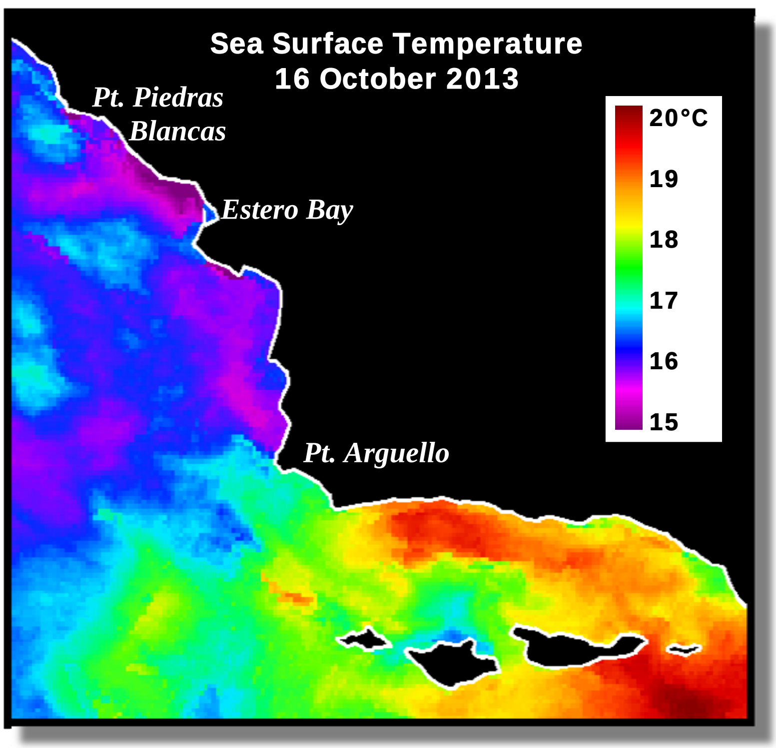
City of Morro Bay and
Cayucos Sanitary District

OFFSHORE MONITORING AND REPORTING PROGRAM

FOURTH QUARTER RECEIVING–WATER SURVEY

OCTOBER 2013



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Report to the

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FOURTH QUARTER RECEIVING–WATER SURVEY

OCTOBER 2013

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

12 November 2013

Reference: Fourth Quarter Receiving-Water Survey Report – October 2013

Dear Mr. Keogh:

The attached report presents results from a quarterly receiving-water survey conducted on Wednesday, 16 October 2013. 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. Quantitative analyses of continuous instrumental measurements and qualitative visual observations confirm that 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 a high level of performance. The measurements delineated a diffuse discharge plume containing low organic loads within a highly localized region surrounding the discharge point. Dilution within the plume exceeded expectations based on modeling and outfall design criteria.

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

Sincerely,

Bonnie Luke
Program Manager

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.

Bruce Keogh

Mr. Bruce Keogh
Wastewater Division Manager
City of Morro Bay

Date 11-12-13

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INTRODUCTION

The City of Morro Bay and the Cayucos Sanitary District (MBCSD) jointly own the wastewater treatment plant operated by the City of Morro Bay. In March 1985, Region IX of the U.S. Environmental Protection Agency (USEPA) and the Central Coast California Regional Water Quality Control Board (RWQCB) 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 October 2013 field survey described in this report was the nineteenth receiving-water survey conducted under the current permit.

The NPDES discharge permit requires seasonal monitoring of offshore receiving-water quality with quarterly surveys. This report summarizes the results of sampling conducted on 16 October 2013. Specifically, this fourth-quarter survey captured ambient oceanographic conditions along the central California coast during the fall 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 monitoring objectives were achieved by empirically evaluating tabulations of instrumental measurements and standard field observations. In addition to the traditional, vertical water-column profiles, instrumental measurements were used to generate horizontal maps from high-resolution data gathered by towing a CTD[1] instrument package repeatedly over the diffuser structure. This allowed for a more precise delineation of the plume's lateral extent.

SURVEY SETTING

The MBCSD treatment plant is located within the City of Morro Bay, which is situated along the central coast of California halfway between Los Angeles and San Francisco. 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 827 m from the shoreline within Estero Bay (Figure 1). The diffuser structure extends an additional 52 m toward the northwest from the outfall terminus and consists of 34 ports that are hydraulically designed to create a turbulent ejection jet that rapidly mixes effluent with receiving seawater upon discharge. Currently, six of the diffuser ports are kept closed, thereby improving effluent dispersion by increasing the ejection velocity from the remaining 28 ports distributed along a 42-m section of the diffuser structure.

Following discharge from the diffuser ports, 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 reach in modeling studies extends 15.2 m from the centerline of the diffuser structure. Beyond the ZID, energetic waves, tides, and coastal currents within Estero Bay further disperse the dilute effluent within the open-ocean receiving waters. Both vertical hydrocasts and horizontal tow surveys are conducted around the diffuser structure to assess the efficacy of the diffuser, to define the lateral extent of the discharge plume, and to evaluate compliance with the NPDES permit limitations.

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

Figure 1. Location of the Receiving-Water Survey Area

Near the diffuser, prevailing flow generally follows bathymetric contours that parallel the north-south trend of the adjacent coastline. Because of the rapid initial mixing achieved within 15 m of the diffuser structure, impingement of unmixed effluent onto the adjacent coastline, 827 m away, is highly unlikely. Nevertheless, in the event of a failure in the treatment plant's disinfection system, collection and analysis of water samples at the eight 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.

Areas of special concern, such as the Morro Bay National Estuary and the Monterey Bay National Marine Sanctuary, are not affected by the discharge because they are even more distant from the outfall location. For example, the southern boundary of the Monterey Bay National Marine Sanctuary is located 38 km to the north, while the entrance to the Morro Bay National Estuary lies 2.8 km south. The southerly orientation of the mouth of the Bay, and the presence of Morro Rock 2 km to the south, serve to further limit seawater exchange between the discharge point and the Bay (Figure 1).

SAMPLING LOCATIONS

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 may influence one or more of these stations. The up-current stations on the opposite side of the diffuser then act as reference stations. Comparisons between the water properties at these antipodal stations quantify departures from ambient seawater properties caused by the discharge and allow compliance with the NPDES discharge permit to be determined.

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. This "*closest approach*" distance can be considerably less than the centerpoint distance normally cited in modeling studies.

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.

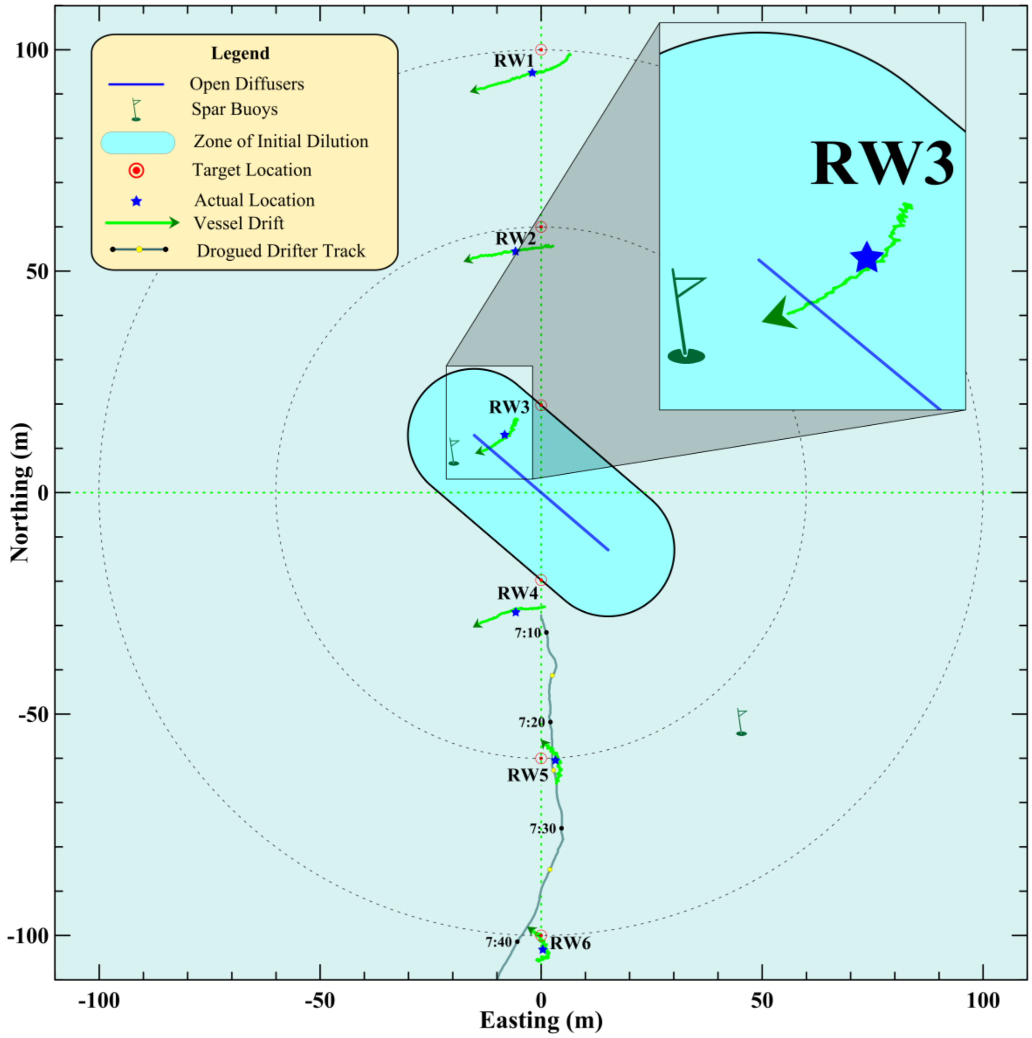

Figure 2. Station Locations

Table 1. Target Locations of the 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

During a diver survey in July 1998, the survey vessel's DGPS navigation system, consisting of a Furuno™ GPS 30 and FBX2 differential beacon receiver, was used to precisely determine the position of the open section of the diffuser structure (MRS 1998) and establish the target locations for the receiving-water monitoring stations shown in Figure 2 and listed in Table 1. Presently, the use of two independent DGPS receivers onboard the survey vessel allows access to two separate land-based beacons for navigational comparison, ensuring extremely accurate and uninterrupted navigational reports.

Recording of DGPS positions at one-second intervals allows precise determination of sampling locations throughout the vertical CTD profiling conducted at the six 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 October 2013 survey is apparent from the length of the green tracklines in Figure 2. The tracklines trace the horizontal movement of the CTD as it was lowered to the seafloor at each station. Their lengths and offsets from the target locations reflect the overall station-keeping ability during the October 2013 survey. Although the duration of the CTD downcasts, which averaged 01:32 (one minute 32 seconds), was consistent among the stations, the lateral movement of the CTD was greater at the four northern stations, where it averaged 16.7 m, while the drift at the Stations RW5 and RW6 was 9 m or less.

The downcasts during the October 2013 survey were conducted progressing from south to north, beginning with Station RW6. As seen in Figure 2, the CTD trajectories do not appear to have been strongly influenced by oceanic flow during the survey, which was predominately to the south, as reflected by the drogued drifter trajectory (Figures 2 and 3). Additionally, the light northeasterly winds experienced during the downcasts at Stations RW6 and RW5 did not appear to affect the drift substantially. Instead, the northerly transport observed at Stations RW6 and RW5 reflects the influence of the vessel's residual momentum as it approached the stations from the south.

Following completion of the downcasts at Stations RW6 and RW5 at around 7:30 AM, however, the strength of the northeasterly winds increased.[5] The predominately west-southwesterly movement of the survey vessel and greater amount drift during the remaining four downcasts (Stations RW4 through RW1) reflects the influence of the increased wind velocity.

Detailed knowledge of the CTD's location during downcasts is important in the interpretation of the water-quality measurements. In particular, because the target locations for Stations RW3 and RW4 lie along the ZID boundary (red ⊙ symbols in Figure 2), knowledge of the CTD's location during the downcasts at those stations is especially important in the compliance evaluation. This is because the receiving-water limitations specified in the COP only apply to measurements recorded along or beyond the ZID boundary, where initial mixing is assumed complete.

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[4] Meteorological and oceanographic conditions include winds, waves, tides, and currents.
[5] Refer to the meteorological and oceanographic observations listed in Table 4 later in this report.

