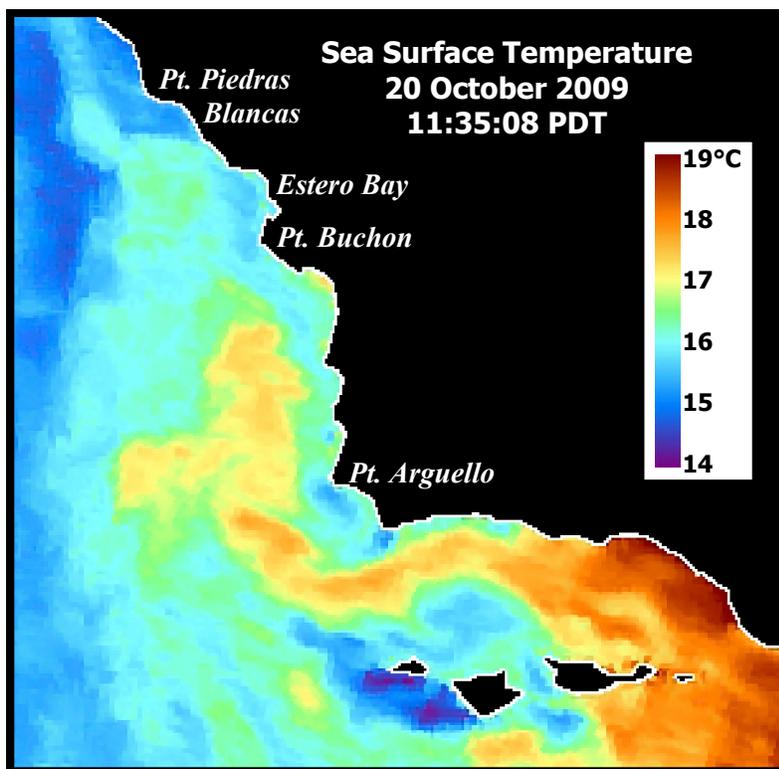


**City of Morro Bay and
Cayucos Sanitary District**

**OFFSHORE MONITORING
AND REPORTING PROGRAM**

**FOURTH QUARTER
RECEIVING-WATER SURVEY
OCTOBER 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**

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OCTOBER 2009

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January 2010

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

25 January 2010

Reference: Fourth Quarter Receiving-Water Survey Report – October 2009

Dear Mr. Keogh:

The attached report presents results from a quarterly receiving-water survey conducted on Tuesday, 20 October 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 autumn 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. In March 1985, Region IX of the U.S. Environmental Protection Agency (USEPA) and the Central Coast California Regional Water Quality Control Board (RWQCB) first issued a National Pollutant Discharge Elimination System (NPDES) permit to the MBCSD partially modifying secondary treatment requirements for the plant's ocean discharge. 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 October 2009 field survey described in this report was the third receiving-water survey conducted under the current permit.

Under the NPDES discharge permit, seasonal monitoring of offshore receiving-water quality is conducted during quarterly surveys. This report summarizes the results of sampling conducted on 20 October 2009. Specifically, this fourth-quarter survey captured ambient oceanographic conditions along the central California coast during the fall 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 discharge permit.

The receiving-water surveys also provide timely assessments of the diffuser structure's performance in dispersing wastewater within 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 prior surveys and original design specifications. As described in this report, no such decline was observed during the October 2009 offshore survey.

These 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-resolution data created by towing the CTD¹ instrument package repeatedly over the diffuser structure. The tow survey is a component of the monitoring program that was added in 2009 to assist in the precise delineation of the lateral extent of the effluent plume, which tends to be highly localized around the discharge point. 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 wide zone of initial dilution surrounding the outfall. As described in this report, the data collected during the October 2009 survey delineated the presence of dilute effluent undergoing turbulent mixing within the water column immediately south 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.

¹ The instrument package is capable of *in situ* measurements of conductivity, temperature, and depth (CTD), as well as dissolved oxygen, transmissivity, and pH.

² A navigational survey on 6 July 2005 benchmarked the locations of the surfzone sampling stations along the adjacent shoreline. The beginning of the section of the diffuser structure containing open diffuser ports lies 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

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 limits 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.

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, in the event that a failure in the treatment plant's disinfection system occurs, collection and analysis of water samples at the surfzone sampling stations shown in Figure 1 would be conducted to monitor for potential shoreline impingement. These surfzone samples would be analyzed for total and fecal coliform, and enterococcus bacterial densities.

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 help determine 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).

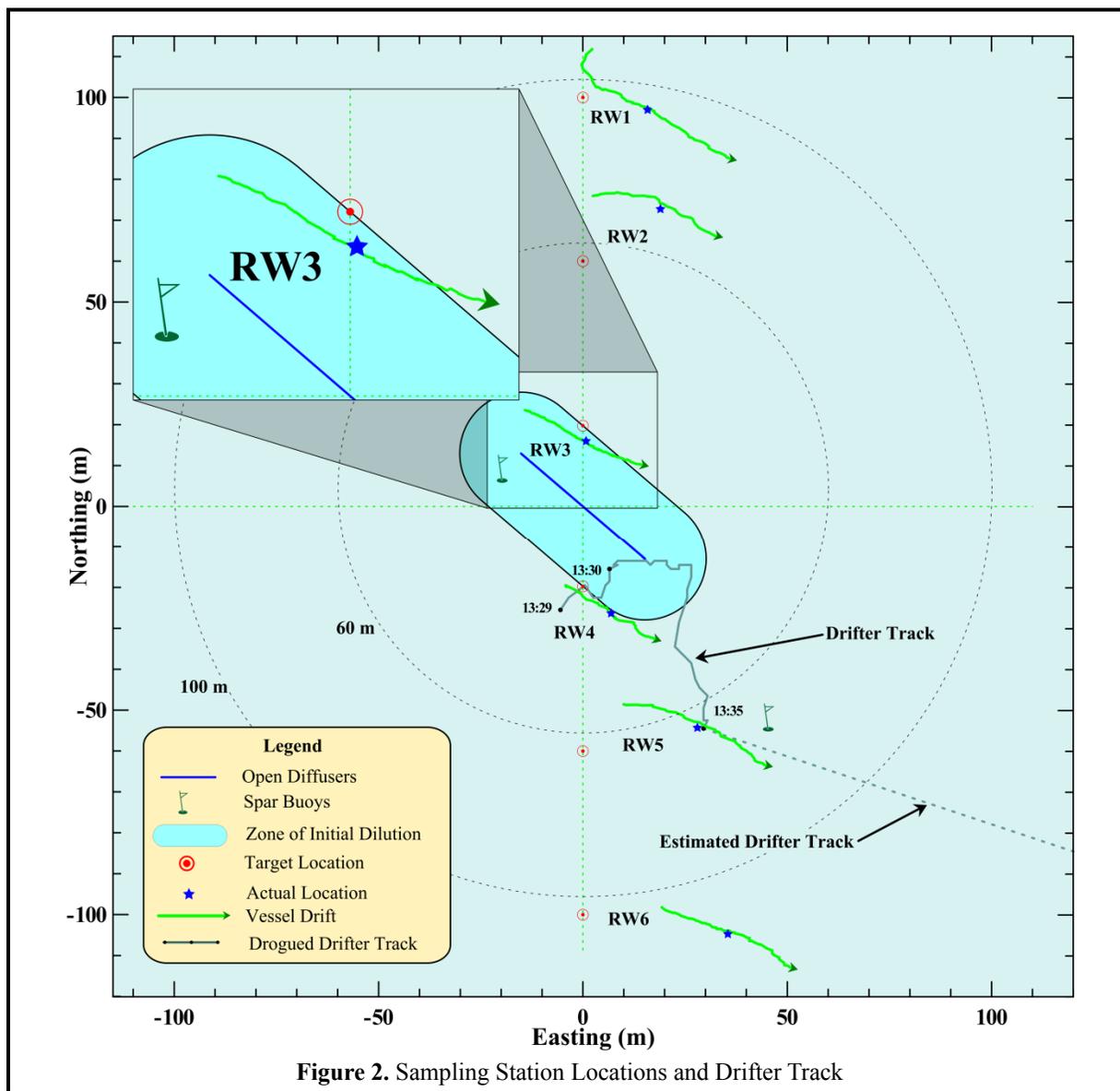


Table 1. Target Locations of the Offshore Receiving-Water Monitoring Stations

Station	Description	Latitude	Longitude	Center Distance ³ (m)	Closest Approach Distance ⁴ (m)
RW1	Upcoast Midfield	35° 23.253' N	120° 52.504' W	100	88.4
RW2	Upcoast Nearfield	35° 23.231' N	120° 52.504' W	60	49.4
RW3	Upcoast ZID	35° 23.210' N	120° 52.504' W	20	15.0
RW4	Downcoast ZID	35° 23.188' N	120° 52.504' W	20	15.0
RW5	Downcoast Nearfield	35° 23.167' N	120° 52.504' W	60	49.4
RW6	Downcoast Midfield	35° 23.145' N	120° 52.504' W	100	88.4

³ Distance to the center of the open diffuser section

⁴ Distance to the closest open diffuser port

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 1998) 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.

Frequent recording of DGPS positions allows precise determination of sampling locations throughout the vertical CTD profiling at individual stations, as well as during the tow survey. Knowledge of the precise location of individual CTD measurements relative to the diffuser is critical for accurate interpretation of the water-property fields. During vertical-profile sampling, the actual measurement locations rarely coincide with the target coordinates listed in Table 1 because winds, waves, and currents induce unavoidable horizontal offsets (drift). Even during quiescent metocean⁵ conditions, the residual momentum of the survey vessel as it approaches the target locations can create perceptible offsets. Using DGPS however, these offsets can be resolved and the vessel location can be precisely tracked throughout sampling at each station.

The magnitude of the drift at each of the six stations during the October 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 October 2009 survey. During the time it took the CTD to traverse the water column to the seafloor, which averaged 1 min 16 s, the instrument package moved as much as 43.7 m laterally (at RW1). The average drift for all the stations was 34.6 m, which was about five-times greater than that of most prior surveys.

