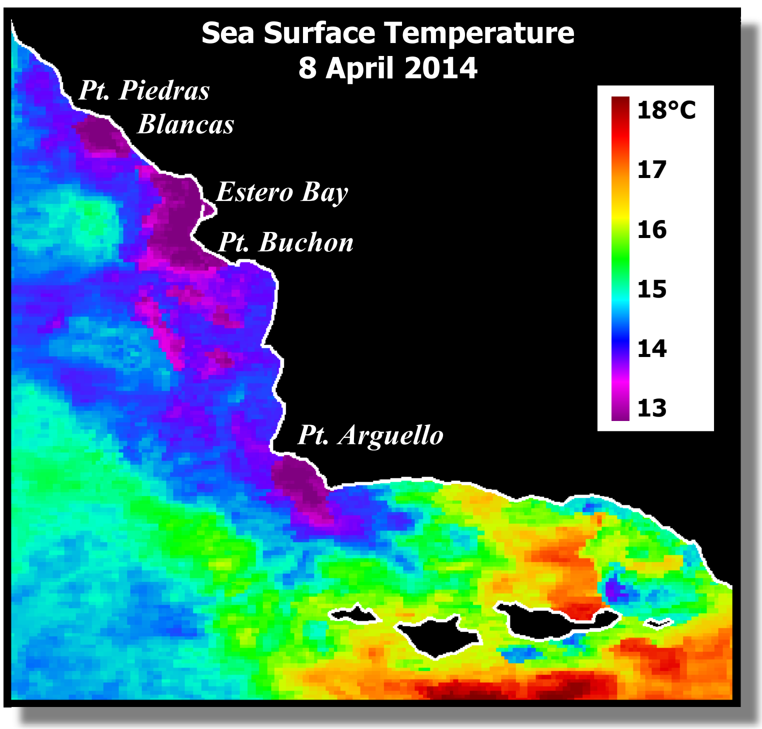
City of Morro Bay and
Cayucos Sanitary District

OFFSHORE MONITORING AND REPORTING PROGRAM

SECOND QUARTER RECEIVING–WATER SURVEY

APRIL 2014



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Report to the

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SECOND QUARTER RECEIVING–WATER SURVEY

APRIL 2014

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May 2014

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

27 May 2014

Reference: Second Quarter Receiving-Water Survey Report – April 2014

Dear Mr. Keogh:

The attached report presents results from a quarterly receiving-water survey conducted on Wednesday 9 April 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

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 May 27, 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 April 2014 field survey described in this report was the twenty-first 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 9 April 2014. Specifically, this second-quarter survey captured ambient oceanographic conditions along the central California coast during the spring 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.

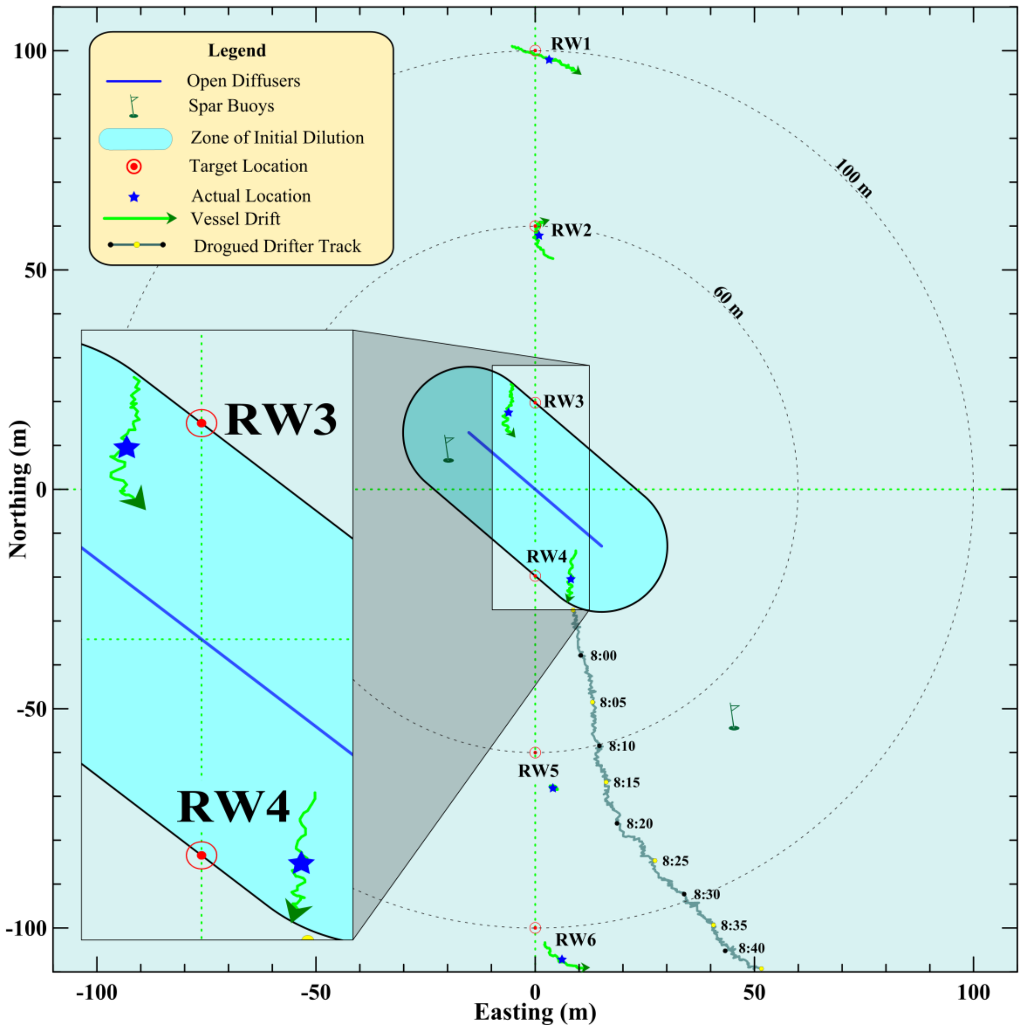

Figure 2. Station Locations

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 April 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 April 2014 survey. During the time it took the CTD to traverse the water column to the seafloor, which averaged 1 min 21 s, the instrument package moved as much as 15.7 m laterally (Station 6). The CTD traversed various smaller distances at other stations, with an average drift among all stations of 9.6 m, which is consistent with most prior surveys.

The downcasts during the April 2014 survey were conducted progressing from north to south, beginning with Station RW1. As seen in Figure 2, the CTD movement varied among stations. The movement at Stations RW1 and RW6 was consistent with the southeastward movement of the drifter and prevailing northwesterly winds.[5] In contrast, the CTD movement at the remaining stations was influenced by the vessel's residual momentum immediately prior to each downcast. For example, the drift was only 0.6 m at Station RW5 because the vessel approached the station from the east and its residual momentum temporarily counteracted the effects of transport by the southeasterly current and wind flow.

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. During the April 2014 survey, however, all of the CTD data at both RW3 and RW4 was collected within the ZID (see the inset in Figure 2). Therefore, all of the measurements at these stations were excluded from the 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

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.

high level of effectiveness in effluent dispersal. In fact, without the occasional measurements recorded within the ZID due to vessel drift, the extremely dilute discharge plume might remain undetected within all the 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 April 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 April 2014 Survey

	Time (PDT)				Closest Approach	
Station	**Downcast**	**Upcast**	**Latitude**	**Longitude**	**Range[6](m)**	**Bearing[7](ºT)**
RW1	7:53:12	7:54:55	35° 23.252' N	120° 52.502' W	87.0	12
RW2	7:59:05	8:00:27	35° 23.230' N	120° 52.503' W	47.8	20
RW3	8:05:33	8:06:51	35° 23.209' N	120° 52.508' W	**9.4**[8]	41
RW4	8:10:33	8:11:43	35° 23.188' N	120° 52.499' W	**10.2**[8]	221
RW5	8:16:07	8:17:34	35° 23.162' N	120° 52.501' W	56.2	191
RW6	8:22:13	8:23:21	35° 23.141' N	120° 52.500' W	94.6	185

OCEANOGRAPHIC PROCESSES

The trajectory of a satellite-tracked drogued drifter measured oceanic flow throughout the April 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 April 2014 survey, the drifter was deployed near the diffuser structure at 7:45 AM, and was recovered at 9:47 AM at a location 221 m to the southeast (124ºT[9]) of its original release point (Red dots in Figure 3). The drifter traveled 253 m along a curved path. However, both the direction and speed of the flow changed during the course of the survey. During the first hour of the survey, when vertical profiling was being conducted, the flow was directed toward the south-southeast (154ºT). Current speed remained relatively constant at 3.1 cm/s during this time, as shown by the uniform spacing between the green and

[6] Distance from the closest open diffuser port to the average profile location.
[7] Angle measured clockwise relative to true north from the closest diffuser port to the average profile location.
[8] All of the CTD measurements collected at Station RW3 and RW4 were located within the ZID boundary (refer to the inset in Figure 2).
[9] Direction measured clockwise relative to true (rather than magnetic) north.

