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

21 November 2005

Reference: Quarterly Receiving-Water Report – October 2005

Dear Mr. Keogh:

Enclosed is the Quarterly Report for the Water-Quality Survey conducted on 5 October 2005. This fourth-quarter survey assessed the effectiveness of effluent dispersion during autumnal 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.

This survey was unusual because it included an extra vertical profile of instrumental data that was collected very close to a diffuser port. The additional profile captured the turbulent discharge jet of wastewater as it was ejected from the diffuser port. These data documented rapid mixing within the jet that resulted in dilution levels that were close to the dilution predicted by modeling of the entire mixing process, including dilution resulting from the subsequent rise of the buoyant plume through the water column. These results confirmed that the diffuser structure and the outfall were attaining dilution levels far beyond those prescribed in the discharge permit.

Other high-precision measurements clearly delineated very slight lateral perturbations in all six seawater properties. These measurements demonstrated that the detectable effluent signature was confined to the zone of initial dilution where receiving-water limitations do not apply. Moreover, the discharge-related anomalies in temperature, dissolved oxygen, and pH were generated by the upward displacement of ambient seawater, rather than the presence of wastewater constituents. 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 this report.

Sincerely,

Douglas A. Coats, Ph.D.
Program Manager

Enclosure (Seven 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.

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Mr. Bruce Ambo
City of Morro Bay

Date ______________________________

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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). The 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 a new discharge permit (RWQCB 1998).

As part of the new 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 5 October 2005. Specifically, this fourth-quarter survey was conducted in October to capture ambient oceanographic conditions along the central California coast during the early fall season.

The water-quality surveys also provide timely assessments of the performance of the diffuser structure in dispersing wastewater within highly 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.

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 October 2005 field survey was the twenty-eighth 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 (≤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[1] instrument package between stations now provides a more synoptic snapshot of the water properties immediately surrounding the diffuser structure. Consequently,

[1] Conductivity, Temperature, and Depth (CTD) were the original measurements collected 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 highly 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 28 of the subsequent water-quality surveys (MRS 2000, 2001, 2002, 2003, 2004, 2005), 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 dispersed 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 October 2005 survey. In addition, for the first time since monitoring began, opportunistic sampling allowed the CTD instrument package to pass extremely close to a diffuser port, and capture the dilution process associated with the turbulent discharge jet.

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[2]. 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 remaining 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 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.

[2] 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

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. Similarly, although the entrance to the Morro Bay National Estuary lies only 2.8 km to the south of the discharge, 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 blocks the direct incursion of unmixed wastewater into 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).

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 diffuser centroid. 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[1] (m)	Center Distance[2] (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	Onshore ZID	35° 23.199' N	120° 52.489' W	15.0	23
11	Onshore Nearfield	35° 23.199' N	120° 52.464' W	46.7	60
12	Onshore 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

[1] Distance to the closest open diffuser port.
[2] Distance to the center of open diffuser section.

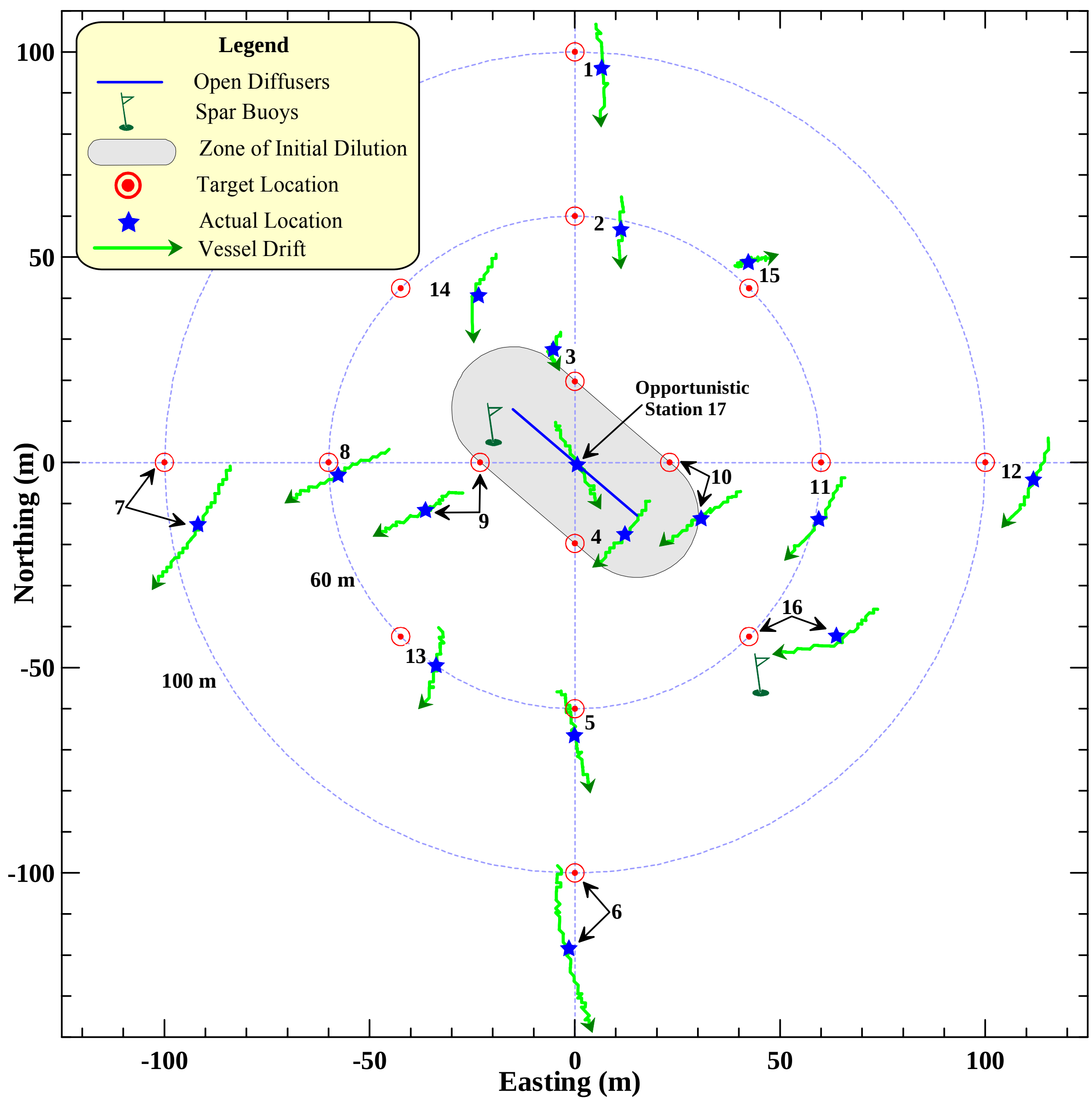

Figure 2. Offshore Water Sampling Locations on 5 October 2005

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. In addition, during the October 2005 survey, an additional CTD profile was collected within the effluent plume that was visible on the sea surface near the diffuser structure. This opportunistic hydrocast was designated Station 17. Water-quality sampling at this location, which was directly over the diffuser structure, is not required as part of the monitoring program. The sampling was conducted instead to take advantage of an opportunity to measure the details of the discharge plume while it was mixing with receiving waters.

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 ±15 m, a span equal to half 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 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 is apparent in Figure 2 from the length of the green tracklines. These tracklines trace the horizontal location of the CTD instrument package as it was lowered to the seafloor at each station.

The CTD tracklines shown in Figure 2 reveal that a substantial amount of lateral drift occurred during the vertical casts at nearly all the stations. During the time it took the CTD to traverse the water column to the seafloor, which averaged 1m 14s, the instrument package moved an average of 21.9 m laterally. At stations close to the diffuser structure, this large 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 collected 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 has occurred. The vertical casts at Stations 3, 4, and 10 traversed the boundary of the ZID. Strictly speaking, only a portion of the data collected within those casts are subject to the receiving-water limitations specified in the NPDES discharge permit. Additionally, none of the measurements collected at the opportunistic Station 17 are subject to the limitations.

Compliance assessments notwithstanding, measurements collected 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 collected 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 21.9 m average drift experienced during sampling at each station 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 October 2005 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 15.6 m closest-approach distance specified for Station 10 would suggest that all of the data at Station 10 was collected outside of the ZID. In reality, as shown by the green trackline in Figure 2, the

Table 2. Average Coordinates of Vertical Profiles during the October 2005 Survey

	Time (PDT)				Closest Approach	
Station	**Downcast**	**Upcast**	**Latitude**	**Longitude**	**Range[1](m)**	**Bearing[2](ºT)**
1	10:41:24	10:42:32	35° 23.251' N	120° 52.500' W	86.0	15
2	10:37:03	10:38:03	35° 23.230' N	120° 52.497' W	51.3	31
3	10:27:24	10:28:28	35° 23.214' N	120° 52.507' W	**17.8** [3]	34
4	10:22:32	10:23:39	35° 23.190' N	120° 52.496' W	**5.3** [3]	214
5	10:16:14	10:17:49	35° 23.163' N	120° 52.504' W	55.5	196
6	10:08:17	10:09:58	35° 23.135' N	120° 52.505' W	106.6	189
7	11:19:37	11:20:54	35° 23.191' N	120° 52.565' W	81.6	250
8	11:24:46	11:26:09	35° 23.197' N	120° 52.542' W	45.4	250
9	11:30:05	11:31:12	35° 23.193' N	120° 52.528' W	32.4	221
10	11:35:41	11:36:45	35° 23.192' N	120° 52.484' W	**15.6** [3]	92
11	11:40:42	11:41:45	35° 23.192' N	120° 52.465' W	44.3	91
12	11:47:58	11:49:09	35° 23.197' N	120° 52.430' W	97.0	85
13	11:15:16	11:16:33	35° 23.172' N	120° 52.526' W	59.4	221
14	10:44:33	10:45:43	35° 23.221' N	120° 52.519' W	29.1	343
15	10:50:03	10:51:15	35° 23.225' N	120° 52.476' W	64.7	41
16	11:50:42	11:51:53	35° 23.176' N	120° 52.462' W	56.6	121
17 [4]	10:29:38	10:31:00	35° 23.199' N	120° 52.504' W	**0.1** [5]	221

[1] Distance from the closest open diffuser port. Observations collected within the ZID shown in bold
[2] Direction measured clockwise in degrees from true north from the closest diffuser port to the actual sampling location.
[3] Portions of the CTD (Conductivity-Temperature-Depth) cast were within the ZID boundary.
[4] Station 17 was an opportunistic hydrocast within the surface signature of the effluent plume.
[5] All of the CTD cast was within the ZID boundary.

deeper measurements at Station 10 were collected 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-9, moderately strong winds from the north prevailed throughout the survey. These winds, combined with oceanic currents directed toward the south, resulted in a southward drift at nearly all of the stations during the October 2005 survey.

The strong southward current flow that prevailed during the October 2005 survey was documented by the satellite-tracked drifter, whose path is shown by the grey line with black dots in Figure 3. The drifter is designed to drift with 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 south of the diffuser structure at 09:53. The drifter was recovered just over an hour later, at 10:55 PDT. It had traveled 394 m toward the southeast (152°T) at an average speed of 10.7 cm/s or 0.21 knots.

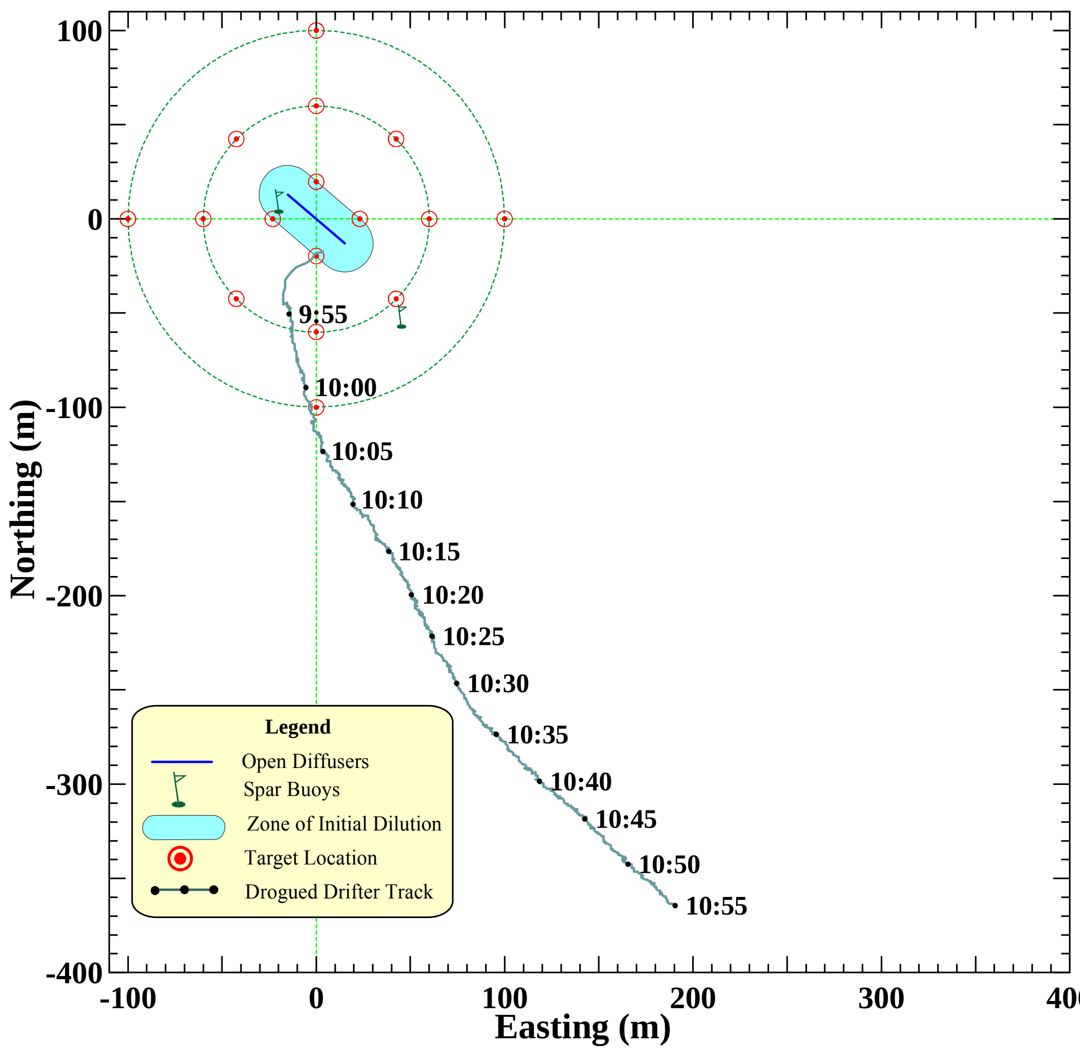

Figure 3. Drifter Trajectory on 5 October 2005

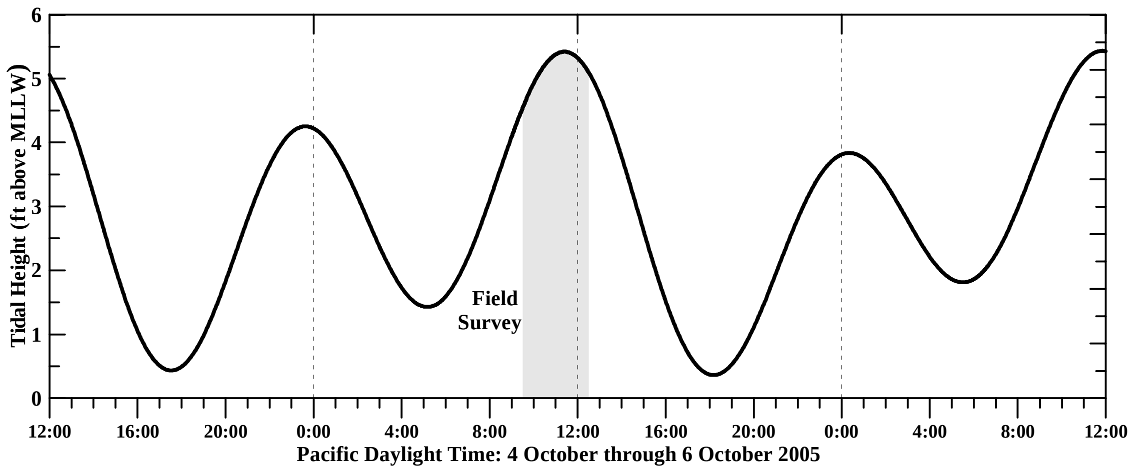

Figure 4. Estero Bay Tidal Level during the Field Survey of 5 October 2005

The strong southward flow that was measured by the drogued drifter was inconsistent with the incoming (flood) tide that prevailed during the survey (Figure 4). In the absence of external influences, a flood tide normally induces a weak northeastward flow in the survey region. However, the flow is often also influenced by external processes, such as wind-generated upwelling. Strong upwelling conditions prevailed just prior to the survey, as seen in the satellite image on the cover of this report. The image was recorded the day before the survey when skies were clear enough for sea-surface temperatures to be measured by infrared sensors on one of NOAA's polar orbiting satellites.

