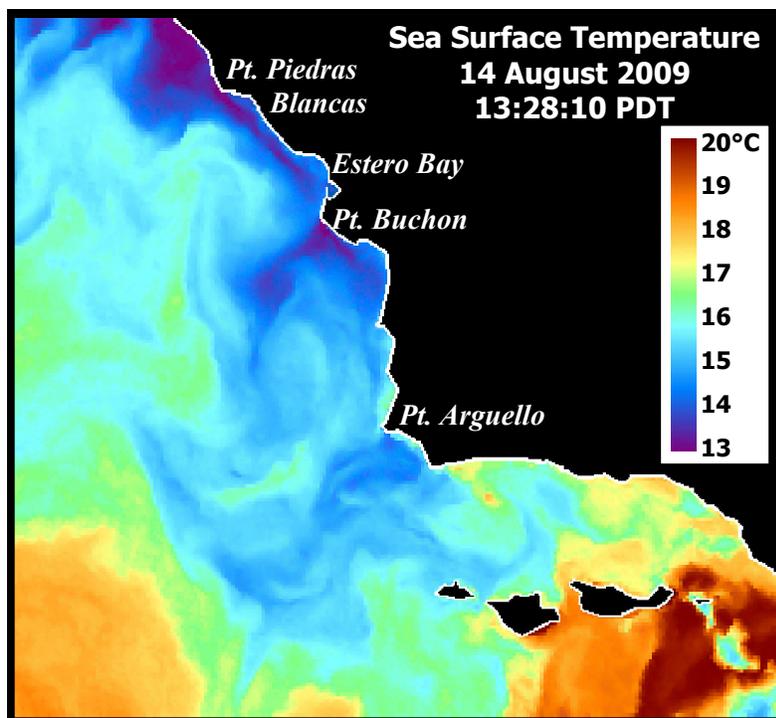


**City of Morro Bay and
Cayucos Sanitary District**

OFFSHORE MONITORING AND REPORTING PROGRAM

**THIRD QUARTER
RECEIVING-WATER SURVEY
AUGUST 2009**



Marine Research Specialists

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

**Report to the
City of Morro Bay and
Cayucos Sanitary District**

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Morro Bay, California 93442
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**OFFSHORE MONITORING
AND REPORTING PROGRAM**

**THIRD QUARTER
RECEIVING-WATER SURVEY**

AUGUST 2009

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October 2009

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

28 October 2009

Reference: Third Quarter Receiving-Water Survey Report – August 2009

Dear Mr. Keogh:

The attached report presents results from a quarterly receiving-water survey conducted on Wednesday, 12 August 2009. The survey was conducted in accordance with the requirements of the NPDES permit issued to the City and District for discharge of treated wastewater to Estero Bay. The report evaluated compliance with permit limitations and assessed the effectiveness of effluent dispersion during summer oceanographic conditions. Based on report's quantitative analyses of continuous instrumental measurements and qualitative visual observations, the wastewater discharge complied with the receiving-water limitations specified in the permit, and with the objectives of the California Ocean Plan.

The offshore measurements also confirmed that the diffuser structure and treatment plant continued to operate at high performance levels. The measurements delineated a diffuse discharge plume containing low organic loads within a highly localized region immediately surrounding the discharge point. Dilution within the plume exceeded expectations based on modeling and outfall design criteria.

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

Sincerely,

Bonnie Luke
Program Manager

Enclosures (5)

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

Mr. Bruce Ambo
City of Morro Bay

Date _____

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INTRODUCTION

The City of Morro Bay and the Cayucos Sanitary District (MBCSD) jointly own the wastewater treatment plant operated by the City of Morro Bay. Region IX of the U.S. Environmental Protection Agency (USEPA) and the Central Coast California Regional Water Quality Control Board (RWQCB) originally issued a National Pollutant Discharge Elimination System (NPDES) permit to the MBCSD, modifying secondary treatment requirements, in March 1985. Following extensive evaluation processes, the permit has been re-issued three times, in March 1993 (RWQCB-USEPA 1993ab), December 1998 (RWQCB-USEPA 1998ab), and January 2009 (RWQCB-USEPA 2009). The August 2009 field survey described in this report was the second receiving-water survey conducted under the current permit.

Seasonal monitoring of offshore receiving-water quality is conducted during quarterly surveys. This quarterly report summarizes the results of sampling conducted on 12 August 2009. Specifically, this third-quarter survey captured ambient oceanographic conditions along the central California coast during the summer season. Analyses of the survey's measurements assessed compliance with the objectives of the California Ocean Plan (COP) as promulgated by the receiving-water limitations specified in the NPDES discharge permit.

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

Both monitoring objectives were achieved by evaluating empirical tabulations of instrumental measurements and standard field observations. In addition to the traditional vertical water-column profiles, instrumental measurements were also used to generate horizontal maps from high-spatial-resolution data created by towing the CTD¹ instrument package repeatedly over the diffuser structure. The tow survey is a new component of the monitoring program that was added to assist in the precise delineation of the lateral extent of the effluent plume, which tends to be highly localized around the discharge point. The significantly wider station pattern used in surveys conducted prior to 1999 rarely resulted in detection of the presence of the dilute wastewater signature. However, with the advent of increased navigational accuracy from differential global positioning systems (DGPS), and closer station spacing adopted in 1999, the presence of well-mixed effluent near the diffuser structure was detected in all forty-two of the subsequent receiving-water surveys (MRS 2000 – 2008). With the addition of the horizontal towing described in this report, the actual extent of the plume can now be accurately determined.

Precise delineation of the effluent plume is important for assessing compliance because half of the receiving-water limitations apply only beyond the narrow 15-m zone of initial dilution surrounding the outfall. Also, the high-resolution data gathered with the CTD's sensitive sensors during the tow survey better quantify the amplitudes of effluent-related perturbations compared to vertical CTD casts. As described in the Methods Section, the CTD's sensors are capable of detecting minute changes in water properties, and the amplitudes of discharge-related salinity anomalies, in particular, reveal the details of dilution as the effluent plume disperses within receiving waters. Dilution factors computed from salinity measurements provide insight into the current operational performance of the outfall and diffuser structure. As described in this report, the data collected during the August 2009 survey delineated the

¹ Conductivity, Temperature, and Depth (CTD) were the original measurements recorded by this type of instrument package, but the moniker now connotes a package capable of *in situ* measurement of dissolved oxygen, transmissivity, and pH as well.

presence of dilute effluent undergoing turbulent mixing within the stratified water column immediately surrounding, and southwest of the diffuser structure.

SAMPLING LOCATIONS

The survey area surrounds the seafloor location where treated wastewater is discharged within Estero Bay along the central coast of California (Figure 1). Effluent is carried from the onshore treatment plant through a 1,450-m long outfall pipe, which terminates at a diffuser structure on the seafloor approximately 827 m from the shoreline.² The diffuser structure extends an additional 52 m toward the northwest from the outfall terminus.

Twenty-eight of 34 available ports discharge effluent along a 42-m section of the diffuser structure. The remaining six diffuser ports remain closed to improve dispersion by increasing the ejection velocity from the open ports. The diffuser ports were hydraulically designed to create a turbulent ejection jet that rapidly mixes effluent with receiving seawater immediately upon discharge. Additional turbulent mixing occurs as the buoyant plume of dilute effluent rises through the water column. Most of this buoyancy-induced mixing occurs within a zone of initial dilution (ZID), whose lateral extent in modeling studies extends approximately 15 m from the centerline of the diffuser structure.

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

Similarly, the entrance to the Morro Bay National Estuary lies 2.8 km south of the discharge; the southerly orientation of the mouth of the Bay and the presence of Morro Rock restrict direct seawater exchange between the discharge point and the Bay. Morro Rock is the largest physiographic feature of the adjacent coastline and extends into Estero Bay approximately 2 km south of the point of discharge (Figure 1).

Near the diffuser, prevailing currents generally follow bathymetric contours that parallel the north-south trend of the adjacent coastline. Because of the rapid initial mixing achieved within 15 m of the diffuser structure, impingement of unmixed effluent onto the adjacent coastline is highly unlikely. Nevertheless, should a failure in the treatment plant's disinfection system occur, the discharge permit requires subsequent collection and analysis of water samples along the shoreline at the surfzone sampling stations shown in Figure 1. These surfzone samples would be analyzed for total and fecal coliform, and Enterococcus bacterial densities.

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



Figure 1. Location of the Receiving-Water Survey Area within Estero Bay

Table 1. Target Locations of the Offshore Receiving-Water Monitoring Stations

Station	Description	Latitude	Longitude	Closest Approach Distance ¹ (m)	Center Distance ² (m)
RW1	Upcoast Midfield	35° 23.253' N	120° 52.504' W	88.4	100
RW2	Upcoast Nearfield	35° 23.231' N	120° 52.504' W	49.4	60
RW3	Upcoast ZID	35° 23.210' N	120° 52.504' W	15.0	20
RW4	Downcoast ZID	35° 23.188' N	120° 52.504' W	15.0	20
RW5	Downcoast Nearfield	35° 23.167' N	120° 52.504' W	49.4	60
RW6	Downcoast Midfield	35° 23.145' N	120° 52.504' W	88.4	100

¹Distance to the closest open diffuser port.

²Distance to the center of open diffuser section.

As shown in Figure 2, the offshore sampling pattern consists of six fixed offshore stations located within 100 m of the outfall diffuser structure. The red ⊙ symbols in the Figure indicate the target locations of the sampling stations (Table 1). The stations are situated at three distances relative to the center of the diffuser structure and lie along a north-south axis at the same water depth (15.2 m) as the center of the diffuser. Depending on the direction of the local oceanic currents at the time of sampling, the discharge could conceivably influence one or more of these stations. Under those circumstances, the up-current stations on the opposite side of the diffuser can act as reference stations. Comparisons of water properties at these antipodal stations quantify departures from ambient seawater properties that are used to evaluate compliance with the NPDES discharge permit.

The finite size of the diffuser is an important consideration in the assessment of wastewater dispersion close to the discharge. Although the discharge is considered a “point source” for modeling and regulatory purposes, it does not occur at a point of infinitesimal size. Instead, the discharge is distributed along a 42 m section of the seafloor, and, ultimately, the amount of wastewater dispersion at a given point in the water column is dictated by its distance from the closest diffuser port, rather than its distance from the center of the diffuser structure. Therefore, 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 specified in the discharge permit only became feasible after the advent of DGPS. The accuracy of traditional navigation systems such as LORAN or standard GPS is typically ±15 m, a span equal to half the total width of the ZID itself. DGPS incorporates a second signal from a fixed, land-based beacon that continuously transmits position errors in standard GPS readings to the DGPS receiver onboard the survey vessel, thereby providing an extremely stable and accurate offshore navigational reading with position errors of less than 2 m.

