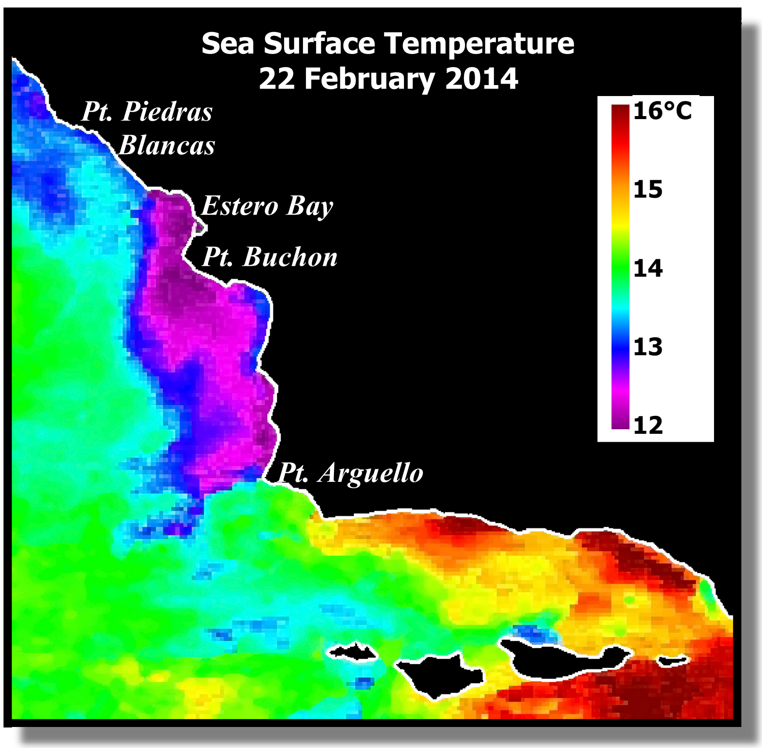
City of Morro Bay and
Cayucos Sanitary District

OFFSHORE MONITORING AND REPORTING PROGRAM

FIRST QUARTER RECEIVING–WATER SURVEY

FEBRUARY 2014



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Report to the

City of Morro Bay and
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FEBRUARY 2014

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

3 April 2014

Reference: First Quarter Receiving-Water Survey Report – February 2014

Dear Mr. Keogh:

The attached report presents results from a quarterly receiving-water survey conducted on Tuesday, 25 February 2014. 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 April 3, 2014

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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 February 2014 field survey described in this report was the twentieth 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 25 February 2014. Specifically, this first-quarter survey captured ambient oceanographic conditions along the central California coast during the winter season. The survey's measurements were used to assess the discharge's compliance with the objectives of the California Ocean Plan (COP) and the Central Coast Basin Plan (RWQCB 1994) as promulgated by the receiving-water limitations specified in the NPDES discharge permit.

The 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.

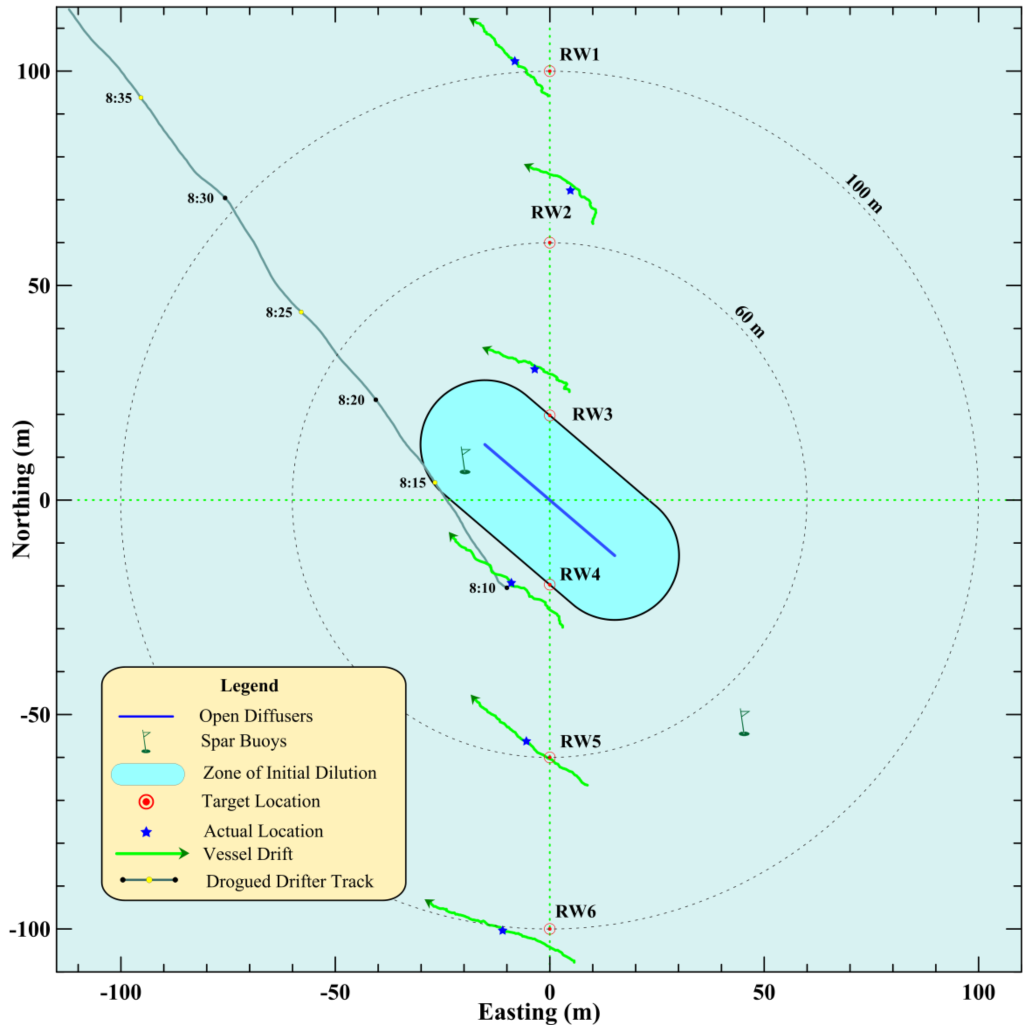

Figure 2. Station Locations

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 February 2014 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 February 2014 survey. During the time it took the CTD to traverse the water column to the seafloor, which averaged 1 min 43 s, the instrument package moved as much as 36 m laterally (Station 6). The CTD traversed a similar distance at other stations, with an average drift among all stations of 27.9 m, which is much larger than that of most prior surveys.

The downcasts during the February 2014 survey were conducted progressing from north to south, beginning with Station RW1. As seen in Figure 2, the CTD movement was exceptionally consistent among all stations and appears to have been strongly influenced by oceanic flow during the survey, which was toward the north-northwest, as reflected by the drogued drifter trajectory (Figures 2 and 3). In contrast, the prevailing light southeasterly winds during the survey did not perceptibly affect the CTD drift.[5] Similarly, the vessel's residual momentum as it approached the stations from the northwest was too small to counteract the rapid CTD transport by the prevailing currents.

Detailed knowledge of the CTD's location during downcasts is important for 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. Although it was not the case during the February 2014 survey, some or all measurements at those stations are often collected within the ZID, and are therefore excluded from compliance evaluations.

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 and a half decades, however, demonstrates that it has maintained a high level of effectiveness in effluent dispersal. In fact, without the occasional measurements recorded

[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.

within the ZID due to vessel drift, the extremely dilute discharge plume might remain undetected within all vertical profiles collected during a given survey.

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 February 2014 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 February 2014 Survey

Station	Time (PST)		Latitude	Longitude	Closest Approach	
	Downcast	Upcast			Range[6] (m)	Bearing[7] (ºT)
RW1	8:15:45	8:17:36	35° 23.254' N	120° 52.509' W	89.7	4
RW2	8:24:58	8:26:28	35° 23.238' N	120° 52.501' W	62.6	19
RW3	8:33:10	8:34:51	35° 23.216' N	120° 52.506' W	21.2	33
RW4	8:42:25	8:44:03	35° 23.189' N	120° 52.510' W	20.4	221
RW5	8:51:01	8:52:26	35° 23.169' N	120° 52.508' W	47.8	206
RW6	9:00:42	9:02:54	35° 23.145' N	120° 52.511' W	91.1	197

OCEANOGRAPHIC PROCESSES

The trajectory of a satellite-tracked drogued drifter documented the oceanic flow during the February 2014 survey (Figure 3). 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 two decades. 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 February 2014 survey, the drifter was deployed near the diffuser structure at 8:10 AM, and was recovered at 10:40 AM at a location 735 m to the north-northwest of its original release point (Red dots in 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 course of the entire survey, the drifter measured an average flow speed of 8.1 cm/s (0.158 kt), which is one of the highest average speeds ever recorded in the monitoring program. At this transport rate, the effluent would have experienced a relatively brief, 3-minute residence time within the ZID.