It has not always been possible to determine which measurements were subject to permit limits within hydrocasts near the ZID boundary, however. For example, prior to 1999 and before the advent of DGPS, CTD locations could not be determined with sufficient accuracy to establish whether the average station position 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 mandates identification of a single position for all of the CTD data collected at a particular station. Thus, for regulatory reporting, and for consistency with past surveys, the October 2013 survey also identifies a single sampling location for each station. These average station positions are identified by the blue stars in Figure 2, and are listed in Table 2 along with their distances from the diffuser structure.

Table 2. Average Position of Vertical Profiles during the October 2013 Survey

Station	Time (PDT)		Latitude	Longitude	Closest Approach	
	Downcast	Upcast			Range[6] (m)	Bearing[7] (ºT)
RW1	7:51:13	7:52:43	35° 23.250' N	120° 52.505' W	83.0	9
RW2	7:46:01	7:47:28	35° 23.228' N	120° 52.508' W	42.6	13
RW3	7:38:10	7:39:51	35° 23.206' N	120° 52.509' W	**4.7**[8]	41
RW4	7:30:56	7:32:30	35° 23.184' N	120° 52.508' W	24.2	221
RW5	7:24:13	7:25:39	35° 23.166' N	120° 52.502' W	48.9	194
RW6	7:16:42	7:18:19	35° 23.143' N	120° 52.504' W	91.4	189

As seen in Figure 2, the entire downcast at Station RW3 occurred within the ZID boundary. As a result, none of the measurements recorded by the CTD at Station RW3 was subject to the compliance analysis (Table 2). Additionally, during the downcast at Station RW3, the CTD actually passed directly over the diffuser structure as it approached the seafloor. As seen in the inset of Figure 2, the dark blue line denotes the location of the diffuser structure, while the dark green arrowhead at the end of the light green trajectory trace indicates where the CTD encountered the seafloor. After accounting for the diameter of the diffuser pipe, navigational data indicates the CTD was less than 0.5 m from the diffuser when it impinged on the seafloor, and the average CTD position determined for this station (dark blue star) was only 4.7 m from the diffuser structure.

Compliance assessments notwithstanding, measurements acquired 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, demonstrates that it has maintained a high level of effectiveness in effluent dispersal. In fact, without the occasional measurements recorded within the ZID due to vessel drift, the extremely dilute discharge plume might remain undetected within all vertical profiles collected during a given survey.

6 Distance from the closest open diffuser port to the average profile location.
7 Angle measured clockwise relative to true north from the closest diffuser port to the average profile location.
8 All of the CTD measurements collected at Station RW3 were located within the ZID boundary (refer to the inset in Figure 2).

OCEANOGRAPHIC PROCESSES

The trajectory of a satellite-tracked drogued drifter documented the oceanic flow during the October 2013 survey (Figure 2). Modeled after the curtain-shade design of Davis et al. (1982) and drogued at mid-depth (7 m), a drifter has been deployed during each of the quarterly water column surveys conducted over the past decade. In this configuration, the oceanic flow field rather than surface wind dictates the drifter's trajectory, providing a good assessment of the plume's movement after discharge.

During the October 2013 survey, the drifter was deployed near the diffuser structure at 7:08 AM, and was recovered at 9:22 AM at a location 307 m to the south and slightly east of its original release point (Figure 3). The green and black dots in Figure 3 show the drifter's progress at five- and ten-minute intervals throughout the survey. Over the entire course of the survey, the drifter measured an average flow speed of 3.8 cm/s (0.075 kt). At this transport rate, the effluent would have experienced a relatively brief, 6-minute residence time within the ZID.

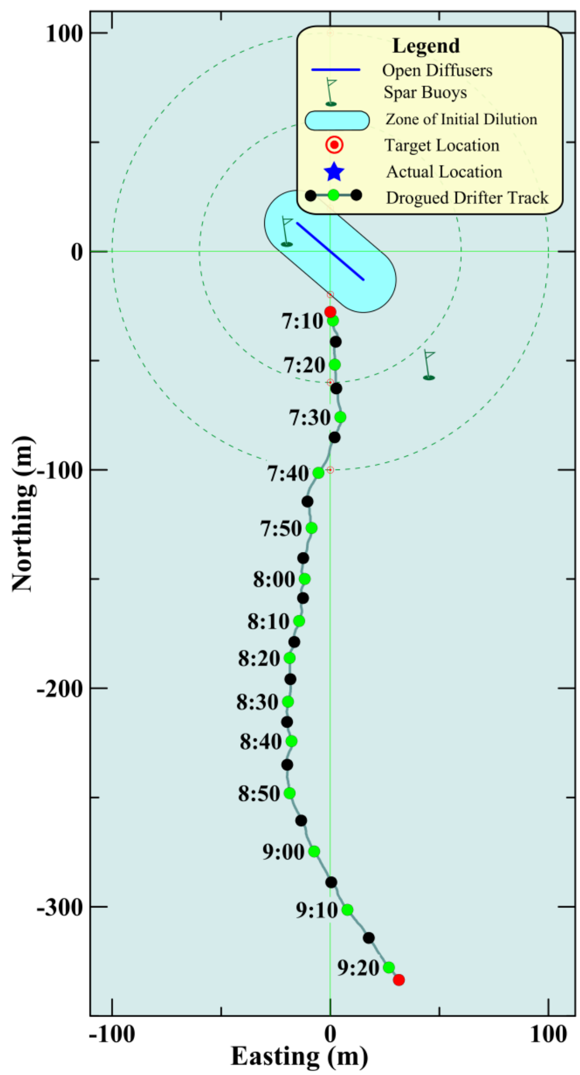

Figure 3. Drogued Drifter Trajectory

Throughout most of the October 2013 survey, the oceanic flow maintained a relatively constant speed of about 3.6 cm/s (0.070 kt) along a path traveling almost due south (185ºT[9]). After 8:45 AM, however, flow speed increased to 5.0 cm/s (0.097 kt) as reflected by the increased distance between the time stamps in the figure. Additionally, the direction of the flow shifted more to the east (152ºT). During this period, the plume's residence time within the ZID was only five minutes.

The change in flow coincided with the decreasing influence of the flood tide that prevailed during the initial part of the survey (Figure 4). Tidal elevations throughout the survey were comparatively high, resulting in hydrocasts that were approximately 1 m deeper than in most other surveys. Vertical profiles normally extend to a maximum depth of 16 m. However, the hydrocast data collected during the October 2013 survey[10] extended to at least 17 m at all stations, and even reached 18 m at Station RW3. As described previously, the hydrocast at Station RW3 was unusual in that the CTD impinged on the seafloor very close to the diffuser structure (<0.5 m) (Refer to the inset in Figure 2). It is likely that the greater bottom depth measured at this station resulted from the CTD's encounter with the scour depression surrounding the diffuser structure.

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[9] Direction measured clockwise relative to true (rather than magnetic) north.
[10] Refer to Table 5 later in this report.

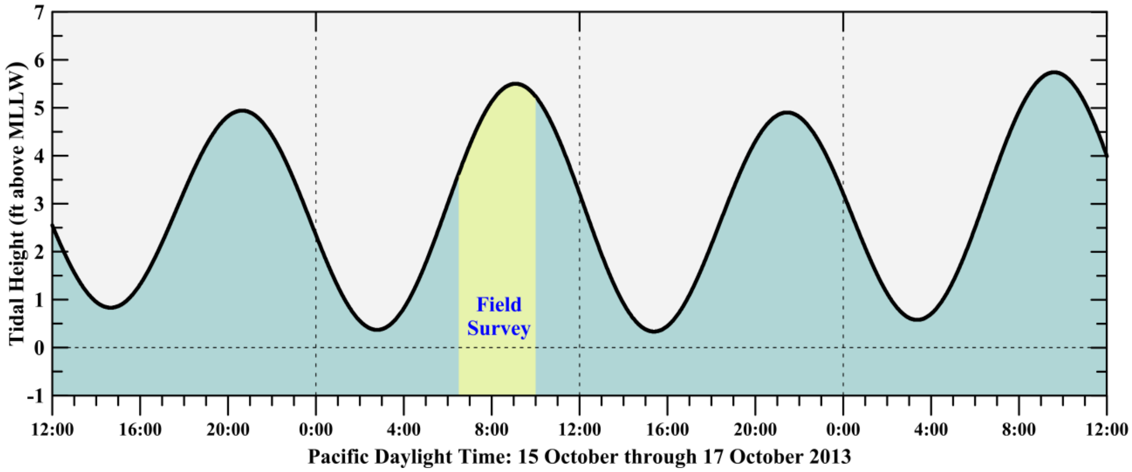

Figure 4. Tidal Level during the October 2013 Survey

The southward oceanic flow observed throughout the survey was inconsistent with the direction of flow normally associated with flood tides, which is typically toward the northeast. However, coastal currents within Estero Bay are often more-strongly influenced by external processes, such as wind-generated upwelling, downwelling, or the passing of offshore eddies propagating along the coastline. During the October 2013 survey, the prevailing southerly flow was largely attributable to upwelling processes. Upwelling winds such as those that prevailed in the days just prior to the survey (last yellow diamond in Figure 5) typically induce a southerly (offshore) flow in the upper water column, and a northerly (shoreward) flow close to the seafloor.

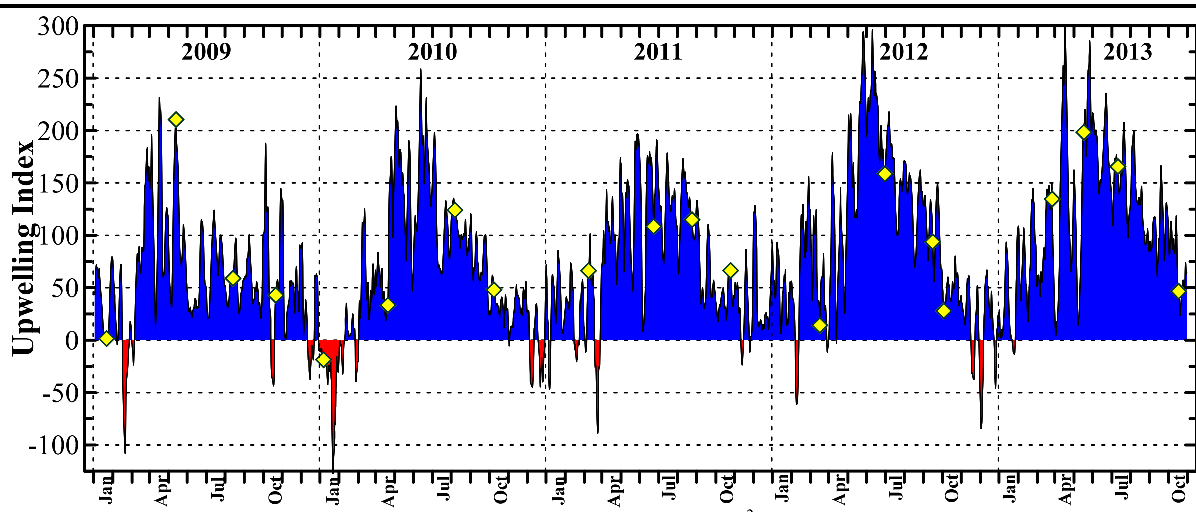

Figure 5. Five-Day Average Upwelling Index ($m^3/s/100$ m of coastline)

Upwelling season normally begins sometime during late March and or early April as shown by the positive (blue) upwelling indices in Figure 5. At the onset of upwelling season, there is a transition to more persistent southeastward winds along the central California coast that is initiated by the stabilization of a high-pressure field over the northeastern Pacific Ocean. Clockwise winds around this pressure field drive prevailing northwesterly winds along the central California coast. These winds move warmer surface waters southward and offshore, allowing deep, cool, nutrient-rich waters to move shoreward and upwell near the coast.

The nutrient-rich seawater that is brought to the sea surface near the coast by upwelling enables phytoplanktonic blooms that are the foundation of the productive marine fishery found along the central California coast. The cross-shore flow associated with persistent upwelling conditions also enhances vertical stratification of the water column. The presence of denser water at depth produces a shallow thermocline (<10 m) that is commonly maintained throughout summer and into fall.

In contrast, downwelling events, indicated by the negative (red shaded) indices in Figure 5, occur infrequently, and almost exclusively in winter, when passing storms temporarily reverse the normal wind pattern and drive surface waters shoreward. As the surface waters approach the coastline, they downwell, producing nearly uniform seawater properties throughout the water column.

The satellite image on the cover of this report documents the lingering influence of upwelling on sea-surface temperatures on the day of the October 2013 survey. The image was recorded by infrared sensors on one of NOAA’s polar orbiting satellites. The distinctive thermal signature of upwelling is apparent in the cover image, as a band of cooler nearshore sea-surface temperatures shown in purple (<16˚C) along the central coast.

