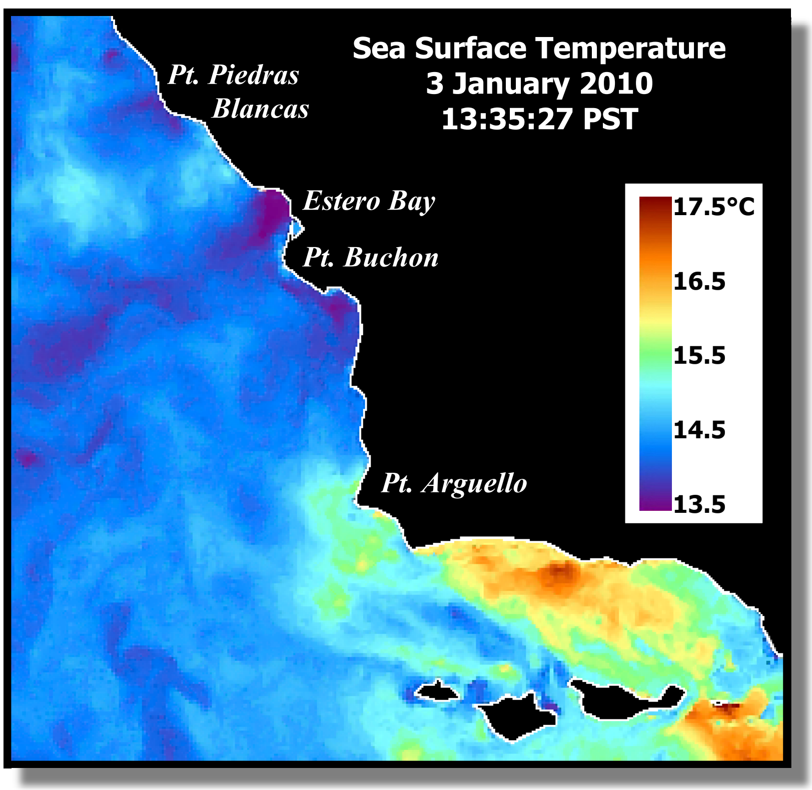
City of Morro Bay and
Cayucos Sanitary District

OFFSHORE MONITORING AND REPORTING PROGRAM

FIRST QUARTER RECEIVING–WATER SURVEY

JANUARY 2010



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Report to the

City of Morro Bay and Cayucos Sanitary District

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JANUARY 2010

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April 2010

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

29 April 2010

Reference: First Quarter Receiving-Water Survey Report – January 2010

Dear Mr. Keogh:

The attached report presents results from a quarterly receiving-water survey conducted on Tuesday, 5 January 2010. 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 winter 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 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 northeast 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,

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.

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Mr. Rob Livick
Interim Director of Public Services
City of Morro Bay

Date ______________________________

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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) issued the first National Pollutant Discharge Elimination System (NPDES) permit to the MBCSD. The permit incorporated partially modified 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 January 2010 field survey described in this report was the fourth 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 5 January 2010. Specifically, this first-quarter survey captured ambient oceanographic conditions along the central California coast during the winter season. The survey's measurements were used to assess the discharge's compliance with the objectives of the California Ocean Plan (COP) and the central coast Basin Plan (RWQCB 1994) as promulgated by the receiving-water limitations specified in the NPDES discharge permit.

The receiving-water survey also provided a current assessment 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 compared to original design specifications. As described in this report, no such decline was observed during the January 2010 survey.

The 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 CTD[1] instrument package repeatedly over the diffuser structure. The tow survey component of the monitoring program 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 determination of the plume's spatial extent is important for assessing compliance with water-quality objectives that only apply beyond the narrow 15-m wide zone of initial dilution surrounding the outfall. As described in this report, the data collected during the January 2010 survey delineated the presence of dilute effluent undergoing turbulent mixing within the water column immediately northeast 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. The diffuser structure extends an additional 52 m toward the northwest from the outfall terminus.

[1] Conductivity, temperature, and depth (CTD)

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 six other 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 of a failure in the treatment plant's disinfection system, collection and analysis of water samples at the surfzone sampling stations shown in Figure 1 would be conducted to monitor for potential shoreline impacts. 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).

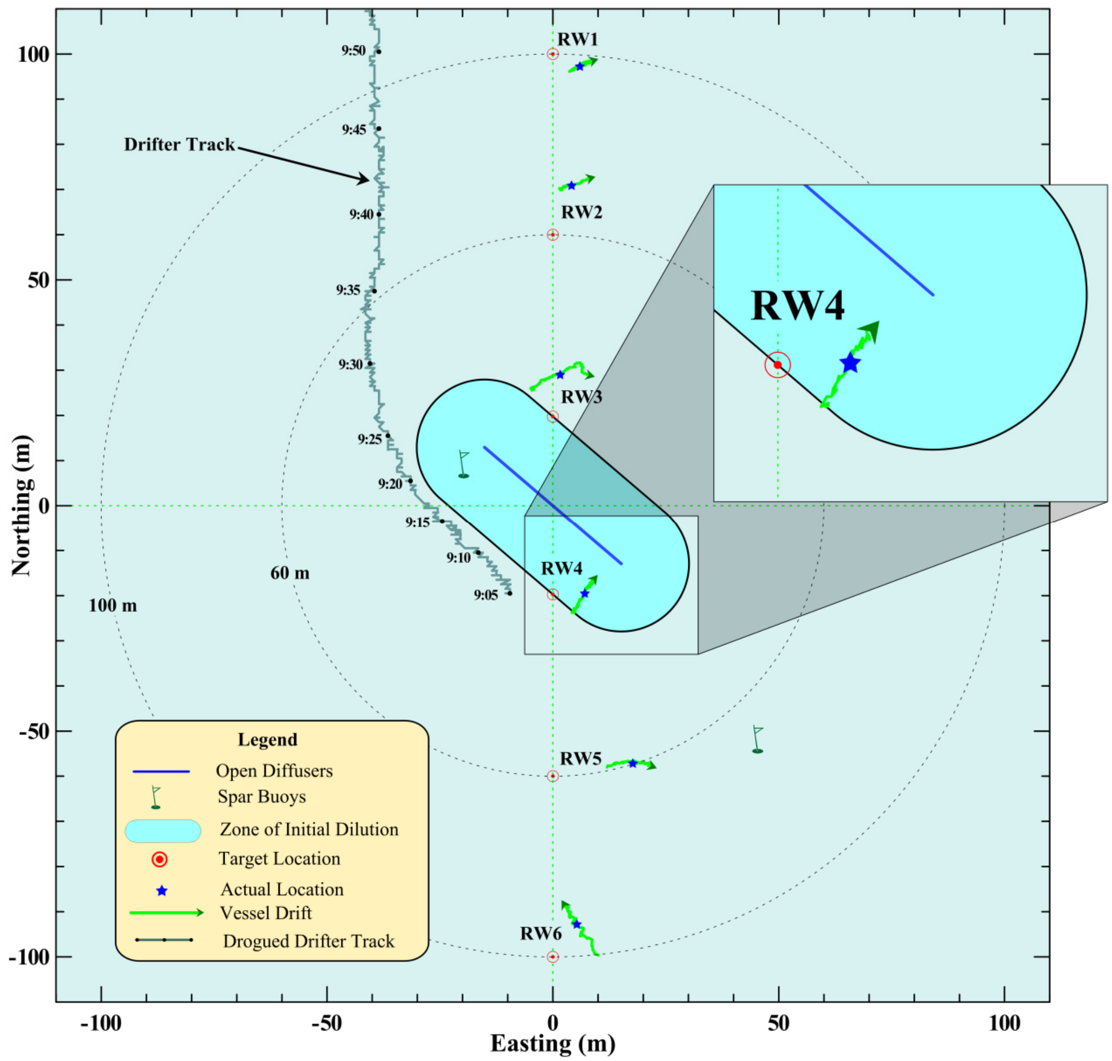

Figure 2. Sampling Station Locations and Drifter Track

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

Station	Description	Latitude	Longitude	Center Distance[2] (m)	Closest Approach Distance[3] (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

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

Another important consideration for compliance evaluation is the ability to determine the actual location of the measurements. Discerning small spatial separations within the compact sampling pattern only became feasible after the advent of Differential Global Positioning Systems (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. Real-time correction for these position errors provides 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 further ensures extremely accurate and uninterrupted navigational reports.

Frequent recording of DGPS positions at one-second intervals allows precise determination of sampling locations throughout the vertical CTD profiling conducted 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 metocean[4] 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 quantified, 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 January 2010 survey is apparent from the length of the green tracklines in Figure 2. These tracklines trace the horizontal movement of the CTD as it was lowered to the seafloor. Their length and offset from the target locations reflect the overall station-keeping ability during the January 2010 survey. During the time it took the CTD to traverse the water column and reach the seafloor, which averaged 1 min 24 s, the instrument package moved an average of 9.2 m, which was comparable to most prior surveys.

The CTD trajectories shown by the tracklines in Figure 2 often reflect complex interactions between surface currents and wind forces that act on the survey vessel during sampling. Due to the calm sea conditions at the time of the January 2010 survey; however, the tracklines in the Figure primarily reflect the residual momentum of the survey vessel as it approached each target location. As seen in Figure 2, the vessel approached most stations from the southwest. Although brief thrust reversals were successful at eliminating the majority of residual vessel momentum prior to initiation of the downcast, a limited northeastward drift is apparent at most stations.

Lateral movement of the CTD during the vertical hydrocasts can complicate the assessment of compliance with discharge limitations at stations close to the diffuser structure because receiving-water limitations only apply to measurements recorded beyond the ZID boundary. For example, the mean location of Station RW4 was only 10.2 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 RW4. However, closer inspection of the actual CTD trajectory during the downcast at RW4,

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[4] Meteorological and oceanographic conditions include winds, waves, tides, and currents.

as shown by the green arrow, indicates that the CTD traversed the ZID boundary en route to the seafloor, and that a limited number of measurements recorded by the CTD near the sea surface at the beginning of the downcast were subject to permit limitations.

Determining which measurements are 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 located within the ZID, much less how the CTD was moving laterally during the hydrocast. 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 January 2010 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 January 2010 Survey

	Time (PST)				Closest Approach	
Station	**Downcast**	**Upcast**	**Latitude**	**Longitude**	**Range[1](m)**	**Bearing[2](ºT)**
RW1	9:39:59	9:41:18	35° 23.252' N	120° 52.500' W	87.0	14
RW2	9:35:58	9:37:04	35° 23.237' N	120° 52.501' W	61.1	18
RW3	9:31:03	9:32:39	35° 23.215' N	120° 52.503' W	23.2	41
RW4	9:26:49	9:28:29	35° 23.188' N	120° 52.499' W	**10.2** [3]	221
RW5	9:23:32	9:24:53	35° 23.168' N	120° 52.492' W	44.2	177
RW6	9:18:55	9:20:17	35° 23.149' N	120° 52.500' W	80.3	187

[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] Most of the CTD cast at this station was located within the ZID boundary.