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

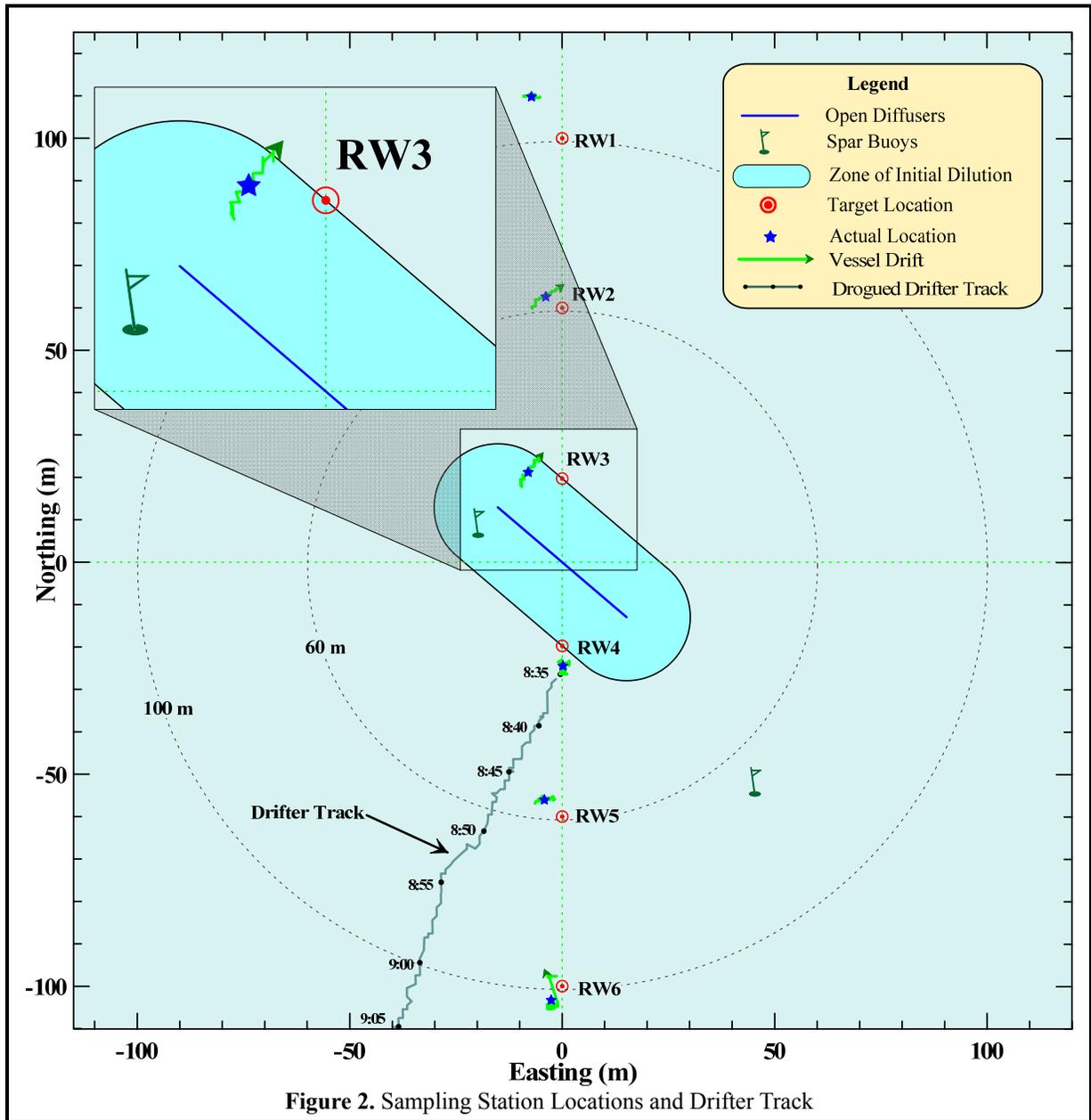


Figure 2. Sampling Station Locations and Drifter Track

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

The magnitude of the horizontal drift at each of the six stations during the August 2009 survey is apparent from the length of the green tracklines in Figure 2. These tracklines trace the horizontal location of the CTD instrument package as it was lowered to the seafloor and reflect the overall station-keeping difficulty experienced during the August 2009 survey. During the time it took the CTD to traverse the water column to the seafloor, which averaged 1 min 21 s, the instrument package moved as much as 8.4 m laterally (at RW3). The average drift for all the stations was 6.1 m, which was comparable to that of most prior 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 2, winds were mild throughout the survey and their influence was minimal. Additionally, transport induced by the prevailing current during the August 2009 survey, which is reflected by the drifter trajectory in Figure 2, was directed toward the south-southwest. Instead, the survey vessel’s residual momentum as it approached Stations RW2, RW3, and RW6 from the south and southwest was responsible for the northerly movement of the CTD during the hydrocasts at those stations. Brief thrust reversals prior to initiating the downcast were more successful at eliminating residual momentum at the other stations. The influence of vessel momentum was apparent from the vessel’s track before each downcast was conducted, although these portions of the vessel tracks are not shown in Figure 2.

Table 2. Standard Meteorological and Oceanographic Observations

Station	Location		Diffuser Distance (m)	Time (PDT)	Air Temp (°C)	Cloud Cover (%)	Wind Avg (kt)	Wind Max (kt)	Wind Dir (from) (°T)	Swell Ht/Dir (ft/°T)	Secchi Depth (m)
	Latitude	Longitude									
RW1	35° 23.256' N	120° 52.504' W	92.9	9:08:55	13.6	100	2.3	3.0	NW	1-2 NW	9.0
RW2	35° 23.233' N	120° 52.501' W	54.2	9:03:36	15.5	100	1.1	2.2	NW	1-2 NW	9.0
RW3	35° 23.211' N	120° 52.505' W	16.4	8:59:23	15.1	100	1.4	2.4	NW	1-2 NW	9.0
RW4	35° 23.189' N	120° 52.507' W	16.4	8:54:53	15.8	100	1.4	1.9	NW	1-2 NW	8.0
RW5	35° 23.167' N	120° 52.504' W	48.8	8:49:46	14.5	100	2.1	2.6	NW	1-2 NW	8.5
RW6	35° 23.145' N	120° 52.503' W	86.8	8:45:11	19.1	100	0.8	1.2	NW	1-2 NW	8.0

Though generally small, lateral movement of the CTD during the downcasts can complicate compliance assessments at Stations RW3 and RW4 because the target locations for these two stations lie on the ZID boundary. For example, during the August 2009 survey, the CTD track in Figure 2 indicates that much of the data collected at Station RW3 was recorded within the ZID boundary, where three of the six receiving-water limitations evaluated as part of this survey do not apply. The green arrows in Figure 2 point toward the bottoms of the hydrocasts, and indicate that, as the CTD traversed the ZID boundary at RW3, only the measurements recorded by the CTD close to the seafloor were subject to the permit limitations. Because the shallowest measurements at RW3 were collected within the ZID, they were not subject to three of the receiving-water limitations specified in the NPDES discharge permit.

Identification of measurements subject to compliance within a given hydrocast only became relevant after the advent of DGPS. Prior to 1999, CTD locations could not be determined with sufficient accuracy or precision to establish whether a station was actually sampled within the ZID, much less how the CTD was moving laterally during the cast. Because of these navigational limitations, sampling was presumed to occur at a single, imprecisely determined, horizontal location. Federal and State reporting of monitoring data still requires identification of a single position for all of the CTD data collected at a particular station. Thus, for regulatory reporting, and for consistency with past surveys, the August 2009 survey identifies a single sampling location for each station. These average station positions are shown by blue stars in Figure 2, and are listed in Table 3 with their distances from the diffuser structure. However, as discussed

Table 3. Average Coordinates of Vertical Profiles during the August 2009 Survey

Station	Time (PDT)		Latitude	Longitude	Closest Approach	
	Downcast	Upcast			Range ¹ (m)	Bearing ² (°T)
RW1	9:08:08	9:09:16	35° 23.258' N	120° 52.509' W	97.3	16
RW2	9:02:53	9:04:04	35° 23.233' N	120° 52.507' W	51.1	28
RW3	8:58:47	9:00:04	35° 23.211' N	120° 52.509' W	11.0³	41
RW4	8:54:00	8:55:35	35° 23.186' N	120° 52.504' W	18.4	191
RW5	8:49:04	8:50:29	35° 23.169' N	120° 52.507' W	47.1	176
RW6	8:43:58	8:45:27	35° 23.143' N	120° 52.506' W	92.0	177

¹Distance from the closest open diffuser port to the average station position.

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

³Portions of the CTD cast at this station were located within the ZID boundary.

previously, an average station position that happens to lie within the ZID (RW3) does not imply that all of the measurements collected at that particular station were subject to the receiving-water objectives of the COP. Similarly, an average station position that is outside the ZID does not guarantee that some measurements might not be subject to the COP objectives, although this was not the case during the August 2009 survey.

Compliance assessments notwithstanding, measurements recorded close to the diffuser structure within the ZID, lend valuable insight into the outfall's effectiveness at dispersing wastewater. Low dilution rates and concentrated effluent throughout the ZID would indicate damaged or broken diffuser ports. Additionally, without measurements recorded within the ZID, the extremely dilute discharge plume might go undetected in the vertical profiles collected during a given survey.

OCEANOGRAPHIC PROCESSES

The trajectory of a satellite-tracked drogued drifter documented a weak south-southwestward flow during the August 2009 survey (Figure 3). The drifter is designed to track the subsurface current, with little influence from the wind. As such, the drifter track normally provides a good indication of the plume transport direction at the time of the survey. The grey line with black dots in Figure 3 shows the drifter's trajectory at five minute intervals. The drogued drifter was deployed near Station RW4 at 8:33 PDT and was recovered two hours later, at 10:33 PDT. The trajectory shows that a weak but steady current carried the drifter slowly offshore, toward the south-southwest (208°T). While deployed, the drifter traversed a total of 305 m at an average speed of 4.2 cm/s or 0.08 knots.