METHODS

The 38 ft F/V *Bonnie Marietta*, owned and operated by Captain Mark Tognazzini of Morro Bay, served as the survey vessel on Wednesday, 16 October 2013. Bonnie Luke of Marine Research Specialists (MRS) supervised deck operations as Chief Scientist, and collected auxiliary measurements of biological, meteorological, and oceanographic conditions. Dr. Douglas Coats, provided data-acquisition and navigational support during the survey. Dean Dusette, also of MRS, assisted with Secchi depth measurements during the survey. William Skok assisted with deployment and recovery of the CTD and drifter.

Auxiliary Measurements

Auxiliary measurements and observations were collected during the vertical water-column profiling conducted at each of the six stations. Standard observations of weather and sea conditions, and beneficial uses, were augmented by visual inspection of the sea surface for floating particulates, oil sheens, and discoloration 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, and oceanic flow measurements made throughout the survey using a drogued drifter.

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, Secchi depths measure natural light penetration, which can be limited by increased suspended particulate loads from plankton blooms, onshore runoff, seafloor sediment resuspension, and wastewater discharge. They are also biologically meaningful because the depth of the euphotic zone, where most oceanic photosynthesis occurs, extends to approximately twice the Secchi depth.

Instrumental Measurements

A Sea Bird Electronics SBE-19plusV2 Seacat CTD instrument package collected measurements of conductivity, temperature, light transmittance, dissolved oxygen (DO), pH, and pressure during the October 2013 survey. The six seawater properties used to assess receiving-water quality in this report were derived from the continuously recorded output from the CTD's probes and sensors. Although pressure-housing limitations confine the CTD to depths less than 680 m (Table 3), this is well beyond the maximum depth of the deepest station in the outfall survey.

Table 3. CTD Specifications

Component	Units	Range	Accuracy	Resolution
Housing (19p-1a; Acetron Plastic)	m	0 to 680	—	—
Pump (SBE 5P)	—	—	—	—
Pressure (19p-2h; Strain-Gauge)	dBar	0 to 680	±1.7	± 0.10
Conductivity	Siemens/m	0 to 9	± 0.0005	± 0.00005
Salinity	‰	0 to 58	± 0.004	± 0.0004
Temperature	ºC	–5 to 35	± 0.005	± 0.0001
Transmissivity (WETLabs C-Star)[11]	%	0 to 100	± 0.3	± 0.03
Oxygen (SBE 43)	% Saturation	0 to 120	± 2	—
pH (SBE 18)	pH	0 to 14	± 0.1	—

The precision and accuracy of the various probes, as reported in manufacturer's specifications, are listed in Table 3. 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).

Assessments of all three of the physical parameters (salinity, temperature, and density) helped determine the lateral extent of the effluent plume during the tow 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 the 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. Transmissivity readings are reported relative to 100% transmission in air, so the maximum theoretical transmission in (pure) water is expected to be 91.3%.

Before the first vertical hydrocast at Station RW6, the CTD was held below the sea surface for four minutes. 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.

At 7:53 AM, following completion of the last vertical profile at RW1, the CTD instrument package was brought aboard the survey vessel and reconfigured for horizontal towing with forward-looking probes. The CTD was fitted with a horizontal stabilizer wing and a depth-suppression weight was added to the towline to achieve constant-depth tows. After the reconfigured CTD was deployed, it was towed around

[11] 25-cm path length of red (660 nm) light

and across the ZID at two separate depths, one at mid-depth below the thermocline and one within the surface mixed layer, in accordance with the monitoring requirements of the NPDES discharge permit (Figure 6).

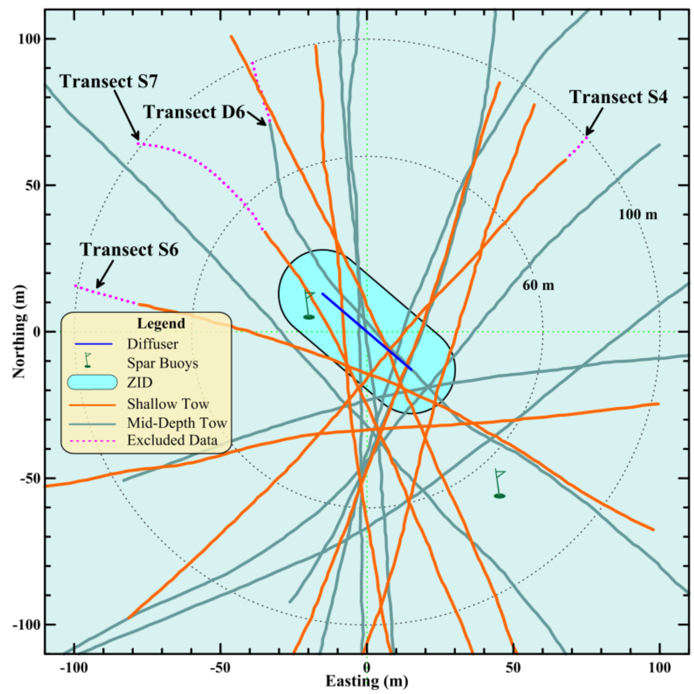

Figure 6. CTD Tracklines during the October 2013 Tow Surveys

Initially, the reconfigured CTD package was towed for 27 minutes at an average depth of 4.41 m, and an average speed of 1.81 m/s, passing over, or near the diffuser structure eight times. Subsequently, nine additional passes were made with the CTD at an average depth of 9.45 m. During this 38-minute mid-depth tow, vessel speed averaged 1.78 m/s. At the observed towing speeds and the 4 Hz sampling rate, at least 2.2 CTD measurements were collected for each meter traversed. This complies with the permit requirement for minimum horizontal resolution of 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 then processed to produce horizontal maps within the upper and sub-thermocline portions of the water column.[12]

Quality Control

During the vertical-profiling and horizontal-towing phases of the survey, real-time data were monitored for completeness and range acceptability. Although real-time monitoring indicated the recorded properties were complete and within acceptable coastal seawater ranges,[13] subsequent post-processing revealed several events that impacted portions of the data, resulting in the adjustment or exclusion of these data prior to initiation of the compliance analysis. For example, review of the tow data revealed that the CTD was tracking at a slightly different depth (>1 m offset) during the initial portion of the shallow tow along Transect S7, and the latter portions of Transects S4 and S6 (purple dotted lines in Figure 6). During the mid-depth tow, the CTD was tracking at a greater depth during the initial portion of Transect D6.

Depth offsets are typically induced by changes in vessel speed that are instituted to prevent the CTD from colliding with the seafloor during the execution of the turns used to align the vessel between each transect. Because of the complex interaction between turn radius, vessel speed, and CTD depth, the CTD's target depth cannot always be precisely maintained.

Because the discharge-related anomalies used in the compliance analysis are identified by comparing the amplitudes of measurements acquired at the same depth level, the ability to resolve anomalies with

[12] Figures 8 and 9 later in this report

[13] Field sampling protocols employed during the survey generally followed the field operations manual for the Southern California Bight Study (SCBFMC 2002), which includes CTD cast-acceptability ranges listed in Table 2 of the manual.

statistical certainty is compromised when data from different depth levels are combined in the horizontal maps. This is particularly true when the water column is stratified, as was the case during the October 2013 survey.

The exclusion of the small portions of Transects S4, S6, S7, and D6 did not, however, adversely affect the compliance analysis because the remaining data adequately covered the 100-m survey area surrounding the diffuser structure. Specifically, the remaining data, shown by the solid orange and blue-green lines in Figure 6, met the permit monitoring requirement of at least five passes near the diffuser structure at each tow depth.

RESULTS

The fourth-quarter receiving-water survey was conducted on the morning of Wednesday, 16 October 2013. The receiving-water survey commenced at 7:08 AM with the deployment of the drogued drifter. Over the following two hours, offshore observations and measurements were collected as required by the NPDES monitoring program. The survey ended at 9:22 AM with the retrieval of the drogued drifter. Collection of required visual observations of the sea surface was unencumbered throughout the survey.

Auxiliary Observations

On the morning of 16 October 2013, skies were clear, with light to moderate northeasterly winds. Average wind speeds, calculated over one-minute intervals, ranged from 2.7 kt to 7.2 kt (Table 4). Similarly, peak wind speeds ranged from 3.9 kt to 9.0 kt. The swell was out of the northwest with a significant wave height of only 1 to 2 feet. Air temperatures remained fairly constant throughout the survey, averaging 19.4°C.

Table 4. Standard Meteorological and Oceanographic Observations

Station	Location[14] Latitude	Longitude	Diffuser Distance (m)	Time (PDT)	Air (°C)	Cloud Cover (%)	Wind Avg (kt)	Wind Max (kt)	Wind Dir (from) (°T)	Swell Ht/Dir (ft/°T)	Secchi Depth (m)
RW1	35° 23.251' N	120° 52.515' W	82.9	7:52:43	—[15]	0	—	—	NE	1-2 NW	5.0
RW2	35° 23.230' N	120° 52.520' W	44.2	7:47:51	19.7	0	7.2	9.0	NE	1-2 NW	5.0
RW3	35° 23.195' N	120° 52.513' W	14.5	7:41:32	19.8	0	5.0	8.1	NE	1-2 NW	4.5
RW4	35° 23.182' N	120° 52.526' W	44.3	7:33:37	19.3	0	5.0	7.9	NE	1-2 NW	4.5
RW5	35° 23.169' N	120° 52.516' W	53.2	7:27:14	19.2	0	2.7	3.9	NE	1-2 NW	5.0
RW6	35° 23.147' N	120° 52.520' W	90.5	7:19:35	19.0	0	3.9	6.0	NE	1-2 NW	5.0

The 4.5-to-5.0 m Secchi depths recorded during the October 2013 survey reflected the presence of a 10-m euphotic zone that extended slightly more than halfway through the water column (Table 4). However, the clarity within the mixed layer near the sea surface was lower than that of the seawater at depth (below 6 m) due to increased planktonic densities that arose because of upwelling in the days prior to the survey. During upwelling, nutrients carried upward into the euphotic zone are assimilated by phytoplankton, whose populations increase. Along with their associated zooplanktonic predators, these elevated plankton densities reduced the transmittance of ambient light in the upper water column.

Communication with plant personnel and subsequent review of effluent discharge properties on the day of the survey, confirm that the treatment process was performing nominally at time of the survey. The 0.821

[14] Locations are the vessel positions at the time the Secchi depths were measured. These typically depart slightly from the CTD profile locations listed in Table 2.
[15] Wind speeds and temperature were not recorded at Station 1.

million gallons of effluent discharged on 16 October had a temperature of 22°C, a suspended-solids concentration of 26 mg/L, and a pH of 7.5. Biochemical oxygen demand (BOD) measured in an effluent sample collected seven days before the survey was 63.2 mg/.

During the October 2013 survey, visual observations demonstrated continued beneficial use of the coastal waters within Estero Bay by both wildlife and recreational users. California brown pelicans (*Pelecanus occidentalis*), Brandt's cormorants (*Phalacrocorax penicillatus*), pelagic cormorants (*Phalacrocorax pelagicus*), and western gulls (*Larus occidentalis*) were all observed transiting the survey area. Additionally, a lone southern sea otter (*Enhydra lutris nereis*) and a pair of royal terns (*Thalasseus maximus*) were noted transiting the survey area.

Small numbers of pedestrians were visible along Atascadero State beach during the latter half of the survey. Additionally, several recreational fishing vessels and a sailboat were observed offshore of the survey area. Within the protected confines of the Morro Bay harbor, approximately eight sea otters were observed clustered together in a raft.

Instrumental Observations

Data collected during vertical profiling were processed in accordance with standard procedures (SCCWRP 2002), and are collated within 0.5-m depth intervals in Table 5. Data collected during the October 2013 survey reflect the presence of a moderately stratified water column indicative of recent upwelling conditions within Estero Bay (Figure 5).

Upwelling of varying intensity occurs most of the year along the central California coast, with the strongest upwelling winds beginning in March or April and extending through the summer. The intensity of upwelling tends to decline into fall, although pulses of sustained northwesterly winds still occur. 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 a small vertical distance. Under highly stratified conditions, isotherms crowd together to form a density interface that restricts the vertical transport of the effluent plume, inhibiting the vertical exchange of nutrients and other water properties, and reducing the initial dilution of the effluent plume.

If strong upwelling winds are not sustained however, the interface between the surface and deep watermasses begins to erode, and the stratification appears as a more gradual vertical change in seawater properties that ultimately extends throughout the water column below the surface mixed layer. This was case during the October 2013 survey. Although winds were mild on the morning of the 16 October, sustained northwesterly winds had prevailed in the days prior to the survey (Figure 5). As a result, a relict upwelling signature appears in each of the vertical profiles (Figure 7).