Compliance assessments notwithstanding, measurements acquired from within the ZID lend valuable insight into the outfall's effectiveness at dispersing wastewater. For example, low dilution rates and concentrated effluent throughout the ZID would indicate 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. The addition of the tow-survey component in the current permit augments the vertical profiles with 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, northward flow during the January 2010 survey (Figure 3). The drogued drifter was deployed south of the diffuser structure near Station RW4 at 9:05 PST, and was recovered at a location 350 m due north of its deployment location two hours later, after having traveled 440 m along a rather circuitous path to get there. The drifter is designed to track the subsurface current, with little influence from wind. As such, the drifter track provides a good indication of the plume's movement at the time of the survey.

During most surveys, the direction of ocean flow remains relatively constant. However, the sinuous drifter path observed during the January 2010 survey documented multiple changes in flow during its two-hour deployment. As a result, the effluent plume's location relative to the diffuser structure changed as the January 2010 survey progressed. For example, during the vertical-profiling conducted at the beginning of the survey, the plume was documented almost due north of the diffuser structure. Later, however, during the tow component of the survey, the plume's position had shifted toward the northeast in response to the development of an eastward component in the ambient flow field that is evident in the drifter track in Figure 3 after 10:30.

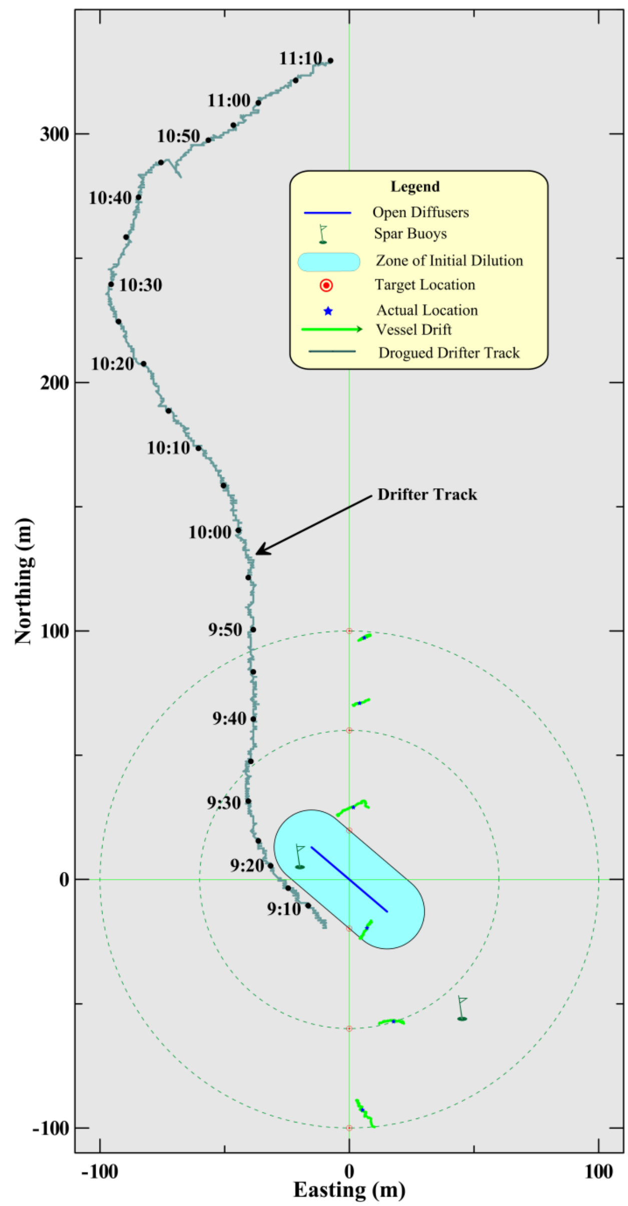

Figure 3. Drogued Drifter Trajectory

In addition to the pronounced shift in the flow field described above, several other less dramatic alterations in flow direction are also apparent in Figure 3. During the first ten minutes of the survey following the deployment of the drifter, and encompassing the vertical cast at Station RW6, flow was directed toward the northwest. Shortly thereafter, the flow direction became due north, and remained so for the next 40 minutes. By the time the tow survey began at 10:15, however, the flow had again acquired a slight westward component.

Despite the observed changes in direction, flow speeds throughout the survey were stable at approximately 5 cm/s, or 0.1 knots. The black dots in Figure 3 show the drifter's progress at five-minute intervals. The uniform spacing between the time stamps reflects the relatively constant speed of the drifter.

The dramatic change in flow direction that occurred at 10:30 PST was unrelated to any change in tidal flow (Figure 4). The incoming (flood) tidal phase that prevailed throughout the survey would not have induced the observed flow reversals noted in the drifter track, although the overall northward prevailing flow may have been strengthened by tidal forces. In the absence of other influences, a flood tide normally induces a weak northeastward onshore flow in the survey region. Consequently, while tides may have enhanced the northward flow component, other metocean processes undoubtedly dictated the detailed flow dynamics seen in Figure 3.

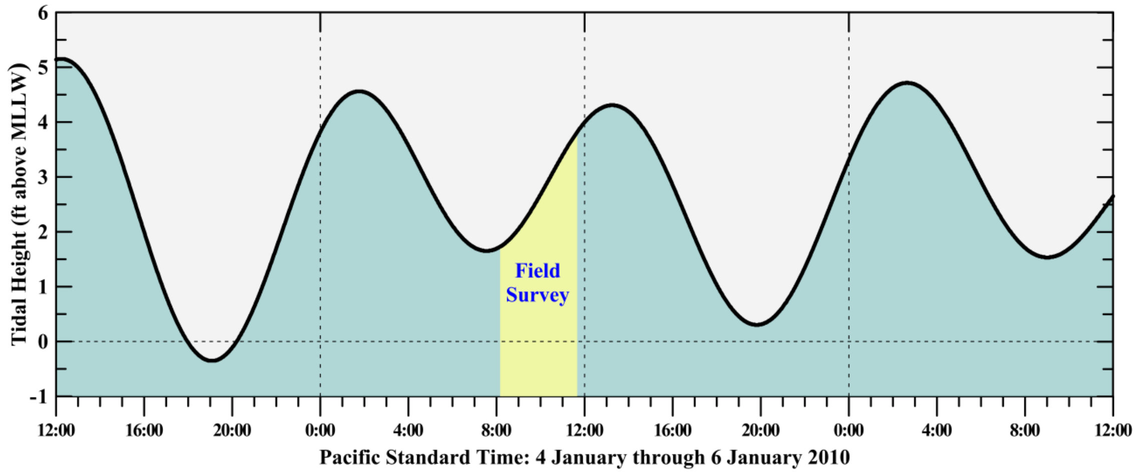

Figure 4. Estero Bay Tidal Level during the January 2010 Survey

Flow within Estero Bay is usually dominated by external processes, such as wind-generated upwelling, downwelling, or offshore eddies migrating past Estero Bay. These external flow influences are apparent in the complexity of sea-surface temperatures depicted in the satellite image on the cover of this report. The cover image was recorded on the afternoon of 3 January 2010, two days prior to 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. Sea surface temperatures in the image were approximately one half-degree warmer than those measured during the survey, two days later (*c.f.*, 13.5°C on the cover image and 12.9°C measured during the survey[5]).

In the cover image, warm water, delineated by yellow and orange shading near Pt. Argeullo, is being carried northward from the Santa Barbara Channel by the Davidson current. A cell of high-atmospheric pressure that stagnated over the western US in January 2010 generated light but sustained northwestward winds along most of the central coast that persisted throughout the month, allowing a strengthening of the northward-flowing Davidson current. These light "Santa Ana" winds are opposite of the southeastward winds that normally prevail in the region, and resulted in downwelling along much of the coast (Figure 5). Downwelling events, indicated by the negative (red) indices in Figure 5 occur infrequently, and almost exclusively in winter, when Santa Ana conditions or 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 the water column. The vertically uniform water column conditions observed during the January survey were typical of downwelling events, although the extended duration of the January downwelling event was unusual.

In contrast to the conditions present during the January 2010 survey, during most of the year upwelling prevails along the central coast. Upwelling normally begins sometime during late March and or early April when there is a spring transition to persistent southeastward-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,

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

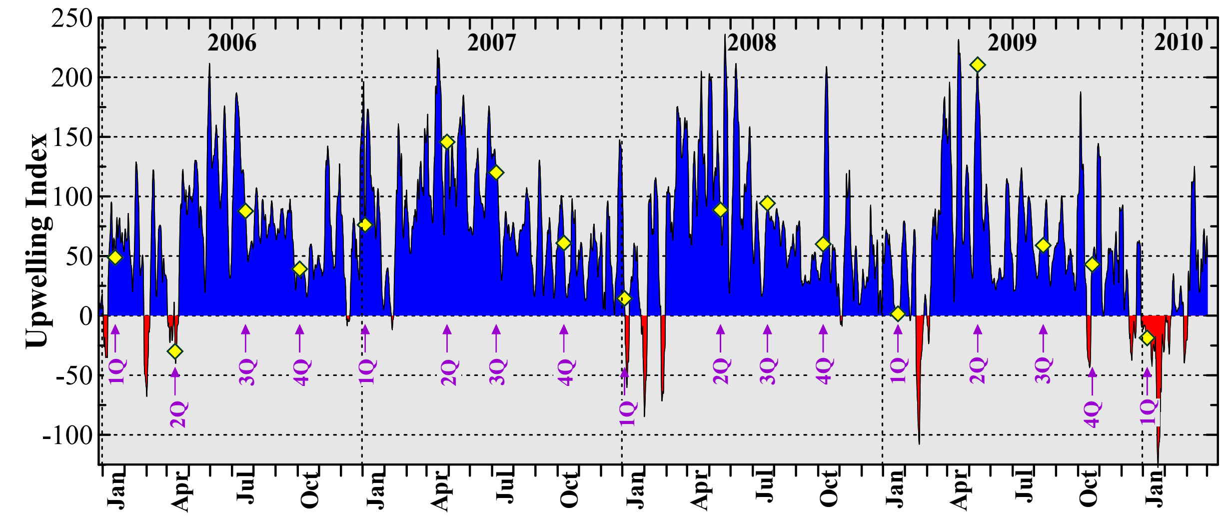

Figure 5. Five-Day Average Upwelling Index (m^3/s/100m of coastline)

upwelling conditions continue to prevail through the summer and fall, as shown by the positive (blue) upwelling indices in 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 5 January 2010. Bonnie Luke of Marine Research Specialists (MRS) was the Chief Scientist and collected auxiliary measurements of biological, meteorological, and oceanographic conditions. Douglas Coats, also of MRS, provided navigational support during the survey. Mark Tognazzini supervised vessel operations, and William Skok acted as marine technician responsible for the CTD and drifter deployments.