[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.

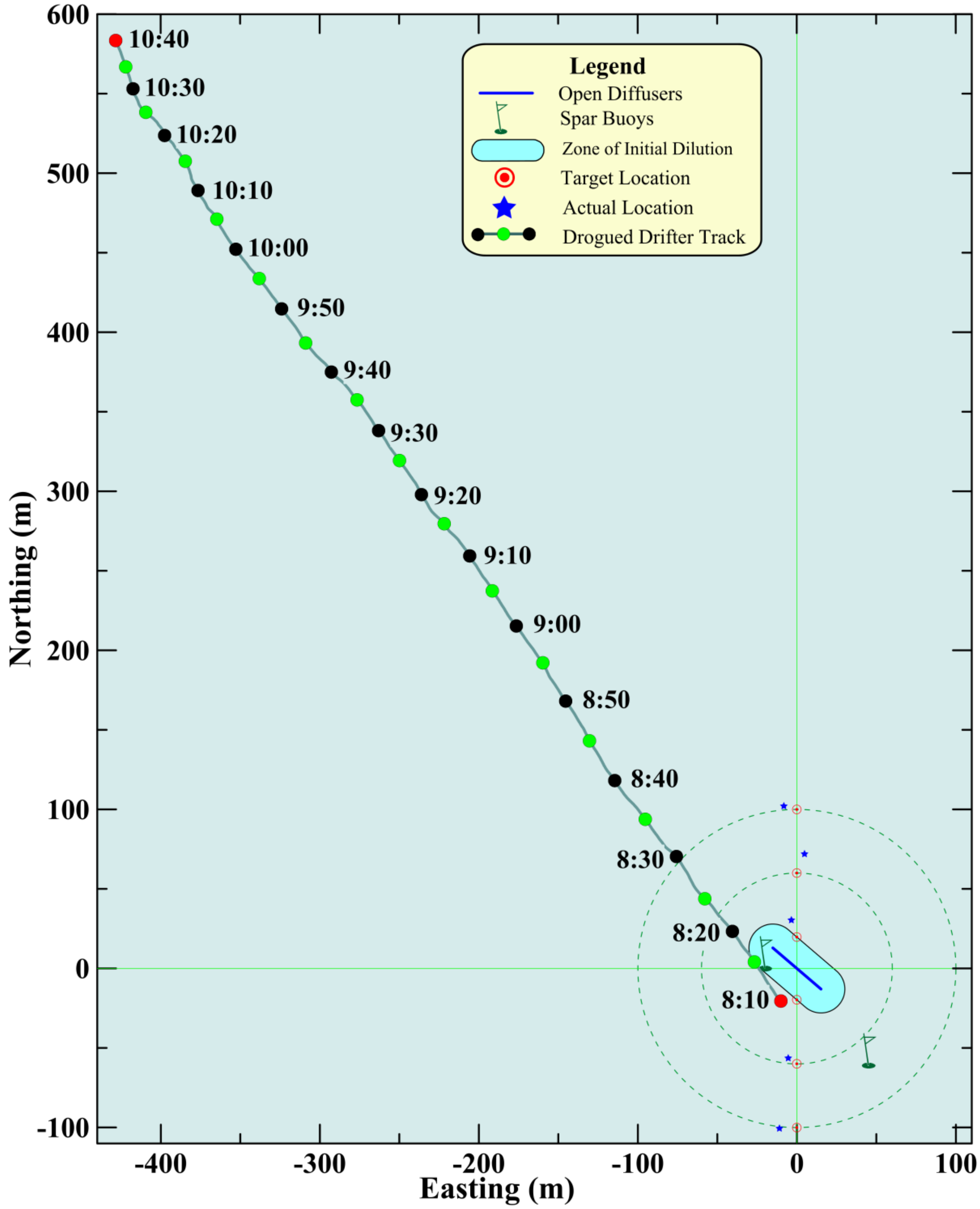

Figure 3. Drogued Drifter Trajectory

The oceanic flow direction remained constant throughout the February 2014 survey, as shown by the drifter's nearly straight trajectory (325ºT[8]). However, the flow speed steadily declined throughout the survey, as reflected by the decreasing distance between the time stamps along the drifter trajectory in Figure 3. During the first hour of the survey, when the vertical profiling was conducted, flow speeds averaged 9.3 cm/s, indicating that the plume residence time was only 2 min 43 s. Subsequently, during the

[8] Direction measured clockwise relative to true (rather than magnetic) north.

shallow tow portion of the survey, which was conducted during the following hour, average flow speed had declined by 15% to 8.0 cm/s, reflecting a slightly longer plume residence time of 3 min 11 s. During the final portion of the survey, encompassing the mid-depth tow, oceanic flow speed had declined to 6.0 cm/s and plume residence time within the ZID had increased to 4 m 15 s.

The dominant oceanographic process that induces a particular flow regime during a given survey is rarely clear. Occasionally, changes in the observed flow within a given survey are correlated with changes in tidal elevation. For example, the onset of an ebb tide at the beginning of the February 2014 survey (Figure 4) suggests that tidal currents would have a steadily increasing influence on the overall oceanic flow regime. Ebb tides normally induce a weak southwestward (offshore) flow in the survey region, indicating other processes were driving the northward regional flow recorded by the survey's drifter within Estero Bay and by the current meter on the Diablo Canyon waverider buoy located offshore Pt. Buchon. It is possible, however, that the increasing strength of a tidally-induced southward flow component during the survey was responsible for the observed steady decrease in flow velocity.

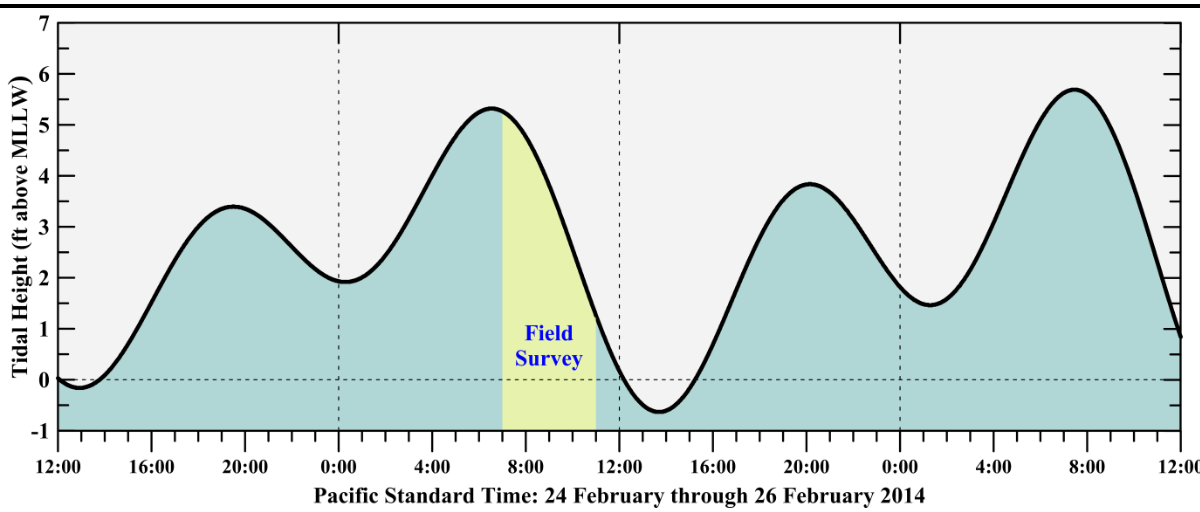

Figure 4. Tidal Level during the February 2014 Survey

Tidal influence notwithstanding, the large-scale regional flow during the survey was clearly dominated by one of the many other external processes that can exert an influence on oceanic flow patterns. Some of the more important of these processes include wind-generated upwelling, downwelling, coastally trapped long-period waves, long-shore pressure gradients, and the passing of offshore eddies propagating along the coastline. Of these, sustained wind-driven upwelling constitutes one of the most prevalent forces that drives the flow and vertical structure of the water column within coastal waters offshore central California.

