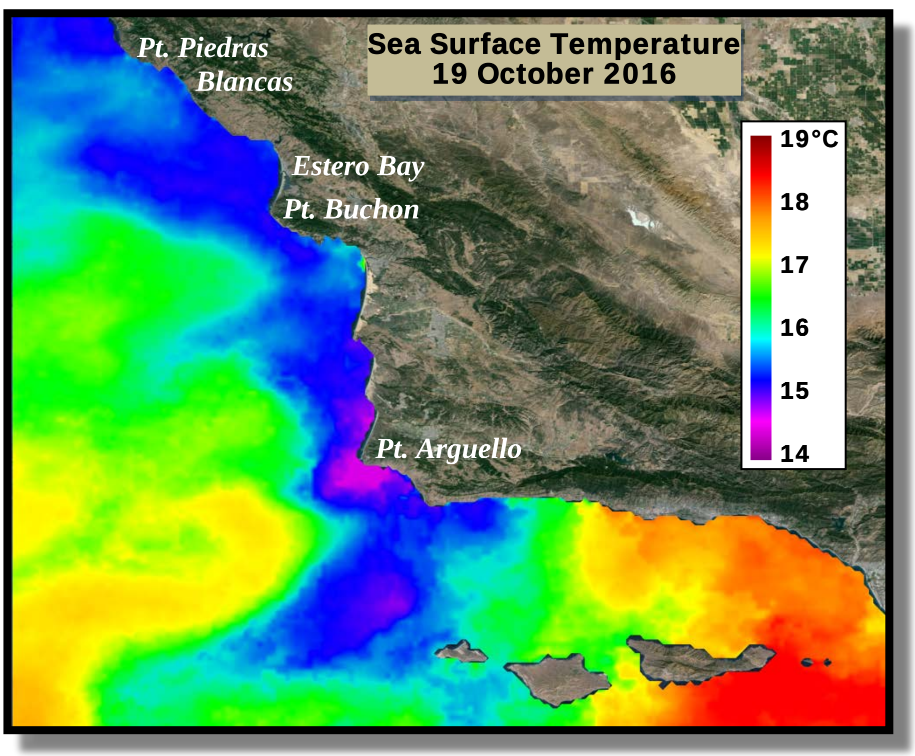
City of Morro Bay and
Cayucos Sanitary District

OFFSHORE MONITORING AND REPORTING PROGRAM

FOURTH QUARTER RECEIVING–WATER SURVEY

OCTOBER 2016



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Report to the

City of Morro Bay and Cayucos Sanitary District

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OCTOBER 2016

Prepared by

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John Gunderlock
Wastewater Treatment Plant Supervisor
City of Morro Bay
955 Shasta Avenue
Morro Bay, CA 93442

18 December 2016

Reference: Fourth Quarter Receiving-Water Survey Report – October 2016

Dear Mr. Gunderlock:

The attached report presents results from a quarterly receiving-water survey conducted on Monday, 24 October 2016. 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 within receiving waters. Quantitative analyses of continuous instrumental measurements and qualitative visual observations confirmed 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 northeast of the discharge point. Dilution within the plume exceeded expectations based on modeling and outfall design criteria.

Contact the undersigned if you have questions regarding the attached report.

Sincerely,

Douglas A. Coats

Douglas A. Coats
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.

Mr. John Gunderlock
Wastewater &Collection Systems Supervisor
City of Morro Bay

Date 12/19/16

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INTRODUCTION

The City of Morro Bay and the Cayucos Sanitary District (MBCSD) jointly own the wastewater treatment plant (WWTP) operated by the City of Morro Bay. In March 1985, Region IX of the U.S. Environmental Protection Agency (USEPA) and the Central Coast California Regional Water Quality Control Board (RWQCB) issued the first National Pollutant Discharge Elimination System (NPDES) permit to the MBCSD. The permit incorporated partially modified secondary treatment requirements for the plant's ocean discharge. The permit has been re-issued three times, in March 1993 (RWQCB-USEPA 1993ab), December 1998 (RWQCB-USEPA 1998ab), and January 2009 (RWQCB-USEPA 2009). The October 2016 field survey described in this report was the thirty-second 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 24 October 2016. Specifically, this fourth-quarter survey captured ambient oceanographic conditions along the central California coast during the fall season. The survey's measurements were used to assess the discharge's compliance with the objectives of the California Ocean Plan (COP) and the Central Coast Basin Plan (RWQCB 1994) as promulgated by the receiving-water limitations specified in the NPDES discharge permit.

The monitoring objectives were achieved by empirically evaluating tabulations of instrumental measurements and standard field observations. In addition to the traditional, vertical water-column profiles, instrumental measurements were used to generate horizontal maps from high-resolution data gathered by towing a CTD[1] instrument package repeatedly over the diffuser structure. This allowed for a more precise delineation of the plume's lateral extent.

SURVEY SETTING

The MBCSD treatment plant is located within the City of Morro Bay, which is situated along the central coast of California halfway between Los Angeles and San Francisco. Effluent is carried from the onshore treatment plant through a 1,450-m long outfall pipe, which terminates at a diffuser structure on the seafloor 827 m from the shoreline within Estero Bay (Figure 1). The diffuser structure extends an additional 52 m toward the northwest from the outfall terminus and consists of 34 ports that are hydraulically designed to create a turbulent ejection jet that rapidly mixes effluent with receiving seawater upon discharge. Currently, six of the diffuser ports are 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 ascends 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 direct 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 single isolated 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 (compare the last two columns of Table 1).

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 no more than 2 m, and often with sub-meter accuracy.

