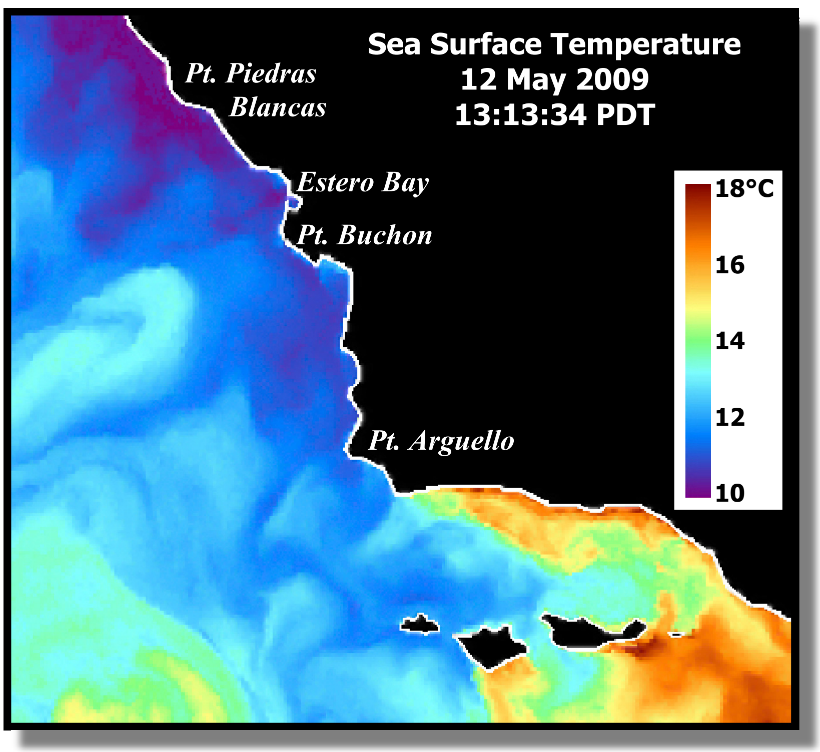
City of Morro Bay and
Cayucos Sanitary District

OFFSHORE MONITORING AND REPORTING PROGRAM

QUARTERLY REPORT

WATER-COLUMN SAMPLING MAY 2009 SURVEY



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Report to the

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OFFSHORE MONITORING AND REPORTING PROGRAM

QUARTERLY REPORT

WATER-COLUMN SAMPLING MAY 2009 SURVEY

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July 2009

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

30 July 2009

Reference: Quarterly Receiving-Water Report – May 2009

Dear Mr. Keogh:

The attached report presents results from the second-quarter water-quality survey conducted on Tuesday, 12 May 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 spring 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 south of 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,

Douglas A. Coats, Ph.D.
Program Manager

Enclosures (5)

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

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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 May 2009 field survey described in this report was the first water-quality survey conducted under the monitoring provisions of the current permit.

Since its inception, the monitoring program has been regularly modified to better evaluate short- and long-term effects of the discharge on receiving waters, benthic sediments, and infaunal communities (RWQCB-EPA 2009). Seasonal monitoring of offshore water quality continues to be a requirement of the current permit provisions. Four quarterly surveys record ambient water properties during winter, spring, summer, and fall conditions. In keeping with the seasonal synopses, this quarterly report summarizes the results of water-quality sampling conducted on 12 May 2009. Specifically, this second-quarter survey captured ambient oceanographic conditions along the central California coast during the spring 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 water-quality 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 May 2009 offshore survey.

Both monitoring objectives were achieved by evaluating empirical tabulations of instrumental measurements and standard field observations, vertical water-column profiles, and horizontal maps generated from high-spatial-resolution data created by towing the CTD[1] instrument package repeatedly over the diffuser structure. The towed survey is a new component of the monitoring program 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 more closely spaced stations specified in the discharge permit that was in effect prior to January 2009, the presence of well-mixed effluent near the diffuser structure was detected in all forty-two of the subsequent water-quality surveys (MRS 2000 - 2008). With the addition of the horizontal towing described in this report, the actual extent of the plume can be determined, in addition to the presence of discharge-related water-quality anomalies.

Precise delineation of the effluent plume is important for assessing compliance because many receiving-water limitations apply only beyond the narrow 15-m zone of initial dilution surrounding the outfall. The high-resolution data gathered from the CTD's sensitive sensors during the towed survey better quantifies the amplitudes of the effluent-related perturbations than when only vertical CTD casts are used. As described in the Methods Section, the CTD's sensors are capable of detecting minute changes in water

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

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 May 2009 survey delineated the presence of dilute effluent undergoing turbulent mixing within the stratified water column 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). A 1,450-m long outfall pipe, which carries the effluent from the onshore treatment plant, terminates at a diffuser structure, which lies on the seafloor approximately 827 m from the shoreline.[2] The diffuser structure extends an additional 52 m toward the northwest from the outfall terminus.

Twenty-eight of 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. For a given flow rate, the diffuser ports were hydraulically designed to create a turbulent ejection jet that rapidly mixes effluent with receiving seawater immediately upon discharge. Additional turbulent mixing occurs as the buoyant plume of dilute effluent rises through the water column. Most of this buoyancy-induced mixing occurs within a zone of initial dilution (ZID), whose lateral extent in modeling studies 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). Its presence further restricts the direct exchange of seawater between the discharge point and the Bay.

Near the diffuser, prevailing currents generally follow bathymetric contours that parallel the north-south trend of the adjacent coastline. Because of the rapid initial mixing achieved within 15 m of the diffuser structure, impingement of unmixed effluent onto the adjacent coastline, 827 m away, is highly unlikely. Nevertheless, 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.

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

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

Table 1. Target Locations of the Offshore Water-Quality 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

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

As shown in Figure 2, the offshore water-sampling design 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 to capture any discharge-related trends in seawater properties. The six stations 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 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 to evaluate compliance with the NPDES discharge permit.

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

Another important consideration for compliance evaluation is the ability to determine the actual location of the measurements. This ability to discern small spatial separations among stations within the compact sampling pattern specified in the discharge permit only became feasible after the advent of DGPS. The accuracy of traditional navigation systems such as LORAN or standard GPS is typically ±15 m, a span equal to half the total width of the ZID itself. 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.

