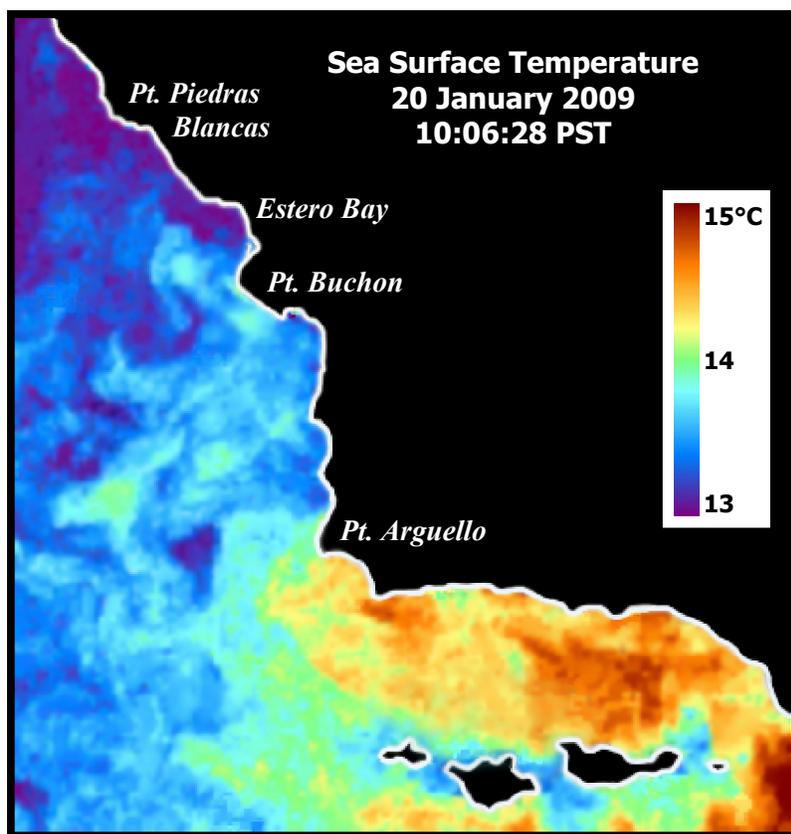


**City of Morro Bay and
Cayucos Sanitary District**

OFFSHORE MONITORING AND REPORTING PROGRAM

QUARTERLY REPORT

WATER-COLUMN SAMPLING JANUARY 2009 SURVEY



Marine Research Specialists

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

Report to
City of Morro Bay and
Cayucos Sanitary District

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Morro Bay, California 93442
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OFFSHORE MONITORING
AND REPORTING PROGRAM

QUARTERLY REPORT
WATER-COLUMN SAMPLING
JANUARY 2009 SURVEY

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February 2009

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

23 February 2009

Reference: Quarterly Receiving-Water Report – January 2009

Dear Mr. Keogh:

The Quarterly Report for the Water-Quality Survey conducted on Tuesday, 20 January 2009, is enclosed with this letter. This first-quarter survey assessed the effectiveness of effluent dispersion during winter oceanographic conditions. Based on quantitative analyses of continuous instrumental measurements and qualitative visual observations, the wastewater discharge complied with the receiving-water limitations specified in the NPDES discharge permit and the objectives of the California Ocean Plan.

Extraordinarily uniform ambient seawater conditions at the time of the survey allowed detection of extremely small perturbations related to the presence of wastewater constituents within and beyond the zone of initial dilution that surrounds the outfall. High-precision measurements clearly delineated discharge-related anomalies in four of the six seawater properties at three of the sixteen sampling stations. The largest of these were measured at depth shortly after discharge and well within the zone of initial dilution, where numerical permit limitations do not apply. Nonetheless, these and the other anomalies met those numerical standards. Coupled with the fact that the dilution measured close to the diffuser structure significantly exceeded expectations based on modeling and outfall design criteria, these measurements confirmed that the diffuser structure and the treatment plant were operating at high performance levels. Accordingly, all measurements indicated low organic loading within the discharged wastewater and an outfall operating as designed.

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

Sincerely,

Douglas A. Coats, Ph.D.
Program Manager

Enclosures (5)

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

Mr. Bruce Ambo
City of Morro Bay

Date _____

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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. Region IX of the U.S. Environmental Protection Agency (USEPA) and the Central Coast California Regional Water Quality Control Board (RWQCB) originally issued a National Pollutant Discharge Elimination System (NPDES) permit to the MBCSD, modifying secondary treatment requirements, in March 1985. Following extensive evaluation processes, the permit has been re-issued twice, in March of 1993 (RWQCB-USEPA 1993ab) and December 1998 (RWQCB-USEPA 1998ab).

As part of the current permit provisions, the previous monitoring program was modified to better evaluate short- and long-term effects of the discharge on receiving waters, benthic sediments, and infaunal communities (RWQCB-EPA 1998b). The program continued to require seasonal water-quality monitoring. The four quarterly surveys record ambient water properties during winter, spring, summer, and fall conditions. In keeping with seasonal synopses, this quarterly report summarizes the results of water-quality sampling conducted on 20 January 2009. Specifically, this first-quarter survey captures ambient oceanographic conditions along the central California coast during the winter season.

The water-quality surveys also provide timely assessments of the diffuser structure's performance dispersing wastewater within stratified receiving waters. Any significant, recent damage to the diffuser structure would be revealed by a decline in the wastewater dispersion in this survey compared to both prior surveys and design specifications. As described in this report, no such decline was observed in the January 2009 field survey.

Both monitoring objectives were achieved by evaluating water-column profiles and cross sections of water-property distributions; these evaluations are presented in Appendix A. Appendix B tabulates instrumental measurements and standard field observations. These data assessed compliance with the objectives of the California Ocean Plan (COP) as promulgated by the NPDES discharge permit.

The January 2009 field survey was the forty-first water-quality survey 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 became possible with the increased navigational accuracy of the differential global positioning satellite (DGPS) system. Commissioned during the March 1998 survey (MRS 1998a), this system precisely documented the location of the open section of the diffuser structure during a diver survey on 29 September 1998 (MRS 1998bc).

The current sampling design also allowed more rapid surveying compared to previous surveys by eliminating the requirement for discrete water samples at individual stations. Using Niskin bottles to collect these samples, was time consuming and interrupted the continuity of measurements collected by the CTD¹ instrument package. Continuous deployment of the CTD between stations now provides a more synoptic snapshot of the water properties immediately surrounding the diffuser structure. Consequently, the extent of the effluent plume and the amplitude of its associated water-property anomalies can be more precisely determined. The CTD instrument package's sensitive sensors, described below in the Methods Section, are capable of detecting minute changes in water properties. Surveys conducted prior to 1999 rarely detected the effluent plume because sampling stations were too far apart to resolve a dilute

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

wastewater signature that is highly localized around the outfall diffuser. After implementing the current sampling design in 1999, all 41 of the subsequent water-quality surveys (MRS 2000 - 2008), including the one described in this report, detected well-mixed effluent near the diffuser structure. Moreover, improved navigation and the denser sampling pattern delineated the lateral extent of the discharge-related perturbations in seawater properties more precisely.

Precision navigation is important for assessing compliance because most receiving-water limitations apply only beyond the narrow zone of initial dilution surrounding the outfall. Additionally, the denser sampling pattern better quantifies the amplitudes of the effluent-related perturbations. The amplitudes of discharge-related salinity anomalies reveal the details of dilution as the effluent plume disperses within



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

receiving waters. Measured dilution factors provide insight into the current operational performance of the outfall and diffuser structure. As described in this report, the data collected during the January 2009 survey delineated the presence of dilute effluent undergoing turbulent mixing within the unstratified water column north of the diffuser structure.

STATION LOCATIONS

The 16 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 extends an additional 52 m toward the northwest from the outfall terminus.

Twenty-eight of the 34 available ports discharge effluent along a 42-m section of the diffuser structure. The other six diffuser ports remain closed to improve dispersion by increasing the ejection velocity from the open ports. For a given flow rate, the diffuser ports were hydraulically designed to create a turbulent ejection jet that rapidly mixes 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 in modeling studies is considered to be approximately 15 m from the centerline of the diffuser structure.

Table 1. Target Locations of the Offshore Water-Quality 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	Shoreward ZID	35° 23.199' N	120° 52.489' W	15.0	23
11	Shoreward Nearfield	35° 23.199' N	120° 52.464' W	46.7	60
12	Shoreward Midfield	35° 23.199' N	120° 52.438' W	85.8	100
13	Southwest Nearfield	35° 23.176' N	120° 52.532' W	59.8	60
14	Northwest Nearfield	35° 23.222' N	120° 52.532' W	40.2	60
15	Northeast Nearfield	35° 23.222' N	120° 52.476' W	59.8	60
16	Southeast Nearfield	35° 23.176' N	120° 52.476' W	40.2	60

¹ Distance to the closest open diffuser port.

² Distance to the center of open diffuser section.

² This distance was determined during a navigational survey 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 lays 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).

Beyond the ZID, 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, the entrance to the Morro Bay National Estuary lies 2.8 km south of the discharge; the southerly orientation of the mouth of the Bay and the presence of Morro Rock restrict direct seawater exchange between the discharge point and the Bay. 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 further restricts the direct exchange of seawater between the discharge point and the Bay.

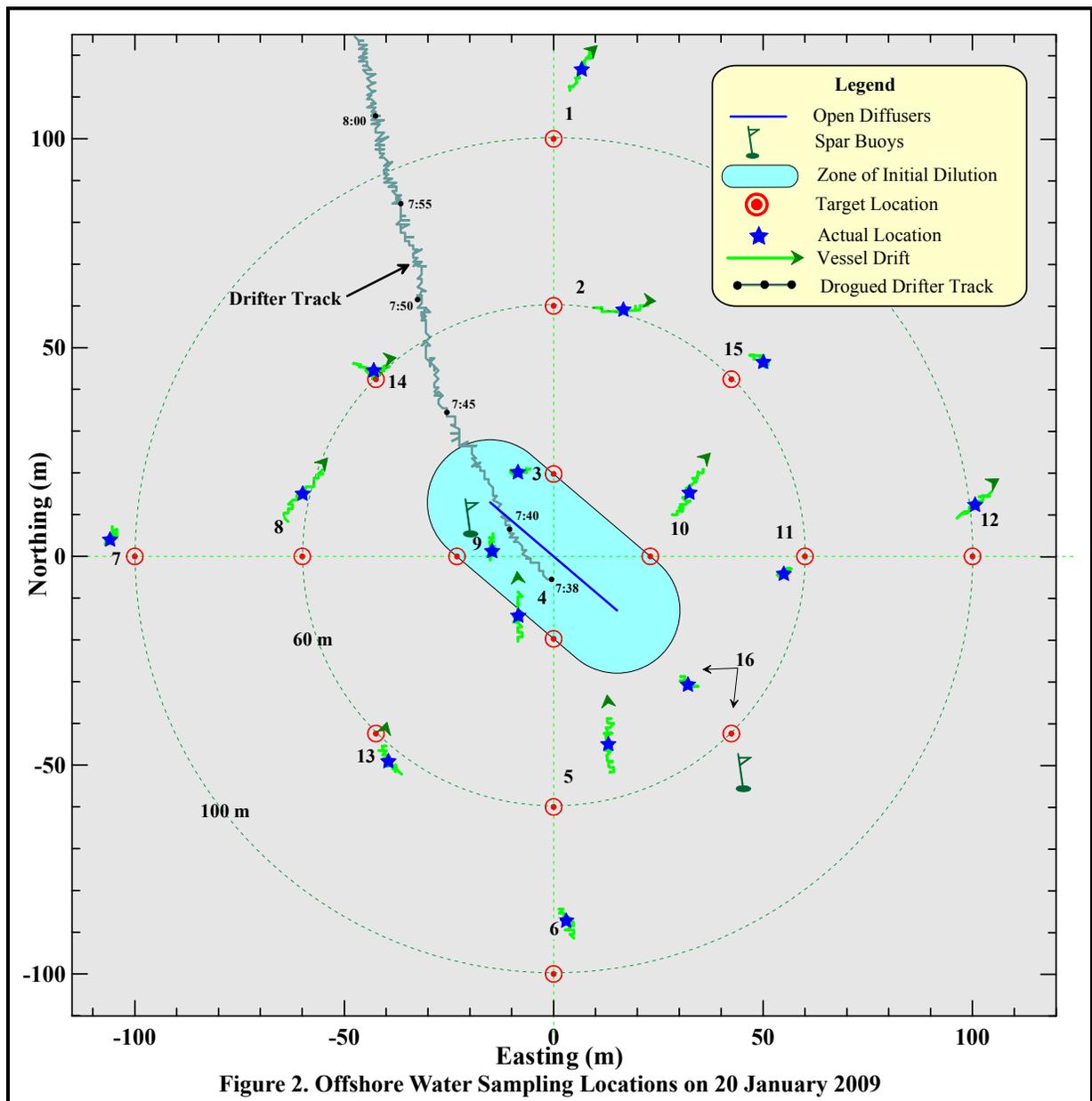


Figure 2. Offshore Water Sampling Locations on 20 January 2009

Near the diffuser, prevailing currents generally follow bathymetric contours that parallel the north-south trend of the adjacent coastline. Because of the 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 annual reports. The instances of elevated beach coliform levels occasionally observed all resulted from onshore, non-point sources and not from the disinfected wastewater discharge from the MBCSD outfall (MRS 2000 - 2008).

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 red  symbols in the Figure indicate the target locations of the 16 offshore sampling stations. The stations are situated at three distances relative to the center of the diffuser structure to capture any discharge-related trends in seawater properties. Six of the stations lie along a north-south axis at the same water depth (15.2 m) as the center of the diffuser. Stations 3 and 4 are positioned at the upcoast and downcoast boundaries of the ZID, 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 are midfield stations 100 m upcoast and downcoast of the centroid. Depending on the direction of the local oceanic currents at the time of sampling, the discharge could conceivably influence one or more of these stations. Under those circumstances, the midfield station on the opposite side of the diffuser acts as a reference station. Comparisons of water properties at these antipodal stations quantify departures from ambient seawater properties to evaluate compliance with the NPDES discharge permit.

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

An important consideration in the assessment of wastewater dispersion close to the discharge is the finite size of the diffuser. Although the discharge is considered a “*point source*” for modeling and regulatory purposes, it does not occur at a point of infinitesimal size. Instead, the discharge is distributed along a 42 m section of the seafloor, and, ultimately, the amount of wastewater dispersion at a given point in the water column is dictated by its distance from the closest diffuser port, rather than its distance from the center of the diffuser structure. The “*closest approach*” distance can be considerably less than the centerpoint distance normally cited in modeling studies (Table 1).

Another important consideration for compliance evaluation is the ability to determine the actual location of the measurements. This ability to discern small spatial separations among stations within the compact sampling pattern specified in the discharge permit only became feasible 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 legally could not be perfectly accurate; 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 SA was turned off in May 2000, the accuracy of standard GPS receivers improved substantially, with horizontal position errors of typically less than 10 m.

Even so, extreme atmospheric conditions and physiographic obstructions still cause refraction of satellite signals, leading to errors in position beyond those introduced by SA. The Differential GPS (DGPS) system, first implemented by the U.S. Coast Guard to enhance offshore navigation, greatly reduces these errors. 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 provides an extremely stable and accurate offshore navigational reading, 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. On 29 July 1998, this navigational system precisely located the position of the open section of the diffuser structure (MRS 1998b) and established the new target locations for the receiving-water monitoring stations shown in Figure 2 and listed in Table 1. The survey vessel is now fitted with two independent DGPS receivers to allow access to two separate land-based beacons for navigational intercomparison, which ensures extremely accurate and uninterrupted navigational reports.

Frequent recording of DGPS readings allows precise determination of sampling locations throughout the vertical CTD profiling at individual stations. Knowledge of the precise location of individual CTD measurements relative to the diffuser position is critical to accurately interpret the water-property fields. During any given survey, the actual sampling locations rarely coincide with the exact target coordinates listed in Table 1 because winds, waves, and currents induce offsets during sampling. The residual momentum of the survey vessel as it approaches the target locations can create an equally important offset. Using DGPS, these offsets can be resolved and the vessel location can be precisely tracked throughout sampling at each station. This is a key consideration for compliance evaluations because vertical profiling conducted at an individual station can cover a large horizontal distance relative to the ZID.

The magnitude of the horizontal drift at each of the stations during the January 2009 survey is apparent from the length of the green tracklines in Figure 2. These tracklines trace the horizontal location of the CTD instrument package as it is lowered to the seafloor. Their lengths reflect the station-keeping difficulty experienced during the January 2009 survey. During the time it took the CTD to traverse the water column to the seafloor, which averaged 1 min 19 s, the instrument package moved as much as 15 m laterally (Station 8). Overall, however, the average drift over all the stations was only 8.5 m, which is typical of most surveys.

The CTD trajectories reflect the complex interaction between surface currents, wind forces, and residual momentum as the vessel approached each station. Generally, winds can move the vessel to a greater degree than current flow. However, as summarized in Table B-9, winds were light and variable during the survey and their influence was generally minimal compared to the northward drift induced by the prevailing current. As shown by the green tracklines in Figure 2, drift at many of the stations had a northward component similar to the drifter track. The eastward component of drift at some stations (1, 2, 10, and 12) arose from prevailing winds when the flow-field drift was counteracted by the residual momentum after the vessel approached those stations from the north. The influence of vessel momentum was determined from the vessel's track before each downcast was conducted, although these portions of the vessel tracks are not shown in Figure 2. For example, the northeastward CTD drift at Station 8, which was the largest drift recorded, resulted from the combined influence of the northward current and the vessel's approach from the southwest.

Though generally small, lateral movement of the CTD during the downcasts can complicate compliance assessments at Stations 3, 4, 9, and 10, whose target locations are on the ZID boundary. Most receiving-water limitations specified in the COP do not apply to measurements recorded within the ZID because initial mixing may not be complete. Turbulence associated with the momentum of the effluent jet and the subsequent rise of the buoyant plume was responsible for initial mixing within the ZID. Permit limitations apply to conditions after this initial mixing is complete at some location beyond the ZID boundary. However, during the January 2009 survey, all or part of the downcasts at three stations (3, 4, and 9) included data collected within the ZID. The measurements recorded at Stations 3 and 9 were not subject

to the permit limitations because the CTD was within the ZID boundary throughout the vertical casts. Similarly, the vertical profile at Station 4 traversed the boundary of the ZID (see the green arrow in Figure 2) and only the shallowest portion of the data recorded during that cast was subject to the receiving-water limitations specified in the NPDES discharge permit.