The CTD trajectories shown by the tracklines in Figure 2 reflect the complex interactions between surface currents, wind forces, and residual momentum as the survey vessel approached each station. Generally, winds affect the vessel's ability to maintain station positioning to a greater degree than current flow. The substantial drift documented during the October 2009 survey was primarily caused by the strong northwest winds, averaging more than 11 knots⁶, that prevailed at the time of the survey. Although receiving-water surveys are generally conducted when metocean conditions are forecast to be at their calmest, sometimes this is not possible. Wind speeds during the October 2009 survey were elevated because the survey was conducted within the relatively short weather window that became available between the passage of several early autumnal storm fronts. Additionally, the survey took place in the afternoon, when wind speeds tend to be higher along the central coast. This was done in order to facilitate the safe completion of the benthic sediment sampling required by the NPDES permit, which took place during the morning hours of 20 October 2009.

⁵ Meteorological and oceanographic conditions include winds, waves, tides, and currents.

⁶ Refer to Table 3 for metocean conditions that were recorded during the survey.

The inevitable lateral movement of the CTD during the vertical hydrocasts complicates the assessment of compliance with discharge limitations at stations close to the diffuser structure because certain receiving-water limitations only apply to measurements recorded beyond the ZID boundary. For example, the mean location of Station RW3 was only 12.7 m from the diffuser and well within the 15-m-wide ZID, as shown by the blue star in the inset of Figure 2. Based on this average station location, one could incorrectly assume that receiving-water criteria, which are applicable only beyond the ZID, do not pertain to any of the data from RW3. However, closer inspection of the actual CTD trajectory during the downcast at RW3, as shown by the green arrow, indicates that the CTD traversed the ZID boundary en route to the seafloor, and that measurements recorded by the CTD at depth were subject to permit limitations.

Identifying which measurements were subject to permit limits within hydrocasts near the ZID boundary only became possible 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 October 2009 survey also identifies a single sampling location for each station. These average station positions are shown by blue stars in Figure 2, and are listed in Table 2 with their distances from the diffuser structure.

Table 2. Average Position of Vertical Profiles during the October 2009 Survey

Station	Time (PDT)		Latitude	Longitude	Closest Approach	
	Downcast	Upcast			Range ¹ (m)	Bearing ² (°T)
RW1	13:45:21	13:46:56	35° 23.251' N	120° 52.494' W	89.6	20
RW2	13:52:14	13:53:18	35° 23.238' N	120° 52.491' W	68.9	30
RW3	13:57:59	13:59:07	35° 23.208' N	120° 52.504' W	12.7 ³	41
RW4	14:01:50	14:02:55	35° 23.185' N	120° 52.499' W	15.6	212
RW5	14:06:12	14:07:37	35° 23.170' N	120° 52.486' W	43.2	163
RW6	14:11:09	14:12:26	35° 23.142' N	120° 52.481' W	93.9	168

¹ Distance from the closest open diffuser port to the average profile location

² Angle measured clockwise relative to true north from the closest diffuser port to the average profile location

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

Compliance assessments notwithstanding, measurements recorded within the ZID and close to the diffuser structure, where initial mixing is ongoing, lend valuable insight into the outfall's effectiveness at dispersing wastewater. For example, low dilution rates and concentrated effluent throughout the ZID would indicate the presence of potentially damaged or broken diffuser ports. Analysis of the outfall's operation over the past two decades, however, suggests that it has maintained a high level of effectiveness in effluent dispersal. In fact, without the occasional measurements recorded within the ZID due to CTD drift, the extremely dilute discharge plume might remain undetected within all vertical profiles collected during a given survey. However, the addition of the tow survey component in the current permit provides nearfield measurements capable of delineating the plume close to the diffuser structure.

OCEANOGRAPHIC PROCESSES

The trajectory of a satellite-tracked drogued drifter documented a weak southeastward flow during the October 2009 survey (Figure 2). 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's movement at the time of the survey. The gray line with black dots in Figure 2 shows the drifter's trajectory during the first eleven minutes following its deployment. At that time, seawater inundated the drifter's navigation electronics and it ceased recording the drifter's position. However, the survey vessel's DGPS precisely measured the drifter-recovery location, allowing the net drifter velocity to be determined during its deployment.

The dashed gray line on Figure 2 estimates the path of the drifter after the instrumentation failure, based on the drifter's recovery location. The drogued drifter was deployed near Station RW4 at 13:29 PDT whereupon it traveled northeastward for one minute, probably under the influence of the vessel's propeller wash. The drifter was retrieved 48 minutes later, at 14:17 PDT. The difference in deployment and recovery locations shows that a weak current carried the drifter slowly shoreward, toward the east-southeast (115°T). While deployed, the drifter traversed a total of 191 m at an average speed of 6.7 cm/s or 0.13 knots.

The shoreward flow component revealed by the drifter track was inconsistent with the outgoing (ebb) tidal flow that prevailed during the October 2009 survey (Figure 3). In the absence of other influences, an ebb tide normally induces a weak southwestward offshore flow in the survey region. However, flow is more often dominated by external processes, such as wind-generated upwelling or passing offshore eddies.

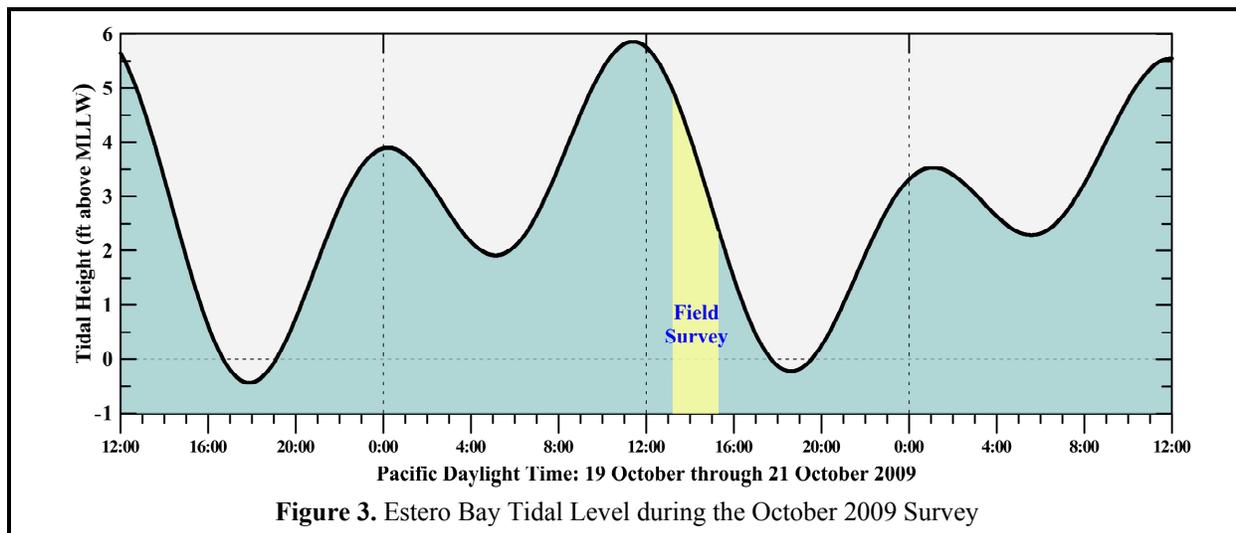
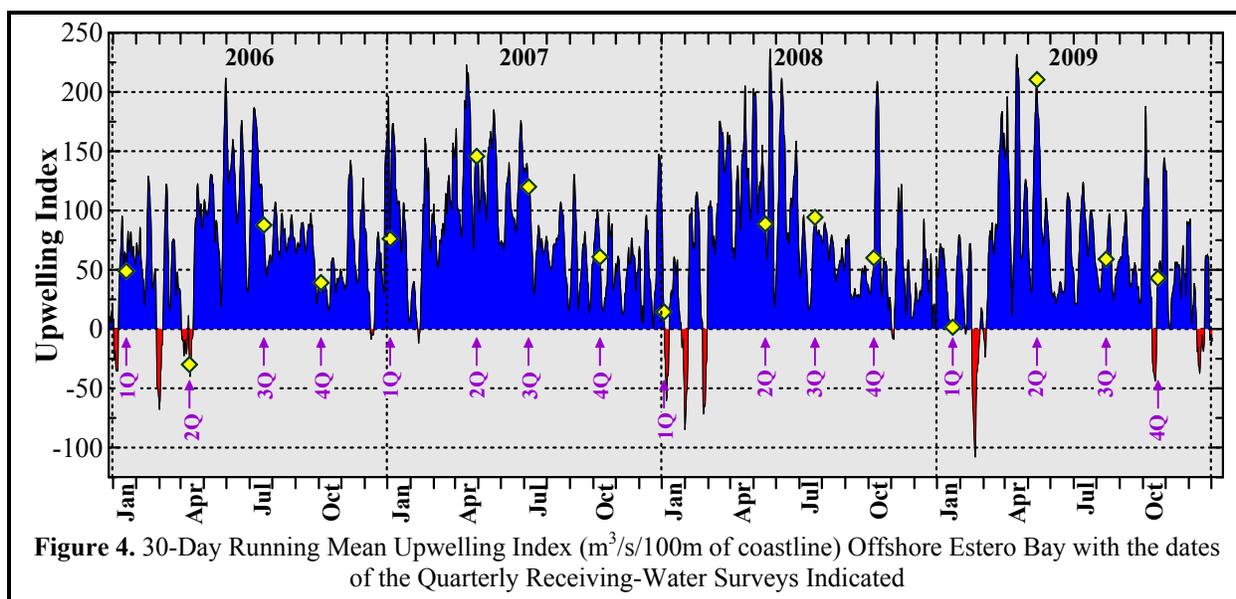


Figure 3. Estero Bay Tidal Level during the October 2009 Survey

The moderate downwelling conditions that preceded the survey were probably mostly responsible for the observed shoreward flow measured by the drifter. In contrast to the moderate upwelling conditions normally present during the fall receiving-water surveys, Figure 4 shows that a significant downwelling event occurred immediately prior to the October 2009 survey. It was associated with an unusual, early season rainstorm that dropped 9.25 inches of rain in the portion of the Santa Lucia Mountains east of Morro Bay. The associated 976-mb atmospheric low represented one of the most intense weather systems seen during the month of October (Lindsey 2009).