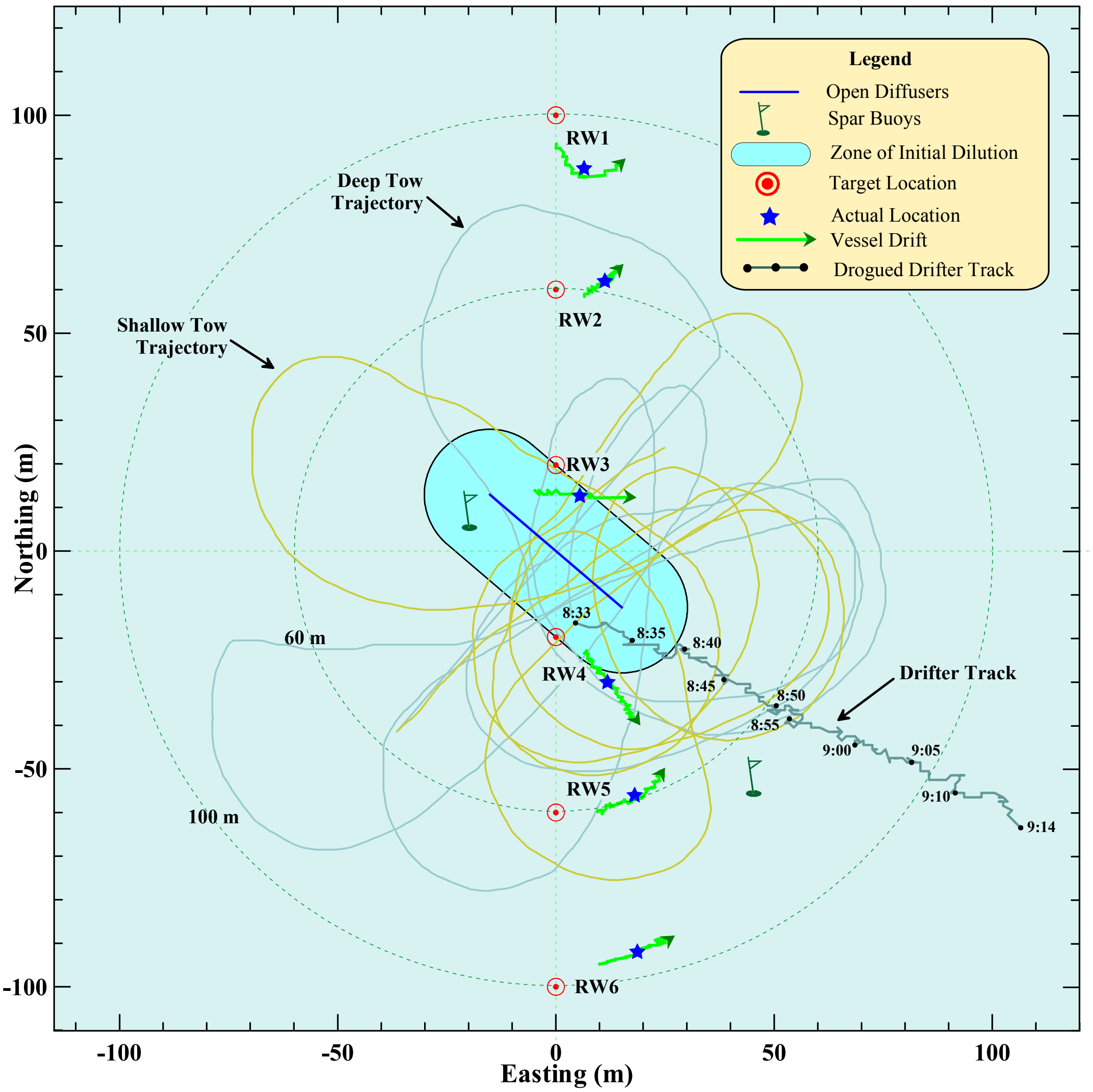

Figure 2. Sampling Station Locations and Tow Trajectories

Frequent recording of DGPS readings 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; at Stations RW3 and RW4, the CTD can actually cross the ZID boundary during the hydrocast (Figure 2).

The magnitude of the horizontal drift at each of the six stations during the May 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. Their lengths reflect the station-keeping difficulty experienced during the May 2009 survey. During the time it took the CTD to traverse the water column to the seafloor, which averaged 1 min 19 s, the instrument package moved as much as 21.6 m laterally (at RW3). Overall, the average drift for all the stations was 16.5 m, which was attributable in part to the windy conditions during the survey.

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. As summarized in Table 2, winds were strong throughout the course of the survey and their influence was substantial when combined with the southeastward transport induced by the prevailing current, as reflected by the drifter trajectory in Figure 2. The CTD was transported shoreward during the hydrocasts at all stations, although there were differences in the individual trajectories due to residual vessel momentum at the start of each of the casts. 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. For example, the northward CTD drift component at RW2, RW5, and RW6 resulted from the vessel's approach from the southwest.

Table 2. Standard Meteorological and Oceanographic Observations

Station	Location Latitude	Location Longitude	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)
RW1	35° 23.249' N	120° 52.498' W	82.7	9:02:20	11.0	0	6.4	7.7	NW	5 NW	4.0
RW2	35° 23.230' N	120° 52.501' W	48.3	8:58:08	11.2	0	5.6	7.0	NW	5 NW	4.0
RW3	35° 23.209' N	120° 52.499' W	19.6	8:54:31	11.1	0	7.9	8.6	NW	5 NW	3.0
RW4	35° 23.185' N	120° 52.496' W	12.7	8:50:38	11.1	0	7.4	8.9	NW	5 NW	5.0
RW5	35° 23.166' N	120° 52.500' W	48.2	8:45:16	10.8	0	7.6	10.2	NW	5 NW	3.0
RW6	35° 23.147' N	120° 52.495' W	83.6	8:41:45	11.1	0	5.8	8.3	NW	5 NW	3.0

Though generally small, lateral movement of the CTD during the downcasts can complicate compliance assessments at Stations RW3 and RW4 because their target locations are on the ZID boundary. Most receiving-water limitations specified in the COP do not apply to measurements recorded within the ZID because initial mixing may not be complete. Turbulence associated with the momentum of the effluent jet and the subsequent rise of the buoyant plume is responsible for initial mixing. These initial mixing processes often extend beyond the ZID boundary when the plume is transported laterally by prevailing currents during its rise through the water column, as was the case during the May 2009 survey.

Nevertheless, the plume modeling used to establish dilution levels assumes quiescent flow conditions, and consequently, permit limitations apply to conditions at any location beyond the ZID boundary. However, because the shallowest measurements at RW3 and RW4 were collected within the ZID, they were not subject to the receiving-water limitations specified in the NPDES discharge permit. The green arrows in Figure 2 point toward the bottoms of the hydrocasts, and indicate that, as the CTD traversed the ZID boundary, the deeper measurements recorded by the CTD became subject to the permit limitations.

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 determine whether a ZID station was actually sampled within the ZID, much less whether 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 May 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 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 (RW4), does not guarantee that some measurements might not still be subject to the COP objectives.

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

	Time (PDT)				Closest Approach	
Station	Downcast	Upcast	Latitude	Longitude	Range[1](m)	Bearing[2](ºT)
RW1	9:01:41	9:03:03	35° 23.247' N	120° 52.500' W	78.1	16
RW2	8:57:48	8:58:57	35° 23.233' N	120° 52.497' W	55.8	28
RW3	8:54:00	8:55:13	35° 23.206' N	120° 52.500' W	**13.3**[3]	41
RW4	8:49:45	8:51:08	35° 23.183' N	120° 52.496' W	**17.3**[3]	191
RW5	8:44:54	8:46:16	35° 23.169' N	120° 52.492' W	43.0	176
RW6	8:40:52	8:42:18	35° 23.149' N	120° 52.492' W	78.9	177

[1] Distance from the closest open diffuser port to the average station position.
[2] Direction measured clockwise in degrees from true north from the closest diffuser port to the average sampling location.
[3] Stations with portions of the CTD cast within the ZID boundary are shown in bold.

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.