The intense upwelling that occurred around the time of the survey was largely responsible for the strong water-column stratification that was evident near the seafloor 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) and purple (12°C) water along the shoreline. At major promontories, this upwelled water extends well offshore of the coast. The satellite image shows that because of coastal upwelling, sea-surface temperatures were near or below 12°C within Estero Bay. This is consistent with the near-surface temperatures measured by the CTD during the survey, which around 11.5°C as shown 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 deep (>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 5 October 2005. 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. Wind speeds and air temperatures were measured with a Kestrel® 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-9). 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. The unusually deep zone observed during the October 2005 survey, which reached to the seafloor at all stations, is not typical of upwelling conditions when increased primary productivity normally results in decreased light transmissivity in the upper water column.

Secchi depths are less precise than measurements collected 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 October 2005 survey, a satellite-tracked drifter was deployed near the center of 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 October 2005 survey was the fourth 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 October 2005 survey, the added satellite-tracking capability of the drifter revealed some curvature in the path of the drifter as 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 for testing and recalibration. Because of increasing temporal drift associated with the aging DO probe, it was replaced with a new DO probe. As is the case before all surveys, the CTD system was recalibrated at the MRS laboratory prior to the October 2005 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 (Na_2SO_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.

A prolonged equilibration time of the pH sensor has been an ongoing challenge that has required removal of temporal trends in the pH data collected in most surveys, even those following the 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 October 2005 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 less than 0.014 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±0.01, 7±0.01, and 10±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 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. Depth 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

Table 3. Instrumental Specifications for CTD Profiler

Component	Depth[1]	Units	Range	Accuracy	Resolution
Housing	600	—	—	—	—
Pump	3400	—	—	—	—
Pressure	680	Psia	0 to 1000	± 5.0	± 0.5
Depth	—	Meters	0 to 690	± 3.0	± 0.3
Conductivity	600	Siemens/m	0 to 6.5	± 0.001	± 0.0001
Salinity	600	‰	0 to 38	± 0.006	± 0.0006
Temperature	600	ºC	–5 to 35	± 0.01	± 0.001
Transmissivity	2000	%	0 to 100	± 0.1	± 0.025
Dissolved Oxygen	200	mg/L	0 to 21.5	± 0.14	± 0.014
Acidity/Alkalinity	200	pH	0 to 14	± 0.1	± 0.006

[1] Maximum depth limit in meters

temperature (°C) and salinity data. It was expressed as 1000 times the specific gravity minus one, which is a unit of sigma-T (σ_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 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 nine-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 deployment 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.

Temporal Trends in the pH Sensor

The pH sensor exhibited a slight temporal drift during the October 2005 survey. Perceptible drift in pH measurements has been consistently observed in prior water-quality surveys as a 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 October 2005 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. The pH measurements at the first station (6) averaged 0.014 pH units lower than the measurements collected later in the deployments. Comparison with Table 3 shows that this artificial reduction in measured pH is smaller than the instrumental accuracy (± 0.1 pH). However, it is larger than the instrumental resolution (±0.006 pH). As a result, slight artificial differences are embedded in the measurements reported at Stations 5 and 6 in Table B-7. Station 6 was the first station occupied during the survey and required the largest adjustment for sensor drift (0.014 pH). Temporal detrending removed these instrumental anomalies, and the results are tabulated in Table B-6.

RESULTS

The water-quality survey for the fourth quarter of 2005 began on Wednesday, 5 October 2005, at 09:53 PDT with the deployment of the drogued drifter. Compared to most prior surveys, the October 2005 water-column survey was conducted slightly later in the day because it followed the collection of benthic sediment samples. Subsequently, all water-column measurements were collected as required by the NPDES monitoring program (Table 2 and B-9). Sunrise was at 07:01 PDT and skies were clear throughout the survey, which ended at 12:30 PDT when the vessel arrived back at port.

Average wind speeds, calculated over one-minute intervals, increased during the survey from approximately 2.1 kt to 7.8 kt, and peak speeds increased from 3.8 kt to 15.2 kt. A 3 ft swell moved through the survey area from the northwest. Atmospheric visibility was greater than 2 nM along the ocean surface owing to the absence of fog and haze. Morro Rock and the shoreline remained visible throughout the survey, and skies were clear. Air temperature increased from 20.8°C to 25.7°C during the course of the survey. The surface seawater temperature (11.5°C) in the survey area was notably cooler than the average air temperature, and 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 visibly apparent near the sea surface when the survey vessel approached the ZID during vertical profiling along the along-shore transect. The plume appeared as a slightly lighter shade of blue-green just below the sea surface. In addition, widely distributed particles of biofilm were apparent within the plume. This material forms on the interior of the outfall pipe, periodically sloughs off, and is ejected through the diffuser ports. Its distinctive coloration, jet black on one side, and bright white on the other, confirms that it was generated by sulfur-reducing bacteria within the outfall. The pieces of biofilm readily break apart and are easily dispersed. Their observed size and integrity during this survey indicates that they did not travel far along the outfall before being discharged. There was no visual evidence of floating particulates, oil and grease, or seawater discoloration directly associated with the discharge of wastewater constituents themselves.

Beneficial Use

During the October 2005 survey, observations of beneficial use demonstrated that the coastal waters in the outfall vicinity continued to be utilized by wildlife and for recreation. Surf scoters (*Melanitta perspicillata*), western gulls (*Larus occidentalis*), two California brown pelicans (*Pelecanus occidentalis californicus*), and a lone California sea lion (*Zalophus californicus*) were observed transiting through, and foraging within the survey area. Surf scoters are common along the Pacific coast in late winter and usually stay some distance from shore, feeding on shellfish. The males are distinguished by a bright red-orange pattern on their bill. Also sighted near the water's surface during the survey was a jellyfish, likely a moon jelly (*Aurelius sp.*). Owing to the prevailing swell and windy weather conditions, no other vessels were observed near the survey area during the course of the survey. No other evidence of beneficial use of receiving waters was noted during the survey.

Ambient Seawater Properties

Data collected during the October 2005 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.

Sharp upwelling-induced vertical gradients are plainly evident below approximately 10 m in most of the vertical profiles shown in Figures A-1 through A-3. A thermocline, where temperature sharply decreases with increasing depth, is evident in nearly all of the vertical profiles shown in Figures A-1 through A-3 (red lines). As described in the following sections, a strong thermocline was not apparent at Stations 4 and 17 because the effluent discharge altered the vertical structure of the water column. However, at the other stations most ambient seawater properties exhibited vertical stratification nearly identical to that of the thermal structure. For example, the shape of the temperature profile at any given station is closely reflected in the profiles of dissolved oxygen (dark blue lines) and pH (gold lines). Similarly, the abrupt decreases in temperature, DO, and pH with depth are mirrored by a pycnocline where density (black lines) sharply increases with depth. Thus, upwelling-induced stratification dictates the vertical structure of all ambient seawater properties except salinity (green lines) and transmissivity (light-blue lines).

Large-scale features of the upwelling process within Estero Bay were previously described by MRS (2005) and Morro Group, Inc. (2000). Near the seafloor, upwelling transports cold, dense seawater onshore to replace nearshore surface waters that are driven offshore by prevailing winds. The low dissolved oxygen found at depth is a clear indicator of its deep offshore origin. Deep offshore waters are undersaturated in oxygen because they have not had direct contact with the atmosphere for long periods of time, and biotic respiration and decomposition have slowly depleted the dissolved-oxygen levels. Similarly, slightly elevated salinity is often indicative of waters that originate in the Southern California Bight and are carried northward by the Davidson undercurrent. These waters differ from the relatively fresh surface water associated with the southward-flowing California Current.

The ambient seawater properties in the upper water column also reflect the increased primary productivity associated with upwelling conditions. Nutrient-rich seawater brought to the sea surface by upwelling enables phytoplanktonic blooms that are the foundation of the productive marine fishery found along the California coast. Slightly reduced water clarity (light-blue lines) above 10 m in the euphotic zone results from an increase in planktonic biomass. The enhanced primary productivity in the upper water column also produces oxygen and consumes carbon dioxide (CO_2). The removal of carbonic acid (dissolved CO_2) accounts for the higher pH found in the upper water column (gold lines). As the ratio of respiration to photosynthesis increases with depth, there is an increase in dissolved CO_2 and a concomitant decline in pH, indicating the slightly more acidic nature of the seawater. Accordingly, respiration consumes oxygen and produces acid, which accounts for the declines in DO and pH within the deep thermocline as seen in Figures A-1 through A-3.

In contrast with other water properties, the vertical profiles of salinity (green lines) do not always exhibit a distinct halocline. Normally, a halocline would be expected in conjunction with the upwelling-induced thermocline. Although not immediately apparent in all of the vertical profiles, salinity was slightly higher near the seafloor than near the sea surface. The slight increase in salinity at depth reflects the onshore transport of a deep water-mass that originated in the more saline waters to the south. However, subtle vertical trends in salinity are difficult to discern because of the presence of large salinity spikes. These salinity spikes are artifacts of the instrumental measurements collected under certain conditions. The spikes are evident as an erroneous zigzag pattern that is present in some of the salinity profiles, at depths coincident with the sharp thermocline. They are particularly apparent at Stations 3 and 10. Salinity spikes are instrumental artifacts arising from the mismatch between conductivity and temperature measurements collected near strong thermal gradients. In a few of the vertical profiles, these spikes mask the presence of the weak halocline.

In contrast to the other water properties, transmissivity also shows a marked reduction immediately above the seafloor at many stations. The distinctive decrease in transmissivity within a thin layer immediately above the seafloor indicates the presence of a bottom nepheloid layer (BNL), which is a widespread phenomenon on continental shelves (Kuehl et al. 1996). The increased turbidity within the BNL is caused by the presence of naturally occurring particulates formed from light-weight flocs of detritus. This detritus is easily suspended by oscillatory bottom currents generated by passing surface gravity waves.

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 below the thermocline at Stations 4 and 17 in the along-shore vertical sections shown in Figures A-4 and A-5. 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 also show that the shallow temperature, DO, and pH anomalies have the same characteristics as ambient waters at depth. They are only apparent because these deep water properties have been displaced upward into the water column where the surrounding seawater characteristics differ. 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 can be evaluated statistically by comparing its amplitude to the natural background variability. To that end, each observation at a particular station was compared with the observations from other stations at the same depth level. Measurements collected 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 collected 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.

Because the opportunistic Station 17 was not part of the regular sampling pattern, and because it captured extremely large discharge-related anomalies, it was not included in the computation of the mean and standard deviation. The mean and standard deviation are intended to be estimates of natural background variability. Nevertheless, anomalies at Station 17 were separately tested for statistically significant departures from background conditions in Table B-8.

In the October 2005 dataset, a number of observations that were found to be statistically significant but were unrelated to the effluent discharge. For example, the deep transmissivity anomalies (Table B-5) at Stations 2 and 10 were artifacts of slight variation in the thickness of the bottom nepheloid layer (BNL). Lateral variability was artificially introduced by differences in the thickness of the BNL and by proximity of the CTD samples to the seafloor; i.e., how far into the BNL the individual measurements were recorded. The 1 m thick BNL had slightly higher turbidity compared to waters immediately above the BNL. Consequently, the vertical sampling interval of 0.5 m spanned a significant portion of this thin layer, which lies immediately above the seafloor. Also, the BNL interface is particularly sharp, so even slight variations in the thickness of the boundary layer between stations appear as "*significant*" lateral variations in transmissivity.

Similarly, the statistically significant reductions in pH at Stations 5 and 6, which are highlighted in Table B-7, were unrelated to the discharge. They were artifacts of the temporal drift in the pH probe that was described previously, in the section entitled *Temporal Trends in the pH Sensor*. Station 6 was the first station occupied during the October 2005 survey, and, as a result, the pH measurements at this location required the greatest adjustment (0.014) to account for ongoing equilibration. Station 5 was the next station sampled during the survey, and it required a smaller adjustment (0.009) to account for equilibration. Most of the anomalous measurements at Stations 5 and 6 (Table B-7) are eliminated (Table B-6) after removal of the slight temporal trend in pH. The only exceptions are some very slight pH anomalies that remained at the seafloor at Station 6 (Table B-6).

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 more than 500 measurements examined for each of the six parameters, it is not surprising that 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 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.

The significant transmissivity anomalies observed at mid-depth at Station 6 (Table B-5) are also examples of false positives detected by the hypothesis tests applied to a randomly varying field. These are positive anomalies, indicating water clarity was higher than the surrounding waters at the same depth. These anomalies are opposite of those that would be generated by the presence of increased particulate loads associated with wastewater discharge. Instead, it was probably an artifact of natural variation in the distribution of suspended ambient particulates within the water column.