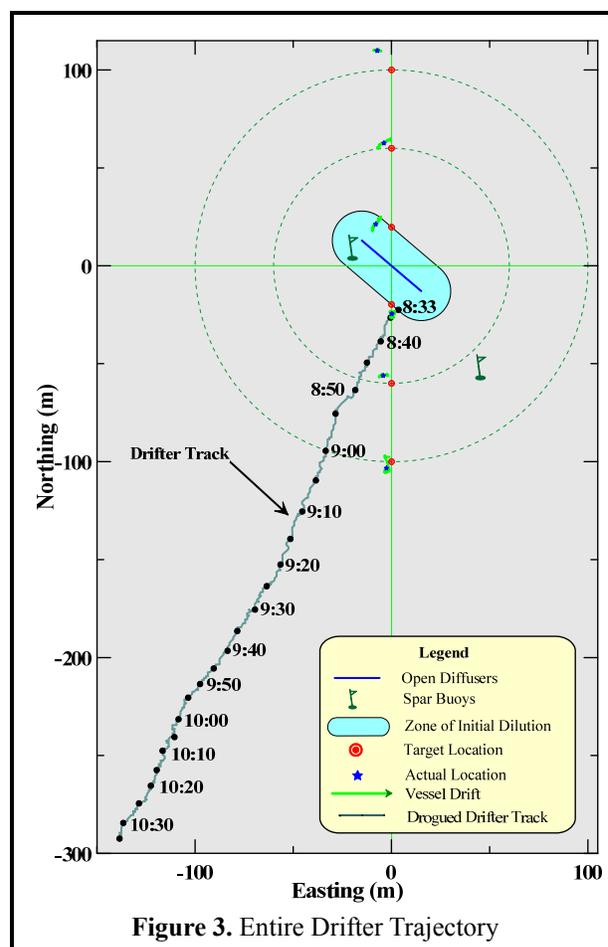
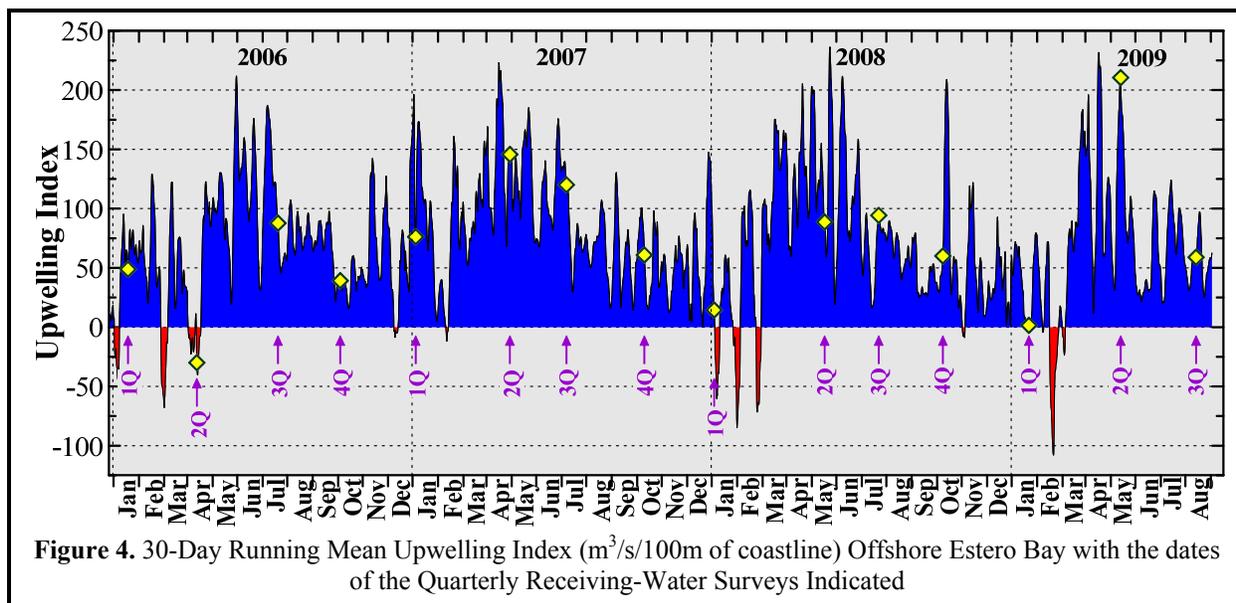
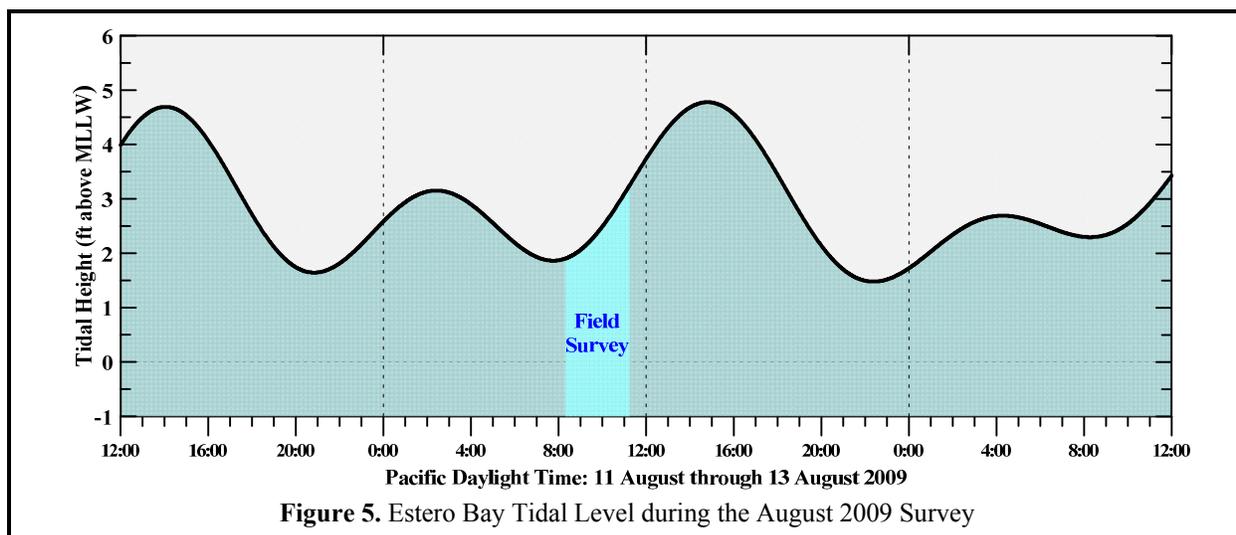


Figure 3. Entire Drifter Trajectory



The drifter's slight westward deviation, apparent between the 8:50 and 8:55 time stamps, resulted from the survey vessel's propeller wash as it passed within a boat length of the drifter.

The offshore flow component revealed by the drifter track was inconsistent with the incoming (flood) tide that occurred during the August 2009 survey. In the absence of other influences, a flood tide normally induces a weak northeastward flow in the survey region. However, flow is more often dominated by external processes, such as wind-generated upwelling or passing offshore eddies. The moderate upwelling conditions (Figure 4) present at the time of the survey were primarily responsible for the observed south-southwestward flow measured by the drifter, although the influence of the flood tide was apparent during the latter half of the survey as a decrease in flow strength. The drifter's average speed during the first half of its deployment was 4.6 cm/s, as compared to 3.5 cm/s during the latter half. This decreasing flow strength probably reflects the increasing influence of the incoming tide (Figure 5).



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 initiated by the stabilization of a high-pressure field over the northeastern Pacific Ocean. Clockwise winds around this pressure field drive the prevailing northwesterly winds along the central California coast. These prevailing winds move warmer surface waters southward and offshore, allowing deep, cool, nutrient-rich waters to move shoreward and upwell near the coast.

Figure 5 shows that the spring upwelling conditions in 2009 began in early March, and were particularly sustained and intense around the time of the spring survey conducted in May. By the time of the August 2009 survey, upwelling strength had moderated somewhat; onshore flow at depth was restricted to a thin seafloor boundary layer whose presence is reflected in the sharp vertical gradients apparent in most seawater properties below 13 m (Figure 6). As described below, the drifter was drogued at 7 m, and thus only reflected the offshore transport that prevailed throughout the rest of the water column.

Although not as intense as earlier in the year, the upwelling winds that prevailed along the central California coast in August 2009 were still strong enough to produce perceptibly cooler sea-surface temperatures close to the coastline. Cooler coastal water, with filaments extending offshore at major promontories, is the typical signature of upwelling conditions in satellite images. The image on the cover of this report depicts these cooler waters, with temperatures below 13°C, in purple. Farther offshore, surface water temperatures were as much as four degrees warmer, as delineated by the areas with light green and yellow shading. The cover image was recorded two days after the August 2009 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 cool sea surface temperatures depicted in the satellite image within Estero Bay were consistent with the low seawater temperatures recorded by the CTD during the survey (Figure 6).

METHODS

The 38 ft F/V *Bonnie Marietta*, owned and operated by Captain Mark Tognazzini of Morro Bay, served as the survey vessel on Wednesday 12 August 2009. Dr. Douglas Coats of Marine Research Specialists (MRS) was the Chief Scientist, Captain Mark Tognazzini supervised vessel operations, and William Skok served as marine technician. Ms. Bonnie Luke, of MRS, provided additional scientific support and collected auxiliary measurements of biological, meteorological, and oceanographic conditions throughout the survey. Mr. Bruce Keogh, the MBCSD Wastewater Division Manager, was also present onboard during the survey.

Auxiliary Measurements

Auxiliary measurements and observations were collected contemporaneously with the vertical water-column profiling conducted at each of the six stations (Table 2). Standard observations of weather and sea conditions, and beneficial uses, were augmented by visual inspection of the sea surface for floating particulates, oil sheens, and discoloration related to the effluent discharge. Other auxiliary measurements collected at each station included wind speeds and air temperatures measured with a handheld Kestrel® 2000 Thermo-Anemometer.

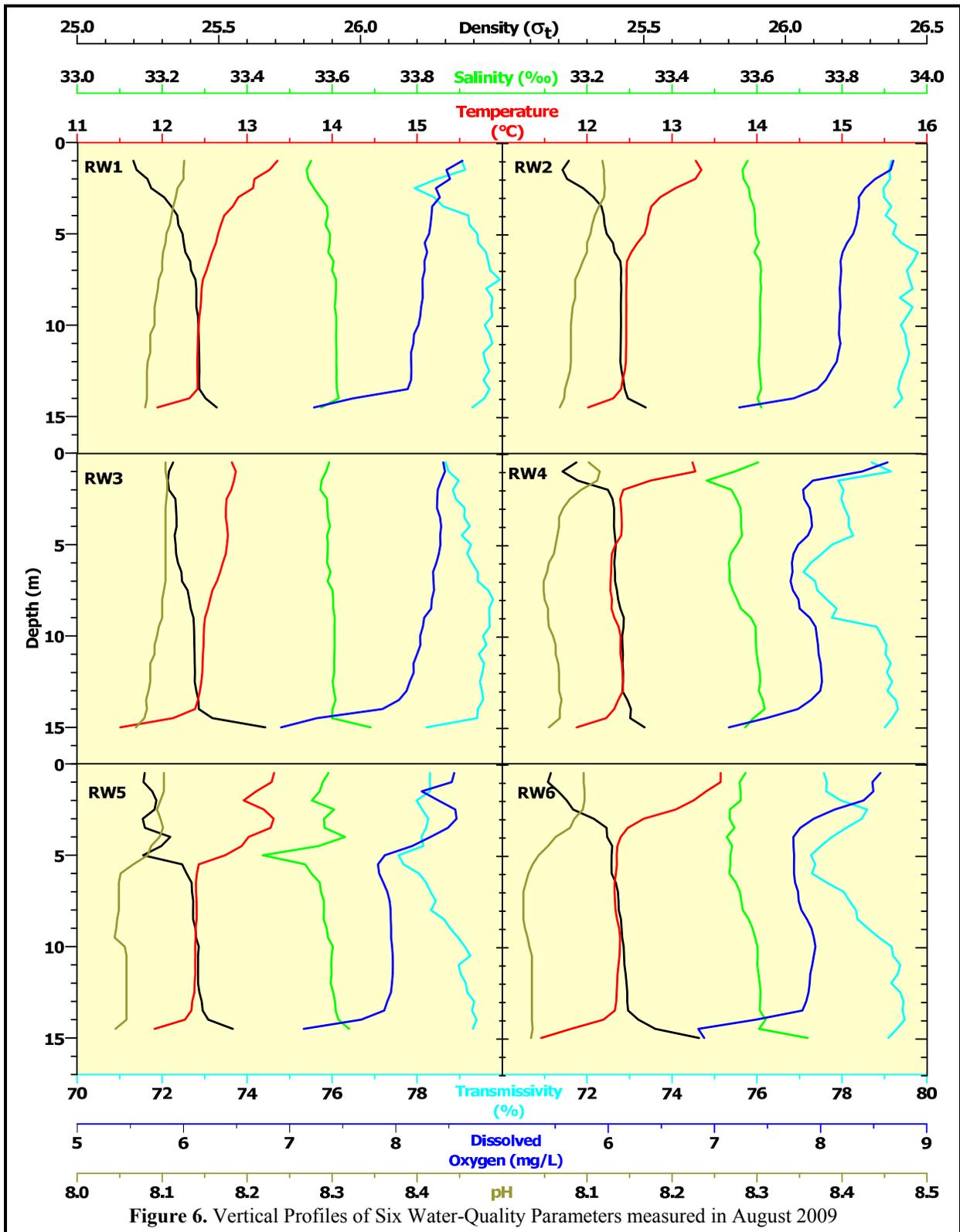


Figure 6. Vertical Profiles of Six Water-Quality Parameters measured in August 2009

