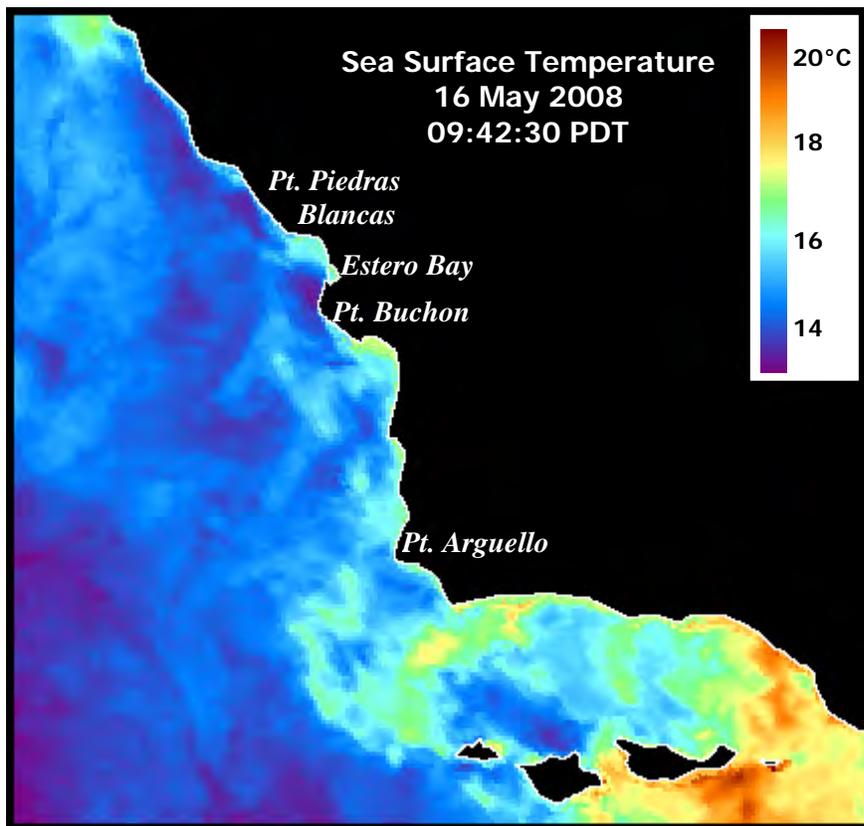


**City of Morro Bay and
Cayucos Sanitary District**

OFFSHORE MONITORING AND REPORTING PROGRAM

QUARTERLY REPORT

WATER-COLUMN SAMPLING MAY 2008 SURVEY



Marine Research Specialists

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Report to
City of Morro Bay and
Cayucos Sanitary District

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OFFSHORE MONITORING
AND REPORTING PROGRAM

QUARTERLY REPORT
WATER-COLUMN SAMPLING
MAY 2008 SURVEY

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

23 June 2008

Reference: Quarterly Receiving-Water Report – May 2008

Dear Mr. Keogh:

Enclosed is the Quarterly Report for the Water-Quality Survey conducted on Friday, 16 May 2008. This second-quarter survey assessed the effectiveness of effluent dispersion during spring oceanographic conditions. Based on quantitative analyses of continuous instrumental measurements and qualitative visual observations, the wastewater discharge was found to be in compliance with the receiving-water limitations specified in the NPDES discharge permit, and with the objectives of the California Ocean Plan.

In addition to capturing the movement and dispersion of the wastewater plume within receiving waters outside of the zone of initial dilution, this survey also serendipitously documented rapid mixing within the turbulent discharge jet formed by wastewater ejection from a diffuser port. These data demonstrated that the momentum of the jet diluted the effluent to levels that were close to the dilution predicted by modeling of the entire mixing process, including dilution resulting from the subsequent rise of the buoyant plume through the water column. Plume measurements collected higher in the water column documented a 400-fold dilution that was three times higher than that predicted by the plume modeling used to establish effluent limits in the discharge permit. These results confirmed that the diffuser structure and the outfall were attaining dilution levels that significantly exceeded those anticipated by modeling and outfall design criteria. All of the measurements were indicative of low organic loading within the effluent, and of an outfall operating as designed to achieve acceptable dilution levels for wastewater.

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

Sincerely,

Douglas A. Coats, Ph.D.
Program Manager

Enclosure (Five Report Copies)

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

Mr. Bruce Ambo
City of Morro Bay

Date _____

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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. A National Pollutant Discharge Elimination System (NPDES) permit, modifying secondary treatment requirements, was originally issued to the MBCSD in March 1985. The permit was issued by Region IX of the U.S. Environmental Protection Agency (USEPA) and the Central Coast California Regional Water Quality Control Board (RWQCB). Following extensive evaluation processes, the permit has been re-issued twice, once in March of 1993 (RWQCB-USEPA 1993ab) and again in 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 include a requirement for water-quality monitoring performed on a seasonal basis. The four quarterly surveys are intended to record ambient water properties that approximate winter, spring, summer, and fall conditions. In keeping with seasonal synopses, this quarterly report summarizes the results of water-quality sampling conducted on 16 May 2008. Specifically, this second-quarter survey captures ambient oceanographic conditions along the central California coast during the spring season.

The water-quality surveys also provide timely assessments of the performance of the diffuser structure in dispersing wastewater within stratified receiving waters. Any significant, recent damage to the diffuser structure would be revealed by a decline in the level of wastewater dispersion measured in this survey compared to that of prior surveys, and compared to design specifications. As described in this report, no such decline was observed in the May 2008 field survey.

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

The May 2008 field survey was the thirty-eighth water-quality survey to be conducted under the monitoring provisions of the current permit. Compared to the previous permit, the number of stations increased from 11 to 16, and the stations were relocated closer (≤ 100 m) to the diffuser structure. Sampling at these more closely spaced stations could only be achieved because of the availability of increased navigational accuracy that resulted from implementation of the differential global positioning satellite (DGPS) system. This system was commissioned during the March 1998 survey (MRS 1998a) and was subsequently employed in the precise determination of the open section of the diffuser structure during a diver survey on 29 September 1998 (MRS 1998bc).

The current sampling design also allowed surveying to be conducted more rapidly than previous surveys by eliminating the requirement for collection of discrete water samples at individual stations. These samples were collected using Niskin bottles, which was time consuming and interrupted the continuity of instrumental measurements recorded by the CTD¹ instrument package. Continuous deployment of the CTD between stations 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 sensitive sensors onboard the

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.

CTD instrument package are capable of detecting minute changes in water properties. These sensors are described in the Methods Section below.

Surveys conducted prior to 1999 rarely detected the effluent plume because sampling stations were too widely separated to resolve the dilute wastewater signature that is highly localized around the outfall diffuser. With the implementation of the current sampling design in 1999, the presence of well-mixed effluent near the diffuser structure was found in all of the subsequent water-quality surveys (MRS 2000–2008), including the one described in this report. Moreover, improved navigation, in concert with the denser sampling pattern, more precisely delineated the lateral extent of the discharge-related perturbations in seawater properties.

Precision navigation is important for assessing compliance because most receiving-water limitations apply only beyond the narrow zone of initial dilution that surrounds the outfall. Additionally, the amplitudes of the discharge-related perturbations can be better determined by the denser sampling pattern. The amplitudes of discharge-related salinity anomalies reveal the details of dilution as the effluent plume disperses within receiving waters. Measured dilution factors lend insight into the current operational performance of the outfall and diffuser structure. As described in this report, the presence of dilute effluent north of the diffuser structure that was continuing to undergo turbulent mixing within the strongly stratified water column was delineated by the data collected during the May 2008 survey.

STATION LOCATIONS

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

Twenty-eight of the 34 available ports discharge effluent along a 42 m section of the diffuser structure. The 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, which serves to rapidly mix effluent with receiving seawater immediately upon discharge. Additional turbulent mixing occurs as the buoyant plume of dilute effluent rises through the water column. Most of this buoyancy-induced mixing occurs within a zone of initial dilution (ZID), whose lateral extent in modeling studies is considered to be approximately 15 m from the centerline of the diffuser structure.

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

Similarly, the entrance to the Morro Bay National Estuary lies 2.8 km south of the discharge and direct seawater exchange between the discharge point and the Bay is restricted by the southerly orientation of the mouth of the Bay, and by the presence of Morro Rock. Morro Rock is the largest physiographic

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



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

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.

Near the diffuser, prevailing currents generally follow bathymetric contours, which 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 in the annual reports. The instances of elevated beach coliform levels that are occasionally observed have all resulted from onshore non-point sources rather than the discharge of disinfected wastewater 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 target locations of the 16 offshore sampling stations are indicated by the red ⊙ symbols in the Figure. The stations are situated at three distances relative to the center of the diffuser structure in order 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, at a distance of 15 m from the closest diffuser ports (Table 1). Stations 2 and 5 are located at nearfield distances (60 m) from the diffuser centroid. Stations 1 and 6 represent midfield stations, and are situated 100 m upcoast and downcoast of the centroid. Depending on the direction of the local oceanic currents at the time of sampling, one or more of these stations could conceivably be influenced by the discharge. Under those circumstances, the midfield station on the opposite side of the diffuser can act as a reference station. Comparisons of water properties at these antipodal stations quantify departures from ambient seawater properties so that compliance with the NPDES discharge permit can be evaluated.

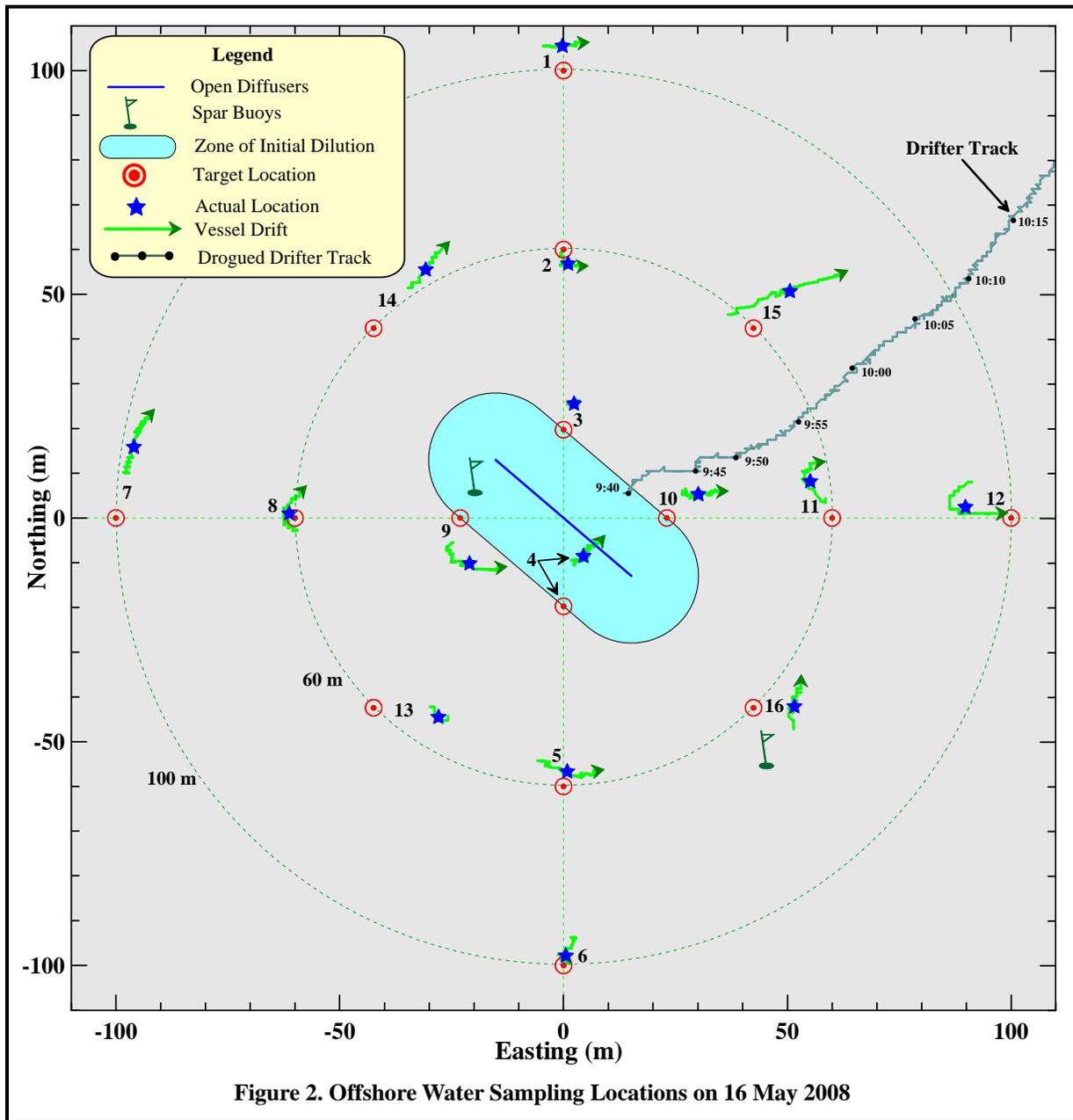
Six other stations (7 through 12) are aligned along a cross-shore transect in a pattern matching that of the along-shore transect. The remaining four stations (13 through 16) measure the nearfield influence of effluent transported by ocean currents flowing at oblique angles to the bathymetry.

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

¹Distance to the closest open diffuser port.

²Distance to the center of open diffuser section.



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. Because of this distributed discharge, the amount of wastewater dispersion at a given point in the water column is dictated by its distance to the closest diffuser port, rather than its distance to the center of the diffuser structure. 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. The ability to discern small spatial separations among stations within the compact

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

Even so, extreme atmospheric conditions and physiographic obstructions can still cause satellite signals to bounce around, leading to errors in position beyond those that were previously introduced by SA. These other errors are greatly reduced with the Differential GPS (DGPS) system that was first implemented by the U.S. Coast Guard to enhance offshore navigation. 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. This navigational system was used on 29 July 1998 to precisely locate the position of the open section of the diffuser structure (MRS 1998b) and establish the new target locations for the receiving-water monitoring stations shown in Figure 2 and listed in Table 1. 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 crucial for accurate interpretation of the water-property fields. During any given survey, the actual sampling locations rarely coincide with the exact target coordinates listed in Table 1. Winds, waves, and currents induce offsets during sampling. Equally important are the offsets caused by the residual momentum of the survey vessel upon its approach to the target locations. 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 that occurred at each of the stations during the May 2008 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 capability during the May 2008 survey. During the time it took the CTD to traverse the water column to the seafloor, which averaged 1 min 30 s, the instrument package moved as much as 26.4 m laterally (Station 15). Overall, however, the drift was only 9.4 m when averaged over all the stations. This amount of drift is fairly 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-7, winds were light and variable during the survey. As a result, their influence was minimal compared to the northeastward drift induced by the prevailing current. As shown by the green tracklines in Figure 2, the drift direction at many stations was similar to that of the drifter track. Nevertheless, at some stations, the CTD drift was also perceptibly influenced by the vessel's residual momentum left after its approach to the target coordinates. The

influence of vessel momentum was evaluated at each station by examining the vessel's track immediately prior to the downcast. For example, the increased amount of drift observed at Station 15 was caused by residual momentum as the vessel approached from the southwest. At other stations where the net CTD drift was comparatively small, namely Stations 2, 3, 6, and 13, the vessel approach was from the northeast and the vessel momentum counteracted the influence of current drift.