The onset of upwelling-dominated processes begins with a rapid intensification of southeastward-directed winds along the central coast during late March and or early April as shown by the positive (blue) upwelling indices in Figure 5. This transition to more persistent southeastward winds 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.

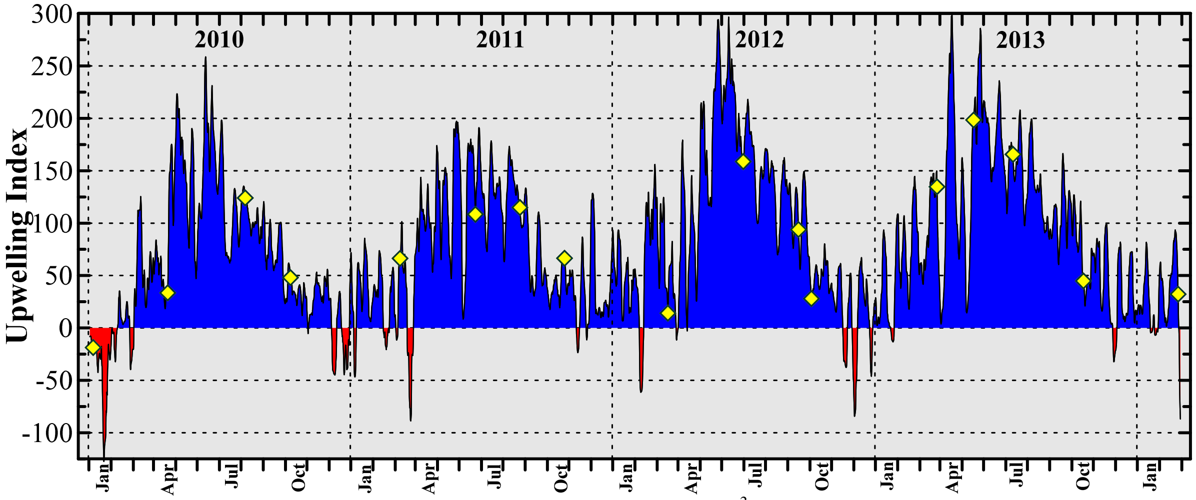

Figure 5. Five-Day Average Upwelling Index (m^3/s/100 m of coastline)

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. As a result, some degree of upwelling is almost always present during offshore surveys (yellow diamonds in Figure 5). During winter, upwelling is typically weak, and occasionally downwelling events, indicated by the negative (red shaded) indices in Figure 5, occur 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.

In the weeks and months prior to the February 2014 survey (last yellow diamond in Figure 5), upwelling winds were generally weak. Nevertheless, a brief pulse of upwelling winds immediately prior to the survey produced a pattern of sea surface temperatures within the region that is indicative of upwelling processes. This weak upwelling pattern was captured by the satellite image shown on the cover of this report. The image was recorded by infrared sensors on one of NOAA's polar orbiting satellites during a period of relatively cloudless skies three days prior to the survey. Although the presence of a pool of cooler upwelled water is visually apparent close to the south-central coastline (purple and dark blue shading), the 2°C contrast between nearshore and offshore sea-surface temperatures was small compared to that of typical upwelling events. Cross-shore counter-flows at the sea surface and seafloor were generated by this mild upwelling event, and as a result, the water column was weakly stratified at the time of the February 2014 survey.

METHODS

The 38 ft F/V *Bonnie Marietta*, owned and operated by Captain Mark Tognazzini of Morro Bay, served as the survey vessel on Tuesday, 25 February 2014. 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. William Skok assisted with deployment and recovery of the CTD and drifter. Jordan Davis, an engineering intern with the Public Works Department, assisted with the survey and acted as the client representative.

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 February 2014 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)[9]	%	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

[9] 25-cm path length of red (660 nm) light

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 RW1, 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 9:03 AM, following completion of the last vertical profile at RW6, 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 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).

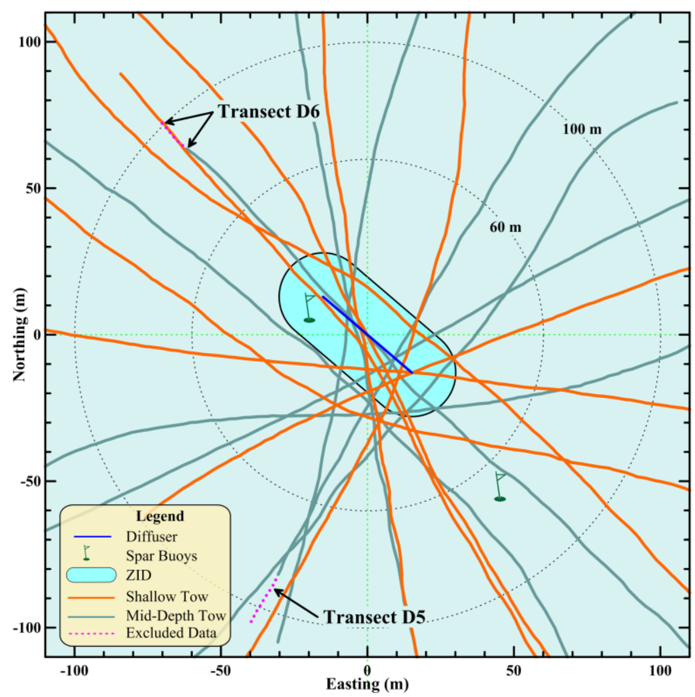

Figure 6. CTD Tracklines during the February 2014 Tow Surveys

Initially, the reconfigured CTD package was towed for 37 minutes at an average depth of 4.69 m, and an average speed of 1.69 m/s, passing over, or near the diffuser structure eight times. Subsequently, eight additional passes were made with the CTD at an average depth of 7.57 m. During this 35-minute mid-depth tow, vessel speed averaged 1.70 m/s. At the observed towing speeds and the 4 Hz sampling rate, at least 2.3 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.[10]

[10] Figures 8 and 9 later in this report

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,[11] 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 last portion of the mid-depth tow along Transect D5, and the initial portion of Transect D6 (purple dotted lines in Figure 6).

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 at these times.

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 statistical certainty is compromised when data from different depth levels are combined in the horizontal maps. This is true whenever the water column is stratified, even if the stratification was weak, as was the case during the February 2014 survey.

The exclusion of the small portions of Transects D5 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 first-quarter receiving-water survey was conducted on the morning of Tuesday, 25 February 2014. The receiving-water survey commenced at 8:08 AM with the deployment of the drogued drifter. Over the following 2.5 hours, offshore observations and measurements were collected as required by the NPDES monitoring program. The survey ended at 10:40 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 25 February 2014, skies were overcast, with light to moderate southeasterly winds. Average wind speeds, calculated over one-minute intervals, ranged from 4.4 kt to 6.9 kt (Table 4). Similarly, peak wind speeds ranged from 6.7 kt to 8.3 kt. The swell was out of the northwest with a significant wave height of only 1 foot. Air temperatures remained fairly constant throughout the survey, averaging 10.7°C.

[11] 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.

Table 4. Standard Meteorological and Oceanographic Observations

Station	Location[12] Latitude	Location[12] Longitude	Diffuser Distance (m)	Time (PST)	Air (°C)	Cloud Cover (%)	Wind Avg (kt)	Wind Max (kt)	Wind Dir (from) (°T)	Swell Ht/Dir (ft/°T)	Secchi Depth (m)
RW1	35° 23.271' N	120° 52.523' W	120.1	8:19:00	10.1	100	4.4	6.7	NE	1 NW	5.5
RW2	35° 23.240' N	120° 52.518' W	63.6	8:27:44	10.4	100	6.9	8.3	NE	1 NW	5.0
RW3	35° 23.217' N	120° 52.529' W	29.8	8:36:25	10.2	100	6.7	8.1	NE	1 NW	5.0
RW4	35° 23.205' N	120° 52.532' W	27.4	8:45:17	11.0	100	4.9	6.7	NE	1 NW	5.0
RW5	35° 23.185' N	120° 52.528' W	42.9	8:53:41	11.0	100	6.9	8.1	NE	1 NW	5.0
RW6	35° 23.161' N	120° 52.550' W	98.2	9:06:01	11.5	100	4.7	7.8	NE	1 NW	5.0

The 5.0 m Secchi depths recorded during the February 2014 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 slightly lower than that of the seawater at depth (below 10 m) due to marginally increased planktonic densities that arose because of weak 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 during the February 2014 survey.