In the October 2005 dataset, the presence of statistical significant anomalies that are unrelated to the discharge was caused by the relatively low level of overall variability in ambient seawater properties. Other surveys, such as the July 2005 survey, have exhibited much higher vertical stratification. In those cases, slight anomalies of the magnitudes encountered during the October 2005 survey would not be found significant. Because it is more difficult to reliably discern small differences in a noisy field of

Table 4. Discharge-Related Water-Property Anomalies[a]

Perturbation[b]	Station	Depth Range	Depth of Extremum	Property	Magnitude	Process
P1 Dilution≥429:1	4	1.0 to 12.5 m	**8.5 m**	**Salinity**	**–0.078 ‰**	**Effluent**
		1.0 to 12.5 m	**2.0 m**	**Temperature**	**–0.48 ºC**	**Entrainment**
		1.0 to 11.0 m	**1.0 m**	**Dissolved Oxygen**	**–1.04 mg/L**	**Entrainment**
		1.0 to 14.5 m	**2.5 m**	**pH**	**–0.048 pH**	**Entrainment**
P2 Dilution≥346:1	17	4.0 to 8.5 m	**4.0 m**	**Salinity**	**–0.097 ‰**	**Effluent**
		4.5 to 8.5 m	5.5 m	Temperature	–0.37 ºC	Entrainment
		3.5 to 4.0 m	4.0 m	Density	–0.047 σ_t	Effluent
		4.0 to 8.5 m	**5.5 m**	**Dissolved Oxygen**	**–0.94 mg/L**	**Entrainment**
		6.5 to 10.0 m	**9.0 m**	**pH**	**–0.045 pH**	**Entrainment**
P3 Dilution≥100:1	17	14.0 to 16.0 m	**15.5 m**	**Salinity**	**–0.331 ‰**	**Effluent**
				Density	**–0.274 σ_t**	
				Transmissivity	**–3.69 %**	

[a] Anomalies shown in bold type were statistically significant
[b] Perturbations consist of a group of spatially consistent anomalies in different seawater properties

measurements than in a uniform field, statistical significance is a function of overall variability during a given survey.

Discharge-Related Perturbations

During the October 2005 survey, three perturbations in seawater properties were unequivocally related to the discharge (Perturbations P1, P2, and P3 in Table 4). A discharge-related perturbation is a group of anomalies in one or more seawater properties that are 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, anomalies in temperature, DO, and pH were generated by the entrainment of naturally occurring seawater within the rising effluent plume. The connection between deep ambient seawater and the shallow anomalies is particularly apparent in the middle and bottom frames of Figure A-5.

In contrast, the salinity, density, and transmissivity anomalies could only have been generated by the presence of wastewater constituents. The top and bottom frames of Figure A-4, and the top frame of Figure A-5, show that portions of these anomalies were vertically isolated. More importantly, the seawater properties within these anomalies were far different than the ambient seawater properties, even at depth. Consequently, they could not have been generated by entrainment of ambient water within the rising effluent plume. Specifically, salinities well below 33.5‰ are delineated in green and red in the upper frame of Figure A-4. These salinities are lower than the lowest ambient salinity (33.54‰) that was measured in ambient seawater during the October 2005 survey. Ambient conditions are well-represented by the cross-shore vertical sections shown in Figures A-6 and A-7. As shown by the salinity scale in the top frame of Figure A-6, the salinity in naturally occurring seawater did not drop much below 33.54‰ during the survey. The same argument applies to the density and transmissivity anomalies observed at Station 17.

Conversely, the entrainment-generated anomalies reflect ambient conditions below the thermocline at depth. This strongly suggests that these anomalies were produced by the upward displacement of ambient bottom water, rather than the presence of effluent constituents. Namely, these entrainment-generated anomalies were produced when ambient seawater at depth was entrained in the rising effluent plume.

After being displaced upward, the differing bottom-water properties are juxtaposed with shallow-water properties, and the contrast becomes apparent as an anomaly. Figures A-6 and A-7 show that during the October 2005 survey, the presence of a deep watermass caused seawater within the deep thermocline to be naturally low in temperature, pH, and DO. The vertical sections shown in Figures A-4 and A-5 show that these low ambient seawater properties at depth are comparable to the properties observed in the anomalies within the upper water column at Stations 4 and 17.

Moreover, the presence of wastewater constituents alone could not have induced the DO and thermal anomalies. Wastewater is generally warmer and tends to have a higher DO concentration than seawater at depth. If wastewater properties were materially contributing to the perturbations, then positive thermal and DO anomalies would be generated by the presence of effluent particulates. Instead, the opposite was the case; the perturbations were cooler and less oxygenated than the surrounding shallow seawater. These are characteristics of deep ambient seawater, not wastewater. Although reductions in DO can be caused by oxygen-demanding material in wastewater, this has not been the case with the MBCSD discharge. Most of the oxygen-demanding material is removed in the treatment process, and the resulting effluent has historically had low biochemical oxygen demand (MRS 2005). Instead, because of its recent contact with the atmosphere, wastewater generally has higher DO than ambient seawater at depth, which has depleted oxygen levels due to respiration and decay over a long period since its equilibration with the atmosphere.

Without this naturally occurring stratification, entrainment of deep ambient seawater within the rising effluent plume would not produce obvious differences between the entrained water and shallow water properties. Thus, the entrained deep seawater acts as a tracer of the effluent plume after discharge. These same entrainment-generated anomalies could just as easily have been produced by the discharge of warm seawater, containing no suspended solids or other contaminants whatsoever. Conversely, they would not be apparent in unstratified receiving waters. This indicates why many of the receiving-water limitations specified in the COP explicitly state that limitations only apply to impacts caused by the presence of wastewater constituents, and, by implication, not to changes generated by the entrainment of ambient seawater. Entrainment-generated impacts are largely dictated by existing ambient seawater stratification rather than the quality of discharged wastewater. Naturally occurring vertical differences in seawater properties are eventually mixed throughout the water column by natural nearshore processes; plume entrainment simply serves to accelerate this process within a localized area.

The collection of data at an opportunistic station (Station 17) located directly over the outfall was a first for water-quality monitoring. As shown in Figure 2, the CTD traversed a section of the diffuser structure and probably passed within a meter of a discharge port. As a result, measurements within Perturbation P3 were collected within the turbulent discharge jet shortly after the wastewater was ejected from the port. The resulting negative salinity and density anomalies had the largest amplitudes ever recorded in two decades of monitoring. This unusual encounter is delineated in red, just above the seafloor in the top and bottom frames of Figure A-4, and in the very large excursion in the vertical profile in the bottom left corner of Figure A-3.

It is noteworthy that there were no anomalies in temperature, DO, and pH associated with this perturbation. This supports the hypothesis that the properties of discharged wastewater contribute little to shallow anomalies in temperature, DO, and pH, and that they are generated instead by the upward displacement of ambient waters. There was also a moderate drop in transmissivity (-3.69%) associated with this perturbation. Again this transmissivity anomaly was relatively small in amplitude, considering the close proximity of the measurement to the point of discharge. It was particularly apparent because of the consistently high ambient transmissivity (>77%) that prevailed during the October 2005 survey. The high water clarity was also reflected in the unusually large Secchi depths measured during the survey. For the first time in recent memory, the euphotic zone reached the seafloor at all stations.

Initial Dilution Computations

The amplitude of negative salinity anomalies at Stations 4 and 17 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. That 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, computations of dilution based on salinity anomalies within the perturbations at Stations 4 and 17 demonstrate that the effluent plume actually achieved far higher dilutions at the predicted trapping depth. Moreover, the October 2005 measurements demonstrated that the plume was not trapped at depth, and, in fact, rose to the sea surface where even higher dilutions were achieved. More importantly, the measurements at Station 17 demonstrated that mixing within the turbulent discharge jet very close to a diffuser port achieved a dilution (100:1) comparable to the total dilution (133:1) predicted by conservative modeling. Thus, rapid mixing associated with the momentum of the discharge jet was capable of achieving the dilution levels predicted by modeling, without even considering the additional dilution that is achieved by the buoyant rise of the plume. All of this demonstrates that the diffuser structure was operating far more efficiently than predicted by the modeling.

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 were thought to be necessary in order to meet Ocean-Plan standards.

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

$$C_e \equiv C_o + D\left(C_o - C_s\right) \qquad \textbf{Equation 1}$$

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,
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:

$$D = \frac{-C_o}{\left(C_o - C_s\right)} \equiv \frac{-C_o}{A}$$ **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 33.6‰), and
$A = C_o – C_s$ = the salinity anomaly.

Computed dilutions during the stratified conditions of the October 2005 survey demonstrate that the modeled dilution factors are more conservative than those actually achieved by the diffuser structure. Specifically, dilutions exceeding 346:1 were measured in the upper water column at Stations 4 and 17, across a depth range encompassing the 6.4 m trapping depth predicted by modeling. This dilution was determined from the largest-amplitude salinity anomaly (–0.097‰) that was observed at Station 17 within Perturbation P2 (Table 4). Equation 2 computes a dilution ratio of 346:1 associated with this measured salinity anomaly. Smaller-amplitude salinity anomalies observed at other depth levels within Perturbation P2, which extends from 4 m to 8.5 m, yield even higher dilution ratios. Similarly, the smaller-amplitude salinity anomalies associated with Perturbation P1 at Station 4, which extends from 1 m to 12.5 m, yield dilution ratios of at least 429:1 (Table 4).

The largest-amplitude salinity anomaly (–0.331‰) measured in water-quality surveys conducted over the past decade was measured during the October 2005 Survey within Perturbation P3 (Table 4). The anomaly was measured 1.5 m above the seafloor within the turbulent discharge jet emanating from one of the 28 diffuser ports. The salinity anomaly was also associated with an extremely low density (–0.274 σ_t), indicating that the plume was highly buoyant, and would rise rapidly through the water column as it mixed with surrounding seawater. From Equation 2, a dilution ratio of 100:1 was associated with this measured salinity anomaly. The measured dilution within the discharge jet (100:1) was close to the final dilution (133:1) predicted by modeling a 9 m rise of the plume through the water column. This demonstrates that the momentum of the discharge jet alone is capable of achieving dilution levels close to the permit-specified dilution ratio, without even considering the additional dilution achieved when the plume reaches equilibrium within the water column. This also explains why the discharge consistently meets receiving water limitations, and why the presence of dilute wastewater particulates is rarely detected in the upper water column, beyond the ZID.

In particular, the smallest dilution (346:1) computed from salinity data collected in the upper water column during the October 2005 survey was more that 2.5 times higher than the 133:1 critical dilution used to establish permitted limitations on contaminant concentrations within wastewater discharged from the MBCSD treatment plant. The dilution computation demonstrates that, during the October 2005 survey, the outfall was performing better than designed, and was rapidly diluting effluent more than 340-fold. 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 October 2005 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 October 2005 water-quality survey.

Although statistically significant discharge-related reductions in all six of the water properties were observed during the October 2005 survey, they were all measured very close to the outfall, and well within the boundary of the ZID at Stations 4 and 17 (Figure 2). Receiving-water 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 large anomalies in salinity, density, and turbidity that were associated with Perturbation P3 (Table 4). This large seawater perturbation was measured at Station 17 just above the seafloor near a diffuser port. The very low density associated with this perturbation was indicative of a highly buoyant plume that would undergo significant additional mixing as it rose through the water column.

Accordingly, the amplitudes of the shallower salinity anomalies at Stations 4 and 17 (Perturbations P1 and P2) were much smaller than those associated with deep Perturbation P3. The smaller-amplitude salinity anomalies indicate that buoyancy-induced mixing had increased dilution by more than three-fold relative to the dilution measured within the turbulent jet. However, the two shallow perturbations were also associated with statistically significant reductions in temperature, DO, and pH. Clearly, the shallow anomalies in the temperature, DO, and pH were not caused by the presence of wastewater constituents. Otherwise, anomalies in these properties would also have been apparent at much higher amplitudes in the measurements of wastewater that were recorded shortly after ejection in Perturbation P3. Instead, the shallow anomalies in temperature, DO, and pH were generated by the upward displacement of deep ambient seawater that was entrained by the rising effluent plume. This is an important consideration because some of the seawater limitations promulgated in the COP restrict attention to changes caused by the presence of waste materials.

Outfall Performance

The large salinity anomaly measured in the turbulent ejection jet close to a diffuser port demonstrated that the receiving-water objectives of the COP were being met at depth, well within the ZID. These high-precision observations demonstrated that the turbulent jet was achieving dilutions approaching the minimum critical dilution of 133:1 specified in the NPDES permit. Thus, the dilution objective was being nearly achieved without consideration of the substantial additional dilution provided by the buoyant plume's subsequent rise through the water column. With the added buoyancy-induced mixing, measured dilutions increased three fold, to at least 346:1. 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 well within the ZID. A dilution of 346:1 was determined from the salinity anomaly located in the upper water column at Station 17. This is more than 2.5 times the minimum critical dilution of 133:1 specified in the NPDES permit. With the higher dilution ratio that was determined from actual measurements during the October 2005 survey, contaminant concentrations within the wastewater could have been more than double 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 October 2005 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

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; or*
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-6, 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 beyond the ZID. As show in Table B-5, significant anomalies in the transmissivity field were found at Stations 2, 6, and 10. However, the set of transmissivity anomalies observed in the water column at Station 6 were associated with an increase in water clarity, not a reduction. The significant transmissivity reduction at Station 10 was recorded within 2 m of the seafloor, where the instrument package was well within the ZID. This is apparent from the green line at Station 10 in Figure 2, which traces of the path of the CTD during its descent. The darker green arrow marks the bottom of the cast, which was close to the diffuser structure.

Although the statistically significant reduction in transmissivity recorded at Station 2 was located beyond the boundary of the ZID, it was not generated "…*as the result of the discharge of waste*" (SWRCB 1997). As discussed in the *Lateral Variability* section, the anomaly was an artifact of slight variation in the thickness of the bottom nepheloid layer (BNL). It was unrelated to the wastewater discharge because Station 2 is located north of the diffuser structure (Figure 2), while the transport of the effluent plume was toward the south. Strong southward flow is reflected in the drifter track shown in Figure 3. Moreover, Station 3, which is located between the outfall and Station 2, showed no evidence of a plume signature, and had no anomalous transmissivity readings.

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. Thus, the slightly reduced DO concentrations observed near the sea surface at Station 4, which were generated by entrainment of ambient seawater, would not be subject to the limitations for that reason alone. However, they also are not subject to the limitations because they were recorded well within the ZID. Even so, all of the statistically significant DO anomalies complied with the numerical limits specified in the permit. Specifically, none of the anomalous DO concentrations fell below the 5 mg/L minimum specified in the Basin Plan and the NPDES discharge permit (Table B-4 and B-8). This contrasts with the ambient DO concentrations within the seafloor water mass, which was below 5 mg/L at the majority of stations. As described previously, the depletion of DO in the seafloor water mass occurred naturally, due to respiration and oxidation after a long period without being refreshed by direct contact with the atmosphere. Given the presence of the these naturally low DO concentrations, the discharge-related anomalies at Stations 4 and 17 would have to be considered too small"*…to be depressed more than 10 percent from that which occurs naturally*."

pH

As with the statistically significant anomalies in other seawater properties, the discharge-related pH anomalies were restricted to the ZID, where the receiving-water limitations in the permit do not apply. As described previously, the deep isolated pH anomaly highlighted in Table B-6 at Station 6, was an instrumental artifact due to incomplete equilibration of the sensor. In any regard, all of the significant anomalies complied with the numerical limits specified in the permit. In fact, the range in pH among all of the measurements was only 0.017 pH units, so none of the measurements can be considered changed by '*…more than 0.2 pH units from that which occurs naturally*.' The range across the entire pH field remained between 8.102 and 8.187, 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

The total range in temperature of 0.8ºC across all observations was largely due to naturally occurring vertical stratification. Even if changes this large were generated by the discharge, they would be considered too small '*…to adversely affect beneficial uses….*' The observed temperature range was much less than the large-scale spatial variability in sea-surface temperature shown in the satellite image on the cover of this report. The small, discharge-induced decreases in temperature (≤-0.48ºC), which are visually apparent in the vertical sections at Stations 4 and 17, resulted from the upward displacement of naturally occurring, cooler bottom water, rather than as a result of warmer wastewater constituents.