Although small and comparable to the survey vessel's 12-m length, drift in the CTD location during the downcasts complicates the assessment of compliance with discharge limitations at stations close to the diffuser structure. Receiving-water limitations specified in the COP only apply to measurements recorded beyond the ZID boundary. Within the ZID, rapid turbulent mixing associated with the momentum of the effluent jet and the rise of the buoyant plume is expected, and the limitations apply to conditions after this initial mixing is complete. Specifically, during the May 2008 survey, none of the measurements recorded at Station 4 were subject to the limitations because the CTD was within the ZID boundary throughout the entire vertical cast at that station.

Compliance assessments notwithstanding, measurements recorded close to the diffuser structure within the ZID lend valuable insight into the outfall's effectiveness at dispersing wastewater during the May 2008 survey. Damaged or broken diffuser ports would be reflected by low dilution rates and measurements of concentrated effluent throughout the ZID. 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 denser sampling pattern that is now in use was instituted.

Surveys prior to 1999 also predated the advent of DGPS. Consequently, the 9.4-m average drift experienced during sampling at individual stations in the May 2008 survey would not have been resolved with the navigation available prior to 1999. In fact, before 1999 sampling was presumed to occur at a single, imprecisely determined, horizontal location near each station. Federal and State reporting of monitoring data still depends on identification of a single position for all of the CTD data collected at a particular station. Thus, for regulatory reporting, and for historical consistency with past surveys, a single sampling location was also reported for each station during the May 2008 survey. These positions were based on the average locations shown for each station by the blue stars in Figure 2. The average positions are also listed in Table 2, along with their distance from the diffuser structure. However, when CTD casts traverse the ZID boundary, an average reported station position that happens to lie within the ZID does not imply that all of the measurements collected at that particular station are exempt from the receiving-water objectives in the discharge permit.

FLOW FIELD

A satellite-tracked drifter documented the prevailing north northeastward flow during the May 2008 survey. The drifter is designed to track the subsurface current, with little influence from the wind. As in past reports, its trajectory is shown by the grey line with black dots in Figure 3. Each dot along the drifter track represents a time span of five minutes. The drogued drifter was deployed near Station 10 at 9:40 PDT and was recovered an hour and forty-six minutes later, at 11:26 PDT. In contrast to the steady transport direction seen in most other surveys, the drifter executed a gradual arc during the May 2008 survey in response to a steady weakening of the eastward flow component. Immediately after deployment, the drifter traveled almost due east, while at the time of its recovery, its movement was predominantly northward.

Similar changes in flow direction would have gone undetected in drifter data collected prior to 2005, when only the deployment and recovery locations of the drifter were recorded. For example, based solely on the deployment and recovery locations during the May 2008 survey, the drifter traversed a total of 311

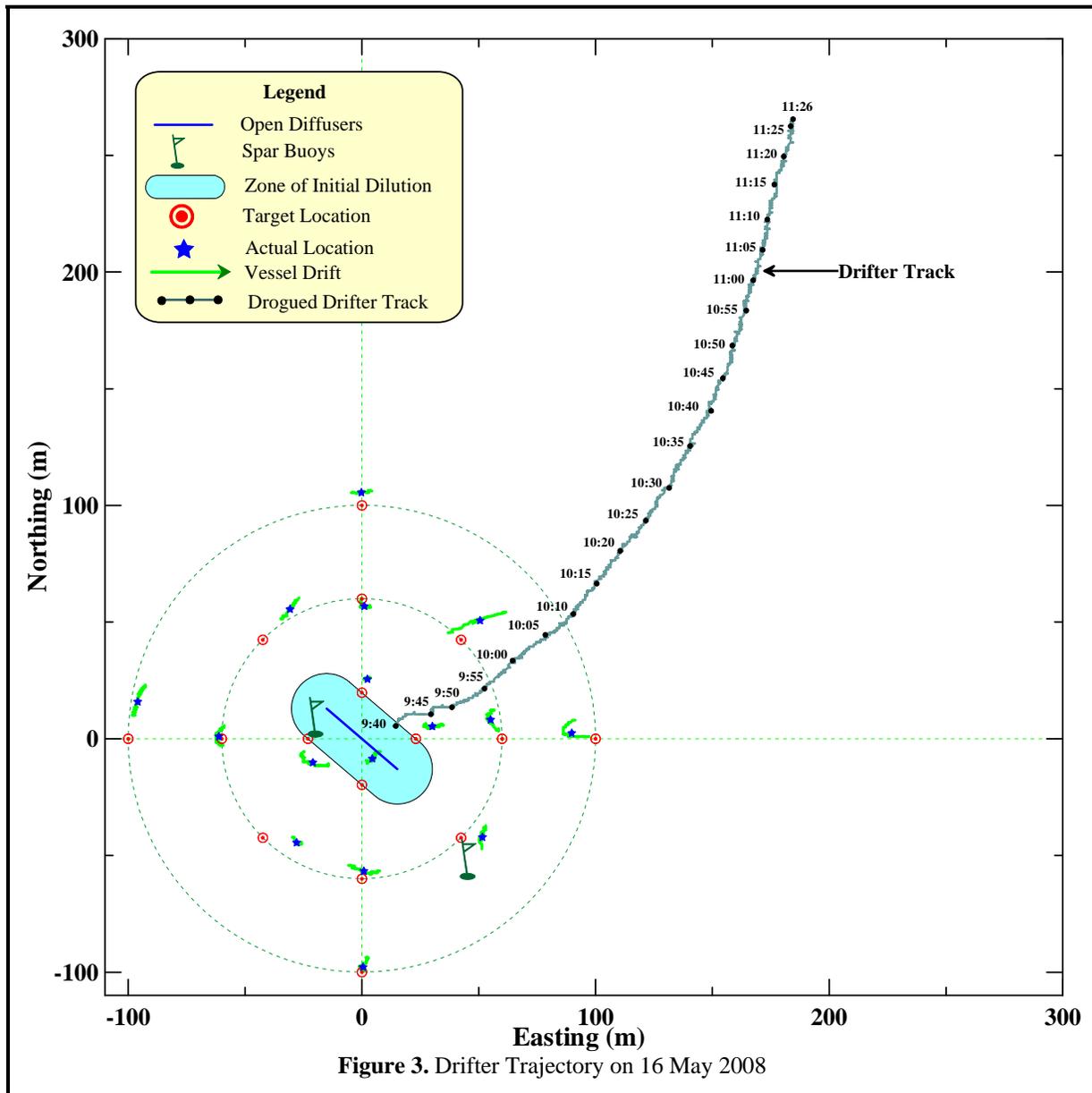


Figure 3. Drifter Trajectory on 16 May 2008

m toward the north northeast (33°T) at an average speed of 4.89 cm/s or 0.095 knots. However, the continuous drifter-location data that was available throughout the May 2008 deployment provides a much more accurate determination of the flow field and its temporal variation. The drifter actually travelled a total of 369 m at an average speed of 5.81 cm/s or 0.113 knots because of the curvature of its trajectory.

The observed change in flow direction may have been related to an intensification of ebb tidal flow (Figure 4). In the absence of other external influences, an ebb tide normally induces a weak southwestward (offshore) flow in the survey region. During the May 2008 survey, the influence of strengthening tidal flow may have been responsible for the observed weakening of the onshore (eastward) component of the prevailing currents. Nonetheless, the predominantly northeastward prevailing flow was in general opposition to the flow direction typically induced by an ebb tide acting alone.

Table 2. Average Coordinates of Vertical Profiles during the May 2008 Survey

Station	Time (PDT)		Latitude	Longitude	Closest Approach	
	Downcast	Upcast			Range ¹ (m)	Bearing ² (°T)
1	10:35:47	10:37:11	35° 23.256' N	120° 52.504' W	93.9	9
2	10:41:02	10:42:22	35° 23.230' N	120° 52.503' W	46.9	20
3	10:44:18	10:45:40	35° 23.213' N	120° 52.502' W	21.1	41
4	10:48:20	10:49:58	35° 23.194' N	120° 52.501' W	3.5³	221
5	10:52:28	10:53:59	35° 23.168' N	120° 52.503' W	45.8	198
6	10:56:19	10:58:02	35° 23.146' N	120° 52.504' W	86.0	190
7	10:30:14	10:32:00	35° 23.208' N	120° 52.567' W	80.9	272
8	10:26:09	10:27:43	35° 23.200' N	120° 52.544' W	47.6	256
9	10:22:08	10:23:43	35° 23.194' N	120° 52.518' W	21.2	221
10	10:17:47	10:19:27	35° 23.202' N	120° 52.484' W	23.7	41
11	10:13:55	10:15:18	35° 23.204' N	120° 52.468' W	45.3	62
12	10:09:13	10:10:52	35° 23.200' N	120° 52.445' W	76.2	78
13	11:18:33	11:19:49	35° 23.175' N	120° 52.522' W	51.9	221
14	11:11:20	11:12:36	35° 23.229' N	120° 52.524' W	45.5	340
15	11:05:28	11:06:59	35° 23.226' N	120° 52.471' W	71.5	41
16	11:01:30	11:02:50	35° 23.176' N	120° 52.470' W	46.6	129

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

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

³All of the CTD cast was within the ZID boundary.

Despite some evidence of tidal influence, the flow within Estero Bay is more often dominated by external processes, such as wind-generated upwelling or passing offshore eddies. For example, the shoreward-directed flow that was observed during the May 2008 survey may be indicative of a brief relaxation in the strong upwelling conditions that prevailed during the weeks and months leading up to the survey. In contrast to the offshore-directed surface flow observed during upwelling conditions, relaxation of the prevailing northwesterly winds allows warm offshore surface waters to be transported shoreward where the surface mixed layer increases in thickness and the thermocline is driven to greater depth. As a result,

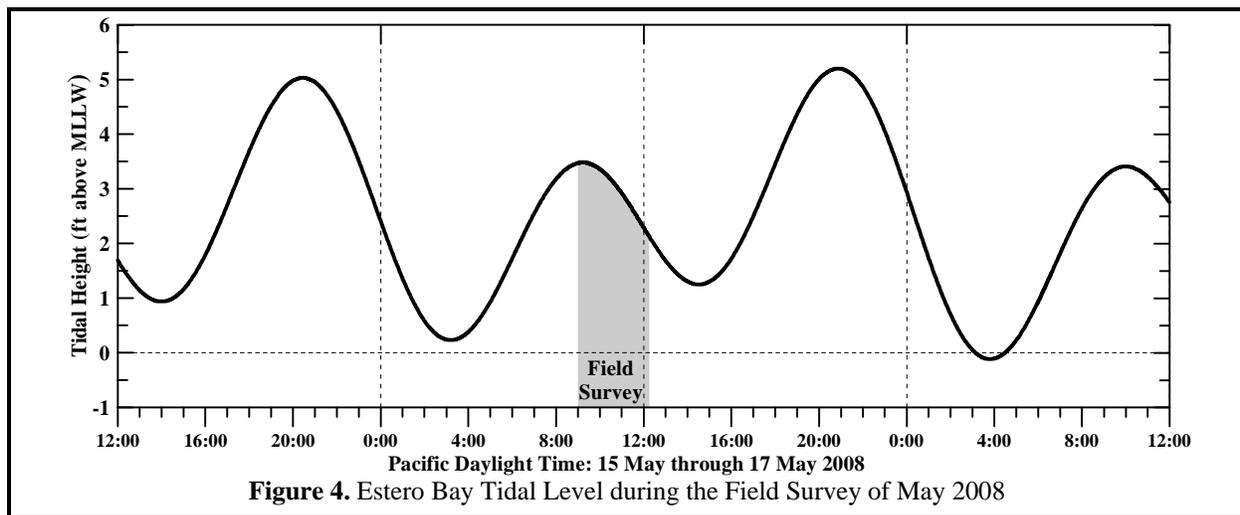


Figure 4. Estero Bay Tidal Level during the Field Survey of May 2008

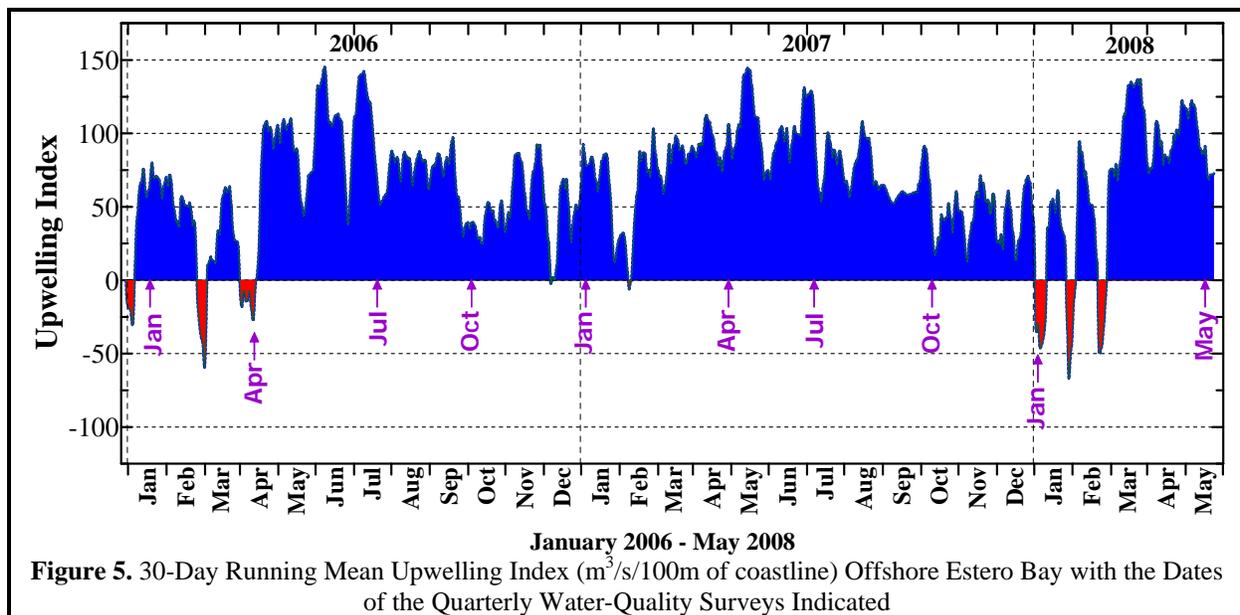
near-coastal sea-surface temperatures tend to be slightly warmer, than offshore surface waters, whereas during upwelling, nearshore seawater temperature is much colder.