Additionally, at all six stations, a Secchi disk was lowered through the water column to determine its depth of disappearance. Secchi depths provide a visual measure of near-surface turbidity or water clarity. The depth of disappearance is inversely proportional to the average amount of organic and inorganic suspended material along a line of sight in the upper water column. As such, the Secchi depth measures natural light penetration, which can be limited by increased suspended particulate loads from plankton blooms, onshore runoff, seafloor resuspension, and wastewater discharge. It is also biologically significant because the depth of the euphotic zone, where most oceanic photosynthesis occurs, extends to approximately twice the Secchi depth.

Secchi depths recorded during the August 2009 survey ranged between 8 and 9 m, and documented the uniformly high water clarity that was present throughout most of the water column at the time of the survey. Although the measured Secchi depths suggested that the euphotic zone extended to the seafloor at all stations, in actuality it did not due to the presence of a thin, turbid benthic nepheloid layer (BNL) immediately above the seafloor. As in past surveys, the BNL observed during the August 2009 survey was associated with the onshore movement of a deep, upwelling watermass. The increased BNL turbidity is particularly apparent in the vertical profile of transmissivity at RW3, shown in light blue in the left middle frame of Figure 6. Because of its narrow depth range, most other CTD profiles failed to capture its presence, and the Secchi disk never extended into the BNL before disappearing from sight.

The satellite-tracked drifter deployed near the open section of the diffuser structure during the August 2009 survey was drogued at mid-depth (7 m) using the curtain-shade design of Davis et al. (1982). In this configuration, the oceanic flow field rather than surface winds dictated the drifter's trajectory. The times and precise positions of the drifter deployment and recovery were recorded to determine the overall strength and direction of plume transport during the sampling effort. In addition, the drifter was fitted with a GPS receiver to record the drifter position throughout its deployment.

Instrumental Measurements

A Sea Bird Electronics SBE-19 Seacat CTD instrument package was deployed in both a vertical water-profiling mode, as well as a horizontal tow configuration during the August 2009 survey. It collected measurements of conductivity, temperature, light transmittance, dissolved oxygen (DO), pH, and pressure at a sampling rate of 2 Hz (0.5-s intervals). A submersible pump on the CTD continuously flushed water through the conductivity cell and oxygen plenum at a constant rate, independent of the CTD's motion through the water column.

The CTD instrument package receives regular maintenance and calibration. After the October 2001 survey, the CTD was returned to the factory for comprehensive testing, repair, and calibration. The DO and pH sensors were returned to the factory in May 2003 and again 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 calibrated at the MRS laboratory prior to the August 2009 survey. The upper-bound DO calibration point at full saturation was established by immersing the CTD in an aerated, temperature-controlled calibration tank. In addition to oxygen readings at full saturation, a zero-oxygen calibration point was determined by filling the oxygen-sensor plenum with an 8% solution of sodium sulfite (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 in previous surveys, the pre-cruise calibration coefficients determined by MRS closely corresponded with prior factory calibrations.

The six seawater properties used to assess receiving-water quality in this report were derived from the continuously recorded output of the CTD's probes and sensors. Pressure housing limitations on the combination oxygen/pH sensor confine the CTD to depths less than 200 m (Table 4), which is well

Table 4. Instrumental Specifications for the CTD Instrument Package

Component	Depth¹	Units	Range	Accuracy	Resolution
Housing	600	—	—	—	—
Pump	3400	—	—	—	—
Pressure	680	Psia	0 to 1000	± 5.0	± 0.5
Depth	—	Meters	0 to 690	± 3.0	± 0.3
Conductivity	600	Siemens/m	0 to 6.5	± 0.001	± 0.0001
Salinity	600	‰	0 to 38	± 0.006	± 0.0006
Temperature	600	°C	-5 to 35	± 0.01	± 0.001
Transmissivity	2000	%	0 to 100	± 0.1	± 0.025
Dissolved Oxygen	200	mg/L	0 to 21.5	± 0.14	± 0.014
Acidity/Alkalinity	200	pH	0 to 14	± 0.1	± 0.006

¹ Maximum depth limit in meters

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 listed in Table 4. Salinity (‰) was calculated from conductivity measurements reported in units of Siemens/m. Density was derived from contemporaneous temperature (°C) and salinity data, and was expressed as 1000 times the specific gravity minus one, which is a unit of sigma-T (σ_t).

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

During the pre-cruise calibration, coefficients for the pH (alkalinity) sensor were determined from a linear regression of output voltage after immersion in five separate buffered solutions of known pH. Buffering solutions with a pH of 4±0.01, 6±0.01, 7±0.01, and 10±0.02 were used to bracket the range of in situ measurements. The SeaTech transmissometer was air calibrated by fitting the voltages recorded with and without blocking of the light transmission path in air, as recommended by the manufacturer (SBE 1989). Algorithms that converted sensor voltage to engineering units during processing of the field data relied on calibration coefficients determined before the survey.

Comparison with the factory calibration of the entire CTD package conducted in December 2001, and the more recent June 2006 replacement and calibration of the DO probe, confirmed the continued accuracy and stability of the temperature, pressure, and conductivity sensors, as well as the operational integrity of the oxygen and pH probes. To correct for a slight drift in the pressure strain gauge since its calibration in 2001, a -0.25 Psia offset was incorporated in the conversion to depth measurements. In addition, pH measurements collected during the first vertical profile at RW6 were adjusted upward to remove a slight temporal trend that arose from the sensor's ongoing equilibration. The upward adjustment was less than 0.01 pH units. There was no perceptible drift in the DO sensor during the August 2009 survey, although corrections for slight temporal drift in that sensor has also occasionally been necessary in the past.

Before initial deployment for the vertical hydrocasts, the CTD was held below the sea surface for a four-minute equilibration period. Subsequently, the CTD was raised to within 0.5 m of the sea surface and

profiling commenced. The CTD was lowered at a continuous rate of speed to the seafloor. Measurements at all six stations were collected during a 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.

Tow Survey

Following the vertical CTD casts collected at the six stations, the CTD was continuously towed around and across the ZID at two separate depths in accordance with the receiving-water monitoring requirements of the current NPDES discharge permit. At 9:33 PDT, following the last vertical profile at RW1, the CTD instrument package was fitted with a depth-suppressor and horizontal stabilizer to achieve constant-depth tows with forward-looking sensor probes. Fifteen meters of towline were deployed and the reconfigured CTD package was towed at an average depth of 3.05 m, and an average speed of 1.7 m/s for 27 min, passing near the diffuser structure seven times (Figure 7). Subsequently, an additional 8 m of towline was paid-out, and seven additional passes were made at an average depth of 6.71 m.

During the 24-minute deep-tow survey, vessel speed averaged 1.6 m/s. At the observed towing speeds and a 2 Hz sampling rate, 1.2 CTD measurements were collected for each meter traversed, which complies with the permit requirement for at least one sample per meter.

Contemporaneous navigation fixes recorded onboard the survey vessel were adjusted for CTD setback and aligned with time stamps on the internally recorded CTD data. The resulting data for the six seawater properties were processed to produce horizontal maps at a mid-depth level below the thermocline (Figure 8), and within the shallow mixed layer (Figure 9).