Compliance assessments notwithstanding, measurements recorded close to the diffuser structure within the ZID lend valuable insight into the outfall's effectiveness at dispersing wastewater. Low dilution rates and concentrated effluent throughout the ZID would indicate damaged or broken diffuser ports. Without measurements recorded within the ZID, the discharge plume might go undetected. This was the case in nearly every water-quality survey conducted prior to 1999, before the present denser sampling pattern was instituted.

Surveys prior to 1999 also lacked the benefit of DGPS. Consequently, the average 8.5-m drift experienced during the January 2009 survey would not have been resolved with the navigation available at that time, and there would have been no indication that the CTD's location changed relative to the ZID during the casts. As a result, before 1999, sampling was presumed to occur at a single, imprecisely determined, horizontal location. Federal and State reporting of monitoring data still requires identification of a single position for all of the CTD data collected at a particular station. Thus, for regulatory reporting, and for consistency with past surveys, the January 2009 survey also identifies a single sampling location for each station. These average station positions are shown by blue stars in Figure 2 and are listed in Table 2 with their distances from the diffuser structure. However, based on the foregoing discussion, an average station position that happens to lie outside the ZID does not imply that all of the measurements collected at that particular station were subject to the receiving-water objectives in the discharge permit.

Table 2. Average Coordinates of Vertical Profiles during the January 2009 Survey

Station	Time (PST)		Latitude	Longitude	Closest Approach	
	Downcast	Upcast			Range ¹ (m)	Bearing ² (°T)
1	8:52:17	8:53:27	35° 23.262' N	120° 52.500' W	106.1	12
2	8:48:21	8:49:27	35° 23.231' N	120° 52.493' W	56.2	34
3	8:42:31	8:43:53	35° 23.210' N	120° 52.510' W	9.9 ³	41
4	8:38:21	8:39:51	35° 23.191' N	120° 52.510' W	16.2 ⁴	221
5	8:34:40	8:36:04	35° 23.175' N	120° 52.495' W	31.9	184
6	8:30:33	8:31:56	35° 23.152' N	120° 52.502' W	75.1	189
7	8:00:13	8:01:45	35° 23.201' N	120° 52.574' W	91.2	264
8	8:03:39	8:05:03	35° 23.207' N	120° 52.544' W	44.8	273
9	8:07:07	8:08:20	35° 23.200' N	120° 52.514' W	8.5 ³	221
10	8:13:53	8:15:00	35° 23.207' N	120° 52.483' W	32.8	221
11	8:17:14	8:18:31	35° 23.197' N	120° 52.468' W	40.8	77
12	8:20:33	8:21:53	35° 23.206' N	120° 52.438' W	89.2	73
13	9:01:33	9:02:45	35° 23.177' N	120° 52.531' W	58.0	221
14	7:54:37	7:56:24	35° 23.223' N	120° 52.532' W	42.2	319
15	8:55:43	8:56:50	35° 23.224' N	120° 52.471' W	68.0	41
16	8:26:21	8:27:29	35° 23.182' N	120° 52.483' W	24.4	136

¹ Distance from the closest open diffuser port to the average station position. Stations with some observations collected within the ZID are shown in bold.

² Direction measured clockwise in degrees from true north from the closest diffuser port to the average sampling location.

³ The entire CTD cast was within the ZID boundary.

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

In particular, the deepest measurements at Station 4 were not subject to receiving-water limitations, even though the average Station 4 location (16.2 m) was outside the ZID. Moreover, the average 16-m distance listed in Table 2 offers little insight into the true proximity of individual measurements relative to the discharge. During the Station-4 hydrocast, the CTD began its descent 26.5 m from the diffuser structure and crossed the ZID boundary at depth of 11.9 m. The measurements recorded below this depth were all within the ZID, and, when the CTD reached the seafloor, it was only 11.9 m from the diffuser structure. This lateral movement is not reflected in the closest-approach distance of 16.2 m listed in Table 2 for Station 4.

FLOW FIELD

The trajectory of a satellite-tracked drogued drifter documented a moderately strong north-northwestward flow during the January 2009 survey (Figure 3). The drifter is designed to track the subsurface current, with little influence from the wind. As such, the drifter track provides a good indication of the plume transport direction at the time of the survey. The grey line with black dots in Figure 3 shows the drifter's trajectory. Each dot along the drifter track represents a time span of five minutes. The drogued drifter was deployed near Station 4 at 7:38 PST and recovered one hour and twenty-eight minutes later, at 9:06 PST. The trajectory shows that a moderate, steady current carried the drifter rapidly north-northwest (344°T) and out of the survey area. While deployed, the drifter traversed a total of 436 m at an average speed of 8.26 cm/s or 0.16 knots.

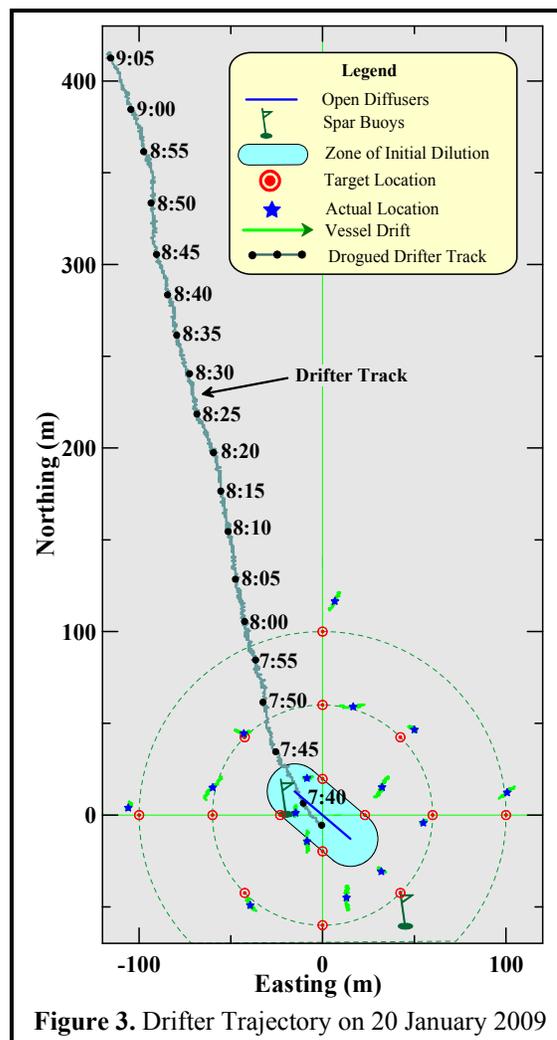


Figure 3. Drifter Trajectory on 20 January 2009

The northward flow component revealed by the drifter track was inconsistent with the outgoing (ebb) tide that occurred throughout the January 2009 survey (Figure 4). Ebb tides normally induce a weak southwestward flow in the survey region; however, during the week of the survey, a northward-directed coastal flow prevailed within Estero Bay and throughout the south-central coastal region of California, as seen in the image on the cover of this report. Northward flow was also recorded at the Diablo Canyon waverider buoy located offshore Pt. Buchon. This large-scale regional flow overwhelmed any tidal influence in the survey area.

Although, as stated above, flow can be tidally influenced, within Estero Bay flow is usually dominated by external processes, such as wind-generated upwelling or passing offshore eddies. Beginning with an intensification of southeastward-directed winds in early spring and continuing throughout most of the year, surface waters are driven southward and offshore. To replace these coastal surface waters, deep, cool, nutrient-rich waters upwell near the coast. During the winter season, however, these upwelling winds occasionally relax and the influence of more-remote forces becomes apparent. Such was the case during the January 2009 survey.

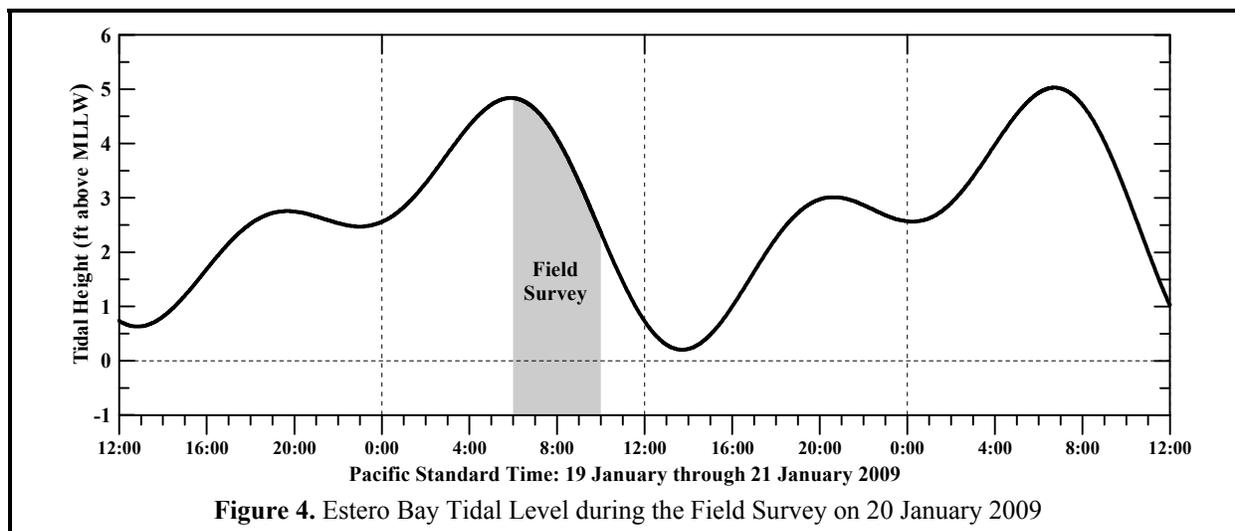


Figure 4. Estero Bay Tidal Level during the Field Survey on 20 January 2009

The January 2009 survey was unique because it was conducted during the middle of a comparatively rare, sustained lull in upwelling conditions. The satellite image on the cover of this report captured this event. It was recorded at 10:00 AM on the day of the survey by infrared sensors on one of NOAA’s polar orbiting satellites, during a period of relatively cloudless atmospheric conditions. It depicts the uniform sea-surface temperatures that were present along the south-central California coast at the time of the survey. The overall contrast in sea-surface temperature across the entire region shown was less than two degrees. This extraordinarily small temperature range contrasts starkly with images recorded during most other offshore surveys when some degree of upwelling is almost always present (Figure 5).

Consequently, satellite images of this area of the coast usually encompass a much greater temperature range, typically between 6°C and 12°C. The greater temperature range results from a large contrast between coastal and offshore surface temperatures. During these periods, the upwelling signature is reflected in much colder seawater the near the coastline, and occasionally extending offshore at major promontories such as Pt. Piedras Blancas, Pt. Buchon, and Pt. Arguello.

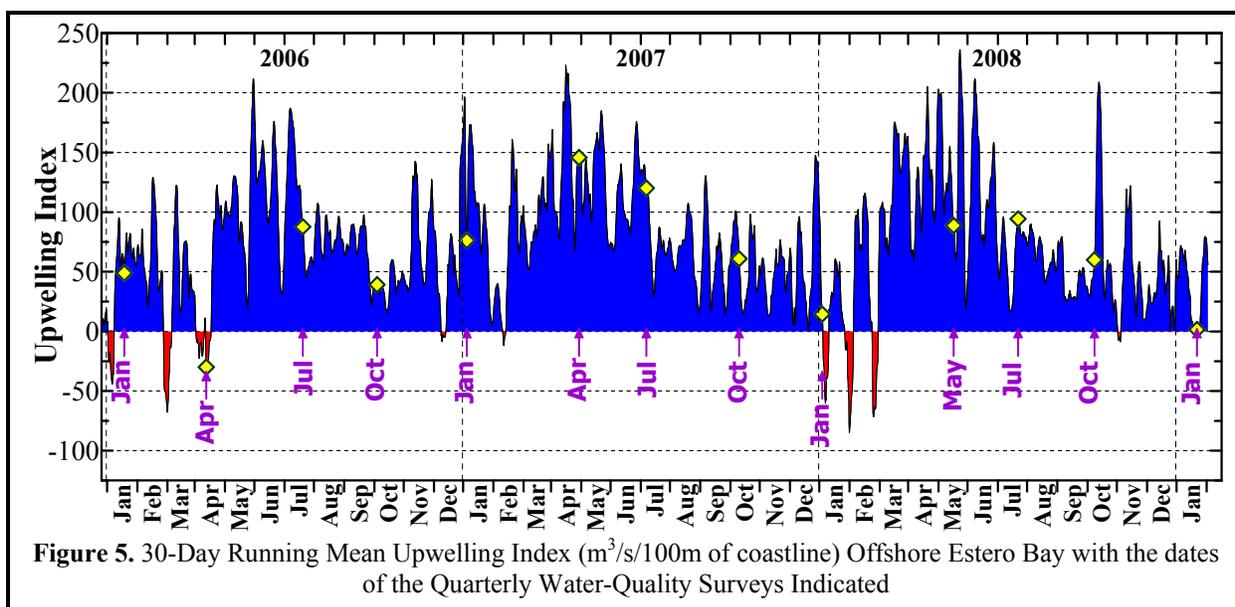


Figure 5. 30-Day Running Mean Upwelling Index ($m^3/s/100m$ of coastline) Offshore Estero Bay with the dates of the Quarterly Water-Quality Surveys Indicated

Within the January 2009 cover image, a diffuse flow of warmer water, delineated in light blue and yellow, can be observed emanating from the Southern California Bight and extending northward along the south-central coast. This broad, northward flow is a surface manifestation of the Davidson Undercurrent, which, when southward winds relax, carries warm water out of the Bight. During upwelling events, the cross-shore flow pattern is generally far more complex; satellite images commonly show offshore transport of cool water extending offshore the major promontories of Pt. Piedras Blancas, Pt. Buchon, and Pt. Arguello. Additionally, upwelling-induced cross-shore flow strongly stratifies the water column as deep, cold offshore waters are carried shoreward at depth to replace warmer surface waters that are driven offshore by the prevailing winds. In contrast, when upwelling is not present, the water column in the survey area tends to be vertically uniform, as was the case during the January 2009 survey.

Only during two other recent surveys, in April 2006 and January 2008, were upwelling winds similarly absent. In the case of the April 2006 survey, northwestward winds induced downwelling near the coast, as reflected by the negative upwelling indices shown in red in Figure 5. Similarly, upwelling was not occurring during the January 2008 survey, which preceded an extended period of winter storms. In both cases, the water column was largely unstratified, with low turbidity and uniform sea surface temperatures throughout the region, as was the case in the January 2009.

METHODS

The 38 ft F/V *Bonnie Marietta*, owned and operated by Captain Mark Tognazzini of Morro Bay, served as the survey vessel on Tuesday 20 January 2009. Dr. Douglas Coats of Marine Research Specialists (MRS) was the Chief Scientist, Captain Mark Tognazzini supervised vessel operations, and his son, Mr. Marc T. Tognazzini served as marine technician. Ms. Bonnie Luke and Mr. Tyler Eck, both of MRS, provided additional scientific support and collected auxiliary measurements of meteorological and oceanographic conditions throughout the survey. These measurements included Secchi depths and the standard observations for weather, sea conditions, and water clarity/coloration listed in Table B-9. A Kestrel[®] 2000 Thermo-Anemometer measured wind speeds and air temperatures. The crew collected these auxiliary observations contemporaneously with the rapid water-column profiling conducted at each station using a CTD instrument package.

Auxiliary Measurements

At all stations, lowering a Secchi disk through the water column determined 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 biologically significant because the depth of the euphotic zone, where most oceanic photosynthesis occurs, extends to approximately twice the Secchi depth.

Secchi depths recorded during the January 2009 survey averaged between 7 and 8 m, and reached 8.5 m at Station 9. The high seawater clarity during the survey reflected a euphotic zone that extended almost all the way to the seafloor at most of the stations. A deeper-than-usual euphotic zone is typical of wind-relaxation events when unstratified conditions and decreased primary production, namely decreased phytoplankton density, increases the transmission of ambient light throughout the water column. The absence of other confounding factors, such as high onshore runoff, strong winds, and high waves, also contributed to the unusually high seawater clarity during the January 2009 survey.

The transmissometer mounted on the CTD instrument package provides more precise and site-specific measures of turbidity than the Secchi depth measurements. Nonetheless, the uniformly high

transmissivity measured throughout the survey echoed the high seawater clarity reflected by the deep Secchi measurements. At all locations, even within the discharge plume at Station 3, more than 75% of a light beam was transmitted across a 0.25-m path (Table B-5). Measurements of light transmittance recorded below the maximum Secchi depth of 8.5 m demonstrated that high water clarity was present throughout the water column, even close to the seafloor. Both sets of measurements captured the slight increase in turbidity associated with the presence of wastewater particulates within the plume at Station 3. The 7-m Secchi depth measured at Station 3 was significantly³ shallower than the 7.9-m average depth measured at other stations, reflecting an encounter with the upper portion of the effluent plume. Most of the plume was located below 8 m at that station, as shown by the reduced transmissivity recorded by the CTD between 8 m and 15 m (Table B-5, middle-left frame of Figure A-1, top frame of Figure A-5).

The satellite-tracked drifter deployed near the open section of the diffuser structure during the January 2009 survey was drogued at mid-depth (7 m) using the curtain-shade design of Davis et al. (1982). In this configuration, the oceanic flow field rather than surface winds largely dictated the drifter's trajectory. The times and precise positions of the drifter deployment and recovery were recorded to determine the overall strength and direction of plume transport during the January 2008 sampling effort. In addition, the January 2009 survey was the sixteenth MBCSD survey to record the drifter position throughout its deployment, rather than merely calculating the average flow velocity solely from the vessel position at the time of the drifter's deployment and recovery.

Instrumental Measurements

An electronic instrument package equipped with a number of probes and sensors was deployed in a vertical water-profiling mode. The Sea Bird Electronics SBE-19 Seacat CTD package collected measurements of conductivity, salinity, temperature, light transmittance, dissolved oxygen (DO), pH, density, and pressure throughout the water column 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.

The CTD instrumentation receives regular maintenance and calibration. After the January 2001 survey, the CTD was returned to the factory for comprehensive testing, repair, and calibration. Temporal drifts in the oxygen and alkalinity readings during the January 2001 survey indicated that an accumulation of marine growth had degraded the sensitivity of these probes. During the factory repair, both the pH probe and the electrolyte in the oxygen sensor were replaced. The entire CTD system was then calibrated 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 they confirmed the accuracy and stability of the refurbished sensors. The DO and pH sensors were again returned to the factory in May 2003 and in June 2006 for testing and calibration. Because of increasing temporal drift associated with the aging DO probe, it was replaced on both occasions with a new DO probe.