The brief relaxation of upwelling conditions which coincided with the May 2008 survey is apparent in the satellite image on the cover of this report. The image was recorded the day of the survey when skies were clear enough for sea-surface temperatures to be measured by infrared sensors on one of NOAA's polar orbiting satellites. The satellite image depicts slightly warmer sea-surface temperatures within northern Estero Bay and elsewhere along the central California coastline, with temperatures at or above 16°C delineated in light green and yellow.

Despite the brief relaxation of northwesterly winds on the day of the survey, consistently strong upwelling conditions prevailed during the prior two-and-a-half months (Figure 5). As a result, the relict vertical structure of seawater properties measured during the May 2008 survey remained indicative of upwelling processes. As described later in this report, the distribution of seawater properties during the survey was highly diagnostic of upwelling conditions, namely strong vertical stratification with a sharply defined, shallow thermocline.

Upwelling season normally begins sometime during late March and or early April when there is a "spring transition" to more persistent southward-directed winds along the central California coast. This transition is marked by the stabilization of a high atmospheric pressure field over the northeastern Pacific Ocean. Clockwise winds around this pressure field drive the prevailing northwesterly winds along the Central Coast. These prevailing winds move surface waters southward and offshore. To replace these coastal surface waters, deep, cool, nutrient-rich waters upwell near the coast.

The spring upwelling conditions in 2008 were particularly sustained and intense. The monthly average seawater temperature measured near the upwelling center at Pt. Buchon for the month of April was 9.7°C, which was the coldest for any month since 1976, when the Diablo Canyon Ocean Lab began regular measurements. Although it is not apparent in the 30-day running average data shown in Figure 5, the 6-hour upwelling index data recorded confirmed that upwelling winds relaxed briefly around the time of the survey. This brief relaxation in upwelling winds was caused by an eastward shift in the location of the high atmospheric pressure field, which is normally positioned over the northeastern Pacific Ocean during



the spring. Its temporary relocation over the western United States around the time of the survey briefly generated weak Santa Ana winds, which are warm, dry, gusty offshore-directed winds that oppose and weaken the southeastward directed winds that normally prevail along the central California coast during the spring. However, the Santa Ana conditions were neither, strong enough nor sustained long enough to defuse the upwelling signature in seawater properties that was generated by the unusually intense southeastward winds that prevailed prior to the survey.

METHODS

The 38 ft F/V *Bonnie Marietta*, owned and operated by Captain Mark Tognazzini of Morro Bay, served as the survey vessel on 16 May 2008. Dr. Douglas Coats of Marine Research Specialists (MRS) was the Chief Scientist while Captain Mark Tognazzini supervised vessel operations and Mr. William Skok acted as marine technician. Mr. Dylan Wade, Senior Civil Engineer for the City of Morro Bay, served as the client representative onboard the vessel during the survey. 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 included Secchi depth measurements and standard observations for weather, sea conditions, and water clarity/coloration as recorded in Table B-7. Wind speeds and air temperatures were measured with a Kestrel[®] 2000 Thermo-Anemometer. These auxiliary observations were collected contemporaneously with the rapid water-column profiling that was conducted at each station using a CTD instrument package.

The second-quarter 2008 water-quality survey was conducted substantially later in the season than past surveys, which have always occurred in April. Two factors contributed to this circumstance. First, during the beginning of April, the survey vessel was in dry dock in southern California receiving hull maintenance and repainting. Unfortunately, the vessel was detained in dry dock for an unexpectedly long period due to the sustained high winds which continued throughout April and into May, and which precluded spray application of bottom paint. Additionally, and regardless of boat availability, the sustained winds complicated the selection of an appropriate weather window that would have been suitable for surveying. In any regard, the survey conformed to the NPDES discharge requirement for conducting a survey during the second quarter. Nevertheless, on 23 April 2008, Mr. David LaCaro of the RWQCB staff was informed of the anticipated delay in conducting the second-quarter 2008 survey.

Auxiliary Measurements

At all stations, a Secchi disk was lowered through the water column to determine its depth of disappearance (Table B-7). Secchi depths provide a visual measure of near-surface turbidity or water clarity. The depth of disappearance is inversely proportional to the average amount of organic and inorganic suspended material along a line of sight in the upper water column. As such, the Secchi depth measures natural light penetration, which can be limited by increased suspended particulate loads from plankton blooms, onshore runoff, seafloor resuspension, and wastewater discharge. It is also of biological significance because the depth of the euphotic zone, where most oceanic photosynthesis occurs, extends to approximately twice the Secchi depth. Secchi depths averaged slightly less than 6 m during the May 2008 survey, reflecting the presence of a relatively deep, 12-m euphotic zone that spanned the majority of the water column but did not reach the seafloor at any of the monitoring stations. A deep euphotic zone is atypical of upwelling conditions when increased primary production, namely increased phytoplankton density, decreases the transmission of ambient light through the near-surface mixed layer. The high near-surface transmissivity (>70%) recorded during the May survey demonstrates that the brief relaxation in upwelling that occurred around the time of the survey was sufficient to limit the availability of nutrients that normally drive primary production. As discussed above, however, this relaxation in southward

directed winds was both too transient and too weak to eliminate the water column stratification produced by prolonged intense upwelling in the weeks and months prior to the survey.

For the most part, the distribution of Secchi depths measured at the 16 stations lends little insight into spatial variability in ambient light penetration. Secchi depths are less precise than measurements recorded by the transmissometer mounted on the CTD instrument package. They can also be biased. For example, the visibility of the disk, and hence its depth of disappearance, depends on the amount of natural light available at the time of the measurement. Thus, the Secchi depth reading can artificially change by as much as 0.5 m depending on whether the sample is taken on the sunny or shady side of the survey vessel. During the May survey, Secchi depth measurements were collected in a consistent manner to minimize the effects of varying lighting conditions. Nevertheless, temporal drift in the measurements can be introduced as the sun rises in the sky, or as a cloud cover changes as the survey progresses. Neither of these influences were particularly evident during the May 2008 survey, so the Secchi depth measurements accurately reflect general turbidity levels within the upper portion of the water column, even though little credence can be ascribed to the small differences among stations. Nevertheless, Secchi depths are also useful because they include waters within a meter of the sea surface where, because of the physical size of the CTD package, the transmissometer cannot accurately record turbidity.

During the May 2008 survey, a satellite-tracked drifter was deployed near the open section of the diffuser structure. The drifter was drogued at mid-depth (7 m) using the curtain-shade design of Davis et al (1982). In this configuration, the drifter's trajectory was largely dictated by the oceanic flow field rather than by surface winds. The times and precise positions of the drifter deployment and recovery were recorded to determine the overall strength and direction of plume transport during the May 2008 sampling effort. In addition, the May 2008 survey was the thirteenth 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. Knowledge of the drifter trajectory throughout its deployment is of interest because it can reveal vagaries in the drifter's trajectory and speed that would otherwise go unnoticed. For example, it revealed the curious arc in the drifter path that occurred as the ebb tidal flow increased in strength (Figure 3).

Instrumental Measurements

Vertical water-column profiling was conducted using an electronic instrument package equipped with a number of probes and sensors. A Sea Bird Electronics SBE-19 Seacat CTD package was used to collect profiles of conductivity, salinity, temperature, light transmittance, dissolved oxygen (DO), pH, density, and pressure at each station. A submersible pump on the CTD continuously flushed water through the conductivity cell and oxygen plenum at a constant rate, independent of the CTD's motion through the water column. During the May 2008 survey, a strand of bull kelp became entrained on the CTD during transit between the last two stations, Station 14 and Station 13, however, the kelp strand was removed before the subsequent downcast and no irregular measurements were recorded.

The CTD instrumentation receives regular maintenance and calibration. After the January 2001 survey, the CTD was returned to the factory for full testing, repair, and calibration. Temporal drifts in the oxygen and alkalinity readings during the January 2001 survey indicated that the sensitivity of these probes had degraded because of an accumulation of marine growth. 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 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 May 2008 survey. Calibration at upper-bound DO concentrations was established by immersing the CTD in an aerated, temperature controlled calibration tank. In addition to oxygen readings at full saturation, a zero-oxygen calibration point was determined by filling the oxygen-sensor plenum with an 8% solution of sodium sulfite (Na_2SO_3). Oxygen calibration coefficients were determined by regression analysis of sensor-membrane current and temperature, as recommended by the manufacturer (SBE 1993). As with prior factory calibrations, pre-cruise calibration coefficients determined by MRS closely corresponded to those determined by the factory.

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 ($^{\circ}\text{C}$) and salinity data. It was expressed as 1000 times the specific gravity minus one, which is a unit of sigma-T (σ_t).

Table 3. Instrumental Specifications for CTD Instrumentation Package

Component	Depth ¹	Units	Range	Accuracy	Resolution
Housing	600	—	—	—	—
Pump	3400	—	—	—	—
Pressure	680	Psia	0 to 1000	± 5.0	± 0.5
Depth	—	Meters	0 to 690	± 3.0	± 0.3
Conductivity	600	Siemens/m	0 to 6.5	± 0.001	± 0.0001
Salinity	600	‰	0 to 38	± 0.006	± 0.0006
Temperature	600	$^{\circ}\text{C}$	-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

¹Maximum depth limit in meters

All three of the physical parameters (salinity, temperature, and density) were used to determine the lateral extent of the effluent plume. Additionally, they quantified the 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, consisting of 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). Revised calibration coefficients determined after the survey were used in the algorithms that converted sensor voltage to engineering units when the field data were processed. Comparison with the factory calibration of the entire CTD package that was conducted in December 2001, and the more recent June 2006 replacement and calibration of the DO probe, confirmed the continued accuracy and stability of the temperature, pressure, and conductivity sensors, as well as the operational integrity of the oxygen and pH probes.

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

In comparison to past surveys, the May 2008 survey was unique in that there was no temporal drift exhibited in either the DO or pH sensors. Perceptible drift in pH measurements has been consistently observed in prior water-quality surveys as the result of ongoing sensor equilibration during profiling. For the pH sensor, prolonged exposure to the atmosphere between surveys has resulted in the largest offsets and also affected 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 May 2008 survey, however, obviated the need for mid-survey adjustments for pH drift.

Previous additional attempts to mitigate sensor drift have included prolonging the soak time of the CTD prior to profiling. Soak times of six minutes at the beginning of a survey were found to reduce, but not entirely eliminate sensor drift. During the May survey, a tube filled with seawater was placed around the pH sensor while in transit to the survey site to limit atmospheric exposure of the probe immediately prior to deployment. This technique was successful at further ameliorating perceptible sensor drift.

RESULTS

The second-quarter water-quality survey began on Friday, 16 May 2008, at 9:40 PDT with the deployment of the drogued drifter. Subsequently, all water-column measurements were collected as required by the NPDES monitoring program (Tables 2 and B-7). Sunrise was at 5:58 PDT and skies were clear throughout the survey, which ended at 11:26 PDT with the retrieval of the drogued drifter. Atmospheric visibility was clear along the ocean surface owing to the absence of low-lying fog. As a result, Morro Rock and the shoreline remained visible throughout the survey.

Average wind speeds, calculated over one-minute intervals, varied throughout the survey, ranging from 0.4 kt to 4.0 kt, with the highest speeds recorded at the beginning of the survey (Table B-7). Corresponding peak-wind speeds ranged from 0.8 kt to 5.8 kt. In accordance with these light and variable winds, seas were calm with a significant wave height of two to four feet, mostly due to a gentle swell out of the northwest. Air temperatures warmed from 15°C to 20°C as the morning survey progressed.

The discharge plume was not visible near the sea surface at any time during the survey. Throughout the survey, there was also no visual evidence of floating particulates, oil and grease, or seawater discoloration associated with the discharge; however, small strips of biofilm, which grow on the interior of the discharge piping, were evident within the water column near the ZID.

Beneficial Use

During the May 2008 survey, observations of beneficial use demonstrated that the coastal waters within Estero Bay continued to be utilized by wildlife and for recreation. California brown pelicans (*Pelecanus occidentalis californicus*), Heermann's gulls (*Larus heermanni*), and western gulls (*Larus occidentalis*) were observed during transit to and from the survey area, and during the course of the survey. Pelagic and Brandt's cormorants (*Phalacrocorax*), which nest on Morro Rock, were also observed passing through the survey area. Additionally, several Pigeon Guillemots (*Cepphus Columba*) were noted within the confines of the harbor. In addition to avian fauna, southern sea otters (*Enhydra lutris*) were observed while in transit to the survey site and at a distance from the site. A total of 9 juvenile and adult sea lions were observed in the area throughout the course of the survey. Pieces of detached bull kelp (*Nereocystis luetkeana*) were also noted drifting in the survey area and during transit to the survey area.

Pedestrians and surfers and kayakers were observed utilizing the beach and nearshore waters north of Morro Rock. In particular, a large group (+20) of students or tourists appeared to gather and walk, as a group, along a portion of the beach during the survey.

Ambient Seawater Properties

Data collected during the May 2008 survey documented a strongly stratified water column that was produced by the intense upwelling conditions present in the days prior to the survey. Upwelling results in an influx of dense, cold, saline water at depth that normally leads to a sharp thermocline, halocline, and pycnocline where temperature, salinity, and density change rapidly over short vertical distances. Under heavily stratified conditions, isotherms crowd together to form a thermocline that restricts the vertical transport of the effluent plume and reduces its dispersion.

Strong upwelling-induced vertical gradients are plainly evident between depths of 2 m and 7 m in the vertical profiles at all sixteen stations (Figures A-1 through A-3). Across that 5-m interface, changes in temperature and density spanned a substantial portion of the overall range in those properties. The 2.8°C average temperature decrease (red lines) accounted for 60% of the overall temperature range, while the 0.56σ_t density increase (black lines) constituted 48% of the overall density variation.

In contrast, most of the ambient variability in transmissivity (light blue lines), DO concentrations (dark blue lines), and pH (olive lines) occurred below the strong thermocline. This is expected because strong stratification impedes the vertical exchange and mixing of water parcels. As a result, both ambient seawater properties and dilute effluent tend to become trapped below the 7-m base of the thermocline. The ambient seawater characteristics of this deep watermass reflect its deeper, offshore origins. For example, DO concentrations were comparatively low and strongly decreased with depth because biotic respiration and decomposition had slowly depleted oxygen levels in the watermass since its contact with the atmosphere. Biotic respiration and decomposition also produced CO₂ (carbonic acid), which resulted in measurably lower pH (more acidic) with increasing depth within the watermass.