Auxiliary Measurements

Auxiliary measurements and observations were collected during 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.

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 sediment 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.

The 5-m Secchi depths recorded at the three stations (Stations 4, 5, and 6) unaffected by the northerly flowing plume indicated a moderate level of ambient water clarity during the January 2010 survey (Table 3). The Secchi depths reflected the presence of a 10-m euphotic zone that spanned two-thirds of the 15-m

Table 3. Standard Meteorological and Oceanographic Observations

Station	Location[7] Latitude	Location[7] Longitude	Diffuser Distance (m)	Time (PST)	Air (°C)	Cloud Cover (%)	Wind Avg (kt)	Wind Max (kt)	Wind Dir (from) (°T)	Swell Ht/Dir (ft/°T)	Secchi Depth (m)
RW1	35° 23.255' N	120° 52.499' W	92.5	9:40:42	17.2	10	1.8	3.0	NW	1-3/WNW	4.0
RW2	35° 23.234' N	120° 52.501' W	55.5	9:36:30	15.9	0	2.7	5.0	NW	1-3/WNW	3.0
RW3	35° 23.212' N	120° 52.501' W	21.7	9:31:48	19.4	0	1.2	2.5	NW	1-3/WNW	3.0
RW4	35° 23.189' N	120° 52.504' W	13.2	9:27:33	19.0	0	1.7	3.6	NW	1-3/WNW	5.0
RW5	35° 23.169' N	120° 52.495' W	42.9	9:24:47	19.8	0	1.3	1.9	NW	1-3/WNW	5.0
RW6	35° 23.150' N	120° 52.506' W	79.5	9:20:44	21.1	0	1.1	2.7	NW	1-3/WNW	5.0

water column. In reality, the euphotic zone may have been less than 10 m at the time of the survey, however, because of the presence of a turbid benthic nepheloid layer (BNL) immediately above the seafloor.[6] BNLs are observed in the CTD measurements during most surveys but are not reflected in Secchi depths because the disk does not extend into the BNL before disappearing from sight. In addition, turbidity within the January 2010 BNL was enhanced by the presence of particulates from the discharge of dredging spoils on the beach immediately adjacent to the survey area.

The satellite-tracked drifter deployed near the diffuser structure during the January 2010 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 dictate 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 which continuously recorded the drifter's position throughout its deployment. These detailed measurements were essential in evaluating observed alterations in the plume's direction that occurred between the vertical and tow components of the January 2010 survey due to changes in ambient flow direction within the water column.

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 January 2010 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 January 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 January 2010 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 established through regression analysis of sensor-

6 The increased BNL turbidity is apparent in the vertical profiles of transmissivity, shown by the light blue lines in Figure 7.
7 Locations are the vessel positions recorded at the time the Secchi depth was measured.

membrane current and temperature, as recommended by the manufacturer (SBE 1993). As in previous surveys, the pre-cruise calibration coefficients determined by MRS closely corresponded with prior factory calibrations.

The six seawater properties used to assess receiving-water quality in this report were derived from the continuously recorded output of the CTD's probes and sensors. Pressure housing limitations on the combination oxygen/pH sensor confine the CTD to depths less than 200 m (Table 4), which is well beyond the maximum depth of the deepest station in the outfall survey. The precision and accuracy of the various probes, as reported in manufacturer's specifications, are listed in Table 4. Salinity (‰) was calculated from conductivity measurements reported in units of Siemens/m. Density was derived from contemporaneous temperature (°C) and salinity data, and was expressed as 1000 times the specific gravity minus one, which is a unit of sigma-T (σ_t).

Table 4. CTD Specifications

Component	Depth[8]	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

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 0.072 pH units.

[8] Maximum depth limit in meters

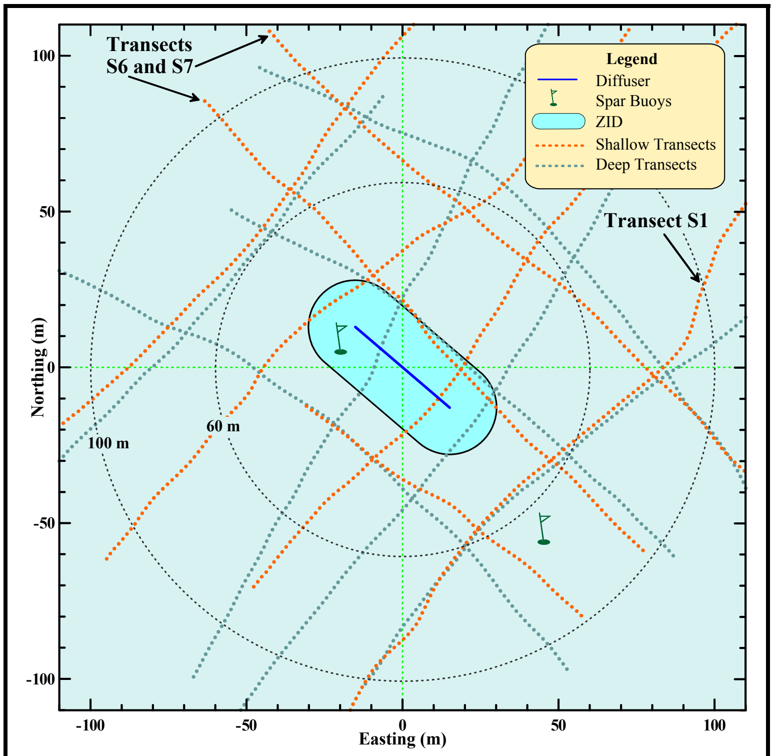

Figure 6. CTD Tracklines during the Tow Surveys

DO data collected during the first two vertical profiles were compromised by incomplete evacuation of air from the ducting leading from the DO plenum to the pump on the CTD. As a result, DO measurements at Stations RW5 and RW6 were artificially reduced by as much as 0.5 mg/L. Because the compromised DO measurements were collected well south of the diffuser structure, however, they did not affect compliance evaluation because the direction of plume transport was toward the north. A similar problem with air in the ducting occurred at the beginning of the tow survey, and led to the exclusion of DO data from shallow Transect S1 (Figure 6). Again, however, because these DO data were collected well south of the diffuser structure and beyond the influence of the plume, their exclusion did not affect the compliance evaluation.

Before initial deployment for the vertical hydrocasts, the CTD was held below the sea surface for a six-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 9:43 PST, following the last vertical profile at RW1, the CTD instrument package was fitted with a depth-suppressor and horizontal stabilizer to achieve constant-depth tows with forward-looking sensor probes. Fifteen meters of towline were deployed and the reconfigured CTD package was towed at an average depth of 3.47 m, and an average speed of 1.62 m/s for 26 min, passing near the diffuser structure seven times (Figure 6). Subsequently, an additional 8 m of towline was paid-out, and eight passes were made at an average depth of 6.56 m.

During the 27-minute mid-depth-tow survey, vessel speed averaged 1.60 m/s. At the observed towing speeds and a 2 Hz sampling rate, 1.25 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.[9]

RESULTS

The first-quarter receiving-water survey began approximately two hours after sunrise at 09:05 PST on the morning of Tuesday, 5 January 2010, following 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 11:10 PST with the recovery of the CTD from its mid-depth-tow configuration and the retrieval of the drogued drifter. Skies were clear throughout the survey, although a fog line persisted well offshore. Nevertheless, observations of beneficial use and the collection of required visual observations of the sea surface were unencumbered.

Auxiliary Observations

Winds were mild throughout the January 2010 survey. Average wind speeds, calculated over one-minute intervals, ranged from 1.1 to 2.7 kt, while peak wind speeds ranged from 1.9 to 5.0 kt (Table 3). There was a swell out of the northwest with a significant wave height of 1 to 3 feet. Air temperatures were consistently warmer than average surface-water temperatures, varying from 15.9°C to 21.1°C.

During the January 2010 survey, visual observations demonstrated continued beneficial use of the coastal waters within Estero Bay by both wildlife and recreational users. Wildlife sightings during the survey were dominated by Brandt's cormorants (*Phalacrocorax penicillatus*), pelagic cormorants (*Phalacrocorax pelagicus*), and western gulls (*Larus occidentalis*). In addition, California brown pelicans (*Pelecanus occidentalis californicus*), pigeon guillemots (*Cepphus Columba*), and common murres were encountered within the confines of the harbor mouth near Morro Rock, and en route to the survey site. Rafting otters were also noted within the harbor mouth, including at least one juvenile.

Beach usage by pedestrians during the January 2010 survey was limited due to the ongoing discharge of dredged materials from the harbor mouth onto the adjacent beach. Spoils from the maintenance dredging at the Morro Bay harbor entrance were being released on the beach immediately shoreward of the survey area. The sediment-laden slurry flowed down the beach and into the surfzone, where it was visually apparent as a turbid plume extending throughout much of the nearshore littoral zone shoreward of the survey area. The influence of the dredge spoils was reflected in a marked increase in near-bottom turbidity within all six vertical CTD profiles. It was also apparent as a localized increase in turbidity within the surfacing wastewater plume. As discussed below, the observed increases in turbidity within the plume were far larger than those that would be generated by the presence of wastewater particulates alone. Instead, the increased turbidity within the rising effluent plume was caused by the entrainment of dredge material. There was no evidence of wastewater-related floating particulates, oil sheens, or discoloration of the sea surface observed at any of the stations during vertical profiling, or at any other time during the survey.

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 January 2010 survey reflect weakly stratified conditions indicative of the prevailing downwelling conditions. Downwelling events are rare and brief compared to the upwelling conditions that prevail most

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9 Figures 8 and 9 present the horizontal maps of seawater properties measured during the January survey.