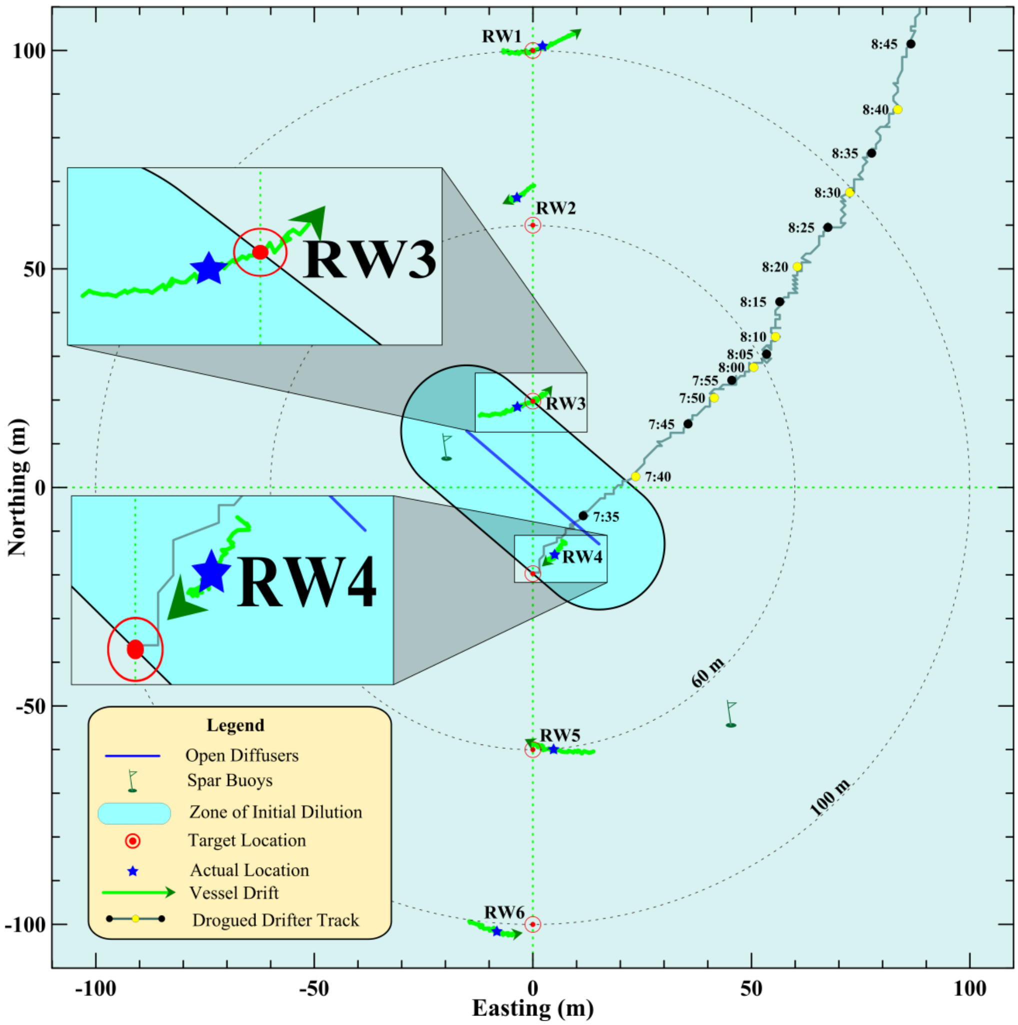

Figure 2. Station Locations

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 new 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 intercomparison, 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 downcasts during the October 2016 survey were conducted progressing from north to south, beginning with Station RW1. The magnitude of the drift at each of the six stations during the October 2016 survey is apparent from the length of the green tracklines in Figure 2. The tracklines trace the horizontal movement of the CTD as it was lowered to the seafloor at each station. Their lengths and offsets from the target locations reflect the overall station-keeping ability during the October 2016 survey.

The time it took the CTD to traverse the water column to the seafloor, which averaged 1 min 20 s, was consistent among stations, while the lateral distance traversed by the instrument package varied considerably among the stations, as did the direction of the drift (Figure 2). The lateral distance traversed by the instrument package during the downcasts ranged from less than 6 m at Stations RW2 and RW4 to over 16 m at Stations RW1 and RW3. The lateral movement of the CTD movement at any given time is typically determined by the complex interplay between the external influences of winds and currents, and the vessel's residual momentum immediately prior to each downcast. The extended drift toward the northeast at Stations RW1 and RW3 resulted from the combined effects of residual momentum as the vessel approached the station from the southwest, and northeastward current flow delineated by the drogued-drifter trajectory.[5] In contrast, the influence of northeastward current transport was partially countered by vessel momentum as it approached Stations RW2 and RW4 from the northeast. The influence of offshore prevailing winds on vessel transport during the downcasts was probably negligible because they were uniformly light throughout the survey.[6]

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

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[4] Meteorological and oceanographic conditions include winds, waves, tides, and currents.
[5] Refer to the partial drogued drifter track shown in Figure 2 and the full track in Figure 3 later in this report.
[6] Refer to Table 4 later in this report.

During the October 2016 survey, only the deeper portion[7] of the data collected at Station RW3 was subject to a compliance assessment because the downcast began inside the ZID and traversed the ZID boundary as it approached the seafloor during its transport toward the northeast.[8] Thus, only the data recorded within 2 m of the seafloor at Station RW3 were subject to the compliance analysis. This was the case even though the average location of the CTD data (blue star in the upper-left inset in Figure 2) was only 3.7 m from the target location (red target symbol in the inset). Similarly, none of the data collected at Station RW4 was subject to a compliance assessment because CTD remained within ZID throughout the downcast (lower left inset in Figure 2).