Although salinity anomalies provide the best tracer of discharged effluent, their actual amplitude (≤0.331‰) was small compared to spatial differences in salinity that occur along the south-central California coast. In any regard, the observed range in both the measured temperature (0.8ºC) and salinity (0.33‰) across all data collected during the October 2005 survey was too small to be considered harmful to marine biota or deleterious to beneficial uses.

Conclusions

All of the measurements collected during the October 2005 survey complied with receiving-water limitations specified in the NPDES discharge permit. The discharge-related anomalies in temperature, DO, and pH that were found within the water column at Stations 4 and 17, were largely caused by the upward displacement of ambient seawater, and not the presence of wastewater constituents. Salinity measurements collected close to a diffuser port demonstrated that discharged wastewater was undergoing rapid mixing within the turbulent discharge jet. The dilution levels achieved by the momentum of the jet alone were close to that predicted by modeling for the entire dilution process. This confirmed that the diffuser structure and the outfall were operating better than would be expected from the modeling.

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APPENDIX A

Water Quality Profiles and Vertical Sections

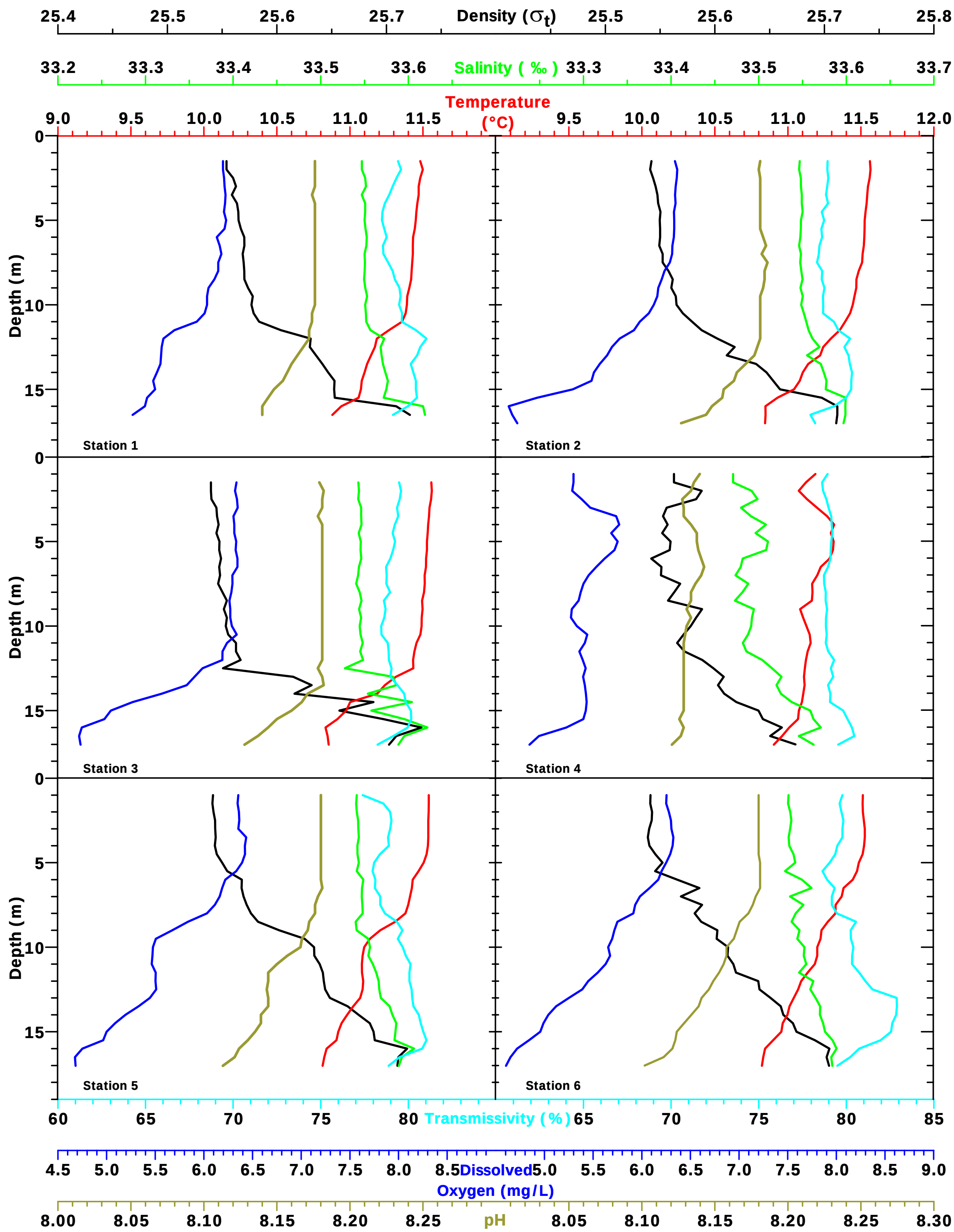

Figure A-1. Vertical Profiles of Water-Quality Parameters for Stations 1 through 6 measured on 5 October 2005

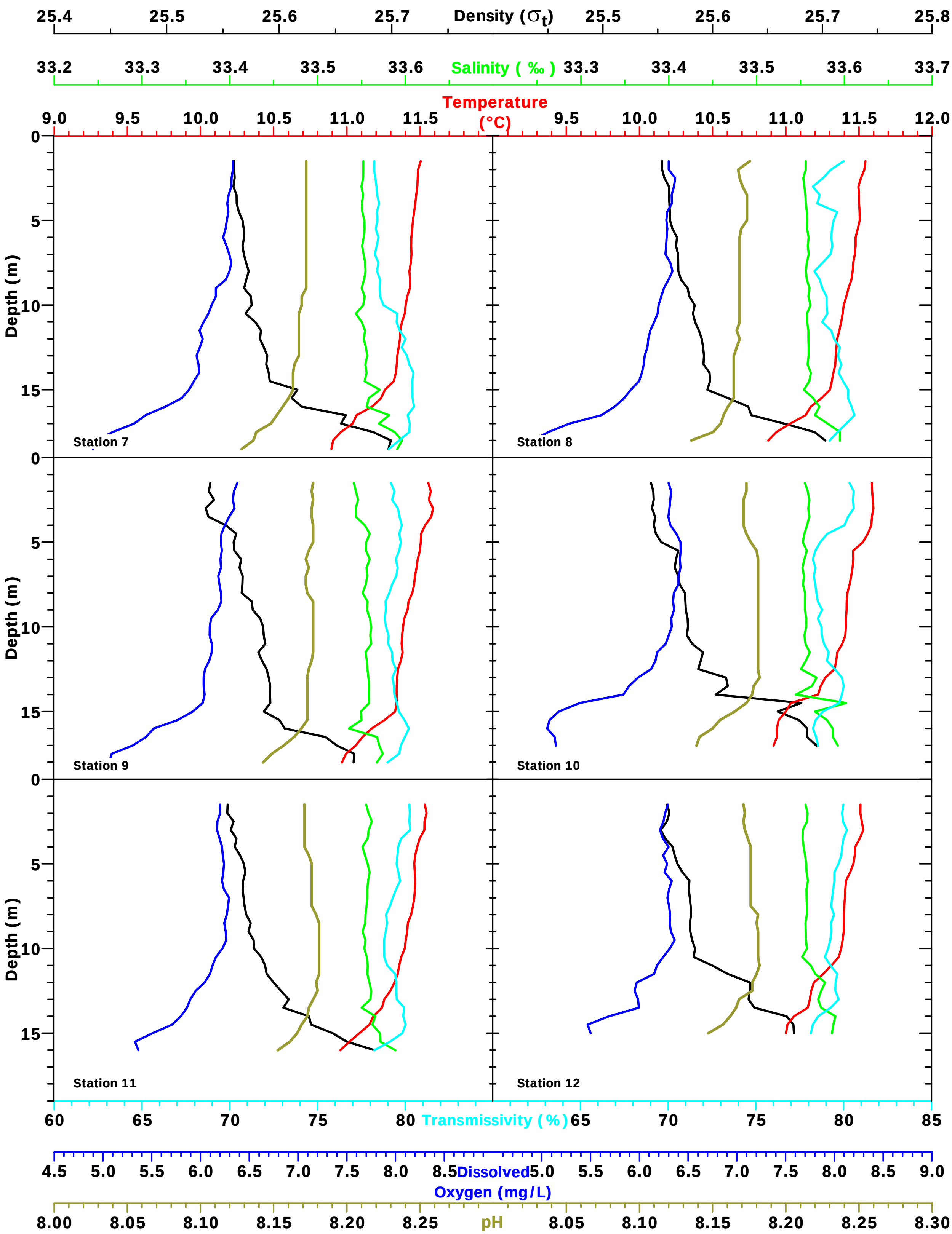

Figure A-2. Vertical Profiles of Water-Quality Parameters for Stations 7 through 12 measured on 5 October 2005

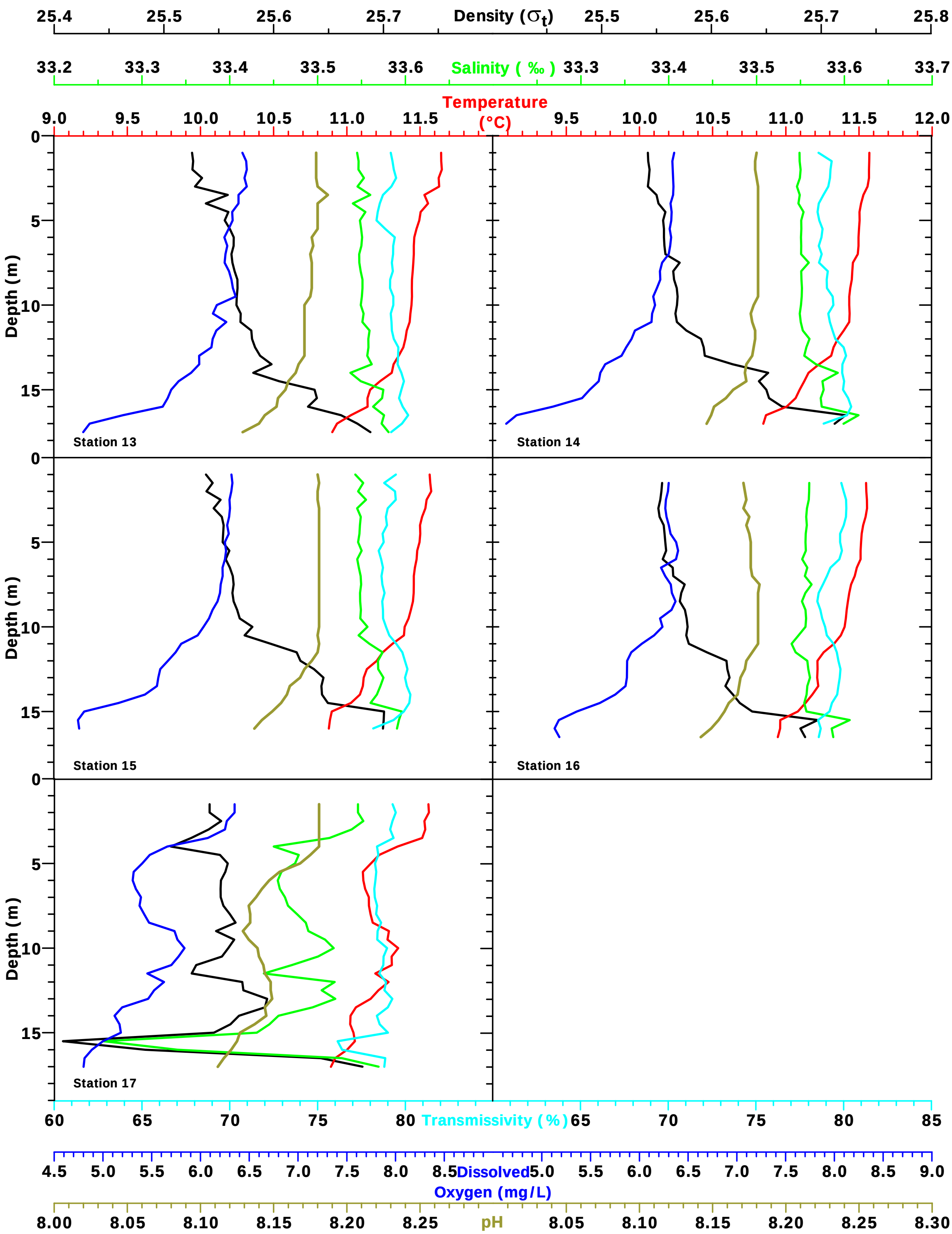

Figure A-3. Vertical Profiles of Water-Quality Parameters for Stations 13 through 17 measured on 5 October 2005