Table 5. Vertical Profile Data Collected on 5 January 2010

Depth (m)	Temperature (°C)						Salinity (‰)					
	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6
0.5	12.875	12.873	12.868	12.907	12.894	12.882	33.350	33.338	33.304	33.357	33.364	33.399
1.0	12.874	12.874	12.867	12.900	12.890	12.880	33.353	33.337	33.307	33.359	33.370	33.397
1.5	12.871	12.874	12.867	12.895	12.886	12.878	33.363	33.337	33.305	33.364	33.375	33.397
2.0	12.867	12.871	12.864	12.886	12.877	12.876	33.375	33.341	33.314	33.374	33.382	33.397
2.5	12.869	12.868	12.862	12.880	12.877	12.876	33.373	33.356	33.338	33.379	33.382	33.398
3.0	12.868	12.868	12.862	12.875	12.875	12.875	33.378	33.365	33.342	33.384	33.383	33.399
3.5	12.865	12.867	12.862	12.871	12.875	12.875	33.382	33.375	33.346	33.388	33.390	33.399
4.0	12.868	12.866	12.859	12.870	12.875	12.874	33.384	33.380	33.358	33.389	33.391	33.400
4.5	12.868	12.866	12.855	12.868	12.874	12.873	33.385	33.385	33.375	33.390	33.392	33.400
5.0	12.862	12.867	12.852	12.867	12.871	12.872	33.387	33.389	33.385	33.392	33.393	33.400
5.5	12.858	12.868	12.853	12.867	12.870	12.872	33.390	33.389	33.383	33.392	33.393	33.400
6.0	12.857	12.868	12.857	12.868	12.867	12.871	33.391	33.389	33.369	33.392	33.394	33.400
6.5	12.856	12.867	12.859	12.868	12.868	12.871	33.392	33.390	33.360	33.391	33.395	33.399
7.0	12.856	12.865	12.859	12.867	12.868	12.869	33.392	33.391	33.357	33.392	33.395	33.400
7.5	12.855	12.864	12.860	12.863	12.868	12.867	33.392	33.391	33.357	33.393	33.395	33.400
8.0	12.852	12.863	12.859	12.859	12.867	12.866	33.393	33.391	33.360	33.395	33.395	33.401
8.5	12.850	12.861	12.858	12.853	12.867	12.866	33.393	33.392	33.364	33.395	33.396	33.401
9.0	12.850	12.860	12.857	12.851	12.866	12.864	33.393	33.392	33.368	33.397	33.395	33.401
9.5	12.851	12.861	12.855	12.850	12.858	12.864	33.394	33.392	33.380	33.397	33.397	33.400
10.0	12.852	12.861	12.855	12.849	12.853	12.860	33.393	33.392	33.380	33.396	33.396	33.400
10.5	12.851	12.857	12.855	12.849	12.854	12.855	33.393	33.393	33.379	33.395	33.397	33.402
11.0	12.850	12.854	12.856	12.848	12.848	12.851	33.394	33.393	33.384	33.396	33.398	33.401
11.5	12.848	12.856	12.856	12.845	12.847	12.851	33.394	33.393	33.386	33.397	33.397	33.401
12.0	12.850	12.856	12.858	12.844	12.846	12.844	33.394	33.393	33.387	33.396	33.398	33.402
12.5	12.851	12.855	12.863	12.843	12.844	12.844	33.393	33.394	33.390	33.397	33.398	33.402
13.0	12.851	12.855	12.859	12.843	12.844	12.841	33.394	33.393	33.391	33.397	33.398	33.402
13.5	12.851	12.852	12.858	12.843	12.843	12.841	33.393	33.393	33.391	33.397	33.398	33.402
14.0	12.850	12.849	12.853	12.844	12.845	12.840	33.394	33.393	33.392	33.397	33.398	33.402
14.5	12.849	12.847	12.850	12.848	12.849	12.841	33.394	33.395	33.394	33.397	33.399	33.402
15.0				12.848		12.849				33.397		33.404

Table 5. Vertical Profile Data Collected on 5 January 2010 (continued)

Depth (m)	Density (σ_t)						pH					
	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6
0.5	25.139	25.130	25.105	25.139	25.147	25.176	8.747	8.743	8.738	8.757	8.729	8.762
1.0	25.142	25.130	25.108	25.141	25.152	25.175	8.747	8.743	8.738	8.757	8.729	8.762
1.5	25.150	25.129	25.106	25.147	25.156	25.175	8.749	8.743	8.738	8.757	8.731	8.762
2.0	25.160	25.133	25.114	25.156	25.164	25.176	8.750	8.743	8.737	8.757	8.733	8.762
2.5	25.158	25.146	25.132	25.161	25.164	25.176	8.752	8.743	8.736	8.760	8.744	8.760
3.0	25.163	25.152	25.136	25.166	25.165	25.178	8.752	8.748	8.738	8.762	8.752	8.762
3.5	25.166	25.161	25.139	25.170	25.170	25.177	8.755	8.749	8.740	8.762	8.752	8.761
4.0	25.167	25.165	25.149	25.170	25.171	25.178	8.756	8.752	8.740	8.762	8.756	8.762
4.5	25.168	25.168	25.163	25.172	25.173	25.178	8.757	8.752	8.743	8.762	8.757	8.761
5.0	25.171	25.171	25.171	25.173	25.174	25.179	8.757	8.754	8.743	8.762	8.757	8.761
5.5	25.174	25.171	25.169	25.173	25.174	25.179	8.757	8.756	8.743	8.762	8.752	8.760
6.0	25.174	25.171	25.157	25.173	25.175	25.179	8.757	8.757	8.743	8.762	8.752	8.759
6.5	25.176	25.172	25.151	25.173	25.176	25.178	8.757	8.757	8.743	8.762	8.752	8.758
7.0	25.176	25.173	25.148	25.173	25.176	25.179	8.755	8.757	8.743	8.762	8.752	8.758
7.5	25.176	25.173	25.148	25.175	25.176	25.180	8.755	8.757	8.743	8.759	8.752	8.754
8.0	25.177	25.174	25.150	25.177	25.176	25.180	8.752	8.757	8.743	8.756	8.752	8.753
8.5	25.178	25.175	25.153	25.179	25.176	25.180	8.753	8.752	8.743	8.752	8.752	8.753
9.0	25.178	25.175	25.157	25.180	25.176	25.181	8.753	8.755	8.743	8.752	8.752	8.753
9.5	25.178	25.175	25.167	25.181	25.179	25.180	8.755	8.752	8.743	8.752	8.750	8.753
10.0	25.177	25.174	25.167	25.181	25.180	25.181	8.757	8.753	8.743	8.749	8.748	8.753
10.5	25.177	25.176	25.166	25.180	25.180	25.183	8.756	8.752	8.743	8.748	8.745	8.748
11.0	25.178	25.177	25.169	25.181	25.182	25.183	8.754	8.751	8.744	8.749	8.744	8.748
11.5	25.179	25.176	25.171	25.182	25.181	25.184	8.753	8.748	8.748	8.748	8.743	8.746
12.0	25.178	25.177	25.171	25.182	25.182	25.186	8.752	8.748	8.750	8.748	8.743	8.744
12.5	25.177	25.177	25.173	25.182	25.183	25.186	8.752	8.748	8.753	8.748	8.743	8.743
13.0	25.178	25.177	25.174	25.182	25.182	25.186	8.752	8.752	8.754	8.748	8.743	8.743
13.5	25.178	25.177	25.175	25.182	25.182	25.186	8.752	8.751	8.756	8.748	8.743	8.743
14.0	25.179	25.178	25.177	25.182	25.183	25.187	8.752	8.749	8.753	8.748	8.741	8.741
14.5	25.179	25.180	25.178	25.181	25.182	25.187	8.751	8.747	8.748	8.745	8.738	8.739
15.0				25.181		25.186				8.743		8.739

Table 5. Vertical Profile Data Collected on 5 January 2010 (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	7.761	7.736	7.775	7.782	7.263	7.837	65.054	61.189	60.971	71.627	71.376	70.896
1.0	7.768	7.736	7.772	7.782	7.361	7.833	65.418	61.954	61.334	71.445	71.619	71.406
1.5	7.769	7.736	7.770	7.793	7.396	7.826	65.916	62.023	60.838	71.487	71.524	72.003
2.0	7.779	7.741	7.767	7.794	7.439	7.823	69.479	62.861	58.379	71.970	71.124	72.276
2.5	7.782	7.755	7.770	7.804	7.468	7.824	69.566	66.058	61.109	71.752	71.289	72.534
3.0	7.786	7.756	7.774	7.805	7.495	7.830	70.241	67.561	62.794	72.166	71.487	72.163
3.5	7.792	7.767	7.776	7.807	7.537	7.834	70.380	69.780	62.767	72.387	71.176	71.769
4.0	7.792	7.774	7.779	7.812	7.539	7.832	71.286	70.462	61.422	72.673	71.077	71.981
4.5	7.798	7.778	7.773	7.810	7.564	7.836	71.529	71.011	60.431	72.927	71.298	71.961
5.0	7.797	7.786	7.778	7.810	7.602	7.831	71.304	71.871	63.329	73.153	72.007	72.202
5.5	7.789	7.794	7.781	7.812	7.602	7.815	70.963	71.851	62.679	73.475	72.549	72.696
6.0	7.788	7.792	7.785	7.811	7.609	7.813	70.205	72.064	63.675	73.564	73.209	73.036
6.5	7.784	7.791	7.785	7.809	7.633	7.788	70.006	72.183	63.181	73.746	73.003	73.201
7.0	7.785	7.795	7.781	7.806	7.633	7.742	69.829	72.192	62.384	73.927	73.426	73.658
7.5	7.783	7.797	7.783	7.795	7.630	7.717	69.939	72.349	62.412	73.737	73.294	73.886
8.0	7.787	7.794	7.778	7.780	7.650	7.713	70.179	72.823	61.827	73.459	73.078	74.500
8.5	7.782	7.786	7.779	7.773	7.656	7.713	71.519	72.071	61.450	72.481	73.304	74.361
9.0	7.784	7.790	7.782	7.767	7.657	7.693	73.736	72.188	61.067	72.264	73.073	74.245
9.5	7.785	7.793	7.781	7.760	7.647	7.690	74.481	71.632	60.967	72.031	73.389	74.428
10.0	7.784	7.791	7.784	7.755	7.660	7.682	74.867	70.729	60.409	71.761	71.800	74.022
10.5	7.785	7.781	7.782	7.754	7.636	7.652	73.853	67.907	60.766	71.702	71.653	73.703
11.0	7.785	7.770	7.796	7.754	7.643	7.640	72.467	63.366	63.413	71.737	71.534	72.657
11.5	7.782	7.778	7.794	7.750	7.647	7.644	70.081	63.103	67.497	71.693	71.251	72.450
12.0	7.779	7.778	7.803	7.740	7.648	7.629	68.217	66.766	71.105	70.299	70.686	71.974
12.5	7.778	7.777	7.822	7.741	7.649	7.620	68.487	65.244	72.327	69.376	69.657	71.738
13.0	7.775	7.776	7.816	7.732	7.643	7.613	66.358	67.735	71.718	67.974	69.495	69.693
13.5	7.770	7.759	7.810	7.731	7.645	7.600	64.162	68.044	70.962	66.365	67.868	68.097
14.0	7.740	7.744	7.801	7.716	7.631	7.591	61.386	66.943	64.672	59.360	55.394	64.385
14.5	7.672	7.743	7.784	7.691	7.582	7.553	59.347	63.718	52.638	53.365	43.399	58.773
15.0				7.663		7.496				48.633		38.785

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 that are resistant to vertical motion. During 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 January 2010 survey.