In particular, all seawater properties except salinity exhibit steadily increasing or decreasing values below approximately 6 m. Steady decreases in temperature (red lines), DO (dark blue lines), and pH (olive-colored lines) with increasing depth reflect the lingering effects of upwelling in the days prior to the survey. These decreases are mirrored by a pycnocline, where density (black lines) and transmissivity (light blue lines) steadily increase with depth. These gradual vertical changes reflect the presence of a colder, saltier, nutrient-rich but oxygen-poor watermass that migrated shoreward along the seafloor as part of the upwelling process.

Table 5. Vertical Profile Data Collected on 16 October 2013

Depth (m)	Temperature (°C)						Salinity (‰)					
	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6
1.0	13.832	13.846	13.825	13.866	13.825	13.848	33.576	33.574	33.566	33.573	33.567	33.571
1.5	13.835	13.846	13.835	13.786	13.831	13.845	33.576	33.574	33.569	33.561	33.568	33.572
2.0	13.839	13.841	13.844	13.455	13.835	13.844	33.576	33.572	33.570	33.480	33.568	33.572
2.5	13.840	13.840	13.844	13.272	13.822	13.834	33.576	33.574	33.570	33.459	33.567	33.572
3.0	13.839	13.841	13.842	13.307	13.790	13.824	33.576	33.574	33.570	33.485	33.560	33.571
3.5	13.837	13.844	13.840	13.346	13.788	13.817	33.575	33.574	33.570	33.505	33.561	33.571
4.0	13.835	13.848	13.836	13.315	13.785	13.799	33.576	33.574	33.572	33.490	33.562	33.566
4.5	13.836	13.840	13.833	13.310	13.756	13.777	33.576	33.575	33.571	33.485	33.555	33.563
5.0	13.835	13.835	13.830	13.328	13.717	13.682	33.577	33.576	33.573	33.492	33.546	33.547
5.5	13.810	13.827	13.825	13.396	13.685	13.637	33.577	33.577	33.574	33.522	33.541	33.541
6.0	13.764	13.809	13.820	13.379	13.587	13.586	33.578	33.578	33.575	33.512	33.536	33.542
6.5	13.733	13.752	13.779	13.364	13.532	13.548	33.578	33.577	33.573	33.503	33.542	33.549
7.0	13.687	13.686	13.638	13.323	13.545	13.544	33.576	33.576	33.559	33.490	33.557	33.552
7.5	13.649	13.642	13.547	13.320	13.549	13.542	33.575	33.575	33.561	33.488	33.560	33.553
8.0	13.632	13.620	13.592	13.416	13.550	13.541	33.575	33.575	33.574	33.529	33.567	33.556
8.5	13.610	13.605	13.591	13.435	13.551	13.537	33.574	33.575	33.574	33.530	33.573	33.561
9.0	13.582	13.581	13.573	13.528	13.553	13.525	33.571	33.573	33.572	33.572	33.573	33.571
9.5	13.572	13.568	13.562	13.549	13.550	13.520	33.571	33.571	33.570	33.575	33.572	33.572
10.0	13.572	13.555	13.512	13.542	13.541	13.514	33.572	33.570	33.556	33.573	33.573	33.573
10.5	13.570	13.522	13.525	13.538	13.518	13.511	33.571	33.566	33.568	33.572	33.571	33.573
11.0	13.561	13.473	13.536	13.533	13.501	13.499	33.570	33.562	33.568	33.571	33.569	33.571
11.5	13.537	13.426	13.516	13.522	13.496	13.463	33.566	33.560	33.566	33.570	33.569	33.567
12.0	13.492	13.417	13.484	13.509	13.488	13.447	33.560	33.561	33.564	33.569	33.569	33.567
12.5	13.455	13.414	13.401	13.489	13.458	13.399	33.560	33.562	33.559	33.566	33.565	33.566
13.0	13.430	13.393	13.320	13.473	13.397	13.375	33.559	33.561	33.559	33.565	33.562	33.568
13.5	13.390	13.370	13.302	13.432	13.328	13.310	33.559	33.562	33.562	33.563	33.563	33.565
14.0	13.349	13.331	13.297	13.379	13.210	13.266	33.559	33.562	33.564	33.562	33.558	33.565
14.5	13.280	13.273	13.240	13.318	13.066	13.230	33.558	33.563	33.562	33.563	33.559	33.564
15.0	13.215	13.198	13.117	13.278	13.041	13.138	33.560	33.562	33.560	33.553	33.561	33.562
15.5	13.151	13.113	13.096	13.192	12.993	13.057	33.560	33.561	33.563	33.547	33.560	33.562
16.0	13.013	13.047	13.068	13.135	12.945	12.991	33.553	33.560	33.563	33.563	33.560	33.562
16.5	12.862	12.938	12.894	13.060	12.858	12.887	33.553	33.558	33.556	33.562	33.559	33.535
17.0	12.833	12.830	12.834	12.942	12.832	12.828	33.560	33.559	33.561	33.559	33.563	33.562
17.5			12.831	12.876					33.562	33.566		
18.0			12.830						33.564			

Table 5. Vertical Profile Data Collected on 16 October 2013 (continued)

Depth (m)	Density (σ_t)						pH					
	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6
1.0	25.121	25.117	25.115	25.112	25.117	25.115	8.148	8.145	8.147	8.145	8.144	8.147
1.5	25.121	25.117	25.116	25.120	25.116	25.115	8.146	8.144	8.145	8.145	8.142	8.145
2.0	25.120	25.116	25.115	25.125	25.115	25.116	8.147	8.144	8.145	8.132	8.143	8.145
2.5	25.120	25.119	25.115	25.145	25.116	25.118	8.148	8.145	8.144	8.102	8.144	8.142
3.0	25.120	25.118	25.115	25.158	25.118	25.119	8.146	8.145	8.144	8.072	8.138	8.137
3.5	25.120	25.118	25.115	25.166	25.119	25.121	8.148	8.145	8.143	8.058	8.135	8.135
4.0	25.121	25.117	25.117	25.160	25.120	25.120	8.145	8.145	8.142	8.049	8.136	8.133
4.5	25.121	25.119	25.118	25.158	25.121	25.123	8.145	8.143	8.138	8.042	8.136	8.131
5.0	25.122	25.121	25.120	25.159	25.122	25.130	8.142	8.140	8.136	8.039	8.131	8.124
5.5	25.127	25.123	25.122	25.169	25.125	25.135	8.141	8.135	8.133	8.040	8.126	8.119
6.0	25.137	25.128	25.124	25.164	25.141	25.146	8.132	8.132	8.131	8.039	8.115	8.110
6.5	25.144	25.139	25.130	25.161	25.157	25.159	8.119	8.125	8.129	8.040	8.100	8.098
7.0	25.151	25.151	25.148	25.159	25.166	25.162	8.108	8.114	8.120	8.040	8.087	8.090
7.5	25.159	25.160	25.168	25.157	25.167	25.163	8.099	8.102	8.099	8.037	8.080	8.084
8.0	25.162	25.164	25.169	25.170	25.173	25.166	8.091	8.091	8.086	8.039	8.075	8.080
8.5	25.165	25.167	25.169	25.167	25.177	25.170	8.084	8.086	8.079	8.044	8.072	8.077
9.0	25.169	25.170	25.172	25.181	25.177	25.180	8.080	8.081	8.078	8.047	8.069	8.074
9.5	25.171	25.172	25.172	25.179	25.176	25.182	8.078	8.078	8.078	8.056	8.068	8.071
10.0	25.171	25.174	25.172	25.178	25.179	25.184	8.077	8.077	8.076	8.061	8.067	8.068
10.5	25.172	25.177	25.178	25.179	25.182	25.185	8.075	8.078	8.071	8.065	8.066	8.065
11.0	25.172	25.184	25.176	25.179	25.184	25.186	8.075	8.078	8.074	8.066	8.064	8.064
11.5	25.174	25.192	25.179	25.180	25.185	25.190	8.076	8.077	8.073	8.069	8.064	8.064
12.0	25.179	25.195	25.183	25.182	25.186	25.193	8.078	8.075	8.074	8.070	8.064	8.064
12.5	25.186	25.196	25.197	25.184	25.189	25.202	8.078	8.074	8.074	8.072	8.066	8.064
13.0	25.191	25.200	25.213	25.186	25.200	25.209	8.079	8.072	8.069	8.072	8.068	8.058
13.5	25.199	25.205	25.218	25.193	25.214	25.220	8.076	8.070	8.062	8.072	8.062	8.050
14.0	25.207	25.213	25.221	25.203	25.234	25.228	8.070	8.067	8.056	8.069	8.054	8.044
14.5	25.220	25.225	25.231	25.216	25.263	25.235	8.064	8.058	8.052	8.059	8.037	8.038
15.0	25.234	25.240	25.254	25.217	25.270	25.252	8.051	8.049	8.040	8.051	8.024	8.030
15.5	25.247	25.256	25.261	25.229	25.279	25.268	8.038	8.038	8.026	8.040	8.014	8.018
16.0	25.269	25.268	25.266	25.253	25.288	25.281	8.024	8.023	8.017	8.028	8.004	8.005
16.5	25.299	25.288	25.295	25.267	25.305	25.281	8.004	8.010	8.011	8.020	7.992	7.990
17.0	25.310	25.310	25.311	25.288	25.313	25.313	7.985	7.991	7.996	8.008	7.982	7.976
17.5			25.312	25.306					7.986	7.989		
18.0			25.314						7.975			

Table 5. Vertical Profile Data Collected on 16 October 2013 (continued)

Depth (m)	Dissolved Oxygen (mg/L)						Transmissivity (%)					
	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6
1.0	8.858	8.675	8.850	9.156	8.830	8.894	81.640	81.646	81.728	82.087	82.191	81.687
1.5	8.866	8.776	8.831	8.848	8.870	8.797	81.745	81.746	82.066	81.892	82.651	82.151
2.0	8.850	8.794	8.825	8.841	8.799	8.688	81.711	81.969	82.218	81.988	82.538	81.275
2.5	8.845	8.812	8.826	7.338	8.623	8.669	81.772	82.121	82.388	82.185	82.697	82.311
3.0	8.840	8.790	8.772	7.375	8.661	8.665	81.671	81.799	81.704	84.287	82.231	82.095
3.5	8.737	8.748	8.746	7.286	8.691	8.611	81.911	81.923	82.282	84.933	82.397	82.327
4.0	8.784	8.670	8.678	7.300	8.511	8.514	81.609	81.292	82.370	85.469	82.924	82.613
4.5	8.723	8.643	8.643	7.359	8.431	8.251	81.960	81.748	82.510	85.420	82.530	82.449
5.0	8.409	8.556	8.614	7.475	8.263	8.141	82.291	81.641	82.319	85.204	82.066	82.812
5.5	8.153	8.424	8.590	7.414	7.792	7.985	82.182	82.387	82.474	84.977	82.995	82.979
6.0	8.086	8.103	8.322	7.363	7.758	7.825	82.255	82.430	82.239	85.491	83.441	83.087
6.5	7.940	7.910	7.754	7.275	7.806	7.856	83.072	83.308	82.435	85.628	84.498	83.557
7.0	7.863	7.841	7.719	7.369	7.806	7.853	84.118	84.711	82.474	85.494	84.707	84.437
7.5	7.858	7.850	7.882	7.647	7.762	7.817	84.736	84.794	85.318	85.377	84.731	85.058
8.0	7.808	7.807	7.840	7.571	7.763	7.781	85.396	85.117	84.868	85.132	85.321	84.524
8.5	7.802	7.779	7.819	7.866	7.772	7.685	85.398	85.020	85.410	84.978	85.767	84.835
9.0	7.804	7.807	7.865	7.821	7.768	7.699	85.774	85.693	85.427	85.266	84.939	84.931
9.5	7.792	7.808	7.764	7.810	7.756	7.689	85.976	86.085	85.550	85.404	85.310	85.603
10.0	7.793	7.802	7.895	7.816	7.704	7.692	85.729	85.755	85.544	85.521	85.477	85.589
10.5	7.823	7.751	7.855	7.823	7.726	7.668	85.335	85.319	85.461	85.378	85.448	85.076
11.0	7.876	7.683	7.819	7.819	7.718	7.685	86.197	85.996	85.946	85.348	85.851	85.767
11.5	7.801	7.705	7.791	7.804	7.729	7.689	86.244	87.188	86.063	85.622	85.918	85.753
12.0	7.772	7.711	7.532	7.805	7.720	7.492	85.471	87.707	85.567	85.511	85.842	86.164
12.5	7.684	7.606	7.416	7.783	7.414	7.402	86.083	87.851	86.050	85.647	85.553	86.712
13.0	7.590	7.578	7.394	7.673	7.247	7.268	86.825	87.740	86.488	85.797	85.918	87.128
13.5	7.490	7.364	7.323	7.504	6.936	7.222	87.589	87.726	87.916	86.020	86.722	87.794
14.0	7.236	7.142	6.955	7.293	6.658	7.125	88.418	87.841	88.189	85.859	87.502	88.271
14.5	7.052	6.964	6.854	7.193	6.712	6.885	88.313	88.487	88.138	87.161	87.046	88.456
15.0	6.845	6.749	6.840	6.991	6.552	6.685	88.919	88.504	88.250	87.856	88.620	89.036
15.5	6.452	6.623	6.762	6.847	6.412	6.564	89.039	88.990	88.873	88.065	88.837	89.445
16.0	6.218	6.370	6.251	6.699	6.253	6.314	89.444	88.823	89.052	88.249	88.796	89.549
16.5	6.287	6.204	6.280	6.382	6.277	6.264	89.307	89.336	89.444	88.672	88.681	89.583
17.0	6.317	6.315	6.290	6.409	6.315	6.299	88.735	88.648	88.848	89.039	88.154	88.390
17.5			6.299	6.734					88.012	88.256		
18.0			6.307						87.704			