Communication with plant personnel and subsequent review of effluent discharge properties on the day of the survey, confirmed that the treatment process was performing nominally at time of the survey. The 0.771 million gallons of effluent discharged on 25 February had a temperature of 18°C, a suspended-solids concentration of 29 mg/L, a pH of 7.5, and a biochemical oxygen demand (BOD) of 54 mg/L.

During the February 2014 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. Upon arrival at the survey area, numerous cormorants were observed resting, swimming, and foraging at the sea surface. During most surveys, they are typically only sighted in flight.

Small numbers of pedestrians and surfers were visible along Atascadero State beach throughout the survey. Additionally, several recreational fishing vessels were observed during transit to and from the survey area. Lastly, three southern sea otters (*Enhydra lutris nereis*) were observed eating and swimming immediately outside the mouth of Morro Bay harbor.

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 February 2014 survey reflect the presence of a slightly stratified water column indicative of a weak recent upwelling event within Estero Bay (Figure 5).

[12] 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.

Table 5. Vertical Profile Data Collected on 25 February 2014

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	11.654		11.656	11.761	11.766	11.761	33.593		33.554	33.639	33.639	33.639
1.5	11.636	11.639	11.659	11.761	11.771	11.765	33.587	33.589	33.567	33.639	33.639	33.639
2.0	11.641	11.638	11.645	11.761	11.768	11.766	33.590	33.588	33.557	33.639	33.639	33.639
2.5	11.658	11.639	11.630	11.761	11.766	11.761	33.598	33.588	33.558	33.639	33.639	33.639
3.0	11.678	11.640	11.630	11.763	11.761	11.762	33.607	33.589	33.567	33.639	33.639	33.639
3.5	11.698	11.640	11.617	11.761	11.755	11.755	33.616	33.598	33.565	33.639	33.639	33.639
4.0	11.707	11.642	11.612	11.757	11.755	11.754	33.618	33.602	33.568	33.639	33.639	33.639
4.5	11.706	11.646	11.621	11.753	11.751	11.749	33.619	33.602	33.577	33.639	33.639	33.639
5.0	11.733	11.668	11.634	11.753	11.742	11.746	33.630	33.606	33.587	33.639	33.639	33.639
5.5	11.736	11.676	11.647	11.753	11.740	11.746	33.631	33.608	33.589	33.639	33.639	33.639
6.0	11.739	11.673	11.698	11.744	11.738	11.744	33.635	33.606	33.611	33.639	33.639	33.639
6.5	11.742	11.697	11.712	11.735	11.738	11.744	33.637	33.614	33.617	33.639	33.639	33.639
7.0	11.739	11.709	11.695	11.730	11.734	11.745	33.636	33.619	33.606	33.639	33.639	33.639
7.5	11.731	11.709	11.687	11.732	11.726	11.711	33.636	33.620	33.603	33.639	33.639	33.637
8.0	11.719	11.701	11.700	11.726	11.713	11.652	33.637	33.618	33.609	33.639	33.638	33.633
8.5	11.697	11.712	11.701	11.719	11.720	11.618	33.635	33.621	33.608	33.639	33.639	33.632
9.0	11.669	11.698	11.714	11.710	11.732	11.591	33.631	33.615	33.619	33.638	33.639	33.630
9.5	11.647	11.696	11.737	11.690	11.693	11.563	33.627	33.615	33.638	33.637	33.637	33.628
10.0	11.640	11.702	11.730	11.660	11.605	11.545	33.626	33.618	33.634	33.634	33.629	33.628
10.5	11.638	11.695	11.738	11.617	11.555	11.543	33.627	33.614	33.638	33.631	33.627	33.629
11.0	11.630	11.707	11.739	11.582	11.543	11.543	33.629	33.623	33.637	33.629	33.628	33.629
11.5	11.626	11.721	11.734	11.571	11.537	11.536	33.632	33.635	33.637	33.630	33.628	33.630
12.0	11.626	11.719	11.729	11.556	11.536	11.529	33.634	33.638	33.636	33.629	33.629	33.630
12.5	11.622	11.707	11.730	11.546	11.537	11.529	33.633	33.637	33.635	33.629	33.629	33.630
13.0	11.615	11.691	11.727	11.546	11.537	11.530	33.633	33.636	33.635	33.630	33.630	33.630
13.5	11.598	11.655	11.726	11.543	11.537	11.529	33.632	33.634	33.635	33.630	33.630	33.630
14.0	11.594	11.623	11.720	11.543	11.538	11.527	33.633	33.633	33.637	33.630	33.630	33.630
14.5	11.591	11.602	11.625	11.543	11.539	11.525	33.632	33.631	33.630	33.630	33.630	33.630
15.0	11.591	11.605	11.590	11.544	11.538	11.524	33.632	33.632	33.630	33.630	33.630	33.630
15.5	11.587	11.614	11.588	11.544	11.538	11.526	33.632	33.633	33.630	33.631	33.630	33.630
16.0	11.587	11.622	11.582	11.544	11.538	11.526	33.632	33.634	33.629	33.631	33.630	33.630
16.5	11.590	11.621	11.581	11.545	11.539	11.527	33.632	33.634	33.630	33.631	33.630	33.630
17.0			11.580	11.546	11.540	11.529			33.631	33.630	33.631	33.630

Table 5. Vertical Profile Data Collected on 25 February 2014 (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	25.561		25.530	25.577	25.576	25.577	7.954		7.953	7.971	7.974	7.974
1.5	25.560	25.561	25.540	25.577	25.575	25.577	7.953	7.954	7.956	7.972	7.974	7.974
2.0	25.561	25.560	25.535	25.577	25.575	25.576	7.952	7.954	7.954	7.972	7.974	7.974
2.5	25.564	25.560	25.538	25.577	25.576	25.577	7.952	7.954	7.955	7.972	7.974	7.974
3.0	25.567	25.561	25.545	25.577	25.577	25.577	7.952	7.954	7.955	7.972	7.974	7.974
3.5	25.570	25.568	25.546	25.577	25.578	25.578	7.953	7.955	7.955	7.972	7.973	7.973
4.0	25.571	25.570	25.549	25.577	25.578	25.578	7.954	7.955	7.954	7.971	7.973	7.974
4.5	25.571	25.570	25.555	25.578	25.579	25.579	7.955	7.955	7.954	7.971	7.973	7.974
5.0	25.575	25.569	25.560	25.578	25.580	25.580	7.958	7.956	7.954	7.971	7.972	7.974
5.5	25.576	25.569	25.559	25.578	25.581	25.580	7.960	7.955	7.955	7.970	7.972	7.973
6.0	25.578	25.567	25.567	25.580	25.581	25.580	7.961	7.955	7.957	7.970	7.972	7.972
6.5	25.579	25.569	25.569	25.581	25.581	25.580	7.961	7.955	7.957	7.970	7.971	7.972
7.0	25.579	25.571	25.564	25.582	25.582	25.580	7.962	7.957	7.959	7.969	7.971	7.973
7.5	25.581	25.572	25.563	25.582	25.583	25.584	7.963	7.958	7.960	7.968	7.970	7.972
8.0	25.583	25.571	25.565	25.583	25.585	25.593	7.962	7.961	7.960	7.968	7.970	7.970
8.5	25.585	25.572	25.564	25.584	25.584	25.598	7.962	7.960	7.962	7.967	7.969	7.967
9.0	25.588	25.570	25.570	25.586	25.583	25.602	7.960	7.962	7.961	7.967	7.969	7.966
9.5	25.589	25.571	25.581	25.588	25.588	25.605	7.959	7.961	7.962	7.967	7.968	7.966
10.0	25.590	25.571	25.579	25.592	25.598	25.608	7.957	7.960	7.964	7.966	7.966	7.965
10.5	25.591	25.570	25.580	25.598	25.606	25.609	7.956	7.961	7.963	7.965	7.965	7.964
11.0	25.594	25.575	25.579	25.603	25.609	25.610	7.956	7.961	7.964	7.963	7.964	7.964
11.5	25.597	25.581	25.580	25.605	25.610	25.611	7.956	7.961	7.965	7.963	7.961	7.963
12.0	25.598	25.584	25.580	25.607	25.611	25.613	7.956	7.962	7.964	7.961	7.960	7.962
12.5	25.598	25.585	25.580	25.609	25.611	25.613	7.955	7.962	7.965	7.960	7.960	7.962
13.0	25.599	25.588	25.580	25.610	25.611	25.613	7.955	7.962	7.965	7.960	7.960	7.961
13.5	25.602	25.593	25.580	25.610	25.611	25.613	7.955	7.961	7.964	7.959	7.959	7.960
14.0	25.603	25.598	25.583	25.610	25.611	25.613	7.954	7.961	7.964	7.958	7.958	7.959
14.5	25.603	25.601	25.595	25.611	25.611	25.614	7.953	7.958	7.964	7.959	7.958	7.959
15.0	25.603	25.601	25.602	25.611	25.611	25.614	7.954	7.956	7.963	7.958	7.957	7.958
15.5	25.604	25.600	25.602	25.610	25.611	25.614	7.953	7.954	7.960	7.958	7.957	7.959
16.0	25.604	25.599	25.603	25.610	25.611	25.614	7.952	7.954	7.958	7.957	7.957	7.958
16.5	25.603	25.599	25.603	25.610	25.611	25.613	7.952	7.954	7.957	7.957	7.958	7.958
17.0			25.604	25.610	25.611	25.613			7.955	7.956	7.958	7.957