In contrast, the shallow mixed layer within and above the thermocline supported comparatively high pH and DO concentrations. DO concentrations tend to be higher within the surface mixed layer due to gaseous exchange with the overlying atmosphere. However, the shallow DO concentrations measured during the May 2008 survey were greatly supersaturated, with saturation levels exceeding 150%. Saturation levels of 120% are not unusual in the near-surface waters of the open ocean due to bubble entrainment during wave breaking and other processes. However, the unusually high DO saturation observed during the May 2008 survey could only have been produced by biological processes, namely, primary production during the strong upwelling in the days preceding the survey. Kaas et al (1991) documented similar levels of oxygen supersaturation during the late stages of an intense phytoplankton

bloom within a Scandinavian fiord. The excess DO was produced when primary production was enhanced by the availability of nutrients that were brought close to the surface by upwelling.

The shape of the vertical profiles of transmissivity, shown by the light blue lines in Figures A-1 through A-3, departed from the profiles of other seawater properties. At almost all stations, the vertical profiles of transmissivity exhibited a localized minimum below the thermocline. Consequently, light transmissivity within this mid-depth layer was considerably lower than the seawater within the surface mixed layer, as well as being slightly lower than the ambient seawater located near the seafloor. The decreased seawater clarity immediately below the thermocline was probably generated by an accumulation of naturally occurring particulates that were trapped below the thermocline by the sharp density interface.

The shape of the vertical profiles of salinity (green lines) also departed from that of the other ambient seawater properties. The salinity profiles exhibited none of the major vertical trends seen in the other properties; and instead, were characterized by highly localized extrema that coincided with sharp temperature steps. As is usually the case in stratified conditions, naturally occurring, subtle changes in salinity with depth were overwhelmed by the presence of large, artificial salinity spikes. These spikes are instrumental artifacts arising from the mismatch between conductivity and temperature measurements collected near sharp localized thermoclines. The spikes are evident as erroneous zigzag patterns or localized salinity decreases that appear in conjunction with the sharp changes in temperature. Some of the larger erroneous salinity spikes also manifest themselves in the vertical density profiles (black lines). Unless properly identified, salinity spikes can be misinterpreted as a signature of the low-salinity effluent plume.

Lateral Variability

The influence of the effluent discharge can be best identified from localized anomalies in seawater properties, particularly salinity. In contrast to the isolated vertical profiles, discharge-related anomalies become especially apparent in vertical cross-sections, which highlight differences in seawater properties at adjacent stations. Accordingly, all of the cross-sections shown in Figures A-4 and A-5 reflect the influence of the discharge at Stations 1 through 4. The large-amplitude, discharge-related reduction in salinity is especially apparent above the seafloor at Station 4 in the top frame of Figure A-4. Similarly, the discharge related compression of the thermocline at Stations 1, 2, and 3 also resulted in the upward extension of deep seawater characteristics seen in Figure A-5.

The vertical cross-sections also lend insight into the mechanism that caused the discharge-related anomalies in each seawater property, namely, whether the anomaly was induced by the presence of dilute effluent or whether it was generated by the upward displacement of ambient seawater entrained in the rising wastewater plume. For example, the isolated character of the salinity and density anomalies near 15 m at Station 4, which are apparent in the top and bottom frames of Figure A-4, is distinctly different from the entrainment-generated anomalies in the other seawater properties. The localized reductions in salinity and density could only have been induced by the presence of dilute wastewater constituents. They could not have been generated by the displacement of ambient seawater because the measured values were far lower than any other measurement recorded below 10 m. The low salinity associated with dilute wastewater is also delineated by green shading between 5 m and 10 m at Stations 1, 2, and 3 in the top frame of Figure A-4. It traces the northward trajectory of the plume as it rose through the lower portion of the water column and became trapped below the thermocline near Station 1. This northward plume transport is consistent with the northward movement of the drogued drifter.

In contrast to the isolated character of the salinity and density anomalies, other discharge-related anomalies arise because of upward displacement of ambient seawater. These entrainment-generated anomalies are apparent in Figure A-5 as uplifted seawater properties at Stations 1, 2, and 3. At all other stations, DO concentrations below 10 mg/L and pH readings below 8.1, which are delineated by the green

and red shading, are restricted to depths below 10 m (middle and bottom frames in Figures A-5 and A-7). The uplift at Stations 1, 2, and 3 is also apparent in the transmissivity data (top frame of Figure A-5) as an upward displacement of the deep transmissivity minimum, where the red shading delineates transmittance below 50 percent. Entrainment-generated anomalies are distinguished from wastewater-induced anomalies because they have the same characteristics as ambient seawater at depth. Consequently, such anomalies only arise when the water column is stratified such that ambient seawater properties near the seafloor differ significantly from properties in the upper water column.

Entrainment processes are also apparent in the temperature distribution (middle frame of Figure A-4). Upward displacement of cold ambient seawater that was entrained in the rising plume compressed the thermocline at Stations 1, 2, and 3. This thermocline compression is reflected by the crowding of isotherms near 6 m. Also, because of the increased sharpness of the thermocline at these stations, salinity spikes are more prevalent. Particularly large salinity spikes were generated at Stations 1 and 3, as delineated by red shading between 5 m and 10 m in the top frame of Figure A-4.

The foregoing discussion demonstrates that under the heavily stratified conditions that were present during the May 2008 survey, both entrainment-generated and wastewater-induced anomalies became particularly apparent when seawater properties measured at the same depth level were compared at adjacent stations. Because of this, the analysis of lateral variability in seawater properties forms the basis for assessments of water-quality impacts in this report. In particular, the significance of each potential discharge-related anomaly was statistically evaluated by comparing its amplitude to the natural background variability. Each observation at a particular station was compared with the observations from other stations at the same depth level. For example, measurements recorded within 10 m of the sea surface were compared with other measurements at the same depth level below the sea surface. However, deeper measurements were compared with other measurements recorded at the same height above the sloping seafloor. These different depth references are used because deep seawater properties tend to parallel the sloping seafloor rather than the horizontal sea surface.

The statistical significance of departures from ambient seawater properties was computed from the raw CTD data listed in Tables B-1 through B-6. First, anomalies from mean conditions were computed by subtracting a particular measurement from the average of all other measurements at the same depth level, whether measured relative to the sea surface or the seafloor. Natural variability was 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 were those that departed from mean conditions by more than the 95% confidence interval, which is determined from the standard deviation and number of observations used to compute the average. Statistically significant departures from ambient conditions are highlighted in Tables B-1 through B-6 by bold typeface enclosed in boxes.

Based on those statistical hypothesis tests, significant departures from mean conditions were only found to occur in one of the six seawater properties measured in the May 2008 survey (salinity in Table B-2). Out of the 494 salinity observations, seventeen represented statistically significant departures from mean conditions. However, many of these significant departures were contiguous, and of the nine groups of statistically significant salinity anomalies highlighted in the table, only the one located just above the seafloor at Station 4, was actually caused by the presence of the dilute effluent. The remaining statistically significant anomalies occurred in the upper water column at Stations 1, 4, 5, 7, 11, 13, and 14 and were artifacts of salinity spiking.

Salinity spiking is a common occurrence in CTD measurements collected within the upper-ocean thermocline, and is routinely observed in MBCSD surveys conducted when the water column is well stratified (MRS 2001-2008). Salinity spikes are artificially introduced when the CTD instrument package crosses a sharp thermal interface. Salinity is computed from conductivity and temperature readings from

probes that do not measure the same water parcel because the sensors are physically separated on the CTD instrument package. In addition, the sensors do not have the same response times. Consequently, when passing through regions of sharp temperature gradients, the mismatch between the recorded conductivity and temperature measurements results in erroneous spikes in computed salinity. The sharper the thermal gradient, the larger the salinity spike. Although the spikes usually manifest as negative (low) salinity anomalies, positive anomalies sometimes also occur, as documented by the statistically significant positive anomalies highlighted in Table B-2 at Stations 5 and 11. Salinity measurements that are significantly higher than surrounding readings are distinguished by italicized entries surrounded by thin-lined boxes. Because wastewater is far lower in salinity than seawater, these positive salinity anomalies could not have been generated by presence of dilute effluent.

These and other erroneous salinity spikes are apparent as zigzag patterns in the vertical profiles (green lines in Figures A-1 through A-3). However, these profiles reflect smoothed versions of the actual individual CTD measurements; the spikes were actually larger and more localized than depicted in the figures. As is discussed above, the figures and tables presented in this report were based on CTD measurements averaged over 0.5-m depth intervals. Although not shown here, high-resolution vertical profiles of raw temperature and salinity data were reviewed for evidence of salinity spiking. Spikes in the high-resolution profiles were apparent as highly localized outliers in salinity that only occurred within limited regions of the thermocline where the temperature changed abruptly. However, because they were generally less than 0.5 m thick, they appear as weaker, vertically distributed features in the lower-resolution salinity profiles included in this report.

Even without salinity spiking, the presence of statistically significant fluctuations unrelated to the discharge is 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 494 measurements examined for each of the parameters it would not be surprising if a random few departed from the mean by an amount more than the 95% confidence interval. Moreover, when multiple hypotheses are being tested (*i.e.*, one for each observation), the error rate for each individual test should be adjusted to achieve the overall 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 correcting for repeated hypothesis testing, the individual tests are conservative and “*significant*” departures will be found more often than if a single test were being performed at the experiment-wise 95% confidence level.

Discharge-Related Perturbations

In spite of the confounding influence of salinity spiking during the May 2008 survey, four distinct perturbations in seawater properties were unequivocally related to the discharge (Perturbations P1 through P4 in Table 4). A discharge-related perturbation is a group of anomalies in one or more seawater properties that are spatially contiguous at a particular station. In addition, as discussed above, the vertical distribution of seawater properties within and below the perturbation lends insight into which of two possible discharge processes was responsible for generating a particular anomaly. Those anomalies listed with an “Effluent” mechanism in the table were induced by the presence of dilute wastewater constituents, while the “Entrainment” mechanism indicates that the anomalies were largely generated by the upward displacement of ambient seawater entrained within the rising effluent plume.

The mechanism that produced a discharge-related anomaly is an important consideration when assessing the discharge’s compliance with the receiving-water objectives of the COP, and the requirements of the NPDES permit. As indicated in Table 4, only three of the fourteen anomalies unequivocally captured the presence of dilute wastewater. Nine anomalies detected in other water properties were generated by

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

Perturbation ^b	Station	Depth Range	Depth of Extremum	Property	Magnitude	Mechanism
P1 Dilution Indeterminate ^c	1	6.0 to 7.0 m	6.5 m	Salinity	-0.163 ‰	Spike
		6.0 to 6.5 m	6.5 m	Density	-0.119 σ_t	Spike
		7.0 to 8.5 m	7.5 m	Transmissivity	-16.20 %	Entrainment
		7.0 to 9.5 m	8.5 m	DO	-3.00 mg/L	Entrainment
		7.5 to 9.5 m	9.0 m	pH	-0.193	Entrainment
P2 Dilution Indeterminate	2	6.0 to 9.0 m	7.0 m	Transmissivity	-18.77 %	Entrainment
		6.0 to 11.0 m	8.0 m	DO	-3.26 mg/L	Entrainment
		7.0 to 11.0 m	9.0 m	pH	-0.207	Entrainment
P3 Dilution \geq 404:1	3	9.0 to 10.0 m	9.0 m	Salinity	-0.085 ‰	Effluent
		6.0 to 9.5 m	6.5 m	Transmissivity	-21.16 %	Entrainment
		5.5 to 11.5 m	8.5 m	DO	-3.72 mg/L	Entrainment
		7.0 to 11.5 m	9.0 m	pH	-0.221	Entrainment
P4 Dilution \geq 123:1	4	14.5 to 16.5 m	15.0 m	Salinity	-0.274 ‰	Effluent
		14.5 to 16.5 m	15.0 m	Density	-0.235 σ_t	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

^c The computed dilution was confounded by a salinity spike which artificially increased the amplitude of the salinity and density anomalies (see the discussion in the text)

entrainment of ambient seawater within the rising effluent plume, and as such, are not subject to water-quality restrictions that were developed to limit impacts from the presence of wastewater contaminants.

Wastewater-induced anomalies only occur when the contrast between the properties of wastewater and seawater are large enough to remain apparent after rapid initial dilution. Because of the large difference between wastewater and seawater salinity, wastewater-induced anomalies are usually only apparent in the salinity field. Under the right circumstances, however, wastewater-induced anomalies can also arise in density measurements collected close to a diffuser port shortly after discharge. Such was the case in the May 2008 survey when the CTD passed within 1 m of the diffuser structure during the Station 4 hydrocast. During that cast, the vessel drifted toward the northeast and the CTD traversed a large portion of the ZID, eventually passing directly over the diffuser structure shortly before encountering the seafloor (Figure 2).

As described previously, the isolated character of the salinity and density anomalies within Perturbation P4 demonstrate that they could not have been generated by the movement of ambient seawater alone. Specifically, the top frame of Figure A-4 shows that the anomalously low salinity observed near the seafloor at Station 4 was far lower than the ambient salinity of deep seawater at any other station. Furthermore, the bottom frame of Figure A-4 shows that the associated reduction in density was also vertically isolated, indicating that the water-parcel with the anomalous properties was highly buoyant, and was still in the process of rising farther upward into the water column. Accordingly, Perturbation P4 captured the plume signature as it began its rise through the water column and was carried northward by the prevailing flow. The rising plume was further delineated by a shallow salinity anomaly at Station 3 (top frame of Figure A-4). However, as the rising plume encountered and compressed the thermocline at Stations 1 and 2, any remaining wastewater-induced salinity signature was completely overwhelmed by salinity spiking, particularly at Station 1 (Perturbation P1 in Table 4).

The disposition of entrainment-generated anomalies differs from that of the wastewater-induced anomalies. Wastewater-induced anomalies dissipate as the effluent becomes increasingly more dilute as

the plume disperses with distance from the discharge point. In contrast, once ambient seawater has been entrained within the rising plume, and a discharge-related anomaly is created by the juxtaposition of deep and shallow seawater properties, its amplitude is relatively unaffected by further dispersion of the plume within receiving waters. As a result, the amplitudes of the entrainment-generated anomalies in transmissivity, DO, and pH that were observed at Stations 1, 2, and 3 were of similar magnitude (Perturbations P1, P2, and P3 in Table 4). Anomalies with relatively consistent amplitudes (transmissivity \approx 18%, DO \approx 3.5 mg/L, and pH \approx 0.2) were documented at similar depth levels (\approx 8 m) at all three stations where the vertical sections (Figure A-5) show that seawater properties were uniformly uplifted.

Initial Dilution Computations

The amplitude of the spike-free, negative salinity anomalies at Stations 3 and 4 lends 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 the mixing achieved during the buoyant plume's rise through the water column. The dispersion modeling determined that, after initial mixing was complete, 133 parts of ambient water would have mixed with each part of wastewater. The modeling predicted that this dilution would be achieved after the plume rose only 9 m from the seafloor, whereupon it 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 9 m within Perturbation P3 demonstrates that the effluent plume actually achieved a far higher dilution (\geq 404:1) than that predicted by conservative modeling (133:1). The actual difference between measured and predicted dilution is probably much larger because the effluent would continue to undergo significant additional dilution with the plume's continued turbulent rise from the measured 9-m depth, to the 6.4 m trapping depth predicted by modeling. Thus, the rapid mixing associated with the momentum of the discharge jet and the buoyant plume's subsequent rise through the water column was capable of achieving substantially higher dilutions than that predicted by the design modeling. This demonstrates that, during the May 2008 survey, the diffuser structure was operating more efficiently than predicted.