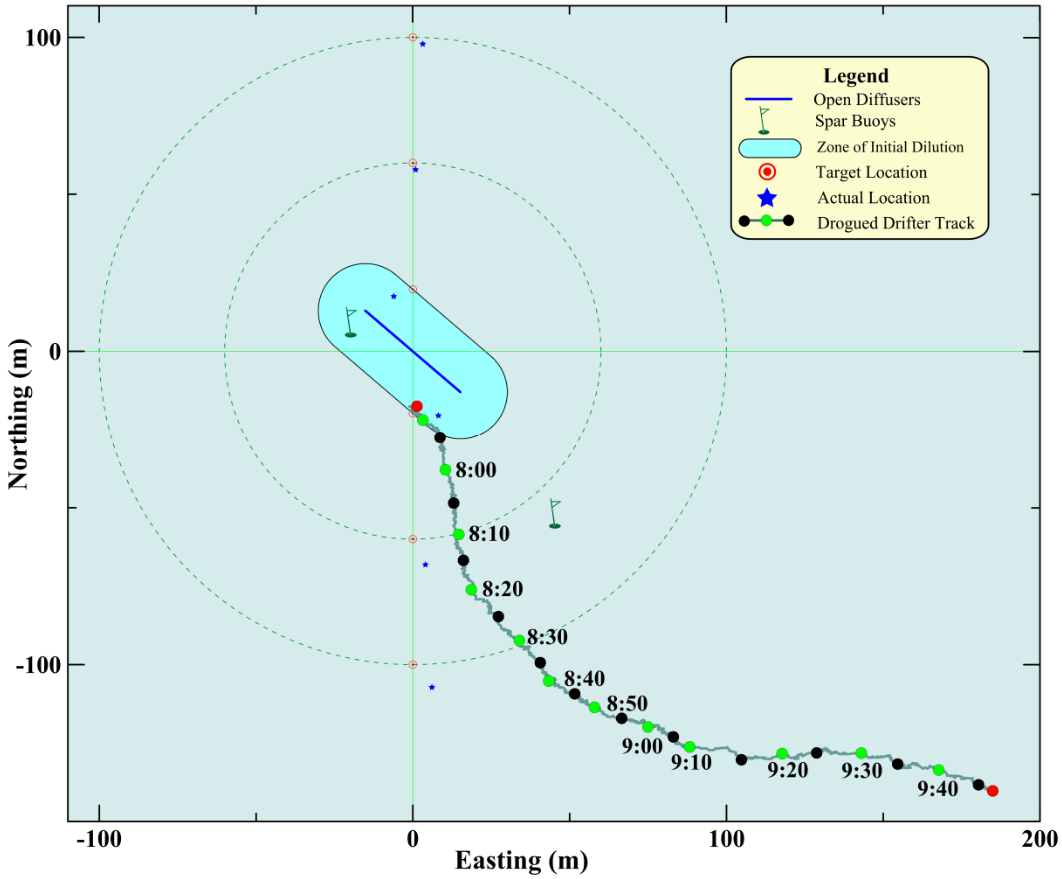

Figure 3. Drogued Drifter Trajectory

black dots in Figure 3. The dots show the drifter's progress at five- and ten-minute intervals. At this transport rate, the effluent would have experienced an eight-minute residence time within the ZID.

During the latter half of the survey, however, when the CTD was being towed horizontally, the drifter traveled eastward (104ºT) at an increased speed of 3.6 cm/s. Thus, during the towing phase of the survey, the plume's residence time within the ZID had decreased to seven minutes.

The overall flow direction observed during the survey was inconsistent with the ebb tide that prevailed throughout the April 2014 survey (Figure 4). Ebb tides normally induce a weak westward (offshore) flow in the survey region. Instead, the eastward flow component may have been caused by other processes such as upwelling. For example, the upwelling winds that prevailed around the time of the survey can induce an easterly flow at depth as deep offshore waters move shoreward and upwell to replace near-surface waters driven offshore by the winds.

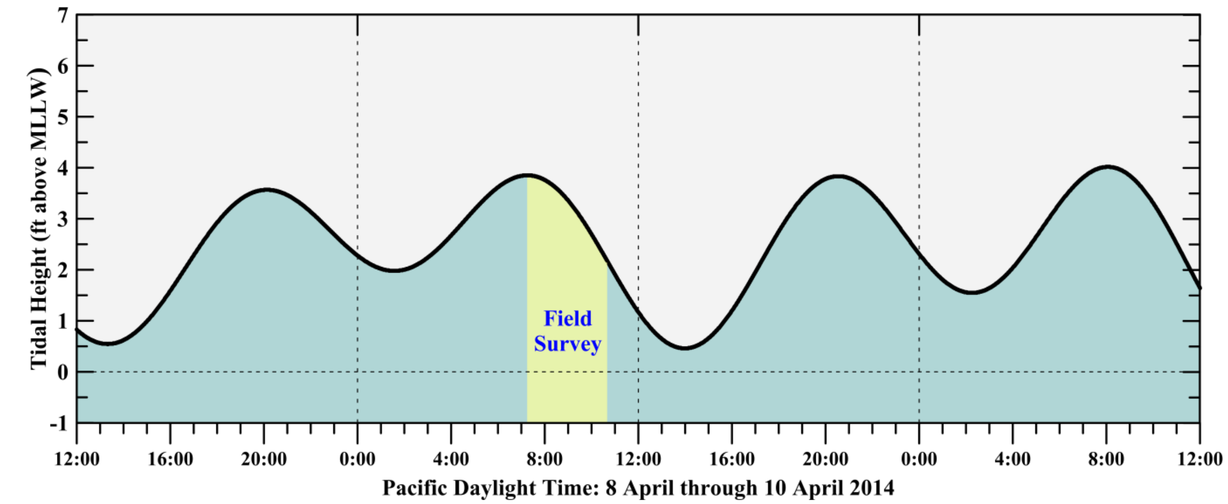

Figure 4. Tidal Level during the April 2014 Survey

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.

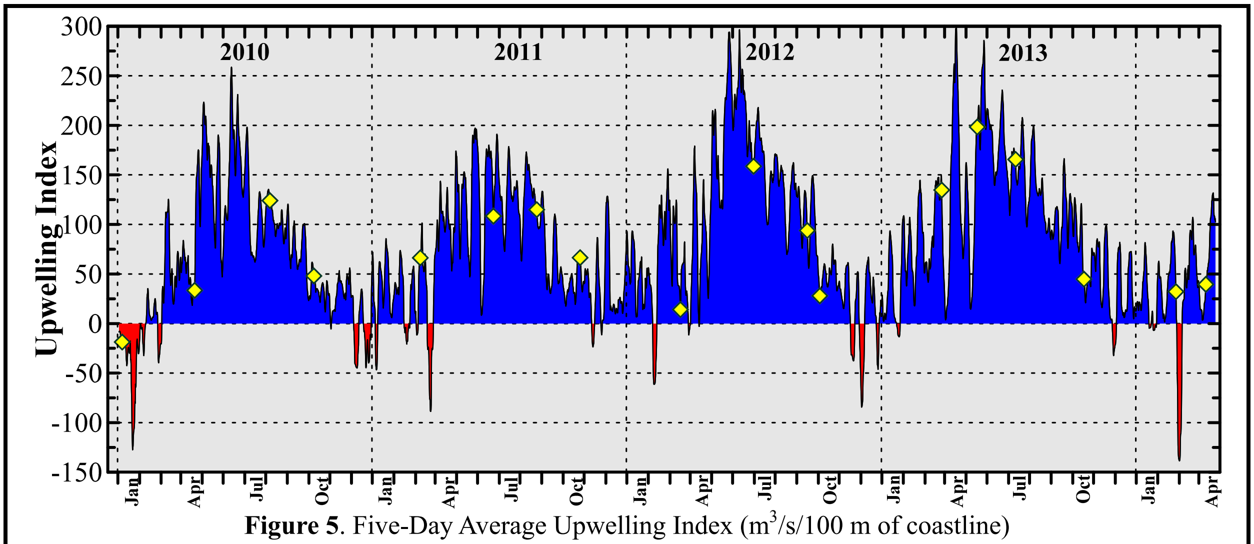

Figure 5. Five-Day Average Upwelling Index (m^3/s/100 m of coastline)

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.