Upwelling conditions normally begin 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. The cross-shore flow results in a strongly stratified water column along the coast. During most years, upwelling conditions continue to prevail through the summer and fall, as shown by the positive (blue) upwelling indices in Figure 4. Downwelling events, indicated by the negative (red) indices occur infrequently, and almost exclusively in winter, when passing storms temporarily reverse the normal wind pattern and drive surface waters shoreward. As the surface waters approach the coastline, they downwell, producing nearly uniform seawater properties throughout a water column with very little stratification.

Reversal of the normal wind pattern just prior to the October 2009 survey resulted in an increase in the strength of the northward-flowing Davidson countercurrent that carries surface waters northward from the Southern California Bight. These warmer, more saline, and less oxygenated waters can be seen extending out of the Santa Barbara Channel and northward along the central coast in the satellite image on the cover of this report. The cover image was recorded on the morning of the October 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 warm (16°C) sea surface temperatures depicted in the satellite image within Estero Bay were consistent with the surface-water temperatures recorded by the CTD during the survey.⁷

METHODS

The 38 ft F/V *Bonnie Marietta*, owned and operated by Captain Mark Tognazzini of Morro Bay, served as the survey vessel on Tuesday 20 October 2009. In contrast to most other receiving-water surveys, the water-quality data were collected in the afternoon because the morning of 20 October was spent collecting benthic sediment samples as part of the discharge permit's annual benthic monitoring requirement. The results of the benthic sediment survey will be presented in the 2009 annual monitoring report. During both surveys, Ms. Bonnie Luke of Marine Research Specialists (MRS) was the Chief Scientist and collected auxiliary measurements of biological, meteorological, and oceanographic conditions. Dr. Douglas Coats, also of MRS, provided navigational support during the survey. Captain Mark Tognazzini supervised vessel operations, and William Skok served as marine technician.

Auxiliary Measurements

Auxiliary measurements and observations were collected contemporaneously with the vertical water-column profiling conducted at each of the six stations (Table 3). 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 potentially 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. As discussed previously, the October 2009 survey was unusual in that average wind speeds were higher than in most other recent receiving-water surveys.

Table 3. Standard Meteorological and Oceanographic Observations

Station	Location ⁸		Diffuser Distance (m)	Time (PDT)	Air (°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° 23.236' N	120° 52.469' W	87.5	13:47:36	16.0	0	12.2	17.3	NW	3-4/NW	7.5
RW2	35° 23.211' N	120° 52.465' W	57.0	13:56:29	15.8	0	13.3	19.7	NW	3-4/NW	7.0
RW3	35° 23.204' N	120° 52.504' W	7.1	13:58:29	15.7	0	13.8	17.7	NW	3-4/NW	6.0
RW4	35° 23.180' N	120° 52.501' W	23.5	14:02:27	15.9	0	12.4	17.5	NW	3-4/NW	5.5
RW5	35° 23.166' N	120° 52.487' W	48.8	14:06:56	15.9	0	11.5	17.1	NW	3-4/NW	7.0
RW6	35° 23.139' N	120° 52.485' W	98.2	14:11:42	15.9	0	13.5	16.7	NW	3-4/NW	7.0

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.

⁷ Refer to Table 5 and Figure 6 for receiving-water properties recorded during the vertical hydrocasts.

⁸ Locations are the vessel positions recorded at the time the Secchi depth was measured.

Secchi depths recorded during the October 2009 survey ranged between 7.0 and 7.5 m at the four stations unaffected by the discharge (Table 3). This reflected the presence of a euphotic zone that spanned most of the 16-m of the water column. This level of increased water clarity is typical of downwelling conditions when phytoplankton growth within the surface mixed layer is limited by the lack of nutrients. Although the measured Secchi depths suggest that the euphotic zone approached the seafloor at most stations, the presence of a thin, turbid benthic nepheloid layer (BNL) immediately above the seafloor prevented natural light from penetrating the entire water column.⁹ Because of its depth, 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 October 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. Although the drifter was fitted with a GPS receiver to record the drifter position continuously, the watertight seal on the GPS failed eleven minutes into its deployment during the October 2009 survey, and subsequent navigational measurements were lost.

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 October 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 June 2006 for testing and calibration. Because of increasing temporal drift associated with aging DO probes, the DO probe was replaced on both occasions. As is the case before all surveys, the CTD system was calibrated at the MRS laboratory prior to the October 2009 survey. The upper-bound DO calibration point at full saturation was established by immersing the CTD in an aerated, temperature-controlled calibration tank. Similarly, 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.

⁹ The increased BNL turbidity is apparent in the vertical profiles of transmissivity, shown by the light blue profiles in Figure 6.

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 beyond the maximum depth of the deepest station in the outfall survey. The precision and accuracy of the various probes, as reported

Table 4. CTD Specifications

Component	Depth¹⁰	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

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, a slight temporal trend in pH measurements arose from the sensor's ongoing equilibration during the survey. The trend was removed by fitting a fourth-degree orthogonal polynomial to the pH time series. The largest adjustment was 0.06 pH units. There was no perceptible drift in the DO sensor during the October 2009 survey, although corrections for slight temporal drift in that sensor have occasionally been necessary in the past.

¹⁰ Maximum depth limit in meters

Before initial deployment for the vertical hydrocasts, the CTD was held below the sea surface for an eight-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 data were downloaded to a portable computer and examined for completeness and range acceptability.

Tow Survey

Following the vertical hydrocasts 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 2:14 PDT, following the last vertical profile at RW6, the CTD instrument package was fitted with a depth-suppressor and horizontal stabilizer to achieve constant-depth tows with forward-looking sensor probes. Sixteen meters of towline were deployed and the reconfigured CTD package was towed at an average depth of 4.32 m, and an average speed of 1.44 m/s for 17 min, passing near the diffuser structure five times (Figure 5). Subsequently, an additional 7 m of towline was paid-out, and five additional passes were made at an average depth of 7.41 m.

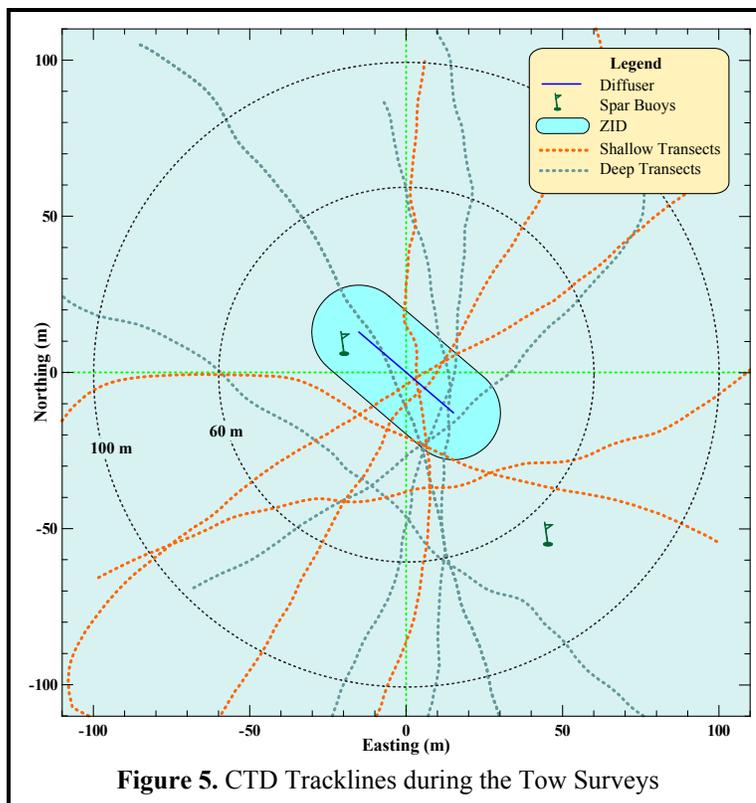


Figure 5. CTD Tracklines during the Tow Surveys

During the 20-minute deep-tow survey, vessel speed averaged 1.4 m/s. At the observed towing speeds and a 2 Hz sampling rate, 1.43 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 within the mid-depth and upper portions of the water column.¹¹

¹¹ Figures 7 and 8 present the horizontal maps of seawater properties measured during the October survey.

RESULTS

The fourth-quarter receiving-water survey began at 13:04 PDT on the afternoon of Tuesday, 20 October 2009, following the completion of the benthic monitoring survey. The receiving-water survey began 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 15:18 PDT with the recovery of the CTD from its deep-tow configuration. Skies were clear throughout the survey and observations of beneficial use and the collection of required visual observations of the sea surface were unencumbered. Although discharge-induced increases in turbidity were evident within limited areas of the upper water column, 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 strong throughout the survey, ranging from 11.5 to 13.8 kt (Table 3). Corresponding, peak wind speeds ranged from 16.7 to 19.7 kt. There was a swell out of the northwest with a significant wave height of 3 to 4 feet, and period of 8 to 11 seconds. A second, 2 to 3 foot long-period southerly swell was mostly buffered by the presence of Morro Rock. Air temperatures varied little during the survey, ranging from 15.7°C to 16.0°C and were comparable to, or slightly warmer than average surface-water temperatures at Stations unaffected by the discharge (15.74°C, Table 5).

During the October 2009 survey, observations demonstrated continued beneficial use of the coastal waters within Estero Bay by both wildlife and recreational users. Given the gusty wind and swell conditions that predominated during the survey, however, few pedestrians were observed using the beach, and no other vessels were observed on the water. Wildlife sightings during the October 2009 survey were similarly scarce. Observed avian fauna included small numbers of California brown pelicans (*Pelecanus occidentalis californicus*), Brandt's cormorants (*Phalacrocorax penicillatus*), pelagic cormorants (*Phalacrocorax pelagicus*), and western gulls (*Larus occidentalis*). Most wildlife was observed within the protected confines of the harbor mouth and immediately around Morro Rock.