As is the case before all surveys, the CTD system was recalibrated at the MRS laboratory prior to the January 2009 survey. The upper-bound DO calibration point at full saturation 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 (Na₂SO₃). Oxygen calibration coefficients were determined by

³ The statistical significance of departures is measured by the probability (p) that the difference could have occurred by chance alone. There was only a 0.4% chance ($p=0.004$) that the 0.9-m reduction in Secchi depth at Station 3 was happenstance. This p -value was well below the 5% threshold prescribed in the COP for evaluating significance.

Table 3. Instrumental Specifications for CTD Instrumentation Package

Component	Depth¹	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	°C	-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

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 with those coefficients determined in the past by the factory.

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

All three of the physical parameters (salinity, temperature, and density) helped determine the lateral extent of the effluent plume. Additionally, they quantified layering, or vertical stratification and stability of the water column, which determines the behavior and dynamics of the wastewater as it mixes with seawater within the ZID. Data on three remaining seawater properties, light transmittance (water clarity), hydrogen-ion concentration (acidity/alkalinity – pH), and dissolved oxygen (DO), further characterized receiving waters and were used to assess compliance with water-quality criteria. Light transmittance was measured as a percentage of the initial intensity of a transmitted beam of light detected at the opposite end of a 0.25-m path. Increased transmittance indicates increased water clarity and decreased turbidity.

During the pre-cruise calibration, coefficients for the pH (alkalinity) sensor were determined from a linear regression of output voltage after immersion in five separate buffered solutions of known pH. Buffering solutions with a pH of 4±0.01, 6±0.01, 7±0.01, 9±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). Algorithms that converted sensor voltage to engineering units during processing of the field data relied on calibration coefficients determined before the survey. Comparison with the factory calibration of the entire CTD package conducted in December 2001, and the more recent June 2006 replacement and calibration of the DO probe, confirmed the continued accuracy and stability of the temperature, pressure, and conductivity sensors, as well as the operational integrity of the oxygen and pH probes.

Before deployment at the initial station, the CTD was held below the sea surface for a six-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 all the

stations were collected during single deployment of the CTD package by towing it below the water surface while transiting between adjacent stations. Upon retrieval of the CTD, the profile data were downloaded to a portable computer and examined for completeness and range acceptability.

Temporal Trends in the DO and pH Sensors

The DO and pH sensors exhibited slight temporal drift during the January 2009 survey. Perceptible drift in pH measurements has been consistently observed in prior water-quality surveys as the result of ongoing sensor equilibration during profiling. The very small drift in the DO sensor is normally imperceptible except during surveys when the range in the ambient DO field is small, as was the case during the January 2009 survey. For the pH sensor, prolonged exposure to the atmosphere between surveys causes the largest offsets and can also affect the dynamic range of the measurements. During past surveys, equilibration offsets were also observed when the CTD was redeployed after being brought onboard to download data during the middle of the survey. Use of a single deployment during the January 2009 survey obviated the need for mid-survey adjustments for pH drift.

Previous attempts to mitigate sensor drift included prolonging the soak time of the CTD prior to profiling. Soak times of six minutes at the beginning of a survey reduced, but did not entirely eliminate, sensor drift. During the January survey, a tube filled with seawater placed around the pH sensor while in transit to the survey site limited atmospheric exposure of the probe immediately prior to deployment. This technique successfully ameliorated further sensor drift.

Temporal drift in the DO and pH sensors was responsible for slight, but perceptibly lower measurements at the first two stations occupied during the CTD deployment. Beginning with Station 14, where the respective DO and pH offsets were -0.08 mg/L and -0.013 pH units, equilibration-related reductions became steadily smaller as the survey progressed. The magnitudes of the offsets for each station were determined by fitting a piecewise continuous linear trend to values recorded near the seafloor, and then computing the difference between the fitted values and values measured near the end of the survey, when the sensors had fully equilibrated.

Removal of the artificial DO and pH trends was important because the drifts were large compared to reported accuracy and precision of the probes. As a result, they could potentially mask smaller-amplitude, discharge-related anomalies. For example, the artificial pH reduction (-0.013 pH) at the beginning of the deployment was twice as large as the instrumental resolution (± 0.006 pH) reported by the probe manufacturer (Table 3). Although the artificial DO reduction (-0.08 mg/L) was less than the sensor's reported accuracy (± 0.14 mg/L), its correction was significant enough to eliminate an erroneous anomaly highlighted in Table B-8 at Station 14. Before correction, the equilibration-related offset in pH at Station 14 also produced an erroneous, statistically significant anomaly that extended throughout the water column (Table B-7). As expected from the temporal trends, the largest of the equilibration-induced anomalies appeared at stations sampled at the beginning of the survey, and correction eliminated the significance of the erroneous DO and pH offsets at the first station (boxes removed from around Station 14 in Tables B-4 and B-6).

RESULTS

The first-quarter water-quality survey began just after sunrise at 07:38 PST on Tuesday, 20 January 2009, with the deployment of the drogued drifter. Subsequently, water-column measurements were collected as required by the NPDES monitoring program (Tables 2 and B-9). Skies were clear throughout the survey, which ended at 9:06 PST with the retrieval of the drogued drifter. Due to the absence of low-lying fog,

atmospheric visibility along the ocean surface was also good. Consequently, Morro Rock and the shoreline remained visible throughout the survey.

Average wind speeds, calculated over one-minute intervals, were light and variable throughout the survey, ranging from 0.6 kt to 3.2 kt (Table B-9). Corresponding, peak wind speeds ranged from 0.9 kt to 5.8 kt. In accordance with these light winds, seas were calm with a significant wave height of approximately 4 ft, mostly due to a long-period swell out of the west. Air temperatures, slightly warmer than sea surface temperatures, ranged between 14.7°C and 18.4°C.

The discharge plume was not visually apparent during the survey, although, as described above, the Secchi depth at Station 3 was slightly shallower because the disk encountered the upper portion of the plume near 7 m. Located entirely within the ZID, this station was undoubtedly influenced by an increase in turbidity due to the presence of the diffuse wastewater particulates within receiving waters that otherwise had extraordinarily high ambient visibility. By the time the effluent plumed moved close to the sea surface at Stations 1 and 2, the wastewater particulates were too diffuse to affect Secchi depths, which were close to the survey average at those stations. Nevertheless, the much-more-sensitive transmissometer on the CTD resolved a slight reduction in water clarity at these stations (top frame of Figure A-5), although the reduction was not statistically significant (no boxes around measurements at Stations 1 and 2 in Table B-5). There was no visual evidence of floating particulates, or oil and grease, at any time during the survey.

Beneficial Use

During the January 2009 survey, observations demonstrated continued beneficial uses of the coastal waters within Estero Bay by wildlife and recreational users. Small numbers of a variety of seabirds were observed during transit to and from the survey area and during the course of the survey. Species included mature California brown pelicans (*Pelecanus occidentalis californicus*), Brandt's cormorants (*Phalacrocorax penicillatus*), pelagic cormorants in breeding plumage (*Phalacrocorax pelagicus*), Heermann's gulls (*Larus heermanni*), and western gulls (*Larus occidentalis*). In addition to avian fauna, several southern sea otters (*Enhydra lutris nereis*) were observed during transit to and from the survey site. On the way to the survey site, three adult females with young pups were observed at different points near the turning of the harbor, just past the US Coast Guard station. A fourth female and pup were seen near the breakwater at the entrance. A lone harbor seal was also spotted at the breakwater. While transiting back to the dock, additional otters were documented within the harbor mouth. A lone otter was observed feeding, while two individual pairs of otters were observed playing with one another. Pieces of detached bull kelp (*Nereocystis luetkeana*) were also noted drifting in the survey area and during transit to the survey area.

Though weather was fair, few humans were documented using the beach and nearshore waters, probably due to the early hour and the combination of a 4-ft swell and high tide, which obscured the lower surfline and beach area from sight during much of the survey.

Ambient Seawater Properties

Data collected during the January 2009 survey reflect the exceptionally uniform, unstratified conditions indicative of a well-mixed water column. Normally, upwelling-induced cross-shore flow creates strong vertical density gradients. The resultant water-column stability inhibits the vertical movement of water parcels. Conversely, when upwelling is minimal or absent, convective cooling and mechanical stirring from winds and waves easily mix seawater properties throughout the entire water column. Additionally, after upwelling winds relax, the depth-averaged seawater temperature near the coast increases because cool deep seawater is no longer transported shoreward. Accordingly, average seawater temperature during

the January 2009 survey (12.45°C) exceeded temperatures normally observed during spring and summer seasons, when upwelling is strongest. During the spring and summer surveys, nearshore seawater temperatures average less than 12°C. Although warmer seawater temperature during winter is contrary to seasonal fluctuations in air temperature, the observed decline in spring and summer water temperatures attests to the importance of upwelling in determining seawater properties.

An unstratified water column, like that observed during the January 2009 survey, lacks buoyant stability, which normally inhibits the vertical exchange of nutrients and other seawater properties. Consequently, water parcels tend to easily move throughout the entire water column, and the resulting vertical exchange rapidly erodes any localized gradients introduced, for example, by seafloor point sources such as the outfall. Enhanced vertical mixing within the unstratified water column of the January 2009 survey is apparent in the straight vertical profiles present in all seawater properties at nearly every station (Figures A-1 through A-3). Their appearance departs markedly from that of most other surveys, where upwelling creates sharply defined vertical changes in seawater properties that are readily apparent in the profiles.

The seawater uniformity during the January 2009 survey is also apparent in the vertical sections shown in Figures A-4 through A-7. Many of the sections exhibit little, if any, difference in seawater properties among the stations, despite an exceedingly small range in scales (shown to the right of the vertical sections). In particular, the cross-shore transect did not encounter the plume and, consequently, the vertical sections shown in Figures A-6 and A-7 exhibit very little variation in any property except, perhaps, transmissivity. These relatively blank vertical sections were not produced in error but simply reflect the extremely well-mixed water column at the time of the survey. Similarly, because dilute wastewater particulates do not induce perceptible thermal and DO offsets, the along-shore vertical sections in those water properties appear uniform as well (middle frames of Figures A-5 and A-6), even though other water properties clearly captured the presence of the plume. The extraordinarily uniform temperature field varied by only 0.1°C across all 490 observations during the January 2009 survey. This contrasts with the 0.1°C vertical variation in temperature measured during the May 2008 survey.

The general absence of thermal variation during the January 2009 survey eliminated the problematic salinity spiking that usually plagues the salinity data. Salinity spikes are instrumental artifacts arising from the mismatch that can occur between conductivity and temperature measurements collected near sharp, localized thermoclines. Because of the absence of sharp vertical gradients in temperature, there were no erroneous instrumental spikes present in the January 2009 salinity data.

Beyond the influence of the discharge, the observed ranges in ambient salinity (0.06‰) and density (0.11σ_t) were similarly limited, with little or no perceptible trend (top and bottom frames of Figure A-6). The range in these properties during the January 2009 survey was approximately one-fourth of the range measured in ambient seawater during most other surveys. Likewise, the respective ranges of 0.37 mg/L for DO and 0.04 units for pH were an order-of-magnitude smaller than the variability found during most other surveys. In fact, no perceptible DO variation was recorded within the effluent plume (middle frame of Figure A-5) even though salinity, density transmissivity, and pH all reflected the presence of wastewater constituents at Stations 1, 2, and 3 (Figures A-4 and A-5).

Transmissivity was the only property to exhibit perceptible vertical structure within ambient seawater during the January 2009 survey (top frame of Figure A-7). However, in contrast to the vertical structure generally seen in seawater properties during other surveys, the vertical gradients in transmissivity were not related to upwelling or density stratification. Instead, the vertical distribution in transmissivity during the January 2009 survey, and during many prior surveys, was related to a reduction in water clarity immediately above the seafloor resulting from the resuspension of surficial sediments. A thin benthic nepheloid layer (BNL) often forms immediately above the seafloor when turbulent shear associated with the bottom boundary layer couples with oscillatory motions generated by surface gravity waves to

Table 4. Discharge-Related Water-Property Anomalies^a

Perturbation ^b	Station	Depth Range	Depth of Extremum	Property	Magnitude	Mechanism
P1 Dilution ≥ 269:1	3	7.5 to 16.5 m	10.5 m	Salinity	-0.124‰	Effluent
		7.5 to 16.5 m	10.5 m	Density	-0.097σ_t	Effluent
		8.0 to 15.0 m	9.5 m	Transmissivity	-2.38%	Effluent
		9.5 to 14.5 m	10.5 m	pH	-0.014	Effluent
P2 Dilution = 696:1	2	0.0 to 9.5 m	2.0 m	Salinity	-0.048‰	Effluent
		0.0 to 9.5 m	2.0 m	Density	-0.036σ_t	Effluent
		0.0 to 9.5 m	1.0 m	Transmissivity	-1.22%	Effluent
P3 Dilution = 1239:1	1	0.0 to 7.0 m	1.5 m	Salinity	-0.027‰	Effluent
		0.0 to 7.0 m	1.5 m	Density	-0.018σ _t	Effluent
		0.0 to 7.0 m	2.5 m	Transmissivity	-0.89%	Effluent

^a Anomalies shown in bold type were statistically significant

^b Perturbations are composed of a group of spatially coincident anomalies in several different seawater properties

resuspend light-weight detritus that has been deposited on the seafloor. This particle-rich BNL is a widespread phenomenon on continental shelves (Kuehl et al. 1996) and is often seen during water-quality surveys conducted for the MBCSD. The thickness of the BNL varies between stations, as does the CTD's penetration into the layer. As a result, the transmissometer only intermittently records the presence of reduced transmissivity associated with the BNL. Accordingly, some stations, such as Station 9, did not indicate the presence of the BNL during the January 2009 survey (top frame of Figure A-7), while adjacent stations, such as Station 7, exhibited statistically significant increases in seafloor transmissivity (shown in bold font in Table B-5).

Lateral Variability

Localized anomalies in seawater properties, particularly salinity, best identify the influence of the effluent discharge. In contrast to an inspection of isolated vertical profiles, discharge-related anomalies become especially apparent in vertical cross-sections, which highlight differences in seawater properties at adjacent stations. For example, although the deep wastewater-induced perturbation at Station 3 is readily apparent in the vertical profiles of salinity (green line) and density (black line) in the middle left frame of Figure A-1, subtler anomalies in other seawater properties, and in all the properties at Stations 1 and 2, are not easily discerned from the vertical profiles.

Instead, vertical sections provide a more effective visualization of the anomalies at these three stations, and they lend insight into their relationships to one another (top and bottom frames of Figures A-4 and A-5). Anomalies caused by the presence of dilute wastewater are plainly evident below 7 m at Station 3 in four of the six seawater properties. Weaker anomalies in salinity, density, and transmissivity are also apparent in the upper water column at Stations 1 and 2 (top and bottom frames of Figure A-4, and top frame of A-5). These anomalies are grouped together within three discharge-related perturbations whose characteristics are tabulated in Table 4. Anomalies were not apparent in the temperature and DO fields at any of the along-shore or cross-shore stations (middle frames of Figures A-4 and A-5).

The three perturbations are consistent with northward transport of increasingly dilute wastewater within the rising effluent plume. All three stations were located near the path of plume transport as depicted by the drogued drifter trajectory shown in Figure 2. Station 3 (Perturbation 1) exhibited the largest and deepest anomalies, consistent with its close proximity to the diffuser structure. As the effluent plume

travelled another 40 m to Station 2, its upper portions approached the sea surface (top and bottom frames of Figure A-4 and top frame of A-5). During transit to Station 2, buoyancy-induced turbulence further dispersed wastewater constituents, causing a 50% reduction in the amplitudes of the anomalies (Perturbation 2 in Table 4). Subsequent transport to Station 1 further dissipated the wastewater signature, down to near-background levels, and further compressed its vertical extent (Perturbation 3 in Table 4).

Several other lateral anomalies were also observed in the CTD data collected during the January 2009 survey, although they were unrelated to the discharge. Anomalies appear as statistically significant departures from mean seawater properties at a given depth level, and they are highlighted in the raw CTD data listed in Tables B-1 through B-8 by values surrounded by boxes. The lateral variability associated with each observation was computed by subtracting a particular measurement from the average of all other measurements at the same depth level. Natural variability was then estimated from the standard deviation of all measurements (excluding the one in question) for a given seawater parameter (e.g., salinity). Statistically significant anomalies departed from mean conditions by more than the 95% confidence interval, whose width is a function of the standard deviation and number of observations used to compute the average.

Certain aspects of the remaining significant anomalies demonstrate why they could not have been caused by the discharge. One of the most telling aspects is that the anomalies were not located in the path of plume transport, as defined by the drogued drifter trajectory. For example, the thermal, DO, and pH anomalies at Station 13 were located on the opposite (southern) side of the diffuser from the direction of plume transport (Tables B-1, B-4, and B-6). Equally important however, the anomalies were not spatially coincident with anomalies in other seawater properties, particularly salinity. Reduced salinity is always associated with the presence of detectable effluent concentrations because the contrast between seawater and effluent salinity is much greater than the contrast for any other seawater property. However, salinity reductions were only apparent at Stations 1, 2, and 3 and were easily ascribed to the discharge.

The sign of anomalies at other stations is another aspect that shows they were unrelated to the discharge. Effluent is more turbid and more acidic (lower pH) than seawater, and it exerts oxygen demand that reduces DO in the receiving waters. Thus, the presence of dilute wastewater could not have caused the positive anomalies, which indicate increased concentrations in DO and pH at Station 13 (Table B-4 and B-6). Similarly, the presence of wastewater particulates would not have produced the significantly increased transmissivity measured near the seafloor at Station 4 (shown by the italic font in Table B-5). Instead, variations in the thickness of the BNL, and the CTD's penetration depth into that layer, generated the seafloor transmissivity anomaly at Station 4, like the one previously discussed at Station 7.

Regardless of their provenance, statistically significant fluctuations unrelated to the discharge are expected from the nature of statistical hypothesis testing itself. From the definition of a 95% confidence level, one “*significant*” departure out of every 20 measurements should occur by chance alone. With 490 measurements examined for each of the parameters, the departure of a random few measurements from the mean by an amount more than the 95% confidence interval would not be surprising. Moreover, when multiple hypotheses are tested (*i.e.*, one for each observation), the error rate for each individual test should be adjusted to achieve the overall experiment-wise 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 correction 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 experiment-wise 95% confidence level.

