073 | 8.066 | 8.051 |
| <b>9.5</b>  | 8.065                           | 8.074 | 8.091 | 8.084 | 8.066 | 8.070 | 8.038 | 8.045 | 8.029 | 7.982 | 7.988 | 7.987 | 8.061 | 8.063 | 8.061 | 8.046 |
| <b>10.0</b> | 8.051                           | 8.069 | 8.088 | 8.087 | 8.061 | 8.062 | 8.034 | 8.047 | 8.029 | 7.972 | 7.983 | 7.984 | 8.061 | 8.053 | 8.047 | 8.034 |
| <b>10.5</b> | 8.032                           | 8.069 | 8.073 | 8.082 | 8.040 | 8.052 | 8.029 | 8.045 | 8.026 | 7.969 | 7.981 | 7.976 | 8.052 | 8.038 | 8.041 | 8.018 |
| <b>11.0</b> | 8.019                           | 8.064 | 8.064 | 8.079 | 8.029 | 8.048 | 8.022 | 8.041 | 8.017 | 7.964 | 7.977 | 7.973 | 8.039 | 8.018 | 8.033 | 8.007 |
| <b>11.5</b> | 8.007                           | 8.059 | 8.060 | 8.079 | 8.024 | 8.040 | 8.017 | 8.034 | 7.993 | 7.958 | 7.972 | 7.966 | 8.019 | 7.998 | 8.029 | 7.985 |
| <b>12.0</b> | 7.999                           | 8.054 | 8.059 | 8.071 | 8.012 | 8.034 | 8.014 | 8.021 | 7.985 | 7.955 | 7.969 | 7.965 | 8.008 | 7.995 | 8.016 | 7.974 |
| <b>12.5</b> | 7.995                           | 8.041 | 8.065 | 8.065 | 8.005 | 8.029 | 8.006 | 7.992 | 7.963 | 7.949 | 7.964 | 7.961 | 7.973 | 7.990 | 8.011 | 7.957 |
| <b>13.0</b> | 7.987                           | 8.027 | 8.071 | 8.059 | 8.004 | 8.024 | 7.992 | 7.979 | 7.946 | 7.944 | 7.955 | 7.955 | 7.957 | 7.981 | 8.002 | 7.943 |
| <b>13.5</b> | 7.990                           | 8.021 | 8.076 | 8.053 | 7.993 | 8.019 | 7.978 | 7.964 | 7.937 | 7.939 | 7.949 | 7.953 | 7.946 | 7.978 | 7.995 | 7.939 |
| <b>14.0</b> | 7.989                           | 8.016 | 8.079 | 8.048 | 7.989 | 8.015 | 7.968 | 7.939 | 7.931 | 7.937 | 7.946 | 7.949 | 7.934 | 7.974 | 7.993 | 7.934 |
| <b>14.5</b> | 7.988                           | 8.009 | 8.079 | 8.038 | 7.988 | 8.012 | 7.933 | 7.925 | 7.924 | 7.933 | 7.942 | 7.946 | 7.922 | 7.973 | 7.992 | 7.931 |
| <b>15.0</b> | 7.985                           | 8.004 | 8.080 | 8.032 | 7.983 | 8.008 | 7.919 | 7.916 | 7.919 | 7.932 | 7.940 |       | 7.912 | 7.968 | 7.990 | 7.928 |
| <b>15.5</b> | 7.985                           | 8.000 | 8.074 | 8.021 | 7.978 | 8.005 | 7.906 | 7.913 | 7.914 | 7.928 |       |       | 7.912 | 7.967 | 7.986 | 7.922 |
| <b>16.0</b> |                                 | 7.993 | 8.064 | 8.017 | 7.978 | 8.004 | 7.897 | 7.910 | 7.911 |       |       |       | 7.906 | 7.968 |       |       |
| <b>16.5</b> |                                 |       | 8.053 | 8.014 | 7.975 | 8.000 | 7.891 | 7.906 | 7.910 |       |       |       | 7.901 | 7.968 |       |       |
| <b>17.0</b> |                                 |       |       |       |       |       | 7.885 | 7.904 |       |       |       |       | 7.892 |       |       |       |
| <b>17.5</b> |                                 |       |       |       |       |       | 7.874 |       |       |       |       |       |       |       |       |       |

<sup>1</sup> Measured pH levels were corrected for temporal drift to account for ongoing equilibration of the pH sensor.