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 October 2009 survey reflect weakly stratified conditions that are indicative of prevailing downwelling conditions. Downwelling events are rare and brief compared to upwelling conditions that prevail most of the time along the central California coast. 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. In contrast, downwelling does not generate significant vertical variations in cross-shore flow, and thus does not result in strongly stratified waters resistant to vertical motion. During weakly stratified downwelling conditions, the discharge plume often rises all the way to the sea surface rather than becoming trapped at depth. Such was the case during the October 2009 survey.

Table 5. Vertical Profile Data Collected on 20 October 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
1.0	15.739			15.159	15.719		33.396			33.319	33.395	
1.5	15.751	15.755	15.756	15.428	15.748		33.398	33.395	33.386	33.329	33.391	
2.0	15.739	15.755	15.743	15.487	15.735	15.717	33.402	33.395	33.394	33.329	33.386	33.392
2.5	15.725	15.753	15.727	15.510	15.729	15.727	33.400	33.395	33.389	33.338	33.387	33.395
3.0	15.733	15.754	15.728	15.504	15.727	15.738	33.400	33.395	33.392	33.324	33.383	33.393
3.5	15.722	15.755	15.702	15.484	15.713	15.740	33.393	33.395	33.373	33.322	33.386	33.391
4.0	15.709	15.742	15.676	15.460	15.719	15.738	33.396	33.388	33.374	33.320	33.384	33.391
4.5	15.657	15.713	15.570	15.459	15.725	15.732	33.391	33.378	33.359	33.314	33.389	33.391
5.0	15.607	15.642	15.530	15.469	15.716	15.727	33.389	33.378	33.353	33.323	33.381	33.393
5.5	15.566	15.636	15.538	15.585	15.650	15.722	33.398	33.366	33.357	33.350	33.383	33.392
6.0	15.549	15.614	15.540	15.623	15.565	15.697	33.403	33.391	33.354	33.368	33.387	33.385
6.5	15.545	15.527	15.513	15.606	15.503	15.615	33.403	33.385	33.356	33.370	33.397	33.392
7.0	15.522	15.492	15.522	15.551	15.480	15.593	33.392	33.374	33.340	33.382	33.395	33.395
7.5	15.507	15.472	15.527	15.523	15.480	15.584	33.394	33.373	33.344	33.390	33.395	33.394
8.0	15.500	15.455	15.499	15.507	15.482	15.515	33.398	33.374	33.354	33.392	33.393	33.399
8.5	15.471	15.447	15.526	15.490	15.473	15.502	33.391	33.375	33.355	33.396	33.394	33.393
9.0	15.456	15.438	15.539	15.481	15.466	15.542	33.388	33.371	33.355	33.396	33.396	33.386
9.5	15.449	15.431	15.533	15.466	15.460	15.518	33.390	33.372	33.350	33.399	33.394	33.392
10.0	15.453	15.429	15.517	15.431	15.451	15.464	33.388	33.376	33.352	33.398	33.395	33.396
10.5	15.446	15.439	15.498	15.423	15.450	15.444	33.391	33.389	33.354	33.398	33.396	33.398
11.0	15.440	15.442	15.448	15.415	15.448	15.439	33.395	33.394	33.378	33.398	33.397	33.397
11.5	15.436	15.441	15.441	15.413	15.434	15.435	33.399	33.395	33.386	33.397	33.396	33.398
12.0	15.430	15.441	15.441	15.415	15.429	15.433	33.399	33.397	33.397	33.397	33.397	33.397
12.5	15.419	15.443	15.437	15.416	15.430	15.435	33.397	33.397	33.398	33.396	33.397	33.396
13.0	15.413	15.443	15.432	15.416	15.430	15.434	33.399	33.397	33.398	33.396	33.395	33.396
13.5	15.400	15.426	15.426	15.416	15.427	15.432	33.399	33.394	33.399	33.397	33.396	33.395
14.0	15.276	15.413	15.413	15.399	15.422	15.426	33.414	33.391	33.397	33.400	33.397	33.396
14.5	15.194	15.388	15.410	15.328	15.382	15.407	33.388	33.393	33.397	33.402	33.386	33.397
15.0	15.050	15.200	15.362	15.217	15.262	15.313	33.410	33.379	33.406	33.406	33.390	33.389
15.5	14.797	14.933	15.172	15.086	15.206	15.202	33.450	33.450	33.405	33.394	33.404	33.421
16.0			15.154						33.395			

Table 5. Vertical Profile Data Collected on 20 October 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
1.0	24.572			24.591	24.576		8.286			8.275	8.289	
1.5	24.572	24.568	24.561	24.591	24.567		8.286	8.279	8.297	8.277	8.291	
2.0	24.577	24.569	24.570	24.577	24.566	24.575	8.286	8.279	8.298	8.277	8.290	8.275
2.5	24.579	24.569	24.570	24.579	24.568	24.574	8.286	8.279	8.295	8.283	8.291	8.277
3.0	24.577	24.569	24.572	24.569	24.566	24.571	8.286	8.280	8.295	8.283	8.289	8.276
3.5	24.574	24.568	24.564	24.573	24.571	24.569	8.287	8.280	8.296	8.283	8.288	8.276
4.0	24.579	24.566	24.570	24.576	24.568	24.569	8.285	8.280	8.296	8.283	8.289	8.276
4.5	24.587	24.565	24.582	24.572	24.570	24.571	8.285	8.280	8.294	8.283	8.288	8.276
5.0	24.596	24.581	24.587	24.577	24.566	24.573	8.285	8.279	8.289	8.283	8.288	8.276
5.5	24.613	24.573	24.587	24.572	24.583	24.573	8.287	8.279	8.285	8.283	8.288	8.276
6.0	24.621	24.597	24.585	24.577	24.605	24.573	8.286	8.279	8.286	8.286	8.287	8.276
6.5	24.621	24.611	24.593	24.582	24.626	24.597	8.286	8.279	8.285	8.287	8.285	8.277
7.0	24.618	24.611	24.578	24.604	24.630	24.604	8.285	8.274	8.284	8.291	8.284	8.272
7.5	24.623	24.615	24.580	24.617	24.630	24.606	8.286	8.274	8.285	8.291	8.284	8.272
8.0	24.628	24.619	24.594	24.621	24.628	24.625	8.289	8.271	8.285	8.294	8.282	8.272
8.5	24.629	24.622	24.589	24.628	24.630	24.623	8.285	8.270	8.284	8.292	8.282	8.272
9.0	24.630	24.620	24.586	24.630	24.633	24.609	8.279	8.270	8.285	8.293	8.282	8.271
9.5	24.632	24.623	24.584	24.636	24.633	24.619	8.279	8.270	8.286	8.294	8.279	8.271
10.0	24.630	24.626	24.588	24.643	24.636	24.634	8.279	8.270	8.286	8.296	8.279	8.272
10.5	24.634	24.634	24.594	24.645	24.637	24.640	8.279	8.271	8.286	8.292	8.280	8.273
11.0	24.639	24.637	24.624	24.646	24.638	24.641	8.278	8.273	8.286	8.294	8.279	8.275
11.5	24.642	24.638	24.631	24.646	24.640	24.642	8.278	8.273	8.285	8.292	8.278	8.276
12.0	24.644	24.640	24.640	24.645	24.642	24.642	8.279	8.277	8.290	8.292	8.274	8.276
12.5	24.645	24.639	24.642	24.645	24.642	24.641	8.279	8.277	8.293	8.292	8.274	8.276
13.0	24.647	24.639	24.643	24.644	24.641	24.640	8.274	8.278	8.294	8.292	8.274	8.276
13.5	24.651	24.640	24.645	24.645	24.642	24.640	8.273	8.274	8.294	8.292	8.269	8.276
14.0	24.689	24.641	24.646	24.651	24.644	24.642	8.272	8.273	8.294	8.291	8.269	8.276
14.5	24.687	24.648	24.646	24.668	24.645	24.647	8.256	8.269	8.291	8.290	8.261	8.277
15.0	24.736	24.679	24.665	24.696	24.674	24.662	8.242	8.259	8.290	8.284	8.254	8.273
15.5	24.736	24.679	24.705	24.716	24.697	24.711	8.242	8.255	8.286	8.268	8.238	8.264
16.0			24.701						8.261			