For the reasons described above, the significant increases in temperature, DO, and pH observed in the upper water column at Station 13 were clearly unrelated to the discharge, although their exact source remains unclear (Tables B-1, B-4, and B-6). One plausible mechanism is the downward mixing of

seawater properties within the surface microlayer. The vessel had an inordinately difficult time acquiring the target location at Station 13, the last station sampled during the survey. It is possible that prop-wash from repeatedly jockeying the vessel mixed the seawater characteristics within the thin surface layer at this location downward into the water column.

Under normal circumstances, the CTD's comparatively large vertical dimension precludes detection of the differing seawater characteristics within the thin surface microlayer, which forms the interface between the warm oxygenated atmosphere and the underlying seawater. Gaseous exchange and enhanced microbial activity along this interface reduce dissolved CO₂ concentrations (carbonic acid) and, consequently, increase pH. With little stratification to inhibit vertical mixing, it is conceivable that prop-wash mixed the microlayer's higher DO and pH several meters downward in the water column just prior to the CTD cast at Station 13.

Discharge-Related Perturbations

The absence of strong stratification during the January 2009 survey has three major implications for the discharge. First, under stratified conditions, anomalies in seawater properties are often generated when ambient seawater is entrained at depth and carried upward in the water column by the rising effluent plume. Vertical differences in ambient seawater properties then become apparent as lateral anomalies produced by the contrast between the seawater properties that were upwardly displaced by the discharge and the shallow seawater properties. However, with little vertical difference in ambient seawater properties, as was the case in the January 2009 survey, the upward displacement of ambient seawater does not produce a lateral contrast. Consequently, during periods of wind-relaxation or downwelling only localized anomalies induced by the presence of dilute wastewater constituents are seen. If entrainment-generated anomalies are observed at all during these non-upwelling periods, they tend to be very weak and generally reflect any small degree of vertical stratification.

Accordingly, the discharge-related anomalies found at Stations 1, 2, and 3 during the January 2009 survey were distinct from ambient seawater, and were not generated by entrainment. The reduced concentrations measured within the anomalies, particularly at Station 3, were much lower than concentrations measured at unaffected Stations. Thus, entrainment could not have generated them. As a result, the anomalies appear spatially isolated and disconnected from the seafloor, as delineated by the red and green shading in the vertical sections in the top and bottom frames of Figures A-4 and A-5.

The second implication of an unstratified water column is that overall variability in the ambient seawater properties is reduced, allowing reliable resolution of even very small wastewater-induced anomalies. This is because it is more difficult to discern small, discharge-related perturbations when background variability is high, than in a uniform field of seawater properties where variability is low. When stratified conditions prevail, the presence of vertical gradients increase the overall variability in seawater properties. High natural variability often effectively masks small-amplitude anomalies, making them less likely to be deemed statistically significant whereas, under unstratified conditions, these same anomalies are readily apparent.

The third and last implication of unstratified conditions is that the discharge plume is more likely to rise all the way to the sea surface, as occurred during the January 2009 survey, thereby achieving a high level of initial dilution. This contrasts with more stratified conditions where the plume can become trapped at depth, long before the full potential of buoyancy-induced turbulent mixing is realized.

Thus, during the January 2009 survey, three perturbations in seawater properties were unequivocally related to the discharge (Perturbations 1, 2, and 3 in Table 4). Discharge-related perturbations are a group of anomalies in one or more seawater properties that are spatially contiguous at a particular station. Normally, anomalies induced by the presence of wastewater constituents are only apparent in the salinity

and density fields, but, because of the otherwise uniform conditions during the January 2009 survey, other characteristics of effluent were also able to be definitively discerned. For example, the high ambient seawater visibility allowed observation of the slightly reduced water clarity caused by the presence of wastewater particulates. Similarly, a reduction in pH at Station 3, though slight, was also identified. Neither of these anomalies would have been apparent against the higher background variability that occurs when the water column is stratified. Moreover, it is noteworthy that thermal and DO anomalies were not apparent, even at Station 3 where the plume was in close proximity (11.7 m) to the diffuser structure. The very small contrast between seawater and wastewater temperature and DO was rapidly dissipated upon ejection from the diffuser ports, and, consequently, their signature is not apparent in the vertical sections.

Also noteworthy are the negative density anomalies associated with all three perturbations. They demonstrate that the effluent plume was highly buoyant both within and beyond the ZID. At each of those three locations, the plume would be expected to continue to rise through the water column and spread laterally, subsequently achieving even higher dilutions. This is particularly true of the subsurface anomaly at Station 3 (delineated in red and green in the bottom frame of Figure A-4). The slug of low-density water is situated just below a layer of higher density seawater (shown in light blue). Such a density inversion reflects a strong buoyancy instability that would rapidly dissipate during turbulent overturn. Rapid, turbulent overturn is precisely the mechanism expected to occur upon discharge of buoyant wastewater. This mechanism is responsible for the substantial additional dilution that occurs after the initial momentum from the turbulent discharge jet begins to decline. Thus, Perturbation 1 captured plume dynamics shortly after discharge and measured the early stages of the dilution process before buoyancy-induced mixing had played a significant role in the dilution process.

The transmissivity anomalies associated with Perturbations 1, 2, and 3 were also relatively rare occurrences because the presence of effluent particulates generated them (top frame of Figure A-5). More than two decades of monitoring has shown that discharge-related anomalies in seawater properties, other than salinity and density, are almost always caused by entrainment. However, because of the high seawater clarity and unstratified conditions prevalent during the survey, the sensitive transmissometer on the CTD captured the plume's particulate signature before it had much of a chance to dissipate. The resulting transmissivity of 76%, although well above the transmissivity of ambient seawater during most other surveys, was 2.4% lower than the average ambient transmissivity measured at the same depth at other stations during the January 2009 survey (Table B-5).

It is also noteworthy that the reduction in pH associated with Perturbation 1 was exceedingly small. Its small amplitude supports the hypothesis that the properties of discharged wastewater contribute little to perturbations in the receiving waters except very close to the discharge. In fact, the range in pH values over the entire water column, including the anomaly, was only 0.044 pH units. Lateral variability of this scale is less than half of the reported accuracy of the CTD sensor (Table 3) and, as such, this anomaly would not be even apparent under stratified conditions.

Perturbation 3 was particularly unusual in that all of the anomalies associated with it were exceedingly small and would have been undetectable within the ambient seawater variability present during most other surveys. Based on analyses of data collected in 40 surveys conducted over the past ten years, salinity anomalies with amplitudes smaller than -0.05‰ usually become indistinguishable from background variation when the dilution exceeds 700-fold. Therefore, it was a rare circumstance to capture the plume signature in Perturbation 3 after dilution by over 1200-fold, and its occurrence at more than 100 m from the diffuser structure attests to the astoundingly uniform conditions within the receiving waters at the time of the January 2009 survey.

Initial Dilution Computations

The amplitudes of the negative salinity anomalies at Stations 2 and 3 lend insight into the 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 under highly stratified conditions where trapping of the plume below the thermocline limited mixing during the buoyant plume's rise through the water column. The dispersion modeling determined that, at the conclusion of initial mixing, 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 would become trapped beneath a thermocline and spread laterally with no further substantive dilution. A 9-m rise translates into a trapping depth that is 6.4 m below the sea surface.

However, as described below, computations of dilution based on the salinity anomaly measured at a depth of 10.5 m within Perturbation 1 demonstrate that the effluent plume actually achieved a much higher dilution ($\geq 269:1$) than the total dilution (133:1) predicted by conservative modeling. This was the case even though the plume was still buoyant at that depth and continued to mix during its rise to the surface at Station 2 (Perturbation 2), where effluent was diluted almost 700-fold. Thus, rapid mixing associated with the momentum of the discharge jet alone was capable of achieving far higher dilutions than predicted by modeling. This demonstrates that, during the January 2009 survey, the diffuser structure was operating more efficiently than predicted by the modeling.

The conservative nature of the critical initial dilution 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 in the COP (SWRCB 1997) using the projected 133-fold dilution determined from the modeling. Use of a higher critical dilution would relax the stringent end-of-pipe effluent limitations thought necessary to meet COP objectives.

End-of-pipe limitations on contaminant concentrations within discharged wastewater were based on the definition of dilution (Fischer et al. 1979). From the mass-balance of a conservative tracer, the concentration of a particular contaminant within effluent before discharge (C_e) can be determined from Equation 1.

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

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

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

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

where: D = the dilution ratio of the volume of seawater mixed with effluent,
 C_o = the salinity of the effluent-seawater mixture after dilution by D ,
 C_s = the background seawater salinity (approximately 33‰), and
 $A = C_o - C_s$ = the salinity anomaly.

The magnitude of the observed salinity anomaly at Station 3 (−0.124‰) was used in Equation 2 to compute the dilution level achieved within Perturbation 1. The computed dilution, listed in the leftmost column of Table 4, demonstrates that the modeled dilution factor (133:1) was significantly more conservative than that actually achieved by the discharge ($\geq 269:1$) at a location well within the ZID (11.7 m from the diffuser structure). The measured dilution was twice the dilution predicted by conservative modeling after an additional rise of 4 m through the water column. This dilution computation demonstrates that, during the January 2009 survey, the outfall was performing far better than designed and was rapidly diluting effluent more than 269-fold within the ZID boundary. 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 January 2009 survey demonstrated that the wastewater discharge complied 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, no particulates of sewage origin were seen floating on the ocean surface at any of the stations sampled during the January 2009 survey, and the discharge complied with all quantitative limits on seawater properties.

Although discharge-related changes in four of the six water properties were observed during the January 2009 survey, the changes were either not statistically significant, were measured within the boundary of the ZID, or resulted from small anomalies exacerbated by the uniformity of surrounding ambient seawater. Receiving-water limitations only apply to statistically significant changes caused by the presence of effluent constituents beyond the ZID boundary. The measurements collected during the January 2009 survey demonstrated that the receiving-water limitations were met within 11.7 m of the discharge (Perturbation 1). Beyond the ZID, the effluent was so highly diluted that only slight changes in seawater properties that were caused by the presence of effluent constituents could be distinguished.

Outfall Performance

The salinity anomaly measured at Station 3, located within 11.7 m of the diffuser, demonstrated that the receiving-water objectives of the COP were met well within the ZID. This and other high-precision observations demonstrated that the diffuser structure was operating better than predicted by modeling, and that discharged wastewater was achieving dilutions well in excess of the minimum critical dilution of 133:1. The amplitude of the largest discharge-related salinity anomaly indicated that wastewater had been diluted more than 269-fold at Station 3. As the effluent plume ascended through the water column and moved northward, it achieved a dilution of nearly 700-fold. Similarly, the exceedingly small salinity anomaly within Perturbation 3 at Station 1 indicated that wastewater constituents had been diluted beyond recognition (1200-fold) by the time the plume reached and dispersed at the sea surface. The high dilution determined from actual measurements at all of these stations demonstrated that the outfall was performing better than expected and that the receiving-water objectives of the COP were achieved.

NPDES Permit Limits

The seawater properties measured during the January 2009 survey were statistically evaluated for compliance with the pertinent receiving-water limitations of 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, and*
4. *Temperature of the receiving water to adversely affect beneficial uses.*

The COP (SWRCB 1997) 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-8, the statistical significance of departures from mean conditions at a given depth level were determined with an analysis of variance that compared a single observation with the mean of a larger set of samples (Sokal and Rohlf 1997, Ury 1976). Although 15 independent hypothesis tests were performed at each depth level, a Bonferroni adjustment to the error rate was not included, so the tests are conservative. Specifically, a 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 applied in the tests was determined from the entire data set to reflect the full range in ambient properties, including vertical variations.

Light Transmittance

Statistical analysis revealed significant reductions in instrumentally recorded light transmittance at three of the sixteen monitoring stations during the January 2009 survey (bold font in Table B-5), as well as a significant increase in light transmittance near the seafloor at Station 4 (thin box surrounding italic font in Table B-5). The significant reduction in transmissivity that extended over the bottom portion of the water column, from 8.0 m to 14.5 m, at Station 3 was the only statistically significant transmissivity anomaly that resulted from the presence of turbid wastewater. Although not statistically significant, instrumentally recorded transmissivity was perceptibly lower at Stations 1 and 2 as well. The accompanying reduction in the penetration of ambient light was quantified by a small reduction in the Secchi depth measured at Station 3. Compared to the 7.9-m average depth measured at all the other stations, this station had a Secchi depth of 7 m (Table B-9). However, this station was located within the ZID, where the COP limitation does not apply. The slight discharge-related anomalies in transmissivity at Stations 1 and 2 were not statistically significant and did not cause “*natural light to be significantly reduced*” (SWRCB 1997). The remaining transmissivity anomalies, located near the seafloor at Stations 4 and 7, were caused by fluctuations in the thickness of the BNL interface that decreased (Station 7) light transmittance due to natural resuspension of surficial sediments and increased (Station 4) transmittance due to variations in the thickness of the later across the sampling stations. Significant reductions in transmissivity were also recorded to the south of the diffuser structure at Station 16, at a location opposite of plume transport and, thus, clearly could not have been generated “*as the result of the discharge of waste.*”

Dissolved Oxygen

Although unstated 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.*” However,

measurements from effluent samples routinely collected prior to discharge demonstrate that the treatment process effectively removed most oxygen-demanding material from the wastestream. As a result, reductions in DO caused by the presence of effluent constituents have never been observed within the receiving waters. This was also the case during the January 2009 survey when obvious, discharge-related anomalies were found in other properties at Stations 1, 2, and 3, while even slight excursions in DO were absent at those locations.

Additionally, the DO limitation does not apply to changes in DO caused by the movement of ambient waters, regardless of whether they are induced by the physics of the discharge. During other surveys, discharge-related DO anomalies have occasionally been observed in the upper water column when deep seawater, naturally depleted in DO, was entrained in the rising effluent plume. As described previously, prop-wash from the survey vessel may have moved highly oxygenated seawater within the surface microlayer downward into the water column, causing the statistically significant DO anomalies observed at Station 13 (Table B-4). However, regardless of their source, these anomalies resulted in increases in DO rather than decreases; therefore, they are not subject to the COP limitations.

Irrespective of their applicability, the data collected during the January 2009 survey met all of the permit's numerical limits on DO concentrations. All of the DO measurements remained between 8.8 and 9.3 and, thus, were well above the 5-mg/L minimum specified in the Basin Plan and the NPDES discharge permit. The total range in DO was only 4% of the average concentration, so no single measurement was “depressed more than 10 percent from that which occurs naturally.”

pH

The only statistically significant lateral anomaly in pH (Table B-6) was the increase observed in the upper water column at Station 13 (Table B-6). As with the DO anomaly, this pH anomaly was unrelated to the discharge and was possibly generated by the downward movement of seawater from within the surface microlayer. In contrast, the pH anomaly at Station 3 was clearly indicative of the presence of dilute wastewater. Not only was the location near the diffuser structure and within the potential path of the discharge plume, it coincided with obvious anomalies in other water properties (Figure A-5) and was consistent with the discharge's lower pH compared to ambient receiving water. Because the anomaly at Station 3 was observed well within the ZID, however, the permit limitation does not apply. Nonetheless, all of the pH measurements, including the anomaly at Station 3, met the numerical limits specified in the discharge permit. All were well above the lower bound pH of 7.0, and the observed pH range of 0.044 was unusually small, so none of the measurements would be considered changed by “more than 0.2 pH units from that which occurs naturally.”

Temperature and Salinity

In accordance with the uniform seawater properties during the January 2009 survey, the total temperature range of 0.1°C was also exceedingly small. Despite this, no thermal variations related to the discharge were detected. Even if the discharge was responsible for a 0.1°C temperature change, it would be considered too small “to adversely affect beneficial uses.” The observed temperature range was also much less than the 2°C range in sea-surface temperature shown in the satellite image on the cover of this report.

Additionally, although salinity anomalies are the best tracers of discharged effluent, the actual maximum amplitude (-0.124‰) of the salinity anomaly observed within the ZID during the January 2009 survey was small compared to the seasonal and spatial differences in salinity along the south-central California coast. For example, seasonal differences in average salinity at this location are six times higher (0.64‰) than the salinity anomaly recorded at Station 3 during the January 2009 survey. In any regard, the

observed ranges in both temperature (0.1°C) and salinity (-0.14‰) across all data collected during the January 2009 survey were too small to harm marine biota or impact beneficial uses.

Conclusions

All measurements recorded during the January 2009 survey complied with the receiving-water limitations specified in the NPDES discharge permit. The discharge-related anomalies in salinity, density, transmissivity, and pH at Stations 1, 2, and 3 were induced by dilute wastewater particulates. Although small in amplitude, these anomalies were apparent largely because of the extraordinary uniformity of the ambient seawater properties at the time of this survey. Dilute wastewater constituents measured at depth within the ZID captured the effluent plume shortly after discharge, while it continued intense initial mixing. Nevertheless, the 269-fold dilution at that location was twice the critical dilution predicted by modeling for the entire dilution process. As the plume drifted north with the prevailing currents, it reached the sea surface at Stations 1 and 2, where dilutions approached 700-fold. All of the observations collected during the January 2009 survey confirmed that the diffuser structure and the outfall continue to operate better than expected from modeling.