Table 5. Vertical Profile Data Collected on 25 February 2014 (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	7.165		7.307	7.625	7.647	7.627	83.315		81.872	82.884	83.100	82.942
1.5	7.203	7.180	7.169	7.623	7.641	7.641	83.314	83.322	83.418	83.127	83.122	82.812
2.0	7.229	7.199	7.142	7.617	7.640	7.621	83.331	83.376	82.836	83.130	83.277	82.892
2.5	7.327	7.198	7.135	7.623	7.594	7.629	83.352	83.390	83.433	83.226	83.347	82.920
3.0	7.402	7.198	7.090	7.619	7.600	7.617	83.306	83.227	83.921	83.278	83.324	82.838
3.5	7.428	7.223	7.083	7.599	7.592	7.612	83.399	83.388	83.910	83.269	83.259	82.932
4.0	7.404	7.233	7.144	7.597	7.544	7.592	83.408	83.569	84.079	83.161	83.295	83.063
4.5	7.527	7.340	7.192	7.582	7.563	7.593	83.363	83.573	84.250	83.133	83.293	83.089
5.0	7.515	7.305	7.245	7.591	7.564	7.595	83.416	83.606	84.097	83.151	83.251	83.079
5.5	7.527	7.330	7.446	7.535	7.551	7.594	83.538	83.702	84.022	83.101	83.299	83.125
6.0	7.555	7.415	7.455	7.534	7.555	7.592	83.552	83.566	83.896	83.163	83.282	83.073
6.5	7.526	7.461	7.346	7.527	7.521	7.597	83.519	83.529	83.542	83.241	83.277	83.133
7.0	7.514	7.439	7.323	7.531	7.498	7.508	83.551	83.461	83.551	83.216	83.248	83.108
7.5	7.478	7.394	7.396	7.513	7.450	7.291	83.691	83.415	83.580	83.284	83.370	83.304
8.0	7.408	7.470	7.390	7.479	7.530	7.217	83.701	83.526	83.601	83.311	83.327	83.774
8.5	7.324	7.363	7.471	7.428	7.534	7.134	83.919	83.463	83.561	83.505	83.378	84.270
9.0	7.240	7.393	7.540	7.362	7.279	7.049	84.124	83.504	83.584	83.545	83.310	84.739
9.5	7.237	7.411	7.479	7.260	6.974	6.968	84.265	83.539	83.601	83.723	83.410	85.551
10.0	7.220	7.380	7.531	7.099	6.950	6.973	84.201	83.562	83.635	83.933	83.906	86.073
10.5	7.215	7.449	7.527	7.040	6.924	6.977	84.441	83.506	83.551	84.458	85.843	86.155
11.0	7.196	7.491	7.501	7.019	6.916	6.932	84.387	83.531	83.520	84.994	86.140	86.227
11.5	7.212	7.476	7.486	6.972	6.926	6.896	84.281	83.546	83.544	85.429	86.349	86.314
12.0	7.197	7.414	7.491	6.955	6.943	6.909	84.335	83.660	83.587	85.693	86.262	86.367
12.5	7.171	7.336	7.480	6.967	6.932	6.909	84.264	83.664	83.542	86.031	86.254	86.310
13.0	7.106	7.219	7.483	6.953	6.927	6.903	84.462	83.837	83.582	86.070	86.235	86.332
13.5	7.108	7.107	7.455	6.952	6.923	6.890	84.862	84.068	83.594	86.040	86.258	86.427
14.0	7.098	7.057	7.073	6.945	6.919	6.890	84.940	84.436	83.679	85.886	86.319	86.371
14.5	7.083	7.096	7.010	6.952	6.927	6.887	85.052	84.954	84.095	85.915	86.241	86.299
15.0	7.064	7.134	7.059	6.955	6.933	6.891	85.080	85.005	84.996	85.871	86.318	86.331
15.5	7.061	7.154	7.025	6.949	6.925	6.890	85.174	84.858	85.268	85.924	86.226	86.365
16.0	7.057	7.136	7.026	6.931	6.911	6.880	85.281	84.822	85.400	85.905	86.378	86.445
16.5	7.079	7.163	7.037	6.933	6.909	6.867	85.200	84.861	85.601	85.855	86.330	86.324
17.0			7.003	6.933	6.910	6.884			85.132	85.938	86.041	86.290

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 the upwelling winds are weak, or occur only briefly, the contrast between the surface and deep watermasses is minimal, and stratification appears as a more gradual vertical change in seawater properties below the surface mixed layer. This was case during the February 2014 survey, and a weak upwelling signature is visually apparent in the vertical profiles at the three southernmost stations (Figure 7def).

In particular, all seawater properties exhibit steadily increasing or decreasing values between 7 m and 10 m. This transition zone separates the surface mixed layer from a deeper seawater mass above the sea floor. Steady decreases in temperature (red lines), salinity (green 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 within the transition zone. These gradual vertical changes reflect the presence of a colder, less-turbid, nutrient-rich but oxygen-poor watermass that migrated shoreward along the seafloor as part of the upwelling process.

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 upwelling facilitated phytoplankton blooms that produced oxygen, consumed carbon dioxide (CO_2), and decreased water clarity (light blue lines). In particular, upwelling around the time of the February 2014 survey resulted in an increased presence of plankton within the surface mixed layer and caused the observed 3% 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 February 2014 survey, however, because the plume extended all the way to the sea surface shortly after discharge. The plume's signature is apparent as a marked reduction in sea-surface salinity at the three northern Stations RW1, RW2, and RW3 (green lines in Figure 7abc). The influence of the discharge is also apparent below the sea surface, where a general lack of a distinct transition zone in all the seawater properties coincides with the observed transition zone at the unaffected stations to the south (*cf*. Figures 7abc with 7def). At the stations to the north of the discharge, mixing associated with the rising discharge plume served to eliminate most of the vertical structure present in ambient seawater at the time of the survey.