Although very weak, some vertical structure is apparent in the vertical profiles as a slight reduction in salinity (light green line), and density (black line) within a 5-m surface mixed layer (Figure 7). In contrast, the 0.028 vertical pH difference (gold line) and the 0.064°C vertical temperature difference (red line) approached the limits of instrumental accuracy. Similarly, vertical differences of 0.15 mg/L in DO (dark blue line) were also negligible except at Stations RW5 and RW6 (dashed dark blue line), where entrainment of air in the sensor duct artificially introduced additional variability.

Transmissivity (light blue line) is the only water property that exhibited a substantial vertical difference within the water column. Although transmissivities approaching 75% were observed at mid-depth at most stations in the vertical profiles, seafloor transmissivities within the BNL were below 60%. Not only is the reduction in BNL transmissivity large compared to prior surveys, but changes in other seawater properties normally seen within the BNL were not present during the January survey. This indicates that the markedly decreased water clarity within the BNL was not solely due to natural oceanographic processes. In fact, water clarity within the BNL during the January survey was substantially diminished by the presence of additional particulates from the shoreline deposition of dredge spoils.

BNLs normally consist of cold, oxygen-poor water that originates deep offshore. The deep offshore origin of these waters is usually 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 CO_2 (carbonic acid) which results in measurably lower pH (more acidic). Transmissivity also drops within the BNL 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. However, the BNL observed in January 2010 was fundamentally different from that of prior surveys. The sharp reductions in DO and pH that are normally observed within the BNL were not present in the January survey. In addition, the January 2010 BNL was much thicker than normal, extending as much as 4 m above the seafloor (e.g., Figure 7d).

These differences indicate that the unusually high turbidity within the January BNL was caused by dredge particulates. At Station RW3, the rising effluent plume entrained this turbid water and carried it upward into the water column. This upward movement was reflected by a distinct reduction in transmissivity throughout most of the water column (light blue line in Figure 7c). Farther north, at Station RW2 (Figure 7b), the plume reached the sea surface, resulting in a reduction in transmissivity within the near-surface layer. This resulting increase in turbidity within the upper water column north of the diffuser structure was visually apparent at the time of the survey, and was reflected in a 2-m reduction in Secchi depth measurements (Table 3). It is also possible that the presence of dredge particulates within the effluent plume caused increases in turbidity as far north as Station RW1, and was responsible for the 1-m reduction in Secchi depth observed there.

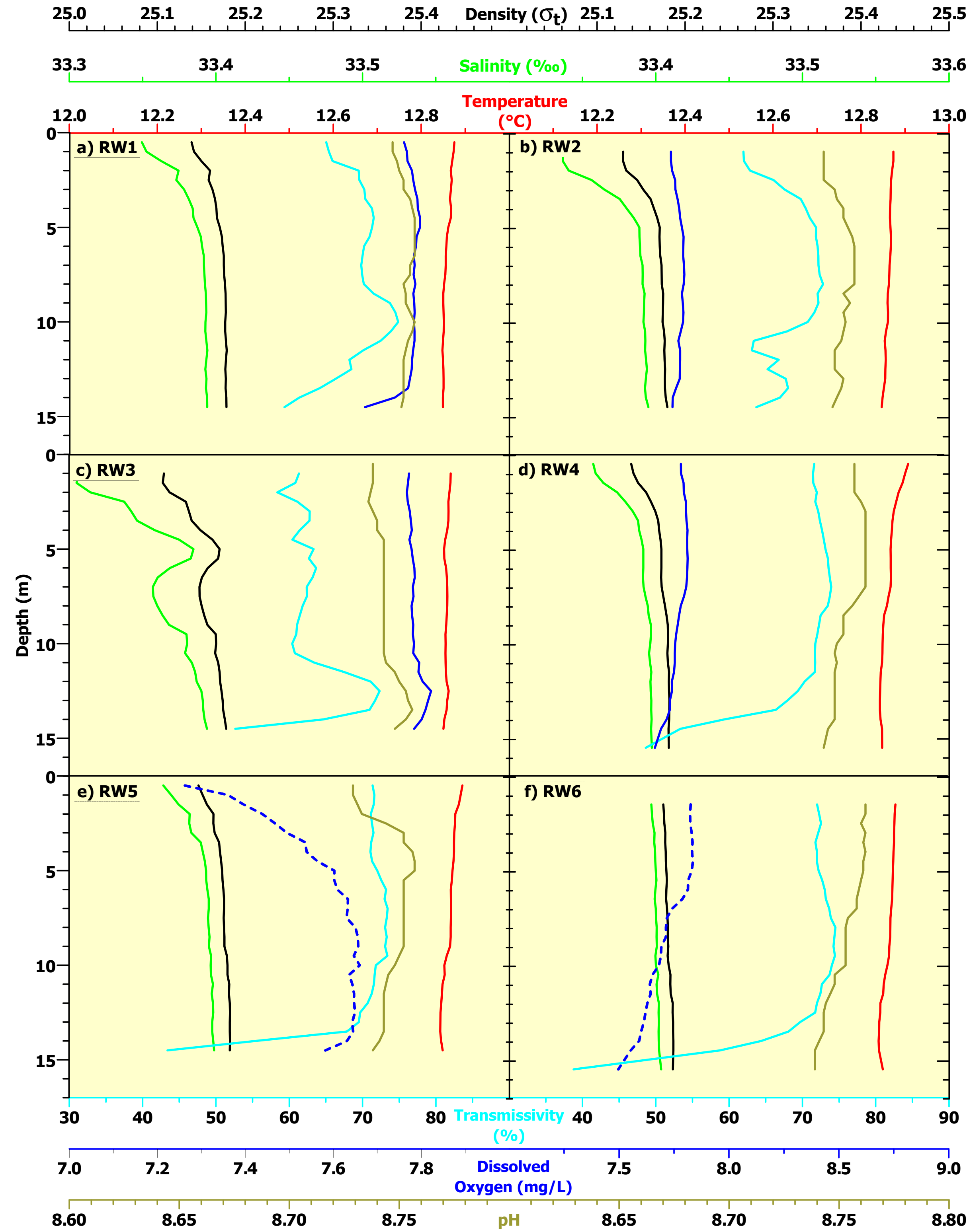

Figure 7. Vertical Profiles of Water-Quality Parameters

Outfall Performance

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 at depth. As a result, these 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 would have been achieved through additional mixing, had the plume continued its ascent all the way to the sea surface.

In the absence of significant stratification during the January 2010 survey, the effluent plume rose to the sea surface as it was transported to the north. The northward transport was rapid enough to carry the rising effluent plume beyond the ZID before reaching the sea surface, and before completing the initial dilution process. Consequently, the signature of the effluent plume was apparent in all of the seawater properties, although the near-surface signatures in temperature, transmissivity, oxygen, and pH were due to the upward displacement of ambient seawater properties rather than effluent particulates, and were therefore unrelated to the outfall performance. Because only the discharge-related anomalies in salinity and density were caused by the presence of dilute wastewater constituents; those properties are best suited to an evaluation of the outfall performance.

The current efficacy of the diffuser structure can be determined through a comparison between measured dilution levels at the time of the survey, and dilutions anticipated from modeling studies that were codified in the discharge permit through limits imposed on effluent constituents. 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 limits 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 mid-depth tow survey conducted during January 2010.

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 January 2010 survey. During the survey, the plume was still highly buoyant near the modeled 9-m trapping depth, and undoubtedly continued to mix as it rose to the sea surface. Nevertheless, even at 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.

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

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

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

Because the salinity concentration in effluent is negligible, C_e is eliminated in Equation 1 and the dilution ratio (D) can be computed from the salinity anomaly ($A = C_o - C_s$) as:

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

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.