Upwelling winds were generally weak in the weeks prior to the April 2014 survey (last yellow diamond in Figure 5). Nevertheless, the strength of the afternoon upwelling winds began increasing in the days prior to the survey, which produced a pattern of sea surface temperatures within the region that is indicative of upwelling processes. This 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 on the day prior to the survey. The presence of a pool of cooler, upwelled water is visually apparent close to the south-central coastline (purple shading), and the 3°C contrast between nearshore and offshore sea-surface temperatures is typical of moderate-strength upwelling events. Cross-shore counter-flows at the sea surface and seafloor were also generated by this upwelling event, and as a result, the water column was moderately stratified at the time of the April 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 Wednesday, 9 April 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.

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 April 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)[10]	%	0 to 100	± 0.3	± 0.03
Oxygen (SBE 43)	% Saturation	0 to 120	± 2	—
pH (SBE 18)	pH	0 to 14	± 0.1	—

The precision and accuracy of the various probes, as reported in manufacturer's specifications, are listed in Table 3. Salinity (‰) was calculated from conductivity measurements reported in units of Siemens/m. Density was derived from contemporaneous temperature (°C) and salinity data, and was expressed as 1000 times the specific gravity minus one, which is a unit of sigma-T (σ_t).

Assessments of all three of the physical parameters (salinity, temperature, and density) helped determine the lateral extent of the effluent plume during the tow phase of the survey. Additionally, during the vertical-profiling phase, they quantified layering, or vertical stratification and stability of the water column, which determines the behavior and dynamics of the effluent as it mixes with seawater within the ZID. Data on the three remaining seawater properties, light transmittance (water clarity), hydrogen-ion concentration (acidity/alkalinity – pH), and dissolved oxygen (DO), further characterized the receiving waters, and were used to assess compliance with water-quality criteria. Light transmittance was measured as a percentage of the initial intensity of a transmitted beam of light detected at the opposite end of a 0.25-m path. Transmissivity readings are reported relative to 100% transmission in air, so the maximum theoretical transmission in (pure) water is expected to be 91.3%.

Before the first vertical hydrocast at Station 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 8:24 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 within the surface mixed layer and one at mid-depth below the thermocline, in accordance with the monitoring requirements of the NPDES discharge permit (Figure 6).

[10] 25-cm path length of red (660 nm) light

Initially, the reconfigured CTD package was towed for 30 minutes at an average depth of 3.05 m, and an average speed of 1.67 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 7.99 m. During this 30-minute mid-depth tow, vessel speed averaged 1.62 m/s. At the observed towing speeds and the 4 Hz sampling rate, at least 2.4 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.[11]

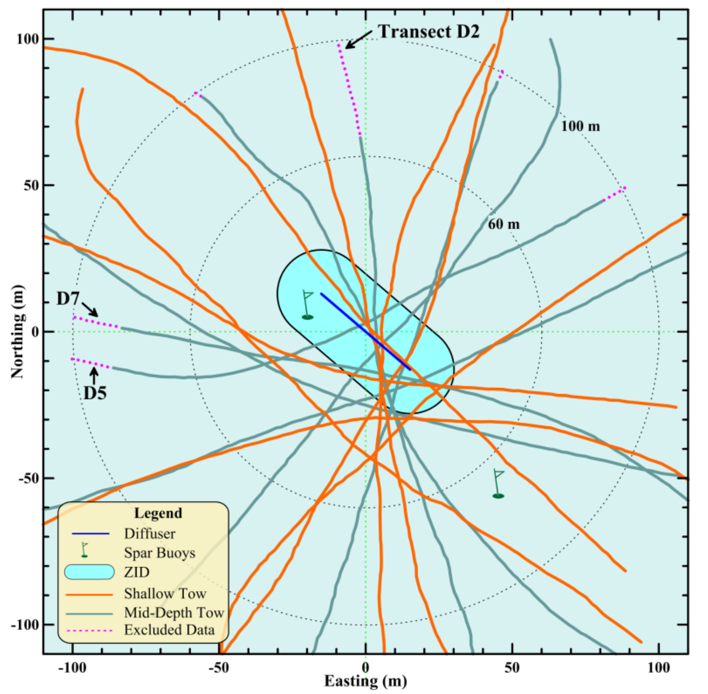

Figure 6. CTD Tracklines during the April 2014 Tow Surveys

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,[12] subsequent post-processing revealed several events that impacted portions of the data, resulting in the adjustment or exclusion of these data prior to initiating 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 Transects D2, D5, and D7 (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, as was the case during the April 2014 survey.

[11] Figures 8 and 9 later in this report

[12] 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[13] Latitude	Longitude	Diffuser Distance (m)	Time (PDT)	Air (°C)	Cloud Cover (%)	Wind Avg (kt)	Wind Max (kt)	Wind Dir (from) (°T)	Swell Ht/Dir (ft/°T)	Secchi Depth (m)
RW1	35° 23.245' N	120° 52.491' W	80.6	7:56:37	10.3	100	1.7	2.4	NW	2 NW	6.0
RW2	35° 23.235' N	120° 52.501' W	57.1	8:01:46	10.0	100	2.3	4.1	NW	2 NW	6.0
RW3	35° 23.200' N	120° 52.504' W	1.4	8:08:20	9.7	100	3.1	4.3	NW	2 NW	6.0
RW4	35° 23.179' N	120° 52.499' W	23.9	8:13:07	9.6	100	4.3	5.6	NW	2 NW	6.0
RW5	35° 23.165' N	120° 52.504' W	52.0	8:17:49	9.4	100	5.7	7.3	NW	2 NW	6.0
RW6	35° 23.141' N	120° 52.490' W	94.2	8:24:46	9.6	100	3.6	5.0	NW	2 NW	6.0

The exclusion of the small portions of Transects D2, D5, and D7 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.

Further quality-control screening identified two sets of anomalous transmissivity measurements that were excised from the data. These data represented large, but short-lived reductions in transmissivity that arise when the CTD encounters a piece of floating kelp, a jellyfish, or other debris that briefly blocks the transmissometer's light path. In contrast, when the plume signature is observed in the transmissivity record, the changes are gradual, of limited amplitude, and can be in either direction relative to average water clarity depending on whether the deep seawater entrained at depth is more or less turbid than mid-depth seawater. In fact, during the April 2014 survey, ambient seawater clarity was higher near the seafloor, and when entrained within the rising effluent plume, it resulted in plume signature characterized by increased transmissivity within the upper water column. Additionally, the locations of the two transmissivity anomalies did not coincide with a low-salinity signature indicating the presence of dilute effluent particulates.

The first event occurred during vertical profiling at Station RW6, and resulted in a 14% decrease in transmissivity lasting one second. When combined with other (normal) transmissivity measurements within the 8-m depth bin, the average reduction in transmissivity was 7%. The second encounter occurred during the mid-depth tow survey along transect D6 when a 2.4% decrease was observed for 0.75 s.

RESULTS

The first-quarter receiving-water survey was conducted on the morning of Wednesday, 9 April 2014. The receiving-water survey commenced at 7:46 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 09:48 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 9 April 2014, skies were overcast, with light northwesterly winds. Average wind speeds, calculated over one-minute intervals, ranged from 1.7 kt to 5.7 kt (Table 4). Similarly, peak wind speeds ranged from 2.4 kt to 7.3 kt. The swell was out of the northwest with a significant wave height of one foot. Air temperatures remained fairly constant throughout the survey, averaging 9.8°C.

The 6.0 m Secchi depths recorded during the April 2014 survey reflected the presence of a 12-m euphotic zone that extended through almost three-fourths of the water column (Table 4). The highest water clarity during the survey was located at mid-depth, with reduced clarity within the mixed layer near the sea surface (above 3 m) due to increased planktonic densities that result from upwelling. 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 April 2014 survey. Even close to the sea surface, however, water clarity was exceptionally high, and exceeded 84.1%. at all six stations.

Although there was no evidence of floating particulates, oil sheens, or any discoloration of the sea surface associated with wastewater constituents, the high water clarity allowed biofilm particulates suspended within the upper water column near the ZID to be visually apparent during portions of the April 2014 survey. Biofilm particulates are not present in wastewater prior to discharge at the treatment plant, but line the interior surface of the outfall pipe. Periodically, small pieces of biofilm detach from the outfall pipe and become entrained within the discharge plume. Depending on the ambient seawater clarity and the vertical extent of the plume within the water column, these particulates are occasionally observed during the water-quality surveys. These are, however, unrelated to the particulate loading within MBCSD effluent, and have little bearing on the transmittance of natural light.

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 0.826 million gallons of effluent discharged on 9 April had a temperature of 18°C, a suspended-solids concentration of 24 mg/L, a pH of 7.6. The biochemical oxygen demand (BOD) of the effluent was measured two days later, on 11 April, at 32.2 mg/L.