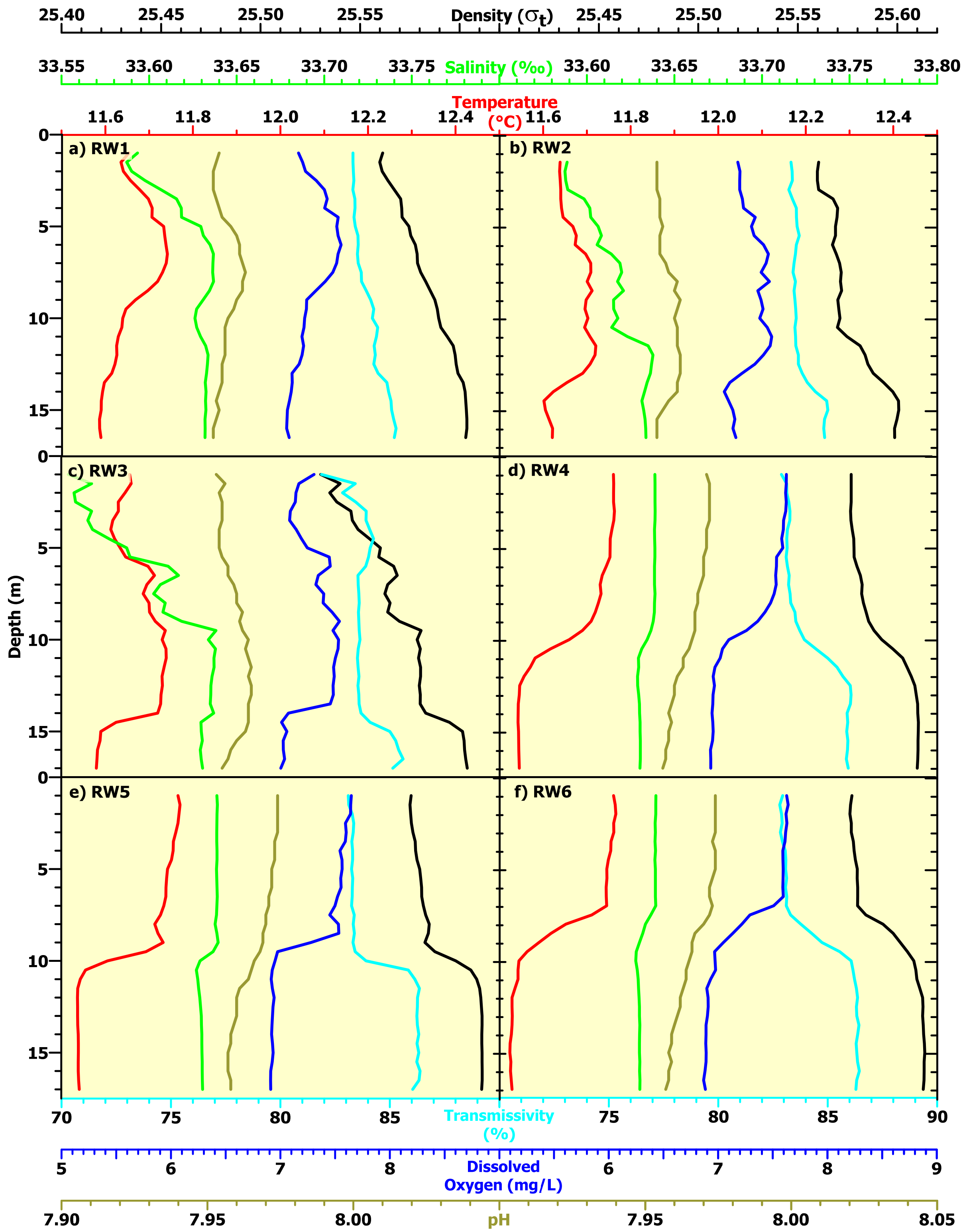

Figure 7. Vertical Profiles of Water-Quality Parameters

Although the presence of dilute effluent within the upper water column was delineated by a sharp reduction in salinity at the three northern stations, changes observed in other water properties 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 created a more vertically uniform water column without the distinct transition zone between 7 m and 10 m. With the exception of salinity, water properties within the upper column at the northern stations were similar to the seawater properties found near the seafloor at stations to the south.

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 to cause a significant contrast between shallow and deep ambient seawater properties.

It also clear that the anomalies in seawater properties within the upper water column at the northern stations were caused by entrainment rather than wastewater loading because for some properties, the offsets were opposite of the changes that would be expected if caused by the presence of wastewater particulates. For example, wastewater discharged on the day of the survey was much warmer (18°C) than the receiving seawater at depth (<12°C). Therefore, 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 was observed in the upper water column at the northern stations as compared to the southern stations could not have been generated by the increased particulate loads associated with effluent. Instead, the transmissivity anomaly in the upper water column at the northern stations 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 Figures 7def).

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 directly over the diffuser structure and within the ZID (Figure 8b). The 7.54-m tow depth was just beneath the majority of the salinity anomaly measured in the upper water column during vertical profiling at the northern stations (green lines in Figure 7abc). The discharge-related reduction in salinity at these stations was most apparent near the sea surface. Even at the 4.69-m depth of the shallow tow, however, only a small localized salinity signature was delineated to the north of the diffuser structure (Figure 9b).

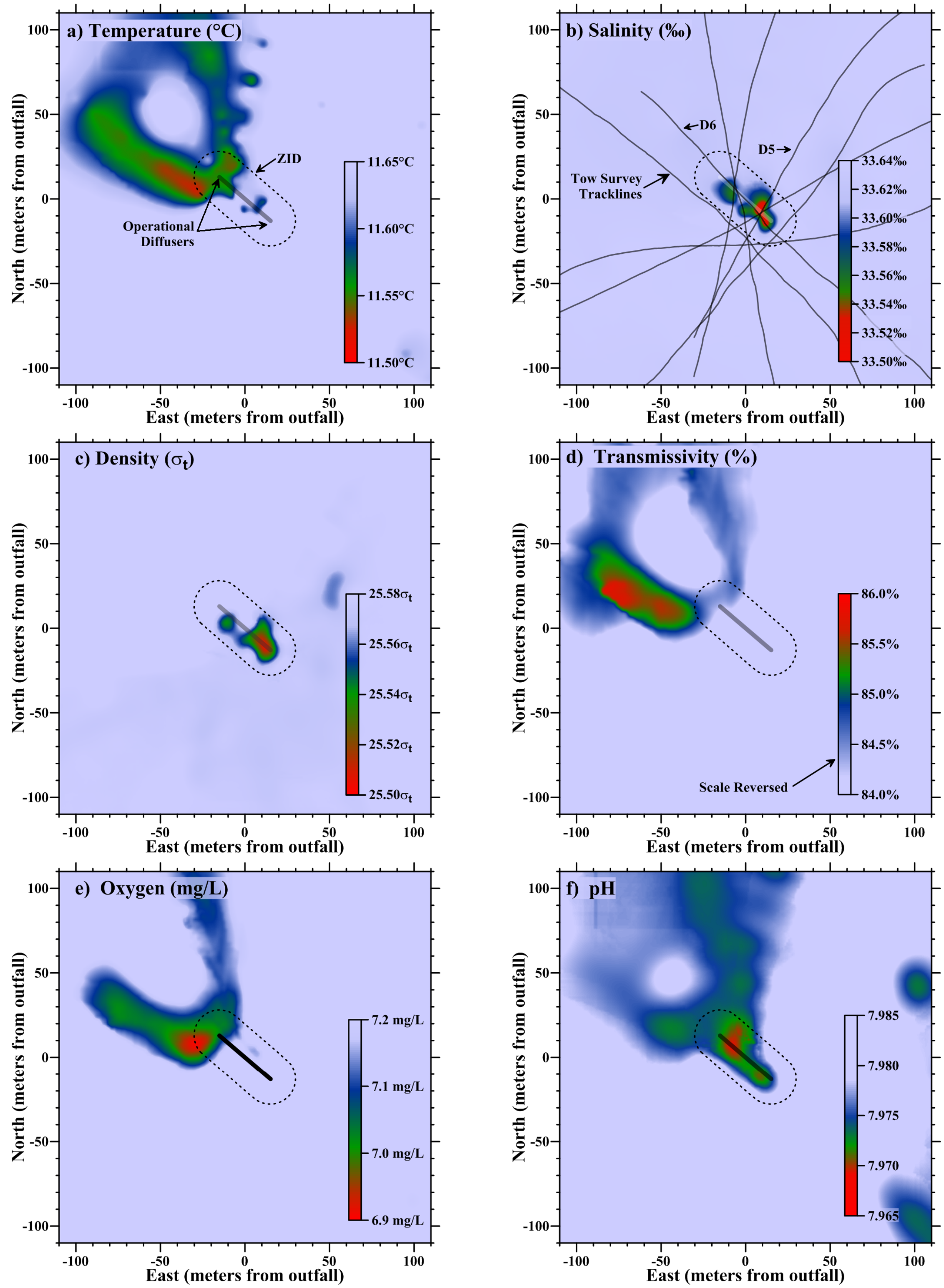

Figure 8. Horizontal Distribution of Mid-Depth Water-Quality Parameters 7.54 m below the Sea Surface