Compliance assessments notwithstanding, measurements acquired within the ZID lend valuable insight into the outfall's effectiveness at dispersing wastewater. For example, low dilution rates and concentrated effluent throughout the ZID would indicate potentially damaged or broken diffuser ports. Analysis of the outfall's operation over the past two and a half decades, however, demonstrates that it has maintained a high level of effectiveness in effluent dispersal. In fact, without the occasional measurements recorded 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 among hydrocasts near the ZID boundary, however. For example, prior to 1999 and before the advent of DGPS, CTD locations could not be determined with sufficient accuracy to establish whether the average station position was located within the ZID, much less how the CTD was moving laterally during the hydrocast. Because of these navigational limitations, sampling was presumed to occur at a single, imprecisely determined, horizontal location. Federal and state reporting of monitoring data still mandates identification of a single position for all of the CTD data collected at a particular station. Thus, for regulatory reporting, and for consistency with past surveys, the October 2016 survey also identifies a single sampling location for each station. These average station positions are identified by the blue stars in Figure 2, and are listed in Table 2 along with their distances from the diffuser structure.

Table 2. Average Position of Vertical Profiles during the October 2016 Survey

	Time (PDT)				Closest Approach	
Station	**Downcast**	**Upcast**	**Latitude**	**Longitude**	**Range[9] (m)**	**Bearing[10] (ºT)**
RW1	9:15:47	9:17:18	35° 23.254' N	120° 52.503' W	89.9	11
RW2	9:20:10	9:21:24	35° 23.235' N	120° 52.506' W	54.7	12
RW3	9:24:40	9:25:59	35° 23.209' N	120° 52.506' W	**11.8**[11]	41
RW4	9:28:13	9:29:37	35° 23.191' N	120° 52.501' W	**8.3**[12]	210
RW5	9:33:14	9:34:31	35° 23.167' N	120° 52.501' W	48.0	192
RW6	9:36:51	9:38:05	35° 23.144' N	120° 52.509' W	91.6	195

7 Below 14 m
8 Refer to the upper left inset in Figure 2.
9 Distance from the closest open diffuser port to the average profile location
10 Angle measured clockwise relative to true north from the closest diffuser port to the average profile location
11 Some of the CTD measurements were located within the ZID boundary (refer to the upper left inset in Figure 2).
12 All of the CTD measurements were located within the ZID boundary (refer to lower left inset in Figure 2).

OCEANOGRAPHIC PROCESSES

The trajectory of a satellite-tracked drogued drifter measured oceanic flow throughout the October 2016 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, oceanic flow rather than surface wind dictates the drifter's trajectory, which provides a good indication of the plume's movement after discharge, except when the flow field exhibits strong vertical shear.

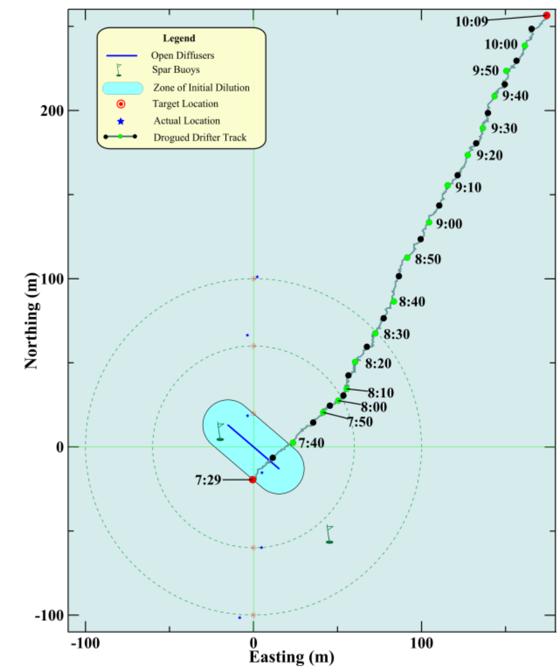

Figure 3. Drogued Drifter Trajectory

During the October 2016 survey, the drifter was deployed near the diffuser structure at 7:29 AM, and was recovered at 10:09 AM at a location 327 m northeast (32ºT[13]) of its original release point (red dots in Figure 3). The nearly linear drifter track demonstrated that mid-depth oceanic current direction was comparatively consistent throughout the survey.

Variation in the drifter's speed, however, exhibited some slight variability. This is apparent from the changes in spacing among the green and black dots in Figure 3, which show the drifter's progress at five- and ten-minute intervals. For 20 minutes after its initial release, the drifter moved rapidly away from the diffuser structure, until around 7:50 AM when it slowed considerably for 30 minutes. After a slight change in direction, the flow velocity remained uniform for the balance of the drifter deployment. On average, the drifter moved at speed of 3.4 cm/s.[14] At that transport rate, effluent would have experienced a seven-and-a-half-minute residence time within the ZID.

The drifter trajectory accurately captured the transport direction of the effluent plume during the survey, as indicated by the northeasterly offset observed in the plume signature delineated during the tow surveys.[15] This consistency in directional offset, as well as the relatively unstratified character of the water column,[16] suggests that vertical shear in the flow field was minimal. Additionally, the slight reduction in flow speed around 8:00 AM may have been related to the change in tides that occurred around that time (Figure 4). Oceanic flow near the survey area can be influenced by a variety of oceanographic processes, including tidal forcing, and upwelling, and by remote processes, such as large-scale along-shore pressure gradients, or the passing of large eddies embedded within the California Current. At any given time, one or more of these processes may influence the observed flow field. For example, in the absence of other influences, the ebb tide that prevailed after 8:00 AM tends to induce a

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13 Direction measured clockwise relative to true (rather than magnetic) north
14 0.067 kt
15 Refer to Figures 9 and 10 later in this report.
16 As indicated by the vertically uniform seawater properties throughout most of the water column as shown in Figure 8 later in this report.