During the April 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*), western grebes (*Aechmophorus occidentalis*), American coots (*Fulica americana*), and western gulls (*Larus occidentalis*) were all observed transiting the survey area. Additionally, southern sea otters (*Enhydra lutris nereis*) were observed inside the mouth of Morro Bay during transit to and from the survey site, while several groups of California sea lions (*Zalophus californianus*) were observed both within the harbor and at the survey site. Despite restricted visibility from low clouds and fog, small numbers of pedestrians were visible along Atascadero State beach periodically throughout the survey.

Instrumental Observations

Data collected during vertical profiling were processed in accordance with standard procedures (SCCWRP 2002), and are collated within 0.5-m depth intervals in Table 5. Data collected during the April 2014 survey reflect the presence of a moderately stratified water column indicative of recent upwelling conditions within Estero Bay (Figure 5).

[13] 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 9 April 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	11.926	11.931	11.880	11.978	11.965	11.982	33.649	33.648	33.649	33.647	33.650	33.653
1.5	11.839	11.932	11.773	11.982	11.947	11.953	33.648	33.648	33.649	33.648	33.648	33.651
2.0	11.737	11.905	11.616	11.966	11.879	11.759	33.648	33.649	33.649	33.648	33.648	33.650
2.5	11.556	11.642	11.463	11.893	11.653	11.398	33.650	33.647	33.651	33.647	33.647	33.649
3.0	11.354	11.377	11.381	11.741	11.451	11.244	33.657	33.652	33.657	33.644	33.652	33.661
3.5	11.252	11.270	11.280	11.600	11.239	11.089	33.664	33.660	33.662	33.646	33.658	33.654
4.0	11.174	11.189	11.162	11.161	11.106	11.016	33.668	33.666	33.667	33.624	33.660	33.662
4.5	11.113	11.093	11.050	10.683	10.975	10.994	33.673	33.671	33.667	33.599	33.654	33.673
5.0	11.079	11.049	10.969	10.643	10.893	10.987	33.677	33.676	33.661	33.606	33.654	33.678
5.5	11.040	11.020	10.894	10.628	10.872	10.989	33.680	33.681	33.657	33.590	33.665	33.682
6.0	11.023	10.976	10.830	10.653	10.885	10.991	33.683	33.685	33.655	33.583	33.673	33.685
6.5	11.009	10.944	10.805	10.682	10.877	10.988	33.685	33.688	33.654	33.604	33.674	33.687
7.0	10.977	10.934	10.768	10.682	10.879	10.980	33.688	33.691	33.652	33.631	33.678	33.689
7.5	10.945	10.926	10.687	10.689	10.872	10.932	33.691	33.693	33.645	33.654	33.680	33.693
8.0	10.923	10.916	10.685	10.728	10.891	10.873	33.694	33.695	33.647	33.687	33.694	33.697
8.5	10.909	10.861	10.664	10.752	10.897	10.847	33.696	33.698	33.651	33.698	33.698	33.700
9.0	10.792	10.788	10.626	10.777	10.842	10.816	33.702	33.704	33.655	33.703	33.702	33.703
9.5	10.729	10.745	10.626	10.769	10.809	10.802	33.710	33.708	33.660	33.705	33.706	33.705
10.0	10.706	10.716	10.635	10.764	10.791	10.795	33.713	33.712	33.668	33.706	33.707	33.706
10.5	10.691	10.711	10.645	10.734	10.774	10.789	33.715	33.713	33.678	33.711	33.709	33.707
11.0	10.654	10.699	10.721	10.724	10.759	10.777	33.717	33.715	33.708	33.713	33.710	33.709
11.5	10.624	10.637	10.736	10.720	10.748	10.752	33.719	33.718	33.713	33.714	33.711	33.709
12.0	10.575	10.579	10.733	10.716	10.739	10.742	33.723	33.721	33.714	33.715	33.712	33.711
12.5	10.561	10.547	10.730	10.701	10.723	10.733	33.725	33.725	33.714	33.715	33.713	33.712
13.0	10.526	10.540	10.726	10.630	10.692	10.687	33.728	33.727	33.715	33.718	33.714	33.714
13.5	10.478	10.508	10.662	10.539	10.649	10.615	33.731	33.728	33.718	33.727	33.717	33.719
14.0	10.490	10.460	10.566	10.414	10.590	10.558	33.733	33.733	33.723	33.736	33.722	33.724
14.5	10.443	10.397	10.536	10.387	10.558	10.528	33.735	33.737	33.727	33.741	33.725	33.727
15.0	10.375	10.390	10.491	10.382	10.510	10.496	33.741	33.739	33.729	33.743	33.729	33.729
15.5	10.368	10.382	10.465	10.380	10.475	10.483	33.744	33.742	33.734	33.744	33.733	33.733
16.0	10.377	10.375	10.443	10.379	10.447	10.447	33.744	33.745	33.737	33.745	33.736	33.736
16.5	10.350	10.377	10.383	10.378	10.407	10.406	33.748	33.746	33.742	33.746	33.741	33.741

Table 5. Vertical Profile Data Collected on 9 April 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	25.554	25.552	25.563	25.543	25.548	25.547	7.966	7.970	7.969	7.980	7.974	7.976
1.5	25.569	25.552	25.583	25.543	25.549	25.551	7.965	7.969	7.968	7.976	7.977	7.974
2.0	25.589	25.558	25.611	25.545	25.562	25.586	7.964	7.969	7.967	7.976	7.976	7.975
2.5	25.624	25.606	25.641	25.558	25.603	25.652	7.961	7.970	7.963	7.975	7.975	7.972
3.0	25.666	25.658	25.661	25.585	25.644	25.689	7.956	7.963	7.959	7.975	7.972	7.964
3.5	25.690	25.683	25.683	25.613	25.688	25.712	7.949	7.958	7.953	7.975	7.966	7.954
4.0	25.707	25.703	25.709	25.675	25.713	25.730	7.941	7.952	7.946	7.972	7.957	7.945
4.5	25.722	25.724	25.728	25.741	25.732	25.743	7.933	7.943	7.938	7.964	7.949	7.936
5.0	25.732	25.736	25.739	25.753	25.747	25.748	7.925	7.937	7.930	7.943	7.942	7.930
5.5	25.741	25.745	25.749	25.744	25.758	25.751	7.919	7.930	7.922	7.925	7.931	7.926
6.0	25.746	25.756	25.759	25.734	25.763	25.754	7.917	7.925	7.916	7.911	7.922	7.924
6.5	25.750	25.764	25.762	25.744	25.765	25.755	7.913	7.921	7.909	7.900	7.919	7.921
7.0	25.758	25.768	25.767	25.766	25.768	25.758	7.911	7.918	7.903	7.896	7.915	7.921
7.5	25.766	25.771	25.776	25.782	25.770	25.770	7.908	7.916	7.899	7.892	7.913	7.919
8.0	25.772	25.774	25.778	25.802	25.778	25.783	7.907	7.912	7.892	7.890	7.910	7.917
8.5	25.776	25.786	25.784	25.806	25.780	25.791	7.904	7.910	7.890	7.889	7.910	7.916
9.0	25.801	25.804	25.795	25.805	25.793	25.798	7.902	7.908	7.887	7.890	7.909	7.912
9.5	25.819	25.815	25.798	25.808	25.802	25.803	7.898	7.903	7.884	7.891	7.908	7.910
10.0	25.826	25.823	25.803	25.810	25.806	25.805	7.894	7.901	7.882	7.892	7.906	7.909
10.5	25.830	25.825	25.809	25.819	25.810	25.807	7.892	7.899	7.881	7.893	7.904	7.906
11.0	25.838	25.828	25.819	25.823	25.814	25.809	7.889	7.897	7.882	7.892	7.903	7.905
11.5	25.845	25.841	25.820	25.824	25.816	25.814	7.884	7.894	7.884	7.893	7.901	7.904
12.0	25.856	25.854	25.821	25.825	25.819	25.817	7.882	7.889	7.885	7.894	7.900	7.903
12.5	25.860	25.863	25.822	25.828	25.822	25.820	7.878	7.886	7.887	7.894	7.899	7.902
13.0	25.869	25.866	25.824	25.843	25.829	25.830	7.874	7.883	7.889	7.892	7.898	7.900
13.5	25.879	25.872	25.837	25.866	25.839	25.846	7.869	7.881	7.890	7.892	7.895	7.900
14.0	25.879	25.884	25.858	25.895	25.853	25.860	7.864	7.875	7.889	7.888	7.894	7.896
14.5	25.888	25.898	25.866	25.903	25.861	25.867	7.862	7.870	7.885	7.882	7.890	7.894
15.0	25.905	25.901	25.876	25.905	25.872	25.875	7.857	7.865	7.882	7.878	7.886	7.888
15.5	25.908	25.905	25.884	25.906	25.881	25.880	7.854	7.862	7.879	7.873	7.882	7.884
16.0	25.907	25.908	25.890	25.907	25.889	25.889	7.851	7.860	7.876	7.868	7.880	7.882
16.5	25.914	25.908	25.905	25.908	25.900	25.900	7.847	7.855	7.867	7.863	7.874	7.877