Table 5. Vertical Profile Data Collected on 20 October 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
1.0	8.038			7.933	8.125		77.157			70.122	78.395	
1.5	8.061	8.252	8.191	7.992	8.117		77.298	78.796	78.065	73.408	78.665	
2.0	8.075	8.258	8.166	8.037	8.105	8.145	78.572	78.783	78.350	74.563	78.354	77.982
2.5	8.096	8.264	8.173	8.018	8.116	8.158	79.100	78.757	77.617	75.715	78.459	78.386
3.0	8.095	8.262	8.149	8.005	8.094	8.176	78.751	78.912	78.085	75.550	78.363	78.362
3.5	8.109	8.234	8.139	7.992	8.108	8.179	78.841	78.797	77.571	75.380	78.239	78.314
4.0	8.105	8.238	8.094	7.999	8.115	8.161	79.031	78.805	77.243	75.118	78.320	78.383
4.5	8.085	8.215	8.046	8.016	8.121	8.164	78.997	78.065	75.513	75.218	78.393	78.409
5.0	8.079	8.222	8.056	8.104	8.090	8.164	79.207	78.172	75.276	74.819	78.365	78.269
5.5	8.107	8.238	8.064	8.108	8.055	8.149	79.034	77.882	75.664	76.640	78.182	78.466
6.0	8.106	8.189	8.053	8.097	8.046	8.116	78.851	77.838	75.732	77.442	78.292	78.359
6.5	8.106	8.161	8.040	8.065	8.037	8.098	78.931	76.710	75.736	77.050	79.075	78.050
7.0	8.108	8.148	8.063	8.118	8.032	8.100	78.971	76.730	75.554	77.665	78.735	77.968
7.5	8.124	8.153	8.046	8.107	8.033	8.076	79.164	76.900	75.520	77.971	77.733	77.994
8.0	8.135	8.139	8.060	8.101	8.031	8.067	79.010	77.147	75.337	78.389	78.388	78.296
8.5	8.086	8.134	8.090	8.103	8.031	8.074	78.351	77.115	75.698	78.694	78.936	78.252
9.0	8.086	8.119	8.069	8.124	8.043	8.080	78.417	76.917	75.756	79.098	79.020	78.084
9.5	8.097	8.133	8.076	8.086	8.032	8.054	78.431	77.092	75.512	78.992	78.989	78.172
10.0	8.104	8.148	8.049	8.084	8.029	8.053	78.438	77.472	75.403	79.937	79.390	78.616
10.5	8.080	8.168	8.054	8.084	8.046	8.065	78.509	78.736	75.386	80.092	79.341	78.975
11.0	8.113	8.170	8.072	8.057	8.038	8.066	78.735	79.322	76.692	79.457	79.162	79.106
11.5	8.115	8.170	8.091	8.066	8.025	8.054	78.932	79.006	78.638	79.445	78.878	78.969
12.0	8.110	8.167	8.101	8.072	8.027	8.063	78.523	79.220	79.325	79.653	78.871	78.782
12.5	8.090	8.185	8.104	8.057	8.035	8.055	78.080	79.284	79.367	79.607	78.952	78.874
13.0	8.095	8.165	8.107	8.066	8.031	8.050	78.179	79.207	79.398	79.569	78.493	78.794
13.5	8.072	8.124	8.074	8.059	8.025	8.050	77.549	78.414	79.240	79.480	78.559	78.630
14.0	7.984	8.111	8.059	7.990	8.009	8.039	73.251	77.163	78.463	79.166	78.336	78.456
14.5	7.904	8.005	8.075	7.871	7.879	7.958	60.568	76.736	78.486	75.381	74.126	77.963
15.0	7.808	7.855	7.907	7.749	7.784	7.875	56.453	69.400	77.927	67.426	62.978	67.932
15.5	7.902	8.120	7.758	7.802	7.741	7.743	47.833	51.635	61.711	50.701	63.454	56.107
16.0			7.810						59.384			

Although weak, some vertical structure is apparent in the vertical profiles (Figure 6). The layering is consistent among stations, except at RW4 and possibly RW3, where the influence of the rising effluent plume altered the ambient vertical structure. At the other stations, three distinct layers are apparent. A warm surface mixed layer extends to a depth of 3-to-5 m, below which a weak thermocline separates a cooler mid-depth layer (red lines in Figure 6). The mid-depth layer extends to within 2 m of the seafloor where another thermocline separates a cool dense BNL. Vertical gradients in other seawater properties generally track the thermal structure. Particularly sharp vertical gradients separate the narrow seafloor layer. The sharp decline in temperature (red line) within the BNL generally coincides with declines in pH (gold line), transmissivity (light blue line), and DO (dark blue line) with increasing depth. Meanwhile, salinity (green line) and density (black line) tend to exhibit a slight increase with depth.

The vertical differences in seawater properties are a consequence of ambient physical, chemical, and biological processes that prevail at different depth levels. The BNL consists of cold, oxygen-poor water that originates deep offshore. The deep offshore origin of these waters is particularly evident in their lower 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 (more acidic). Transmissivity also drops markedly 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 the offshore surveys conducted for the MBCSD.

At the same time, primary production occurs within the euphotic zone within the upper water column. DO concentrations tend to be higher within the surface mixed layer due to gaseous exchange with the overlying atmosphere. Also, excess oxygen is produced when phytoplankton consume CO₂ and increase pH. However, downwelling conditions around the time of the October survey limited the availability of nutrients for primary productivity. Consequently, vertical changes in DO and pH did not closely track thermal changes within the surface mixed layer.

Outfall Performance

The existing 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 rise through the water column. The dispersion modeling determined that, at the conclusion of initial mixing, 133 parts of ambient water would have mixed with each part of wastewater. The modeling predicts that this level of dilution will be achieved after the plume rises only 9 m from the seafloor, whereupon it becomes trapped beneath the 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 conducted during October 2009.

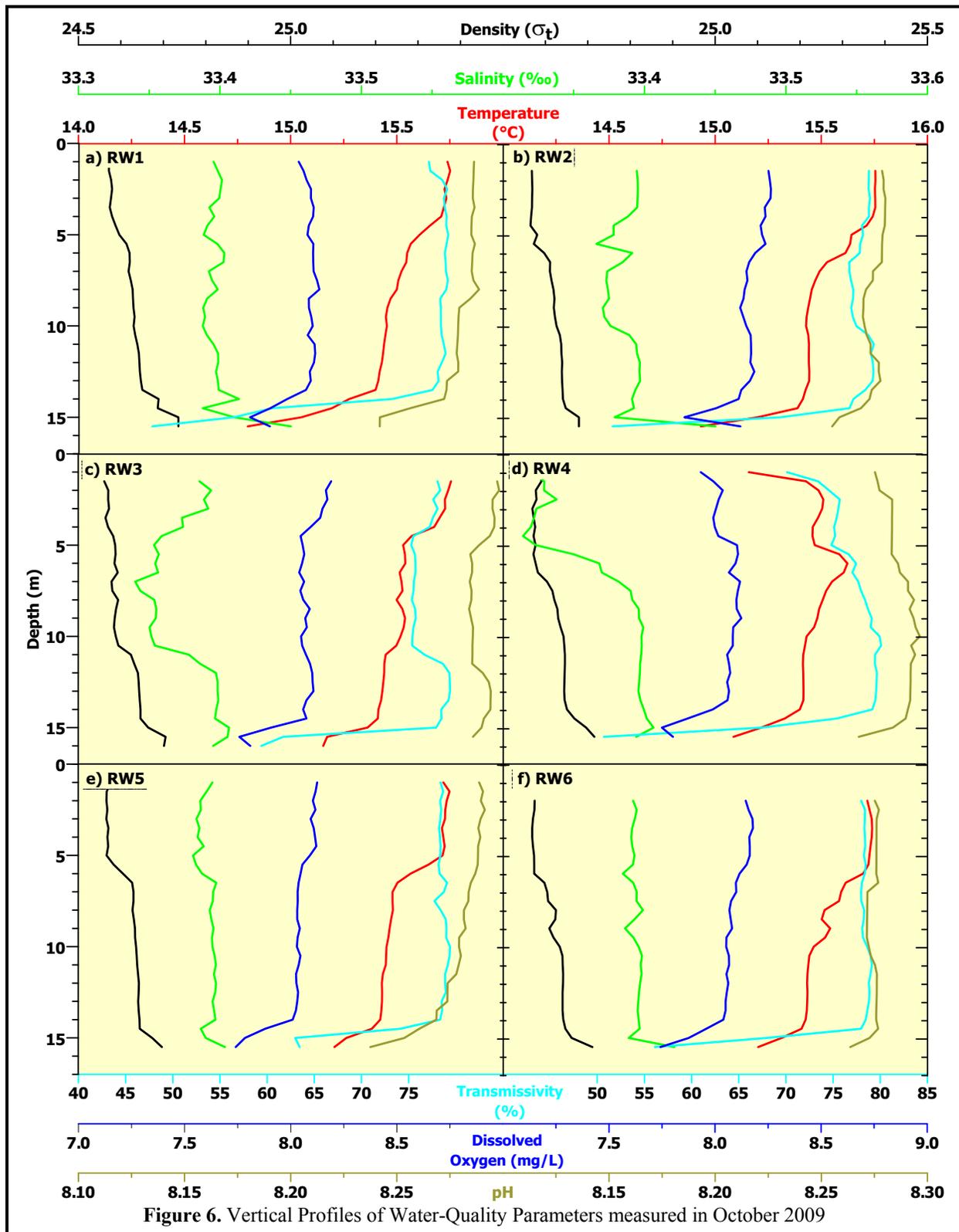


Figure 6. Vertical Profiles of Water-Quality Parameters measured in October 2009

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 October 2009 survey. During the survey, the plume was highly buoyant near 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 far higher dilution levels than predicted by the modeling.

The conservative nature of the critical initial dilution determined from the 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 7b and 8b). 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.