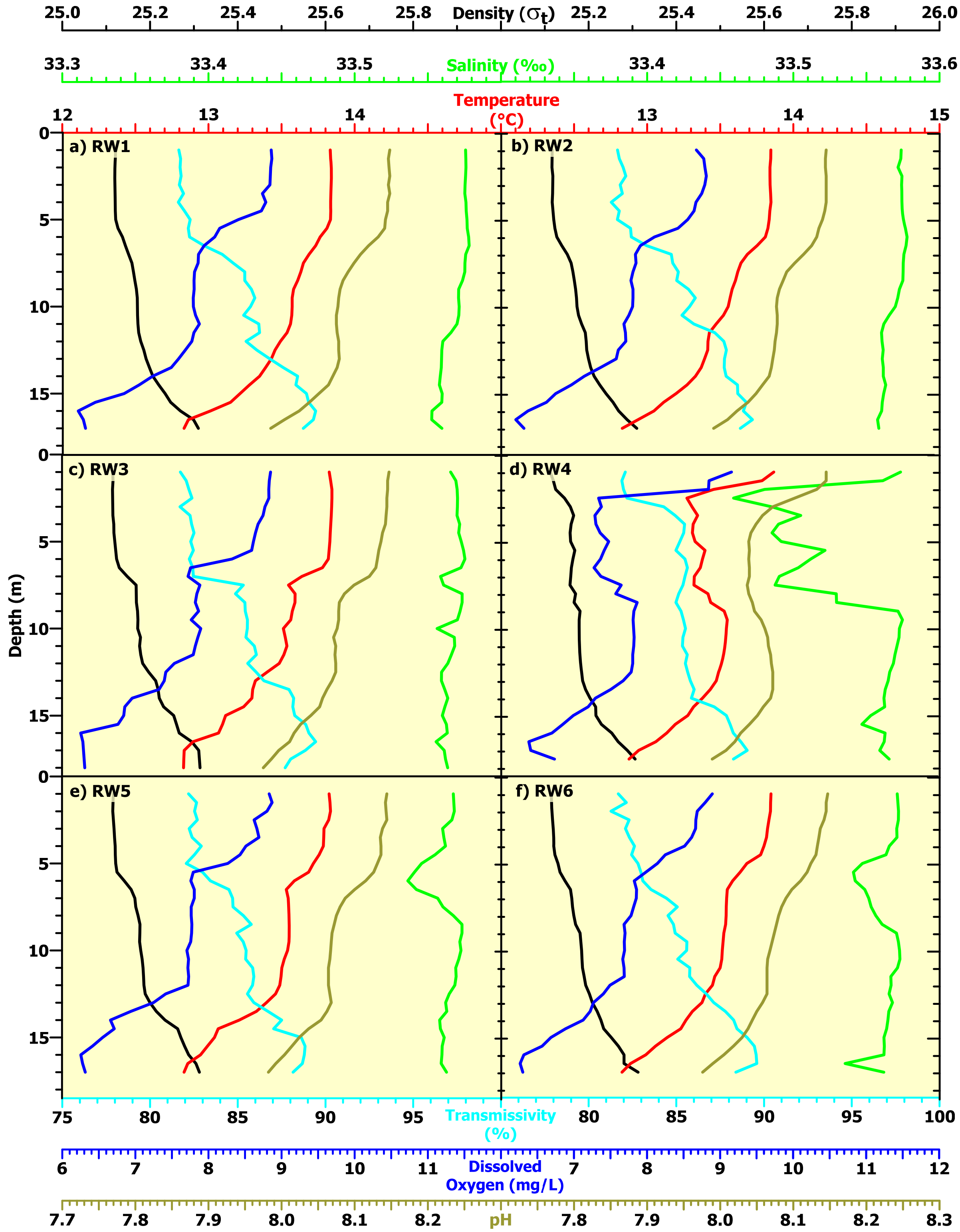

Figure 7. Vertical Profiles of Water-Quality Parameters

Because this deep, offshore water mass had not been in recent direct contact with the atmosphere, biotic respiration and decomposition had depleted its DO levels (dark blue lines). Additionally, at depth, biotic respiration and decomposition produced carbon dioxide (CO_2), and in its dissolved state, the increased concentration of carbonic acid appears as a concomitant decline in pH (olive-colored lines). Meanwhile, within the surface mixed layer, nutrient-rich seawater brought to the sea surface by the recent upwelling facilitated phytoplankton blooms that produced oxygen, consumed carbon dioxide (CO_2), and decreased water clarity (light blue lines). In particular, the presence of plankton within the surface mixed layer caused a 7% decrease in transmissivity at the sea surface compared to the seafloor.

The degree of vertical stratification within ambient seawater is important for understanding the dynamics of the effluent dispersion at the time of the survey. For example, when the water column is strongly stratified by upwelling, the rising plume can become trapped at depth within the water column, thereby limiting its full capacity for dilution. This was not the case during the October 2013 survey, however, because the plume extended almost to the sea surface shortly after discharge. The plume's signature is apparent as a marked reduction in salinity (green line in Figure 7d) below 2 m at Station RW4, as well as in the vertical compression of the surface mixed layer at this location.

At Stations RW5 and RW6 to the south (Figure 7ef), the low salinity plume signature is apparent near 6 m, although its thickness and amplitude are much reduced compared to Station RW4. This indicates that, except close to the diffuser, much of the discharge plume had gravitationally collapsed and spread laterally below the surface mixed layer as it was carried to the south by the prevailing current.

Although the presence of dilute effluent was delineated by a sharp reduction in salinity at Station RW4, changes observed in other water properties within the plume were not caused by the presence of wastewater constituents. Instead, they reflect the presence of ambient seawater that was entrained within the rising effluent plume shortly after its discharge near the seafloor. As these deep seawater properties were carried into the upper water column by the rising plume, they expanded the vertical extent of the deep watermass, and vertically compressed the surface mixed layer. This is apparent from a comparison of the values associated with the red, blue, black, gold, and light blue lines above 8 m at Station RW4 with the deeper portions of those lines at all other stations, including Station RW4.

The effluent plume acquires deep watermass properties because it rapidly entrains bottom seawater shortly after discharge. Close to the seafloor, intense mixing is driven by the momentum of the effluent's ejection from the individual diffuser ports. Subsequent turbulent mixing caused by rise of the plume through the water column is less intense, and as a result, the dilute effluent plume tends to retain the ambient seawater properties it acquired at the seafloor. These deep seawater properties can become apparent as a signature of the buoyant effluent plume when they are juxtaposed against the ambient seawater characteristics in the upper water column. These entrainment-generated anomalies are only apparent, however, when the water column is sufficiently stratified and there is significant contrast between shallow and deep ambient seawater properties.

It also clear that the anomalies in seawater properties within the upper water column at Station RW4 were caused by entrainment rather than the presence of wastewater constituents because for some properties, the offsets were opposite of the changes that would be expected from wastewater particulates. For example, wastewater discharged on the day of the survey was much warmer (22°C) than the receiving seawater at depth (<13°C). Entrainment of bottom seawater is the only mechanism that could have created a plume that was cooler than the surrounding ambient seawater within the upper water column. Similarly, the increased transmissivity (water clarity) that coincided with the shallow salinity anomaly at Station RW4 could not have been generated by the increased particulate loads associated with effluent. Instead, the transmissivity anomaly in the upper water column at Station RW4 reflects the upward transport of the deep watermass, which had higher water clarity than the ambient seawater within the mixed layer (light blue line in at Station RW4 in Figure 7d).

The legacies of entrainment anomalies can be particularly long-lived, remaining apparent within the water column well after completion of the initial dilution process. However, such anomalies are irrelevant to the receiving-water compliance assessment because the permit restricts attention to water-quality changes caused solely by the presence of wastewater constituents. Nevertheless, these anomalies provide useful tracers of the diffuse effluent plume after the completion of the initial dilution process.

These post-initial-dilution signatures of the effluent plume are particularly apparent in maps created from the horizontal tow data (Figures 8 and 9). During the mid-depth tow survey, the presence of wastewater constituents, as indicated by slightly reduced salinity, was largely confined to a small area immediately southwest of the diffuser structure and within the ZID (Figure 8b). The 9.45-m tow depth was just beneath the salinity anomaly measured in the upper water column during vertical profiling at Station RW4 (green line in Figure 7d). In addition, the tow depth was well below the salinity signatures that occurred after the plume's collapse and spreading along its buoyancy equilibrium depth near 6 m at Stations RW5 and RW6 (green lines in Figure 7ef).

As a result, the mid-depth tow captured a slender column of dilute wastewater as the plume was still undergoing rapid initial dilution. The plume's positive buoyancy at this location is reflected by the highly localized, negative density anomaly that was measured in conjunction with the salinity anomaly (Figure 8c). At that location, the plume was lighter than the surrounding waters, indicating that buoyancy forces were still acting on the plume, and that the plume would continue to rise rapidly through the water column.

Additionally, the other ambient seawater properties at this depth were only slightly different from those at the seafloor that were entrained within the rising plume. Because of this limited vertical contrast, entrainment-generated anomalies were only marginally perceptible in the mid-depth horizontal tow maps. Although a slightly lower temperature, DO, and pH were apparent at the same location as the salinity and density anomalies, they were barely perceptible against the backdrop of random fluctuations in those properties that appear as isolated patches that were not spatially coincident with the salinity anomaly (Figure 8aef).

Similarly, the very slight reduction in transmissivity (water clarity) that coincided with the salinity anomaly was too small to be reliably ascribed to the increased presence of wastewater particulates within the plume (Figure 8d). Instead, patches of greater transmissivity reductions were randomly scattered about the mid-depth tow map, reflecting a moderate level of natural variability in ambient water clarity at this depth. Nevertheless, even if the observed reduction in water clarity were wastewater-induced, it would be of little environmental consequence, not only because of its small magnitude relative to natural variability, but also because of its location within the ZID.

In contrast to the highly localized anomalies observed in the mid-depth tow, the shallow tow captured the disposition of the effluent plume near the completion of the initial dilution process and as it was carried southward by the prevailing current (Figure 9). The shallow tow was conducted at a depth of 4.4 m, which was in the midst of the 6-m thick layer of dilute effluent that was located immediately southwest of the diffuser structure near Station RW4 (Figure 7d).