OCEANOGRAPHIC PROCESSES

The trajectory of a satellite-tracked drogued drifter documented a weak southeastward flow during the May 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 transport direction at the time of the survey. The grey line with black dots in Figure 2 shows the drifter's trajectory. Each dot along the drifter track represents a time span of five minutes. The drogued drifter was deployed near Station RW4 at 8:33 PDT and recovered forty-one minutes later, at 9:14 PDT. The trajectory shows that a weak but steady current carried the drifter slowly shoreward toward the east-southeast (115°T). While deployed, the drifter traversed a total of 112 m at an average speed of 4.6 cm/s or 0.09 knots. For much of the survey, the time stamps along the trajectory were evenly spaced, indicating that drifter movement was steady. However, between 8:50 and 8:55, when the survey vessel passed within a boat length of the drifter, the drifter trajectory appeared to be temporarily influenced by propeller wash.

The shoreward flow component measured by the drogued drifter was only partially consistent with the incoming flood tide that prevailed throughout the May 2009 survey (Figure 3). In the absence of other external influences, a flood tide normally induces a weak northeastward flow in the survey region. However, flow is more often influenced by external processes, such as wind-generated upwelling or by passing offshore eddies. During the May 2009 survey, the steady east-southeastward flow measured by the drogue drifter was clearly more influenced by the strong upwelling conditions that prevailed at that time (Figure 4).

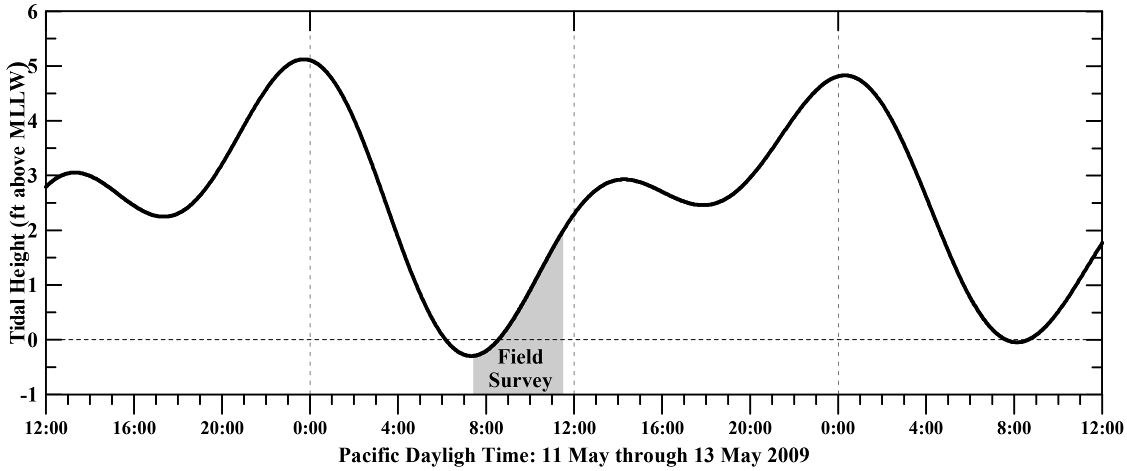

Figure 3. Estero Bay Tidal Level during the May 2009 Offshore Survey

Cross-shore counter-currents are generated during upwelling conditions when warmer surface waters are driven offshore by the prevailing winds and are replaced by shoreward transport of cooler waters at depth. During the May 2009 survey, these warmer surface waters were restricted to an unusually thin 4-m layer. This thin surface mixed layer was contained within the sharp thermocline that is apparent at most stations in the vertical temperature profiles (red lines in Figure 5). As described below, the drifter was drogued at 7 m, and thus reflected the shoreward transport occurring within the deeper uniform layer below the thermocline.

Upwelling season normally begins sometime during late March and or early April when there is a "spring transition" to more persistent southward-directed winds along the central California coast. This transition is 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 Coast. These prevailing winds move surface waters southward and offshore. To replace these coastal surface waters,

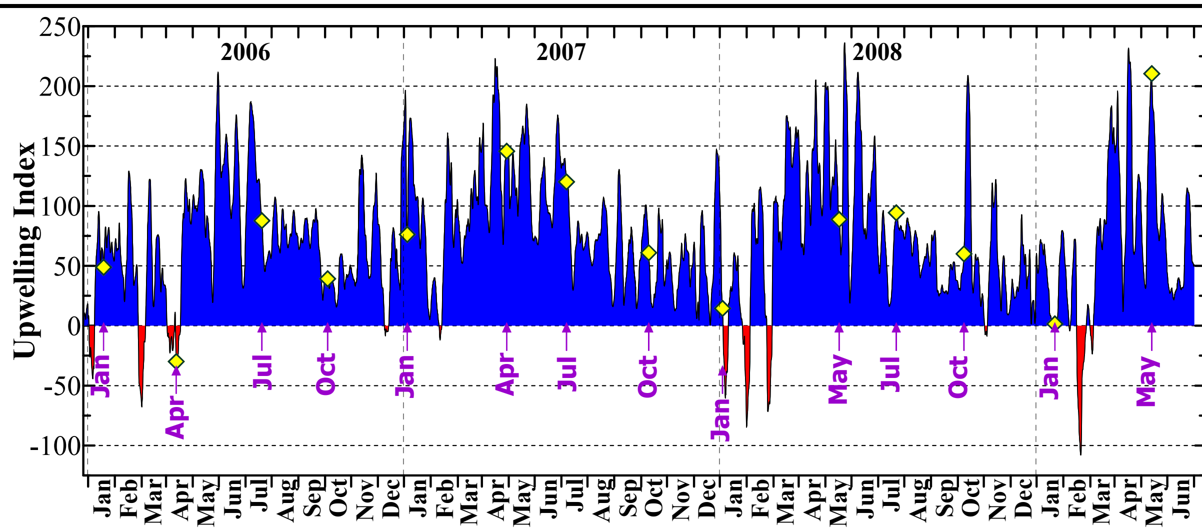

Figure 4. 30-Day Running Mean Upwelling Index (m^3/s/100m of coastline) Offshore Estero Bay with the dates of the Quarterly Water-Quality Surveys Indicated