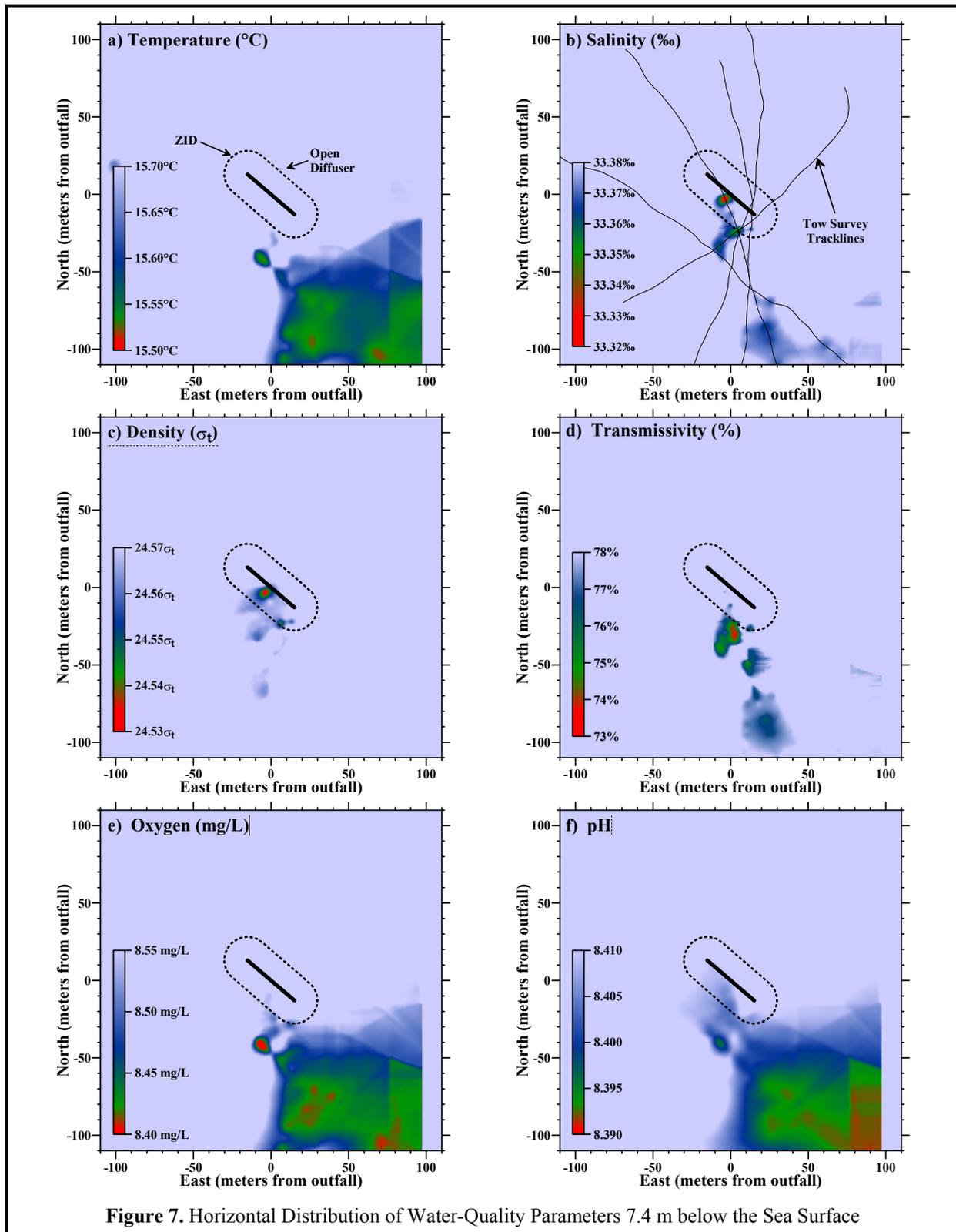


Figure 7. Horizontal Distribution of Water-Quality Parameters 7.4 m below the Sea Surface

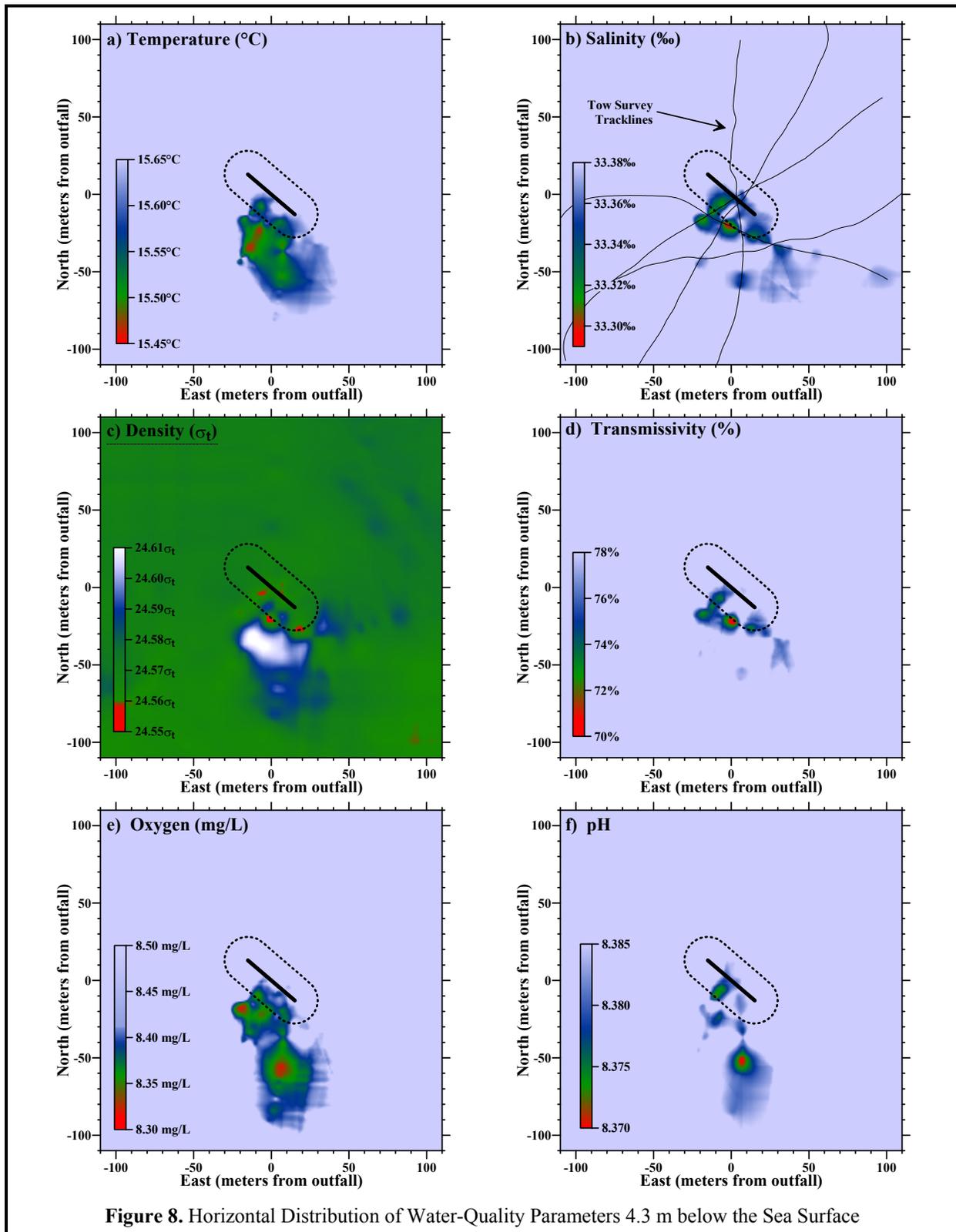


Figure 8. Horizontal Distribution of Water-Quality Parameters 4.3 m below the Sea Surface

Using Equation 2 to recast the salinity distribution shown in Figure 7b, results in the dilution distribution shown in Figure 9. During the mid-depth tow, the lowest salinity (33.296‰) was measured almost directly over the diffuser structure, with a lateral offset of only 4.7 m toward the southwest of the diffuser's centerpoint. This salinity reduction corresponds to a wastewater-induced salinity anomaly of -0.093‰ compared to the mean ambient salinity of 33.389‰, which was measured at that depth at locations well beyond the influence of the discharge. This indicates that the wastewater had already been diluted 358-fold at that location. A larger area of low salinity was also delineated farther south, near the ZID boundary (dark blue shading in Figure 7b). However, the associated salinity anomalies at that location were not as pronounced and dilutions exceeded 388-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 ($>358:1$) during the October 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 as it was slowly transported toward the southeast with the prevailing current (Figure 8b). Beyond the ZID, at 4.7 m below the sea surface, wastewater had been diluted more than 400-fold (Figure 10).

These dilution computations demonstrate that, during the October 2009 survey, the outfall was performing better than designed and was rapidly diluting effluent more than 350-fold prior to completing the initial-dilution process. This dilution level is more than two-and-a-half times greater than the 133:1 critical dilution used to establish end-of-pipe permit limitations on contaminant concentrations within wastewater discharged from the MBCSD treatment plant. Consequently, during the October 2009 survey, the COP receiving-water objectives were being easily met by the limits on chemical concentrations within discharged wastewater that are promulgated by the NPDES discharge permit issued to the MBCSD.

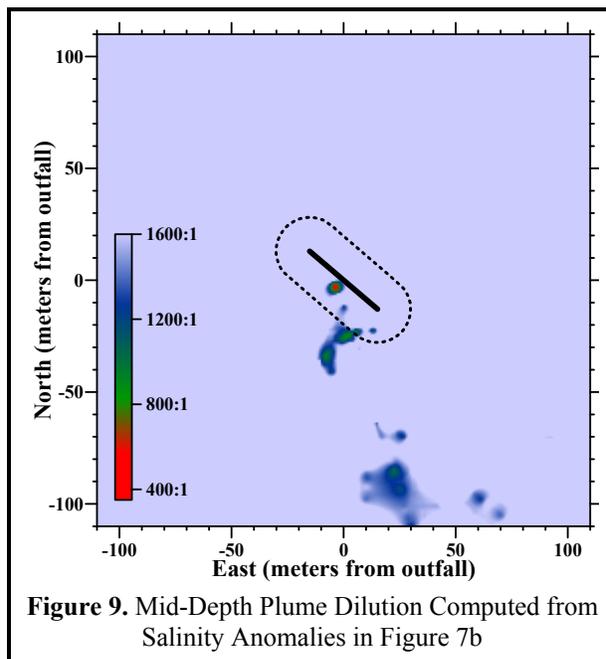


Figure 9. Mid-Depth Plume Dilution Computed from Salinity Anomalies in Figure 7b

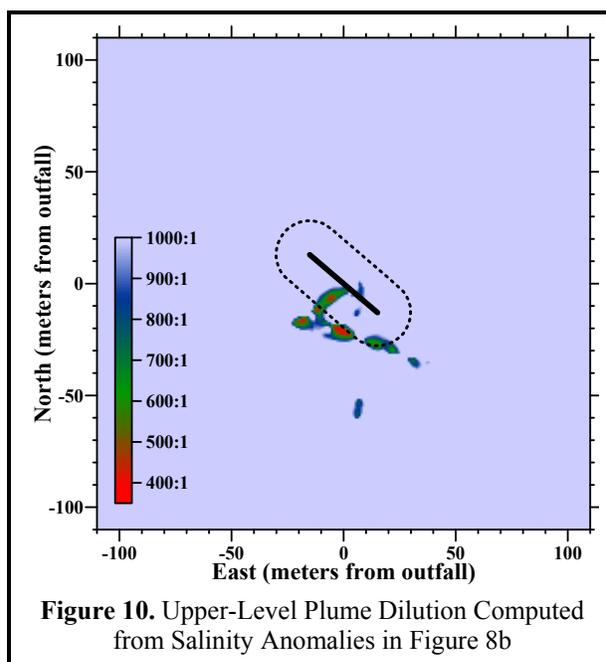


Figure 10. Upper-Level Plume Dilution Computed from Salinity Anomalies in Figure 8b

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 the characteristics of the surrounding seawater. The deep seawater characteristics are carried upward into the water column with the rising plume. As the plume rises and continues to mix, its buoyancy is reduced. In the presence of a sharp thermocline, it can achieve buoyant equilibrium near the base of the thermocline, whereupon it stops rising and spreads laterally. Trapping of the effluent plume at depth reduces the amount of initial dilution that is achieved through additional mixing, if the plume is allowed to continue its ascent all the way to the sea surface.