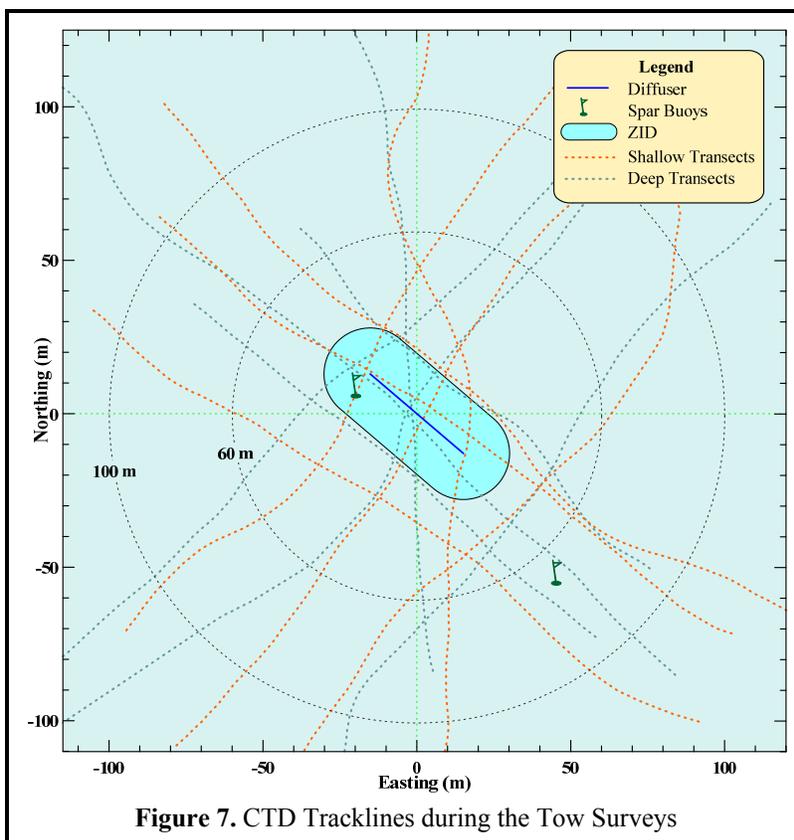


Figure 7. CTD Tracklines during the Tow Surveys

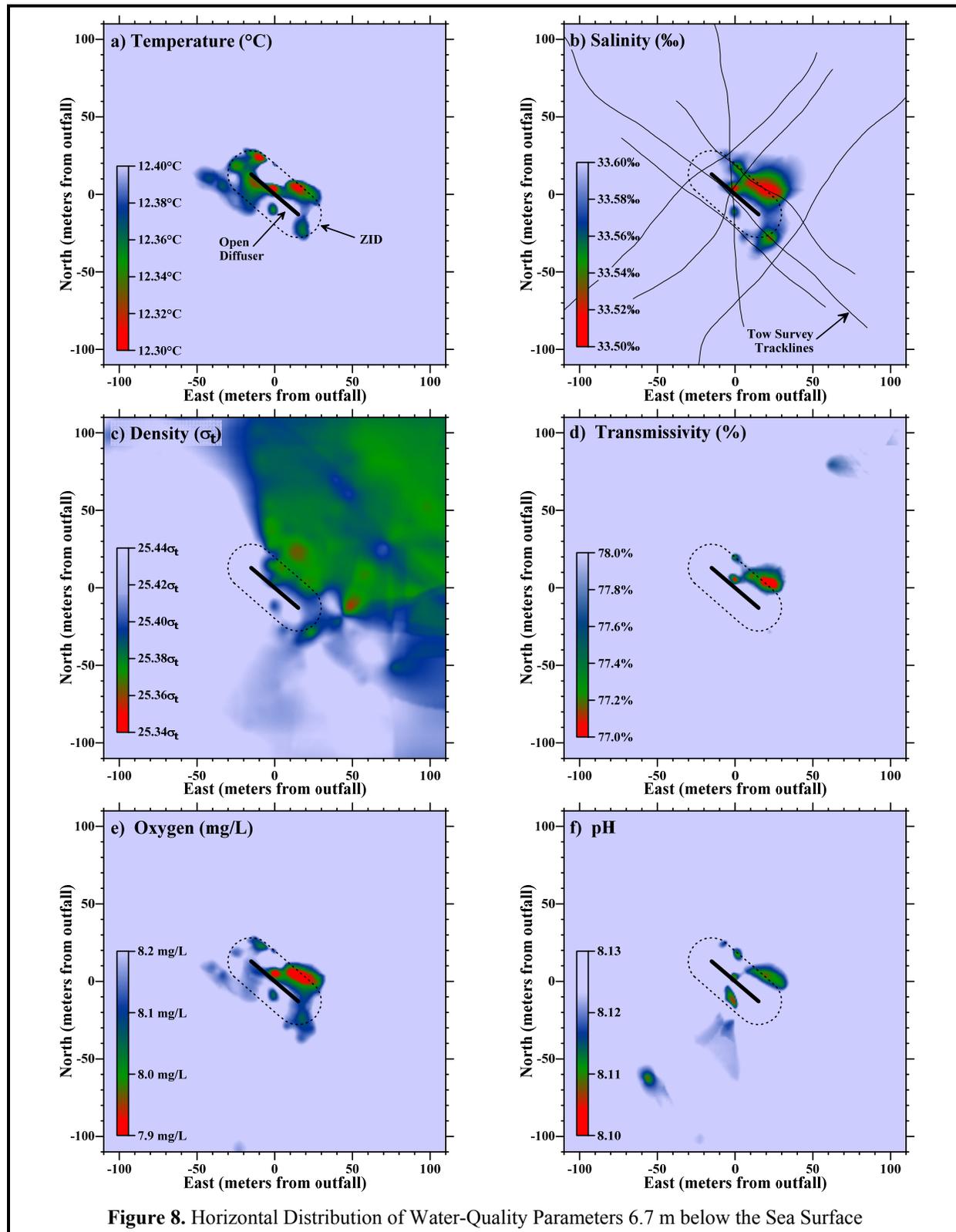
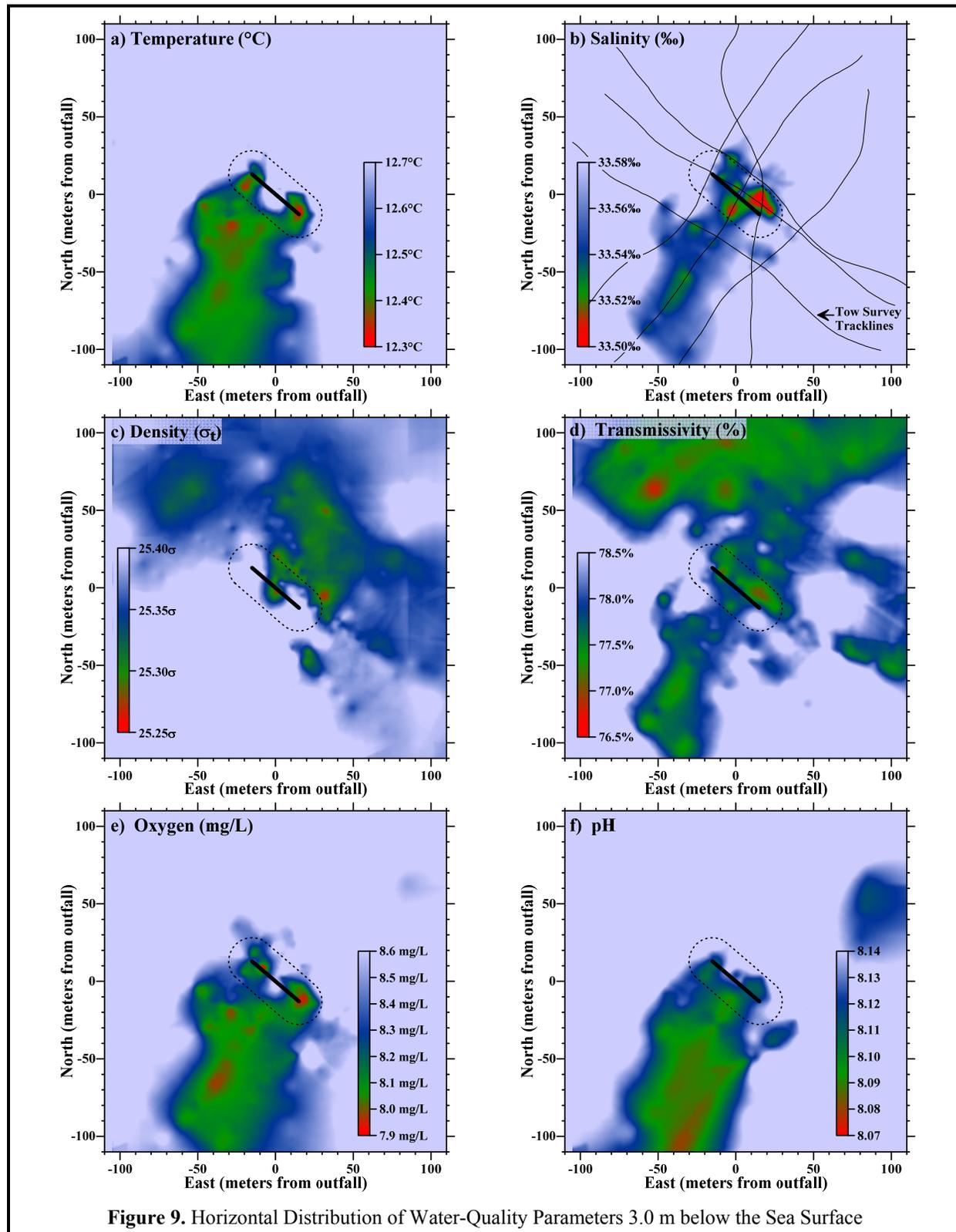


Figure 8. Horizontal Distribution of Water-Quality Parameters 6.7 m below the Sea Surface



RESULTS

The third-quarter receiving-water survey began approximately two hours after sunrise at 08:31 PDT on Wednesday, 12 August 2009, with the deployment of the drogued drifter. Over the following two hours, offshore observations and measurements were collected as required by the NPDES monitoring program. The survey ended at 10:27 PDT with the recovery of the CTD from its deep-tow configuration. Skies were overcast throughout the survey. Although atmospheric visibility along the ocean surface and out to sea was good, low-lying fog along the shoreline partially obscured portions of the surfzone and Morro Rock throughout much of the survey. However, observations of beneficial use and collection of required visual observations of the sea surface were unencumbered. No evidence of floating particulates, oil sheens, or discoloration of the sea surface were observed at any of the stations during vertical profiling, or at any other time during the survey.

Auxiliary Observations

Average wind speeds, calculated over one-minute intervals, were light and variable throughout the survey, ranging from 0.8 to 2.3 kt (Table 2). Corresponding, peak wind speeds ranged from 1.2 to 3.0 kt. A long-period swell out of the northwest had a significant wave height of 1 to 2 feet. Air temperatures varied substantially, from 13.6°C to 19.1°C, in response to changes in wind velocity. For the most part, however, air temperatures were substantially warmer than the surface water temperature (<13.6°C, Table 5).

During the August 2009 survey, observations demonstrated continued beneficial use of the coastal waters within Estero Bay by both wildlife and recreational users. Although only limited numbers of pedestrians were observed using the beach, sightings of several recreational fishing vessels and a kelp cutter were noted offshore during the course of the survey.

Wildlife sightings during the August 2009 survey were particularly abundant. Large numbers of California brown pelicans (*Pelecanus occidentalis californicus*), Brandt's cormorants (*Phalacrocorax penicillatus*), pelagic cormorants (*Phalacrocorax pelagicus*), and western gulls (*Larus occidentalis*) were observed during transit to and from the survey area and during the course of the survey. Additionally, eight southern sea otters (*Enhydra lutris nereis*) were observed during transit to the survey site: six were seen inside breakwater of the Morro Bay harbor mouth, and two more were observed en route to the site. During the survey itself, four otters and several California sea lions (*Zalophus californianus*) were observed transiting within several hundred yards of the outfall. Additionally, pieces of detached bull kelp (*Nereocystis luetkeana*) were evident on the sea surface throughout the greater survey area.

Instrumental Observations

Data collected during vertical profiling were processed in accordance with standard procedures (SCCWRP 2002), and are collated within 0.5-m depth intervals in Table 5. Data collected during the August 2009 survey reflect the classical, stratified conditions that are indicative of prevailing upwelling conditions. Upwelling results in an influx of dense, cold, saline water at depth and often leads to a sharp thermocline, halocline, and pycnocline where temperature, salinity, and density change rapidly over short vertical distances. Highly stratified waters inhibit vertical exchange of nutrients and other water properties, and can reduce dilution of materials introduced by seafloor point sources, such as ocean outfalls.