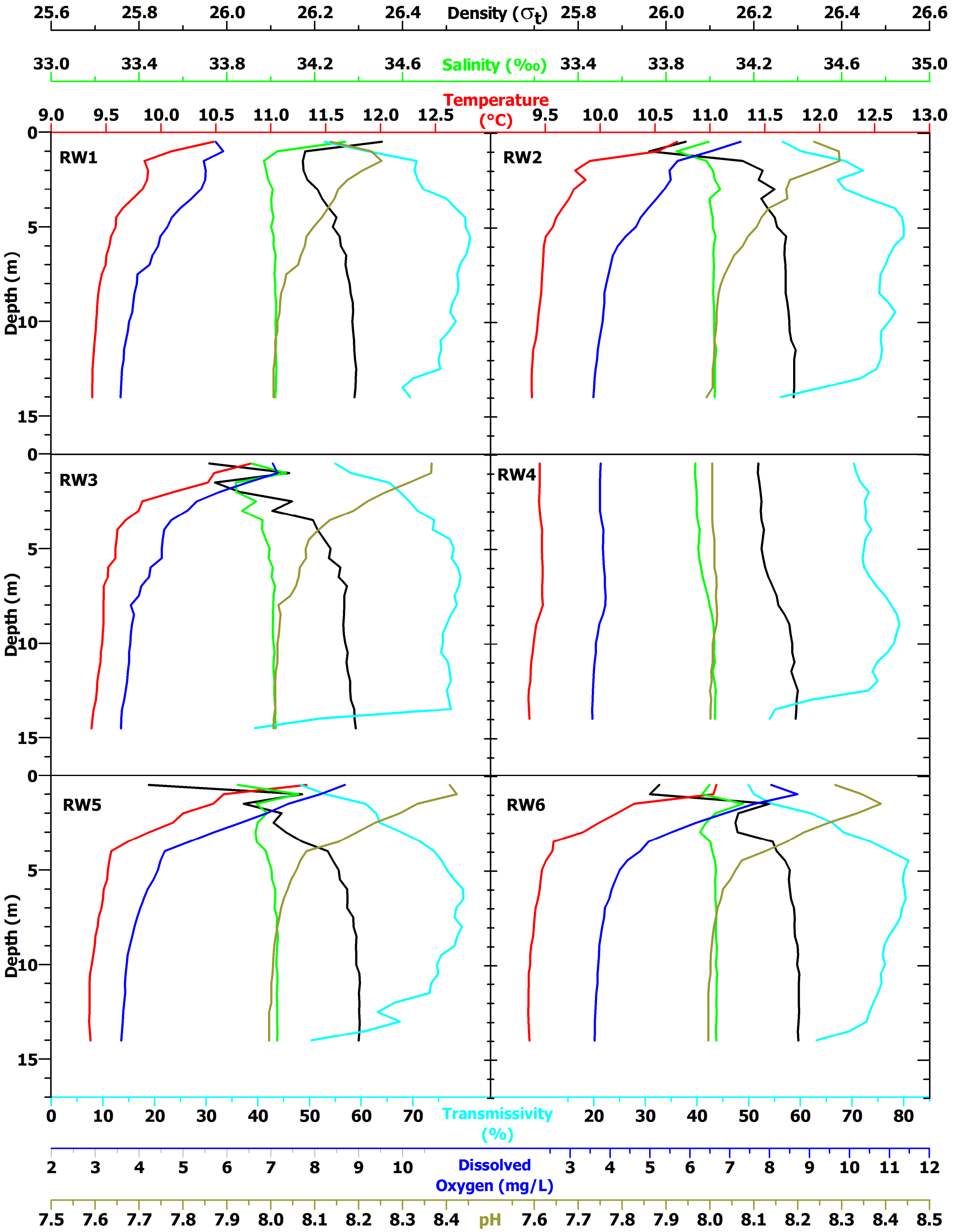

Figure 5. Vertical Profiles of Six Water-Quality Parameters measured in May 2009

deep, cool, nutrient-rich waters upwell near the coast. The spring upwelling conditions in 2009 began in early March, and were particularly sustained and intense around the time of the May 2009 survey (Figure 4).

Southeastward winds that prevailed along the central California coast in May 2009 resulted in cooler sea-surface temperatures close to the coastline around the time of the survey. The satellite image on the cover of this report depicts these cooler waters, with temperatures near 10°C, in purple. Farther offshore, surface water temperatures were as much as four degrees warmer, as delineated by the areas with light blue shading. The cover image was recorded on the day of the survey when skies were clear enough for sea-surface temperatures to be measured by infrared sensors on one of NOAA's polar orbiting satellites. Accordingly, the colder sea surface temperatures depicted by dark blue and purple shading in the satellite image within Estero Bay were consistent with the low seawater temperatures recorded by the CTD during the survey (Figure 5).

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 12 May 2009. Dr. Douglas Coats of Marine Research Specialists (MRS) was the Chief Scientist, Captain Mark Tognazzini supervised vessel operations, and William Skoke 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.

Auxiliary Measurements

Auxiliary measurements and observations were collected contemporaneously with the vertical water-column profiling conducted at each of the six stations. 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 (Table 2).

Additionally, at all six stations, a Secchi disk was lowered through the water column to determine its depth of disappearance (Table 2). 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 May 2009 survey ranged between 3 and 4 m at the five stations unaffected by the discharge. This reflected the presence of a restricted 8-m euphotic zone that spanned only approximately half of the water column. A limited euphotic zone is typical of upwelling conditions when increased plankton densities result in a decrease in water clarity within the surface mixed layer.

The satellite-tracked drifter deployed near the open section of the diffuser structure during the May 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.

Table 4. Instrumental Specifications for the CTD Instrumentation Package

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

[1] Maximum depth limit in meters

Instrumental Measurements

A Sea Bird Electronics SBE-19 Seacat CTD instrument package was deployed in both a vertical water-profiling mode and a towed configuration during the May 2009 survey and 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 instrumentation 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 May 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 from the probes and sensors on the CTD. Pressure housing limitations on the combination oxygen/pH sensor confine the CTD to depths less than 200 m (Table 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 in manufacturer's specifications, are also 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 towed 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 wastewater 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, 9±0.01, and 10±0.02 were used to bracket the range of in situ measurements. The SeaTech transmissometer was air calibrated by fitting the voltages recorded with and without blocking of the light transmission path in air, as recommended by the manufacturer (SBE 1989). Algorithms that converted sensor voltage to engineering units during processing of the field data relied on calibration coefficients determined before the survey.

Comparison with the factory calibration of the entire CTD package conducted in December 2001, and the more recent June 2006 replacement and calibration of the DO probe, confirmed the continued accuracy and stability of the temperature, pressure, and conductivity sensors, as well as the operational integrity of the oxygen and pH probes. 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. There was no perceptible drift in the pH and DO sensors during the May 2009 survey, although corrections for slight temporal drift in these sensors has occasionally been necessary in past surveys.

Before initial deployment for the vertical hydrocasts, the CTD was held below the sea surface for a nine-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.

Towed Survey

Following the vertical CTD casts collected at the six stations, the CTD was continuously towed around and across the zone of initial dilution 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 so that the reconfigured CTD package would tow at a depth of approximately 6.08 m given a vessel speed of 1.34 m/s, which corresponds to 800 rpm on the engine's tachometer. This satisfied the permit requirement for a towed survey in the upper water column near the base of the thermocline. At this speed, 1.5 CTD measurements were collected for each meter traversed, which complies with the permit requirement for at least one sample per meter. The CTD was towed continuously for 17 minutes along the yellow trackline shown in Figure 2. The vessel passed over the diffuser structure seven times to delineate the extent and magnitude of seawater anomalies associated with the wastewater plume as it underwent mixing within the thermocline. This satisfied the permit requirement for at least five passes through the ZID.