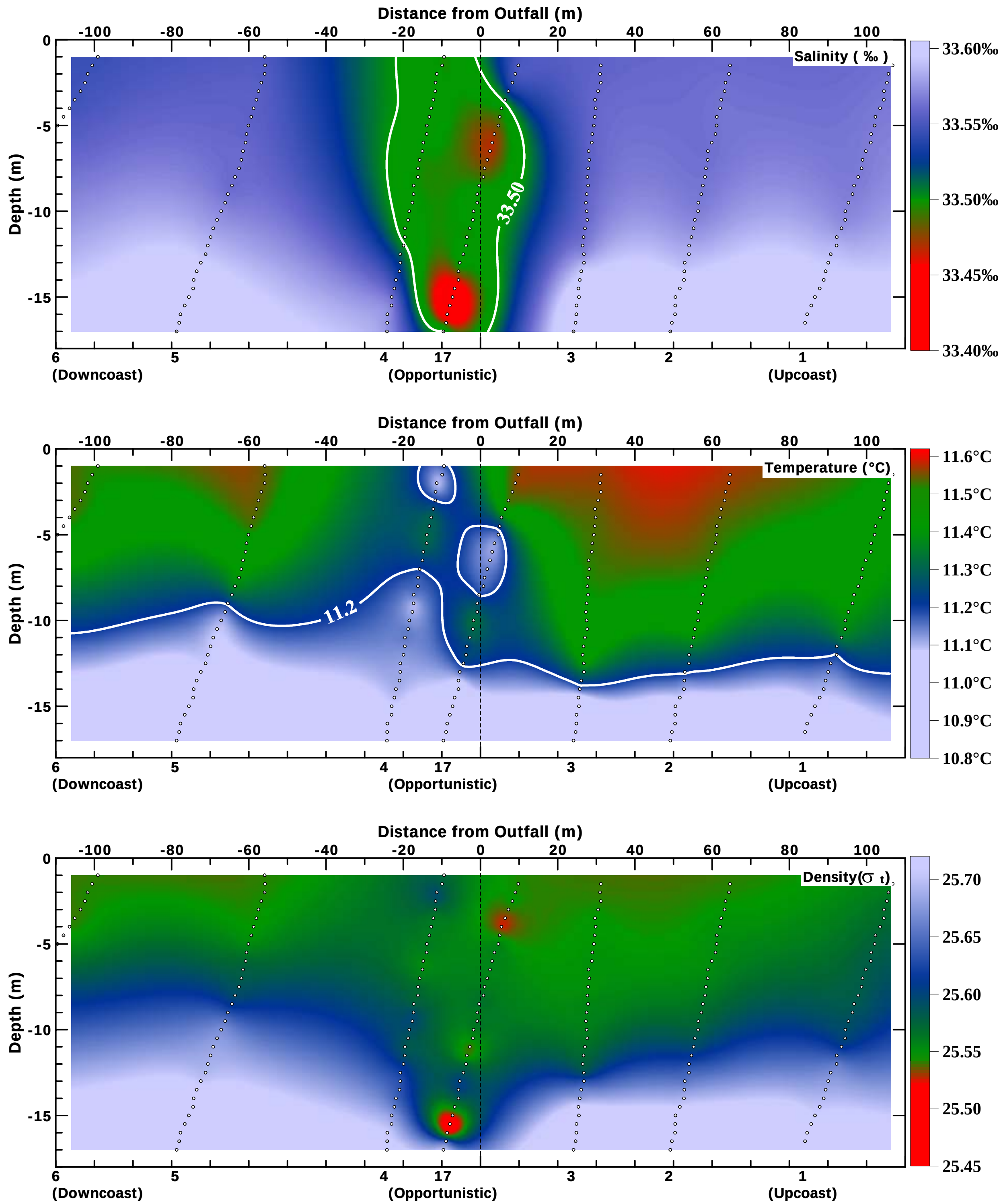

Figure A-4. Along-Shore Transects of Salinity, Temperature, and Density on 5 October 2005

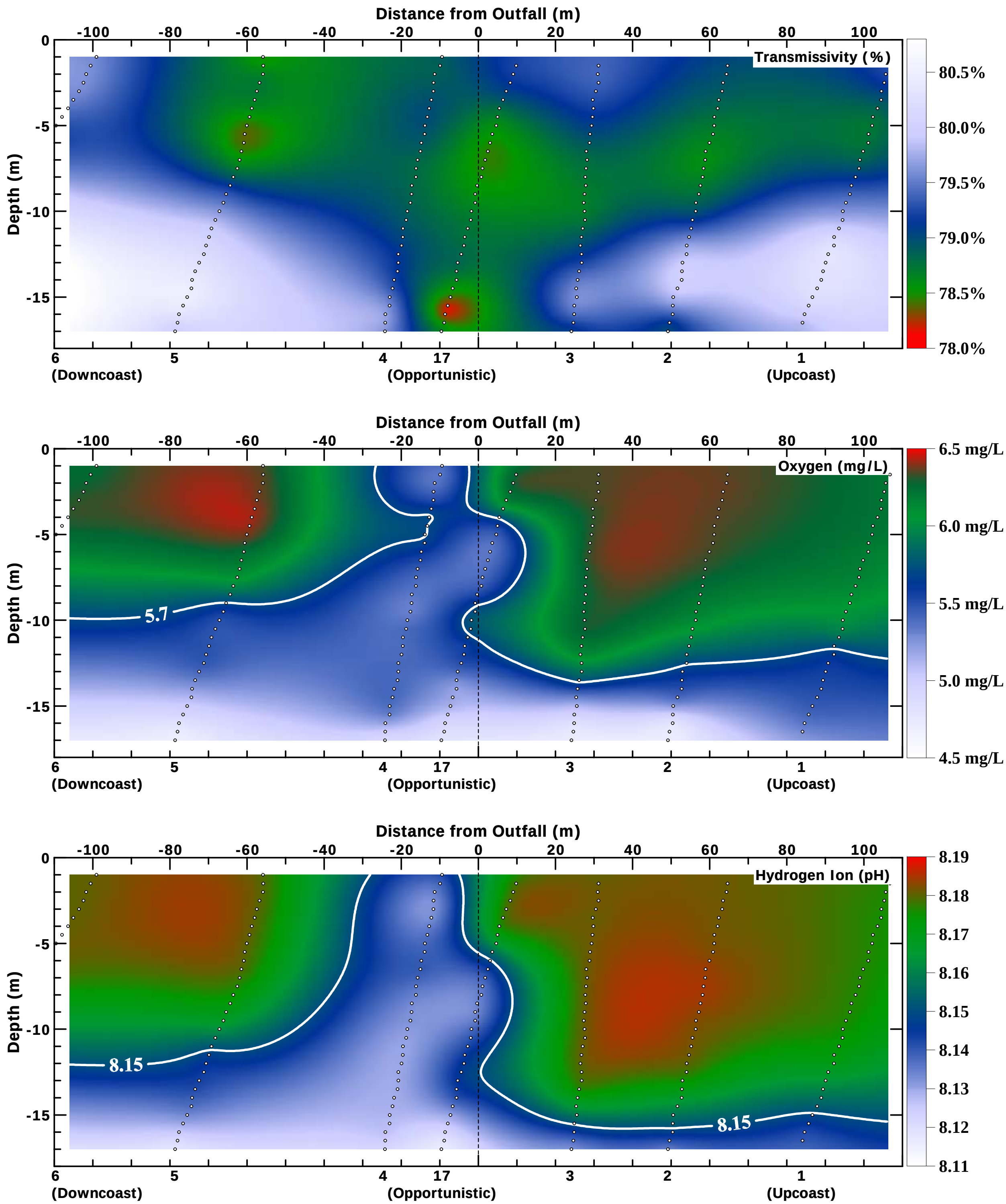

Figure A-5. Along-Shore Transects of Transmissivity, Oxygen, and pH on 5 October 2005

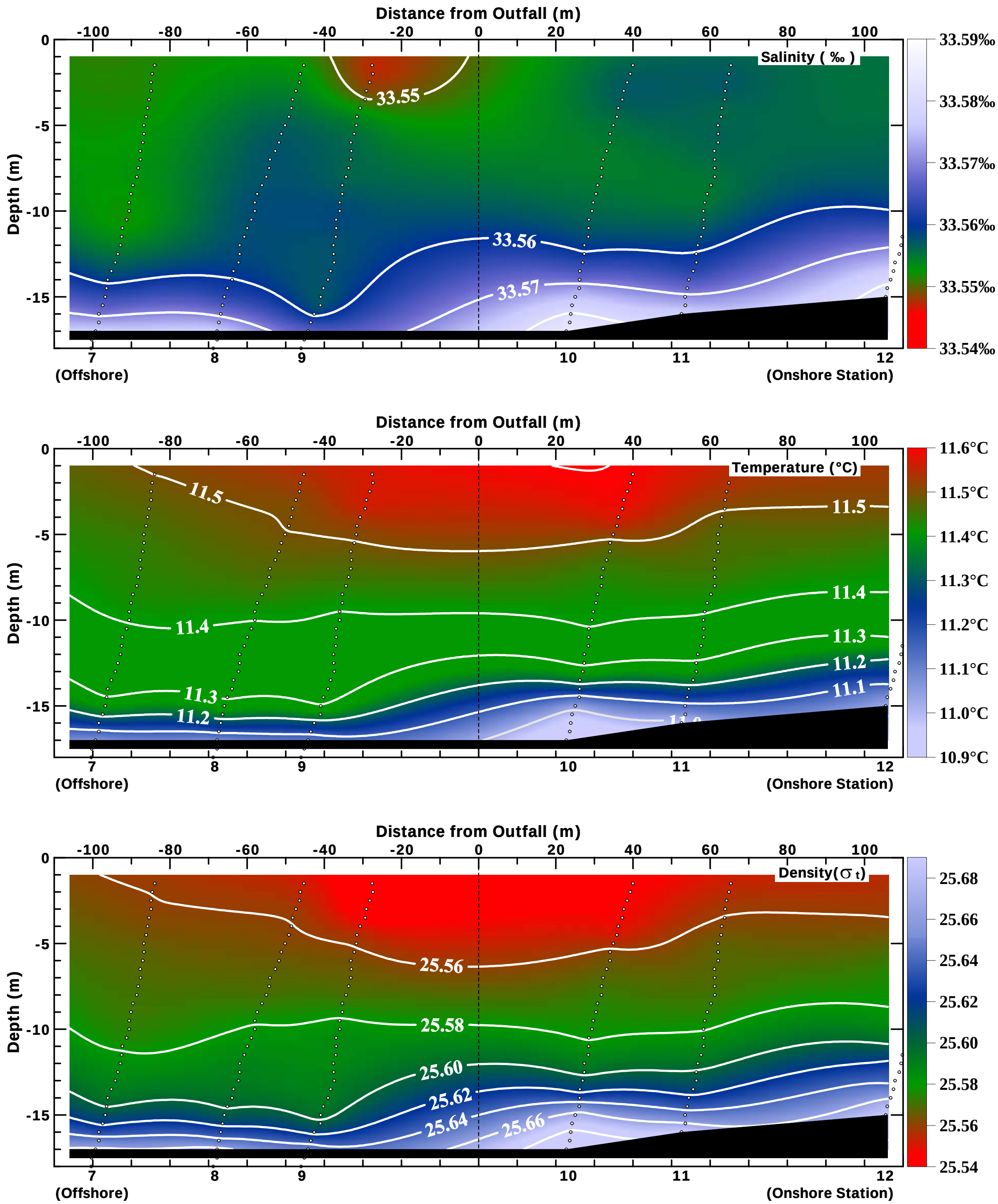

Figure A-6. Cross-Shore Transects of Salinity, Temperature, and Density on 5 October 2005

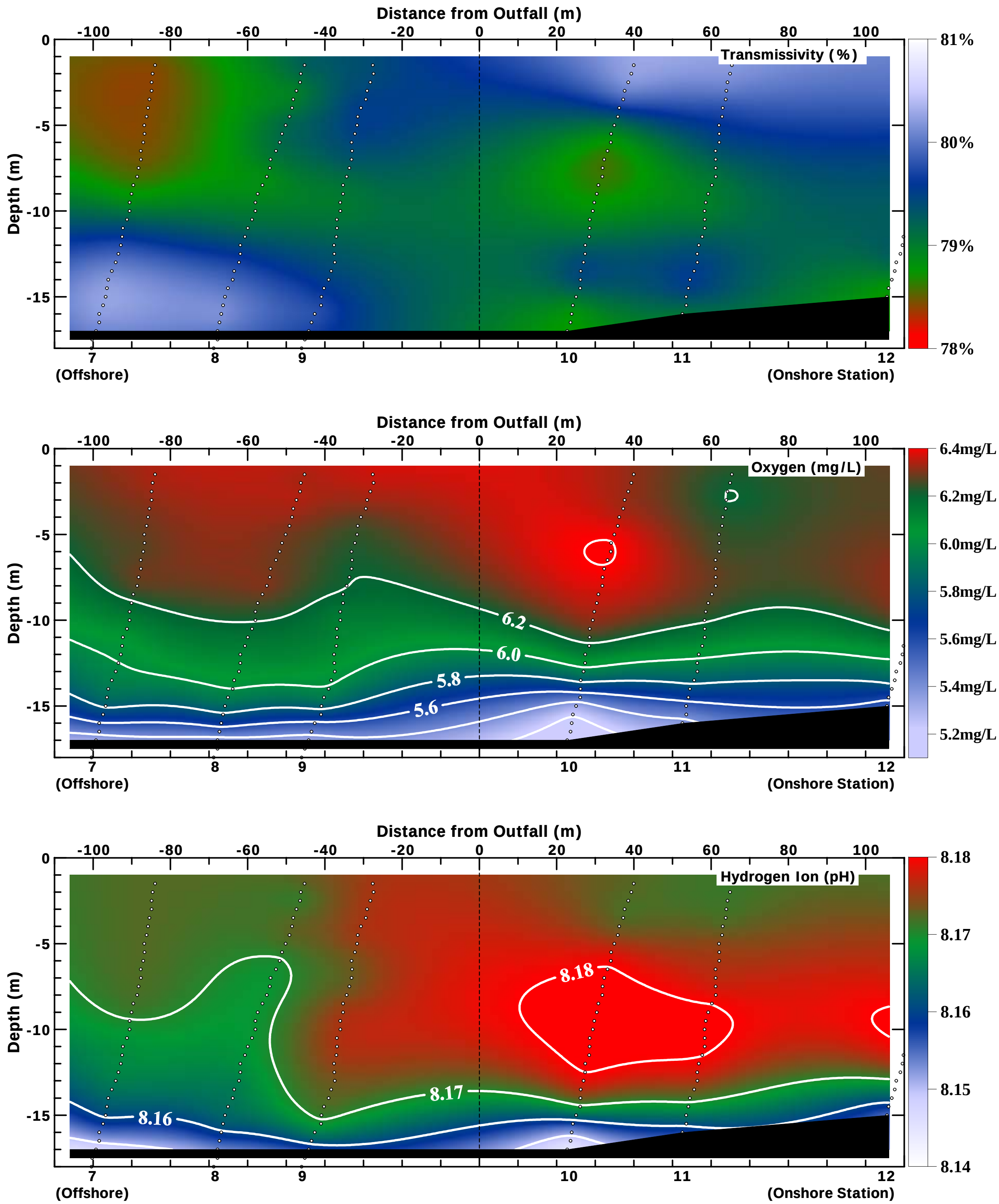

Figure A-7. Cross-Shore Transects of Transmissivity, Oxygen, and pH on 5 October 2005