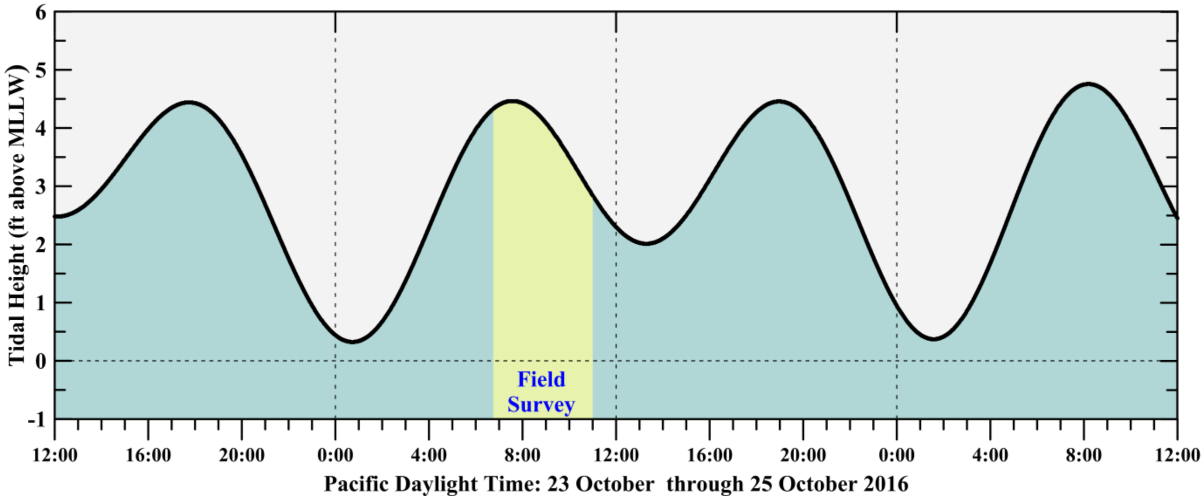

Figure 4. Tidal Level during the October 2016 Survey

weak southwestward (offshore) flow in the survey region. During a brief period after the slack tide, this tidal influence may have temporarily counteracted the strong northeasterly flow that dominated throughout the rest of the survey.

Normally along this section of coastline, currents within the survey area are largely determined by the prevailing wind field. Strong and steady northwesterly winds cause upwelling within the water column and produce a system of vertical countercurrents (Figure 5). In the upper water column, net wind-driven Ekman transport occurs at a 90º angle to the prevailing wind.[17] As a result, warm ocean waters within the surface mixed layer are driven offshore (southwestward) in response to the along-shore winds (toward the southeast). Near the coast, these warm surface waters are replaced by deep, cool, nutrient-rich waters that well up from below. The upwelled waters originate farther offshore and move shoreward (northeastward) along the seafloor as part of the upwelling process. Thus, upwelling establishes a vertical shear in the flow within the survey area.

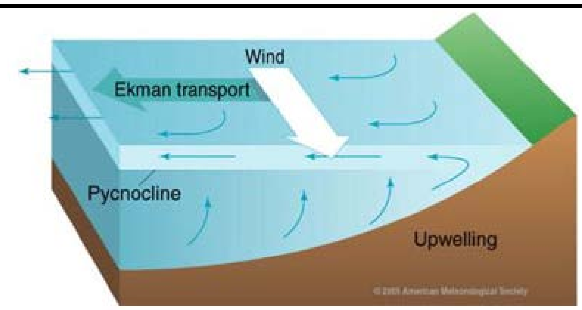

Figure 5. Schematic of Upwelling Processes

The onset of these 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 6. 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. The October 2016 survey was conducted well after the onset of this spring transition, and during a period when upwelling events had become weaker and less prevalent. The last yellow diamond in Figure 6 (refer to the inset) indicates that upwelling winds were weak at the time the survey. The survey was conducted during a rapid relaxation of upwelling forces following a mild wind event that peaked three days prior to the survey. Immediately following the survey, winds reversed direction and resulted in a comparatively rare downwelling event.

[17] http://oceanmotion.org/html/background/upwelling-and-downwelling.htm

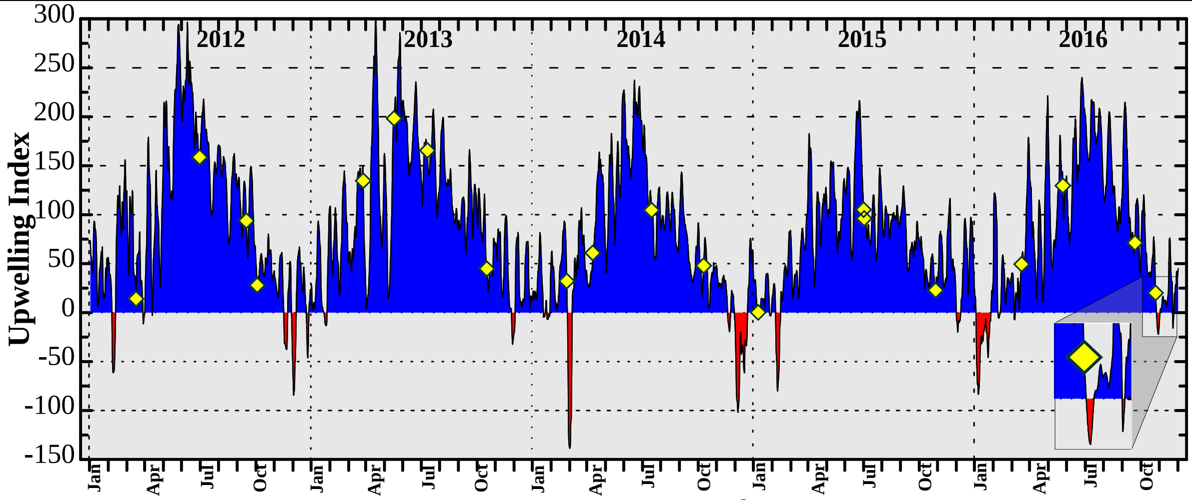

Figure 6. Five-Day Average Upwelling Index ($m^3/s/100$ m of coastline)