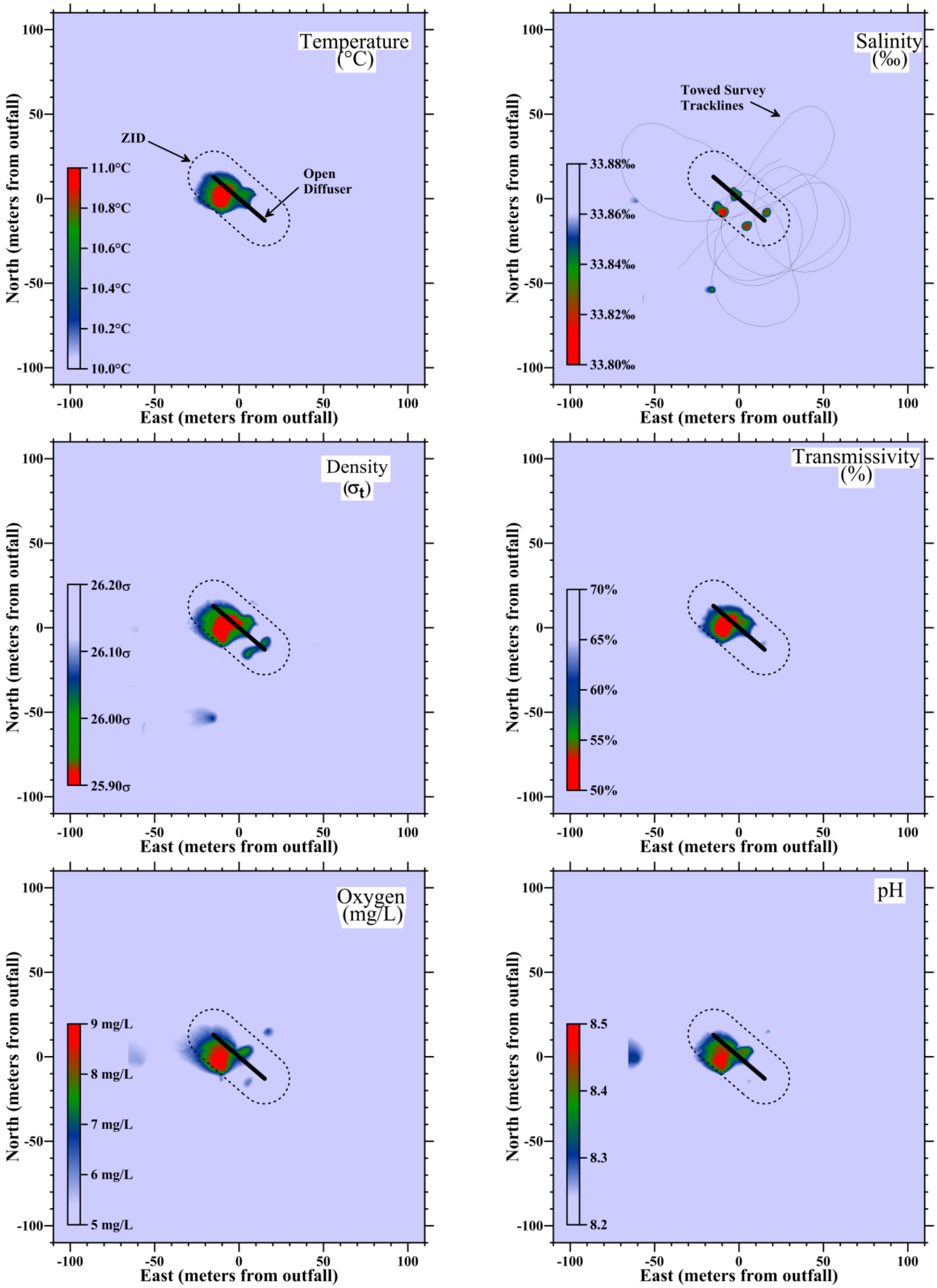

Figure 6. Horizontal Distribution of Water-Quality Parameters at 6.1 m below the Sea Surface

At 10:13 PDT, the CTD was redeployed with 15 m of towline, and was towed for 20 minutes at a speed of 1.17 m/s along the light-blue trackline shown in Figure 2. The CTD was towed over the diffuser structure nine times at a nominal depth of 10.6 m, or 3.65 m above the seafloor. This complied with the permit requirement for towing within 5 m of the bottom.

Contemporaneous navigation fixes were continuously collected throughout both of these tow deployments. The position of seawater measurements was determined by aligning the time stamps on the internally recorded CTD data with the digital navigation log. The data for the shallow survey were combined to produce the horizontal maps shown in Figure 6. The distributions of seawater properties at depth did not reveal the signature of the plume due to its exceedingly limited lateral extent near the seafloor, and because of the high level of random noise introduced by slight variations in depth during the tow, which caused the CTD to move in and out of a sharply defined bottom nepheloid layer. The deep-tow data were not analyzed further in this report.

RESULTS

The second-quarter water-quality survey began an hour and a half after sunrise at 08:33 PDT on Tuesday, 12 May 2009, with the deployment of the drogued drifter. Over the following two hours, all offshore observations and measurements were collected as required by the NPDES monitoring program. The survey ended at 10:33 PDT with the recovery of the CTD from its deep-tow configuration. Skies were clear throughout the survey, and in the absence of low-lying fog, atmospheric visibility along the ocean surface was good. Morro Rock and the shoreline remained visible throughout the survey, and 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 moderately strong and variable throughout the survey, ranging from 5.8 to 7.6 kt (Table 2). Corresponding, peak wind speeds ranged from 7.0 to 10.2 kt. In accordance with these winds, the surface sea state was composed of short-period wind-driven waves. Scattered white caps became more prevalent toward the end of the survey. A long-period swell out of the northwest had a significant wave height of five feet. Air temperature near 11°C was comparable with sea surface temperature.

Although, the discharge plume was not visually apparent during the survey, the Secchi depth of 5 m at RW4 was perceptibly deeper than at other stations, which measured 4 m, or less. Increased near-surface water clarity immediately south of the diffuser structure near RW4 was confirmed by instrumental measurements collected during vertical profiling (Figure 5).

During the May 2009 survey, observations demonstrated continued beneficial use of the coastal waters within Estero Bay by wildlife and recreational users. Limited numbers of pedestrians were observed using the beach during the course of the survey. Small numbers of California brown pelicans (*Pelecanus occidentalis californicus)*, Brandt's cormorants (*Phalacrocorax penicillatus*), pelagic cormorants (*Phalacrocorax pelagicus*), and western grebes (*Aechmophorus occidentalis*) were observed during transit to and from the survey area and during the course of the survey. Additionally, two gray whales (*Eschrichtius robustus*) were observed just outside the breakwater of the Morro Bay harbor mouth during transit to the survey site.