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APPENDIX A

Water Quality Profiles and Cross Sections

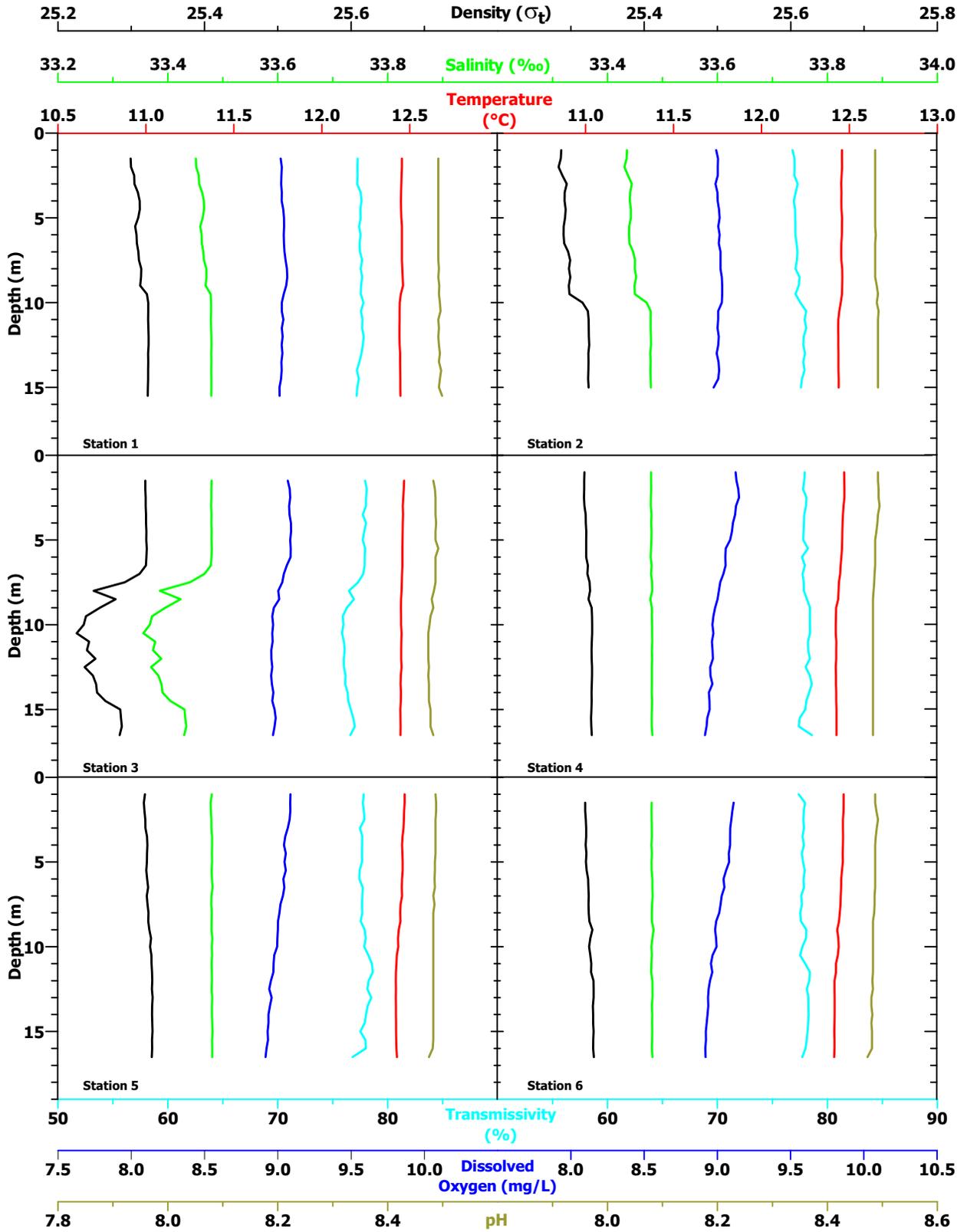


Figure A-1. Vertical Profiles of Water-Quality Parameters for Stations 1 through 6 measured on 20 January 2009

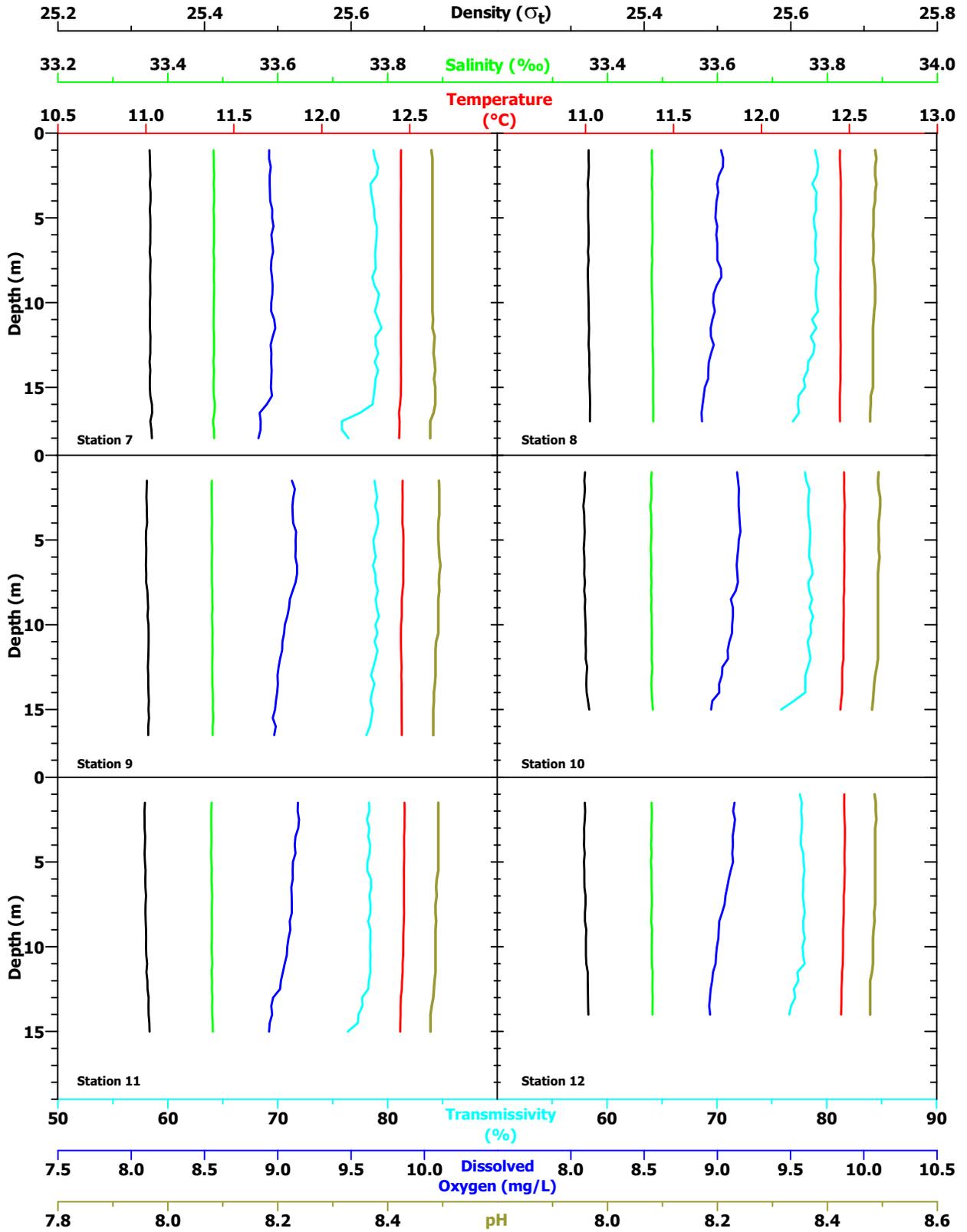


Figure A-2. Vertical Profiles of Water-Quality Parameters for Stations 7 through 12 measured on 20 January 2009

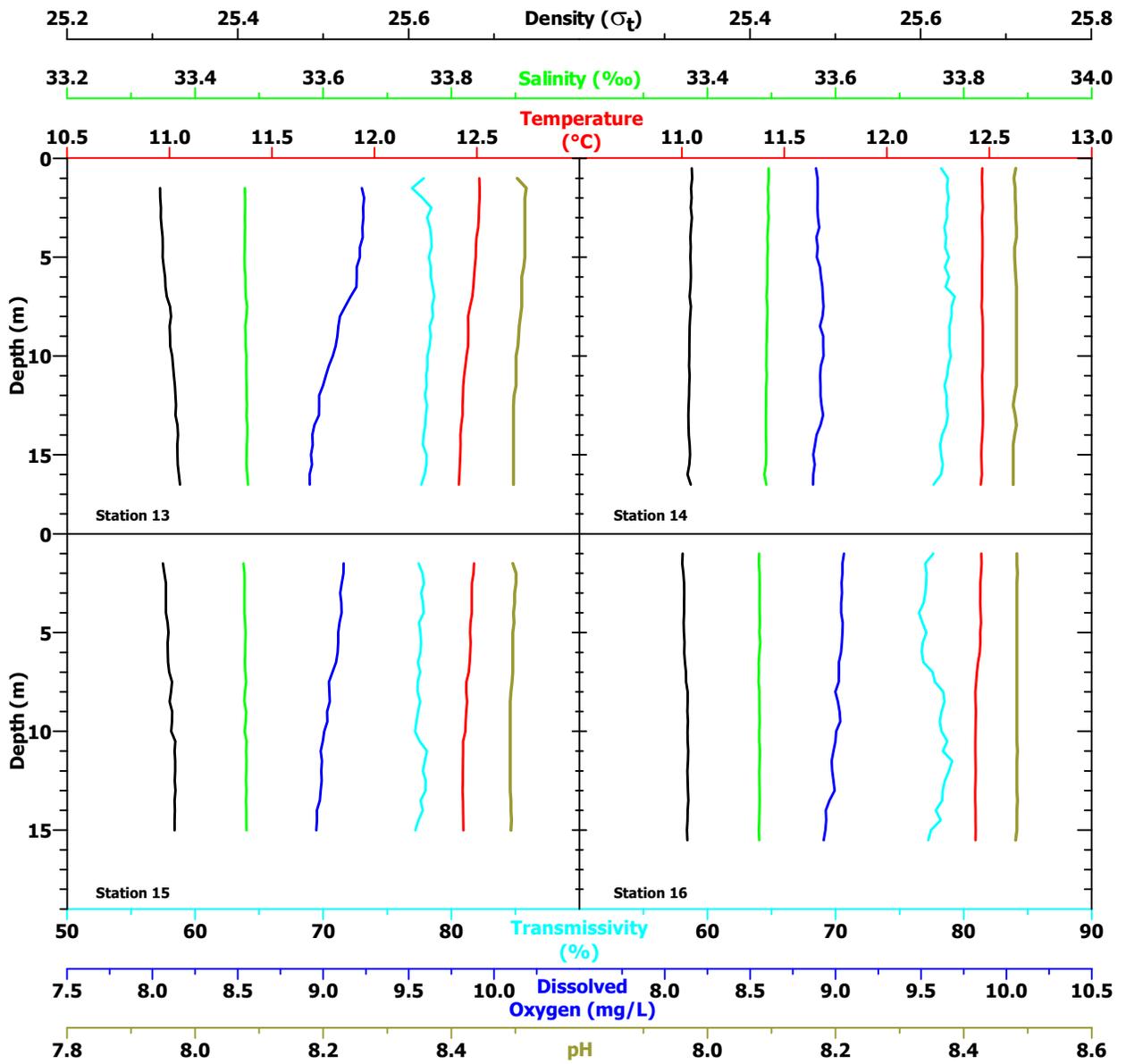


Figure A-3. Vertical Profiles of Water-Quality Parameters for Stations 13 through 16 measured on 20 January 2009

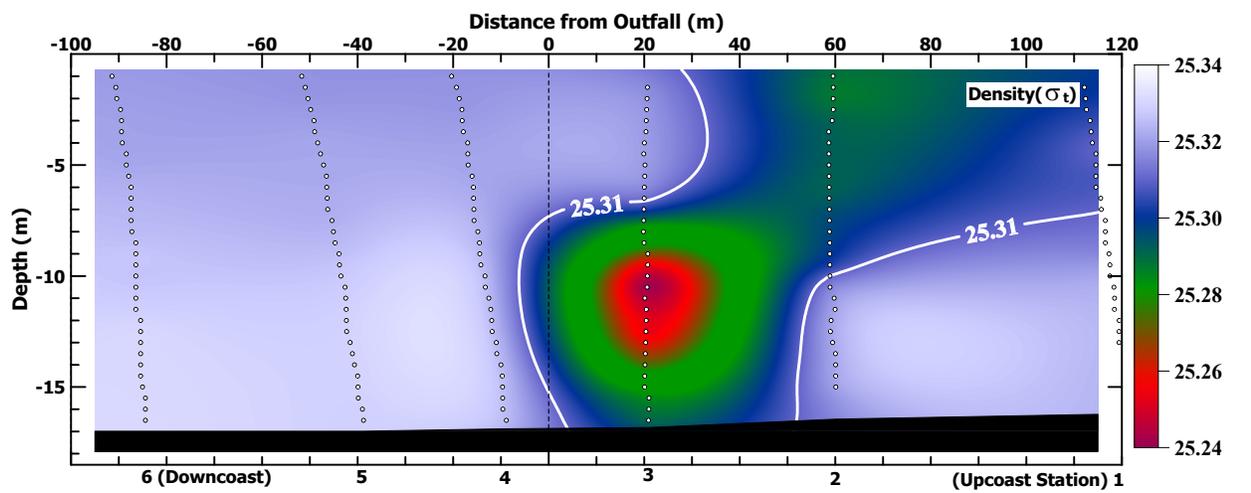
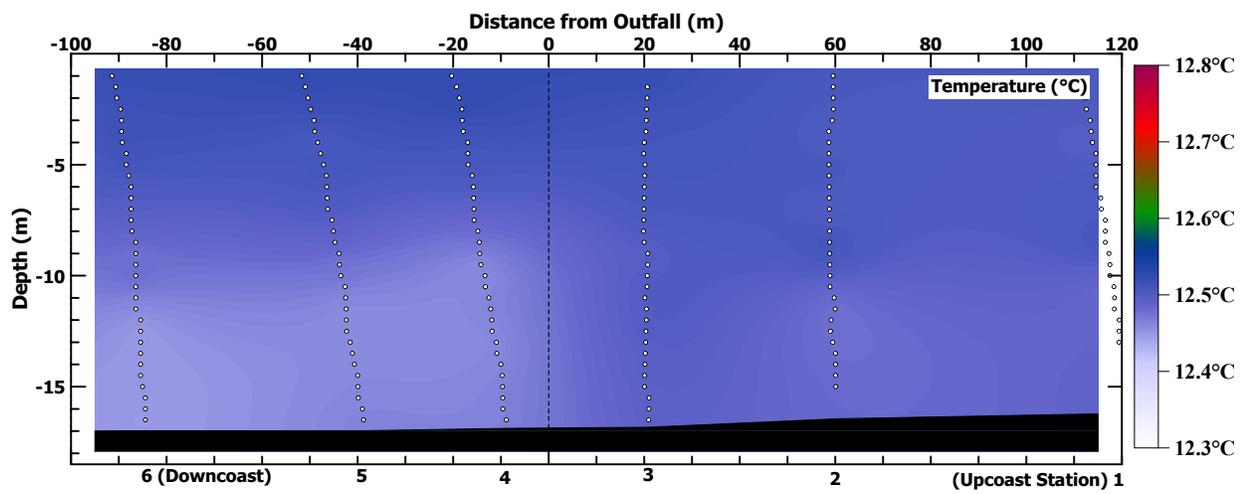
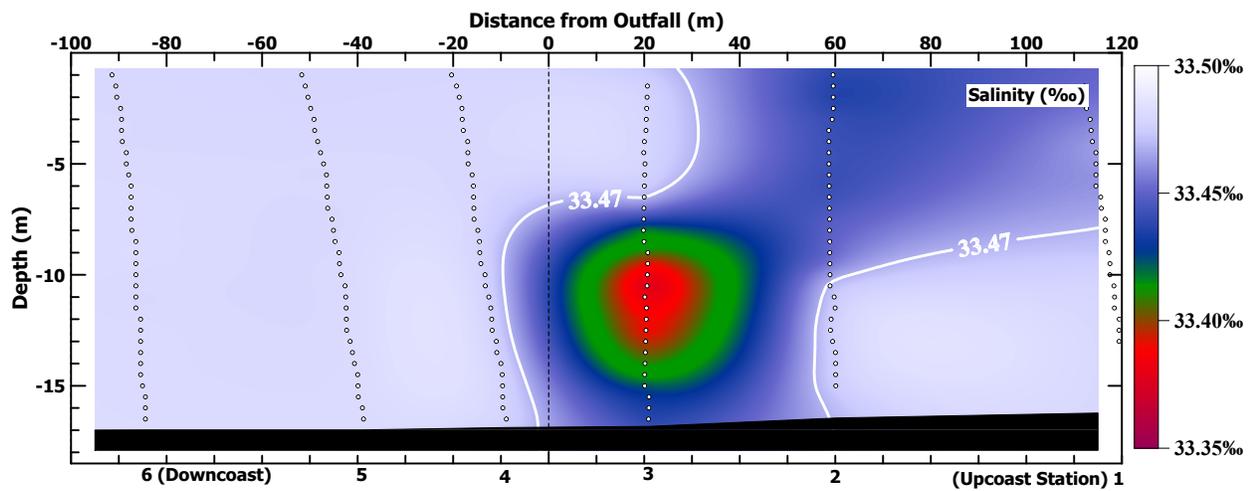


Figure A-4. Along-Shore Transects of Salinity, Temperature, and Density on 20 January 2009

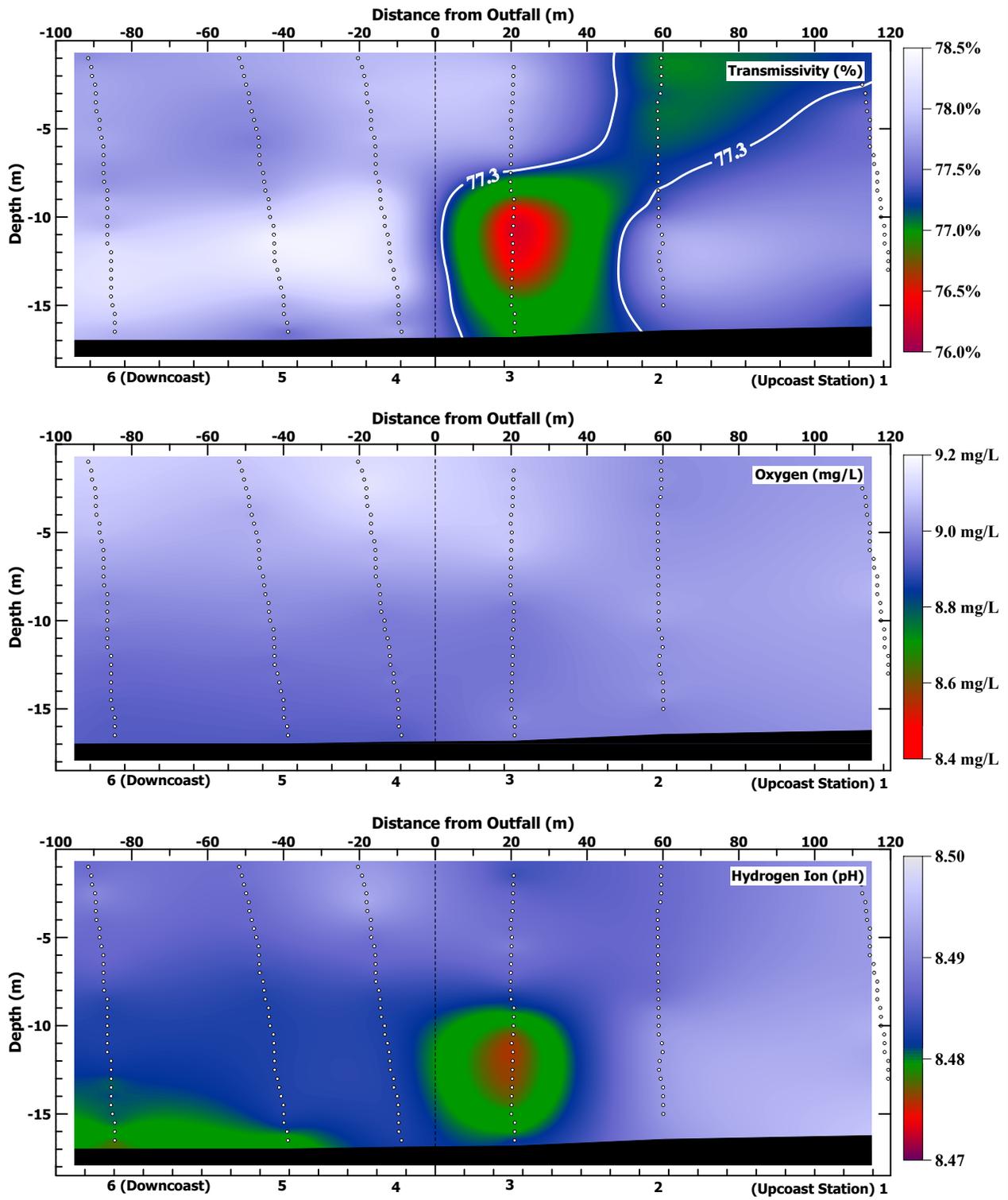


Figure A-5. Along-Shore Transects of Transmissivity, Oxygen, and pH on 20 January 2009