Some degree of upwelling is almost always present during offshore surveys (other yellow diamonds in Figure 6). Throughout most of the year, the nutrient-rich seawater 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 vertical counterflow associated with persistent upwelling conditions also enhances vertical stratification of the water column. The influx of cold dense water at depth produces a thermocline that is commonly maintained throughout summer and into early fall. During late fall and winter, upwelling is typically weak, and occasionally downwelling events, indicated by the negative (red shaded) indices in Figure 6, 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.

Although upwelling winds were negligible at the time of the October 2016 survey, winds during the week prior to the survey were strong enough to produce a pattern of sea surface temperatures indicative of mild upwelling processes within the central-coast region. 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 five days prior to the survey. The presence of pools of cooler, upwelled water is visually apparent along the south-central coastline (dark -blue and magenta shading), although the 3°C contrast between these sea-surface temperatures and temperatures farther offshore (in green and yellow) indicates that the upwelling event was weaker than those of the spring and summer seasons, when the cross-shore temperature contrast is often double that observed during the 19 October upwelling event.

As described below, only weak stratification was present throughout most of the water column at the time of the October 2016 survey. The increased stratification observed within a thin 2-m layer immediately above the seafloor was probably an artifact of the prior week's mild upwelling event. Overall, however, the generally weak stratification indicates that strong upwelling-induced vertical counterflow was absent at the time of the October 2016 survey. Thus, the strong northeastward oceanic flow measured within northern Estero Bay during the survey was not dominated either tidal or upwelling forcing. Instead, it is likely that it was largely driven by other external oceanographic processes, such as large-scale along-shore pressure gradients, or the passing of a large eddy associated with the California Current.[18]

[18] Note the eddy-like feature delineated in yellow in the lower left portion of the cover image

METHODS

The 38 ft F/V *Bonnie Marietta*, owned and operated by Captain Mark Tognazzini of Morro Bay, served as the survey vessel on Monday, 24 October 2016. Douglas Coats of Marine Research Specialists (MRS) supervised scientific operations as Chief Scientist, and provided data-acquisition and navigational support during the survey. He also assisted with the deployment and recovery of the CTD and drifter, and collected meteorological measurements at each station. Crewmember William Skok managed deck operations and collected Secchi Depth measurements at each station.

Auxiliary Measurements

Auxiliary measurements and observations were collected at each of the six stations after completion of the vertical profiling phase of the survey. 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 effluent discharge. Other auxiliary measurements collected at each station included wind speeds and air temperatures measured with a handheld Holdpeak 866B Digital Thermo-Anemometer, and oceanic flow measurements made throughout the survey area using the aforementioned 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 material suspended 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, is limited to approximately twice the Secchi depth.

Instrumental Measurements

A Sea Bird Electronics SBE-19plusV2 Seacat CTD instrument package collected measurements of conductivity, temperature, light transmittance, dissolved oxygen (DO), pH, and pressure during the October 2016 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. The entire CTD was returned to the factory in January 2015 for full calibration and servicing. The transmissometer and DO probe were returned to the manufacturer in January 2016 for further servicing, repair, and calibration.

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)[19]	%	0 to 100	± 0.3	± 0.03
Oxygen (SBE 43)	% Saturation	0 to 120	± 2	—
pH (SBE 18)	pH	0 to 14	± 0.1	—

[19] 25-cm path length of red (650 nm) light

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 towing phase of the survey. Additionally, during the vertical-profiling phase, they quantified layering, or vertical stratification and stability of the water column, which determines the behavior and dynamics of the effluent as it mixes with seawater within and beyond 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 beginning the mid-depth tow survey at 7:44 AM, the CTD was deployed beneath the sea surface for a seven-minute equilibration period prior to positioning the vessel for the first transect. Prior to deployment, the CTD package had been configured for horizontal towing with forward-looking probes. The protective cage around the CTD was fitted with a horizontal stabilizer wing and a depth-suppression weight was added to the towline to achieve near constant-depth tows.

Eight transects of mid-depth data were collected at an average depth of 8.84 m and an average speed of 1.93 m/s over the span of 37 minutes (blue-green lines in Figure 7). Subsequently, at 8:24 AM, eight additional passes were made with the CTD at an average depth of 3.66 m (orange lines). During this 38-minute shallow tow, vessel speed averaged 1.67 m/s. At the observed towing speeds and the 4 Hz sampling rate, at least 2.1 CTD measurements were collected for each meter traversed. This complies with the NPDES discharge permit requirement for minimum horizontal resolution of at least one sample per meter during at least five passes around and across the ZID at two separate depths, one within the surface mixed layer and one at mid-depth within the thermocline.