The conservative nature of the dilution ratio determined from modeling is an important consideration because it was used to specify permit limitations on chemical concentrations in wastewater discharged from the treatment plant. These end-of-pipe effluent limitations were back-calculated from the receiving-water objectives listed in the COP (SWRCB 1997) using the 133:1 dilution ratio determined from the modeling. Use of a higher critical dilution ratio would relax the stringent end-of-pipe effluent limitations that were thought to be necessary in order to meet Ocean-Plan 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 ratio of the volume 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 also 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 magnitudes of the observed salinity anomalies within Perturbations P3 and P4 were used in Equation 2 to compute the actual dilution levels associated with the perturbations (left column of Table 4). There was no perceptible discharge-related salinity anomaly associated with Perturbation P2 and the statistically significant salinity anomaly associated with Perturbation P1 was an artifact of salinity spiking unrelated to the discharge. Perturbation P4, which was measured approximately 1 m from the diffuser structure, had the largest-amplitude salinity anomaly (-0.274‰), and lowest measured dilution (123:1). Diffuser ports are situated every 1.5 m along diffuser structure, so Perturbation P4 was, at most, only 1.8 m from a port, and well within the turbulent ejection jet emanating from that port. At 22 m from the diffuser, Perturbation P3 evinced a smaller-amplitude salinity anomaly (-0.085‰) that reflects the additional dilution achieved with turbulence generated by the plume's 7 m rise in the water column. Finally, after additional mixing during northward transport over a distance of 25 m, and a buoyant rise of an additional 2 m (Perturbation P2), the salinity signature became imperceptible.

Perturbation P4 was measured within the turbulent discharge jet emanating from one of the 28 diffuser ports. The salinity anomaly was also associated with an extremely low density ($-0.235 \sigma_t$), indicating that the plume was highly buoyant, and would rise rapidly through the water column as it mixed with surrounding seawater. The measured dilution within this discharge jet (123:1) was close to the final dilution (133:1) predicted by modeling after a 9 m rise of the plume through the water column. This demonstrates that the momentum of the discharge jet alone is capable of achieving dilution levels close to the permit-specified dilution ratio, without even considering the additional dilution achieved as the plume reaches equilibrium within the water column.

The dilution computations demonstrate that, during the May 2008 survey, the outfall was performing far better than designed, and was rapidly diluting effluent more than 100-fold within as little as 1 m of the discharge point. In addition, the larger measureable dilution (404:1) was three times higher than the 133:1 critical dilution used to establish permitted limitations on contaminant concentrations within wastewater discharged from the MBCSD treatment plant. 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 May 2008 survey demonstrated that the wastewater discharge was in compliance with the receiving-water limitations specified in the NPDES permit, and with the water-quality objectives of the COP (SWRCB 1997) and the Central Coast Basin Plan (RWQCB 1994). Specifically, there were no particulates of sewage origin seen floating on the ocean surface at any of the stations sampled during the May 2008 water-quality survey, and the discharge complied with all quantitative limits on seawater properties.

Although discharge-related changes in five of the six water properties were observed during the May 2008 survey, the changes were not statistically significant, were measured within the boundary of the ZID, or resulted from the displacement of ambient seawater rather than the presence of effluent constituents. Receiving-water limitations only apply to statistically significant changes caused by the presence of effluent constituents beyond the ZID boundary. The measurements collected during the May 2008 survey demonstrated that the receiving-water limitations were close to being met within 2 m of the discharge (Perturbation P4). Beyond the ZID, the effluent had experienced such a high level of dilution that no significant changes in seawater properties were caused by the presence of effluent constituents. Moreover, the discharge-related anomalies in transmissivity, DO, and pH recorded during the survey were all generated by the upward displacement of ambient seawater, rather than the presence of dilute effluent. This is an important consideration because seawater limitations promulgated in the COP restrict attention to changes caused by the presence of waste materials, not the movement of ambient seawater.

Outfall Performance

The small, mid-depth salinity anomaly captured just beyond the ZID boundary at Station 3, demonstrated that the receiving-water objectives of the COP were being met. At that point, the dilution was four times higher than the minimum critical dilution of 133:1. Similarly, the amplitude of the salinity anomaly measured within the ZID at Station 4 indicates that wastewater had been diluted more than 123-fold within 2 m of the diffuser structure. Thus, the high dilution ratios that were determined from actual measurements during the May 2008 survey demonstrated that the outfall was performing better than expected, and that the limits on wastewater contaminant concentrations specified in the MBCSD NPDES discharge permit would easily meet the receiving-water objectives of the California Ocean Plan (COP).

NPDES Permit Limits

The seawater properties measured during the May 2008 survey were statistically evaluated for compliance with the pertinent receiving-water limitations promulgated by the NPDES discharge permit and the COP. Specifically, the permit and COP state that the discharge shall not cause the occurrence of the following conditions.

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

The COP (SWRCB 1997) further defines a “significant” difference as “...a statistically significant difference in the means of two distributions of sampling results at the 95 percent confidence level.” For

each observation in Tables B-1 through B-6, 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, p228; Ury 1976). Although 15 independent hypothesis tests were performed at each depth level, no Bonferroni adjustment to the error rate was included, so the tests are conservative. Specifically, Bonferroni adjustment indicates that the actual confidence level for the overall null hypothesis test for differences in properties is higher, around 99.7%, rather than the 95% level that applies to a single test. The standard deviation that was applied in the tests was determined from the entire data set to reflect the full range in ambient properties, including vertical variations.

Light Transmittance

Based on the statistical analysis, none of the measurements exhibited significant reductions in instrumentally recorded light transmittance (Table B-6). Despite their large amplitude, exceeding 16%, the discharge-related reductions in transmissivity at Stations 1, 2, and 3 were not determined to be statistically significant because the ambient variability was naturally high during the May 2008 survey. In addition, the anomalies were not induced by the presence of wastewater particulates but were generated by the upward displacement of naturally turbid seawater. Thus, the observed reductions in transmissivity were not generated “...as the result of the discharge of waste” (SWRCB 1997). Moreover, the anomalies were located at a depth of 6.5 m and deeper (Table 4), so it is not surprising that the Secchi depths (Table B-7), which averaged 6 m, were not affected by the slight uplift in the turbid layer of ambient seawater at Stations 1, 2, and 3. Because little natural light penetrates below the Secchi depth, these transmissivity anomalies did not reflect a significant “...reduction in the transmittance of natural light...”

Dissolved Oxygen

Although it is not explicitly stated in the NPDES discharge permit, the COP specifies that the DO limitation only applies to reductions that occur “...as a result of the discharge of oxygen demanding waste materials.” However, effluent samples routinely collected prior to discharge demonstrate that the treatment process is highly effective at removing oxygen demanding material from the wastestream. As a result, reductions in DO caused by the presence of wastewater constituents have never been observed within the receiving waters. Additionally, the DO limitation does not apply to reductions in DO caused by the movement of ambient waters, regardless of whether or not they were induced by the physics of the discharge. The discharge-related DO reductions (Perturbations P1, P2, and P3) were all generated by the entrainment and upward displacement of ambient seawater that was naturally depleted in oxygen. Although, the observed DO anomalies would not be subject to COP limitations for that reason alone, none of the DO anomalies were found to be statistically significant (Table B-5). Regardless, all of the DO measurements collected during the May 2008 survey complied with the numerical limits on DO concentrations. Specifically, none of the DO concentrations measured during the May 2008 survey fell below the 5-mg/L minimum specified in the Basin Plan and the NPDES discharge permit. In fact, none of the 494 measurements collected fell below 6.2 mg/L.

pH

None of the pH measurements were found to depart from mean conditions by more than the 95% confidence interval. As with the other water-quality parameters, the three pH reductions associated with Perturbations P1, P2, and P3 were all generated by the upward displacement of ambient seawater at depth, which is naturally low in pH. Because of their lack of statistical significance, and the fact that they were not generated by the presence of wastewater constituents, none of the observed pH anomalies were subject to the numerical limits specified in the discharge permit. Regardless of regulatory applicability, all

three anomalies complied with the limits. The pH ranged between 7.8 and 8.2 within these perturbations and thus did not exceed the lower (7.0 pH) and upper (8.3 pH) bounds on discharge-induced pH changes. Because natural oceanic processes were responsible for the large vertical variations in pH measurements, none of the measurements would be considered changed by “...more than 0.2 pH units from that which occurs naturally.”

Temperature and Salinity

Thermal stratification induced by upwelling led to a large temperature range of 4.7°C across all observations, and no statistically significant anomalies were observed in the temperature field in the May 2008 survey (Table B-1). Similarly, none of the perturbations in Table 4 included a thermal anomaly. Because no wastewater-induced thermal anomalies were observed (Table 4), the discharge could not “...adversely affect beneficial uses...”

Additionally, although salinity anomalies provide the best tracers of discharged effluent, the actual maximum amplitude (-0.274‰) of the largest salinity anomaly observed during the May 2008 survey was small compared to the seasonal and spatial differences in salinity that occur along the south-central California coast. For example, seasonal differences in average salinity at this location are more than two times higher (0.64‰) than the salinity anomaly recorded at Station 4 during the May 2008 survey. In any regard, the observed ranges in both the reported temperature (4.7°C) and salinity (0.45‰) across all data collected during the May 2008 survey were too small to be considered harmful to marine biota or deleterious to beneficial uses.

Conclusions

All of the measurements recorded during the May 2008 survey complied with the receiving-water limitations specified in the NPDES discharge permit. The discharge-related anomalies in transmissivity, DO, and pH that were found within the water column at Stations 1, 2, and 3 were not statistically significant, were caused by the upward displacement of ambient seawater, and met the numerical limits specified in the discharge permit even though the limits only apply to statistically significant changes caused by the presence of wastewater particulates.

Salinity measurements collected close to a diffuser port demonstrated that discharged wastewater was undergoing rapid mixing within the turbulent discharge jet. The dilution levels achieved by the momentum of the jet alone were close to that predicted by modeling for the entire dilution process. This confirmed that the diffuser structure and the outfall were operating better than would be expected from the modeling.

REFERENCES

- California Department of Fish and Game (CDFG). 2000. Black Rockfish, *Sebastes melanops*, 1993-1999 Commercial Catch by Ports & Blocks. In: Volume 1, Marine Fisheries Profiles. California Department of Fish and Game, Marine Region. December 2000.
- Davis, R.E., J.E. Dufour, G.J. Parks, and M.R. Perkins. 1982. Two Inexpensive Current-Following Drifters. Scripps Institution of Oceanography, University of California, San Diego, La Jolla, California. SIO Reference No. 82-28. December 1982.
- Dohl, T.D., R.C. Guess, M.L. Duman, R.C. Helm. 1983. Cetaceans of central and northern California, 1980-1983: status, abundance, and distribution. Prepared for the U.S. the Department of the Interior, Minerals Management Service, Pacific OCS Region, Los Angeles, California. pp. 284.
- Fischer, H.B., E.J. List, R.C.Y. Koh, J. Imberger, and N.H. Brooks. 1979. Mixing in Inland and Coastal Waters. New York: Academic Press, 483 p.
- Herzing, D.L. and B.R. Mate. 1984. Gray whale migration along the Oregon coast, 1978-1981. In: M.L. Jones, S.L. Swartz, and S. Leatherwood [Eds.]. The Gray Whale, *Eschrichtius robustus*. Academic Press: Orlando, Florida. pp. 289-307.
- Kass, H. Larsen, J. Møhlenberg, F. Richardson, K. 1991. The *Chrysochromulia polylepis* bloom in the Kattegat (Scandinavia) May-June 1988. Distribution, primary production and nutrient dynamics in the late stage of the bloom. *Marine Ecology Progress Series*. 79:151-161.
- Kuehl, S.A., C.A. Nittrouer, M.A. Allison, L. Ercilio, C. Faria, D.A. Dukat, J.M. Jaeger, T.D. Pacioni, A.G. Figueiredo, and E.C. Underkoffler 1996. Sediment deposition, accumulation, and seabed dynamics in an energetic fine-grained coastal environment. *Continental Shelf Research*, 16: 787-816.
- Marine Research Specialists (MRS). 1998a. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, Water Column Sampling, March 1998 Survey. Prepared for the City of Morro Bay, CA. April 1998.
- Marine Research Specialists (MRS). 1998b. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, Semiannual Benthic Sampling Report, April 1998 Survey. Prepared for the City of Morro Bay, CA. July 1998.
- Marine Research Specialists (MRS). 1998c. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, Water Column Sampling, July 1998 Survey. Prepared for the City of Morro Bay, CA. August 1998.
- Marine Research Specialists (MRS). 2000. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 1999 Annual Report. Prepared for the City of Morro Bay, California. February 2000.
- Marine Research Specialists (MRS). 2001. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 2000 Annual Report. Prepared for the City of Morro Bay, California. February 2001.

- Marine Research Specialists (MRS). 2002. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 2001 Annual Report. Prepared for the City of Morro Bay, California. February 2002.
- Marine Research Specialists (MRS). 2003. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 2002 Annual Report. Prepared for the City of Morro Bay, California. February 2003.
- Marine Research Specialists (MRS). 2004. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 2003 Annual Report. Prepared for the City of Morro Bay, California. February 2004.
- Marine Research Specialists (MRS). 2005. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 2004 Annual Report. Prepared for the City of Morro Bay, California. February 2005.
- Marine Research Specialists (MRS). 2006. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 2005 Annual Report. Prepared for the City of Morro Bay, California. February 2006.
- Marine Research Specialists (MRS). 2007. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 2006 Annual Report. Prepared for the City of Morro Bay, California. February 2008.
- Marine Research Specialists (MRS). 2008. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 2007 Annual Report. Prepared for the City of Morro Bay, California. February 2008.
- Morro Group, Inc. 2000. MFS Globenet Corp./WorldCom Network Services Fiber Optic Cable Project Final Environmental Impact Report. SCH No. 98091053. Volume I. Submitted to: County of San Luis Obispo Department of Planning and Building. Prepared in association with Arthur D. Little, Inc. and Marine Research Specialists. January 2000.
- Regional Water Quality Control Board (RWQCB) - Central Coast Region. 1994. Water Quality Control Plan (Basin Plan) Central Coast Region. Available from the RWQCB at 81 Higuera Street, Suite 200, San Luis Obispo, California. 148p. + Appendices.
- Regional Water Quality Control Board (RWQCB) - Central Coast Region. 1998. Administrative Extension of Waste Discharge Requirements/National Pollution Discharge Elimination System (NPDES) CA0047881, Order 92-67. Letter to Mr. William Boucher, Director of Public Works, City of Morro Bay from Roger W. Briggs, Executive Officer. 10 April 1998.
- Regional Water Quality Control Board (RWQCB) - Central Coast Region and the Environmental Protection Agency (EPA) – Region IX. 1998a. Waste Discharge Requirements (Order No. 98-15) and National Pollutant Discharge Elimination System (Permit No. CA0047881) for City of Morro bay and Cayucos Sanitary District, San Luis Obispo County. 11 December 1998.