Table 5. Vertical Profile Data Collected on 12 May 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	10.478	10.700	10.821	9.449	11.324	11.059	34.339	33.993	33.912	33.933	33.850	33.997
1.0	10.094	10.526	10.485	9.447	10.570	11.032	34.029	33.848	34.069	33.931	34.126	33.965
1.5	9.847	9.906	10.428	9.447	10.475	10.309	33.969	33.984	33.840	33.935	33.935	34.151
2.0	9.881	9.771	10.113	9.446	10.201	10.155	33.979	34.013	33.844	33.938	33.984	34.025
2.5	9.873	9.866	9.828	9.443	10.106	9.989	33.988	34.022	33.934	33.940	33.940	33.981
3.0	9.830	9.760	9.796	9.448	9.892	9.841	34.008	34.046	33.869	33.939	33.930	33.955
3.5	9.741	9.717	9.677	9.459	9.697	9.575	34.002	33.997	33.963	33.944	33.936	34.001
4.0	9.652	9.656	9.601	9.471	9.546	9.564	34.004	34.003	33.959	33.954	33.978	34.010
4.5	9.590	9.599	9.596	9.469	9.529	9.506	34.012	34.012	33.977	33.950	33.989	34.022
5.0	9.586	9.567	9.584	9.469	9.516	9.468	34.001	34.012	33.994	33.947	34.004	34.028
5.5	9.546	9.505	9.585	9.471	9.509	9.457	34.013	34.025	33.990	33.951	34.005	34.023
6.0	9.528	9.487	9.517	9.476	9.478	9.447	34.012	34.017	34.009	33.959	34.021	34.024
6.5	9.501	9.483	9.516	9.475	9.471	9.433	34.022	34.016	34.004	33.967	34.020	34.024
7.0	9.494	9.477	9.477	9.471	9.458	9.410	34.019	34.018	34.019	33.978	34.017	34.028
7.5	9.459	9.471	9.479	9.472	9.431	9.402	34.017	34.017	34.012	33.990	34.028	34.029
8.0	9.442	9.467	9.474	9.479	9.421	9.396	34.020	34.016	34.011	33.998	34.027	34.027
8.5	9.430	9.461	9.476	9.449	9.403	9.389	34.020	34.015	34.011	34.009	34.032	34.027
9.0	9.420	9.450	9.474	9.417	9.394	9.371	34.024	34.017	34.008	34.016	34.029	34.031
9.5	9.416	9.440	9.469	9.406	9.383	9.362	34.024	34.019	34.009	34.018	34.027	34.031
10.0	9.408	9.431	9.464	9.393	9.369	9.363	34.021	34.019	34.012	34.020	34.024	34.027
10.5	9.403	9.423	9.451	9.384	9.353	9.350	34.022	34.018	34.016	34.018	34.030	34.031
11.0	9.395	9.411	9.450	9.372	9.349	9.350	34.023	34.021	34.012	34.022	34.030	34.030
11.5	9.389	9.389	9.434	9.366	9.349	9.347	34.022	34.029	34.013	34.011	34.027	34.030
12.0	9.383	9.384	9.420	9.365	9.349	9.346	34.023	34.024	34.017	34.020	34.029	34.029
12.5	9.375	9.378	9.414	9.348	9.349	9.345	34.025	34.023	34.016	34.027	34.028	34.030
13.0	9.374	9.375	9.406	9.347	9.345	9.347	34.023	34.022	34.016	34.023	34.029	34.029
13.5	9.373	9.375	9.386	9.351	9.350	9.351	34.023	34.022	34.021	34.023	34.029	34.027
14.0	9.374	9.379	9.374	9.354	9.358	9.354	34.020	34.021	34.020	34.021	34.029	34.029
14.5			9.367						34.022			
15.0												

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

Depth (m)	Density (sigma-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	26.353	26.045	25.960	26.210	25.822	25.984	8.136	8.237	8.366	8.005	8.407	8.285
1.0	26.178	25.962	26.142	26.209	26.171	25.964	8.229	8.293	8.365	8.005	8.423	8.346
1.5	26.173	26.174	25.973	26.212	26.039	26.236	8.252	8.295	8.315	8.005	8.334	8.389
2.0	26.175	26.220	26.030	26.215	26.124	26.164	8.208	8.240	8.262	8.005	8.294	8.335
2.5	26.183	26.211	26.148	26.217	26.106	26.158	8.175	8.182	8.220	8.005	8.237	8.270
3.0	26.206	26.248	26.103	26.215	26.135	26.162	8.153	8.173	8.188	8.005	8.196	8.214
3.5	26.216	26.217	26.196	26.217	26.172	26.243	8.145	8.176	8.134	8.005	8.154	8.175
4.0	26.232	26.231	26.206	26.223	26.230	26.252	8.130	8.134	8.109	8.007	8.081	8.126
4.5	26.249	26.248	26.221	26.220	26.241	26.271	8.116	8.117	8.087	8.010	8.067	8.072
5.0	26.241	26.253	26.236	26.218	26.255	26.282	8.097	8.106	8.079	8.010	8.058	8.058
5.5	26.257	26.273	26.232	26.221	26.257	26.280	8.081	8.086	8.080	8.010	8.046	8.046
6.0	26.259	26.270	26.259	26.226	26.274	26.282	8.077	8.074	8.066	8.010	8.038	8.029
6.5	26.272	26.270	26.255	26.233	26.274	26.284	8.068	8.055	8.063	8.014	8.029	8.025
7.0	26.270	26.272	26.273	26.242	26.274	26.291	8.062	8.044	8.057	8.015	8.023	8.017
7.5	26.274	26.273	26.267	26.252	26.288	26.293	8.035	8.033	8.044	8.013	8.019	8.013
8.0	26.279	26.272	26.267	26.256	26.288	26.293	8.031	8.025	8.017	8.015	8.015	8.009
8.5	26.282	26.272	26.267	26.270	26.295	26.294	8.023	8.019	8.022	8.016	8.011	8.006
9.0	26.286	26.276	26.265	26.281	26.294	26.300	8.021	8.017	8.020	8.015	8.008	8.004
9.5	26.287	26.279	26.266	26.284	26.294	26.301	8.020	8.015	8.018	8.010	8.006	8.002
10.0	26.286	26.281	26.269	26.287	26.295	26.298	8.015	8.015	8.015	8.006	8.005	8.001
10.5	26.288	26.281	26.275	26.287	26.302	26.304	8.015	8.013	8.015	8.006	8.004	8.001
11.0	26.290	26.285	26.272	26.292	26.303	26.303	8.010	8.010	8.015	8.006	8.001	7.998
11.5	26.290	26.295	26.275	26.285	26.300	26.303	8.010	8.010	8.011	8.003	8.001	7.996
12.0	26.291	26.292	26.281	26.292	26.302	26.303	8.009	8.009	8.010	8.004	8.001	7.996
12.5	26.294	26.292	26.281	26.300	26.301	26.303	8.006	8.006	8.010	8.000	7.996	7.996
13.0	26.293	26.292	26.282	26.298	26.303	26.302	8.006	8.006	8.010	8.003	7.996	7.996
13.5	26.293	26.292	26.290	26.297	26.302	26.300	8.006	8.006	8.010	8.001	7.996	7.996
14.0	26.291	26.290	26.291	26.295	26.300	26.301	8.006	7.993	8.007	8.001	7.996	7.996
14.5			26.294						8.006			
15.0												