Table 5. Vertical Profile Data Collected on 12 August 2009

Depth (m)	Temperature (°C)						Salinity (‰)					
	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6
0.5			12.819	13.241	13.317	13.573			33.593	33.603	33.591	33.573
1.0	13.357	13.280	12.866	13.274	13.287	13.572	33.550	33.578	33.586	33.548	33.578	33.559
1.5	13.263	13.345	12.844	12.745	13.106	13.401	33.540	33.566	33.575	33.482	33.571	33.561
2.0	13.087	13.274	12.812	12.427	12.958	13.253	33.544	33.569	33.572	33.540	33.552	33.562
2.5	13.069	13.039	12.758	12.391	13.196	13.042	33.557	33.581	33.588	33.552	33.605	33.536
3.0	12.896	12.860	12.750	12.401	13.312	12.667	33.572	33.584	33.589	33.561	33.581	33.536
3.5	12.831	12.757	12.749	12.406	13.277	12.480	33.588	33.592	33.590	33.563	33.582	33.547
4.0	12.730	12.725	12.763	12.409	13.017	12.396	33.590	33.595	33.595	33.562	33.631	33.529
4.5	12.692	12.709	12.774	12.402	12.936	12.357	33.584	33.595	33.588	33.565	33.569	33.542
5.0	12.657	12.679	12.762	12.333	12.742	12.349	33.595	33.597	33.590	33.553	33.437	33.537
5.5	12.634	12.593	12.749	12.292	12.430	12.351	33.595	33.604	33.589	33.539	33.537	33.537
6.0	12.589	12.521	12.713	12.286	12.408	12.340	33.591	33.594	33.588	33.534	33.551	33.535
6.5	12.554	12.471	12.682	12.283	12.397	12.324	33.604	33.607	33.596	33.536	33.571	33.550
7.0	12.521	12.464	12.645	12.277	12.399	12.324	33.600	33.610	33.589	33.535	33.574	33.560
7.5	12.479	12.465	12.591	12.274	12.404	12.328	33.609	33.608	33.601	33.543	33.581	33.563
8.0	12.464	12.463	12.564	12.294	12.406	12.335	33.609	33.610	33.602	33.553	33.581	33.567
8.5	12.459	12.462	12.538	12.288	12.405	12.353	33.608	33.608	33.603	33.562	33.580	33.581
9.0	12.452	12.463	12.504	12.322	12.393	12.377	33.606	33.607	33.606	33.586	33.587	33.590
9.5	12.437	12.462	12.492	12.371	12.393	12.389	33.610	33.608	33.606	33.597	33.590	33.595
10.0	12.429	12.461	12.488	12.395	12.389	12.386	33.610	33.608	33.606	33.597	33.602	33.601
10.5	12.422	12.461	12.486	12.394	12.390	12.381	33.609	33.607	33.606	33.598	33.599	33.602
11.0	12.419	12.462	12.479	12.393	12.388	12.370	33.610	33.607	33.605	33.599	33.598	33.601
11.5	12.416	12.459	12.475	12.411	12.389	12.359	33.610	33.606	33.605	33.603	33.599	33.604
12.0	12.414	12.457	12.472	12.417	12.381	12.355	33.610	33.604	33.605	33.607	33.597	33.606
12.5	12.414	12.443	12.461	12.422	12.380	12.348	33.611	33.606	33.601	33.608	33.602	33.609
13.0	12.415	12.418	12.444	12.422	12.354	12.344	33.610	33.608	33.604	33.604	33.607	33.607
13.5	12.416	12.400	12.422	12.367	12.343	12.326	33.611	33.610	33.608	33.613	33.608	33.607
14.0	12.321	12.309	12.386	12.320	12.268	12.193	33.616	33.601	33.601	33.618	33.615	33.621
14.5	11.944	12.013	12.127	12.225	11.911	11.811	33.574	33.610	33.600	33.591	33.640	33.604
15.0			11.507	11.878		11.459			33.691	33.572		33.719

Table 5. Vertical Profile Data Collected on 12 August 2009 (continued)

Depth (m)	Density (σ_t)						pH					
	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6
0.5			25.339	25.263	25.238	25.172			8.104	8.102	8.102	8.096
1.0	25.199	25.235	25.324	25.213	25.234	25.162	8.126	8.118	8.104	8.115	8.102	8.096
1.5	25.210	25.213	25.320	25.267	25.265	25.198	8.125	8.120	8.106	8.112	8.102	8.097
2.0	25.248	25.229	25.324	25.374	25.280	25.228	8.125	8.120	8.106	8.093	8.098	8.097
2.5	25.262	25.286	25.347	25.390	25.273	25.251	8.118	8.121	8.105	8.080	8.094	8.095
3.0	25.307	25.324	25.349	25.395	25.231	25.324	8.116	8.120	8.104	8.072	8.098	8.085
3.5	25.332	25.351	25.350	25.395	25.239	25.369	8.113	8.114	8.104	8.067	8.101	8.080
4.0	25.354	25.359	25.351	25.395	25.329	25.371	8.111	8.109	8.104	8.067	8.097	8.063
4.5	25.357	25.362	25.344	25.398	25.297	25.389	8.109	8.106	8.104	8.065	8.087	8.054
5.0	25.372	25.369	25.348	25.402	25.233	25.387	8.105	8.104	8.104	8.063	8.083	8.043
5.5	25.376	25.392	25.349	25.399	25.371	25.386	8.104	8.100	8.104	8.061	8.066	8.036
6.0	25.382	25.398	25.356	25.396	25.386	25.387	8.101	8.100	8.104	8.055	8.051	8.031
6.5	25.399	25.418	25.368	25.398	25.404	25.402	8.100	8.095	8.104	8.053	8.049	8.028
7.0	25.402	25.421	25.370	25.399	25.405	25.409	8.100	8.091	8.104	8.049	8.049	8.025
7.5	25.417	25.419	25.390	25.406	25.410	25.411	8.096	8.086	8.102	8.049	8.049	8.025
8.0	25.420	25.421	25.396	25.410	25.409	25.412	8.095	8.086	8.100	8.050	8.049	8.025
8.5	25.421	25.420	25.401	25.418	25.409	25.420	8.093	8.086	8.100	8.054	8.047	8.025
9.0	25.420	25.419	25.410	25.430	25.417	25.422	8.091	8.083	8.100	8.054	8.046	8.027
9.5	25.426	25.420	25.412	25.429	25.420	25.424	8.091	8.082	8.096	8.055	8.044	8.030
10.0	25.428	25.420	25.413	25.424	25.429	25.429	8.091	8.081	8.094	8.060	8.056	8.032
10.5	25.429	25.419	25.414	25.425	25.427	25.431	8.086	8.081	8.091	8.063	8.058	8.035
11.0	25.430	25.419	25.415	25.427	25.426	25.432	8.086	8.081	8.091	8.063	8.058	8.035
11.5	25.430	25.419	25.415	25.426	25.427	25.436	8.086	8.081	8.086	8.066	8.058	8.035
12.0	25.431	25.418	25.416	25.428	25.427	25.439	8.083	8.081	8.086	8.067	8.058	8.035
12.5	25.431	25.422	25.415	25.427	25.431	25.442	8.082	8.080	8.086	8.067	8.058	8.035
13.0	25.431	25.428	25.420	25.425	25.440	25.442	8.082	8.077	8.084	8.067	8.058	8.035
13.5	25.431	25.433	25.428	25.442	25.443	25.445	8.082	8.074	8.081	8.070	8.058	8.035
14.0	25.453	25.444	25.429	25.455	25.462	25.481	8.082	8.073	8.082	8.068	8.058	8.035
14.5	25.492	25.507	25.478	25.453	25.550	25.541	8.080	8.068	8.079	8.068	8.045	8.036
15.0			25.664	25.503		25.695			8.069	8.055		8.034

Table 5. Vertical Profile Data Collected on 12 August 2009 (continued)

Depth (m)	Dissolved Oxygen (mg/L)						Transmissivity (%)					
	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6
0.5			8.446	8.631	8.549	8.564			78.668	78.700	78.307	77.575
1.0	8.627	8.686	8.463	8.391	8.526	8.488	79.050	79.163	78.744	79.154	78.301	77.640
1.5	8.476	8.660	8.427	7.927	8.244	8.497	79.132	79.113	78.978	77.910	78.307	77.627
2.0	8.510	8.515	8.394	7.836	8.400	8.406	78.465	79.134	78.843	78.036	77.987	77.973
2.5	8.377	8.418	8.389	7.846	8.560	8.133	77.943	78.976	78.912	77.984	78.119	78.595
3.0	8.414	8.360	8.387	7.897	8.572	7.935	78.400	78.992	79.121	78.058	78.263	78.466
3.5	8.342	8.364	8.416	7.913	8.490	7.809	78.614	79.162	79.110	78.160	78.215	78.101
4.0	8.335	8.349	8.426	7.920	8.327	7.744	79.205	79.025	79.238	78.161	78.100	77.766
4.5	8.326	8.336	8.418	7.881	8.153	7.745	79.232	79.278	79.051	78.265	78.147	77.502
5.0	8.313	8.308	8.419	7.790	7.896	7.752	79.419	79.203	79.271	77.767	77.564	77.270
5.5	8.272	8.250	8.404	7.745	7.831	7.750	79.438	79.395	79.180	77.527	77.681	77.373
6.0	8.295	8.208	8.381	7.730	7.843	7.750	79.621	79.784	79.295	77.268	78.042	77.293
6.5	8.269	8.188	8.350	7.737	7.882	7.760	79.673	79.682	79.428	77.094	78.213	77.642
7.0	8.271	8.194	8.355	7.717	7.919	7.788	79.720	79.527	79.429	77.366	78.314	78.039
7.5	8.251	8.188	8.359	7.739	7.941	7.794	79.949	79.591	79.674	77.417	78.439	78.174
8.0	8.251	8.180	8.339	7.792	7.950	7.819	79.626	79.662	79.785	77.643	78.325	78.328
8.5	8.253	8.184	8.333	7.803	7.952	7.872	79.775	79.362	79.696	77.874	78.629	78.365
9.0	8.238	8.187	8.267	7.899	7.956	7.915	79.743	79.662	79.703	77.761	78.778	78.609
9.5	8.230	8.177	8.254	7.953	7.955	7.937	79.768	79.534	79.707	78.817	78.966	78.873
10.0	8.212	8.176	8.229	7.965	7.964	7.952	79.589	79.387	79.552	78.938	79.127	79.167
10.5	8.171	8.173	8.231	7.977	7.970	7.937	79.710	79.491	79.631	79.050	79.254	79.201
11.0	8.164	8.187	8.200	7.982	7.971	7.922	79.770	79.519	79.453	79.023	78.979	79.373
11.5	8.143	8.169	8.166	8.001	7.970	7.903	79.560	79.581	79.574	79.146	79.028	79.314
12.0	8.144	8.152	8.169	8.008	7.963	7.897	79.607	79.538	79.541	79.055	79.147	79.160
12.5	8.146	8.098	8.131	8.013	7.954	7.887	79.699	79.438	79.480	79.181	79.181	79.372
13.0	8.143	8.049	8.101	7.997	7.919	7.865	79.563	79.365	79.524	79.068	79.344	79.448
13.5	8.112	7.968	8.029	7.911	7.890	7.829	79.704	79.320	79.555	79.264	79.293	79.424
14.0	7.597	7.747	7.874	7.787	7.674	7.392	79.585	79.421	79.430	79.319	79.401	79.478
14.5	7.230	7.234	7.257	7.489	7.133	6.849	79.299	79.233	79.412	79.186	79.310	79.291
15.0			6.919	7.137		6.904			78.223	79.008		79.088

Upwelling-induced vertical gradients are plainly evident in the vertical profiles of seawater properties shown in (Figure 6). Most of the profiles reflect the presence of three distinct water masses. Sharp vertical gradients separate very thin surface and seafloor layers from a relatively uniform mid-depth layer that spans most of the water column. Sharp near-surface and seafloor thermoclines (red line) and pycnoclines (black line) generally coincide with declines in pH (gold line) and DO (dark blue line) with increasing depth. Meanwhile, salinity (green line) tends to exhibit a slight increase with depth, although this subtle vertical gradient is occasionally obscured by salinity spikes.