- Regional Water Quality Control Board (RWQCB) - Central Coast Region and the Environmental Protection Agency (EPA) – Region IX. 1998b. Monitoring and Reporting Program No. 98-15 for City of Morro Bay and Cayucos Sanitary District, San Luis Obispo County. 11 December 1998.
- Reilly, S.B. 1984. Assessing gray whale abundance: a review. In: M.L. Jones, S.L. Swartz, and S. Leatherwood [Eds.]. *The Gray Whale, Eschrichtius robustus*. Orlando, Florida: Academic Press. pp. 203-223.
- Rice, D.W., A.A. Wolman and H.W. Braham. 1984. The gray whale, *Eschrichtius robustus*. In: J.M. Briewick and H.W. Braham [Eds.]. *The Status of Endangered Whales*. Mar. Fish. Rev. 46(4):7-14.
- Rugh, D.J. 1984. Census of gray whales at Unimak Pass, Alaska: November-December 1977-1979. In: M.L. Jones, S.L. Swartz, and S. Leatherwood. (Eds.). *The Gray Whale, Eschrichtius robustus*. Orlando, Florida: Academic Press. pp. 225-248.
- Sea-Bird Electronics, Inc. (SBE) 1989. Calculation of M and B Coefficients for the Sea-Tech Transmissometer. Application Note No. 7, Revised September 1989.
- Sea-Bird Electronics, Inc. (SBE) 1993. SBE 13/22/23/30 Dissolved Oxygen Sensor Calibration and Deployment. Application Note No. 13-1, rev B, Revised April 1993.
- Sokal, R.R. and F.J. Rohlf. 1997. *Biometry: the Principals and Practice of Statistics in Biological Research*, 3rd ed. New York: W.H. Freeman and Company, 850 p.
- Southern California Bight Pilot Project Field Coordination Team (SCBPPFCT). 1995. *Field Operation Manual for Marine Water-Column, Benthic, and Trawl monitoring in Southern California*. August 22, 1995.
- State Water Resources Control Board (SWRCB). 1997. *Water quality control plan, ocean waters of California, California Ocean Plan*. California Environmental Protection Agency. Effective July 23, 1997.
- Sund, P.N. and J.L. O'Connor. 1974. Aerial observations of gray whales during 1973. Mar. Fish. Rev. 36(4):51-55.
- Tetra Tech. 1992. *Technical Review City of Morro Bay, CA Section 301(h) Application for Modification of Secondary Treatment Requirements for a Discharge into Marine Waters*. Prepared for the U.S. Environmental Protection Agency, Region IX, San Francisco, CA by Tetra Tech, Inc., Lafayette, CA. February 1992.
- Ury, H.K. 1976. A comparison of four procedures for multiple comparisons among means (pairwise contrasts) for arbitrary sample sizes. *Technometrics*, 18: 89-97.

APPENDIX A

Water Quality Profiles and Cross Sections

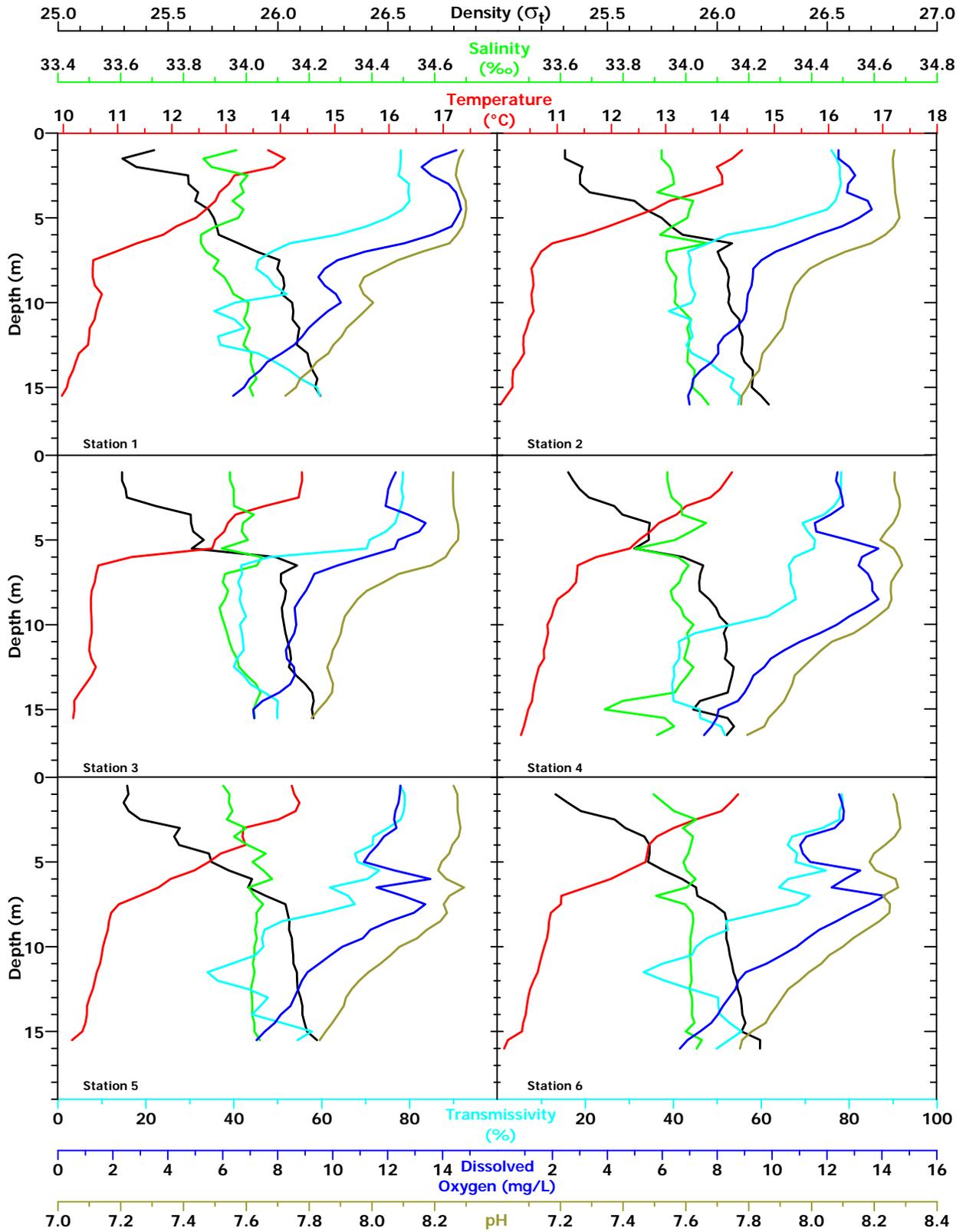


Figure A-1. Vertical Profiles of Water-Quality Parameters for Stations 1 through 6 measured on 16 May 2008

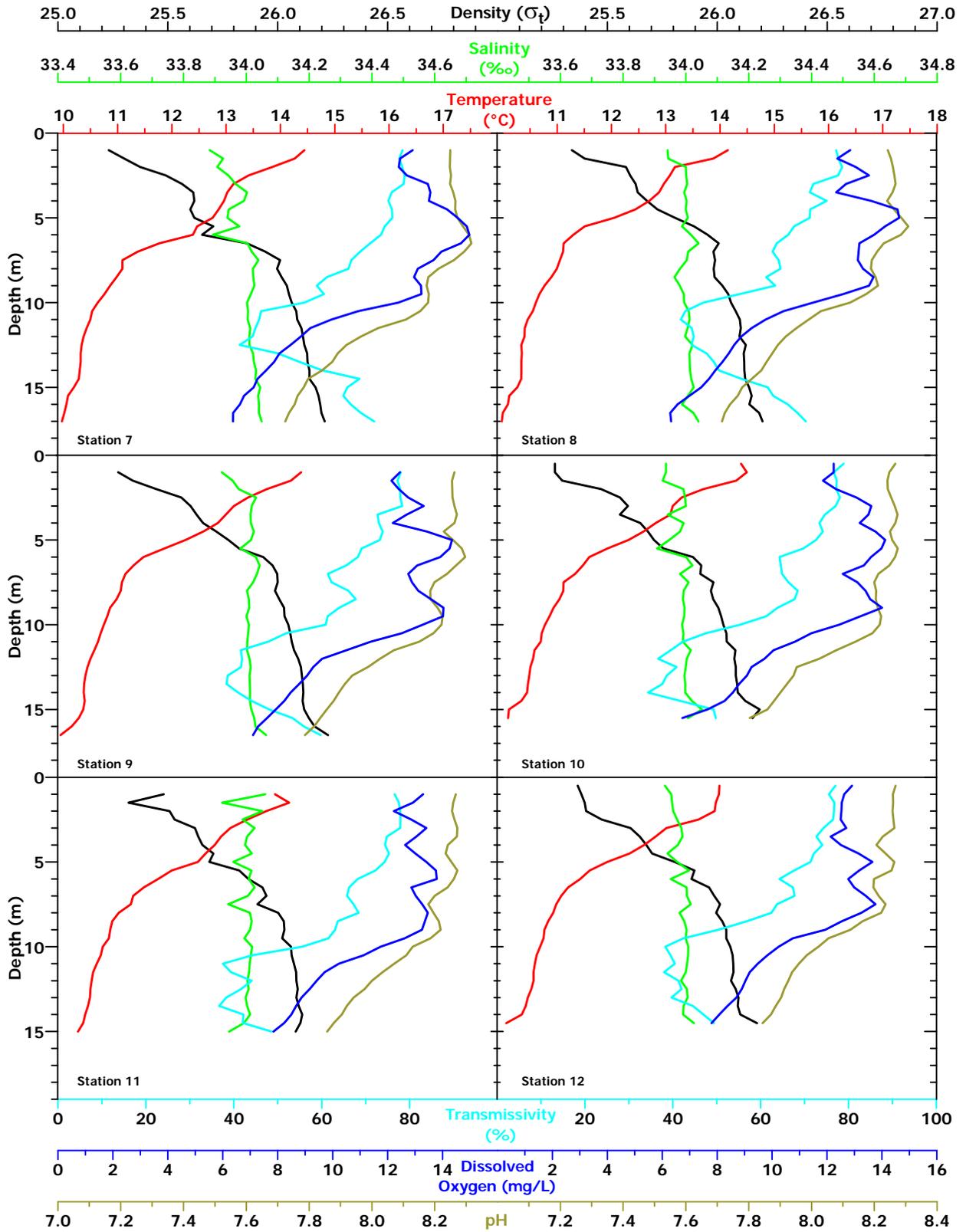


Figure A-2. Vertical Profiles of Water-Quality Parameters for Stations 7 through 12 measured on 16 May 2008

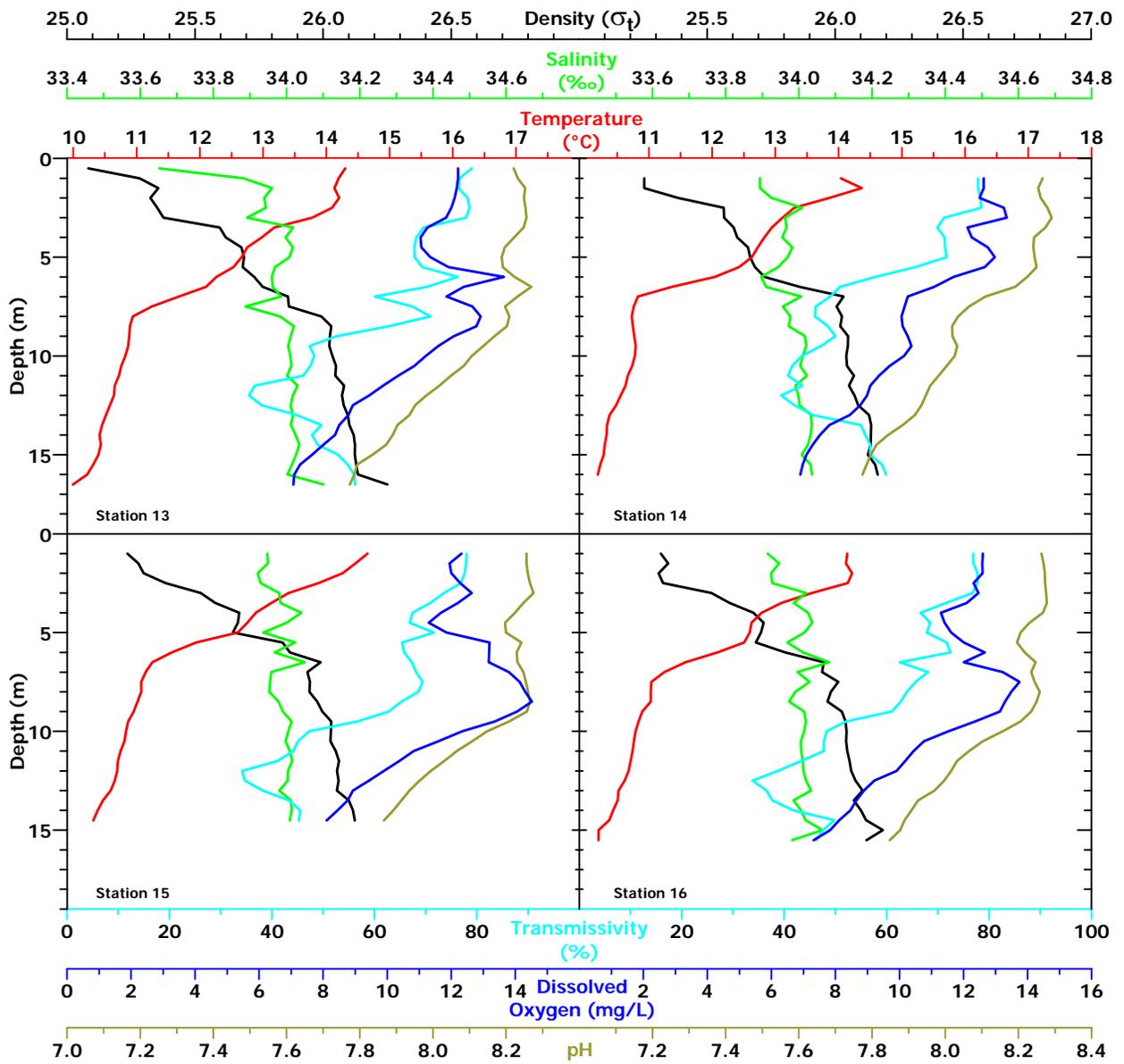


Figure A-3. Vertical Profiles of Water-Quality Parameters for Stations 13 through 16 measured on 16 May 2008