APPENDIX B

Tables of Profile Data and Standard Observations

Table B-1. Seawater Temperature on 5 October 2005

Depth (m)	Temperature (°C)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1.0				11.19	11.54	11.51							11.64	11.57	11.57	
1.5	11.48	11.56	11.56	**11.12**	11.54	11.51	11.51	11.54	11.56	11.59	11.53	11.51	11.65	11.57	11.57	11.55
2.0	11.50	11.57	11.56	**11.07**	11.54	11.51	11.49	11.54	11.57	11.59	11.55	11.51	11.65	11.57	11.58	11.55
2.5	11.48	11.56	11.56	**11.13**	11.54	11.52	11.48	11.51	11.56	11.59	11.53	11.52	11.63	11.57	11.55	11.55
3.0	11.47	11.55	11.55	11.20	11.54	11.53	11.48	11.50	11.59	11.60	11.53	11.53	11.63	11.56	11.54	11.56
3.5	11.47	11.54	11.54	11.27	11.54	11.53	11.47	11.50	11.58	11.59	11.50	11.51	11.53	11.53	11.51	11.55
4.0	11.46	11.54	11.54	11.32	11.53	11.52	11.47	11.50	11.54	11.58	11.48	11.47	11.56	11.51	11.50	11.53
4.5	11.46	11.53	11.53	11.29	11.53	11.51	11.46	11.50	11.51	11.56	11.47	11.47	11.50	11.50	11.50	11.52
5.0	11.45	11.53	11.53	11.31	11.51	11.49	11.45	11.51	11.50	11.53	11.46	11.46	11.50	11.50	11.50	11.51
5.5	11.44	11.53	11.53	11.31	11.47	11.47	11.45	11.49	11.50	11.46	11.46	11.44	11.48	11.50	11.48	11.51
6.0	11.43	11.52	11.52	11.29	11.43	11.44	11.44	11.48	11.48	11.46	11.47	11.41	11.46	11.50	11.48	11.51
6.5	11.43	11.52	11.52	11.23	11.42	11.38	11.44	11.48	11.48	11.46	11.46	11.41	11.46	11.50	11.47	11.48
7.0	11.43	11.51	11.51	11.20	11.41	11.37	11.44	11.47	11.47	11.45	11.46	11.40	11.46	11.49	11.46	11.47
7.5	11.43	11.51	11.51	11.17	11.40	11.33	11.44	11.46	11.46	11.44	11.45	11.40	11.45	11.46	11.46	11.45
8.0	11.42	11.48	11.51	11.17	11.38	11.33	11.43	11.46	11.45	11.42	11.44	11.40	11.45	11.45	11.46	11.43
8.5	11.42	11.47	11.49	11.16	11.31	11.27	11.43	11.45	11.42	11.42	11.42	11.40	11.45	11.45	11.45	11.42
9.0	11.41	11.47	11.50	11.08	11.21	11.23	11.43	11.43	11.42	11.42	11.41	11.40	11.44	11.44	11.44	11.42
9.5	11.39	11.46	11.49	11.10	11.14	11.22	11.41	11.41	11.39	11.41	11.40	11.39	11.44	11.43	11.42	11.41
10.0	11.39	11.44	11.49	11.13	11.10	11.20	11.40	11.40	11.38	11.41	11.40	11.38	11.44	11.43	11.39	11.40
10.5	11.38	11.43	11.48	11.15	11.09	11.20	11.40	11.39	11.38	11.41	11.37	11.36	11.43	11.44	11.39	11.38
11.0	11.36	11.39	11.46	11.16	11.08	11.18	11.38	11.38	11.37	11.39	11.36	11.31	11.43	11.43	11.31	11.33
11.5	11.27	11.36	11.44	11.14	11.08	11.14	11.37	11.37	11.38	11.35	11.35	11.26	11.41	11.40	11.25	11.26
12.0	11.18	11.29	11.43	11.12	11.09	11.09	11.36	11.35	11.37	11.34	11.33	11.19	11.40	11.36	11.20	11.22
12.5	11.17	11.24	11.43	11.12	11.09	11.07	11.35	11.35	11.35	11.33	11.30	11.17	11.39	11.33	11.14	11.22
13.0	11.14	11.22	11.32	11.11	11.07	11.04	11.35	11.34	11.34	11.27	11.26	11.16	11.35	11.31	11.11	11.21
13.5	11.12	11.14	11.24	11.11	11.02	11.01	11.34	11.34	11.34	11.24	11.24	11.15	11.32	11.23	11.11	11.22
14.0	11.10	11.10	11.19	11.11	10.98	11.00	11.34	11.33	11.34	11.22	11.18	11.06	11.31	11.16	11.09	11.18
14.5	11.08	11.08	11.00	11.10	10.94	10.96	11.32	11.31	11.34	11.03	11.15	11.01	11.23	11.13	11.03	11.13
15.0	11.08	11.04	10.97	11.08	10.92	10.96	11.26	11.30	11.33	11.00	11.09	11.00	11.16	11.09	10.90	11.08
15.5	11.06	10.93	10.91	11.07	10.91	10.90	11.23	11.24	11.26	10.95	11.02		11.14	11.07	10.88	10.96
16.0	10.94	10.85	10.83	11.01	10.84	10.84	11.17	11.17	11.17	10.94	10.96		11.14	11.01	10.88	10.96
16.5	10.88	10.85	10.85	10.96	10.82	10.83	11.07	11.14	11.11	10.94			11.03	10.86		10.95
17.0		10.84	10.85	10.90	10.81	10.82	11.04	11.03	11.06	10.92			10.93	10.85		
17.5							10.96	10.94	10.99				10.90			
18.0							10.91	10.88	10.97							
18.5							10.89									

[1] Values enclosed in boxes were significantly lower than the mean of other temperature measurements at the same depth.

Table B-2. Salinity[1] on 5 October 2005

Depth (m)	Salinity (‰)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1.0				**33.471**	33.541	33.534							33.545	33.549	33.543	
1.5	33.547	33.547	33.543	**33.471**	33.541	33.534	33.552	33.556	33.541	33.555	33.555	33.556	33.547	33.549	33.552	33.560
2.0	33.547	33.546	33.544	**33.492**	33.541	33.536	33.552	33.556	33.544	33.558	33.558	33.558	33.547	33.550	33.546	33.560
2.5	33.551	33.548	33.543	**33.499**	33.543	33.537	33.552	33.553	33.546	33.560	33.562	33.558	33.553	33.549	33.555	33.560
3.0	33.552	33.548	33.546	**33.480**	33.543	33.536	33.550	33.555	33.544	33.559	33.558	33.553	33.546	33.546	33.545	33.557
3.5	33.547	33.549	33.546	**33.491**	33.544	33.534	33.552	33.556	33.544	33.560	33.557	33.552	33.560	33.549	33.549	33.557
4.0	33.551	33.549	33.547	**33.508**	33.542	33.535	33.551	33.556	33.554	33.558	33.551	33.554	33.540	33.548	33.548	33.557
4.5	33.551	33.550	33.543	**33.496**	33.542	33.540	33.551	33.557	33.560	33.555	33.554	33.555	33.555	33.554	33.548	33.556
5.0	33.550	33.548	33.546	33.511	33.544	33.542	33.553	33.558	33.556	33.553	33.557	33.557	33.548	33.551	33.546	33.556
5.5	33.551	33.548	33.546	**33.509**	33.541	33.530	33.554	33.558	33.555	33.557	33.559	33.557	33.550	33.551	33.550	33.556
6.0	33.553	33.548	33.546	**33.482**	33.549	33.549	33.553	33.559	33.560	33.555	33.558	33.559	33.551	33.551	33.545	33.552
6.5	33.552	33.546	33.544	**33.480**	33.547	33.560	33.551	33.558	33.556	33.552	33.557	33.557	33.550	33.551	33.547	33.558
7.0	33.550	33.548	33.543	**33.474**	33.547	33.536	33.552	33.560	33.557	33.554	33.557	33.557	33.547	33.551	33.549	33.555
7.5	33.551	33.547	33.541	**33.488**	33.548	33.551	33.554	33.557	33.555	33.553	33.556	33.557	33.548	33.560	33.550	33.563
8.0	33.550	33.549	33.545	**33.481**	33.548	33.542	33.555	33.556	33.551	33.555	33.555	33.557	33.549	33.551	33.548	33.556
8.5	33.550	33.550	33.547	**33.473**	33.540	33.538	33.553	33.557	33.557	33.555	33.554	33.556	33.551	33.551	33.549	33.552
9.0	33.551	33.548	33.544	**33.495**	33.541	33.547	33.550	33.560	33.556	33.555	33.551	33.556	33.551	33.552	33.549	33.556
9.5	33.553	33.550	33.546	**33.492**	33.554	33.544	33.554	33.559	33.560	33.557	33.555	33.556	33.551	33.551	33.549	33.556
10.0	33.551	33.549	33.545	**33.491**	33.556	33.552	33.552	33.561	33.561	33.557	33.553	33.557	33.549	33.551	33.557	33.556
10.5	33.552	33.552	33.546	**33.488**	33.554	33.551	33.544	33.557	33.560	33.555	33.556	33.552	33.552	33.549	33.547	33.548
11.0	33.552	33.554	33.548	**33.482**	33.560	33.554	33.550	33.558	33.561	33.556	33.557	33.562	33.551	33.550	33.559	33.540
11.5	33.557	33.557	33.545	**33.486**	33.563	33.546	33.554	33.559	33.555	33.561	33.557	33.567	33.559	33.553	33.574	33.545
12.0	33.573	33.561	33.548	**33.504**	33.566	33.562	33.553	33.559	33.556	33.556	33.559	33.578	33.558	33.560	33.569	33.558
12.5	33.568	33.569	33.528	**33.515**	33.567	33.559	33.555	33.559	33.557	33.551	33.561	33.574	33.558	33.557	33.569	33.559
13.0	33.570	33.555	33.582	33.526	33.569	33.565	33.557	33.559	33.558	33.568	33.560	33.570	33.557	33.554	33.575	33.561
13.5	33.571	33.571	33.586	**33.520**	33.579	33.570	33.555	33.558	33.559	33.563	33.550	33.574	33.562	33.568	33.572	33.558
14.0	33.574	33.574	33.554	33.525	33.582	33.570	33.556	33.562	33.559	33.545	33.566	33.590	33.537	33.593	33.568	33.557
14.5	33.577	33.577	33.604	33.538	33.586	33.574	33.554	33.560	33.559	33.602	33.562	33.588	33.549	33.575	33.560	33.554
15.0	33.575	33.577	33.558	33.559	33.585	33.576	33.571	33.554	33.549	33.567	33.571	33.586	33.575	33.576	33.596	33.557
15.5	33.572	33.599	33.596	33.563	33.584	33.584	33.558	33.565	33.550	33.580	33.572		33.574	33.573	33.593	33.606
16.0	33.617	33.599	33.622	33.571	33.607	33.589	33.556	33.572	33.536	33.587	33.589		33.563	33.574	33.591	33.586
16.5	33.619	33.599	33.596	**33.546**	33.593	33.583	33.582	33.567	33.568	33.587			33.576	33.616		33.587
17.0		33.597	33.589	**33.563**	33.589	33.584	33.570	33.581	33.570	33.593			33.573	33.599		
17.5							33.588	33.595	33.574				33.581			
18.0							33.596	33.595	33.568							
18.5							33.591									

[1] Values enclosed in boxes were significantly lower than the mean of other salinity measurements at the same depth or at the same distance above the seafloor.

Table B-3. Seawater Density on 5 October 2005

	Density (sigma-t)															
Depth (m)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
1.0				25.563	25.542	25.541							25.526	25.542	25.538	
1.5	25.554	25.542	25.540	25.563	25.541	25.541	25.560	25.554	25.539	25.544	25.554	25.559	25.527	25.542	25.545	25.555
2.0	25.554	25.541	25.540	25.588	25.542	25.543	25.560	25.554	25.538	25.546	25.554	25.561	25.526	25.544	25.539	25.554
2.5	25.560	25.544	25.540	25.583	25.544	25.542	25.560	25.556	25.542	25.546	25.559	25.558	25.535	25.543	25.552	25.553
3.0	25.563	25.546	25.545	25.556	25.544	25.540	25.559	25.560	25.535	25.545	25.557	25.553	25.528	25.542	25.545	25.552
3.5	25.559	25.548	25.545	25.553	25.544	25.539	25.562	25.560	25.537	25.548	25.562	25.557	25.558	25.550	25.553	25.553
4.0	25.564	25.548	25.547	25.557	25.543	25.540	25.562	25.561	25.553	25.547	25.561	25.564	25.538	25.552	25.555	25.557
4.5	25.565	25.550	25.545	25.552	25.545	25.546	25.564	25.561	25.562	25.548	25.565	25.565	25.559	25.558	25.554	25.557
5.0	25.565	25.550	25.548	25.560	25.550	25.552	25.567	25.561	25.560	25.553	25.569	25.568	25.555	25.556	25.554	25.558
5.5	25.567	25.550	25.547	25.559	25.555	25.545	25.568	25.563	25.560	25.569	25.570	25.573	25.560	25.557	25.560	25.559
6.0	25.570	25.550	25.549	25.542	25.568	25.566	25.569	25.568	25.566	25.567	25.568	25.579	25.564	25.557	25.556	25.556
6.5	25.570	25.549	25.547	25.551	25.568	25.586	25.567	25.567	25.565	25.566	25.568	25.578	25.564	25.557	25.560	25.565
7.0	25.569	25.552	25.548	25.551	25.570	25.569	25.569	25.569	25.568	25.569	25.568	25.579	25.562	25.558	25.563	25.565
7.5	25.570	25.552	25.546	25.568	25.573	25.588	25.571	25.569	25.567	25.570	25.569	25.580	25.563	25.571	25.564	25.576
8.0	25.570	25.558	25.550	25.563	25.576	25.582	25.573	25.569	25.567	25.575	25.571	25.580	25.565	25.565	25.563	25.573
8.5	25.570	25.562	25.554	25.557	25.583	25.588	25.571	25.571	25.576	25.575	25.575	25.579	25.567	25.566	25.564	25.571
9.0	25.574	25.560	25.552	25.588	25.602	25.602	25.569	25.577	25.577	25.576	25.573	25.580	25.567	25.568	25.567	25.576
9.5	25.578	25.564	25.554	25.583	25.625	25.602	25.575	25.579	25.583	25.577	25.577	25.581	25.567	25.569	25.569	25.577
10.0	25.577	25.565	25.553	25.578	25.634	25.612	25.576	25.584	25.586	25.578	25.578	25.584	25.566	25.569	25.581	25.578
10.5	25.579	25.571	25.556	25.571	25.634	25.612	25.570	25.582	25.586	25.577	25.584	25.583	25.570	25.567	25.574	25.577
11.0	25.584	25.579	25.563	25.566	25.639	25.617	25.579	25.584	25.588	25.581	25.587	25.600	25.570	25.569	25.597	25.579
11.5	25.604	25.588	25.563	25.572	25.642	25.619	25.584	25.588	25.581	25.591	25.59	25.614	25.580	25.577	25.621	25.596
12.0	25.631	25.602	25.567	25.589	25.643	25.640	25.583	25.590	25.585	25.589	25.595	25.634	25.580	25.591	25.624	25.614
12.5	25.630	25.618	25.551	25.599	25.644	25.641	25.586	25.591	25.589	25.587	25.601	25.634	25.583	25.593	25.637	25.614
13.0	25.636	25.611	25.615	25.608	25.648	25.651	25.589	25.592	25.591	25.612	25.608	25.633	25.588	25.594	25.645	25.616
13.5	25.642	25.638	25.632	25.603	25.665	25.660	25.589	25.592	25.592	25.614	25.604	25.638	25.598	25.619	25.644	25.613
14.0	25.647	25.647	25.616	25.608	25.675	25.663	25.591	25.597	25.592	25.603	25.626	25.667	25.581	25.652	25.644	25.620
14.5	25.653	25.653	25.688	25.620	25.685	25.671	25.592	25.598	25.592	25.681	25.628	25.674	25.605	25.643	25.649	25.626
15.0	25.652	25.660	25.657	25.640	25.688	25.675	25.616	25.595	25.586	25.659	25.647	25.674	25.637	25.650	25.701	25.637
15.5	25.653	25.698	25.697	25.644	25.689	25.691	25.611	25.614	25.600	25.679	25.660		25.639	25.652	25.700	25.697
16.0	25.709	25.712	25.732	25.661	25.719	25.705	25.620	25.633	25.605	25.686	25.684		25.631	25.664	25.700	25.681
16.5	25.721	25.712	25.709	25.650	25.711	25.702	25.659	25.635	25.641	25.686			25.661	25.722		25.685
17.0		25.711	25.703	25.674	25.710	25.704	25.655	25.665	25.651	25.695			25.676	25.712		
17.5							25.683	25.693	25.667				25.688			
18.0							25.699	25.703	25.666							
18.5							25.697									