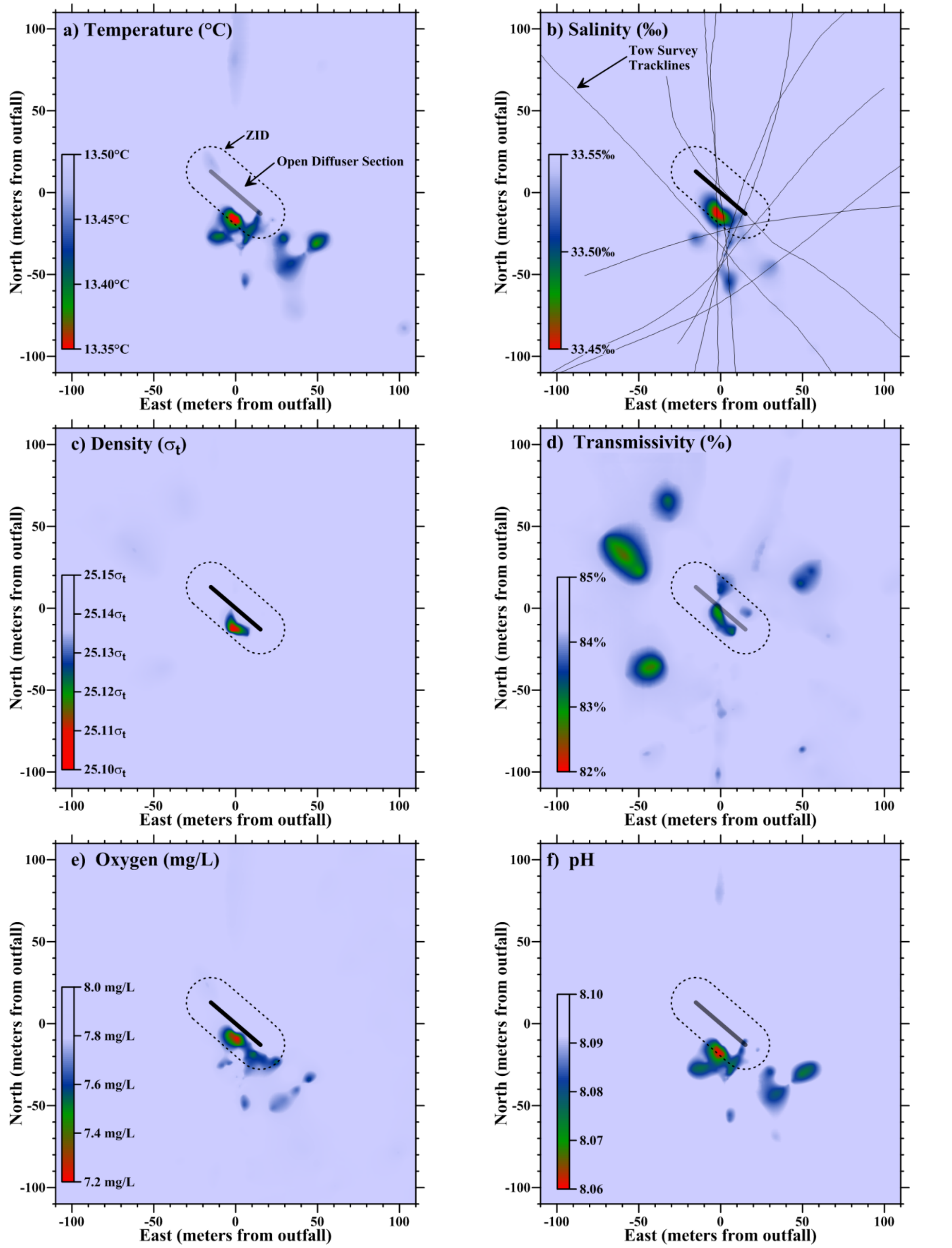

Figure 8. Horizontal Distribution of Mid-Depth Water-Quality Parameters 9.45 m below the Sea Surface

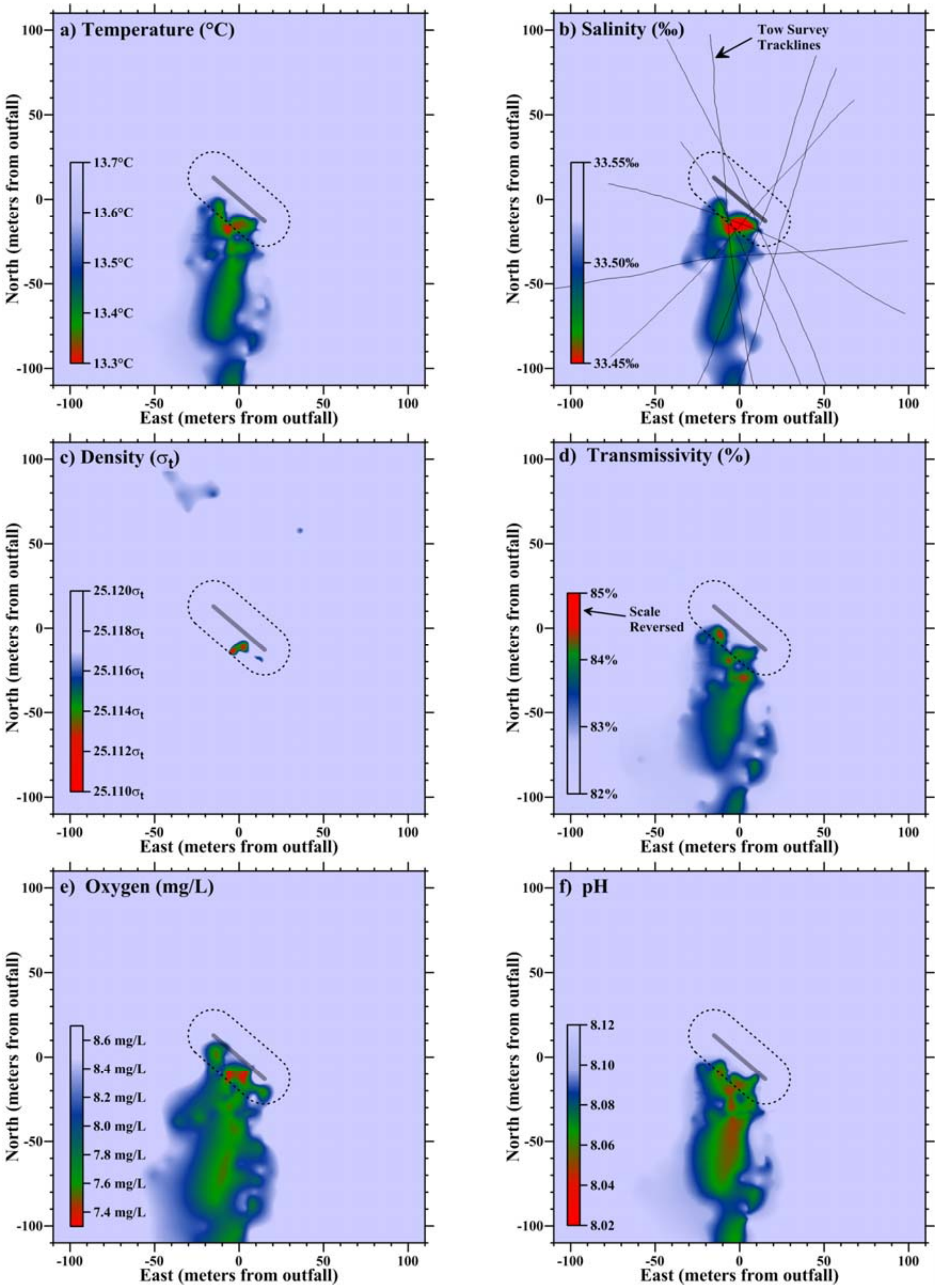

Figure 9. Horizontal Distribution of Shallow Water-Quality Parameters 4.4 m below the Sea Surface

The largest salinity reduction was located within the ZID and was coincident with the isolated salinity anomaly that had been observed during the mid-depth tow (red shading in Figure 9b). The shallow tow measurements also captured the weaker signature of the plume after it collapsed about its equilibrium depth and was transported southward toward Stations RW5 and RW6 (Figure 7ef). Because of the additional dilution achieved during the plume's collapse about its equilibrium depth, the amplitude of the southern salinity anomalies are only about half that of the ZID anomaly (green and blue shading in Figure 9b). The absence of a corresponding density signature to the south demonstrates that the plume had reached buoyant equilibrium as it passed beyond the ZID boundary and thus, had completed the initial dilution process (Figure 9c).

As with the mid-depth tow, the origin of the shallow anomalies in temperature, transmissivity, DO, and pH differed from that of the salinity anomaly, even though their spatial distributions were consistent. The salinity reduction directly reflects the concentration of wastewater particulates at any given location because the vertical contrast in the salinity is small, while the salinity contrast between wastewater and ocean water is large. Thus, the shallow salinity anomaly could not have easily been generated by the upward displacement of ambient seawater alone.

The opposite is the case for the anomalies in other water properties. For those properties, the vertical contrast in ambient seawater was much more influential than the wastewater-seawater contrast. As a result of the upward displacement of bottom seawater in the rising effluent plume, the concentrations observed within the plume signature during the shallow tow were equivalent to those measured at depth beyond the influence of the discharge. In addition, because the plume was measured higher in the water column during the shallow tow, the lateral contrasts between ambient concentrations within and outside of the plume were much larger and far more apparent than when they were juxtaposed at mid-depth. For example, the difference in the temperature contrast observed at mid-depth was only 0.15°C (see the scale in Figure 8a), while the temperature contrast observed during the shallow tow was two-and-a-half times larger (0.4°C in Figure 9a).

Similar increases were evident in the DO and pH ranges for the shallow tow, but the most telling difference is between the mid-depth and shallow tow transmissivity maps. While there was no clear plume signature in the transmissivity distribution at mid-depth (Figure 8d), the transmissivity distribution mapped during the shallow tow exhibits a distinctive spatial pattern that matches the overall plume distribution (Figure 9d). More importantly, the plume was significantly less turbid than the surrounding seawater at that depth level (4.4m). Therefore, the scale is reversed in Figure 9d so that the shading highlights areas with higher transmissivity than the surrounding ambient seawater. The higher water clarity observed within the plume at the shallow tow depth and within the upper mixed layer where primary productivity was ongoing, could only have been generated by the entrainment of less turbid seawater at depth.

Outfall Performance

The efficacy of the outfall can be evaluated through a comparison of dilution levels measured at the time of the October 2013 survey, and dilutions anticipated from modeling studies that were codified in the discharge permit through limits imposed on effluent constituents. Specifically, the critical initial dilution applicable to the MBCSD outfall was conservatively estimated to be 133:1 (Tetra Tech 1992). That is, dispersion modeling estimated that, at the conclusion of the minimum expected initial mixing, 133 parts of ambient seawater would have mixed with each part of wastewater.

The 133:1 dilution estimate was based on worst-case modeling under highly stratified conditions, where trapping of the plume below a strong thermocline would curtail the additional buoyant mixing normally experienced during the plume's rise through the water column. Additionally, the modeling assumed quiescent oceanic flow conditions, thereby restricting initial mixing processes to the ZID. Under those conditions, the modeling predicted that a 133:1 dilution would be achieved after the plume rose only 9 m from the seafloor, whereupon it would become trapped, ceasing to rise further in the water column, and spread laterally with no further dilution occurring. A 9-m rise at the MBCSD outfall translates into a trapping depth that is 6.4 m below the sea surface. As described below, however, the observed dilution levels during the October 2013 survey were higher than the 133:1 predicted by the modeling, and were measured at depths greater than the trapping depth 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. Application of a higher critical dilution would relax the stringent end-of-pipe effluent limitations thought necessary to meet COP objectives after initial dilution is complete.

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 chemical constituent 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 receiving-water 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 layers of significantly lower salinity were apparent in the vertical profiles measured at Stations RW4, RW5, and RW6 (green lines in Figure 7bcdef), and in patches within and south of the ZID in both tow-survey maps (Figures 8b and 9b). These localized salinity anomalies document mixing processes within the effluent plume shortly after it emanated from a diffuser port and rose through the water column.

These salinity anomalies measure the magnitude of wastewater dilution at these various stages of the initial mixing process. By rearranging Equation 1, the dilution ratio (D) can be computed from the salinity anomaly ($A = C_o - C_s$) as:

$$D \equiv \frac{(C_e - C_o)}{\left(C_o - C_s\right)} \propto -A^{-1} \qquad \text{Equation 2}$$

The salinity concentration within MBCSD effluent (C_e)[16] is generally small compared to that of the receiving seawater and, after dilution by more than 133-fold, the salinity of the effluent-seawater mixture is close to ambient salinity. Consequently, to a close approximation, dilution levels are inversely proportional to the amplitude of the salinity anomaly. Thus, a lower effluent dilution at a given location within the receiving waters is directly mirrored by a larger salinity reduction.

Some of the lowest salinities (<33.43‰) measured during the October 2013 survey were recorded within 10 m of the diffuser during the fourth transect of the mid-depth tow survey (red shading southwest of the diffuser structure in Figure 8b). This measured salinity corresponds to a 0.14‰ reduction below the mean ambient salinity of 33.56‰ that was measured at depth but well beyond the influence of the discharge. From Equation 2, that salinity anomaly corresponds to a dilution of 237-fold (Figure 10). This is 77% greater than the 133:1 critical initial dilution used to establish limits on contaminant concentrations in wastewater.