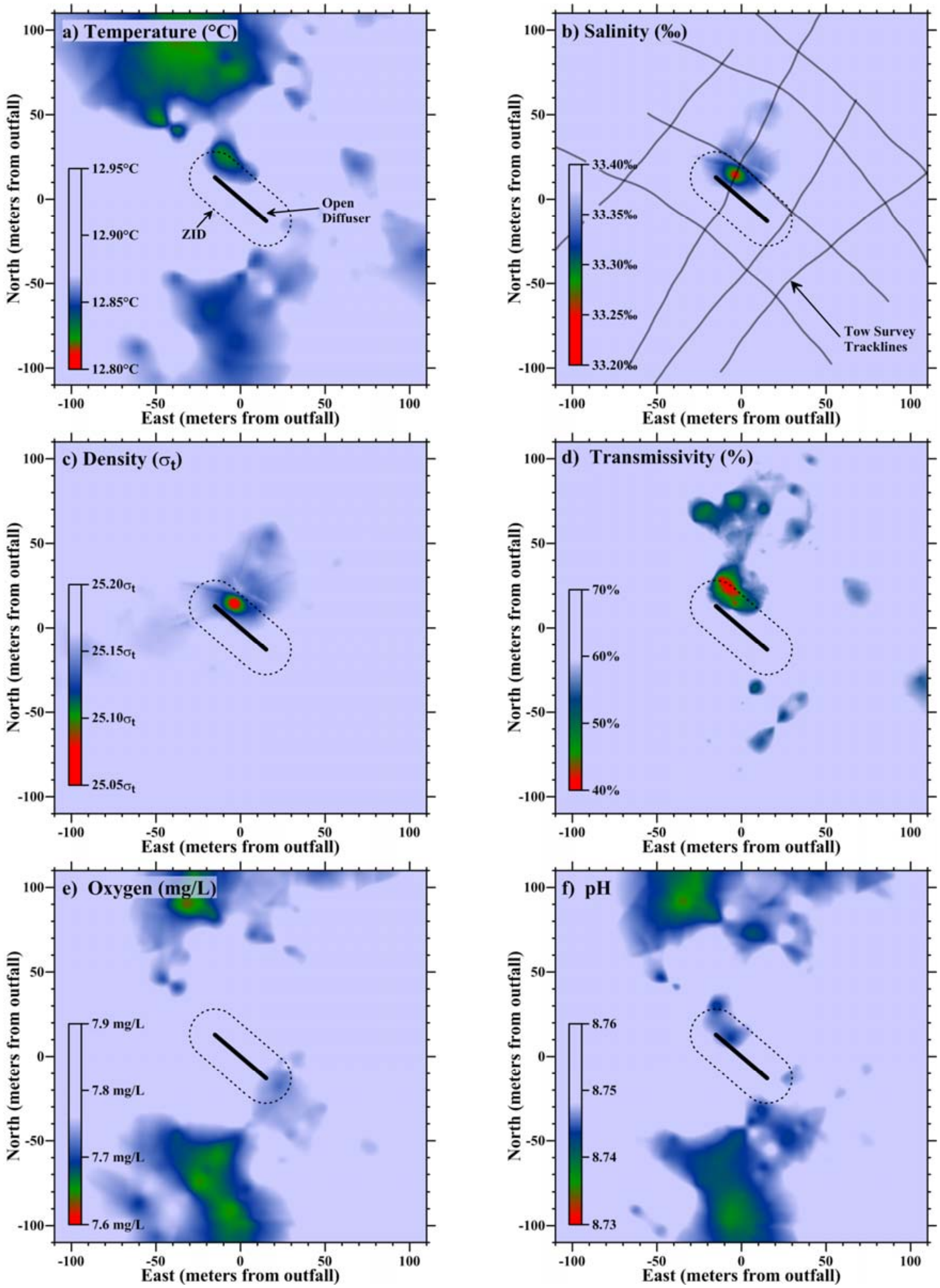

Figure 8. Horizontal Distribution of Mid-Depth Water-Quality Parameters 6.6 m below the Sea Surface

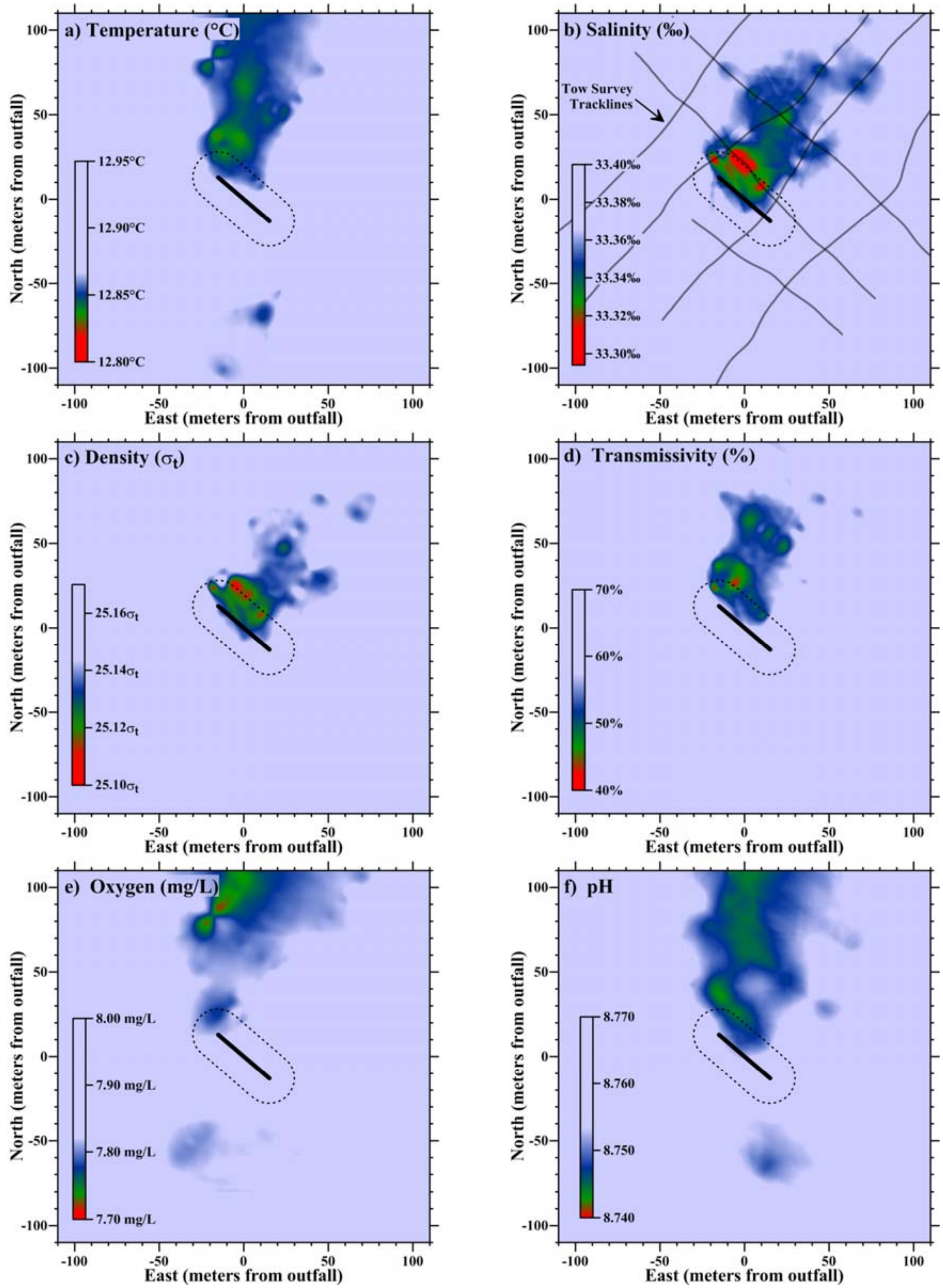

Figure 9. Horizontal Distribution of Shallow Water-Quality Parameters 3.5 m below the Sea Surface

The mid-depth tow captured the plume signature while it was undergoing intense initial mixing during its rise through the water column. Using Equation 2 to recast the salinity distribution shown in Figure 8b, results in the mapping of a highly localized plume signature that is largely restricted to the ZID and covers a 140-m^2 area (Figure 10). During the mid-depth tow, the lowest salinity (33.210‰) was measured close to the northern boundary of the ZID, 15.5 m from the diffuser structure. This salinity reduction corresponds to a wastewater-induced salinity anomaly of –0.183‰ below the mean ambient salinity of 33.394‰ that was measured at the same depth level well beyond the influence of the discharge. This maximum salinity anomaly corresponds to wastewater diluted by more than 180-fold.

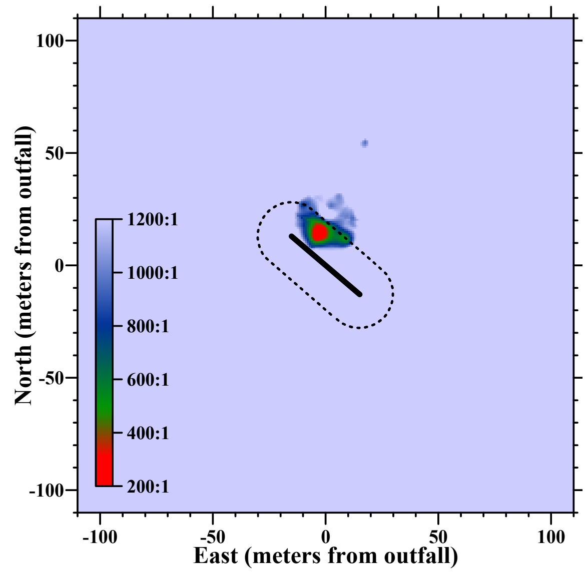

Figure 10. Mid-Depth Plume Dilution Computed from Salinity Anomalies in Figure 8b

A large negative density anomaly coincided with the plume's salinity signature (Figure 8c). Its presence demonstrates that the highly buoyant plume was continuing to undergo intense mixing at that location. These plume signatures were observed northeast of the diffuser structure, at a location consistent with northeastward transport recorded by the drogued drifter trajectory near the end of its deployment (Figure 3).

The high-resolution salinity measurements collected during the January 2010 mid-depth-tow demonstrate that that the modeled dilution factor (133:1) was significantly more conservative than that actually achieved by the discharge (>180:1). Moreover, the plume was not trapped at the depth assumed in the conservative dilution model. Instead, it continued to mix as it rose through the water column, spreading as it was slowly transported northeast with the prevailing current. This was confirmed during the shallow-tow survey when, dilutions exceeding 260-fold were found within a more widespread plume signature (Figure 11). At that depth, the plume had expanded to cover a 240-m^2 area that extended well beyond the ZID boundary toward the northeast. As with the mid-depth plume signature, the associated negative density anomaly (Figure 9c) demonstrated that the plume was still buoyant at 3.5 m, and would continue to undergo significant additional dilution during its rise to the sea surface.

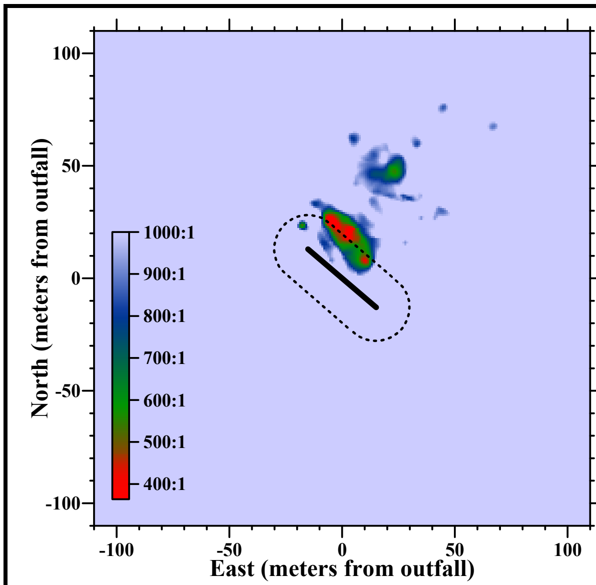

Figure 11. Shallow Plume Dilution Computed from Salinity Anomalies in Figure 9b

These dilution computations demonstrate that, during the January 2010 survey, the outfall was performing better than designed and was rapidly diluting effluent more than 260-fold well before completing the initial-dilution process. This dilution level is nearly twice 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 January 2010 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.

COMPLIANCE

This section evaluates the compliance of the MBCSD discharge with the six permit limits listed in Table 6. The water-quality limitations are based on criteria in the COP, the Central-Coast Basin Plan, and other state and federal policies that were designed to protect marine life and beneficial uses of ocean waters. Because the limits only pertain to changes in water properties that are caused by the presence of wastewater constituents beyond the ZID, instrumental measurements undergo a series of screening procedures prior to numeric comparison with the permit thresholds.