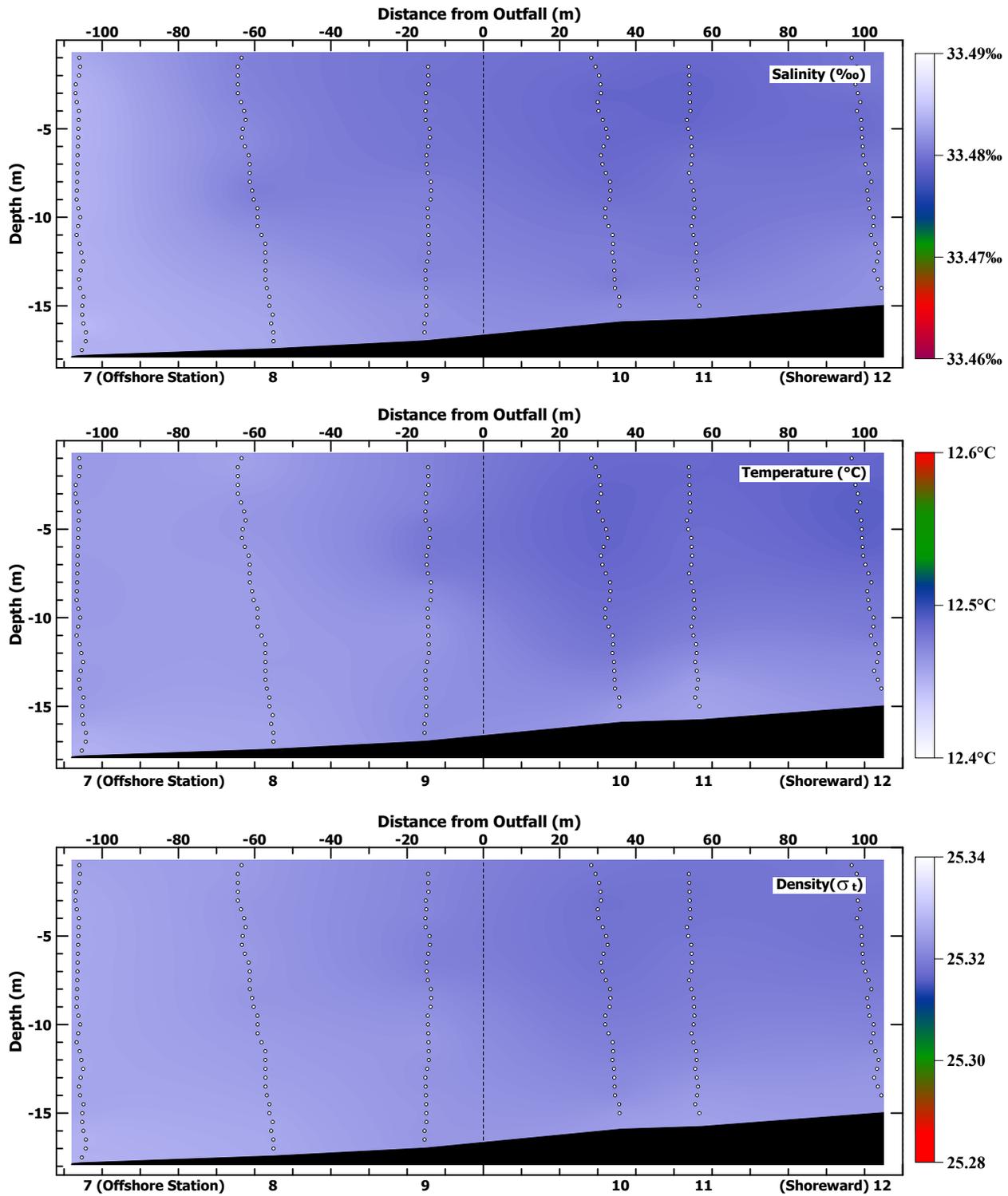


Figure A-6. Cross-Shore Transects of Salinity, Temperature, and Density on 20 January 2009

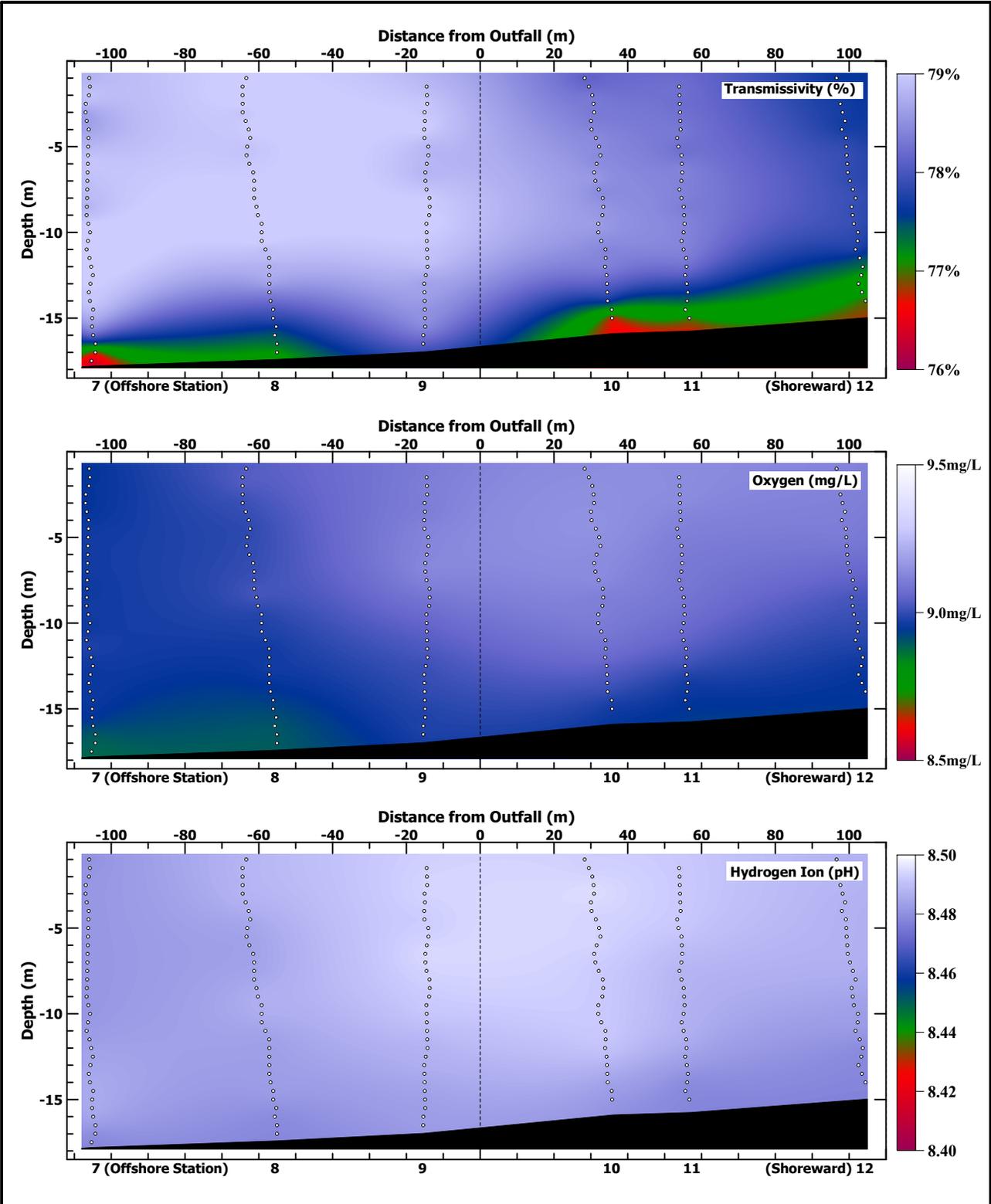


Figure A-7. Cross-Shore Transects of Transmissivity, Dissolved Oxygen, and pH on 20 January 2009

APPENDIX B

Tables of Profile Data and Standard Observations

Table B-1. Seawater Temperature¹ on 20 January 2009

Depth (m)	Temperature (°C)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0.5																12.47
1.0		12.46		12.47	12.47	12.47	12.45	12.45		12.47		12.47	12.51	12.46		12.46
1.5	12.46	12.46	12.47	12.47	12.47	12.47	12.45	12.45	12.46	12.47	12.47	12.47	12.51	12.47	12.49	12.46
2.0	12.46	12.46	12.47	12.47	12.47	12.47	12.45	12.45	12.46	12.47	12.47	12.47	12.51	12.47	12.48	12.46
2.5	12.45	12.46	12.46	12.47	12.47	12.46	12.45	12.45	12.46	12.47	12.47	12.47	12.51	12.47	12.48	12.46
3.0	12.45	12.45	12.46	12.47	12.47	12.46	12.45	12.45	12.46	12.47	12.47	12.47	12.51	12.46	12.48	12.46
3.5	12.45	12.46	12.46	12.46	12.46	12.46	12.45	12.45	12.46	12.47	12.47	12.47	12.51	12.47	12.48	12.46
4.0	12.45	12.45	12.46	12.46	12.46	12.46	12.45	12.45	12.46	12.47	12.47	12.47	12.50	12.47	12.48	12.46
4.5	12.45	12.46	12.46	12.46	12.46	12.46	12.45	12.45	12.46	12.47	12.47	12.47	12.50	12.47	12.47	12.46
5.0	12.45	12.46	12.46	12.46	12.46	12.46	12.45	12.45	12.47	12.47	12.47	12.47	12.49	12.47	12.47	12.46
5.5	12.46	12.46	12.46	12.46	12.46	12.46	12.45	12.45	12.46	12.47	12.47	12.47	12.49	12.46	12.47	12.46
6.0	12.46	12.46	12.46	12.45	12.46	12.45	12.45	12.45	12.46	12.47	12.47	12.47	12.49	12.46	12.47	12.45
6.5	12.46	12.45	12.46	12.45	12.46	12.45	12.45	12.45	12.46	12.47	12.47	12.47	12.48	12.46	12.46	12.45
7.0	12.46	12.45	12.46	12.45	12.46	12.45	12.45	12.45	12.46	12.47	12.47	12.47	12.48	12.46	12.46	12.44
7.5	12.46	12.45	12.46	12.44	12.45	12.45	12.45	12.45	12.46	12.47	12.47	12.47	12.47	12.46	12.45	12.44
8.0	12.46	12.46	12.45	12.44	12.45	12.45	12.45	12.45	12.46	12.47	12.47	12.47	12.46	12.47	12.45	12.43
8.5	12.46	12.46	12.45	12.44	12.45	12.44	12.45	12.45	12.45	12.47	12.47	12.47	12.46	12.47	12.45	12.43
9.0	12.46	12.46	12.45	12.42	12.44	12.43	12.45	12.45	12.46	12.47	12.46	12.46	12.46	12.47	12.45	12.43
9.5	12.45	12.46	12.45	12.42	12.43	12.44	12.45	12.45	12.46	12.47	12.46	12.46	12.46	12.47	12.45	12.43
10.0	12.44	12.45	12.45	12.42	12.44	12.44	12.45	12.45	12.45	12.47	12.46	12.46	12.45	12.47	12.44	12.43
10.5	12.44	12.44	12.45	12.42	12.43	12.43	12.45	12.45	12.45	12.47	12.46	12.46	12.44	12.47	12.43	12.43
11.0	12.44	12.44	12.45	12.43	12.42	12.42	12.45	12.45	12.45	12.47	12.46	12.46	12.44	12.47	12.43	12.43
11.5	12.44	12.44	12.45	12.43	12.42	12.42	12.45	12.45	12.45	12.47	12.46	12.46	12.43	12.47	12.43	12.43
12.0	12.44	12.44	12.45	12.43	12.42	12.42	12.45	12.45	12.45	12.47	12.46	12.46	12.43	12.47	12.43	12.43
12.5	12.44	12.44	12.45	12.42	12.42	12.42	12.45	12.45	12.45	12.46	12.46	12.46	12.43	12.47	12.43	12.43
13.0	12.45	12.44	12.45	12.42	12.42	12.42	12.45	12.45	12.45	12.46	12.45	12.46	12.43	12.47	12.43	12.43
13.5	12.45	12.44	12.45	12.42	12.42	12.42	12.45	12.45	12.45	12.46	12.45	12.45	12.42	12.47	12.43	12.43
14.0	12.45	12.44	12.45	12.43	12.42	12.42	12.45	12.45	12.45	12.46	12.45	12.45	12.42	12.47	12.43	12.43
14.5	12.45	12.44	12.45	12.43	12.42	12.42	12.45	12.45	12.45	12.45	12.45	12.45	12.42	12.46	12.43	12.43
15.0	12.45	12.44	12.45	12.43	12.42	12.41	12.45	12.45	12.45	12.45	12.45	12.45	12.42	12.46	12.43	12.43
15.5	12.45		12.45	12.43	12.42	12.41	12.45	12.45	12.45				12.42	12.46		12.43
16.0			12.45	12.43	12.42	12.42	12.45	12.45	12.45				12.41	12.46		
16.5			12.45	12.43	12.43	12.41	12.44	12.45	12.46				12.41	12.46		
17.0							12.44	12.45								
17.5							12.44									
18.0							12.44									

¹ Values enclosed in boxes were significantly different from other temperature measurements at the same depth.

Table B-2. Salinity¹ on 20 January 2009

Depth (m)	Salinity (‰)																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
0.5																33.496	
1.0		33.435		33.479	33.480		33.483	33.481		33.480						33.496	33.481
1.5	33.451	33.435	33.480	33.479	33.478	33.480	33.484	33.481	33.480	33.479	33.480	33.480	33.478	33.494	33.475	33.480	
2.0	33.452	33.431	33.479	33.479	33.478	33.480	33.484	33.481	33.480	33.480	33.479	33.481	33.478	33.495	33.477	33.481	
2.5	33.456	33.437	33.479	33.479	33.479	33.480	33.484	33.481	33.480	33.480	33.479	33.481	33.478	33.494	33.477	33.481	
3.0	33.457	33.444	33.479	33.479	33.479	33.481	33.483	33.480	33.480	33.478	33.479	33.480	33.478	33.495	33.477	33.482	
3.5	33.462	33.441	33.479	33.480	33.480	33.481	33.484	33.481	33.480	33.479	33.479	33.480	33.478	33.494	33.477	33.481	
4.0	33.465	33.440	33.479	33.479	33.480	33.480	33.484	33.481	33.481	33.480	33.479	33.479	33.478	33.494	33.477	33.482	
4.5	33.466	33.442	33.480	33.480	33.480	33.481	33.483	33.481	33.480	33.480	33.479	33.480	33.477	33.494	33.478	33.482	
5.0	33.464	33.442	33.479	33.480	33.481	33.480	33.484	33.481	33.480	33.480	33.479	33.479	33.477	33.494	33.479	33.481	
5.5	33.459	33.440	33.480	33.479	33.480	33.480	33.484	33.482	33.481	33.479	33.480	33.480	33.477	33.494	33.478	33.482	
6.0	33.461	33.439	33.479	33.478	33.480	33.482	33.484	33.482	33.480	33.479	33.479	33.480	33.479	33.494	33.478	33.481	
6.5	33.462	33.440	33.478	33.480	33.481	33.482	33.484	33.482	33.480	33.480	33.480	33.480	33.479	33.493	33.478	33.480	
7.0	33.465	33.446	33.467	33.479	33.479	33.482	33.483	33.481	33.480	33.479	33.481	33.481	33.479	33.492	33.478	33.480	
7.5	33.466	33.450	33.440	33.481	33.479	33.481	33.484	33.482	33.480	33.480	33.480	33.481	33.481	33.493	33.480	33.480	
8.0	33.470	33.449	33.385	33.481	33.480	33.481	33.484	33.480	33.481	33.479	33.480	33.480	33.480	33.493	33.478	33.481	
8.5	33.470	33.452	33.423	33.478	33.480	33.481	33.484	33.480	33.481	33.480	33.480	33.479	33.478	33.493	33.477	33.481	
9.0	33.469	33.449	33.395	33.481	33.479	33.484	33.484	33.480	33.481	33.480	33.480	33.481	33.479	33.493	33.480	33.481	
9.5	33.478	33.450	33.371	33.481	33.481	33.481	33.484	33.481	33.480	33.480	33.480	33.481	33.479	33.492	33.479	33.482	
10.0	33.479	33.471	33.367	33.481	33.480	33.480	33.484	33.481	33.481	33.480	33.480	33.481	33.480	33.492	33.477	33.481	
10.5	33.479	33.478	33.355	33.481	33.480	33.481	33.484	33.482	33.481	33.481	33.480	33.480	33.480	33.492	33.481	33.481	
11.0	33.478	33.478	33.377	33.481	33.480	33.480	33.483	33.482	33.481	33.480	33.481	33.481	33.480	33.492	33.480	33.482	
11.5	33.479	33.478	33.373	33.481	33.480	33.479	33.483	33.482	33.481	33.481	33.480	33.482	33.480	33.492	33.480	33.482	
12.0	33.479	33.479	33.388	33.481	33.480	33.482	33.484	33.482	33.481	33.480	33.481	33.482	33.481	33.492	33.480	33.481	
12.5	33.479	33.479	33.369	33.481	33.480	33.482	33.484	33.482	33.481	33.482	33.480	33.482	33.481	33.491	33.479	33.481	
13.0	33.479	33.478	33.383	33.481	33.481	33.482	33.484	33.483	33.481	33.480	33.481	33.482	33.480	33.491	33.480	33.481	
13.5	33.479	33.478	33.388	33.481	33.480	33.481	33.483	33.483	33.481	33.480	33.481	33.482	33.482	33.491	33.480	33.482	
14.0	33.479	33.478	33.390	33.481	33.480	33.481	33.484	33.483	33.482	33.480	33.481	33.482	33.481	33.491	33.480	33.481	
14.5	33.479	33.478	33.405	33.481	33.481	33.481	33.484	33.483	33.482	33.481	33.482		33.481	33.492	33.480	33.481	
15.0	33.479	33.479	33.430	33.481	33.481	33.481	33.483	33.483	33.482	33.482	33.482		33.481	33.492	33.480	33.480	
15.5	33.479		33.432	33.480	33.481	33.481	33.484	33.483	33.483				33.480	33.491		33.481	
16.0			33.433	33.481	33.481	33.481	33.486	33.483	33.481				33.482	33.489			
16.5			33.429	33.481	33.481	33.482	33.485	33.483	33.482				33.483	33.492			
17.0								33.482	33.483								
17.5								33.484									
18.0								33.484									

¹ Values enclosed in boxes were significantly different from the other salinity measurements at the same depth.