**Table B-8. Ancillary Observations on 19 July 2006 during the Receiving-Water Survey**

| Station | Location      |                | Diffuser Distance (m) | Time (PDT) | Air Temperature (°C) | Cloud Cover (%) | Wind Avg (kt) | Wind Max (kt) | Wind Dir (from) (°T) | Swell Ht/Dir (ft/°T) | Secchi Depth (m) |
|---------|---------------|----------------|-----------------------|------------|----------------------|-----------------|---------------|---------------|----------------------|----------------------|------------------|
|         | Latitude      | Longitude      |                       |            |                      |                 |               |               |                      |                      |                  |
| 1       | 35° 23.252' N | 120° 52.502' W | 97.5                  | 07:50:27   | 18.3                 | 0               | 0.3           | 0.7           | ESE                  | 1-2/W                | 3.5              |
| 2       | 35° 23.234' N | 120° 52.502' W | 64.5                  | 07:46:48   | 18.5                 | 0               | 0.5           | 1.1           | ESE                  | 1-2/W                | 3.5              |
| 3       | 35° 23.211' N | 120° 52.506' W | 21.8                  | 07:40:44   | 16.4                 | 0               | 0.3           | 0.6           | ESE                  | 1-2/W                | 3.5              |
| 4       | 35° 23.190' N | 120° 52.503' W | 17.7                  | 07:37:35   | 16.7                 | 0               | 0.6           | 1.3           | ESE                  | 1-2/W                | 3.5              |
| 5       | 35° 23.168' N | 120° 52.505' W | 57.5                  | 07:29:48   | 15.3                 | 0               | 1.1           | 1.6           | ESE                  | 1-2/W                | 4.0              |
| 6       | 35° 23.141' N | 120° 52.506' W | 107.5                 | 07:26:29   | 16.8                 | 0               | 1.1           | 2.0           | ESE                  | 1-2/W                | 4.0              |
| 7       | 35° 23.199' N | 120° 52.569' W | 98.5                  | 08:22:57   | 18.5                 | 0               | 0.5           | 0.9           | ESE                  | 1-2/W                | 3.5              |
| 8       | 35° 23.201' N | 120° 52.542' W | 57.6                  | 08:29:27   | 15.4                 | 0               | 2.3           | 3.7           | ESE                  | 1-2/W                | 3.5              |
| 9       | 35° 23.201' N | 120° 52.518' W | 20.7                  | 08:32:55   | 15.8                 | 0               | 2.0           | 2.6           | ESE                  | 1-2/W                | 4.0              |
| 10      | 35° 23.199' N | 120° 52.493' W | 16.5                  | 08:38:40   | 15.7                 | 0               | 1.5           | 2.8           | ESE                  | 1-2/W                | 4.0              |
| 11      | 35° 23.201' N | 120° 52.466' W | 58.8                  | 08:41:52   | 15.3                 | 0               | 1.5           | 2.9           | ESE                  | 1-2/W                | 3.5              |
| 12      | 35° 23.199' N | 120° 52.433' W | 107.5                 | 08:44:43   | 16.9                 | 0               | 1.1           | 2.5           | ESE                  | 1-2/W                | 3.5              |
| 13      | 35° 23.178' N | 120° 52.531' W | 56.6                  | 08:55:29   | 18.5                 | 0               | 0.5           | 1.2           | ESE                  | 1-2/W                | 3.5              |
| 14      | 35° 23.224' N | 120° 52.533' W | 62.9                  | 07:59:40   | 15.7                 | 0               | 0.8           | 1.3           | ESE                  | 1-2/W                | 4.0              |
| 15      | 35° 23.221' N | 120° 52.473' W | 63.0                  | 07:54:42   | 18.9                 | 0               | 0.6           | 1.1           | ESE                  | 1-2/W                | 3.5              |
| 16      | 35° 23.173' N | 120° 52.476' W | 63.7                  | 08:48:33   | 18.4                 | 0               | 0.9           | 1.9           | ESE                  | 1-2/W                | 3.5              |

There was no visual expression of the effluent plume at the sea surface. Neither odors nor debris of sewage origin were observed at any time during the survey.

Tidal Conditions (Pacific Daylight Time)

Low Tide: 01:07 0.57 ft  
 High Tide: 07:26 2.92 ft  
 Low Tide: 11:37 2.18 ft  
 High Tide: 18:31 5.48 ft