Table 6. Permit Provisions Addressed by the Offshore Receiving-Water Surveys

Limit #	Limit
P1	Floating particles or oil and grease to be visible on the ocean surface
P2	Aesthetically undesirable discoloration of the ocean surface
P3	Temperature of the receiving water to adversely affect beneficial uses
P4	Significant reduction in the transmittance of natural light at any point outside the ZID
P5	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
P6	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

The quantitative analyses described in this section focus on water-property excursions caused by the presence of wastewater constituents, their proximity to the ZID, and their amplitude compared to the range in ambient fluctuations. The results of these analyses applied to the January 2010 data demonstrate that the MBCSD discharge complied with the NPDES discharge permit. Moreover, although observations within the ZID are not subject to compliance evaluations, they still often meet the prescribed limits because observed dilution levels frequently exceed the conservative design specifications assumed in the discharge permit. Thus, the quantitative evaluation described in this section documents an outfall and treatment process that was performing at high level during January 2010.

Permit Provisions

A detailed understanding of ambient seawater properties, and their natural variability within the region surrounding the outfall, is an integral part of the compliance evaluation presented in this section. The offshore receiving-water surveys are designed to assess compliance with objectives dealing with undesirable alterations to six physical and chemical characteristics of seawater (Table 6). Other components of the monitoring program address the remaining permit limits.

The permit states that wastewater constituents within the discharge shall not cause the limits listed in Table 6 to be exceeded. The first two receiving-water limits, P1 and P2, rely on qualitative visual observations for compliance evaluation. As described previously, no floating wastewater materials, oil, grease, or discoloration of the sea surface was observed during the January 2010 survey that was associated with the discharge. Although the ongoing disposal of dredge spoils to the nearshore environment did have a visible effect on the clarity of the nearshore waters directly adjacent to the outfall, this discoloration was not related to the discharge.

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 numeric limits P5 and P6 on absolute values of DO (>5 mg/L) and pH (7.0 to 8.3), which echo Basin Plan objectives, can be directly compared with observed excursions caused by the presence of wastewater constituents. However, other narrative limits, which arise from the COP, define unacceptable water-quality impacts in terms of "*significant*" excursions beyond that which occurs "*naturally*." Quantitative evaluation of these limits requires a comparison of any excursion with numerical thresholds that reflect the natural variation in transmissivity, DO, and pH within the receiving waters surrounding the outfall. The 23-year record of quarterly receiving-water surveys conducted as part of the MBCSD monitoring program provides the necessary insight into this natural temporal and spatial variation in ambient seawater properties close to the outfall.

The oceanographic processes described previously determine the spatial distribution of ambient seawater properties near the outfall, and how it changes seasonally. Of particular interest are upwelling and downwelling processes that not only determine average properties at a given time, but also the degree of water-column stratification, or spatial variability during any given survey. An accurate characterization of stratification helps distinguish between discharge-related changes that arise from the presence of wastewater constituents, which are subject to a compliance evaluation, and changes that arise from the upward movement of ambient seawater, which is specifically excluded from the compliance evaluation. For the most part, however, temporal differences in seawater properties among surveys are far larger than spatial differences within individual surveys. For example, when the water column is moderately to highly stratified, vertical differences in seawater properties tend to be much larger than lateral differences. Even when the water column is only weakly stratified, however, such as during the January 2010 survey, vertical differences in transmissivity can result in significant lateral differences due to the plume's upward displacement of turbid seawater within BNLs.

Lines of Evidence

Evaluating whether any of the 4,412 CTD measurements collected in January 2010 exceeds a permit limit is a complex process. For example, apparently significant excursions in an individual seawater property may be unrelated to the presence of wastewater constituents, and may instead be due to any number of confounding factors. These confounding factors include statistical uncertainties, instrumental errors, natural processes, anthropogenic influences unrelated to the discharge, entrainment and upward transport of ambient bottom waters in the rising effluent plume, and ongoing initial mixing within and beyond the ZID.

Because of this complexity, compliance is evaluated using a "*multiple-lines-of evidence*" (LOE) approach similar to that used to implement sediment-quality guidelines for California estuaries (SWRCB 2009). Specifically, each receiving-water observation was screened for compliance by evaluating the measurement with a sequence of twelve questions (lines of evidence), identified in Table 7. Evidence for the existence of an out-of-compliance event would be indicated by affirmative answers to several of the questions. As described below, detailed analysis demonstrates that there were no out-of-compliance events associated with receiving-water limitations during the January 2010 survey.

Table 7. Lines of Evidence used to evaluate whether an individual Receiving-Water Measurement exceeded a Permit Limit

LOE#	LOE Question
LOE#01	Was the measurement collected beyond the 15.2-m ZID boundary?
LOE#02	Was the measurement associated with a quantifiable salinity anomaly (550:1 dilution level) indicative of the presence of wastewater constituents?
LOE#03	Was the salinity anomaly (dilution level) unaffected by salinity spiking?
LOE#04	Was the measurement located along the path of expected plume trajectory?
LOE#05	If the measurement was from the tow-survey, was its depth consistent with other measurements from the same tow, or if measured in a vertical profile, was it measured at a depth level other than the sea surface or seafloor and where there were an adequate number of similar measurements for comparison?
LOE#06	Did any of the seawater properties associated with the measurement depart significantly from the natural range in ambient seawater variability at the time of the survey?
LOE#07	Did the measurement exceed its respective numerical permit limit?
LOE#08	Was the direction (sign) of the anomaly consistent with the expected difference between wastewater and seawater properties?
LOE#09	Was the anomaly spatially coincident with anomalies in other seawater properties?
LOE#10	Was anomaly directly related to the presence of wastewater constituents rather than the entrainment and displacement of ambient seawater having anomalous properties due to the presence of dredge spoils, stormwater runoff, or a benthic boundary layer?
LOE#11	Was there an upset in the WWTP process, or were there known problems with the outfall that would account for the anomalous measurement?
LOE#12	Was the probe that measured the seawater property functioning correctly at the time of the measurement?

Completion of Initial Dilution

The COP states that compliance with its receiving-water objectives "*shall be determined from samples collected at stations representative of the area within the waste field where initial dilution is completed.*" Initial dilution includes the mixing that occurs from the turbulence associated with both the ejection jet, and the buoyant plume's subsequent rise in the water column. During the plume's rise in the water column, strong currents can transport it a substantial distance from the discharge point. This was the case during the January 2010 survey, when the signature of the positively buoyant plume was transported beyond the ZID boundary by prevailing northeastward currents. The strongly negative density anomalies associated with the signature indicated that the plume was continuing to undergo initial mixing well beyond the boundaries of the ZID (Figure 9c).

However, the COP also states that dilution estimates shall be based on "*the assumption that no currents, of sufficient strength to influence the initial dilution process, flow across the discharge structure.*" Because of this, modeling used to establish the MBCSD critical initial dilution of 133:1 assumed completion of dilution within a standard regulatory mixing distance equal to the 15.2-m water depth of the discharge. For the purposes of screening receiving-water data for compliance, the conservative 15.2-m distance threshold is used to restrict attention to post-dilution observations in LOE#01.

Application of the ZID-distance threshold (LOE#01) to the original 4,412 receiving-water observations eliminates 272 receiving-water observations from further consideration because they were collected within the ZID (Table 8). The remaining 4,140 observations are carried forward in the compliance analysis.

Table 8. Observations Screened by Lines of Evidence

LOE#	LOE	Independent[10]	Sequential[11]
Total	Total CTD Observations	4,412	4,412
LOE#01	Within ZID	272	4,140
LOE#02	Non Wastewater	4,336	35
LOE#03	Salinity Spike	0	35
LOE#04	Off Plume Path	2,192	35
LOE#05	Depth Excursion	0	35
LOE#06	Within Natural Variation	4,268	23[12]
LOE#07	Within Numerical Limit	0[13]	23
LOE#08	Opposite Sign (pH)	4412[13]	23
LOE#09	Non Coincident	—[14]	23
LOE#10	Non Discharge	137[15]	0
LOE#11	Normal Plant Performance	—[16]	0
LOE#12	Probe Malfunction	610[17]	0

Presence of Wastewater Constituents

The MBCSD discharge permit restricts application of the numerical receiving-water limits to excursions caused by the presence of wastewater constituents. This confines the compliance analysis to changes caused "*as the result of the discharge of waste*," as specified in the COP, rather than anomalies that arise from the movement of ambient seawater entrained in the effluent plume. Analyses conducted on quarterly receiving-water surveys over the last decade have demonstrated that the direct influence of dilute wastewater is almost never observed in any seawater property other than salinity, except very close (<1 m) to a diffuser port and within its ejection jet.

In fact, negative salinity anomalies are the only consistent indicator of the presence of wastewater constituents within receiving water. Salinity in wastewater is negligible compared to that of the receiving seawater, so the presence of a distinct salinity minimum provides *de facto* evidence of the presence of wastewater constituents. Because of the large difference between the nearly fresh wastewater and the saltier receiving waters, salinity provides a powerful tracer of dilute wastewater that is unrivaled by other seawater properties. Other properties do not exhibit such a large contrast between wastewater and seawater. As such, their signatures dissipate rapidly upon discharge with very little mixing. Wastewater's lack of salinity, however, provides a powerful marker that allows the presence of effluent constituents to be identified even after dilution many times greater than the 133-fold critical initial dilution assumed in the discharge permit.

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[10] Number of CTD observations eliminated by an LOE, independent of the other LOEs
[11] Number of CTD observations of potential compliance interest remaining after sequential application of LOEs
[12] Only the transmissivity values associated with these 23 observations exceeded natural variability thresholds.
[13] All of the pH observations exceeded the Basin Plan limit of 8.3 (LOE#7), but an increase in pH could not have been caused by wastewater, which has a pH of 7.8 (MRS 2010) and is well below the pH of ambient receiving waters (LOE#08)
[14] LOE was not applied because all observations were eliminated from further compliance evaluation through application of other LOEs
[15] Number of transmissivity observations that were too low to be caused by the discharge of wastewater particulates
[16] Based on telephone communication with plant personnel during the survey and subsequent review of effluent discharge properties on 5 January, the treatment process was performing nominally.
[17] Number of DO observations compromised by air in the ducting; none of which were measured near the plume

As described previously, wastewater-induced reductions in salinity can be used to directly determine the amount of dilution achieved by initial mixing. Based on statistical analysis of the natural variability in salinity readings measured near the outfall over a five-year period between 2004 and 2008, the smallest reduction in salinity that can be reliability detected within receiving waters is 0.062‰, which reflects a conservative dilution level of at least 542-fold when substituted into Equation 2. The actual maximum dilution is probably even smaller than this threshold because C_o, the salinity of the dilute wastewater, will be far less than the 33.59‰ background salinity (C_s) actually applied in the equation. Regardless, it is fair to say that wastewater-induced salinity reductions that are smaller than 0.062‰, cannot be reliably discerned against the backdrop of natural variation.