Table B-4. Dissolved Oxygen[1] on 5 October 2005

	Dissolved Oxygen (mg/L)															
Depth (m)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
1.0				**5.30**	6.35	6.25							6.43	6.36	6.32	
1.5	6.20	6.34	6.34	**5.30**	6.35	6.25	6.33	6.30	6.38	6.30	6.20	6.29	6.47	6.34	6.33	6.30
2.0	6.20	6.37	6.32	**5.29**	6.36	6.28	6.33	6.30	6.34	6.33	6.20	6.27	6.47	6.34	6.32	6.29
2.5	6.21	6.36	6.34	**5.38**	6.36	6.30	6.32	6.37	6.33	6.32	6.17	6.25	6.45	6.35	6.30	6.27
3.0	6.21	6.35	6.35	5.47	6.35	6.31	6.32	6.35	6.35	6.31	6.17	6.21	6.47	6.35	6.30	6.27
3.5	6.22	6.34	6.30	5.74	6.43	6.32	6.29	6.33	6.29	6.30	6.20	6.24	6.39	6.34	6.29	6.28
4.0	6.22	6.35	6.31	5.77	6.42	6.32	6.28	6.33	6.25	6.32	6.22	6.30	6.39	6.32	6.27	6.30
4.5	6.21	6.33	6.31	5.69	6.42	6.29	6.29	6.28	6.22	6.38	6.23	6.24	6.32	6.33	6.29	6.32
5.0	6.23	6.33	6.33	5.75	6.39	6.25	6.27	6.28	6.21	6.42	6.24	6.28	6.33	6.33	6.25	6.38
5.5	6.21	6.33	6.33	5.72	6.33	6.20	6.26	6.29	6.22	6.42	6.23	6.26	6.29	6.31	6.26	6.40
6.0	6.13	6.33	6.34	5.62	6.22	6.17	6.23	6.28	6.20	6.42	6.22	6.33	6.24	6.33	6.25	6.38
6.5	6.16	6.31	6.34	5.53	6.19	6.08	6.27	6.28	6.21	6.42	6.24	6.30	6.28	6.32	6.23	6.22
7.0	6.18	6.31	6.29	5.45	6.16	5.98	6.29	6.27	6.18	6.40	6.29	6.29	6.26	6.30	6.23	6.26
7.5	6.15	6.29	6.29	5.40	6.11	5.93	6.32	6.32	6.19	6.40	6.28	6.31	6.25	6.23	6.21	6.32
8.0	6.15	6.23	6.28	5.37	6.03	5.91	6.30	6.34	6.21	6.35	6.27	6.32	6.29	6.21	6.20	6.33
8.5	6.11	6.20	6.26	5.35	5.84	5.75	6.26	6.30	6.22	6.35	6.24	6.31	6.32	6.21	6.18	6.37
9.0	6.05	6.17	6.27	5.28	5.68	5.72	6.16	6.25	6.18	6.36	6.26	6.32	6.33	6.18	6.12	6.33
9.5	6.03	6.16	6.27	5.27	5.51	5.70	6.16	6.22	6.11	6.33	6.26	6.36	6.36	6.14	6.09	6.21
10.0	6.03	6.12	6.29	5.33	5.48	5.65	6.11	6.20	6.10	6.33	6.22	6.31	6.17	6.16	6.03	6.24
10.5	6.01	6.07	6.34	5.44	5.47	5.67	6.08	6.19	6.09	6.30	6.16	6.25	6.13	6.13	5.97	6.15
11.0	5.93	5.98	6.24	5.41	5.46	5.63	6.03	6.15	6.12	6.27	6.12	6.18	6.27	6.13	5.80	6.02
11.5	5.70	5.92	6.19	5.36	5.50	5.55	5.99	6.11	6.11	6.18	6.10	6.15	6.16	5.95	5.74	5.92
12.0	5.58	5.77	6.19	5.39	5.50	5.45	6.02	6.09	6.09	6.16	6.04	5.97	6.13	5.92	5.67	5.87
12.5	5.57	5.69	5.99	5.42	5.51	5.39	5.99	6.08	6.05	6.12	5.95	5.95	6.11	5.86	5.59	5.87
13.0	5.56	5.64	5.90	5.40	5.44	5.25	5.96	6.05	6.03	5.99	5.90	5.99	5.99	5.82	5.57	5.87
13.5	5.55	5.57	5.82	5.41	5.33	5.12	5.98	6.05	6.03	5.89	5.86	6.00	5.99	5.65	5.55	5.86
14.0	5.52	5.51	5.57	5.43	5.19	5.04	5.99	6.03	6.04	5.84	5.80	5.69	5.90	5.60	5.43	5.75
14.5	5.48	5.48	5.27	5.43	5.09	4.99	5.93	6.00	6.02	5.39	5.71	5.47	5.78	5.58	5.16	5.59
15.0	5.50	5.29	5.04	5.42	5.00	4.96	5.88	5.91	5.92	5.17	5.51	5.50	5.70	5.49	4.81	5.36
15.5	5.42	4.92	4.98	5.40	4.97	4.84	5.81	5.84	5.77	5.08	5.33		5.66	5.41	4.74	5.17
16.0	5.39	4.63	4.75	5.22	4.75	4.72	5.64	5.75	5.52	5.05	5.36		5.61	5.11	4.76	5.13
16.5	5.27	4.67	4.72	4.94	4.68	4.65	5.44	5.61	5.44	5.13			5.21	4.74		5.18
17.0		4.72	4.73	4.85	4.68	4.61	5.32	5.28	5.31	5.14			4.86	4.63		
17.5							5.10	5.07	5.09				4.80			
18.0							4.93	4.90	5.06							
18.5							4.90									

[1] Values enclosed in boxes were significantly lower than the mean of other dissolved oxygen measurements at the same depth.

Table B-5. Light Transmittance[1] across a 0.25-m path on 5 October 2005

	Light Transmittance (%)															
Depth (m)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
1.0				78.93	77.40	79.77							79.17	78.57	79.46	
1.5	79.41	78.94	79.48	78.62	78.58	79.62	78.24	80.00	79.18	80.34	80.24	79.98	79.27	79.32	78.79	79.86
2.0	79.59	78.92	79.59	78.68	78.96	79.73	78.22	79.28	79.39	80.57	80.25	79.91	79.34	79.25	79.41	80.00
2.5	79.33	78.98	79.51	78.86	79.03	79.83	78.29	78.82	79.25	80.53	80.23	79.96	79.48	79.22	79.45	80.14
3.0	79.11	78.91	79.36	78.98	78.97	79.78	78.36	78.24	79.58	80.57	80.28	80.19	79.20	79.13	79.00	80.15
3.5	78.91	78.84	79.43	79.14	78.85	79.77	78.40	78.64	79.67	80.25	79.76	79.99	78.73	78.85	78.90	80.13
4.0	78.66	78.96	79.24	79.17	78.90	79.49	78.51	78.49	79.80	80.05	79.60	79.91	78.54	78.58	78.95	80.01
4.5	78.53	78.61	79.11	79.21	78.38	79.37	78.37	79.63	79.65	79.06	79.55	79.87	78.43	78.52	78.70	79.79
5.0	78.50	78.73	79.25	79.14	78.05	79.06	78.41	79.43	79.74	78.67	79.50	79.71	78.36	78.61	78.77	79.80
5.5	78.62	78.58	79.13	79.11	77.96	78.64	78.32	79.34	79.65	78.39	79.61	79.47	78.86	78.80	78.48	79.89
6.0	78.77	78.62	78.98	79.10	78.12	78.90	78.47	79.29	79.46	78.25	79.70	79.47	79.40	78.73	78.62	79.75
6.5	78.55	78.47	78.74	78.95	78.09	79.33	78.37	79.36	79.57	78.39	79.48	79.40	79.31	78.58	78.73	79.25
7.0	78.57	78.43	78.77	78.73	78.40	79.18	78.26	79.25	79.48	78.30	79.29	79.35	79.30	78.75	78.64	79.05
7.5	78.86	78.33	78.75	78.73	78.41	79.18	78.47	78.80	79.24	78.38	79.12	79.28	79.23	78.60	78.70	78.81
8.0	79.11	78.62	78.96	78.83	78.66	79.46	78.39	78.33	79.08	78.45	78.90	79.44	79.28	79.10	78.82	78.57
8.5	79.24	78.60	78.61	78.82	79.35	**80.56**	78.56	78.64	78.87	78.52	78.96	79.27	79.14	79.03	78.69	78.50
9.0	79.50	78.76	78.70	78.90	79.67	80.25	78.55	78.78	78.89	78.77	78.89	79.29	79.13	79.05	78.73	78.68
9.5	79.56	78.67	78.62	78.84	79.40	80.27	78.57	79.02	78.82	78.52	78.78	79.24	79.32	79.37	78.73	78.77
10.0	79.48	78.68	78.45	78.84	79.69	80.40	78.75	79.02	78.91	78.73	78.79	79.11	79.32	79.42	78.91	78.94
10.5	79.65	78.68	78.47	78.89	79.86	80.33	79.54	79.07	79.04	78.76	78.80	78.93	79.17	79.12	79.09	79.04
11.0	79.63	79.29	78.83	78.83	80.12	80.33	79.50	78.78	79.03	78.88	78.97	79.26	79.21	79.21	79.48	79.42
11.5	80.44	79.55	78.88	78.98	80.07	80.74	79.68	79.29	79.25	79.15	79.43	79.64	79.24	79.37	79.83	79.61
12.0	81.04	80.22	78.90	79.31	80.07	**81.09**	80.01	79.46	79.27	79.05	79.49	79.54	79.34	79.52	79.97	79.70
12.5	80.69	79.90	79.04	79.12	80.19	**81.50**	79.79	79.78	79.47	79.50	79.49	79.53	79.60	80.00	80.12	79.82
13.0	80.50	80.13	78.97	79.26	80.22	**82.87**	80.10	79.68	79.27	79.90	79.51	79.72	79.59	80.14	79.98	79.77
13.5	80.14	80.20	79.38	78.96	80.30	**82.90**	80.22	79.87	79.35	80.01	79.94	79.26	79.56	79.93	80.08	79.70
14.0	80.28	80.32	79.77	79.10	80.60	**82.85**	80.47	79.72	79.37	79.90	79.88	78.55	79.77	79.92	80.29	79.63
14.5	80.44	80.29	79.85	79.07	80.71	**82.62**	80.39	79.97	79.53	79.74	80.02	78.24	79.92	80.03	80.23	79.33
15.0	80.43	80.28	80.15	79.82	80.86	**82.56**	80.40	80.27	79.64	78.81	79.83	78.13	79.78	79.97	79.91	79.19
15.5	80.49	79.99	80.17	80.07	81.03	**81.96**	80.41	80.25	79.95	**78.39**	79.12		79.64	80.26	79.32	78.54
16.0	79.99	79.31	79.97	80.31	80.79	80.73	80.49	80.45	80.21	**78.25**	78.24		79.85	80.43	78.18	78.69
16.5	79.13	**77.95**	79.15	80.46	79.50	80.23	80.13	80.61	79.98	78.43			80.16	80.19		78.58
17.0		**78.22**	78.25	79.55	78.89	79.49	80.25	80.15	79.74	78.54			79.81	78.86		
17.5							80.23	79.65	79.65				79.20			
18.0							79.65	79.21	78.99							
18.5							79.06									

[1] Values enclosed in boxes were significantly different from the mean of other transmissivity measurements at the same distance above the seafloor. The thinner boxes encompass values that were significantly higher than the mean of other measurements at the same distance above the seafloor.