Table 5. Vertical Profile Data Collected on 12 May 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	5.745	7.267	7.043	3.760	8.681	8.037	52.949	56.572	54.985	70.350	48.223	49.974
1.0	5.915	6.515	7.147	3.750	8.125	8.692	61.311	60.223	58.016	70.824	53.072	51.000
1.5	5.473	5.691	6.467	3.747	7.399	7.625	70.669	68.589	65.387	71.655	60.839	54.495
2.0	5.519	5.485	5.825	3.747	6.906	6.876	70.311	72.078	67.470	73.244	62.921	62.008
2.5	5.506	5.519	5.317	3.746	6.318	6.156	70.916	67.173	69.338	72.440	63.604	66.235
3.0	5.407	5.357	5.093	3.748	5.707	5.537	72.018	68.607	70.871	72.681	67.797	68.331
3.5	5.197	5.168	4.734	3.782	5.146	4.963	76.469	73.113	74.141	72.574	71.449	73.608
4.0	4.936	4.955	4.572	3.828	4.584	4.751	78.225	78.224	73.808	73.711	74.079	77.326
4.5	4.744	4.766	4.535	3.823	4.484	4.432	80.129	79.689	77.168	72.590	75.573	80.936
5.0	4.641	4.641	4.515	3.821	4.426	4.242	80.189	79.991	77.912	72.325	76.575	80.134
5.5	4.484	4.390	4.516	3.826	4.328	4.138	81.099	80.016	77.459	72.015	78.010	79.784
6.0	4.433	4.189	4.258	3.844	4.192	4.041	80.784	78.139	78.718	72.343	79.713	80.164
6.5	4.304	4.069	4.228	3.868	4.103	3.979	80.237	77.219	79.206	73.420	79.754	80.383
7.0	4.236	4.014	4.050	3.866	4.029	3.866	79.070	76.455	78.880	74.678	78.365	79.688
7.5	3.960	3.959	3.993	3.884	3.953	3.847	78.564	75.472	78.060	76.390	78.032	79.323
8.0	3.949	3.900	3.810	3.880	3.893	3.803	78.833	75.360	78.455	77.545	79.465	78.343
8.5	3.891	3.856	3.882	3.817	3.845	3.761	78.602	75.291	77.353	78.737	78.581	77.049
9.0	3.865	3.854	3.837	3.726	3.791	3.728	77.657	77.061	76.561	79.161	78.033	76.181
9.5	3.845	3.830	3.810	3.687	3.739	3.716	77.211	78.347	75.770	78.561	75.458	75.902
10.0	3.770	3.811	3.800	3.643	3.715	3.702	78.302	77.194	75.807	78.128	74.636	76.358
10.5	3.745	3.768	3.774	3.640	3.697	3.682	77.010	75.612	75.461	76.837	74.892	75.559
11.0	3.701	3.729	3.773	3.607	3.680	3.680	75.382	75.541	76.772	74.820	73.503	75.697
11.5	3.656	3.694	3.742	3.594	3.682	3.651	75.445	75.795	77.116	73.917	73.178	75.002
12.0	3.648	3.673	3.730	3.581	3.662	3.641	74.931	75.491	77.323	74.960	66.479	74.123
12.5	3.609	3.637	3.694	3.566	3.639	3.626	75.260	74.679	76.562	73.162	63.188	73.392
13.0	3.599	3.612	3.663	3.559	3.625	3.617	70.014	71.628	76.952	62.050	67.501	72.793
13.5	3.585	3.596	3.609	3.548	3.613	3.614	67.989	64.173	77.354	55.146	60.839	69.539
14.0	3.577	3.577	3.593	3.556	3.597	3.611	69.403	56.295	52.026	54.134	50.411	63.152
14.5			3.587						39.485			
15.0												

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 May 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 contaminants introduced by seafloor point sources (*e.g.*, ocean outfalls).

Upwelling-induced vertical gradients are plainly evident within the uppermost 5 m of the vertical profiles for most seawater properties at all stations except RW4 (Figure 5). Within this shallow mixed layer, density (black line) and transmissivity (light-blue line) generally increased with depth in conjunction with corresponding declines in temperature (red line), pH (gold line), and DO (dark blue line). Meanwhile, salinity (green line) underwent a slight increase with depth that was predominately masked 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 May 2009 survey. Salinity is computed from conductivity and temperature readings from two separate sensors that do not measure the same water parcel because the sensors are physically separated on the CTD, and because the sensors do not have the same response times. Because density is computed from salinity, it too exhibits a characteristic zigzag pattern in the upper water column, as shown by the black lines in Figure 5, especially at stations RW3, RW5, and RW6.

The vertical differences in seawater properties are a consequence of ambient physical, chemical, and biological processes that prevail during upwelling. The cold deep watermass that is transported shoreward during upwelling has characteristics that reflect its deep, offshore origins. For example, DO concentrations are comparatively low because biotic respiration and decomposition have slowly depleted oxygen levels in this deeper watermass since its contact with the atmosphere. Biotic respiration and decomposition also produce CO_2 (carbonic acid) which results in measurably lower pH (more acidic).

At the same time, phytoplankton growth, or 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 CO_2 and increase pH. During the May 2009 survey, surface DO concentrations were supersaturated. Increased primary production, namely, an increased density of phytoplanktonic organisms, decreases the transmission of ambient light though the near-surface mixed layer. This accounts for the near-surface reduction in transmissivity reflected by the light-blue lines in the vertical profiles in Figure 5. However, in addition to its reduction in the surface euphotic layer, and in contrast to other seawater properties, transmissivity also drops sharply near the seafloor. This seafloor reduction in water clarity is even apparent at RW4, where the rising effluent plume had mixed all the other seawater properties to near uniformity. The reduced water clarity near the seafloor during the May 2009 survey was caused by the presence of light-weight flocs of detritus that are resuspended by the turbulence generated by bottom currents. Particle-rich bottom-nepheloid layers (BNLs) are a widespread phenomena on continental shelves (Kuehl et al. 1996) that are frequently observed during the offshore water-quality surveys conducted for the MBCSD.

Outfall Performance

The condition and efficacy of the outfall and diffuser structure on 12 May 2009 can be determined from dilution levels measured during the survey. Dilution levels can be computed from the salinity distribution at the time of the survey. Isolated patches of low salinity are apparent in the towed-survey map shown in the upper right frame of Figure 6. These localized salinity anomalies undoubtedly reflected the presence of dilute wastewater within the effluent plume as it rose and spread within the water column. The salinity anomalies coincided spatially with anomalies in other seawater properties, further confirming its discharge origin. Salinity anomalies lend insight into the effectiveness of the outfall at dispersing effluent, while the associated anomalies in other seawater properties lend insight into compliance with the receiving-water objectives of the COP and NPDES discharge permit, as described below.

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 constituents in effluent prior to discharge. The critical initial dilution applicable to the MBCSD outfall was conservatively estimated to be 133:1 (Tetra Tech 1992). This estimate was based on worst-case modeling under highly stratified conditions where trapping of the plume below the thermocline restricted mixing during the buoyant plume's rise through the water column. The dispersion modeling determined that, at the conclusion of initial mixing, 133 parts of ambient water would have mixed with each part of wastewater. The modeling predicted that this dilution would be achieved after the plume rose only 9 m from the seafloor, whereupon it would become trapped beneath a thermocline and spread laterally with no further substantive dilution. A 9-m rise at the outfall translates into a trapping depth that is 6.4 m below the sea surface, slightly below the depth of the shallow towed survey. However, as described below, during the May 2009 survey the plume was still buoyant at that tow depth, and it continued to mix during its rise to the surface. Moreover, it had achieved a higher dilution level 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.

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

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

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

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

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 in the upper-right frame of Figure 6 results in the dilution distribution shown in Figure 7. It demonstrates that the magnitude of the observed salinity anomaly (> –0.185‰) represents a dilution exceeding 182 fold. Moreover, the plume was continuing to rise within the water column, and ultimately achieve much higher dilutions when it reached the sea surface. These measurements demonstrate that the modeled dilution factor (133:1) was significantly more conservative than that actually achieved by the discharge (>182:1) during the May 2009 survey. This dilution computation demonstrates that, during the May 2009 survey, the outfall was performing better than designed and was rapidly diluting effluent more than 182-fold prior to completing the initial-dilution process. Consequently, during the May 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.