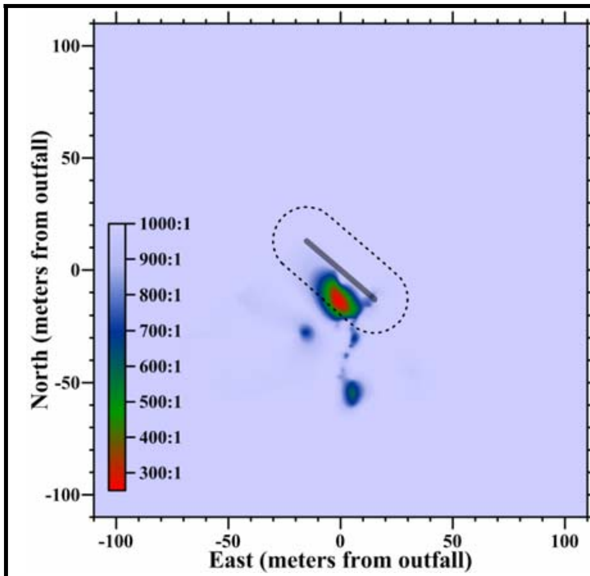

Figure 10. Mid-Depth Plume Dilution Computed from Salinity Anomalies in Figure 8b

In addition, this dilution was measured at a depth of 8.8-m, which was 2.4 m below the 6.4-m trapping depth identified in the modeling that established the 133:1 minimum dilution ratio. According to the conservative modeling results, dilution levels would be expected to be less than 133:1 at that depth level. Instead, the much higher dilutions measured during the mid-depth tow indicate that the diffuser structure was dispersing the effluent far more efficiently than predicted by the modeling, even before the completion of the initial dilution process.

As expected, dilution levels measured beyond the ZID and after completion of the initial dilution process during the shallow tow were substantially higher (green shading in Figure 11). The lowest dilution measured during the shallow tow was located to the south of the southern ZID boundary and demonstrated that effluent had been diluted at least 275-fold at the completion of the initial dilution process.

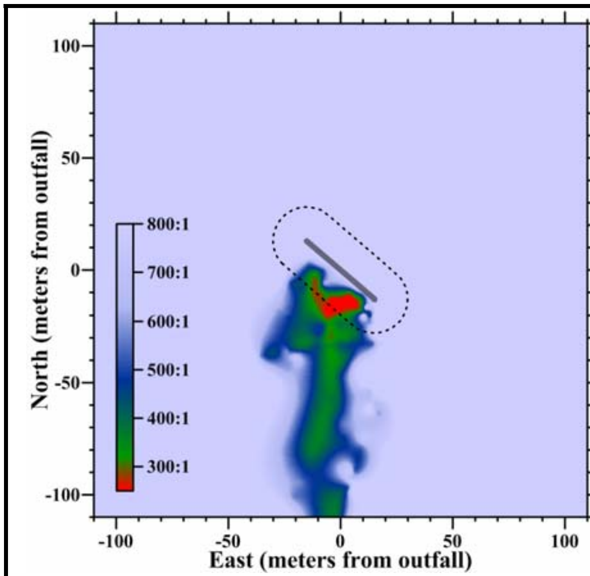

Figure 11. Shallow Plume Dilution Computed from Salinity Anomalies in Figure 9b

The dilution computations demonstrate that, during the October 2013 survey, the outfall was performing better than designed and was rapidly diluting effluent more than 237-fold immediately after discharge, and well before completion of the initial-dilution process. After initial dilution was complete, effluent had been diluted at least 275-fold.

[16] Wastewater samples have an average salinity of 0.995‰.

These dilution levels easily exceeded the 133:1 critical initial dilution used to establish end-of-pipe permit limitations on contaminant concentrations within wastewater discharged from the MBCSD treatment plant. This demonstrates that, during the October 2013 survey, the COP receiving-water objectives were being 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 compliance with the water-quality limitations listed in the NPDES permit (Table 6). The limits themselves 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. Specifically, the quantitative analyses described in this section focus on water-property excursions caused by the presence of wastewater constituents beyond the ZID whose amplitudes can be reliably discerned against the backdrop of ambient fluctuations. A detailed understanding of ambient seawater properties, and their natural variability within the region surrounding the outfall is therefore an integral part of the compliance evaluation presented in this section.

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% 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 results of these analyses applied to the October 2013 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 often met the prescribed limits because actual dilution levels routinely exceeded 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 a high level during the October 2013 survey.

Permit Provisions

The offshore receiving-water surveys are designed to assess compliance with objectives dealing with undesirable alterations to six physical and chemical characteristics of seawater. Specifically, 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. No floating wastewater materials, oil, grease, or discoloration of the sea surface were observed during the October 2013 survey.

Compliance with the remaining four receiving-water limitations is quantitatively evaluated through a comparison between instrumental measurements and numerical limits listed in the NPDES permit. For example, in P5 and P6, the fixed numeric limits on absolute values of DO (>5 mg/L) and pH (7.0 to 8.3) can be directly compared with field measurements within the dilute wastewater plume beyond the ZID. However, both P5 and P6 also contain narrative limits, which originate in the COP, and define unacceptable water-quality impacts as "*significant*" excursions beyond those that occur "*naturally*." Quantitative evaluation of these limits requires a further comparison of field measurements with numerical thresholds that reflect the natural variation in transmissivity, DO, and pH within the receiving waters surrounding the outfall.

Natural variation in seawater properties is driven by a variety of oceanographic processes. These processes determine the range in ambient seawater properties caused by natural spatial variation within the survey region at a given time (e.g., vertical stratification), and by temporal variations caused by seasonal and interannual influences (e.g., El Niño and La Niña). 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, present during any given survey.

Screening of Measurements

Evaluating whether any of the 10,799 CTD measurements collected during the October 2013 survey exceeded a permit limit can be a complex process. For example, although apparently significant excursions in an individual seawater property may be related to the presence of wastewater constituents, they may also result from instrumental errors, natural processes, entrainment of ambient bottom waters in the rising effluent plume, statistical uncertainty, ongoing initial mixing within and beyond the ZID, or other anthropogenic influences (e.g., dredging discharges or oil spills).

Because of this complexity, measurements were first screened to determine whether numerical limits on individual seawater properties apply (Table 7). The screening procedure sequentially applies three questions to restrict attention to: 1) the oceanic area where permit provisions apply; 2) changes due to the presence of wastewater particulates; and 3) changes large enough to be reliably detected against the backdrop of natural variation. The measurements that make it through the screening process, if any, can then be compared with Basin-Plan numerical limits and COP allowances.

Table 7. Receiving-Water Measurements Screened for Compliance Evaluation

Topic Addressed	Screening Question	Answer No	Answer Yes[17]	*Parameter*
Location	1. Was the measurement collected beyond the 15.2-m ZID boundary where modeling assumes that initial dilution is complete?	*1,243*	*9,556*	All
Wastewater Constituents	2. Did the beyond-ZID measurement coincide with a quantifiable salinity anomaly (≤550:1 dilution level) indicating the presence of detectable wastewater constituents?	*8,880*	*676*	All
Natural Variation	3. Did seawater properties associated with the wastewater measurements depart significantly from the expected range in ambient seawater properties at the time of the survey?	*676*	*0*	Temperature
		676	*0*	Transmissivity
		676	*0*	DO
		676	*0*	pH

[17] Number of remaining CTD observations of potential compliance interest based on this screening question

The following subsection provides additional lines-of-evidence that demonstrate compliance with numerical permit limits independent of the screening process. The rationale for evaluating observations for compliance analysis is provided in the following description of the three screening steps.

1. Measurement Location: 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 through the water column.

Although currents often transport the plume beyond the ZID before the initial dilution process is complete, the COP 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, the regulatory mixing distance, which is equal to the 15.2-m water depth of the discharge, provides a conservative boundary to screen receiving-water data for subsequent compliance evaluation. Application of this initial screening question to the October 2013 dataset eliminated 1,243 of the original 10,799 receiving-water observations from further consideration because they were collected within the ZID (Table 7, Question 1). The remaining 9,556 observations were carried forward in the compliance analysis.

2. 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 waters. Wastewater salinity 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 contrast between the nearly fresh wastewater and the salty receiving water, salinity provides a powerful tracer of dilute wastewater that is unrivaled by other seawater properties. Other properties do not exhibit such a large contrast and, as such, their wastewater signatures dissipate rapidly upon discharge with very little mixing. Wastewater's lack of salinity, however, provides a powerful tracer 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.

As described in the previous section, wastewater-induced reductions in salinity can be used to determine the amount of dilution achieved by initial mixing. Based on statistical analyses 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‰. This represents a dilution level of 542-fold. Salinity reductions that are smaller than 0.062‰ cannot be reliably discerned against the backdrop of natural variation and would not result in discernible changes in other seawater properties. Eliminating those measurements from further evaluation restricts attention to excursions in temperature, light transmittance, DO, and pH that are potentially related to the presence of wastewater constituents.

As shown in Figures 8b, 9b, 10 and 11, the largest discharge-related salinity anomalies measured during the October 2013 survey were restricted to a localized area within and just to the south of the ZID boundary. A total of 676 measurements collected from beyond the ZID had significant reductions in salinity that unequivocally identified the presence of dilute wastewater constituents. The remaining 8,880 observations that were measured outside the ZID during the October 2013 survey did not have salinity reductions that were greater than the 0.062‰ detection level (Table 7).

3. Natural Variation: 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 ambient seawater was relocated (upward) 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 presence of wastewater constituents. Thus, quantifying the natural variability around the outfall is necessary for determining whether a particular observation warrants comparison with the numeric permit limits.

A statistical analysis of receiving-water data previously collected around the outfall was used to establish the range in natural conditions surrounding the outfall (first three columns of Table 8). These natural-variability ranges were used to identify significant departures from ambient conditions that could be indicative of adverse discharge-related effects on water quality. The same five-year database used to establish the 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 (-1.38 mg/L), and pH (± 0.094). These were combined with 95th percentiles determined from the October 2013 ambient seawater data, to establish time-specific natural-variability thresholds in a manner analogous to COP Appendix VI. The percentiles were determined from October 2013 vertical profile data, excluding measurements potentially affected by the discharge.

Table 8. Compliance Thresholds

Water Quality Property	95% Confidence Bound[18]	95th Percentile[19,20]	Natural Variability Threshold[21]	COP Allowance[22]	Basin Plan Limit[23]	Extremum[24]
Temperature (ºC)	0.82	13.84	>14.66	—	—	≤13.87
Transmissivity (%)	-10.2	81.7	<71.5	—	—	≥78.9
DO (mg/L)	-1.38	6.29	<4.91	<4.42	<5.00	≥6.20
pH (minimum)	-0.094	7.993	<7.899	<7.699	<7.000	≥7.975
pH (maximum)	0.094	8.145	>8.239	>8.439	>8.300	≤8.157

[18] 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 remaining observations for each of the six seawater properties accurately quantified the inherent uncertainty in defining the range in natural conditions.

[19] 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% confidence level*." Accordingly, COP effluent analyses (Step 9 in Appendix VI, Page 42, Ibid.) are based "*the one-sided, upper 95% confidence bound for the 95th percentile*."

[20] The 95th-percentile quantifies natural variability in seawater properties during the July 2013 survey, and was determined from vertical-profiles data unaffected by the discharge.

[21] 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 left and are specific to the July 2013 survey. They do not include the COP allowances specified in the column to the right.

[22] 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.*"

[23] 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. The Basin Plan upper-bound pH objective for ocean waters is 8.5, but a more-stringent upper-bound objective of 8.3, which applies to individual beneficial uses, was implemented in the MBCSD discharge permit.

[24] Maximum or minimum value measured during this survey

Temperature, transmissivity, and DO concentrations associated with the 676 remaining measurements of potential compliance interest were all well within their respective ranges of natural variability (Table 7, Question 3). As such, the screening process unequivocally eliminated all of the remaining CTD measurements collected during the October 2013 survey from further consideration. In fact, all of the documented excursions in these properties were the result of physical processes unrelated to the presence of wastewater constituents, namely, entrainment of near-bottom seawater within the rising effluent plume. During periods when the water column is stratified, as it was during the October 2013 survey, ambient seawater properties near the seafloor differ from those within the rest of the water column, and their juxtaposition within the rising effluent plume appears as lateral anomalies within the upper water column. Regardless, if the presence of wastewater particulates had contributed to the measured decreases in DO and pH, their influence would still have been well within the natural range of the ambient seawater properties at the time of the survey. Consequently, their influence on water quality would not be considered environmentally significant.