Table B-6. Detrended[1] pH[2] on 5 October 2005

	Hydrogen Ion Concentration (pH)															
Depth (m)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
1.0				**8.140**	8.180	8.180							8.179	8.180	8.180	
1.5	8.176	8.181	8.179	**8.136**	8.180	8.180	8.172	8.175	8.177	8.173	8.171	8.171	8.179	8.179	8.181	8.171
2.0	8.176	8.180	8.182	**8.134**	8.180	8.180	8.172	8.167	8.176	8.173	8.171	8.172	8.179	8.179	8.180	8.172
2.5	8.176	8.181	8.181	**8.128**	8.180	8.180	8.172	8.168	8.177	8.171	8.171	8.171	8.179	8.180	8.180	8.173
3.0	8.176	8.181	8.181	**8.129**	8.180	8.180	8.172	8.170	8.176	8.171	8.171	8.172	8.180	8.181	8.181	8.171
3.5	8.174	8.181	8.178	**8.129**	8.180	8.180	8.172	8.173	8.176	8.171	8.171	8.174	8.187	8.181	8.181	8.175
4.0	8.176	8.181	8.181	**8.134**	8.180	8.180	8.172	8.173	8.177	8.171	8.171	8.176	8.180	8.181	8.181	8.173
4.5	8.176	8.181	8.181	**8.138**	8.180	8.180	8.172	8.173	8.177	8.173	8.174	8.176	8.180	8.181	8.181	8.175
5.0	8.176	8.181	8.181	**8.138**	8.180	8.181	8.172	8.173	8.177	8.176	8.176	8.176	8.180	8.181	8.181	8.176
5.5	8.176	8.181	8.181	**8.139**	8.180	8.181	8.172	8.169	8.174	8.180	8.176	8.176	8.180	8.181	8.181	8.176
6.0	8.176	8.183	8.181	**8.141**	8.180	8.181	8.172	8.168	8.172	8.181	8.176	8.176	8.176	8.181	8.181	8.176
6.5	8.176	8.185	8.181	**8.143**	8.181	8.181	8.172	8.168	8.174	8.181	8.176	8.176	8.177	8.181	8.181	8.176
7.0	8.176	8.182	8.181	**8.141**	8.178	8.178	8.172	8.168	8.172	8.181	8.176	8.176	8.175	8.181	8.181	8.177
7.5	8.176	8.186	8.181	**8.137**	8.176	8.176	8.172	8.168	8.172	8.181	8.176	8.176	8.176	8.181	8.181	8.182
8.0	8.176	8.184	8.181	**8.134**	8.176	8.173	8.172	8.168	8.173	8.181	8.179	8.181	8.176	8.181	8.181	8.181
8.5	8.176	8.184	8.181	**8.134**	8.172	8.167	8.172	8.168	8.177	8.181	8.181	8.180	8.176	8.181	8.181	8.181
9.0	8.176	8.183	8.181	**8.131**	8.171	8.165	8.172	8.168	8.177	8.181	8.181	8.181	8.176	8.181	8.181	8.181
9.5	8.176	8.181	8.181	**8.134**	8.167	8.163	8.169	8.168	8.177	8.181	8.181	8.181	8.175	8.181	8.181	8.181
10.0	8.176	8.181	8.181	**8.131**	8.166	8.158	8.169	8.168	8.177	8.181	8.181	8.181	8.171	8.178	8.181	8.181
10.5	8.174	8.181	8.181	**8.130**	8.157	8.158	8.167	8.168	8.177	8.181	8.181	8.181	8.171	8.176	8.180	8.181
11.0	8.174	8.181	8.181	**8.129**	8.150	8.156	8.167	8.168	8.177	8.181	8.181	8.182	8.171	8.177	8.181	8.181
11.5	8.172	8.181	8.181	**8.129**	8.144	8.153	8.167	8.166	8.177	8.181	8.181	8.180	8.171	8.179	8.180	8.177
12.0	8.172	8.181	8.181	**8.129**	8.144	8.149	8.167	8.168	8.176	8.181	8.179	8.177	8.171	8.179	8.176	8.173
12.5	8.168	8.179	8.178	**8.129**	8.143	8.146	8.167	8.166	8.174	8.181	8.180	8.177	8.171	8.178	8.171	8.172
13.0	8.164	8.177	8.181	**8.129**	8.144	8.141	8.167	8.164	8.173	8.182	8.177	8.168	8.171	8.177	8.168	8.169
13.5	8.160	8.171	8.182	**8.129**	8.144	8.139	8.164	8.164	8.173	8.178	8.174	8.166	8.167	8.173	8.161	8.168
14.0	8.157	8.165	8.171	**8.129**	8.139	8.134	8.163	8.164	8.173	8.177	8.173	8.162	8.165	8.172	8.159	8.167
14.5	8.154	8.163	8.167	**8.129**	8.139	**8.129**	8.163	8.164	8.173	8.173	8.169	8.157	8.160	8.173	8.155	8.161
15.0	8.148	8.156	8.160	8.129	8.135	**8.124**	8.163	8.164	8.173	8.165	8.166	8.147	8.158	8.164	8.149	8.158
15.5	8.144	8.155	8.150	8.126	8.130	8.123	8.160	8.164	8.173	8.155	8.161		8.153	8.159	8.142	8.154
16.0	8.140	8.148	8.144	8.129	8.124	8.121	8.156	8.160	8.169	8.150	8.153		8.152	8.151	8.137	8.149
16.5	8.140	8.144	8.137	8.127	8.121	8.115	8.152	8.157	8.164	8.141			8.144	8.149		8.142
17.0		8.127	8.128	8.121	8.113	8.102	8.148	8.155	8.157	8.139			8.140	8.146		
17.5							8.138	8.150	8.149				8.129			
18.0							8.136	8.135	8.143							
18.5							8.128									

[1] Measured pH levels were corrected for temporal drift to account for ongoing equilibration of the pH sensor.

[2] Values enclosed in boxes were significantly lower than the mean of other pH measurements at the same depth.

Table B-7. Uncorrected pH on 5 October 2005

	Alkalinity (pH)															
Depth (m)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
1.0				**8.136**	8.171	8.166							8.194	8.180	8.180	
1.5	8.176	8.181	8.179	**8.132**	8.171	8.166	8.186	8.188	8.181	8.173	8.171	8.171	8.194	8.179	8.181	8.171
2.0	8.176	8.180	8.182	**8.130**	8.171	8.166	8.186	8.180	8.180	8.173	8.171	8.172	8.194	8.179	8.180	8.172
2.5	8.176	8.181	8.181	**8.124**	8.171	8.166	8.186	8.181	8.181	8.171	8.171	8.171	8.194	8.180	8.180	8.173
3.0	8.176	8.181	8.181	**8.125**	8.171	8.166	8.186	8.183	8.180	8.171	8.171	8.172	8.195	8.181	8.181	8.171
3.5	8.174	8.181	8.178	**8.125**	8.171	8.166	8.186	8.186	8.180	8.171	8.171	8.174	8.202	8.181	8.181	8.175
4.0	8.176	8.181	8.181	**8.130**	8.171	8.166	8.186	8.186	8.181	8.171	8.171	8.176	8.195	8.181	8.181	8.173
4.5	8.176	8.181	8.181	**8.134**	8.171	8.166	8.186	8.186	8.181	8.173	8.174	8.176	8.195	8.181	8.181	8.175
5.0	8.176	8.181	8.181	**8.134**	8.171	8.167	8.186	8.186	8.181	8.176	8.176	8.176	8.195	8.181	8.181	8.176
5.5	8.176	8.181	8.181	**8.135**	8.171	8.167	8.186	8.182	8.178	8.180	8.176	8.176	8.195	8.181	8.181	8.176
6.0	8.176	8.183	8.181	**8.137**	8.171	8.167	8.186	8.181	8.176	8.181	8.176	8.176	8.191	8.181	8.181	8.176
6.5	8.176	8.185	8.181	**8.139**	8.172	8.167	8.186	8.181	8.178	8.181	8.176	8.176	8.192	8.181	8.181	8.176
7.0	8.176	8.182	8.181	**8.137**	8.169	8.164	8.186	8.181	8.176	8.181	8.176	8.176	8.190	8.181	8.181	8.177
7.5	8.176	8.186	8.181	**8.133**	8.167	8.162	8.186	8.181	8.176	8.181	8.176	8.176	8.191	8.181	8.181	8.182
8.0	8.176	8.184	8.181	**8.130**	8.167	8.159	8.186	8.181	8.177	8.181	8.179	8.181	8.191	8.181	8.181	8.181
8.5	8.176	8.184	8.181	**8.130**	8.163	8.153	8.186	8.181	8.181	8.181	8.181	8.180	8.191	8.181	8.181	8.181
9.0	8.176	8.183	8.181	**8.127**	8.162	8.151	8.186	8.181	8.181	8.181	8.181	8.181	8.191	8.181	8.181	8.181
9.5	8.176	8.181	8.181	**8.130**	8.158	8.149	8.183	8.181	8.181	8.181	8.181	8.181	8.190	8.181	8.181	8.181
10.0	8.176	8.181	8.181	**8.127**	8.157	8.144	8.183	8.181	8.181	8.181	8.181	8.181	8.186	8.178	8.181	8.181
10.5	8.174	8.181	8.181	**8.126**	8.148	8.144	8.181	8.181	8.181	8.181	8.181	8.181	8.186	8.176	8.180	8.181
11.0	8.174	8.181	8.181	**8.125**	8.141	8.142	8.181	8.181	8.181	8.181	8.181	8.182	8.186	8.177	8.181	8.181
11.5	8.172	8.181	8.181	**8.125**	**8.135**	8.139	8.181	8.179	8.181	8.181	8.181	8.180	8.186	8.179	8.180	8.177
12.0	8.172	8.181	8.181	**8.125**	**8.135**	**8.135**	8.181	8.181	8.180	8.181	8.179	8.177	8.186	8.179	8.176	8.173
12.5	8.168	8.179	8.178	**8.125**	**8.134**	**8.132**	8.181	8.179	8.178	8.181	8.180	8.177	8.186	8.178	8.171	8.172
13.0	8.164	8.177	8.181	**8.125**	8.135	**8.127**	8.181	8.177	8.177	8.182	8.177	8.168	8.186	8.177	8.168	8.169
13.5	8.160	8.171	8.182	**8.125**	8.135	**8.125**	8.178	8.177	8.177	8.178	8.174	8.166	8.182	8.173	8.161	8.168
14.0	8.157	8.165	8.171	**8.125**	8.130	**8.120**	8.177	8.177	8.177	8.177	8.173	8.162	8.180	8.172	8.159	8.167
14.5	8.154	8.163	8.167	**8.125**	8.130	**8.115**	8.177	8.177	8.177	8.173	8.169	8.157	8.175	8.173	8.155	8.161
15.0	8.148	8.156	8.160	8.125	8.126	**8.110**	8.177	8.177	8.177	8.165	8.166	8.147	8.173	8.164	8.149	8.158
15.5	8.144	8.155	8.150	8.122	8.121	**8.109**	8.174	8.177	8.177	8.155	8.161		8.168	8.159	8.142	8.154
16.0	8.140	8.148	8.144	8.125	8.115	**8.107**	8.170	8.173	8.173	8.150	8.153		8.167	8.151	8.137	8.149
16.5	8.140	8.144	8.137	8.123	8.112	**8.101**	8.166	8.170	8.168	8.141			8.159	8.149		8.142
17.0		8.127	8.128	8.117	8.104	**8.088**	8.162	8.168	8.161	8.139			8.155	8.146		
17.5							8.152	8.163	8.153				8.144			
18.0							8.150	8.148	8.147							
18.5							8.142									

[1] Values enclosed in boxes were significantly lower than the mean of other measurements at the same depth.

Table B-8. Seawater Properties at Opportunistic Station 17 on 5 October 20

Depth (m)	Temperature	Salinity	Density	pH	DO	Transmissivity
1.5	11.56	33.546	25.542	8.181	6.35	79.28
2.0	11.56	33.546	25.542	8.181	6.35	79.45
2.5	11.53	33.552	25.552	8.181	6.27	79.27
3.0	11.54	33.539	25.541	8.181	6.25	79.14
3.5	11.52	33.514	25.525	8.181	6.07	79.32
4.0	11.35	**33.450**	25.506	8.181	5.66	78.39
4.5	11.22	**33.479**	25.551	8.175	5.48	78.46
5.0	11.16	**33.474**	25.558	8.168	5.40	78.28
5.5	11.11	**33.459**	25.556	8.154	**5.32**	78.34
6.0	11.11	**33.455**	25.552	8.147	**5.30**	78.29
6.5	11.13	**33.457**	25.552	**8.142**	5.34	78.24
7.0	11.15	**33.463**	25.552	**8.138**	5.39	78.26
7.5	11.15	**33.466**	25.554	**8.133**	5.38	78.39
8.0	11.16	**33.477**	25.560	**8.134**	5.42	78.34
8.5	11.18	**33.487**	25.565	**8.134**	5.47	78.62
9.0	11.29	**33.490**	25.548	**8.129**	5.73	78.42
9.5	11.28	**33.509**	25.564	**8.133**	5.76	78.40
10.0	11.35	33.518	25.559	**8.139**	5.84	78.96
10.5	11.31	**33.501**	25.553	**8.140**	5.77	78.76
11.0	11.31	**33.471**	25.529	8.143	5.70	78.74
11.5	11.19	**33.439**	25.525	8.144	5.46	78.52
12.0	11.29	33.520	25.571	8.148	5.63	78.90
12.5	11.22	**33.505**	25.573	8.148	5.53	78.81
13.0	11.16	**33.520**	25.594	8.149	5.46	79.26
13.5	11.06	**33.494**	25.592	8.144	5.20	79.00
14.0	11.03	**33.456**	25.569	8.145	5.12	**78.38**
14.5	11.02	**33.445**	25.561	8.137	5.17	**78.53**
15.0	11.05	**33.431**	**25.546**	8.127	5.18	79.01
15.5	11.06	**33.256**	**25.408**	8.125	5.00	**76.14**
16.0	11.00	**33.341**	**25.483**	8.121	4.89	**76.41**
16.5	10.92	**33.528**	25.643	8.116	4.81	78.86
17.0	10.89	33.57	25.68	8.11	4.80	78.80

[1] Values enclosed in boxes were significantly different than the mean of other measurem

Table B-9. Ancillary Observations on 5 October 2005 during the Receiving-Water Survey

Station	Location		Diffuser Distance	Time	Air Temperature	Cloud Cover	Wind Avg	Wind Max	Wind Dir (from)	Swell Ht/Dir	Secchi Depth
	Latitude	Longitude	(m)	(PDT)	(°C)	(%)	(kt)	(kt)	(°T)	(ft/°T)	(m)
1	35° 23.230' N	120° 52.516' W	60.4	10:44:01	21.5	0	5.7	7.6	NW	3-4/NW	10.5
2	35° 23.219' N	120° 52.502' W	37.6	10:38:49	22.9	0	2.1	3.8	NW	3-4/NW	9.5
3	35° 23.216' N	120° 52.502' W	31.7	10:27:26	22.3	0	2.3	5.9	NW	3-4/NW	8.5
4	35° 23.178' N	120° 52.516' W	42.3	10:24:58	21.7	0	4.3	7.2	NW	3-4/NW	8.0
5	35° 23.129' N	120° 52.501' W	128.7	10:20:01	21.3	0	3.9	10.5	NW	3-4/NW	8.5
6	35° 23.115' N	120° 52.497' W	155.3	10:10:46	20.8	0	2.6	6.2	NW	3-4/NW	9.0
7	35° 23.178' N	120° 52.585' W	128.4	11:21:58	23.0	0	4.3	6.7	NW	3-4/NW	9.0
8	35° 23.192' N	120° 52.560' W	84.9	11:26:51	24.3	0	7.8	15.2	NW	3-4/NW	9.5
9	35° 23.185' N	120° 52.549' W	72.5	11:32:11	25.7	0	6.3	13.7	NW	3-4/NW	10.0
10	35° 23.186' N	120° 52.501' W	25.1	11:37:51	24.6	0	4.4	6.9	NW	3-4/NW	8.5
11	35° 23.183' N	120° 52.488' W	38.2	11:43:16	23.4	0	7.6	9.4	NW	3-4/NW	8.0
12	35° 23.180' N	120° 52.461' W	74.5	11:50:45	24.2	0	5.5	9.3	NW	3-4/NW	9.5
13	35° 23.166' N	120° 52.539' W	81.0	11:17:16	23.1	0	3.1	5.8	NW	3-4/NW	9.5
14	35° 23.197' N	120° 52.523' W	28.7	10:47:06	23.5	0	5.6	11.5	NW	3-4/NW	9.5
15	35° 23.216' N	120° 52.460' W	74.0	10:52:32	22.5	0	4.7	7.1	NW	3-4/NW	9.0
16	35° 23.165' N	120° 52.487' W	69.2	11:52:58	24.2	0	5.1	6.7	NW	3-4/NW	9.5
17	35° 23.185' N	120° 52.499' W	26.9	10:31:32	—	—	—	—	—	—	8.0

The signature of the effluent plume, apparent as a slightly lighter color, was visible at the sea surface within the ZID near Stations 3 and 17. Neither odors nor debris of sewage origin were observed at any time during the survey.

Tidal Conditions (Pacific Daylight Time)
Low Tide: 05:10 1.43 ft
High Tide: 11:24 5.42 ft
Low Tide: 18:10 0.36 ft