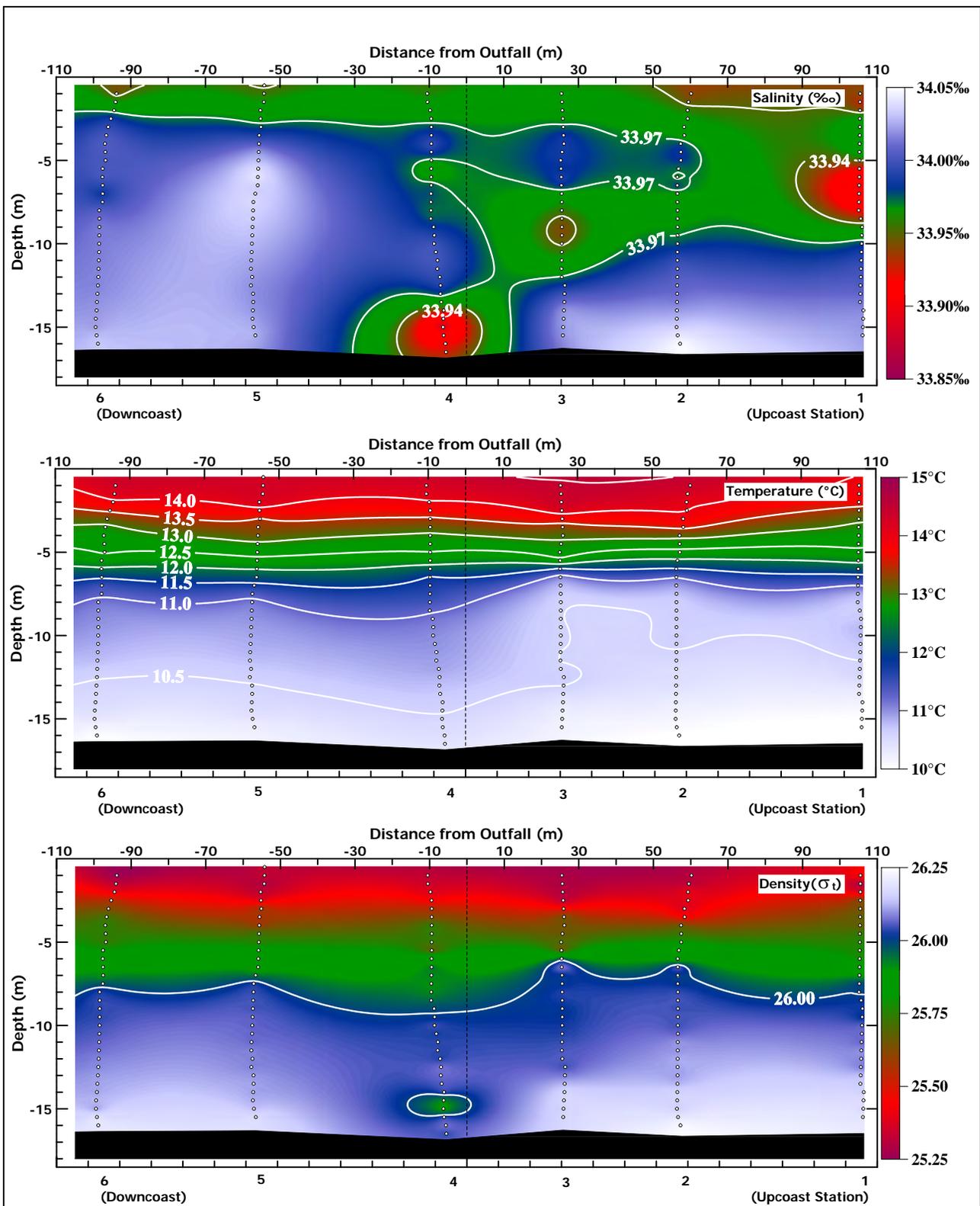


Figure A-4. Along-Shore Transects of Salinity, Temperature, and Density on 16 May 2008

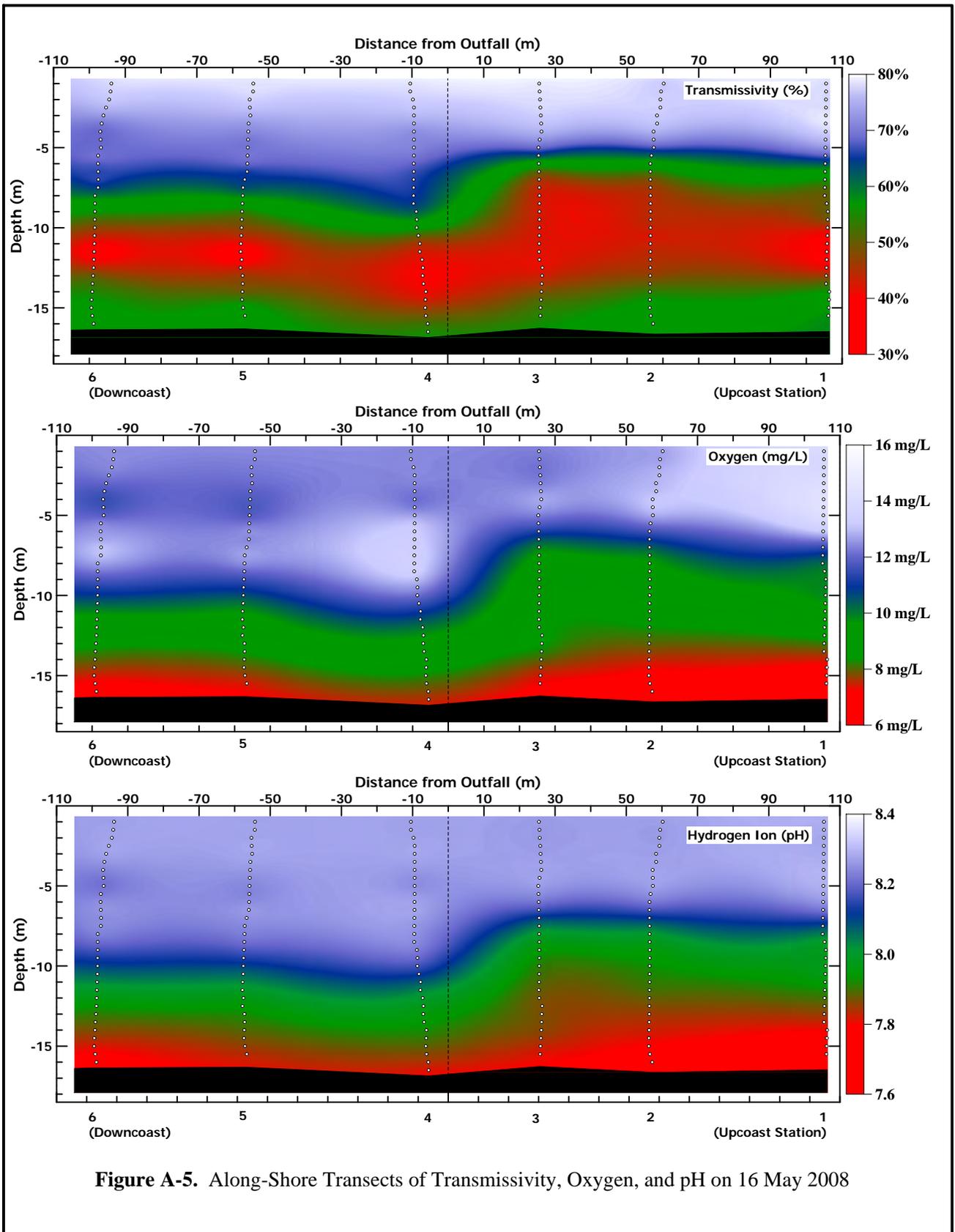


Figure A-5. Along-Shore Transects of Transmissivity, Oxygen, and pH on 16 May 2008

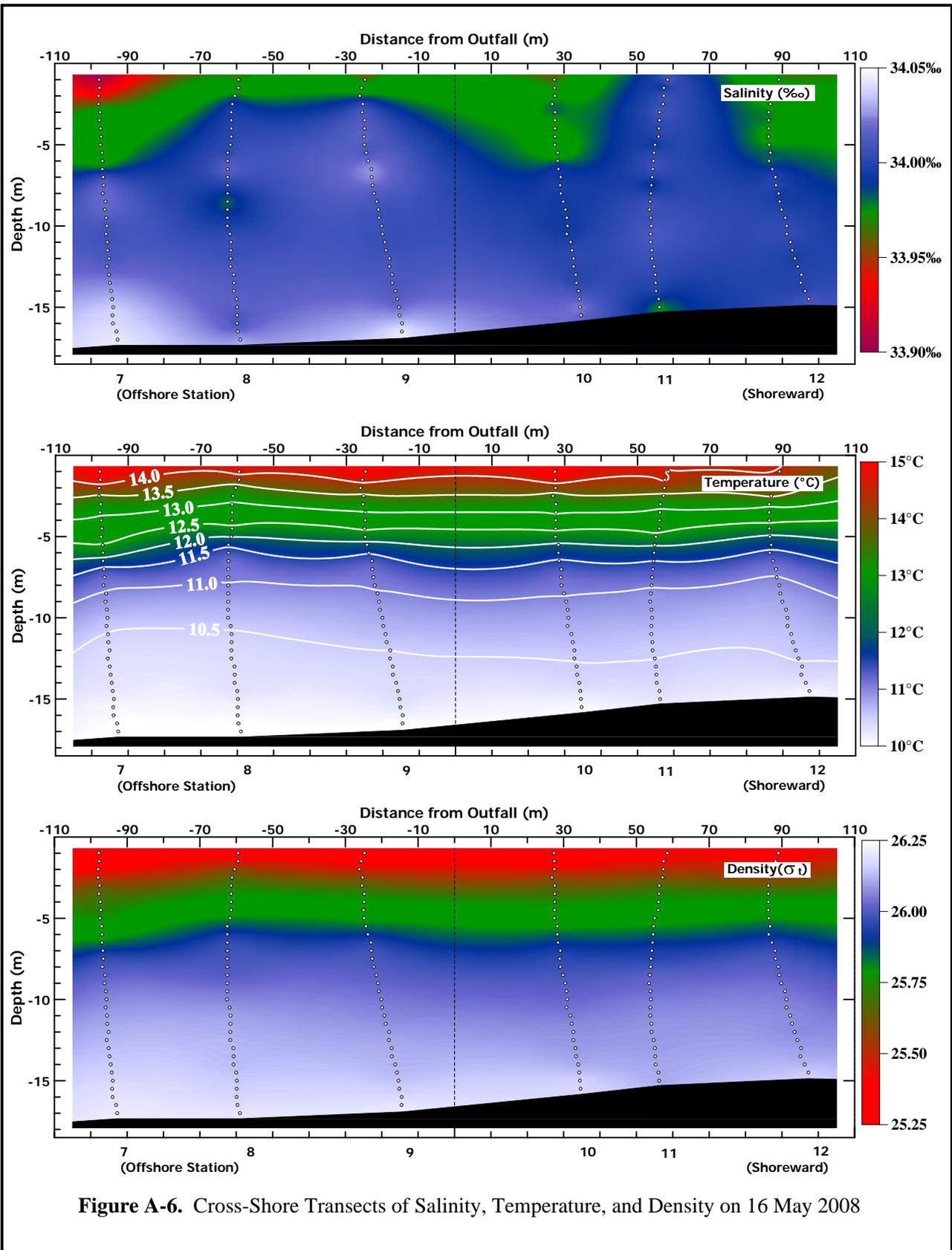


Figure A-6. Cross-Shore Transects of Salinity, Temperature, and Density on 16 May 2008

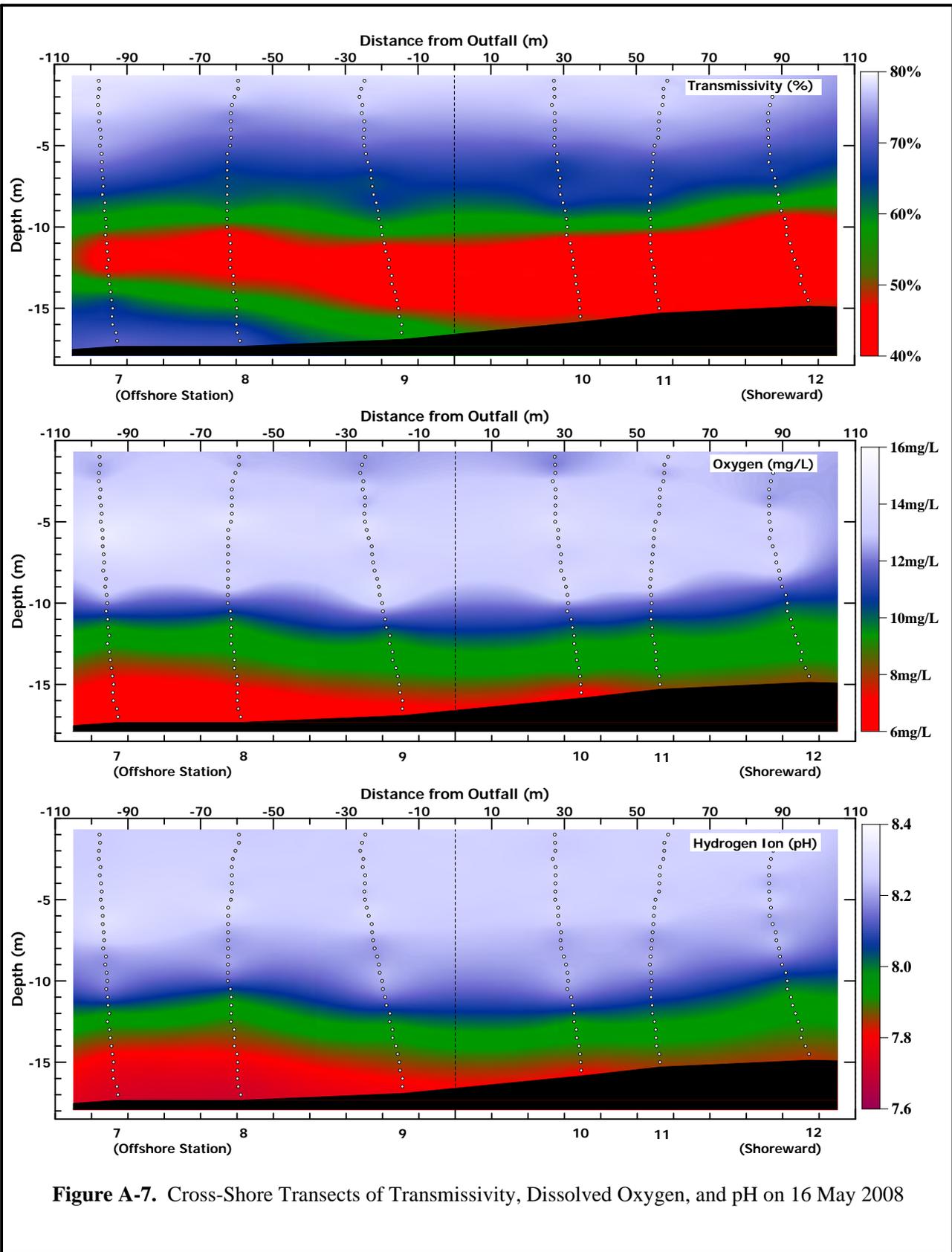


Figure A-7. Cross-Shore Transects of Transmissivity, Dissolved Oxygen, and pH on 16 May 2008