Although two thermoclines were present at the time of the October 2009 survey, neither was strong enough to prevent the effluent plume's eventual rise to the sea surface. The signature of the plume at the sea surface is apparent in the visual difference in the shallow portions of the vertical profiles at RW4 (Figure 6d). Compared to the profiles at other stations, temperature (red), salinity (green), DO (dark blue), transmissivity (light blue), and pH (gold) were all perceptibly lower near the sea surface at RW4. However, only the reduced salinity reflects the presence of dilute wastewater constituents at that location. Reductions in the other seawater properties were caused by entrainment of ambient seawater properties during turbulent mixing within the BNL shortly after discharge. These BNL properties, namely low temperature, DO, transmissivity, and pH, were carried upward with the rising effluent plume. As the plume neared the sea surface at RW4, these properties contrasted starkly with the shallow water properties at the other stations (see also Table 5).

Entrainment-generated anomalies in temperature, DO, and pH are also apparent at mid-depth levels southeast of the diffuser structure (shaded areas in the lower right quadrant of Figure 7aef). These anomalies reflect the character of the effluent plume after initial dilution is largely complete. The amplitudes of these anomalies are extraordinarily small (0.1°C, 0.1 mg/L, and 0.01 pH) although their location is consistent with the direction of plume transport predicted by the drogued drifter. They also coincide with more-localized areas of very small but perceptible salinity and transmissivity anomalies (dark blue shading near the southern extent of the maps in Figure 7bd). The salinity anomalies measured in this region indicate dilutions that exceed 1000-fold (Figure 9). Statistical analysis of historical receiving-water data has demonstrated that wastewater constituents that have been diluted more than approximately 500-fold are too diffuse to be reliably detected. Therefore, the observed perturbations in temperature, DO, and pH likely arose from the upward displacement of ambient seawater rather than the presence of dilute wastewater constituents. Finally, no tangible density perturbations coincide with these entrainment-generated anomalies (Figure 7c), indicating that they were neutrally buoyant and not likely to undergo significant additional buoyancy-induced mixing.

Apart from these mid-depth entrainment anomalies, which reveal the southeastward transport of effluent after completion of initial dilution, ongoing initial dilution within the rising effluent plume is also apparent at mid-depth. The mixing dynamics of the rising effluent plume are delineated by the negative density anomalies apparent within, and near the ZID boundary immediately south of the diffuser structure (shading in Figure 7c). These highly localized areas of buoyant seawater reflect the dynamics of the effluent plume as it was continuing to mix and rise within the water column. Dilutions as low as 360-fold were measured within of the 5 m of the diffuser structure at this depth level (red shading in Figure 9).

The shallow tow survey captured the discharge plume after it had risen farther in the water column and entered the mixed layer just below the sea surface (Figure 8). At this level, the plume had spread laterally and its buoyancy dynamics were more complex. Due to the substantial contrast with shallow seawater properties, entrainment-generated anomalies in temperature, transmissivity, DO, and pH were more apparent immediately south of the ZID boundary at this depth level (Figure 8adef), as compared to the mid-depth level (Figure 7). Salinity anomalies were both more widespread near the ZID boundary (Figure 8b) and more pronounced (red shading in Figure 10). Actual dilutions at this location along the southern ZID boundary exceeded 330-fold, however, and since the plume was still buoyant there (red shading in Figure 8c), additional dilution would be achieved as the plume continued its rise to the sea surface.

This was not the case within the region of entrainment-generated anomalies immediately south of the ZID where densities in the anomalies were higher than the surrounding seawater (white shading in Figure 8c). These are areas where the effluent plume overshot its equilibrium level. Subsequently, the negatively buoyant plume would have sunk within the water column before overshooting the equilibrium level yet again. This slowly damped vertical oscillatory motion is a well-recognized phenomenon in atmospheric and oceanic dynamics when a parcel of water is vertically displaced within a statically stable environment. However, prior to the implementation of horizontal CTD tows in the MBCSD receiving-water program, this phenomenon was rarely captured. These buoyancy oscillations serve to further disperse the effluent plume, although at the point captured in the Figures, the wastewater constituents had already been diluted beyond recognition (dilutions greater than 800-fold indicated by the absence of shading in Figure 10), leaving only entrainment-generated anomalies (Figure 8ade).

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 October 2009 survey demonstrated that the wastewater discharge complied with the 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). Although discharge-related changes in all six seawater properties were observed during the October 2009 survey, the changes were either not of significant magnitude, were measured within the boundary of the ZID where mixing is still expected to take place, or were not directly caused by the presence of wastewater constituents within the water column. Beyond the ZID, the effluent was so dilute 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

The first two receiving-water limitations rely on visual observations for compliance evaluation. There was no visual evidence of any debris of potential wastewater origin observed at the sea surface 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.

Increased turbidity associated with the upward displacement of BNL particulates was visually apparent within the water column at various times during the survey. However, as described in the previous section, these particulates were of natural origin and not comprised of wastewater constituents, therefore their visibility beneath the sea surface did not constitute an adverse impact to receiving-water quality.

Instrumental Observations

Compliance with the remaining four receiving-water limitations can be quantitatively evaluated through comparison of instrumental measurements and specific numerical limits listed in the NPDES permit. For example, the third column of Table 6 specifies numeric limits identified in the NPDES permit for DO and pH that restrict excursions caused by the presence of wastewater constituents. However, several additional narrative limits in the permit define unacceptable water-quality impacts in terms of excursions beyond conditions that are deemed to occur “naturally.” Thus, to establish numerical thresholds for comparison with data collected during the receiving-water surveys, the “natural” range in conditions that occurs in the survey area needs to be identified.

Table 6. Screening for Significant Deviations from Natural Conditions

Water Quality Property	Plume Extrema ¹²	NPDES Permit Limit ¹³	Natural Variability Threshold ¹⁴	95 th 15 Percentile ¹⁶	95% ¹⁵ Confidence Bound ¹⁷	COP Allowance ¹⁸
Temperature (°C)	≤15.70	—	>16.32	15.50	0.82	—
Transmissivity (%)	≥68.4	—	<58.6	68.8	-10.2	—
DO (mg/L)	≥7.93	<5.0	<5.98	8.02	-1.38	-10%
pH (minimum)	≥8.275	<7.0	<7.974	8.268	-0.094	-0.2
pH (maximum)	≤8.410	>8.3	>8.583	8.289	0.094	0.2

¹² The maximum or minimum value measured within the plume during the October 2009 survey. The plume is delineated by wastewater-induced salinity reductions exceeding -0.062‰, which corresponds to a 542:1 dilution and represents smallest change in salinity that can be reliably discerned against the backdrop of natural variability within a given survey.

¹³ Some of the permit limits specify specific numerical values in addition to changes relative to natural conditions.

¹⁴ Thresholds represent limits on wastewater-induced changes to receiving-water properties that significantly exceed natural conditions as specified in the discharge permit and COP. They are determined from the sum of columns to the right and are specific to the October 2009 survey.

¹⁵ The COP (Appendix I, Page 27, 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.” Accordingly, COP effluent analyses (Step 9 in Appendix VI, Page 42, Ibid.) are based “the one-sided, upper 95 percent confidence bound for the 95th percentile.”

¹⁶ The 95th-percentile quantifies natural variability in seawater properties during the October 2009 survey, and is determined from vertical profiles excluding Stations RW3 and RW4 where there was possible influenced by the discharge.

¹⁷ The one-sided confidence bound is used to measure the ability to reliably estimate percentiles within surveys as a whole. They were determined from an analysis of the variability in ambient water-quality data collected during 20 quarterly surveys conducted between 2004 and 2008. Although water-quality observations potentially affected by the presence of wastewater constituents were excluded from the analysis, more than 9,200 observations for each of the six seawater properties accurately quantify the inherent uncertainty in defining the range in natural conditions.

¹⁸ The discharge permit, in accordance with the COP, allows excursions in seawater properties that depart from natural conditions by specified amounts. DO cannot be “depressed more than 10% from that which occurs naturally,” and pH cannot be “changed more than 0.2 units from that which occurs naturally.”

Statistical analyses of the large historical database of receiving-water data collected around the outfall have been used to establish the range of variability in site-specific natural conditions, and the departures from those conditions that could be indicative of adverse effects on water quality. The fourth column in Table 6 lists thresholds for the natural range in seawater properties surrounding the outfall. Measured values that lie outside these ranges can be considered significantly¹⁵ different from natural conditions.

These thresholds were partially determined by the ambient water-quality conditions that prevailed during the October 2009 survey, as represented by the fifth column in Table 6, “95th Percentile.” Conditions during the October 2009 survey can be expected to differ from other surveys due to seasonal and interannual variations in seawater properties. Computing a separate 95th percentile from each survey’s ambient data accounts for these temporal differences among surveys, specifically, how the October 2009 survey differed from natural conditions experienced during other surveys. Because of its inclusion, the thresholds listed in Table 6 are specific to the October 2009 survey. It is important to account for temporal differences among surveys because they constitute 98% of the overall variability in seawater properties observed near the outfall.