Observations eliminated based on the application of LOE#02 restrict attention to wastewater-induced excursions in temperature, light transmittance, DO, and pH that are related to the presence of wastewater constituents. Specifically, application of LOE#02 to the entire January 2010 receiving-water database eliminates 4,336 of the 4,412 observations ("*Independent*" column in Table 8). Only 76 of all the observations had perceptible salinity anomalies and only 35 of those were located beyond the ZID (LOE#01; refer to the "*Sequential*" column in Table 8). The observations eliminated from further compliance evaluation by LOE#02 exhibited extremely small salinity reductions of less than 0.062‰ relative to the average ambient salinity observed during the January 2010 survey. They represent dilutions above 550:1 that are not reliably resolved in the historical database, and that would not result in discernable changes in other seawater properties. Application of the first two lines of evidence leaves 35 measurements that remain of interest from a compliance standpoint.

Salinity Spikes

Salinity spiking occurs due to the physical separation of the conductivity and temperature probes on the CTD package that are used to compute salinity. When the CTD crosses a sharp thermocline, the mismatch between the recorded conductivity and the temperature measurements results in erroneous spikes in computed salinity. Because downwelling resulted in minimal vertical stratification during the January 2010 survey, none of the salinity measurements recorded during the survey appear to have been compromised by salinity spiking. Therefore, the application of LOE#03 did not eliminate any of the remaining 35 measurements from further compliance consideration.

Plume Transport

Some excursions in receiving-water properties are found in locations inconsistent with the path of plume transport (LOE#04), thus adding additional rationale for their exclusion further compliance evaluation. More than a decade of receiving-water monitoring around the MBCSD outfall has demonstrated that the plume signature is almost always exclusively located downstream of the diffuser structure. The only exceptions are rare, and occur when flow speeds are negligible (<1 cm/s), or when there is a complete reversal in flow during the survey. Neither was the case during the January 2010 survey. Although the cross-shore flow component reversed direction during the survey, transport was consistently toward the north at 5 cm/s throughout the survey. The northerly location of the plume signature relative to the diffuser structure was also consistent with this transport. At those transport speeds, the plume traverses the ZID within five minutes. Therefore, even if portions of the plume became trapped at depth, they would be unlikely to spread upstream beyond the ZID in the face of a 5 cm/s current.

Approximately half (2,192) of the CTD observations were recorded south of the diffuser structure (LOE#04, Table 8). Additionally, this line of evidence lends further support for many the observations that were screened out by LOE#01 and LOE#02.

All of the remaining 35 observations were located along the path of plume transport. Nearly all of those 35 measurements were collected in the middle of Transects S6 and S7 (Figure 6), and were clearly associated with the plume as it spread toward the northeast beyond the ZID boundary (Figure 11). However, qualitative consideration of northward plume transport provided important additional support for eliminating 610 erroneous DO measurements from further compliance consideration (LOE#12 in Table 8). These DO measurements were compromised by entrainment of an air bubble in the oxygen sensor's plenum. All of these suspect measurements were recorded south of the diffuser structure, and were therefore also excluded by LOE#04.

LOE#05 is another line of evidence that is important for screening data during most surveys, but had no bearing on the evaluation of the January 2010 data. LOE#05 screens artificial anomalies produced when data from different depth levels are compared. This line of evidence is particularly important when the water column is highly stratified and when high waves cause the CTD to move up and down through the thermocline during the tow surveys. These vertical excursions in the CTD depth can create artificial lateral anomalies in the horizontal tow maps that are easily identified through inspection of the time series of depth measurements recorded by the CTD during each tow. However, neither strong stratification nor high waves were experienced during the January 2010 survey, so application of LOE#05 was unnecessary.

Natural Variability

As stated previously, an integral part of the compliance analysis is determining whether a particular anomalous measurement resulted from the presence of wastewater constituents, or whether it simply became apparent because of the movement of ambient seawater by the plume. If the measurement does not significantly depart from the natural range in ambient seawater properties at the time of the survey, then it is difficult to ascribe the departure to the discharge. Thus, quantifying the natural variability around the outfall is necessary for the evaluation of discharge compliance (LOE#06).

With that in mind, a statistical analysis of the large historical database of receiving-water data collected around the outfall was used to establish the range of variability in natural conditions surrounding the outfall (Table 9). These ranges in natural variability were used to identify significant departures from ambient conditions that could be indicative of adverse effects on water quality from the discharge. The same five-year database used to establish the natural within-survey salinity variation discussed previously was also used to establish one-sided 95% confidence bounds on transmissivity (-10.2%), temperature (+0.82°C), DO (-1.4 mg/L), and pH (± 0.094). These were combined with 95th percentiles determined from the January 2010 ambient seawater data, to establish natural-variability thresholds in a manner analogous to COP Appendix VI. The percentiles were determined from January 2010 vertical profile data, excluding measurements potentially affected by the discharge at Stations RW2 and RW3.

Only 144 CTD measurements exceeded the thresholds of natural variability during the January 2010 survey, eliminating 4,268 observations from further compliance evaluation under LOE#06. All were associated with transmissivity measurements below 49.1% (Table 9); none of the measurements of temperature, DO, or pH ranged beyond their respective natural-variability thresholds. Although the measured pH exceeded the basin-plan numerical limit of 8.3, all of the 4,412 pH measurements recorded during the survey exceeded the limit, and therefore could not have been caused by the MBCSD discharge. Consequently, they did not constitute a violation of the permit provision P6 (Table 6). Transmissivity exhibited marked reductions near the seafloor within the BNL where particulates were being transported into the survey area from an active dredge disposal operation on the adjacent shoreline.

Except where the MBCSD discharge plume entrained and carried the turbid water up into the water column, these marked transmissivity reductions were highly localized near the seafloor. Because of their

Table 9. Thresholds of Significant Departure from Natural Conditions

Water Quality Property	Basin Plan Limit[18]	COP Allowance[19]	Natural Variability Threshold[20]	95th Percentile[21,22]	95% Confidence Bound[23]
Temperature (ºC)	—	—	>13.70	12.88	0.82
Transmissivity (%)	—	—	<49.1	59.3	-10.2
DO (mg/L)	<5.0	-10%	<6.35	7.73	-1.38
pH (minimum)	<7.0	-0.2	<8.647	8.741	-0.094
pH (maximum)	>8.3	0.2	>8.856	8.762	0.094

highly localized nature, the 95th percentiles used to establish the variability thresholds in Table 9 did not encompass these extremely low transmissivities. Thus, as would be expected from a strong anthropogenic influence such as dredge-spoil discharge, the analysis of variance highlighted those unusually turbid measurements as departures from natural conditions.

Of the 35 observations that remained after screening with LOE#01 and LOE#2, 23 had transmissivities below the 49.1% threshold of natural variability (Sequential LOE#06 in Table 8). Of the other 121 low-transmissivity observations, 45 were measured within the ZID (LOE#01), 93 were not associated with significant salinity anomalies (LOE#02), and 17 were both within the ZID and demonstrably unrelated to the presence of dilute wastewater constituents.

Suspended Solids

The compliance-evaluation screening process described above identified 23 transmissivity observations that warranted further examination. All of these unnaturally low transmissivity values were measured in the middle of shallow Transects S6 and S7, which paralleled the diffuser structure and were offset to the northeast, in a direction consistent with plume transport (Figure 6). This reduced transmissivity region within the upper water column is delineated by dark blue shading in Figure 9d. Secchi depths were 2 m shallower at Stations RW2 and RW3, which were also located within the low transmissivity region north of the diffuser structure. The vertical transmissivity profiles at those two stations exhibited marked reductions in transmissivity within the upper water column compared to other stations (light-blue lines in Figures 7bc). However, transmissivities within those profiles did not drop below the 49.1% threshold of natural variation. It was only because of high-resolution data acquired during the tow survey that the

[18] Permit limits P5 and P6 (Table 6) include specific numerical values promulgated in the RWQCB Basin Plan (1994) in addition to changes relative to natural conditions specified in the COP.

[19] 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.*"

[20] 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 January 2010 survey. They do not include the COP allowances specified in the column to the left.

[21] 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*."

[22] The 95th-percentile quantifies natural variability in seawater properties during the January 2010 survey, and is determined from vertical profiles excluding Stations RW3 and RW4 where there was possible influenced by the discharge.

[23] 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.

magnitude and lateral extent of the turbidity anomaly could be delineated. The pattern of reduced transmissivity within the shallow tow-survey (Figure 9d) closely matches the pattern of reduced salinity (Figure 9b) and dilution (Figure 11), indicating that the anomalous transmissivity observations were associated with the effluent plume (LOE#09, spatial coincidence of anomalies).

However, the observed transmissivity reductions were not caused by an excess concentration of wastewater constituents within poorly diluted effluent (LOE#10). Instead, the observed transmissivity reductions were consistent with mixing and upward displacement of already turbid BNL waters within the buoyant effluent plume. Wastewater particulates could not have materially contributed to the observed reductions in transmissivity within the effluent plume because, at the time of the survey, the suspended-solids concentration within discharged effluent was 35 mg/L, which is close to the historical average of 32.6 mg/L (Table 5.1, MRS 2010). After dilution by at least 305-fold, as determined from the largest salinity anomaly associated with the 23 anomalous transmissivity observations, the 35-mg/L suspended-solid concentration within effluent would have been expected to reduce ambient transmissivity by only 0.7%. This reduction is 50-times smaller than the reduction in transmissivity observed during the January 2010 survey. Thus, the presence of dilute wastewater particulates could not have been responsible for the 137 measurements that had reductions exceeding 0.7% (LOE#10 in Table 8), including the 23 that were identified from screening with the other LOEs (Table 8).

CONCLUSIONS

All measurements recorded during the January 2010 survey complied with both the receiving-water limitations specified in the NPDES discharge permit, and the ranges in natural variability that prevailed at the time of the survey. The presence of dilute wastewater constituents was delineated from salinity anomalies 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 upper water column, computed dilution levels of more than 260-fold were double the critical dilution levels predicted by design modeling. Additionally, all of the auxiliary observations collected during the January 2010 survey demonstrated that the discharge complied with the receiving-water limits in the discharge permit and COP. All of these observations demonstrated that the treatment process, diffuser structure, and the outfall continue to perform at levels exceeding design expectations.

Although several discharge-related changes in seawater properties were observed during the January 2010 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.

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