Salinity spikes are instrumental artifacts arising from the mismatch that occurs between conductivity and temperature measurements collected near sharp, localized temperature gradients, such as those found in the upper water column during the August 2009 survey. Salinity is computed from conductivity and temperature readings measured by two separate sensors on the CTD. Due to their differing response times and locations on the CTD, at particularly strong gradients these two sensors actually end up measuring different parcels of water resulting in sharp zigzags or spikes in the graphical data that are not representative of the true salinity. Because density is computed from salinity, this parameter also exhibits a characteristic, artificially induced zigzag pattern in the upper water column, as shown by the black lines in Figure 6, especially at RW5.

The vertical differences in seawater properties are a consequence of ambient physical, chemical, and biological processes that prevail during upwelling. Cold, oxygen-poor water from deep offshore is transported shoreward near the seafloor during upwelling. The deep offshore origin of these waters is particularly evident in their DO concentrations and pH levels. Watermasses that have not had contact with the atmosphere for extended periods traditionally exhibit low DO concentrations because biotic respiration and decomposition have slowly depleted oxygen levels at depth. Biotic respiration and decomposition also produce CO₂ (carbonic acid) which results in measurably lower pH, indicating that the deep water mass is slightly more acidic.

At the same time, primary production near the sea surface is enhanced during upwelling due to the increased availability of nutrients. Normally, DO concentrations tend to be higher within the surface mixed layer due to gaseous exchange with the overlying atmosphere. However, excess oxygen is produced when phytoplankton consume CO₂ and increase pH. During the August 2009 survey, surface DO concentrations were slightly supersaturated. Increased primary production, namely, an increased density of phytoplanktonic organisms, also decreases the transmission of ambient light through the near-surface mixed layer. This accounts for the near-surface reduction in transmissivity reflected by the light-blue lines in the vertical profiles at RW1, RW2, and RW3, which were up-current from the discharge plume's influence. In addition to reduced transmissivity within the surface euphotic layer, transmissivity also drops slightly near the seafloor because of the presence of lightweight flocs of detritus that are resuspended by the turbulence generated by bottom currents. These particle-rich BNLs are a widespread phenomenon on continental shelves (Kuehl et al. 1996) and are frequently observed during offshore surveys conducted for the MBCSD.

Outfall Performance

The present efficacy of the diffuser structure can be determined through a comparison between measured dilution levels, and dilutions anticipated from modeling studies codified in the discharge permit through limits imposed on effluent constituents. The critical initial dilution applicable to the MBCSD outfall is conservatively estimated to be 133:1 (Tetra Tech 1992). This estimate is based on worst-case modeling under highly stratified conditions where trapping of the plume below the thermocline restricts mixing during the buoyant plume's abbreviated rise through the water column. The dispersion modeling determined that, at the conclusion of initial mixing, 133 parts of ambient water will have mixed with each part of wastewater. The modeling predicts that this level of dilution will be achieved after the plume rises

only 9 m from the seafloor, whereupon it becomes trapped beneath a thermocline and spreads laterally with no further substantive dilution. A 9-m rise at the outfall translates into a trapping depth that is 6.4 m below the sea surface, slightly above the depth of the deep tow survey.

As stated previously, turbulence associated with the momentum of the effluent jet and the subsequent rise of the buoyant plume is responsible for initial mixing. The plume modeling used to establish dilution levels assumes quiescent flow conditions, so the initial mixing processes are limited to the ZID. In reality, initial mixing processes often extend beyond the ZID boundary as the plume is transported laterally by prevailing currents during its rise through the water column, as was the case during the August 2009 survey. During the August 2009 survey, the plume was still buoyant at the modeled 9-m trapping depth, and undoubtedly continued to mix as it rose, eventually reaching the sea surface. Moreover, even at depths below the modeled trapping depth, the plume achieved higher dilution levels than that predicted by the modeling.

The conservative nature of the critical initial dilution determined from modeling is an important consideration because it was used to specify permit limitations on chemical concentrations in wastewater discharged from the treatment plant. These end-of-pipe effluent limitations were back calculated from the receiving-water objectives in the COP (SWRCB 2005) using the projected 133-fold dilution determined from the modeling. Use of a higher critical dilution would relax the stringent end-of-pipe effluent limitations thought necessary to meet COP objectives.

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

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

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

By rearranging Equation 1, the actual dilution achieved by the outfall can be determined from measured seawater anomalies. This measured dilution can then be compared with the critical dilution factor determined from modeling. Salinity is an especially useful tracer because it directly reflects the magnitude of ongoing dilution. Wastewater-induced patches of low salinity are apparent near the ZID in the tow-survey maps (Figures 8b and 9b). These localized salinity anomalies reflect the presence of dilute wastewater within the effluent plume as it rose and spread within the water column.

Because the salinity concentration in effluent is negligible, 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 33.8‰), and
 $A = C_o - C_s$ = the salinity anomaly.

Using Equation 2 to recast the salinity distribution shown Figure 8b, results in the dilution distribution shown in Figure 10. At that depth level, the largest salinity anomaly (33.474‰) was measured almost directly over the diffuser structure, with a lateral offset of only 3.5 m toward the northeast. This represents a wastewater-induced salinity anomaly of $-0.126‰$ compared to the mean ambient salinity of $33.600‰$, which was measured at that depth at locations well beyond the influence of the discharge. This maximal salinity anomaly indicates that the wastewater had been diluted 264-fold at that location. A larger area of low salinity was also delineated farther northeast, near the ZID boundary (red shading in Figure 8b), but the associated salinity anomalies at that location were not as pronounced and dilutions exceeded 300-fold.

The high-resolution salinity measurements collected during the deep-tow survey demonstrate that the modeled dilution factor (133:1) was significantly more conservative than that actually achieved by the discharge ($>264:1$) during the August 2009 survey. Moreover, the plume was not trapped at the depth assumed in the dilution model, and continued to mix as it rose through the water column, spreading toward the south-southwest with the prevailing current (Figure 9b). Beyond the ZID, at the 3-m depth level, wastewater had been diluted more than 340-fold (Figure 11).

These dilution computations demonstrate that, during the August 2009 survey, the outfall was performing better than designed and was rapidly diluting effluent more than 264-fold prior to completing the initial-dilution process. Consequently, during the August 2009 survey, the COP receiving-water objectives were being easily met within the ZID by the chemical concentration limits promulgated by the NPDES discharge permit issued to the MBCSD.

Plume Dynamics

Turbulent mixing during the ascent of the buoyant effluent plume is an important part of the initial dilution process. Shortly after ejection from the discharge ports, warm wastewater entrains ambient seawater near the seafloor, and the resulting plume acquires some of the characteristics of the surrounding seawater. Those deep seawater characteristics are carried upward into the water column with the rising plume. As the plume rises and mixes further, its buoyancy is reduced and, in the presence of a sharp

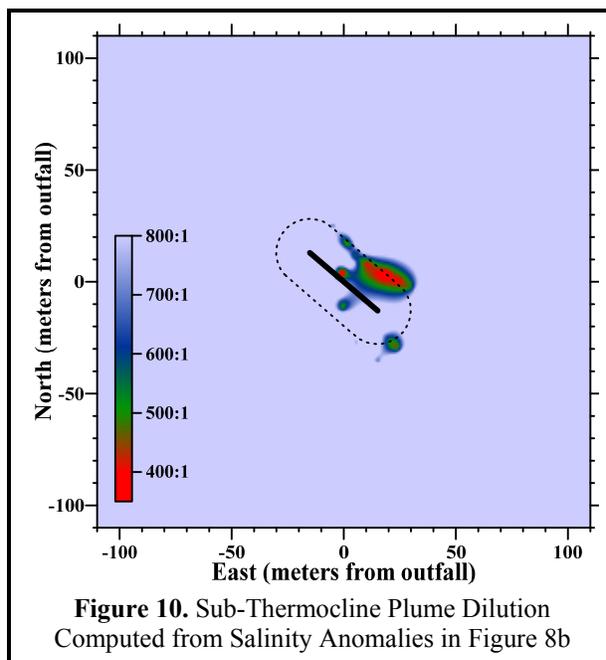


Figure 10. Sub-Thermocline Plume Dilution Computed from Salinity Anomalies in Figure 8b

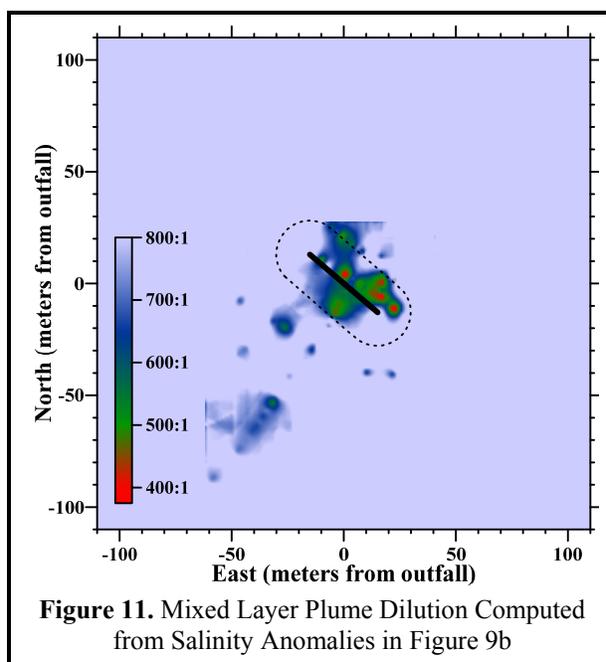


Figure 11. Mixed Layer Plume Dilution Computed from Salinity Anomalies in Figure 9b

thermocline, it can achieve buoyant equilibrium near the base of the thermocline, whereupon it spreads laterally. Trapping of the effluent plume at depth reduces the amount of initial dilution that would normally be achieved through additional mixing if the plume continued its ascent to the sea surface.

Although two thermoclines were present at the time of the August 2009 survey, they were neither deep enough nor strong enough to prevent the effluent plume's eventual rise to the sea surface. This is apparent from the striking contrast between the nearly uniform vertical profiles at RW3, and the complex vertical structure that is apparent in the upper water column at other stations (Figure 6). The vertical uniformity at RW3 was caused by turbulent mixing associated with the rising effluent plume, which carried deeper water properties upward into the water column and eroded the shallow thermocline. This is the case even though RW3 was located north of the diffuser structure, in a direction opposite the prevailing mid-depth flow tracked by the drifter (Figure 3). The presence of dilute wastewater northeast of the diffuser structure was also delineated near RW3 in the deep-tow data (Figure 8). The presence of the plume north of the diffuser is related to strong shoreward transport within the BNL at depth due to upwelling.

Accordingly, the shallow-tow data tend to reflect the expected southwestward offshore-directed flow within the surface mixed layer. Very slight anomalies in salinity, temperature, DO, pH, and, to some extent transmissivity, are apparent to the southwest of the diffuser structure (Figure 9bacfd). However, the seawater anomalies are exceedingly small, and for density and transmissivity, all but lost in the background noise (Figure 9cd). Even with the stronger plume signatures below the surface thermocline, the anomalies are only marginally apparent in water properties other than salinity, and impossible to discern in the density field at depth (Figure 8c).