Other Lines of Evidence

Several additional lines of evidence further support the conclusion that all the CTD measurements collected during the October 2013 survey complied with permit limits P3 through P6 in Table 6. In combination, these lines of evidence provide the "best explanation" of the origin and significance of individual measurements using abductive inference (Suter 2007). This process, which has been used to implement sediment-quality guidelines for California estuaries (SWRCB 2009), emphasizes a pattern of reasoning that accounts for both discrepancies and concurrences among multiple lines of evidence. A best explanation approach serves to limit the uncertainty associated with each individual CTD measurement and provide a more robust compliance assessment. Together, these lines of evidence significantly strengthen the conclusion that the discharge fully complied with the permit at the time of the October 2013 survey.

Insignificant Thermal Impact: Although there are no explicit numerical objectives for discharge-related increases in temperature, a numerical limit can be established for thermal excursions that is based on the requirement that they not adversely affect beneficial uses (P3 in Table 6). Increases in temperature caused by the discharge of warm wastewater constituents could be deemed to adversely affect beneficial uses if they exceeded the natural temperature range observed at the time of the survey (i.e. exceeded 14.66°C in Table 8). However, none of the 10,799 CTD measurements collected during the October 2013 survey exceeded 13.87°C (last column in Table 8). Additionally, as mentioned previously, because the effluent entrained cooler bottom water shortly after discharge, the rising plume actually exhibited a lower temperature than most of the surrounding seawater (Figures 8a and 9a).

Limited Ambient Light Penetration: As with temperature, there are no explicit numerical objectives for discharge-related decreases in transmissivity. However, the COP narrative objective (P4) limiting significant reductions in the transmission of natural light can also be translated into a numerical objective. Specifically, because the COP does not specify an allowance beyond natural conditions, the same threshold on ambient transmissivity variations listed in Table 8 can be interpreted to constitute a numerical limit. However, none of the transmissivity measurements collected during the October 2013 survey were below the 71.5% minimum compliance threshold (Table 8).

Moreover, the COP objective for light penetration only applies to a portion of the transmissivity measurements that were collected. Because natural light is restricted to the euphotic zone, which extends to approximately twice the Secchi depth, the limit on transmissivity reductions during the October 2013 survey only applied to measurements recorded above 10 m (twice the maximum ambient Secchi depth listed in Table 4). Consequently, even if the discharge of wastewater particulates had caused one or more of the 882 transmissivity measurements collected below the euphotic zone to drop below the numeric compliance threshold, it would not have been of regulatory concern because it would not materially impact the penetration of ambient light.

Directional Offset: Analysis of the directional offset of CTD measurements is useful because wastewater and receiving-seawater properties vary from one another in several predictable ways. For example, upon discharge, wastewater is fresher, warmer, and lighter than the ambient receiving waters of Estero Bay. Under most conditions, wastewater is also more turbid than the receiving waters. As such, the presence of wastewater constituents will reduce the salinity, density, and transmissivity of the receiving seawater (negative offset), while temperature will be increased (positive offset). As discussed previously, the reduced temperatures observed in conjunction with the effluent plume (Figures 8a and 9a) could not have been generated by the presence of warmer wastewater constituents. Similarly, the increased transmissivity observed within the discharge plume during the shallow tow (Figure 9d) could not have been generated by an increased wastewater particulate load. In both cases, the directional offsets were opposite of receiving-water impacts expected from the presence of wastewater constituents.

Insignificant Wastewater Particulate Loads: Another independent line of evidence demonstrates that the discharge of wastewater particulates could not have contributed materially to turbidity within the dilute effluent plume. The suspended-solids concentration measured onshore, within the effluent, prior to discharge from the WWTP on 16 October 2013 was 26 mg/L. After dilution by 237-fold, the effluent suspended-solids concentration would have the reduced ambient transmissivity by only 0.8%. This small potential decrease in transmissivity would have been counteracted by the 3% increase caused by the entrainment and upward displacement of relatively clear ambient seawater near the seafloor (Figure 9d).

Similarly, the MBCSD discharge could not have contributed materially to the observed DO fluctuations. The MBCSD treatment process routinely removes 80% or more of the organic material, as demonstrated by the low, 63.2-mg/L BOD measured within the plant's effluent several days prior to the survey. That small amount of BOD would have induced a DO depression of no more than 0.022 mg/L after dilution (MRS 2002). In fact, in the absence of tangible BOD influence, wastewater discharge would actually be expected to increase DO within subsurface receiving waters, rather than decrease it. This is because effluent is oxygenated by recent contact with the atmosphere during the treatment process, whereas receiving waters at depth are typically depleted in DO.

COP Allowances: The COP does not explicitly require that wastewater-induced changes remain within the ranges in natural variation listed in the third column of Table 8, even though these ranges were conservatively used in the data screening process described in the previous subsection. Consideration of these COP allowances in the receiving-water limits provides an additional level of confidence in the compliance evaluation.

For pH, the COP and the discharge permit allow changes up to 0.2 pH units from natural conditions, bringing the minimum allowed pH to 7.699 during the October 2013 survey (fourth column of Table 8). This value is well below the lowest pH measurement of 7.975 recorded during the October 2013 survey (last column of Table 8). Similarly, the lowest DO concentration measured during the survey (6.20 mg/L) was well above both the lower range in natural variation (4.91 mg/L) and the 10% compliance threshold promulgated by the COP (4.42 mg/L).

Natural Variability within and beyond the ZID: Although the permit limits only apply to changes in DO, pH, temperature, and transmissivity beyond the ZID, the examination of measurements acquired within the ZID frequently provides additional valuable insight into the potential for adverse effects on water quality. However, during the October 2013 survey, salinity was the only seawater property that exhibited a perceptible difference from ambient conditions. Regardless of their association with the effluent salinity signature or their proximity to the diffuser structure, none of the 10,799 temperature, DO, and pH observations exceeded the thresholds of natural variability specified in Table 8.

CONCLUSIONS

The quantitative screening analysis demonstrated that all measurements recorded during the October 2013 survey complied with the receiving-water limitations specified in the NPDES discharge permit. This conclusion was further strengthened by other lines of evidence supporting compliance with the discharge permit. Specifically, although discharge-related changes in seawater properties were observed during the October 2013 survey, the changes were either not of significant magnitude (i.e., they were within the natural range of variability that prevailed at the time of the survey), were measured within the boundary of the ZID where initial mixing is still expected to occur, or were not directly caused by the presence of wastewater constituents within the water column.

Shortly after discharge, the outfall was achieving dilution levels in excess of 237-fold, which substantially exceeds the critical dilution levels predicted by design modeling. This dilution level was observed within the submerged discharge plume, and well before the initial dilution process was complete. As the plume continued to rise through the water column, it achieved dilution levels exceeding 275-fold. Lastly, all of the auxiliary observations collected during the October 2013 survey demonstrated that the discharge complied with the narrative receiving-water limits in the discharge permit and the COP. Together, these observations demonstrate that the treatment process, diffuser structure, and the outfall continue to surpass design expectations.

REFERENCES

Davis, R.E., J.E. Dufour, G.J. Parks, and M.R. Perkins. 1982. Two Inexpensive Current-Following Drifters. Scripps Institution of Oceanography, University of California, San Diego, La Jolla, California. SIO Reference No. 82-28. December 1982.

Fischer, H.B., E.J. List, R.C.Y. Koh, J. Imberger, and N.H. Brooks. 1979. Mixing in Inland and Coastal Waters. New York: Academic Press, 482 p.

Kuehl, S.A., C.A. Nittrouer, M.A. Allison, L. Ercilio, C. Faria, D.A. Dukat, J.M. Jaeger, T.D. Pacioni, A.G. Figueiredo, and E.C. Underkoffler 1996. Sediment deposition, accumulation, and seabed dynamics in an energetic fine-grained coastal environment. *Continental Shelf Research*, 16: 787-816.

Marine Research Specialists (MRS). 1998. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, Semiannual Benthic Sampling Report, April 1998 Survey. Prepared for the City of Morro Bay, CA. July 1998.

Marine Research Specialists (MRS). 2002. City of Morro Bay and Cayucos Sanitary District, Supplement to the 2002 Renewal Application For Ocean Discharge Under NPDES Permit No. Prepared for the City of Morro Bay and Cayucos Sanitary District, Morro Bay, CA. July 2002.

Marine Research Specialists (MRS). 2011. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 2010 Annual Report. Prepared for the City of Morro Bay, California. March 2011.

Marine Research Specialists (MRS). 2012. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 2011 Annual Report. Prepared for the City of Morro Bay, California. March 2012.

Marine Research Specialists (MRS). 2013. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 2012 Annual Report. Prepared for the City of Morro Bay, California. March 2013.

National Academy of Sciences. 1993. Managing Wastewater in Coastal Urban Areas. National Research Council Committee on Wastewater Management for Coastal Urban Areas, Water Science and Technology Board, Commission on Engineering and Technical Systems. 477 pp.

Regional Water Quality Control Board (RWQCB) - Central Coast Region. 1994. Water Quality Control Plan (Basin Plan) Central Coast Region. Available from the RWQCB at 81 Higuera Street, Suite 200, San Luis Obispo, California. 148p. + Appendices.

Regional Water Quality Control Board (RWQCB) - Central Coast Region and the Environmental Protection Agency (USEPA) – Region IX. 1992a. Waste Discharge Requirements (Order No. 92-67) and Authorization to Discharge under the National Pollutant Discharge Elimination System (Permit No. CA0047881) for City of Morro Bay and Cayucos Sanitary District, San Luis Obispo County.

Regional Water Quality Control Board (RWQCB) - Central Coast Region and the Environmental Protection Agency (USEPA) – Region IX. 1992b. Monitoring and Reporting Program No. 92-67 for City of Morro Bay and Cayucos Sanitary District, San Luis Obispo County (Permit No. CA0047881).

Regional Water Quality Control Board (RWQCB) - Central Coast Region and the Environmental Protection Agency (USEPA) – Region IX. 1998a. Waste Discharge Requirements (Order No. 98-15) and National Pollutant Discharge Elimination System (Permit No. CA0047881) for City of Morro Bay and Cayucos Sanitary District, San Luis Obispo County. 11 December 1998.

Regional Water Quality Control Board (RWQCB) - Central Coast Region and the Environmental Protection Agency (USEPA) – Region IX. 1998b. Monitoring and Reporting Program No. 98-15 for City of Morro Bay and Cayucos Sanitary District, San Luis Obispo County. 11 December 1998.

Regional Water Quality Control Board (RWQCB) - Central Coast Region and the Environmental Protection Agency (EPA) – Region IX. 2009. Waste Discharge Requirements (Order No. R2-2008-0065) and National Pollutant Discharge Elimination System (Permit No. CA0047881) for the Morro Bay and Cayucos Wastewater Treatment Plant Discharges to the Pacific Ocean, Morro Bay, San Luis Obispo County. Effective 1 March 2009.

Sea-Bird Electronics, Inc. (SBE) 1989. Calculation of M and B Coefficients for the Sea-Tech Transmissometer. Application Note No. 7, Revised September 1989.

Sea-Bird Electronics, Inc. (SBE) 1992. SBE 12/22/22/20 Dissolved Oxygen Sensor Calibration and Deployment. Application Note No. 12-1, rev B, Revised April 1992.

Southern California Bight Field Methods Committee (SCBFMC). 2002. Field Operation Manual for Marine Water-Column, Benthic, and Trawl monitoring in Southern California. Technical Report 259. Southern California Coastal Water Research Project. Westminster, CA. March 2002.

State Water Resources Control Board (SWRCB). 2005. Water Quality Control Plan, Ocean Waters of California, California Ocean Plan. California Environmental Protection Agency. Effective February 14, 2006.

State Water Resources Control Board (SWRCB). 2009. Water Quality Control Plan for Enclosed Bays and Estuaries – Part 1 Sediment Quality. California Environmental Protection Agency. Effective August 22, 2009. sed_qlty_part1.pdf [Accessed 02/26/10].

Suter II, Glenn, W. 2007. Ecological risk assessment, 2nd edition. U. S. Environmental Protection Agency, Cincinnati, Ohio. CRC.

Tetra Tech. 1992. Technical Review City of Morro Bay, CA Section 201(h) Application for Modification of Secondary Treatment Requirements for a Discharge into Marine Waters. Prepared for the U.S. Environmental Protection Agency, Region IX, San Francisco, CA by Tetra Tech, Inc., Lafayette, CA. February 1992.