Table 5. Vertical Profile Data Collected on 9 April 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	6.827	7.195	6.950	7.370	7.445	7.365	85.492	84.739	85.366	84.601	84.304	84.635
1.5	6.648	7.037	6.230	7.066	6.815	6.223	85.685	84.755	85.537	84.574	84.374	84.434
2.0	6.260	6.247	6.112	6.690	6.237	5.699	85.999	84.811	86.205	84.400	84.412	84.813
2.5	5.968	5.919	6.027	6.270	6.057	5.660	86.837	85.860	87.976	84.171	85.282	87.126
3.0	5.891	5.854	5.851	5.870	5.719	5.486	88.042	88.153	88.327	84.626	86.515	88.212
3.5	5.723	5.738	5.650	4.774	5.544	5.504	88.595	88.605	88.533	86.009	87.505	87.918
4.0	5.636	5.607	5.498	4.710	5.357	5.526	88.752	88.716	88.716	87.652	88.050	88.542
4.5	5.593	5.576	5.406	4.853	5.310	5.533	88.607	88.618	88.901	88.239	88.301	89.138
5.0	5.539	5.535	5.269	4.938	5.354	5.548	88.707	88.608	89.003	88.626	89.046	89.362
5.5	5.533	5.485	5.186	5.008	5.395	5.557	88.261	88.907	88.959	88.647	89.165	89.351
6.0	5.516	5.451	5.192	5.054	5.355	5.537	88.196	89.098	89.094	88.630	89.067	89.329
6.5	5.480	5.454	5.100	5.034	5.362	5.498	88.384	89.423	89.184	89.052	89.353	89.408
7.0	5.442	5.428	4.962	5.120	5.351	5.377	88.553	89.653	89.294	89.178	89.542	89.598
7.5	5.417	5.420	5.015	5.161	5.407	5.320	88.966	89.647	89.212	89.323	89.543	89.730
8.0	5.409	5.249	4.948	5.252	5.419	5.309	89.484	89.691	89.202	89.416	89.681	82.776
8.5	5.202	5.163	4.909	5.224	5.297	5.286	89.681	89.819	89.311	90.091	89.804	90.320
9.0	5.132	5.170	4.940	5.203	5.266	5.283	89.923	90.192	89.442	90.340	90.007	90.371
9.5	5.186	5.179	4.951	5.189	5.270	5.276	90.413	90.317	89.542	90.465	90.231	90.586
10.0	5.144	5.183	5.025	5.152	5.241	5.274	90.818	90.725	89.829	90.704	90.503	90.693
10.5	4.992	5.156	5.192	5.210	5.192	5.251	90.728	91.246	89.980	90.791	90.727	90.781
11.0	4.962	4.891	5.175	5.212	5.184	5.200	91.625	91.525	90.214	90.928	90.746	90.999
11.5	4.794	4.770	5.189	5.190	5.190	5.190	91.623	91.778	90.570	91.607	90.820	91.034
12.0	4.819	4.755	5.203	5.074	5.173	5.153	91.482	91.624	90.626	91.918	90.934	91.135
12.5	4.709	4.781	5.194	4.899	5.059	5.000	91.394	91.192	90.927	91.838	91.112	91.302
13.0	4.595	4.694	4.925	4.695	4.953	4.844	90.981	91.141	91.376	91.634	91.274	91.455
13.5	4.633	4.550	4.788	4.478	4.877	4.764	90.503	90.934	91.688	91.407	91.562	91.463
14.0	4.577	4.526	4.786	4.481	4.825	4.754	90.286	90.670	91.938	90.837	91.498	91.584
14.5	4.427	4.552	4.711	4.496	4.704	4.723	90.180	90.319	91.493	89.461	91.451	91.602
15.0	4.452	4.522	4.703	4.494	4.682	4.720	89.756	90.264	91.438	87.865	91.396	91.482
15.5	4.478	4.480	4.665	4.493	4.664	4.573	89.794	90.187	91.347	87.340	91.209	91.448
16.0	4.434	4.475	4.525	4.485	4.514	4.488	89.628	89.593	91.232	86.987	91.130	91.463
16.5	4.493	4.556	4.610	4.480	4.573	4.576	88.710	88.742	90.214	86.595	91.144	88.572

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. An intense upwelling event results in the rapid influx of dense, cold, saline water at depth and leads to a sharp thermocline, halocline, and pycnocline where temperature, salinity, and density change rapidly over a small vertical distance. Under these 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, occur only briefly, or have not occurred recently; the contrast between the surface and deep watermasses is reduced, and stratification appears as a more gradual vertical change in seawater properties below the surface mixed layer. Both types of upwelling signatures are apparent in the April 2014 vertical profiles (Figure 7). A sharply defined interface with large changes in seawater properties over limited vertical extent is apparent between 2 m and 5 m, immediately beneath the relatively uniform surface mixed layer. In the rest of the water column below this shallow thermocline, seawater properties steadily change in a more gradual manner with increasing depth at all the stations unaffected by the discharge (Stations RW1, RW2, and RW6 in Figure 7abf).

In particular, all seawater properties exhibit steadily increasing or decreasing values below the sharply defined shallow thermocline. This transition zone separates the surface mixed layer from a deeper seawater mass immediately above the sea floor. Steady decreases in temperature (red lines), DO (dark blue lines), and pH (olive-colored lines) with increasing depth reflect the lingering effects of upwelling in the days prior to the survey. These decreases are mirrored by a steady increase in density (black lines), and salinity (green lines) with depth within the transition zone. These gradual vertical changes reflect the presence of a colder, saltier, nutrient-rich but oxygen-poor watermass that migrated shoreward along the seafloor as part of the upwelling process. In contrast to the relatively fresh surface waters associated with the southward-flowing California Current, the elevated salinity at depth (green lines in Figure 7) was indicative of waters that originated in the Southern California Bight and were transported northward along the central coast by the Davidson Undercurrent.

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). A recent pulse of upwelling winds produced the more rapid changes in these seawater properties within the upper water column, including an increased presence of plankton within the surface mixed layer that is reflected in the observed 3% decrease in transmissivity at the sea surface compared to the sub-thermocline measurements.

A similar decrease in transmissivity is also apparent within 4 m of the seafloor at most stations (light blue lines in Figure 7abcdf). This decrease was due to the presence of a turbid benthic nepheloid layer (BNL) immediately above the seafloor. BNLs are caused by lightweight flocs of detritus that are resuspended by the turbulence generated by bottom currents. These particle-rich layers are a widespread phenomenon on continental shelves (Kuehl et al. 1996) and are frequently observed during the offshore surveys conducted within Estero Bay.