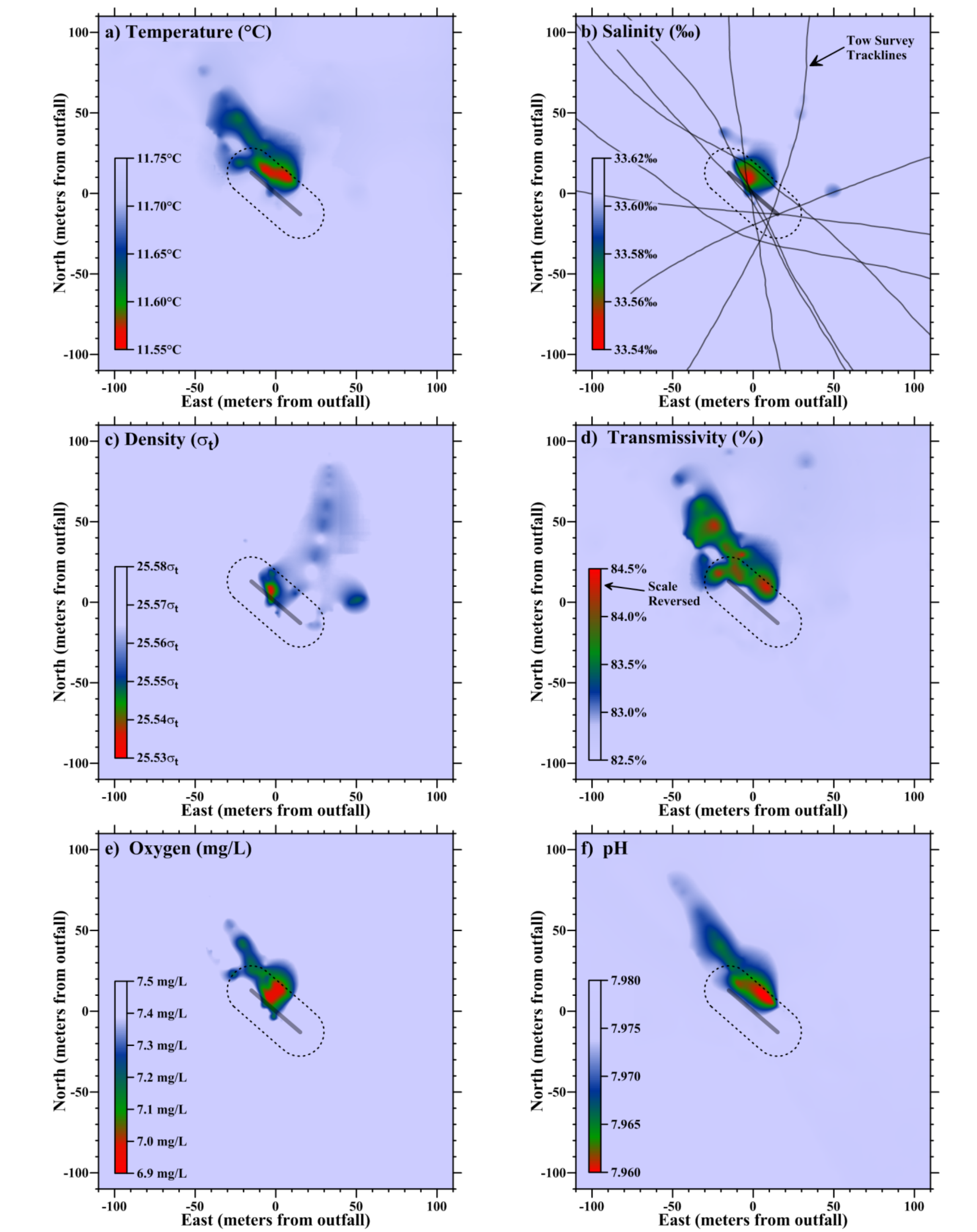

Figure 9. Horizontal Distribution of Shallow Water-Quality Parameters 4.69 m below the Sea Surface

Both the shallow and mid-level horizontal tows captured a slender column of dilute wastewater within the rising plume as it was still undergoing rapid initial dilution. The plume's positive buoyancy is apparent from the highly localized, negative density anomaly that coincided spatially with the salinity anomalies (Figures 8c and 9c). 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.

In contrast, discharge-related anomalies in other seawater properties that were apparent at mid-depth did not coincide spatially with the density and salinity signatures (*cf*. Figures 8adef with 8ab). As described above, these long-lived entrainment signatures were not caused by the presence of wastewater constituents. Instead, they were relicts of the upward displacement of ambient seawater from near the ocean floor within the rising plume. The absence of a salinity anomaly within these entrainment signatures indicates that the initial dilution process had already diluted wastewater constituents beyond recognition at that point. Nevertheless, the lower temperature, DO, and pH, and increased transmissivity associated with the bottom watermass, were carried to the northeast by prevailing currents after having been displaced upward in the water column. Because the rapid mixing associated with initial dilution processes was largely complete at that point however, the signatures of the entrainment anomalies dissipated slowly as they were transported out of the survey area.

Outfall Performance

The efficacy of the outfall can be evaluated through a comparison of dilution levels measured at the time of the February 2014 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 February 2014 survey were much 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. As described above, wastewater-induced regions of slightly lower salinity were apparent in the upper water column in the vertical profiles measured at Stations RW1, RW2, and RW3 (green lines in Figure 7abc), and in localized patches of much larger salinity reductions near the diffuser structure in both tow-survey maps (Figures 8b and 9b). These 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)[13] 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.

The lowest salinities (<33.50‰) measured during the February 2014 survey were recorded within 5 m of the diffuser during the fifth and sixth transects of the mid-depth tow survey (red shading directly over the diffuser structure in Figure 8b). This measured salinity corresponds to a 0.13‰ reduction below the mean ambient salinity of 33.63‰ that was measured at depth but well beyond the influence of the discharge.

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

From Equation 2, that salinity anomaly corresponds to a dilution of 235-fold (Figure 10). This is 77% greater than the 133:1 critical initial dilution used to establish limits on contaminant concentrations in wastewater.

In addition, this dilution was measured at a depth of 7.2 m, which was 0.8 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.

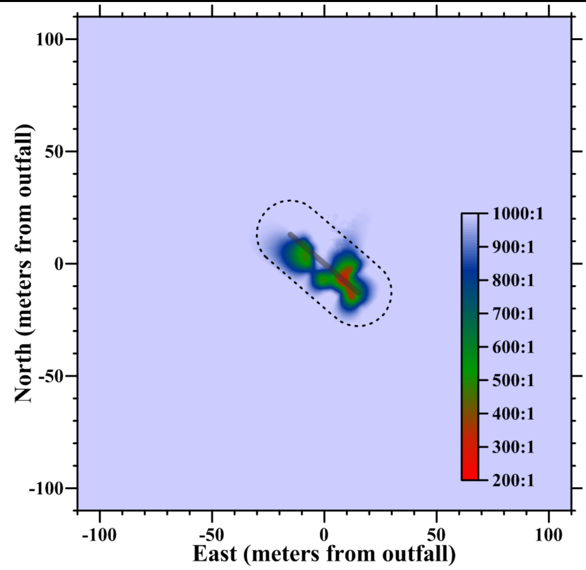

Figure 10. Mid-Depth Plume Dilution Computed from Salinity Anomalies in Figure 8b

As expected, dilution levels measured later in the initial dilution process during the shallow tow were substantially higher (shaded area in Figure 11). The lowest dilution measured during the shallow tow (349:1) was located 2 m north of the diffuser structure at a depth of 4.8 m. As described above, the plume was still buoyant at that location, and consequently, the initial dilution process was not yet complete. Nevertheless, the measured dilution was more than two-and-a-half times greater than predicted by modeling.