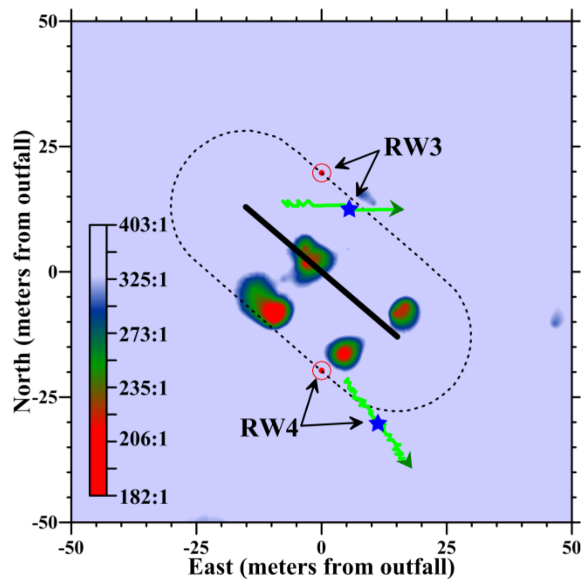

Figure 7. Plume Dilution Computed from Salinity Anomalies in Figure 6

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 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 turbulent mixing during its further ascent to the sea surface.

Although a sharp thermocline was present at the time of the May 2009 survey, it was neither deep enough nor strong enough to prevent the effluent plume's rise to the sea surface. This is apparent from the striking contrast between the nearly uniform vertical profiles at RW4, in the middle-right frame of Figure 5, and the strongly stratified conditions at all the other stations. Because the rising effluent plume carried seawater that was entrained at depth to the sea surface, seawater properties within the upper water column were strikingly different at RW4 from those of the surrounding seawater.

For example, as shown by the light blue lines in Figure 5, entrainment and upward displacement of naturally less-turbid seawater at depth eliminated the near-surface reduction in water clarity that was associated with upwelling-induced planktonic blooms at all other stations. As a result, the transmission of ambient light was higher at RW4, as reflected by the one-meter increase in Secchi depth (Table 2). Thus, although the increase in transmissivity was related to the discharge through the dynamics of plume entrainment, it was not caused by the presence of wastewater particulates which should have resulted in a decrease in near-surface transmissivity.

Plume dynamics are an important consideration because all of the receiving-water limitations imposed by the discharge permit apply only to impacts from the presence of wastewater constituents, and not to discharge-related changes that arise from the displacement of ambient seawater from one location to another. As with transmissivity, near-surface reductions in temperature, dissolved oxygen, and pH that are apparent in the vertical profiles at RW4 are opposite the changes likely to be induced by the presence of incompletely mixed effluent.

In contrast to the entrainment-generated anomalies at RW4, the anomalous seawater properties mapped within the ZID in Figure 6 were caused the presence of dilute effluent. The increase temperature (upper-left frame), DO (lower-left frame), and pH (lower-right frame) would not have been caused by the upward displacement of ambient seawater. As shown in Figure 5, deep seawater is colder, less oxygenated, and more acidic than surface waters. Wastewater, on the other hand, is warmer and less acidic than the receiving waters. Also, because it has been in recent contact with the atmosphere, and because the treatment process removes nearly all of the oxygen-demanding materials, discharged effluent tends to be more oxygenated than seawater at depth. Similarly, in the presence of very high seawater clarity at mid-depth during the May 2009 survey, the diffuse cloud of wastewater particulates appears as a slight decrease in transmissivity (middle-right frame of Figure 6). Lastly, warm wastewater is buoyant upon discharge, and the reduced density observed within the ZID (middle-left frame of Figure 6) demonstrates that the discharge plume was still buoyant when it was encountered by the CTD as it was towed at a depth near 6 m. Thus, the towed survey captured the plume while it was continuing to rise within the water column and experience further initial dilution within the ZID. Upon reaching the sea surface at RW4, the signature of wastewater constituents had entirely dissipated.

COMPLIANCE

Sampling during the May 2009 survey demonstrated that the wastewater discharge complied with the receiving-water limitations specified in the NPDES permit and thereby met 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 applicable narrative limits, and instrumental measurements complied with all quantitative limits on seawater properties.

Although discharge-related changes in all six seawater properties were observed during the May 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. Except for limits on visible debris on the ocean surface and thermal restrictions, receiving-water limitations only apply to statistically significant changes caused by the presence of effluent constituents beyond the ZID boundary. The measurements collected during the May 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 effluent itself, could be distinguished.

Receiving-Water Limitations

The seawater properties measured during the May 2009 survey were evaluated for compliance with the pertinent receiving-water limitations of the NPDES discharge permit. Compliance with some of the other receiving-water limitations, such as those pertaining to bacterial standards, seafloor sediments, algal growth, biological characteristics, and radioactivity is assessed through other components of the monitoring program.

The quarterly water-column sampling described in this report is designed to evaluate receiving-water limitations specified in the permit that state 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*.

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.

Temperature

The total range in temperature of 2ºC across all observations was too minimal "*to adversely affect beneficial uses*." This range was substantially smaller than the large-scale spatial variability in sea-surface temperature shown in the satellite image on the cover of this report. Most of the variation in temperature observed during the stratified conditions of the May 2009 survey was due to naturally occurring vertical stratification. In fact, the highly localized 1ºC thermal anomaly that was measured within the effluent plume during the shallow towed survey (upper-right frame of Figure 6), resulted in an 11ºC subsurface temperature that still well below the highest measured sea surface temperature of 11.3ºC (Table 5).

Light Transmittance

As with the wastewater-induced thermal anomaly observed during the towed survey, the corresponding reduction in transmissivity was too small to be of significance compared to natural variability in seawater clarity at the time of the survey. The 20% reduction in transmissivity observed within the plume (middle-right frame of Figure 6) resulted in a measured transmissivity (50%) that was still well above the lowest transmissivity (39.5%) measured above the seafloor at RW3 (Table 5). More importantly, the discharge-related transmissivity reduction was measured within the ZID, where the permit restrictions do not apply, and at a depth (6.1 m) near the base of the euphotic zone where little ambient light penetrates. Thus, the presence of this cloud of diffuse particulates did not constitute a "*significant reduction in the transmittance of natural light*."

Dissolved Oxygen

Although unstated in the NPDES discharge permit, the COP specifies that the DO limitation only applies to reductions that occur "*as a result of the discharge of oxygen demanding waste materials*." Measurements from 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 May 2009 survey when obvious, wastewater-induced anomalies were found in other seawater properties within the ZID, but corresponding DO concentrations were actually higher than in the surrounding ambient seawater. Therefore, no single measurement was "*depressed more than 10 percent from that which occurs naturally*" as specified in the permit limit.

pH

As with the other permit limits, restrictions on discharge-related changes in pH only apply beyond the ZID after initial dilution is complete. Thus, the numerical permit limits do not apply to changes in pH observed within the effluent plume during the towed survey. Not only was the wastewater-induced pH change restricted to the ZID, but the effluent plume had yet to complete the initial dilution process. As demonstrated by the measurements collected along the ZID boundary at RW4 (Table 5, Figure 5), seawater pH complied with the numerical limits on pH upon completion of dilution. At 0.016 units, the total range in pH remained within the permitted 0.2 units, as well as complying with the prescribed lower and upper bound limits of 7.0 and 8.3.

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