Plume dynamics are an important consideration because the receiving-water limitations imposed by the discharge permit only apply to impacts that arise from the presence of wastewater constituents. Receiving-water modifications arising from the physics of the discharge, such as the entrainment of ambient seawater at depth, and its upward transport by the buoyant effluent plume are not subject to the permit limits. These vertical transport processes are responsible for the singular appearance of the profiles at RW4, RW5, and RW6 (Figure 6), and the widespread signature of the plume that extends to the south-southwest in the shallow-tow data (Figure 9adef). In both cases, the amplitudes of the discharge-related changes in temperature, transmissivity, DO, and pH were out-of-proportion to the contribution of wastewater constituents quantified by salinity anomalies (Figures 9b and 11).

Instead, they arose because the seawater characteristics within the BNL were markedly colder, more turbid and acidic, and less oxygenated than the characteristics throughout the rest of the water column. As the plume rose and mixed with receiving waters upon discharge, these BNL characteristics were carried upward where they juxtaposed with the characteristics of the middle and upper water column. In the absence of the contrast in conditions provided by the unique characteristics of the BNL, the discharge signature would not be apparent in the shallow-tow data. For example, the widespread negative thermal anomalies apparent in Figure 9a could not have been caused by the presence of wastewater constituents, which are warmer than ambient receiving waters. Thus, the discharge-related signatures, seen extending beyond the ZID during the shallow tow (Figure 9), were clearly the result of entrainment of deep bottom waters, and not the presence of wastewater constituents.

COMPLIANCE

The quarterly water-column sampling described in this report is designed to evaluate six receiving-water limitations specified in the NPDES discharge permit. The permit states that wastewater constituents within the discharge shall not cause:

1. *Floating particles or oil and grease to be visible on the ocean surface;*
2. *Aesthetically undesirable discoloration of the ocean surface;*
3. *Temperature of the receiving water to adversely affect beneficial uses;*
4. *Significant reduction in the transmittance of natural light at any point outside the initial dilution zone;*
5. *The DO 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, and*
6. *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.*

Sampling during the August 2009 survey demonstrated that the wastewater discharge complied with these six receiving-water limitations specified in the NPDES discharge permit, thereby meeting the water-quality objectives of the COP (SWRCB 2005) and the Central Coast Basin Plan (RWQCB 1994). Specifically, visual observations of the sea surface met the first two narrative limits, and instrumental measurements complied with the remaining quantitative limits on seawater properties.

Although discharge-related changes in all six seawater properties were observed during the August 2009 survey, the changes were either not of significant magnitude, were measured within the boundary of the ZID, or were not directly caused by the presence of wastewater constituents within the water column. Specifically, the measurements collected during the August 2009 survey demonstrated that the receiving-water limitations were met within the ZID. Beyond the ZID, the effluent was so highly diluted that only slight changes in seawater properties caused by the upward displacement of ambient seawater, rather than the presence of effluent itself, could be distinguished.

Visual Observations

There was no visual evidence of the discharge plume, or of any debris of potential wastewater origin observed at any time during the survey. There was neither an oil sheen nor discoloration apparent on the sea surface anywhere within the survey area. These observations indicate that the discharge complied with the first two receiving-water limits evaluated during the August 2009 survey.

Natural Variability

While the first two limitations described above rely on qualitative visual assessments made during the survey, the remaining four can be quantitatively evaluated through comparison of instrumental measurements with specific numerical limits, and with statistical thresholds defined by the natural range in conditions that occur in the survey area. In the latter case, significant departures from site-specific natural conditions could be indicative of adverse effects on water quality.

The COP (SWRCB 2005) defines a “significant” difference as “a statistically significant difference in the means of two distributions of sampling results at the 95 percent confidence level.” This definition was applied to five years of historical MBCSD survey data to define the range in natural conditions surrounding the outfall (Table 6). These thresholds of natural variation were then compared with the

Table 6. Numerical Thresholds of Natural Variability

Property	Minimum	Maximum	Mean	N	Std. Dev.
Salinity (‰)	— ¹	—	33.58	9251	0.038 ²
Temperature (°C)	—	14.1 ³	12.09	9364	1.21
Transmissivity (%)	57.0 ⁴	—	72.7	9348	9.5
DO (mg/L)	4.42 ⁵	—	7.31	9311	1.46
pH	7.11 ⁶	8.62 ⁶	7.86	9364	0.28

¹ No limits are imposed on salinity, but an ANOVA was performed to establish the amplitude (–0.062‰) of wastewater-induced salinity reductions that can be reliably discerned within a given survey.

² For salinity only, the standard deviation was computed from the variation in salinity measurements within a given survey.

³ The one-sided upper 95% confidence bound used to identify a significant increase in a single temperature measurement

⁴ The one-sided lower 95% confidence bound used to identify a significant decrease in a single transmissivity measurement

⁵ The one-sided lower 95% confidence bound (4.91 mg/L) used to identify a significant decrease in a single DO measurement was adjusted downward by 10% in accordance with the COP limit that states “*depressed more than 10% from that which occurs naturally.*”

⁶ The two-sided 95% confidence bound (7.31 and 8.42) used to identify a significant difference in a single pH measurement was expanded by 0.2 pH units in accordance with the COP limit that states “*changed more than 0.2 units from that which occurs naturally.*”

wastewater-induced anomalies observed during the August 2009 survey to evaluate compliance with the receiving-water objectives.

The thresholds of natural variation were determined from an analysis of variance (ANOVA) in ambient water-quality data collected during 20 quarterly surveys conducted between 2004 and 2008. Water-quality observations that were potentially affected by the presence of wastewater constituents were excluded from the ANOVA. The more-than 9,200 observations that remained for each seawater property document the natural range in seasonal and interannual variation, as well as vertical and lateral variability within individual surveys.

As stated previously, the permit limits only apply to changes induced by the presence of wastewater constituents. Water quality monitoring surrounding the MBCSD outfall over the last decade-and-a-half has demonstrated that salinity reductions provide the best, and often only indicator of the presence of dilute wastewater constituents. This is due to the greater contrast between seawater and effluent salinity as compared to other water properties, such as temperature, transmissivity, DO, and pH.

Although effluent is usually warmer, more turbid (lower transmissivity), and more acidic (lower pH) than the receiving seawater, these differences become imperceptible after only minimal dilution. In contrast, the salinity ANOVA found that a wastewater-induced salinity reduction of only 0.062‰ can be reliably discerned against the backdrop of natural variability within a given survey. This corresponds to a dilution of 542-fold.

For compliance purposes, a slightly more conservative dilution threshold of 550-fold is used to restrict attention to data potentially impacted by wastewater constituents. Thus, water-quality measurements collected outside the red-, and green-shaded areas shown in Figures 10 and 11, are not likely to have been influenced by the presence of wastewater constituents. This includes the discharge-related changes in many water properties that extend far to the southwest in the shallow tow data (Figure 9adef). As discussed previously, those changes resulted from the physical movement of ambient seawater entrained within the effluent plume, and not from the presence of wastewater constituents.

Within the region of wastewater influence, ANOVAs establish statistical thresholds on seawater properties that quantify their naturally occurring ranges surrounding the MBCSD outfall (Table 6). These thresholds augment fixed limits for DO (5 mg/L) and pH (7.0 and 8.3) that are specified in the permit. Based on the ANOVAs, the threshold on site-specific reductions in pH (7.11) are slightly more restrictive than the fixed permit limit (7.0).

The ANOVAs also that ambient seawater temperatures exceeding 14.1°C are rare, occurring in less than one-in-twenty observations, as defined by the 95% confidence interval. If temperatures this high were caused by the presence of warm wastewater, then the discharge could reasonably be assumed to have the potential to “*adversely affect beneficial uses.*” However, ambient seawater temperature fluctuates seasonally, and during a given survey, sea-surface temperatures can uniformly exceed the 14.1°C threshold. Thus, the temperature threshold should only be used as an indicator of adverse discharge affects when ambient temperatures, measured well beyond the influence of the discharge, are well below 14.1°C.

The same caveat applies to the minimum transmissivity threshold of 57%. The ANOVA identified lower ambient transmissivity as unusual, because it occurs less than five percent of the time. If such poor water quality occurs within the euphotic zone, then a “*significant reduction in the transmittance of natural light*” may have occurred. However, the presence of a turbid BNL can dramatically reduce ambient transmissivity during a given survey. When the naturally turbid seawater within the BNL mixes with effluent near the seafloor, and is carried upward by the buoyant plume, it can be mistaken for the signature of wastewater particulates. As with temperature anomalies, the transmissivity threshold should only be used as an indicator of adverse discharge affects when ambient transmissivity measurements measured within the BNL, are well below 57%.

Thus, while the ANOVA-generated thresholds in Table 6 provide a useful screening tool for evaluating whether observed changes within the effluent plume require further investigation, they do not constitute regulatory limits beyond which the discharge can be deemed out of compliance.

Temperature

The highest seawater temperature recorded at any time during the August 2009 survey was 13.4 °C. It was measured 1.0 m below the sea surface at RW1 (Table 5). That station was located well north and up-current of the diffuser structure, where it was far beyond the effluent plume’s sphere of influence. It and all the other temperature measurements were well below the 14.1°C threshold (Table 6), above which temperatures would be high enough “*to adversely affect beneficial uses*” based on normal historical temperatures in the survey area. Thus, the temperature measurements recorded during the August 2009 survey complied with the third receiving-water limit.

Light Transmittance

As with the temperature field, the lowest transmissivity (75.0423%) recorded at any time during the August 2009 survey was well above the minimum transmissivity of 57.0% (Table 6) that has the potential to significantly reduce the penetration of natural light relative to historical levels. Thus, the transmissivity measurements recorded during the August 2009 survey complied with the fourth receiving-water limit because they did not constitute a “*significant reduction in the transmittance of natural light.*”

Dissolved Oxygen

The lowest DO concentration recorded at any time during the August 2009 survey was 6.849 mg/L. It was measured 1.0 m above the seafloor at RW6 (Table 5). This reduced DO concentration at depth was consistent with DO concentrations recorded just above the seafloor at other stations, and reflects the

presence of a naturally occurring BNL and the depletion that results from biotic respiration and decomposition in deep offshore watermasses.

Although unstated in the NPDES discharge permit, the COP specifies that the DO limitation only applies to reductions that occur “*as a result of the discharge of oxygen demanding waste materials.*” Measurement of effluent samples routinely collected prior to discharge demonstrate that the treatment process effectively removes most oxygen-demanding material from the wastestream. As a result, reductions in DO caused by the presence of effluent constituents have never been observed within the MBCSD receiving waters. This was also the case during the August 2009 survey when all receiving-water DO measurements were well above both the numerical limit of 5 mg/L, and the 4.42-mg/L threshold that represents a DO depression of “*more than 10 percent from that which occurs naturally*” (Table 6). Thus, the DO measurements recorded during the August 2009 survey complied with the fifth receiving-water limit.

pH

All of the pH measurements recorded during the August 2009 survey fell within a narrow range between 8.009 and 8.176. The measured range was well within the minimum (7.0) and maximum (8.3) pH limits specified in the discharge permit, as well as the limits of natural pH variability in the survey area identified by the minimum (7.11) and maximum (8.62) thresholds in Table 6. Thus, the pH measurements recorded during the August 2009 survey complied with the sixth and last receiving-water limit.

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