APPENDIX B

Tables of Profile Data and Standard Observations

Table B-2. Salinity¹ on 16 May 2008

Depth (m)	Salinity (‰)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0.5					33.927					33.937		33.933	33.653			
1.0	33.968	33.922	33.948	33.941	33.946	33.897	33.883	33.942	33.922	33.937	34.060	33.953	33.883	33.894	33.947	33.915
1.5	33.863	33.922	33.949	33.941	33.944	33.929	33.926	33.943	33.957	33.926	33.923	33.956	33.961	33.894	33.949	33.946
2.0	33.889	33.949	33.960	33.947	33.956	33.962	33.908	34.000	33.976	33.992	34.051	33.959	33.939	33.925	33.921	33.924
2.5	34.004	33.958	33.960	33.955	33.938	34.033	33.943	34.001	34.031	33.997	33.988	33.972	33.944	34.009	33.929	33.928
3.0	33.981	33.962	33.961	33.986	33.998	33.990	33.966	34.004	34.017	34.000	34.026	33.986	33.892	33.963	33.980	34.020
3.5	33.992	33.909	34.024	33.987	33.961	34.023	34.002	33.994	34.014	33.942	34.002	33.989	34.018	33.967	33.983	33.986
4.0	33.956	34.024	33.990	34.064	34.004	34.016	33.993	34.003	34.015	33.993	33.996	33.975	33.998	33.955	34.041	34.026
4.5	33.991	34.012	33.986	34.017	34.062	34.008	33.944	34.000	34.024	33.981	34.018	33.941	34.017	33.982	34.001	34.037
5.0	33.975	34.005	34.005	33.966	34.020	33.992	33.940	34.006	34.015	33.947	33.959	33.972	34.008	33.970	33.937	34.016
5.5	33.903	33.957	33.922	33.839	34.054	34.002	33.978	33.987	33.981	33.908	34.016	34.010	33.968	33.943	34.024	33.969
6.0	33.856	33.918	34.050	33.974	34.083	34.031	33.894	34.016	34.031	34.000	34.008	33.952	33.960	33.897	33.967	34.012
6.5	33.855	34.069	34.034	34.009	34.007	34.003	34.004	34.040	34.042	34.021	34.027	34.002	33.962	33.911	34.050	34.083
7.0	33.872	33.939	33.932	33.989	34.026	33.905	34.017	34.007	34.034	33.981	34.005	34.003	33.985	34.007	33.958	33.996
7.5	33.912	33.938	33.925	33.980	34.053	33.997	34.039	34.003	34.022	34.009	33.943	34.016	33.888	33.956	33.955	34.029
8.0	33.896	33.950	33.942	33.952	34.032	34.021	34.021	33.981	34.002	33.993	34.012	33.980	33.982	33.977	33.953	33.991
8.5	33.930	33.970	33.932	33.958	34.034	34.024	34.022	33.964	34.008	33.991	34.017	33.995	34.020	33.973	33.978	33.973
9.0	33.947	33.965	33.915	33.983	34.028	34.019	34.026	33.980	34.010	33.996	34.012	34.002	34.012	34.017	33.990	34.014
9.5	33.959	33.968	33.922	33.994	34.033	34.014	34.014	33.994	34.000	33.994	33.994	33.999	34.005	34.021	34.014	34.019
10.0	34.007	33.964	33.931	34.024	34.026	34.015	34.002	33.994	34.008	33.988	34.019	34.008	34.010	34.010	34.005	34.014
10.5	34.004	33.991	33.939	34.004	34.026	34.013	34.006	34.009	34.006	33.992	34.014	34.007	34.013	34.004	33.998	34.006
11.0	33.993	34.017	33.946	34.010	34.021	34.016	34.004	34.012	34.003	33.990	34.011	34.004	34.001	34.022	34.009	34.007
11.5	34.012	34.004	33.956	34.003	34.027	34.016	34.013	34.006	34.003	34.015	34.009	33.999	34.030	33.990	34.016	34.011
12.0	34.001	34.012	33.971	33.994	34.020	34.018	34.010	33.997	34.010	34.003	34.004	33.985	34.017	33.999	34.004	34.012
12.5	33.991	34.009	33.977	34.024	34.015	34.011	34.010	34.022	34.014	34.000	34.007	34.003	34.011	34.002	34.003	34.019
13.0	34.016	34.006	34.002	34.004	34.018	34.020	34.021	34.011	34.010	33.995	33.997	34.006	34.018	34.033	33.980	34.033
13.5	34.013	34.005	34.031	33.982	34.019	34.020	34.024	34.012	34.011	33.998	34.003	33.992	34.012	34.035	34.012	33.986
14.0	34.021	34.029	34.045	33.965	34.018	34.019	34.031	34.013	34.012	33.998	34.012	33.991	34.025	34.032	34.015	34.006
14.5	34.032	34.026	34.033	33.798	34.026	34.027	34.029	34.017	34.012	34.019	33.993	34.025	34.036	34.025	34.008	34.018
15.0	34.011	34.021	34.023	33.742	34.026	33.999	34.044	34.025	34.016	34.051	33.946		34.026	34.008		34.065
15.5	34.022	34.050	34.026	33.933	34.043	34.051	34.038	34.007	34.025	34.007			34.015	34.032		33.982
16.0		34.071		33.962		34.035	34.041	33.987	34.030				34.003	34.036		
16.5				33.908			34.040	34.024	34.062				34.101			
17.0							34.049	34.040								

¹ Values enclosed in boxes differed significantly from the mean of other salinity measurements at the same distance below the sea surface or above the seafloor. The thinner boxes encompass values that were significantly higher than the mean of other measurements at the same distance below the sea surface.

Table B-6. Light Transmittance across a 0.25-m path on 16 May 2008

Depth (m)	Light Transmittance (%)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0.5					77.83					78.89		77.02	79.04			
1.0	77.96	75.94	78.46	78.20	78.87	78.28	78.40	77.20	77.97	76.64	76.62	75.57	76.62	77.83	78.05	76.88
1.5	77.96	77.10	78.43	78.12	78.92	78.57	77.66	77.69	77.23	77.33	77.57	76.81	76.46	77.86	77.91	76.95
2.0	77.92	77.92	78.15	78.14	78.67	77.81	78.32	78.57	77.87	77.23	77.86	76.70	78.22	78.31	77.60	77.74
2.5	77.47	77.83	78.55	77.86	77.98	77.81	78.86	77.64	77.89	78.07	77.93	76.49	78.61	78.50	76.92	77.71
3.0	79.89	78.11	78.11	76.57	75.06	73.90	78.64	72.00	78.30	77.06	77.83	74.28	77.90	71.25	73.61	76.79
3.5	79.72	77.53	77.34	74.26	71.75	67.00	75.96	71.20	72.72	74.63	74.81	72.68	69.64	69.87	70.92	71.58
4.0	80.01	76.88	76.73	69.37	71.62	66.01	75.16	75.04	73.00	73.40	74.40	74.07	68.20	71.33	67.45	66.65
4.5	78.45	75.02	74.59	70.54	67.59	68.17	75.99	71.24	73.86	74.16	75.30	72.08	67.76	71.38	66.87	68.51
5.0	75.07	68.97	70.87	72.23	68.14	67.79	76.07	71.20	73.24	72.58	74.32	71.36	67.86	71.72	71.65	67.84
5.5	70.22	62.83	70.29	71.97	73.12	74.66	74.35	67.59	69.08	69.72	72.24	67.62	69.35	65.66	65.41	71.70
6.0	63.55	52.19	48.12	67.54	70.43	66.11	73.46	66.24	68.26	64.28	68.18	64.26	76.31	57.81	65.82	72.43
6.5	52.75	47.96	41.67	66.25	61.89	64.04	71.05	63.65	65.58	64.58	66.25	67.35	70.23	50.92	67.33	62.58
7.0	48.68	43.29	41.90	66.72	66.01	71.05	68.76	62.73	61.43	64.86	65.78	67.73	60.10	48.98	68.14	68.08
7.5	45.56	43.98	40.99	66.67	67.54	68.18	66.73	64.09	62.26	66.31	67.24	63.74	67.40	46.16	69.40	65.69
8.0	45.11	43.51	41.74	67.43	60.09	60.19	66.12	64.51	66.11	68.41	68.42	62.47	70.97	46.03	68.57	63.92
8.5	47.76	43.75	41.34	67.84	51.01	52.06	61.19	61.26	67.73	67.73	63.66	56.87	62.82	48.52	65.28	62.76
9.0	49.22	44.02	41.92	64.64	47.03	52.41	58.87	63.29	63.99	63.87	63.05	50.38	52.62	50.01	62.81	61.02
9.5	52.05	44.94	42.78	61.54	46.46	47.59	60.52	55.22	61.36	61.25	61.55	42.40	47.38	47.20	56.70	52.04
10.0	40.32	44.19	41.42	53.20	46.77	45.17	56.03	46.95	60.90	55.33	55.52	38.29	48.30	43.42	47.27	48.29
10.5	35.59	38.95	41.86	44.93	44.91	44.18	46.23	42.86	51.96	47.55	44.20	39.47	47.53	41.56	45.10	47.74
11.0	40.18	43.91	42.13	41.18	39.56	37.53	45.79	41.84	47.80	42.33	37.53	40.44	46.13	40.76	44.21	47.72
11.5	42.33	43.78	42.25	41.45	34.01	33.22	44.97	44.32	41.60	39.55	39.40	38.03	36.64	43.54	41.07	43.31
12.0	36.42	44.43	40.72	41.30	36.35	38.07	44.28	44.73	41.90	36.63	44.10	41.33	35.55	39.39	34.21	38.76
12.5	36.96	42.97	40.07	40.06	43.28	43.89	41.36	44.26	41.65	40.90	41.67	41.98	38.03	42.02	34.74	33.81
13.0	45.50	44.27	42.27	40.26	47.78	50.21	50.01	47.69	38.62	38.62	38.28	39.72	44.86	45.60	38.23	36.55
13.5	49.36	47.98	43.75	39.73	46.10	50.24	54.96	49.35	38.37	37.60	36.69	44.58	49.69	54.99	43.31	37.69
14.0	52.68	50.49	46.99	39.88	44.14	50.64	60.19	50.53	40.99	34.36	42.18	46.98	47.87	55.84	45.54	41.77
14.5	55.18	53.76	50.03	40.07	50.97	52.80	68.62	55.63	44.08	41.77	42.05	49.36	48.93	56.81	45.26	49.75
15.0	58.87	53.00	49.88	45.99	57.79	55.50	65.83	61.62	48.07	49.29	48.53		52.92	56.78		47.66
15.5	59.60	55.18	49.91	46.11	54.53	52.69	64.91	62.85	53.36	49.80			54.74	59.08		46.23
16.0		54.76		50.88			49.87	66.62	66.14	55.95			56.03	59.89		
16.5				51.74				68.92	68.39	59.75			56.26			
17.0								71.92	70.23							

Table B-7. Auxiliary Observations on 16 May 2008 during the Quarterly Water-Quality Survey

Station	Location		Diffuser Distance (m)	Time (PDT)	Air Temperature (°C)	Cloud Cover (%)	Wind Avg (kt)	Wind Max (kt)	Wind Dir (from) (°T)	Swell Ht/Dir (ft/°T)	Secchi Depth (m)
	Latitude	Longitude									
1	35° 23.256' N	120° 52.504' W	93.9	10:35:47	15.5	0	3.0	3.6	NW	2-4 WNW	6.5
2	35° 23.230' N	120° 52.503' W	46.9	10:41:02	18.1	0	1.5	3.1	NW	2-4 WNW	6.0
3	35° 23.213' N	120° 52.502' W	21.1	10:44:18	15.2	0	2.4	3.5	NW	2-4 WNW	6.0
4	35° 23.194' N	120° 52.501' W	3.53	10:48:20	15.7	0	1.3	1.9	NW	2-4 WNW	5.5
5	35° 23.168' N	120° 52.503' W	45.8	10:52:28	16.6	0	1.5	2.5	NW	2-4 WNW	6.0
6	35° 23.146' N	120° 52.504' W	86.0	10:56:19	15.9	0	1.3	2.4	NW	2-4 WNW	5.0
7	35° 23.208' N	120° 52.567' W	80.9	10:30:14	14.7	0	1.4	2.9	NW	2-4 WNW	6.0
8	35° 23.200' N	120° 52.544' W	47.6	10:26:09	15.5	0	4.0	5.0	NW	2-4 WNW	6.0
9	35° 23.194' N	120° 52.518' W	21.2	10:22:08	17.8	0	1.7	4.4	NW	2-4 WNW	6.0
10	35° 23.202' N	120° 52.484' W	23.7	10:17:47	15.1	0	2.6	5.0	NW	2-4 WNW	6.0
11	35° 23.204' N	120° 52.468' W	45.3	10:13:55	16.6	0	3.8	5.2	NW	2-4 WNW	7.0
12	35° 23.200' N	120° 52.445' W	76.2	10:09:13	15.0	0	4.0	5.8	NW	2-4 WNW	6.0
13	35° 23.175' N	120° 52.522' W	51.9	11:18:33	16.0	0	2.7	3.4	NW	2-4 WNW	5.5
14	35° 23.229' N	120° 52.524' W	45.5	11:11:20	17.5	0	1.5	2.3	NW	2-4 WNW	6.0
15	35° 23.226' N	120° 52.471' W	71.5	11:05:28	15.9	0	1.5	1.9	NW	2-4 WNW	6.0
16	35° 23.176' N	120° 52.470' W	46.6	11:01:30	19.9	0	0.4	0.8	NW	2-4 WNW	6.0

Neither odors nor debris of sewage origin were observed at any time during the survey. Small strips of biofilm, which grow on the interior of the outfall pipe, were briefly evident within the water column near the ZID.

Tidal Conditions (Pacific Daylight Time)

Low Tide: 03:12 0.2 ft
 High Tide: 09:13 3.5 ft
 Low Tide: 14:30 1.3 ft
 High Tide: 20:52 5.2 ft