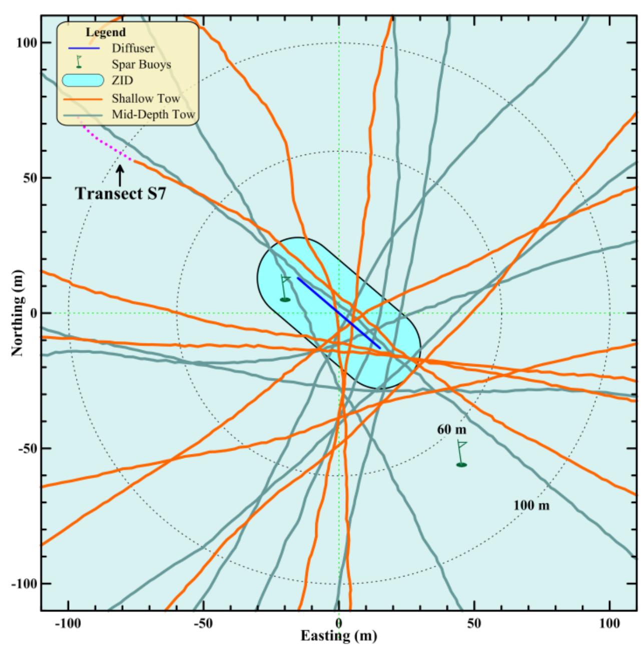

Figure 7. CTD Tracklines during the October 2016 Tow Surveys

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.[20]

At 9:04 AM, following completion of the last shallow transect, the CTD package was brought aboard the survey vessel and reconfigured for vertical profiling. The CTD was redeployed at 9:12 AM, and was held beneath the surface for four minutes as the vessel was repositioned over Station RW1. The CTD was then 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 ocean surface while transiting between adjacent stations.

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,[21] 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. Specifically, review of the tow data revealed that the CTD changed depth when the vessel executed a turn at the end of each transect. These vertical offsets in CTD depth are induced by changes in vessel speed and direction that are instituted to realign 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 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 particularly true whenever the water column is even slightly stratified, as was the case during the October 2016 survey.

However, the exclusion of portions of tow data did not adversely affect the compliance analysis. Only small portions of one transect (S7) exhibited depth offsets within the 100-m survey area (purple dotted line at the upper left of Figure 7). The remaining transects were long enough to fully encompass the 100-m survey area surrounding the diffuser structure. Specifically, the tow data that was included in the compliance analysis, shown by the solid orange and blue-green lines in Figure 7, met the permit monitoring requirement of at least five passes near the diffuser structure at each tow depth.

RESULTS

The fourth-quarter receiving-water survey was conducted on the morning of Monday, 24 October 2016. The receiving-water survey commenced at 7:30 AM with the deployment of the drogued drifter. Over the course of the ensuing two hours, offshore observations and measurements were collected as required by the NPDES monitoring program. The survey ended at 9:41 AM with the retrieval of the drogued drifter. Collection of required visual observations of the sea surface was generally unencumbered throughout the survey.

[20] Figures 9 and 10 later in this report

[21] 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.

Auxiliary Observations

On the morning of 24 October 2016, skies were overcast, with a sustained light offshore breeze out of the east-southeast. Auxiliary observations were collected beginning at 9:53 AM, after completion of the vertical profiling phase of the survey. During the subsequent 15 minutes, each station was re-occupied beginning with Station RW6, and sequentially progressing toward the north. During that time, wind speed and air temperature increased slightly as skies began to clear (Table 4). A swell out of the northwest had a significant wave height of two-to-three feet. Average air temperature (20.0°C) was much warmer than the 13.9°C sea surface temperature.

Table 4. Standard Meteorological and Oceanographic Observations

Station	Location[22] Latitude	Location[22] Longitude	Diffuser Distance (m)	Time (PDT)	Air (°C)	Cloud Cover (%)	Wind Avg (kt)	Wind Dir (from) (°T)	Swell Ht/Dir (ft/°T)	Secchi Depth (m)
RW1	35° 23.254' N	120° 52.501' W	91.5	10:08:27	20.6	70%	2.8	110	2-3 NW	5.0
RW2	35° 23.232' N	120° 52.505' W	49.4	10:06:04	20.5	70%	3.1	110	2-3 NW	5.3
RW3	35° 23.213' N	120° 52.510' W	14.3	10:03:11	20.5	70%	2.7	120	2-3 NW	4.5
RW4	35° 23.190' N	120° 52.503' W	10.7	10:01:13	19.9	70%	2.7	90	2-3 NW	5.0
RW5	35° 23.161' N	120° 52.508' W	60.6	9:58:20	19.6	80%	2.7	110	2-3 NW	5.5
RW6	35° 23.148' N	120° 52.508' W	83.7	9:53:45	19.1	90%	2.3	90	2-3 NW	5.0

Although there was no evidence of floating particulates, oil sheens, or any discoloration of the sea surface associated with wastewater constituents, biofilm particulates suspended within the upper water column were visually apparent during the Secchi depth measurement at Station RW3. Biofilm particulates are not present in wastewater prior to discharge at the treatment plant, but line the interior surface of the outfall pipe. At the higher effluent discharge rates during mid-morning hours, small pieces of biofilm occasionally detach from the outfall pipe and mix with the wastewater discharged offshore. These distinctive black and white particulates have been observed during some of the past water-quality surveys. They are, however, unrelated to the particulate loading within MBCSD effluent, and have little bearing on the transmittance of natural light.

There was no other visually perceptible indication of the presence of the plume within the upper water column near the ZID, such as an area where the coloration or turbidity of seawater differed from surrounding areas. Nevertheless, the slight reduction in Secchi depth (4.5 m) at Station RW3 compared to the average among other stations (5.2 m) suggests that a slightly increased turbidity associated with the effluent plume affected the measurement near the deepest extent of the Secchi measurement. However, because the plume remained submerged near the limit of visual discernment at that location, its visual presence was not otherwise noted during the survey. This hypothesis is supported by the plume-related decrease in turbidity measured at depths below 4 m during the CTD downcast at Station RW3 (light blue line in Figure 8c).