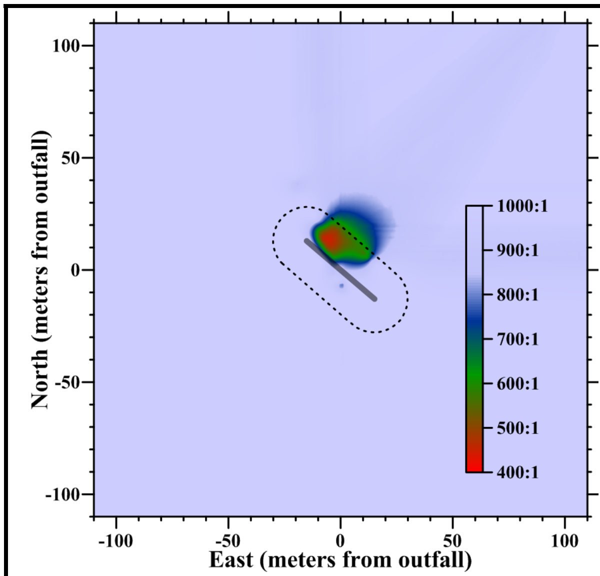

Figure 11. Shallow Plume Dilution Computed from Salinity Anomalies in Figure 9b

The vertical profiles detected the presence of extremely dilute wastewater particulates after the plume had reached the sea surface and completed the initial dilution process. At that point, oceanic flow had transported the plume beyond the ZID, and the largest salinity anomaly (-0.075‰) was detected at the sea surface at Station RW3 (green line in Figure 7c). That measurement, which was recorded 22 m from the diffuser structure, corresponds to a dilution of 435-fold. This indicates that during the February 2014 survey, the outfall was achieving dilution levels more than three-times greater than predicted by modeling after the completion of the initial dilution process.

The dilution computations show that, during the February 2014 survey, the outfall was performing much better than designed and was rapidly diluting effluent more than 235-fold immediately after discharge, and well before completion of the initial-dilution process. After initial dilution was complete, effluent had been diluted at least 435-fold. 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 February 2014 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 of the February 2014 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 February 2014 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. Compliance is demonstrated by the absence of floating wastewater materials, oil, grease, or discoloration of the sea surface during the February 2014 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.

As described previously, natural variation in seawater properties can be determined by a variety of oceanographic processes. These processes establish 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 12,451 CTD measurements collected during the February 2014 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 pertain; 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[14]	*Parameter*
Location	1. Was the measurement collected beyond the 15.2-m ZID boundary where modeling assumes that initial dilution is complete?	*1,452*	*10,999*	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?	*10,992*	*7*	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?	*7*	*0*	Temperature
		7	*0*	Transmissivity
		7	*0*	DO
		7	*0*	pH

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.

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

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 February 2014 dataset eliminated 1,452 of the original 12,451 receiving-water observations from further consideration because they were collected within the ZID (Table 7, Question 1). The remaining 10,999 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 February 2014 survey were restricted to a localized area within the ZID boundary. Seven shallow measurements collected at Station RW3 had much smaller but still detectable reductions in salinity that unequivocally identified the presence of dilute wastewater constituents beyond the ZID. The remaining 10,992 observations that were measured outside the ZID during the February 2014 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 February 2014 ambient seawater data, to establish time-specific natural-variability thresholds in a manner analogous to COP Appendix VI. The percentiles were determined from February 2014 vertical profile data at Stations RW4, RW5, and RW6, thereby excluding measurements potentially affected by the discharge.

Table 8. Compliance Thresholds

Water Quality Property	95% Confidence Bound[15]	95th Percentile[16,17]	Natural Variability Threshold[18]	COP Allowance[19]	Basin Plan Limit[20]	Extremum[21]
Temperature (ºC)	0.82	11.76	>12.58	—	—	≤11.80
Transmissivity (%)	-10.2	82.9	<72.7	—	—	≥81.2
DO (mg/L)	-1.38	6.89	<5.51	<4.96	<5.00	≥6.77
pH (minimum)	-0.094	7.957	<7.863	<7.663	<7.000	≥7.952
pH (maximum)	0.094	7.974	>8.068	>8.268	>8.300	≤7.995

[15] 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.

[16] 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*."

[17] The 95th-percentile quantifies natural variability in seawater properties during the February 2014 survey, and was determined from vertical-profiles data unaffected by the discharge.

[18] 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 February 2014 survey. They do not include the COP allowances specified in the column to the right.

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

[20] 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.

[21] Maximum or minimum value measured during this survey

Temperature, transmissivity, and DO concentrations associated with the 7 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 February 2014 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 February 2014 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 February 2014 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 February 2014 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 12.58°C in Table 8). However, none of the 12,451 CTD measurements collected during the February 2014 survey exceeded 11.80°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 February 2014 survey were below the 72.7% 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 February 2014 survey only applied to measurements recorded above 10 m (twice the average ambient Secchi depth listed in Table 4). Consequently, even if the discharge of wastewater particulates had caused one or more of the 82 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 both tows (Figures 8d and 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 25 February 2014 was 29 mg/L. After dilution by 235-fold, the effluent suspended-solids concentration would have the reduced ambient transmissivity by only 0.9%. This small potential decrease in transmissivity would also have been counteracted by the 3% increase caused by the entrainment and upward displacement of relatively clear ambient seawater near the seafloor (Figures 8d and 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, 54-mg/L BOD measured within the plant's effluent on the day of 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 due to the lack of atmospheric equilibration.

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 7.663 during the February 2014 survey (fourth column of Table 8). This value is well below the lowest pH measurement of 7.952 recorded during the February 2014 survey (last column of Table 8). Similarly, the lowest DO concentration measured during the survey (6.77 mg/L) was well above both the lower range in natural variation (5.51 mg/L) and the 10% compliance threshold promulgated by the COP (6.77 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 February 2014 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 12,451 temperature, DO, and pH observations exceeded the thresholds of natural variability specified in Table 8.

Compliance with Basin-Plan Limits: Permit provisions P5 and P6 (Table 6) combine receiving-water objectives from both the COP and the Basin Plan with regard to DO and pH limitations. As described previously, the COP requires that DO concentrations outside the ZID not be depressed more than 10% from that which occurs naturally, and restricts pH measurements to those within 0.2 units of that which occurs naturally. In contrast, the Basin-Plan's fixed numerical limits do not provide specific guidance as to how they might change in response to widespread changes in oceanographic conditions unrelated to the discharge. Specifically, the fixed numerical limits restrict DO concentrations outside the ZID to no less than 5 mg/L (P5 in Table 6), and pH levels to the 7.0-to-8.3 range (P6).

All 12,451 DO and pH values measured during the February 2014 survey remained well above the Basin Plan's minimum acceptable DO concentration (5 mg/L), and within the specified pH range (Table 8). However, this is often not the case because ambient seawater properties within Estero Bay often range well beyond these fixed limits. In those cases, perfunctory application of the Basin Plan's pH and DO thresholds in a compliance analysis could lead to the incorrect conclusion that the discharge had caused unacceptable reductions in DO or changes in pH.

In fact, the application of the Basin Plan limits to coastal seawaters is flawed. This is apparent from the published range-acceptability criteria that are used to assess the validity of CTD data in this monitoring program and that identify DO and pH values ranging well outside of the Basin Plan limits as typical for this region.[22] Clearly, natural excursions in DO and pH beyond their respective fixed limits were simply not envisioned within coastal waters when the Basin Plan was promulgated in 1972. The fixed Basin Plan limits were largely designed for discharges to onshore surface waters where there is little natural variation in pH and DO within the receiving waters. In fact, natural oceanographic processes, such as upwelling, regularly cause the DO and pH of the ambient receiving water surrounding the MBCSD outfall to range beyond the Basin Plan limits.

In contrast to the Basin Plan limits, the COP recognizes the potential for inherent variation in the receiving-water characteristics and specifies limits on excursions in these two water properties relative to background levels present at the time of the survey. Because the COP receiving-water objectives are designed to be adequately protective of the marine environment, application of the fixed Basin Plan limits to the same receiving-water characteristics already covered by the COP is not only redundant but inappropriate. For these reasons, the Basin Plan limits have been recommended for removal from future MBCSD discharge permits (MRS 2011, 2012, and 2013).

CONCLUSIONS

The quantitative screening analysis demonstrated that all measurements recorded during the February 2014 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 February 2014 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.

[22] The field operations manual for the Southern California Bight Study (SCBFMC 2002)

Shortly after discharge, the outfall was achieving dilution levels in excess of 235-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. The plume achieved dilution levels exceeding 349-fold as it continued to rise through the water column, and levels exceeded 435-fold at the completion of the initial dilution process. These dilution levels far exceeded levels predicted by modeling and incorporated in the discharge permit. Lastly, all of the auxiliary observations collected during the February 2014 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.

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