Table B-3. Seawater Density¹ on 20 January 2009

Depth (m)	Density (sigma-t)																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
0.5																25.332	
1.0		25.287		25.319	25.319		25.325	25.324		25.319						25.333	25.321
1.5	25.299	25.286	25.319	25.318	25.317	25.320	25.326	25.324	25.321	25.318	25.319	25.319	25.309	25.331	25.312	25.321	
2.0	25.300	25.283	25.319	25.318	25.318	25.320	25.326	25.325	25.321	25.319	25.318	25.320	25.309	25.332	25.314	25.322	
2.5	25.304	25.288	25.320	25.318	25.319	25.320	25.326	25.324	25.321	25.318	25.318	25.319	25.310	25.331	25.316	25.323	
3.0	25.304	25.294	25.320	25.319	25.319	25.321	25.325	25.323	25.321	25.317	25.318	25.318	25.310	25.332	25.316	25.323	
3.5	25.309	25.292	25.320	25.320	25.322	25.321	25.326	25.324	25.321	25.318	25.319	25.318	25.311	25.331	25.316	25.323	
4.0	25.312	25.291	25.320	25.320	25.322	25.320	25.326	25.324	25.322	25.318	25.319	25.318	25.312	25.330	25.316	25.323	
4.5	25.312	25.293	25.321	25.321	25.322	25.321	25.325	25.324	25.320	25.319	25.318	25.319	25.312	25.331	25.318	25.323	
5.0	25.310	25.292	25.321	25.321	25.321	25.321	25.326	25.324	25.320	25.318	25.319	25.318	25.312	25.330	25.319	25.323	
5.5	25.305	25.290	25.321	25.321	25.321	25.322	25.326	25.324	25.321	25.318	25.320	25.318	25.313	25.331	25.318	25.324	
6.0	25.307	25.290	25.321	25.321	25.322	25.324	25.326	25.324	25.320	25.318	25.319	25.318	25.315	25.331	25.318	25.323	
6.5	25.308	25.291	25.320	25.323	25.323	25.324	25.326	25.324	25.320	25.319	25.319	25.319	25.315	25.331	25.318	25.324	
7.0	25.310	25.296	25.311	25.323	25.321	25.324	25.325	25.323	25.321	25.318	25.320	25.320	25.317	25.330	25.320	25.325	
7.5	25.311	25.299	25.291	25.326	25.322	25.324	25.326	25.324	25.320	25.319	25.320	25.320	25.321	25.331	25.323	25.325	
8.0	25.314	25.297	25.249	25.326	25.324	25.324	25.326	25.323	25.322	25.318	25.319	25.319	25.322	25.330	25.322	25.327	
8.5	25.313	25.299	25.279	25.324	25.323	25.325	25.326	25.323	25.323	25.320	25.320	25.319	25.320	25.329	25.320	25.327	
9.0	25.312	25.297	25.257	25.328	25.325	25.329	25.326	25.324	25.323	25.319	25.320	25.321	25.321	25.329	25.323	25.327	
9.5	25.321	25.298	25.238	25.329	25.327	25.327	25.326	25.324	25.322	25.320	25.320	25.321	25.321	25.329	25.323	25.327	
10.0	25.323	25.316	25.235	25.329	25.326	25.325	25.326	25.324	25.324	25.320	25.320	25.321	25.323	25.329	25.322	25.327	
10.5	25.323	25.323	25.226	25.329	25.328	25.327	25.326	25.324	25.324	25.320	25.321	25.321	25.324	25.329	25.327	25.327	
11.0	25.323	25.324	25.243	25.329	25.328	25.328	25.326	25.324	25.324	25.320	25.322	25.321	25.325	25.330	25.326	25.328	
11.5	25.323	25.324	25.240	25.328	25.328	25.328	25.326	25.325	25.324	25.321	25.321	25.323	25.326	25.329	25.327	25.328	
12.0	25.324	25.325	25.251	25.328	25.329	25.331	25.326	25.325	25.323	25.320	25.322	25.323	25.327	25.329	25.327	25.327	
12.5	25.324	25.325	25.236	25.329	25.328	25.331	25.326	25.324	25.323	25.322	25.322	25.323	25.328	25.328	25.326	25.327	
13.0	25.323	25.324	25.248	25.329	25.329	25.331	25.326	25.325	25.323	25.321	25.324	25.323	25.327	25.328	25.327	25.328	
13.5	25.323	25.324	25.252	25.329	25.329	25.330	25.325	25.325	25.323	25.321	25.324	25.324	25.329	25.328	25.326	25.328	
14.0	25.323	25.324	25.253	25.328	25.328	25.330	25.326	25.326	25.324	25.322	25.324	25.324	25.330	25.329	25.326	25.327	
14.5	25.323	25.324	25.265	25.328	25.329	25.330	25.325	25.325	25.324	25.323	25.325		25.329	25.330	25.326	25.327	
15.0	25.323	25.324	25.285	25.328	25.329	25.331	25.325	25.326	25.324	25.325	25.325		25.329	25.330	25.326	25.326	
15.5	25.323		25.286	25.328	25.328	25.331	25.326	25.326	25.324				25.330	25.329		25.327	
16.0			25.287	25.328	25.329	25.330	25.328	25.326	25.323				25.331	25.327			
16.5			25.284	25.329	25.328	25.331	25.329	25.326	25.323				25.332	25.331			
17.0							25.326	25.326									
17.5							25.328										
18.0							25.328										

¹ Values enclosed in boxes were significantly different from the other density measurements at the same depth.

Table B-4. Detrended¹ Dissolved Oxygen² on 20 January 2009

Depth (m)	Dissolved Oxygen (mg/L)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0.5														8.97		
1.0		8.99		9.12	9.09		9.02	9.03		9.13				8.98		9.05
1.5	9.02	9.00	9.07	9.13	9.08	9.11	9.02	9.04	9.10	9.14	9.14	9.12	9.23	8.98	9.12	9.04
2.0	9.03	9.00	9.08	9.14	9.09	9.10	9.03	9.04	9.12	9.15	9.14	9.11	9.24	8.98	9.12	9.04
2.5	9.02	9.00	9.08	9.15	9.08	9.10	9.02	9.01	9.11	9.15	9.14	9.12	9.23	8.98	9.11	9.04
3.0	9.02	8.99	9.08	9.13	9.07	9.09	9.02	9.00	9.10	9.15	9.14	9.11	9.23	8.98	9.10	9.04
3.5	9.03	9.00	9.08	9.12	9.05	9.09	9.02	9.01	9.10	9.15	9.12	9.10	9.23	8.99	9.11	9.03
4.0	9.03	9.00	9.09	9.11	9.04	9.09	9.03	8.99	9.10	9.15	9.12	9.11	9.23	8.97	9.11	9.03
4.5	9.04	9.01	9.09	9.10	9.05	9.08	9.04	8.99	9.12	9.16	9.12	9.10	9.21	8.98	9.10	9.04
5.0	9.04	9.02	9.08	9.09	9.05	9.08	9.04	8.99	9.12	9.15	9.10	9.11	9.21	8.98	9.09	9.04
5.5	9.04	9.01	9.09	9.06	9.05	9.06	9.05	9.00	9.12	9.14	9.10	9.09	9.20	8.99	9.09	9.04
6.0	9.04	9.02	9.09	9.05	9.04	9.04	9.04	8.99	9.12	9.14	9.10	9.08	9.20	9.00	9.08	9.03
6.5	9.04	9.01	9.06	9.06	9.04	9.05	9.04	9.00	9.13	9.13	9.09	9.07	9.19	9.01	9.08	9.02
7.0	9.05	9.02	9.04	9.04	9.03	9.03	9.05	9.00	9.13	9.14	9.09	9.06	9.16	9.01	9.05	9.02
7.5	9.05	9.02	9.03	9.02	9.02	9.02	9.04	9.00	9.12	9.14	9.10	9.05	9.13	9.01	9.03	9.02
8.0	9.06	9.02	9.00	9.01	9.01	9.01	9.03	9.02	9.10	9.13	9.10	9.03	9.10	9.01	9.04	9.00
8.5	9.06	9.03	9.01	9.00	9.00	8.99	9.04	9.03	9.08	9.09	9.08	9.01	9.09	8.99	9.04	9.01
9.0	9.06	9.03	8.97	8.98	9.00	8.98	9.04	8.99	9.08	9.11	9.09	9.01	9.08	9.01	9.02	9.02
9.5	9.04	9.03	8.96	8.97	9.00	8.99	9.04	8.97	9.06	9.11	9.07	9.01	9.07	9.01	9.02	9.03
10.0	9.03	9.03	8.97	8.97	9.00	8.99	9.03	8.97	9.05	9.10	9.06	9.00	9.06	9.01	9.01	9.00
10.5	9.03	9.01	8.96	8.97	8.98	8.97	9.03	8.98	9.04	9.10	9.06	8.99	9.03	9.00	9.00	9.00
11.0	9.04	9.01	8.96	8.96	8.97	8.96	9.05	8.97	9.03	9.08	9.05	8.99	9.02	8.99	8.99	8.99
11.5	9.03	9.00	8.96	8.97	8.97	8.97	9.06	8.95	9.03	9.07	9.03	8.97	9.00	9.00	8.99	8.98
12.0	9.03	9.01	8.96	8.97	8.95	8.95	9.04	8.96	9.02	9.07	9.02	8.96	8.98	9.00	8.99	8.98
12.5	9.03	9.01	8.96	8.95	8.94	8.94	9.03	8.98	9.01	9.03	9.02	8.95	8.98	9.00	8.99	8.99
13.0	9.03	9.00	8.95	8.95	8.96	8.94	9.03	8.96	9.00	9.03	8.97	8.95	8.98	9.01	8.99	8.99
13.5	9.02	9.01	8.96	8.97	8.95	8.94	9.03	8.94	9.00	9.01	8.96	8.94	8.95	9.00	8.98	8.96
14.0	9.03	9.01	8.97	8.94	8.94	8.93	9.04	8.94	9.00	9.01	8.96	8.95	8.94	8.97	8.96	8.94
14.5	9.02	9.01	8.96	8.95	8.94	8.93	9.03	8.94	8.99	8.97	8.94		8.94	8.96	8.96	8.95
15.0	9.01	8.97	8.98	8.95	8.93	8.92	9.03	8.91	8.98	8.96	8.94		8.93	8.95	8.96	8.94
15.5	9.01		8.99	8.93	8.93	8.92	9.04	8.91	8.97				8.93	8.96		8.93
16.0			8.98	8.93	8.92	8.92	9.00	8.90	8.99				8.92	8.95		
16.5			8.97	8.92	8.92	8.92	8.96	8.89	8.98				8.92	8.95		
17.0							8.88	8.90								
17.5							8.88									
18.0							8.87									

¹ Measured DO concentrations were corrected for temporal drift to account for ongoing equilibration of the sensor.

² Values enclosed in the box were significantly different from the other DO measurements at the same depth.

Table B-5. Light Transmittance¹ across a 0.25-m path on 20 January 2009

Depth (m)	Light Transmittance (%)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0.5																78.25
1.0		76.83		77.94	77.82	77.37	78.70	78.94		78.02		77.55	77.85	78.76		77.62
1.5	77.27	77.01	77.94	77.90	77.74	77.97	78.85	79.12	78.80	78.12	78.29	77.71	76.93	78.69	77.44	77.00
2.0	77.24	77.02	78.10	77.77	77.84	77.84	79.12	79.23	78.91	78.43	78.32	77.68	77.75	78.82	77.76	77.09
2.5	77.26	76.99	78.03	78.10	77.89	77.82	79.00	79.09	79.05	78.34	78.11	77.74	78.44	78.69	77.87	77.08
3.0	77.22	77.29	78.02	78.04	77.47	77.86	78.44	78.69	78.86	78.31	78.32	77.73	78.12	78.70	77.64	77.01
3.5	77.53	77.11	77.73	77.90	77.69	77.74	78.50	79.08	79.08	78.32	78.23	77.65	78.34	78.48	77.79	76.87
4.0	77.61	76.93	78.03	77.86	77.66	77.86	78.63	79.01	79.14	78.42	78.40	77.64	78.43	78.63	77.83	76.51
4.5	77.51	77.05	77.86	77.83	77.66	77.67	78.76	79.04	78.93	78.50	78.36	77.86	78.46	78.56	77.48	76.77
5.0	77.53	77.07	77.73	77.81	77.65	77.78	78.79	78.82	78.70	78.49	78.16	77.88	78.25	78.85	77.59	77.08
5.5	77.40	77.08	77.95	78.23	77.44	77.94	79.00	78.88	78.78	78.42	78.14	77.97	78.41	78.54	77.63	76.80
6.0	77.52	77.08	77.91	77.68	77.42	77.83	79.01	79.03	78.92	78.40	78.47	77.86	78.40	78.85	77.59	76.72
6.5	77.44	77.18	77.90	77.95	77.73	77.87	78.94	78.95	78.65	78.62	78.49	77.86	78.56	78.59	77.39	76.86
7.0	77.47	77.28	77.78	77.74	77.70	77.62	78.86	79.00	78.87	78.71	78.33	77.83	78.67	79.30	77.57	77.56
7.5	77.67	77.24	77.31	77.85	77.65	77.69	78.88	78.92	78.91	78.31	78.43	77.91	78.49	79.05	77.38	77.75
8.0	77.54	77.09	76.48	77.86	77.69	77.52	78.91	79.24	79.12	78.41	78.43	77.99	78.57	79.04	77.37	78.41
8.5	77.67	77.47	76.92	78.13	77.54	77.59	78.59	79.07	78.91	78.67	78.22	77.85	78.32	78.88	77.56	78.49
9.0	77.58	77.39	76.27	78.42	77.92	78.08	78.81	79.05	79.00	78.43	78.43	77.86	78.38	78.90	77.40	78.27
9.5	77.56	77.10	75.91	78.41	78.00	78.05	79.20	78.99	79.21	78.76	78.43	77.99	78.30	78.88	77.29	78.14
10.0	77.79	77.54	75.98	78.41	77.86	77.73	79.05	79.07	78.88	78.51	78.39	77.80	78.13	78.98	77.16	78.27
10.5	77.57	78.07	75.84	78.42	78.25	77.51	78.85	79.21	79.06	78.56	78.44	77.85	78.16	78.81	77.52	78.72
11.0	77.70	77.92	76.02	78.24	78.57	77.97	79.13	78.66	78.80	78.27	78.40	77.99	78.03	78.71	78.10	78.38
11.5	77.67	78.07	76.09	78.24	78.64	78.40	79.45	79.05	79.05	78.40	78.43	77.33	78.08	78.50	77.94	79.10
12.0	77.82	77.84	76.00	78.40	78.25	78.35	78.88	78.54	78.91	78.51	78.28	77.42	77.95	78.68	77.78	78.85
12.5	77.74	77.81	76.02	78.02	78.16	78.12	78.91	78.89	78.70	78.29	78.24	77.01	78.09	78.66	78.01	78.54
13.0	77.62	77.97	76.16	78.41	78.51	78.27	79.14	78.78	78.49	78.06	77.68	77.13	78.02	78.77	77.99	78.35
13.5	77.42	77.81	76.13	78.58	78.18	78.27	78.82	78.30	78.78	78.05	77.71	76.75	77.96	78.63	77.61	78.32
14.0	77.19	77.91	76.35	78.34	78.03	78.30	79.12	78.26	78.57	78.03	77.34	76.58	77.83	78.31	77.77	77.82
14.5	77.38	77.68	76.40	78.08	77.90	78.24	78.90	77.90	78.45	77.01	77.28		77.77	78.16	77.43	78.21
15.0	77.23	77.59	76.65	77.98	77.51	78.19	78.84	78.03	78.65	75.85	76.38		78.07	78.23	77.19	77.44
15.5	77.17		76.86	77.48	77.97	78.11	78.72	77.43	78.52				78.06	78.36		77.23
16.0			77.01	77.40	78.01	78.00	78.63	77.37	78.38				77.91	78.24		
16.5			76.60	78.57	76.80	77.71	77.48	77.48	78.05				77.65	77.66		
17.0							75.82	76.93								
17.5							75.85									
18.0							76.42									

¹ Values enclosed in the boxes were significantly different from the other transmissivity measurements at the same depth.