Overall, seawater clarity within the upper water column was high compared to upwelling periods when ambient light penetration is markedly reduced by an increased density of planktonic organisms. During upwelling, nutrients carried upward into the euphotic zone are assimilated by phytoplankton, whose

[22] Locations are the vessel positions at the time the Secchi depths were measured. These depart from the CTD profile locations listed in Table 2 because they were collected after completion of the CTD profiling.

populations increase and, along with their associated zooplanktonic herbivores; their elevated densities reduce the transmittance of ambient light. However, the maximum measured Secchi depth of 5.5 at Station RW5 indicates that an 11 m euphotic zone was present during the October 2016 survey (Table 4). While ambient light penetrated the upper two-thirds of the water column, it did not extend into the turbid layer of ambient seawater that was present immediately above the seafloor beneath a depth of 15 m.

Communication with plant personnel and subsequent review of effluent discharge properties on the day of the survey, confirmed that the treatment process was performing well at time of the survey. The 0.712 million gallons of effluent discharged on 24 October had a temperature of 22°C, a suspended-solids concentration of 69 mg/L, and a pH of 7.5. The 3.2 mg/L oil and grease concentration measured within effluent discharged on the day after the survey was below the method quantification threshold. The biochemical oxygen demand (BOD) within an effluent sample collected a week before the survey on 17 October was 76 mg/L.

Instrumental Observations

Data collected during vertical profiling were processed in accordance with standard procedures (SCCWRP 2002), and are collated at 0.5-m depth intervals in Table 5. Data collected during the October 2016 survey reflect weakly stratified conditions within Estero Bay indicative of a relaxation in coastal upwelling following a brief pulse of upwelling wind of limited strength (refer to the inset in Figure 6). As described previously, 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 inhibits the vertical exchange of nutrients and other water properties, traps the effluent plume at depth, and reduces the initial dilution of the effluent plume.

If the upwelling winds are only of moderate strength, occur only briefly, or have not occurred recently; vertical mixing slowly erodes the sharp contrast between the surface and deep watermasses, and stratification appears as a more gradual vertical change in seawater properties that can extend throughout the water column. That was not the case during the October 2016 survey when a sharply defined vertical transition zone immediately above the seafloor was produced by the pulse of upwelling winds that occurred a few days prior to the survey (Figure 8). Compared to the rest of the water column, large changes in seawater properties occurred over a small vertical extent below 15 m. They characterized a transition to a watermass with distinct seawater properties that originated deep offshore.

These sharp vertical changes reflected a transition from established coastal seawater properties to a colder, saltier, nutrient-rich but oxygen-poor watermass that migrated shoreward along the seafloor as part of the upwelling process. This offshore watermass moved shoreward to replace nearshore surface waters that were driven offshore by Ekman transport from the prevailing northwesterly winds (Figure 5). The seawater properties of this deep watermass originated within the northward-flowing Davidson undercurrent that carried more saline and less oxygenated waters out of the Southern California Bight and northward along the central California coast.

Table 5. Vertical Profile Data Collected on 24 October 2016

Depth (m)	Temperature (°C)						Salinity (‰)					
	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6
0.5	13.790	13.785	13.829	13.875	14.006	14.030	33.413	33.412	33.422	33.396	33.462	33.463
1.0	13.775	13.785	13.824	13.885	14.005	14.032	33.409	33.416	33.423	33.412	33.462	33.463
1.5	13.758	13.797	13.823	13.882	14.001	14.035	33.405	33.423	33.424	33.411	33.462	33.464
2.0	13.751	13.821	13.840	13.925	14.000	14.027	33.403	33.435	33.435	33.443	33.464	33.464
2.5	13.751	13.825	13.879	13.945	13.999	14.004	33.403	33.437	33.461	33.452	33.464	33.464
3.0	13.744	13.827	13.886	13.967	13.997	13.990	33.401	33.437	33.464	33.460	33.464	33.463
3.5	13.736	13.854	13.852	13.971	13.996	13.982	33.399	33.448	33.449	33.462	33.464	33.464
4.0	13.736	13.878	13.712	13.966	13.989	13.963	33.400	33.457	33.367	33.464	33.465	33.463
4.5	13.739	13.888	13.648	13.948	13.973	13.940	33.402	33.460	33.345	33.464	33.464	33.463
5.0	13.745	13.887	13.641	13.941	13.959	13.934	33.404	33.460	33.347	33.465	33.464	33.463
5.5	13.797	13.884	13.641	13.929	13.943	13.926	33.427	33.459	33.349	33.464	33.464	33.463
6.0	13.835	13.887	13.663	13.920	13.917	13.915	33.440	33.462	33.365	33.464	33.463	33.464
6.5	13.865	13.885	13.690	13.913	13.908	13.911	33.453	33.462	33.381	33.464	33.464	33.464
7.0	13.870	13.882	13.692	13.910	13.908	13.909	33.455	33.462	33.380	33.464	33.464	33.465
7.5	13.875	13.879	13.707	13.908	13.908	13.906	33.454	33.462	33.389	33.465	33.465	33.465
8.0	13.879	13.876	13.717	13.908	13.907	13.902	33.459	33.462	33.393	33.466	33.465	33.465
8.5	13.872	13.874	13.731	13.905	13.906	13.895	33.462	33.461	33.401	33.466	33.465	33.465
9.0	13.863	13.871	13.722	13.898	13.898	13.889	33.461	33.462	33.400	33.465	33.465	33.465
9.5	13.859	13.865	13.708	13.891	13.891	13.886	33.461	33.461	33.398	33.464	33.465	33.465
10.0	13.856	13.861	13.719	13.886	13.881	13.883	33.461	33.461	33.404	33.464	33.464	33.465
10.5	13.853	13.857	13.727	13.874	13.876	13.873	33.461	33.461	33.407	33.463	33.464	33.464
11.0	13.849	13.852	13.714	13.852	13.868	13.860	33.461	33.461	33.406	33.461	33.463	33.463
11.5	13.843	13.841	13.744	13.846	13.855	13.851	33.461	33.461	33.436	33.462	33.462	33.463
12.0	13.838	13.831	13.767	13.831	13.842	13.830	33.462	33.462	33.447	33.461	33.462	33.461
12.5	13.838	13.830	13.822	13.822	13.810	13.814	33.462	33.462	33.464	33.462	33.460	33.461
13.0	13.818	13.827	13.821	13.812	13.805	13.806	33.462	33.462	33.464	33.462	33.461	33.461
13.5	13.788	13.799	13.818	13.809	13.803	13.789	33.462	33.462	33.464	33.462	33.462	33.462
14.0	13.779	13.758	13.813	13.796	13.789	13.763	33.464	33.464	33.463	33.461	33.462	33.464
14.5	13.767	13.736	13.768	13.792	13.750	13.750	33.465	33.467	33.461	33.462	33.465	33.468
15.0	13.645	13.731	13.652	13.764	13.667	13.713	33.470	33.468	33.461	33.462	33.467	33.470
15.5	13.397	13.584	13.384	13.750	13.559	13.580	33.474	33.471	33.464	33.467	33.472	33.469
16.0	13.346	13.262	13.237	13.684	13.291	13.489	33.492	33.474	33.474	33.470	33.470	33.478
16.5			13.189	13.356	13.182	13.252			33.482	33.461	33.480	33.476
17.0						13.182						33.489