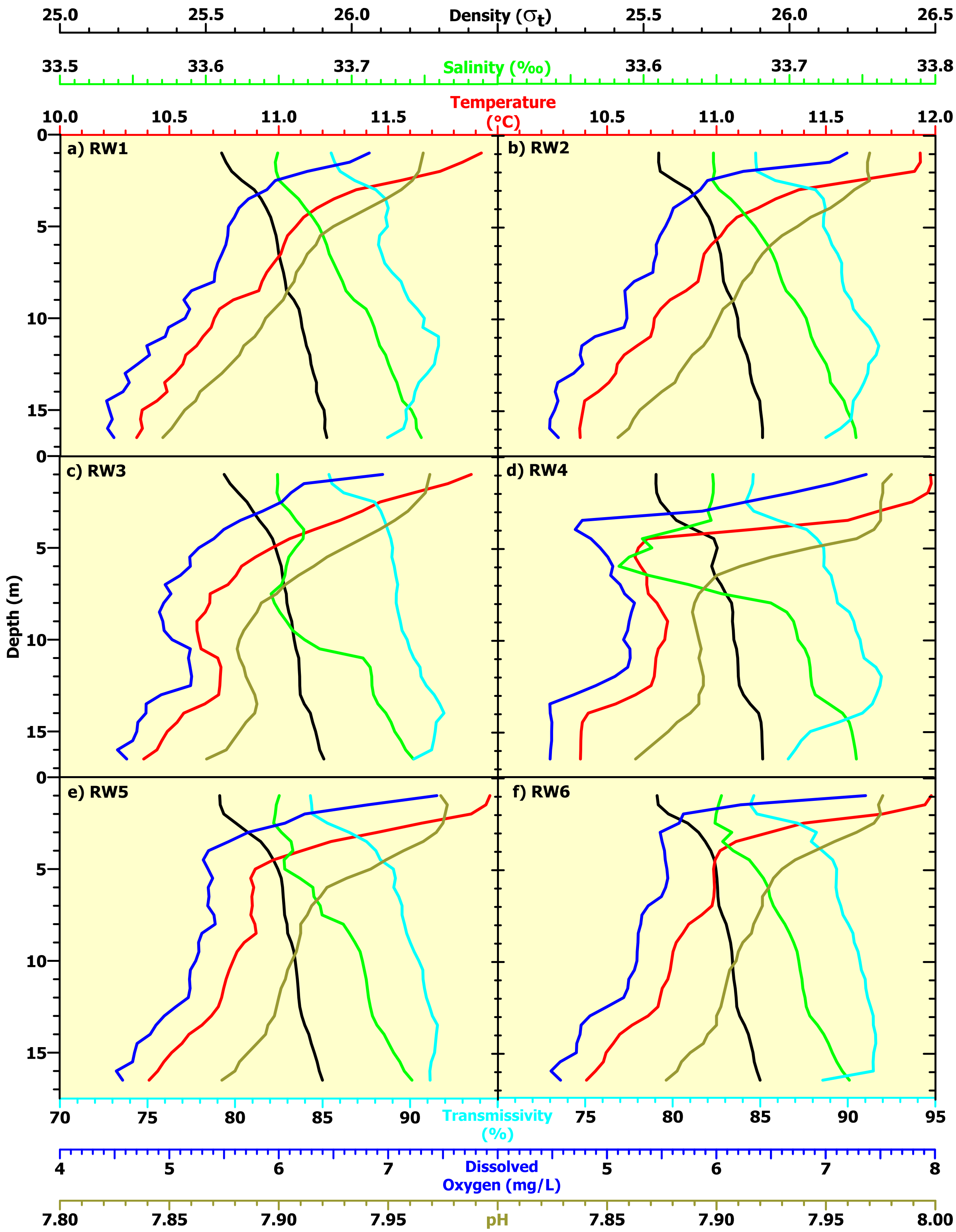

Figure 7. Vertical Profiles of Water-Quality Parameters

The degree of vertical stratification within the receiving 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. To a limited extent, this was the case during the April 2014 survey, when much of the discharge plume spread horizontally below the mixed layer and only reached the sea surface within a localized region directly over the diffuser structure. The increased presence of dilute effluent constituents trapped below the mixed layer is apparent in sharp reductions in salinity at Stations RW3, RW4, and to a lesser extent RW5 (green lines in Figure 7cde). These salinity reductions do not extend through the mixed layer to the sea surface however, indicating that the plume was trapped within the sharp thermocline immediately below 2 m, at least at the locations of these three stations.

Although the presence of dilute effluent within the upper water column was delineated by a sharp reduction in salinity at these three 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 mid-depth water column with a vertical distribution of seawater properties that was more uniform compared to the steadily changing, gradual vertical gradients seen at the other stations (*cf*. the dark blue, red, and olive lines between 3 and 11 m in Figure 7cd as compared to Figure 7ab). With the exception of salinity, mid-depth water properties within the plume at these three stations were similar to the seawater properties found near the seafloor at all stations.

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 mid and upper water column. These entrainment-generated anomalies are only apparent, however, when the water column is sufficiently stratified to cause a perceptible contrast between shallow and deep ambient seawater properties.

It also clear that the anomalies in seawater properties within the upper water column at stations RW3, RW4 and RW5 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 (<11°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 (*cf*. the red lines at 5 m in Figure 7d and 7b). Although not readily apparent in the vertical transmissivity profiles, the shallow tow data also demonstrated that the plume signature was less turbid than the surrounding seawater, and could not have been generated by an increased presence of effluent particulates.

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 rather than a simple relocation of ambient seawater. 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 in the shallow survey (Figure 9), but not the mid-depth survey (Figure 8). During the mid-depth tow survey, the lateral extent of the plume was limited, and presence of wastewater constituents, as indicated by slightly reduced salinity, was largely confined to a small area directly over the diffuser structure (green, and red shading in Figure 8b). In contrast, the distribution of plume-related anomalies in other seawater properties was more difficult to discern (Figure 8acdef). While some anomalies in these other properties coincided with the salinity distribution surrounding the discharge, other, nearly-as-large anomalies are scattered about the maps. These non-plume anomalies arise because the range in values within each individual map was exceedingly small. Slight, random variations due to sampling perturbations such as variations in tow depth, or inherent variability in seawater properties, can therefore, appear as anomalies. For example, as shown by the scales in the upper right corners of the maps, the ranges in temperature (0.08°C), density (0.04), transmissivity (0.6%), DO (0.2 mg/L), and pH (0.02) that characterized the distributions in the horizontal maps at mid-depth were extremely small.

In contrast, the distributions of near-surface seawater properties were more diagnostic of the location and extent of the discharge plume as it spread beneath the thermocline (Figure 9). Because of the increased vertical gradients immediately below the sea surface, ambient seawater properties near the 3-m tow depth differed substantially from those of the rest of the water column, and thus provided a greater contrast with the near-bottom seawater properties that were entrained in the rising effluent plume. As a result, the disposition of the effluent plume could be more easily traced using the entrainment anomalies.

While the largest anomalies in all the seawater properties generally coincided with the salinity anomaly near the ZID (Figure 9b), they also traced the plume as it spread southward, well outside of the ZID. Density was the only property whose anomaly was relatively localized near the discharge point (Figure 9c). This localized density anomaly demonstrates that the plume at that location was less dense than the surrounding seawater, and would be expected to continue to rise within the water column. This suggests that the plume may have actually reached the sea surface within a highly localized area directly over the diffuser structure. At one point during the shallow tow, a reduced amount of surface capillary waves was observed in a limited area directly over the diffuser structure, which lends support to the conclusion that the plume may have extended all the way to the sea surface within the confines of the density anomaly.

Increased transmissivity within the plume is another telling feature of the shallow tow data (note the reversed scale in Figure 9d). As with the reduced temperature within the effluent plume, the presence of wastewater particulates would not be expected to increase seawater clarity. Instead, entrainment of less turbid ambient seawater within the rising effluent plume is the only mechanism that would have created a plume anomaly where transmissivity was higher than the surrounding seawater. As described previously, ambient transmissivity increased with increasing depth throughout most of the water column, but was sharply reduced within the near-surface mixed layer due to an increased planktonic density (light blue lines in Figure 7).

Outfall Performance

The efficacy of the outfall can be evaluated through a comparison of dilution levels measured at the time of the April 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.