The thresholds also incorporate confidence bounds (“95% Confidence Bound”) that capture vertical and lateral variability within surveys as a whole. This within-survey spatial variability accounts for the remaining 2% of overall ambient variability. Lastly, the thresholds for DO and pH include permitted allowances (“COP Allowance”) under the California Ocean Plan for excursions beyond their natural ranges.

Potential out-of-compliance excursions in water quality can be screened by comparing wastewater-induced excursions in receiving-water properties with both the specific NPDES permit limits and the natural variability thresholds listed in Table 6. Changes in water properties caused by the presence of effluent constituents are defined by the maximum or minimum values measured within the effluent plume (“Plume Extrema”). Thus, potential exceedances of receiving-water limits are indicated by plume extrema that lie beyond the limits and thresholds listed in the third and fourth columns of Table 6.

The screening analysis in Table 6 highlighted one potential out-of-compliance case during the October 2009 survey that requires further investigation. Specifically, the maximum pH measured within the plume (8.410) exceeded the numeric maximum (8.3) allowed in the NPDES permit. However, on the day of the survey, the effluent leaving the plant had a much lower pH (7.4) than the receiving seawater. Consequently, the presence of wastewater particulates should have caused a decrease in receiving-water pH, rather than an increase. Thus, in this case, the exceedance does not represent an out-of-compliance event. This conclusion that is further supported by the fact that ambient pH at the time of the survey was abnormally high, with background levels that exceeded the permit limit throughout most of the survey area (light blue shading in Figures 7f and 8f). Within the plume, pH was generally lower (dark blue, green, and red shading), as expected from both entrainment of naturally low pH seawater within the BNL, and the potential presence of lower-pH effluent that was still undergoing dilution.

Delineating Plume Influence

The plume extrema in Table 6 were computed from water properties that coincided with significant reductions in salinity. 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 quickly become imperceptible as the effluent undergoes mixing and dilution. In contrast, 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 (Equation 2).

For compliance purposes, a slightly more conservative dilution threshold of 550-fold was used to restrict attention to data from the October 2009 survey that were potentially impacted by wastewater constituents. Thus, water-quality measurements collected outside the red-shaded areas in Figures 9 and 10, are not likely to have been influenced by the presence of wastewater constituents. This includes the entrainment-generated changes in many water properties that extend toward the southeast in the mid-depth tow data (Figure 7adef). 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. In areas where computed dilutions exceed 550-fold, anomalies in other water properties are not likely to have resulted from the presence of wastewater constituents, and therefore, the permit limits do not apply. If significant departures in receiving-water properties are not apparent in the low-salinity regions where plume dilution is lowest, then discharge-related anomalies will be imperceptible in higher-dilution areas beyond the detectable plume region defined by negative salinity anomalies.

Temperature

Because the thresholds in Table 6 were partially determined by the ambient water properties that prevailed at the time of the October 2009 survey, they lend insight into how different those conditions were compared to other surveys. As described previously, the downwelling event that immediately preceded the October 2009 survey resulted in an unusually high, upper-bound seawater temperature (95th percentile of 15.5°C, 60°F). Accordingly, the threshold for screening of departures from natural thermal conditions was similarly elevated, where only discharge-related temperature increases exceeding 16.32°C could reasonably be assumed to have the potential to “*adversely affect beneficial uses.*” While the 21°C effluent that was discharged from the plant at the time of the survey would normally have resulted in slightly increased receiving-water temperatures in regions of concentrated wastewater constituents, the immediate entrainment and subsequent upward displacement of cooler BNL waters within the effluent plume actually resulted in reductions in temperature within the plume, as shown Figures 7a and 8a..

Light Transmittance

The presence of a turbid BNL during the October 2009 survey established minimum ambient transmissivity levels that were lower than in many other surveys. As a result, the transmissivity threshold for compliance testing was also unusually low (58.6%). The threshold identifies levels where excessive concentrations of wastewater particulates within the euphotic zone could cause a “*significant reduction in the transmittance of natural light*” beyond the ZID. However, transmissivity measured within the plume exceeded 60.4%, even within the localized reductions seen in the upper water column during the tow surveys (Figures 7d and 8d). In addition, the observed transmissivity reductions were consistent with mixing and upward displacement of the naturally turbid BNL waters within the buoyant effluent plume, and were not caused by an excess concentration of wastewater constituents within poorly diluted effluent. The suspended-solid concentration measured within effluent discharged at the time of the survey (23 mg/L) was close to the 20-mg/L annual average, and would have reduced transmissivity by only 0.3% after a 358-fold dilution. In contrast, transmissivity within the BNL was 30% lower than in the upper water column (e.g., Station RW1 in Figure 6a and Table 5); a difference that could easily account for the 8% reductions observed near the ZID boundary during the tow survey.

Dissolved Oxygen

The lowest DO concentration recorded within the plume (7.93 mg/L) was nearly 2 mg/L higher than the October-2009 threshold on natural conditions (5.98 mg/L), and nearly 3 mg/L higher than the minimum allowable concentration in the permit (5-mg/L). In the case of DO, the natural-variability threshold was substantially more stringent than the numeric limit listed in the NPDES permit because the seawater surrounding the outfall was close to 100% saturation due to the influence of downwelling processes. A slight 5% depletion in DO saturation within the BNL arose naturally from biotic respiration and decomposition inherent in such layers at depth. As with temperature and transmissivity, these slight DO reductions within the BNL were entrained within the rising effluent plume, and resulted in the patterns observed during the tow survey (Figures 7e and 8e).

However, as specified in the COP, DO limitations only apply to reductions that occur “*as a result of the discharge of oxygen demanding waste materials.*” Influent and effluent samples collected two days before the survey demonstrated that the treatment process was efficiently removing 80% of the oxygen-demanding material from the wastestream. Because the treatment process routinely removes the great majority of oxygen-demanding material, reductions in DO caused by the presence of effluent constituents have never been observed within the receiving waters. This was also the case during the October 2009 survey when all receiving-water DO measurements were well above both the numerical limit of 5 mg/L, and the 5.98-mg/L threshold that represents a DO depression of “*more than 10 percent from that which occurs naturally.*”

pH

All of the receiving-water measurements recorded during the October 2009 survey fell within a pH range between 8.24 and 8.42. This very narrow measured range was well within the minimum (7.974) and maximum (8.583) thresholds of natural pH variability present at the time of the survey, as well as the minimum (7.0) numeric limit identified in the NPDES permit. Although measurements both within and beyond the plume exceeded the 8.3 upper-bound limit specified in the permit, these exceedances could not have been caused by the presence of wastewater constituents. As described previously, effluent pH was much lower at the time of the survey and could not have caused an increase in ambient pH levels. Instead, receiving-water pH levels both within the plume and beyond were naturally elevated above the permit limit due to the unusual downwelling conditions that preceded the survey. The upwelling index in Figure 4 shows that a major upwelling event preceded the downwelling conditions identified during the survey. Similar to the effects seen in temperature and DO, the uptake of carbonic acid by primary production during the upwelling event increased surface pH, which was subsequently mixed downward into the water column by downwelling.

Summary

All measurements recorded during the October 2009 survey complied with both the numerical receiving-water limitations specified in the NPDES discharge permit, and the thresholds on natural variability that prevailed at the time of the survey. The presence of dilute wastewater constituents was delineated within a discharge plume that was localized near, and within the ZID. Observed excursions in other receiving-water properties were associated with the entrainment and upward displacement of ambient seawater within the buoyant effluent plume rather than the presence of wastewater constituents. Within the mid- and upper water column, dilution levels of more than 335-fold were more than double the critical dilution levels predicted by design modeling. Additionally, all of the auxiliary observations collected during the October 2009 survey complied with the receiving-water limits in the discharge permit and COP. They demonstrated that the treatment process, diffuser structure, and the outfall continue to perform at levels exceeding design expectations.

REFERENCES

- 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.
- 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.
- 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.
- Lindsey, J.C. 2009. 10/14/09 Weather Forecast (Rain Totals). Email To: Oceanographic and Meteorology Observations and Forecasts for DCPD {PG&E Internal}; From: owner-dcpp-weather@pge.com; on behalf of, Lindsey, John C [JCL5@pge.com]. Sent: Wed 10/14/2009 9:21 AM.
- Marine Research Specialists (MRS). 1998. 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). 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.
- Marine Research Specialists (MRS). 2009. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 2008 Annual Report. Prepared for the City of Morro Bay, California. February 2009.
- 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 and the Environmental Protection Agency (USEPA) – Region IX. 1993a. Waste Discharge Requirements (Order No. 92-67) and Authorization to Discharge under the National Pollutant Discharge Elimination System (Permit No. CA0047881) for City of Morro Bay and Cayucos Sanitary District, San Luis Obispo County.
- Regional Water Quality Control Board (RWQCB) - Central Coast Region and the Environmental Protection Agency (USEPA) – Region IX. 1993b. Monitoring and Reporting Program No. 92-67 for City of Morro Bay and Cayucos Sanitary District, San Luis Obispo County (Permit No. CA0047881).
- Regional Water Quality Control Board (RWQCB) - Central Coast Region and the Environmental Protection Agency (USEPA) – 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 (USEPA) – 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.
- Regional Water Quality Control Board (RWQCB) - Central Coast Region and the Environmental Protection Agency (EPA) – Region IX. 2009. Waste Discharge Requirements (Order No. R3-2008-0065) and National Pollutant Discharge Elimination System (Permit No. CA0047881) for the Morro Bay and Cayucos Wastewater Treatment Plant Discharges to the Pacific Ocean, Morro Bay, San Luis Obispo County. Effective 1 March 2009.
- 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.
- State Water Resources Control Board (SWRCB). 2005. Water Quality Control Plan, Ocean Waters of California, California Ocean Plan. California Environmental Protection Agency. Effective February 14, 2006.
- 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.