Table B-6. Detrended¹ pH² on 20 January 2009

Depth (m)	Hydrogen Ion Concentration (pH)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0.5														8.481		
1.0		8.487		8.492	8.487	8.487	8.479	8.487		8.493		8.486	8.503	8.478		8.483
1.5	8.492	8.487	8.483	8.492	8.488	8.487	8.481	8.489	8.493	8.492	8.492	8.488	8.517	8.480	8.496	8.483
2.0	8.492	8.487	8.486	8.493	8.488	8.489	8.481	8.487	8.494	8.493	8.492	8.488	8.515	8.480	8.501	8.484
2.5	8.492	8.487	8.487	8.493	8.487	8.492	8.481	8.487	8.494	8.496	8.492	8.489	8.515	8.481	8.501	8.483
3.0	8.492	8.487	8.487	8.495	8.487	8.490	8.481	8.489	8.494	8.496	8.492	8.487	8.515	8.481	8.499	8.483
3.5	8.492	8.487	8.487	8.492	8.487	8.488	8.481	8.487	8.494	8.495	8.492	8.487	8.515	8.482	8.499	8.483
4.0	8.492	8.487	8.488	8.491	8.487	8.487	8.481	8.487	8.492	8.493	8.492	8.487	8.515	8.482	8.497	8.483
4.5	8.492	8.487	8.487	8.489	8.487	8.487	8.481	8.484	8.492	8.493	8.492	8.487	8.515	8.479	8.498	8.483
5.0	8.492	8.487	8.487	8.487	8.486	8.487	8.481	8.484	8.492	8.494	8.492	8.487	8.515	8.479	8.496	8.483
5.5	8.492	8.487	8.492	8.487	8.486	8.487	8.481	8.484	8.493	8.493	8.492	8.487	8.513	8.480	8.496	8.483
6.0	8.492	8.488	8.487	8.487	8.485	8.487	8.481	8.483	8.494	8.495	8.489	8.487	8.510	8.481	8.496	8.483
6.5	8.492	8.487	8.487	8.487	8.486	8.487	8.481	8.484	8.496	8.493	8.488	8.487	8.510	8.482	8.496	8.483
7.0	8.492	8.487	8.487	8.486	8.483	8.486	8.481	8.484	8.494	8.492	8.489	8.487	8.510	8.482	8.496	8.483
7.5	8.492	8.487	8.487	8.485	8.485	8.486	8.481	8.483	8.493	8.492	8.487	8.487	8.510	8.482	8.495	8.483
8.0	8.493	8.487	8.484	8.484	8.483	8.485	8.481	8.485	8.494	8.492	8.487	8.485	8.508	8.482	8.493	8.483
8.5	8.492	8.487	8.480	8.483	8.483	8.483	8.481	8.486	8.492	8.492	8.488	8.486	8.506	8.482	8.492	8.483
9.0	8.494	8.490	8.483	8.483	8.483	8.483	8.481	8.487	8.492	8.492	8.487	8.484	8.505	8.482	8.492	8.483
9.5	8.493	8.492	8.478	8.483	8.483	8.483	8.481	8.487	8.492	8.492	8.487	8.483	8.504	8.482	8.492	8.483
10.0	8.495	8.490	8.476	8.483	8.483	8.483	8.481	8.487	8.492	8.492	8.487	8.483	8.501	8.482	8.492	8.483
10.5	8.496	8.493	8.474	8.483	8.483	8.483	8.481	8.485	8.492	8.492	8.487	8.483	8.501	8.482	8.492	8.483
11.0	8.492	8.492	8.474	8.483	8.483	8.483	8.482	8.484	8.488	8.492	8.487	8.483	8.501	8.482	8.492	8.484
11.5	8.493	8.492	8.474	8.483	8.483	8.483	8.481	8.483	8.487	8.492	8.487	8.481	8.501	8.482	8.492	8.483
12.0	8.492	8.492	8.474	8.483	8.483	8.482	8.485	8.483	8.487	8.492	8.485	8.478	8.498	8.479	8.492	8.483
12.5	8.493	8.492	8.475	8.483	8.483	8.483	8.484	8.483	8.487	8.490	8.484	8.478	8.497	8.477	8.492	8.483
13.0	8.495	8.492	8.474	8.483	8.483	8.480	8.483	8.483	8.487	8.487	8.483	8.478	8.497	8.480	8.492	8.483
13.5	8.493	8.492	8.475	8.483	8.483	8.480	8.485	8.483	8.486	8.485	8.480	8.478	8.497	8.482	8.493	8.484
14.0	8.497	8.492	8.475	8.483	8.483	8.482	8.486	8.483	8.484	8.484	8.478	8.478	8.497	8.479	8.493	8.483
14.5	8.495	8.492	8.475	8.483	8.483	8.480	8.484	8.483	8.484	8.483	8.478		8.497	8.477	8.494	8.483
15.0	8.493	8.492	8.478	8.483	8.483	8.481	8.486	8.483	8.483	8.481	8.478		8.497	8.477	8.493	8.483
15.5	8.499		8.478	8.483	8.483	8.481	8.486	8.479	8.483				8.497	8.477		8.481
16.0			8.478	8.483	8.482	8.481	8.486	8.479	8.483				8.497	8.477		
16.5			8.483	8.483	8.475	8.473	8.483	8.478	8.483				8.497	8.477		
17.0							8.477	8.478								
17.5							8.477									
18.0							8.477									

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

² Values enclosed in the box were significantly different from the other pH measurements at the same depth.

Table B-7. Uncorrected pH¹ on 20 January 2009

Depth (m)	Hydrogen Ion Concentration (pH)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0.5														8.468		
1.0		8.487		8.492	8.487	8.487	8.476	8.487		8.493		8.486	8.503	8.465		8.483
1.5	8.492	8.487	8.483	8.492	8.488	8.487	8.478	8.489	8.493	8.492	8.492	8.488	8.517	8.467	8.496	8.483
2.0	8.492	8.487	8.486	8.493	8.488	8.489	8.478	8.487	8.494	8.493	8.492	8.488	8.515	8.467	8.501	8.484
2.5	8.492	8.487	8.487	8.493	8.487	8.492	8.478	8.487	8.494	8.496	8.492	8.489	8.515	8.468	8.501	8.483
3.0	8.492	8.487	8.487	8.495	8.487	8.490	8.478	8.489	8.494	8.496	8.492	8.487	8.515	8.468	8.499	8.483
3.5	8.492	8.487	8.487	8.492	8.487	8.488	8.478	8.487	8.494	8.495	8.492	8.487	8.515	8.469	8.499	8.483
4.0	8.492	8.487	8.488	8.491	8.487	8.487	8.478	8.487	8.492	8.493	8.492	8.487	8.515	8.469	8.497	8.483
4.5	8.492	8.487	8.487	8.489	8.487	8.487	8.478	8.484	8.492	8.493	8.492	8.487	8.515	8.466	8.498	8.483
5.0	8.492	8.487	8.487	8.487	8.486	8.487	8.478	8.484	8.492	8.494	8.492	8.487	8.515	8.466	8.496	8.483
5.5	8.492	8.487	8.492	8.487	8.486	8.487	8.478	8.484	8.493	8.493	8.492	8.487	8.513	8.467	8.496	8.483
6.0	8.492	8.488	8.487	8.487	8.485	8.487	8.478	8.483	8.494	8.495	8.489	8.487	8.510	8.468	8.496	8.483
6.5	8.492	8.487	8.487	8.487	8.486	8.487	8.478	8.484	8.496	8.493	8.488	8.487	8.510	8.469	8.496	8.483
7.0	8.492	8.487	8.487	8.486	8.483	8.486	8.478	8.484	8.494	8.492	8.489	8.487	8.510	8.469	8.496	8.483
7.5	8.492	8.487	8.487	8.485	8.485	8.486	8.478	8.483	8.493	8.492	8.487	8.487	8.510	8.469	8.495	8.483
8.0	8.493	8.487	8.484	8.484	8.483	8.485	8.478	8.485	8.494	8.492	8.487	8.485	8.508	8.469	8.493	8.483
8.5	8.492	8.487	8.480	8.483	8.483	8.483	8.478	8.486	8.492	8.492	8.488	8.486	8.506	8.469	8.492	8.483
9.0	8.494	8.490	8.483	8.483	8.483	8.483	8.478	8.487	8.492	8.492	8.487	8.484	8.505	8.469	8.492	8.483
9.5	8.493	8.492	8.478	8.483	8.483	8.483	8.478	8.487	8.492	8.492	8.487	8.483	8.504	8.469	8.492	8.483
10.0	8.495	8.490	8.476	8.483	8.483	8.483	8.478	8.487	8.492	8.492	8.487	8.483	8.501	8.469	8.492	8.483
10.5	8.496	8.493	8.474	8.483	8.483	8.483	8.478	8.485	8.492	8.492	8.487	8.483	8.501	8.469	8.492	8.483
11.0	8.492	8.492	8.474	8.483	8.483	8.483	8.479	8.484	8.488	8.492	8.487	8.483	8.501	8.469	8.492	8.484
11.5	8.493	8.492	8.474	8.483	8.483	8.483	8.478	8.483	8.487	8.492	8.487	8.481	8.501	8.469	8.492	8.483
12.0	8.492	8.492	8.474	8.483	8.483	8.482	8.482	8.483	8.487	8.492	8.485	8.478	8.498	8.466	8.492	8.483
12.5	8.493	8.492	8.475	8.483	8.483	8.483	8.481	8.483	8.487	8.490	8.484	8.478	8.497	8.464	8.492	8.483
13.0	8.495	8.492	8.474	8.483	8.483	8.480	8.480	8.483	8.487	8.487	8.483	8.478	8.497	8.467	8.492	8.483
13.5	8.493	8.492	8.475	8.483	8.483	8.480	8.482	8.483	8.486	8.485	8.480	8.478	8.497	8.469	8.493	8.484
14.0	8.497	8.492	8.475	8.483	8.483	8.482	8.483	8.483	8.484	8.484	8.478	8.478	8.497	8.466	8.493	8.483
14.5	8.495	8.492	8.475	8.483	8.483	8.480	8.481	8.483	8.484	8.483	8.478		8.497	8.464	8.494	8.483
15.0	8.493	8.492	8.478	8.483	8.483	8.481	8.483	8.483	8.483	8.481	8.478		8.497	8.464	8.493	8.483
15.5	8.499		8.478	8.483	8.483	8.481	8.483	8.479	8.483				8.497	8.464		8.481
16.0			8.478	8.483	8.482	8.481	8.483	8.479	8.483				8.497	8.464		
16.5			8.483	8.483	8.475	8.473	8.480	8.478	8.483				8.497	8.464		
17.0							8.474	8.478								
17.5							8.474									
18.0							8.474									

¹ Values enclosed in the boxes were significantly different from the mean of other pH measurements at the same depth level.

Table B-8. Uncorrected Dissolved Oxygen¹ on 20 January 2009

Depth (m)	Dissolved Oxygen (mg/L)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0.5														8.88		
1.0		8.99		9.12	9.09		8.94	9.03		9.13				8.89		9.05
1.5	9.02	9.00	9.07	9.13	9.08	9.11	8.94	9.04	9.10	9.14	9.14	9.12	9.23	8.89	9.12	9.04
2.0	9.03	9.00	9.08	9.14	9.09	9.10	8.95	9.04	9.12	9.15	9.14	9.11	9.24	8.89	9.12	9.04
2.5	9.02	9.00	9.08	9.15	9.08	9.10	8.94	9.01	9.11	9.15	9.14	9.12	9.23	8.89	9.11	9.04
3.0	9.02	8.99	9.08	9.13	9.07	9.09	8.94	9.00	9.10	9.15	9.14	9.11	9.23	8.89	9.10	9.04
3.5	9.03	9.00	9.08	9.12	9.05	9.09	8.94	9.01	9.10	9.15	9.12	9.10	9.23	8.90	9.11	9.03
4.0	9.03	9.00	9.09	9.11	9.04	9.09	8.95	8.99	9.10	9.15	9.12	9.11	9.23	8.89	9.11	9.03
4.5	9.04	9.01	9.09	9.10	9.05	9.08	8.96	8.99	9.12	9.16	9.12	9.10	9.21	8.89	9.10	9.04
5.0	9.04	9.02	9.08	9.09	9.05	9.08	8.96	8.99	9.12	9.15	9.10	9.11	9.21	8.89	9.09	9.04
5.5	9.04	9.01	9.09	9.06	9.05	9.06	8.97	9.00	9.12	9.14	9.10	9.09	9.20	8.91	9.09	9.04
6.0	9.04	9.02	9.09	9.05	9.04	9.04	8.96	8.99	9.12	9.14	9.10	9.08	9.20	8.91	9.08	9.03
6.5	9.04	9.01	9.06	9.06	9.04	9.05	8.96	9.00	9.13	9.13	9.09	9.07	9.19	8.92	9.08	9.02
7.0	9.05	9.02	9.04	9.04	9.03	9.03	8.97	9.00	9.13	9.14	9.09	9.06	9.16	8.92	9.05	9.02
7.5	9.05	9.02	9.03	9.02	9.02	9.02	8.96	9.00	9.12	9.14	9.10	9.05	9.13	8.93	9.03	9.02
8.0	9.06	9.02	9.00	9.01	9.01	9.01	8.95	9.02	9.10	9.13	9.10	9.03	9.10	8.92	9.04	9.00
8.5	9.06	9.03	9.01	9.00	9.00	8.99	8.96	9.03	9.08	9.09	9.08	9.01	9.09	8.91	9.04	9.01
9.0	9.06	9.03	8.97	8.98	9.00	8.98	8.96	8.99	9.08	9.11	9.09	9.01	9.08	8.93	9.02	9.02
9.5	9.04	9.03	8.96	8.97	9.00	8.99	8.96	8.97	9.06	9.11	9.07	9.01	9.07	8.93	9.02	9.03
10.0	9.03	9.03	8.97	8.97	9.00	8.99	8.95	8.97	9.05	9.10	9.06	9.00	9.06	8.93	9.01	9.00
10.5	9.03	9.01	8.96	8.97	8.98	8.97	8.95	8.98	9.04	9.10	9.06	8.99	9.03	8.91	9.00	9.00
11.0	9.04	9.01	8.96	8.96	8.97	8.96	8.97	8.97	9.03	9.08	9.05	8.99	9.02	8.91	8.99	8.99
11.5	9.03	9.00	8.96	8.97	8.97	8.97	8.98	8.95	9.03	9.07	9.03	8.97	9.00	8.91	8.99	8.98
12.0	9.03	9.01	8.96	8.97	8.95	8.95	8.96	8.96	9.02	9.07	9.02	8.96	8.98	8.91	8.99	8.98
12.5	9.03	9.01	8.96	8.95	8.94	8.94	8.95	8.98	9.01	9.03	9.02	8.95	8.98	8.92	8.99	8.99
13.0	9.03	9.00	8.95	8.95	8.96	8.94	8.95	8.96	9.00	9.03	8.97	8.95	8.98	8.93	8.99	8.99
13.5	9.02	9.01	8.96	8.97	8.95	8.94	8.95	8.94	9.00	9.01	8.96	8.94	8.95	8.91	8.98	8.96
14.0	9.03	9.01	8.97	8.94	8.94	8.93	8.96	8.94	9.00	9.01	8.96	8.95	8.94	8.89	8.96	8.94
14.5	9.02	9.01	8.96	8.95	8.94	8.93	8.95	8.94	8.99	8.97	8.94		8.94	8.88	8.96	8.95
15.0	9.01	8.97	8.98	8.95	8.93	8.92	8.95	8.91	8.98	8.96	8.94		8.93	8.87	8.96	8.94
15.5	9.01		8.99	8.93	8.93	8.92	8.96	8.91	8.97				8.93	8.88		8.93
16.0			8.98	8.93	8.92	8.92	8.92	8.90	8.99				8.92	8.87		
16.5			8.97	8.92	8.92	8.92	8.87	8.89	8.98				8.92	8.87		
17.0							8.88	8.90								
17.5							8.88									
18.0							8.87									

¹ Values enclosed in the boxes were significantly different from the other DO measurements at the same depth level.

Table B-9. Auxiliary Observations on 20 January 2009 during the Quarterly Water-Quality Survey

Station	Location		Diffuser Distance (m)	Time (PST)	Air Temperature (°C)	Cloud Cover (%)	Wind Avg (kt)	Wind Max (kt)	Wind Dir (from) (°T)	Swell Ht/Dir (ft/°T)	Secchi Depth (m)
	Latitude	Longitude									
1	35° 23.262' N	120° 52.500' W	106.1	8:52:17	15.5	0	1.9	4.9	NW	4 W	8.0
2	35° 23.231' N	120° 52.493' W	56.2	8:48:21	18.4	0	0.6	1.4	NW	4 W	8.0
3	35° 23.210' N	120° 52.510' W	9.9	8:42:31	15.8	0	1.4	2.1	NW	4 W	7.0
4	35° 23.191' N	120° 52.510' W	16.2	8:38:21	16.1	0	1.8	2.6	NW	4 W	7.5
5	35° 23.175' N	120° 52.495' W	31.9	8:34:40	16.4	0	3.2	4.9	NW	4 W	7.5
6	35° 23.152' N	120° 52.502' W	75.1	8:30:33	16.0	0	2.7	3.2	NW	4 W	7.5
7	35° 23.201' N	120° 52.574' W	91.2	8:00:13	15.6	0	1.9	2.5	NW	4 W	8.0
8	35° 23.207' N	120° 52.544' W	44.8	8:03:39	17.4	0	0.7	0.9	NW	4 W	8.0
9	35° 23.200' N	120° 52.514' W	8.5	8:07:07	16.5	0	2.3	4.1	NW	4 W	8.5
10	35° 23.207' N	120° 52.483' W	32.8	8:13:53	17.2	0	1.5	2.7	NW	4 W	8.0
11	35° 23.197' N	120° 52.468' W	40.8	8:17:14	16.7	0	1.8	3.1	NW	4 W	7.5
12	35° 23.206' N	120° 52.438' W	89.2	8:20:33	17.1	0	1.9	4.1	NW	4 W	8.0
13	35° 23.177' N	120° 52.531' W	58.0	9:01:33	14.7	0	2.7	4.0	NW	4 W	8.0
14	35° 23.223' N	120° 52.532' W	42.2	7:54:37	17.1	0	1.9	3.2	NW	4 W	8.0
15	35° 23.224' N	120° 52.471' W	68.0	8:55:43	17.1	0	1.0	1.9	NW	4 W	8.0
16	35° 23.182' N	120° 52.483' W	24.4	8:26:21	16.0	0	3.1	5.8	NW	4 W	8.0

Although extraordinarily high seawater clarity prevailed at all stations, the signature of the effluent plume was not visible at any time during the survey. Neither odors nor debris of sewage origin were observed at any time during the survey.

Tidal Conditions (Pacific Standard Time)

High Tide: 05:35 4.84 ft

Low Tide: 13:42 0.20 ft

High Tide: 20:37 3.01 ft