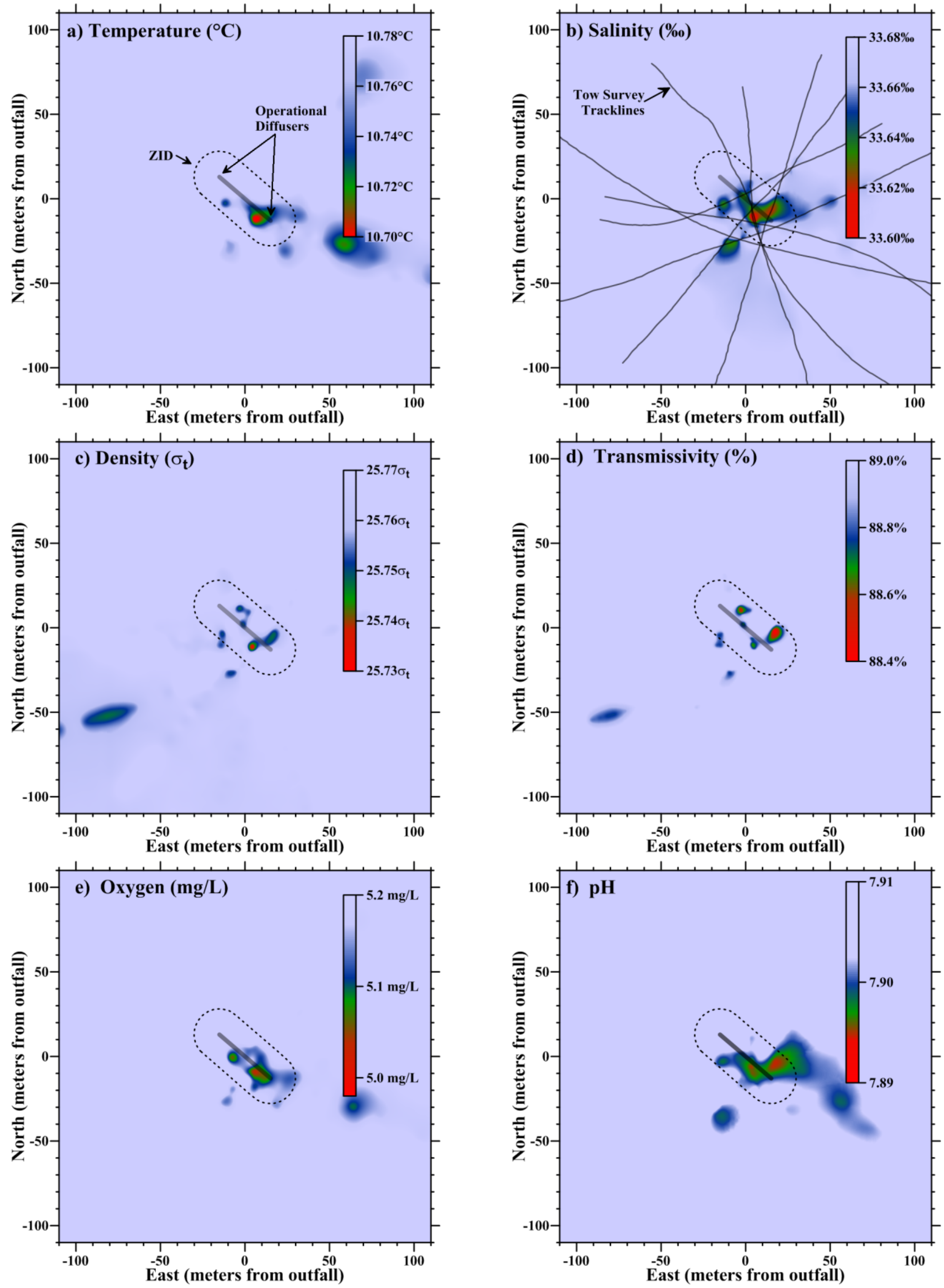

Figure 8. Horizontal Distribution of Mid-Depth Water-Quality Parameters 7.99 m below the Sea Surface

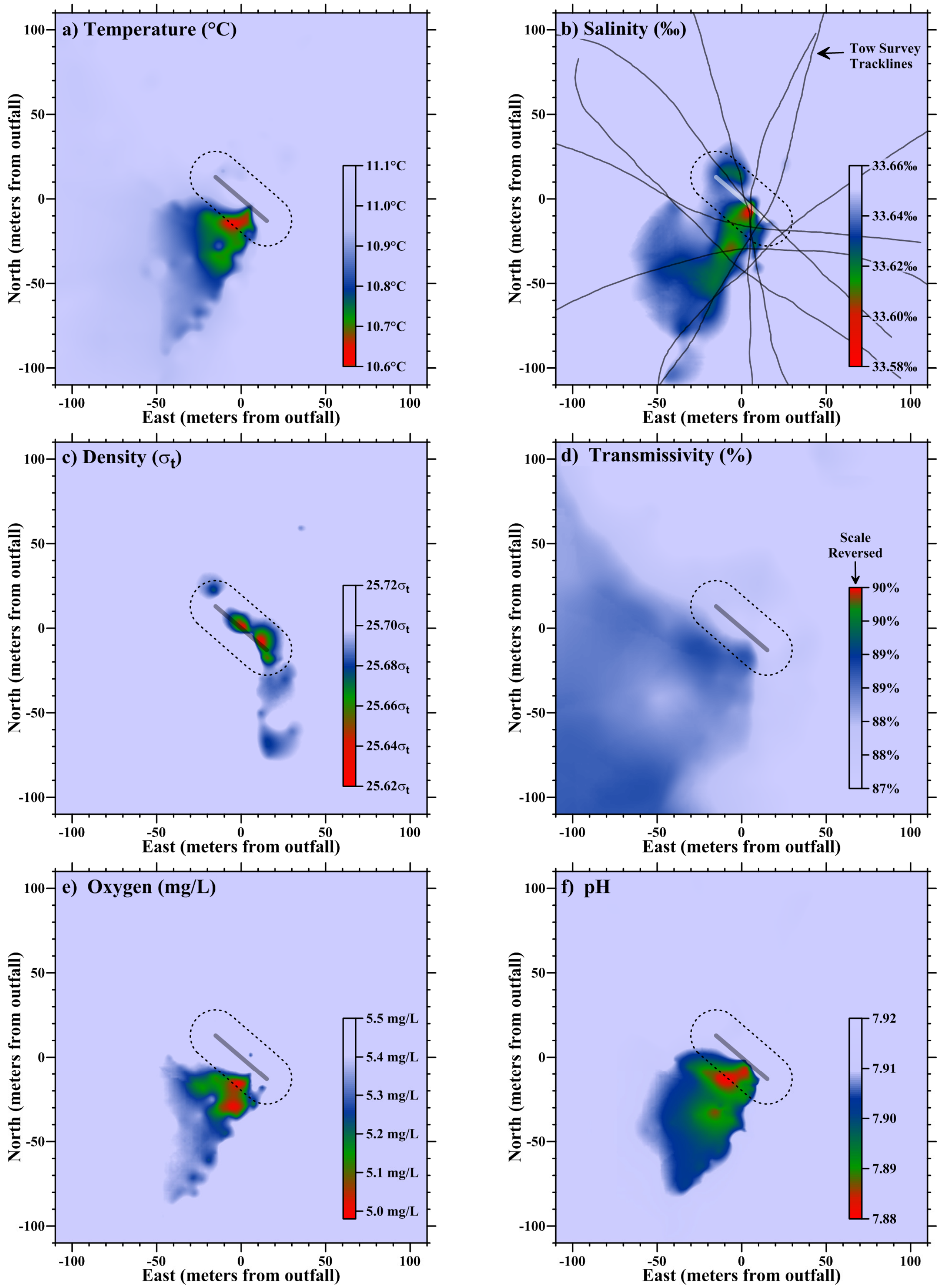

Figure 9. Horizontal Distribution of Shallow Water-Quality Parameters 3.05 m below the Sea Surface

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 April 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 mid and upper water column in the vertical profiles measured at Stations RW3, RW4, and RW5 (green lines in Figure 7abc), and in localized patches of much larger salinity reductions near the diffuser structure in both of the 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)[14] 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 (<33.58‰) measured during the April 2014 survey were recorded within 5 m of the diffuser during the first transect of the shallow tow survey, and the second transect of the mid-depth tow survey (red shading directly over the diffuser structure in Figures 8b and 9b). The lowest of these measured salinities corresponded to a reduction of 0.121‰ below the mean ambient salinity (33.697‰) measured at a corresponding depth level, but well beyond the influence of the discharge.

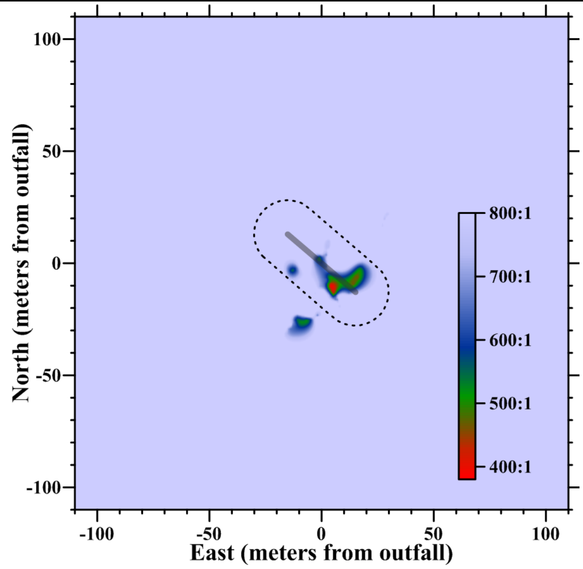

Figure 10. Mid-Depth Plume Dilution Computed from Salinity Anomalies in Figure 8b

From Equation 2, that salinity anomaly corresponds to a dilution of 269-fold (Figure 10), which is double 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 8.2 m, which was 1.8 m deeper than 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 much 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 shortly after discharge and well before the completion of the initial dilution process.

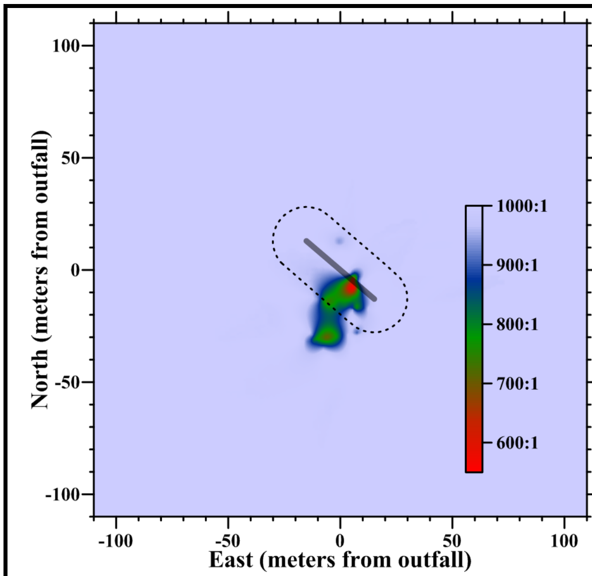

Figure 11. Shallow Plume Dilution Computed from Salinity Anomalies in Figure 9b

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 (393:1) was located 0.5 m south of the diffuser structure at a depth of 3.1 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 nearly three times greater than predicted by modeling.

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

The vertical profiles also detected the presence of extremely dilute wastewater particulates in the portion of the plume that began spreading laterally at mid-depth within the ZID. The largest salinity anomaly (-0.1‰) was detected at 6 m below the sea surface at Station RW4 (green line in Figure 7c). That measurement was recorded 8 m from the diffuser structure at a depth close to the trapping depth predicted by modeling. Nevertheless, the measured salinity anomaly corresponded to a dilution of 324-fold. This indicates that during the April 2014 survey, the outfall was achieving dilution levels more than double the dilution predicted by modeling after the completion of the initial dilution process.

The dilution computations show that, during the April 2014 survey, the outfall was performing much better than designed and was rapidly diluting effluent more than 269-fold immediately after discharge, and well before completion of the initial-dilution process. After initial dilution was complete, effluent had been diluted at least 324-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 April 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 April 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 April 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 was demonstrated by the absence of floating wastewater materials, oil, grease, or discoloration of the sea surface during the April 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 result from 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 10,427 CTD measurements collected during the April 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 remain after the screening process has been concluded 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[15]	*Parameter*
Location	1. Was the measurement collected beyond the 15.2-m ZID boundary where modeling assumes that initial dilution is complete?	*1,340*	*9,087*	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?	*9,050*	*37*	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?	*37*	*0*	Temperature
		37	*0*	Transmissivity
		37	*0*	DO
		37	*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.

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 April 2014 dataset eliminated 1,340 of the original 10,427 receiving-water observations from further consideration because they were collected within the ZID (Table 7, Question 1). The remaining 9,087 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

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

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 definitive 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 were measured during the tow surveys and were largely restricted to a localized area within the ZID boundary. Six additional mid-depth measurements collected at Station RW4 also had detectable reductions in salinity that unequivocally identified the presence of dilute wastewater constituents within the ZID. In contrast, only 37 measurements beyond the ZID had dilutions less than 550:1 (Table 7). These were located within a small isolated region 26 m southwest of the diffuser structure (green shading beyond the ZID in Figure 10). The remaining 9,050 observations that were measured outside the ZID during the April 2014 survey did not have salinity reductions that were greater than the 0.062‰ detection level.

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 95^{th} percentiles determined from the April 2014 ambient seawater data, to establish time-specific natural-variability thresholds in a manner analogous to COP Appendix VI. The percentiles were determined from April 2014 vertical profile data at Stations RW1, RW2, and RW6, thereby excluding measurements potentially affected by the discharge.

Temperature, transmissivity, pH, and DO concentrations associated with the 37 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 April 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.

Table 8. Compliance Thresholds

Water Quality Property	95% Confidence Bound[16]	95th Percentile[17,18]	Natural Variability Threshold[19]	COP Allowance[20]	Basin Plan Limit[21]	Extremum[22]
Temperature (ºC)	0.82	11.91	>12.73	—	—	≤11.98
Transmissivity (%)	-10.2	84.8	<74.6	—	—	≥82.8
DO (mg/L)	-1.38	4.48	<3.10	<2.79	<5.00	≥4.43
pH (minimum)	-0.094	7.859	<7.765	<7.565	<7.000	≥7.847
pH (maximum)	0.094	7.970	>8.064	>8.264	>8.300	≤7.980

During periods when the water column is stratified, as it was during the April 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 April 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 April 2014 survey.

[16] 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.

[17] 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*."

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

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

[20] 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.*"

[21] 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.

[22] Maximum or minimum value measured during this 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 12.73°C in Table 8). However, none of the 10,427 CTD measurements collected during the April 2014 survey exceeded 11.98°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 April 2014 survey were below the 74.6% 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 April 2014 survey only applied to measurements recorded above 12 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 54 transmissivity measurements collected below the euphotic zone to drop below the numeric compliance threshold, it would not have been of regulatory concern because they would not have materially impacted the penetration of ambient light.

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

Insignificant Wastewater Particulate Loads: Another independent line of evidence demonstrates that the discharge of wastewater particulates could not have contributed materially to turbidity within the dilute effluent plume. The suspended-solids concentration measured onshore, within the effluent, prior to discharge from the WWTP on 9 April 2014 was 24 mg/L. After dilution by 269-fold, the effluent suspended-solids concentration would have the reduced ambient transmissivity by only 0.7%. This small potential decrease in transmissivity would also have been counteracted by the 2% increase caused by the entrainment and upward displacement of relatively clear ambient seawater at mid-depth (Figure 9d).

Similarly, the MBCSD discharge could not have contributed materially to the observed DO fluctuations. The MBCSD treatment process routinely removes 80% or more of the organic material, as demonstrated by the low, 32-mg/L BOD measured within the plant's effluent two days after 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 7.565 during the April 2014 survey (fourth column of Table 8). This value is well below the lowest pH measurement of 7.847 recorded during the April 2014 survey (last column of Table 8). Similarly, the lowest DO concentration measured during the survey (4.43 mg/L) was well above both the lower range in natural variation (3.10 mg/L) and the 10% compliance threshold promulgated by the COP (2.79 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 April 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 10,427 temperature, DO, pH, and transmissivity observations exceeded the thresholds of natural variability specified in Table 8.

Non-Discharge-Related Excursions beyond the 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).

While all 10,427 pH values measured during the April 2014 survey remained well within the Basin Plan's acceptable range, the same was not true for the DO measurements. Although all of the observed DO concentrations were within the ambient range measured at the time of the survey, and therefore complied with the COP portion of the permit provision, 266 observations fell below the 5 mg/L Basin-Plan threshold.

These low DO concentrations arose because the deep watermass that was transported shoreward and into the survey area by upwelling was naturally depleted in oxygen. Accordingly, all of the DO concentrations measured below a depth of 12.5 m were below the 5-mg/L Basin Plan threshold (dark blue lines in Figure 6). Where the rising plume carried these naturally low DO concentrations upward, sub-5-mg/L concentrations were also observed, even in the upper water column in localized areas within the ZID (Figures 7cd, 8e, and 9e). DO concentrations in ambient seawater that range below 5 mg/L have also been observed in a number of past water-quality surveys in conjunction with upwelling events (MRS 2011, 2012, 2013, and 2014). In those cases, as well as in the April 2014 survey, 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.

Instead, the application of Basin Plan limits to coastal seawaters is flawed. Because the lower DO concentrations observed in this and prior surveys were naturally occurring and, as described above, because the amount of oxygen-demanding material in the effluent was too small to have caused a material reduction in ambient DO, the low DO concentrations are not of compliance interest even though they were below the Basin Plan threshold. Regardless, DO depletion from the discharge of municipal effluent is generally "*not of ecological concern in the ocean or open coastal waters*," and when it is of concern, such as within estuaries, it is *"more likely to result from eutrophication by nutrients rather than point source inputs of BOD*" (Page 9 of National Academy of Sciences 1993).

This conclusion is further supported by published range-acceptability criteria that are used to assess the validity of CTD data in this and other monitoring programs. These criteria identify DO and pH values ranging well outside of the Basin Plan limits as typical of ambient seawater in this region.[23] 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 also inappropriate. For these reasons, the Basin Plan limits have been recommended for removal from compliance evaluations in future MBCSD discharge permits (MRS 2011, 2012, 2013, and 2014).

CONCLUSIONS

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

Shortly after discharge, and well before the initial dilution process was complete, the effluent was achieving dilution levels in excess of 269-fold, which substantially exceeds the critical dilution levels predicted by design modeling. The submerged discharge plume achieved even higher dilution levels, exceeding 324-fold, as it continued to spread within the ZID. As it rose through the water column and approached the sea surface, near the completion of the initial mixing process, levels exceeded 393-fold. Beyond the ZID, and after initial mixing was complete, the wastewater had been diluted at least 443-fold. All of these measured dilution levels far exceeded levels that were predicted by modeling and that were incorporated in the discharge permit as limits on contaminant concentrations within effluent prior to discharge. Lastly, all of the auxiliary observations collected during the April 2014 survey demonstrated that the discharge complied with the narrative receiving-water limits in the discharge permit and the COP.

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

Together, these observations demonstrate that the treatment process, diffuser structure, and the outfall continue to surpass design expectations at the time of the April 2014 survey.

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