Table 5. Vertical Profile Data Collected on 24 October 2016 (continued)

Depth (m)	Density (σ_t)						pH					
	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6
0.5	25.004	25.007	25.005	24.984	24.997	24.993	7.940	7.937	7.943	7.944	7.963	7.965
1.0	25.004	25.007	25.005	24.984	24.997	24.993	7.939	7.937	7.942	7.943	7.963	7.963
1.5	25.004	25.010	25.006	24.984	24.998	24.993	7.936	7.937	7.942	7.944	7.963	7.965
2.0	25.005	25.015	25.011	24.999	25.000	24.995	7.933	7.938	7.944	7.946	7.962	7.964
2.5	25.004	25.015	25.023	25.002	25.001	24.999	7.934	7.943	7.947	7.951	7.962	7.964
3.0	25.005	25.015	25.024	25.004	25.001	25.002	7.933	7.944	7.950	7.953	7.963	7.963
3.5	25.005	25.018	25.020	25.005	25.001	25.004	7.932	7.943	7.948	7.955	7.962	7.963
4.0	25.005	25.020	24.985	25.008	25.003	25.007	7.932	7.946	7.931	7.955	7.963	7.962
4.5	25.006	25.021	24.981	25.011	25.006	25.012	7.931	7.951	7.920	7.954	7.962	7.960
5.0	25.007	25.020	24.984	25.013	25.009	25.013	7.933	7.953	7.917	7.953	7.957	7.958
5.5	25.013	25.020	24.986	25.015	25.012	25.015	7.935	7.952	7.916	7.954	7.958	7.956
6.0	25.016	25.022	24.993	25.017	25.017	25.018	7.940	7.952	7.919	7.952	7.955	7.956
6.5	25.020	25.022	25.000	25.018	25.019	25.019	7.943	7.953	7.922	7.953	7.952	7.954
7.0	25.020	25.023	24.999	25.019	25.020	25.020	7.948	7.953	7.922	7.952	7.954	7.954
7.5	25.019	25.024	25.003	25.020	25.020	25.021	7.950	7.953	7.924	7.951	7.952	7.952
8.0	25.022	25.024	25.004	25.021	25.020	25.022	7.951	7.952	7.924	7.949	7.952	7.951
8.5	25.025	25.024	25.007	25.021	25.020	25.023	7.952	7.953	7.927	7.948	7.952	7.952
9.0	25.026	25.025	25.008	25.022	25.022	25.024	7.952	7.952	7.929	7.948	7.951	7.950
9.5	25.027	25.026	25.009	25.023	25.024	25.025	7.953	7.952	7.928	7.949	7.950	7.949
10.0	25.028	25.027	25.012	25.024	25.025	25.025	7.954	7.953	7.928	7.950	7.951	7.952
10.5	25.028	25.028	25.012	25.026	25.026	25.026	7.952	7.952	7.929	7.949	7.951	7.951
11.0	25.029	25.029	25.015	25.029	25.027	25.028	7.953	7.952	7.928	7.949	7.951	7.952
11.5	25.031	25.031	25.031	25.030	25.029	25.030	7.953	7.952	7.933	7.951	7.952	7.951
12.0	25.032	25.033	25.035	25.033	25.031	25.033	7.953	7.952	7.937	7.951	7.953	7.952
12.5	25.032	25.034	25.037	25.035	25.036	25.036	7.952	7.950	7.945	7.950	7.951	7.952
13.0	25.036	25.035	25.037	25.037	25.038	25.038	7.953	7.951	7.948	7.951	7.952	7.953
13.5	25.043	25.041	25.038	25.038	25.039	25.042	7.950	7.951	7.949	7.951	7.950	7.954
14.0	25.046	25.050	25.039	25.040	25.042	25.049	7.949	7.948	7.948	7.950	7.951	7.950
14.5	25.049	25.057	25.046	25.042	25.053	25.055	7.946	7.943	7.948	7.950	7.949	7.944
15.0	25.078	25.059	25.070	25.048	25.071	25.064	7.941	7.941	7.940	7.949	7.939	7.941
15.5	25.131	25.091	25.126	25.054	25.097	25.091	7.920	7.936	7.912	7.948	7.929	7.933
16.0	25.159	25.159	25.164	25.070	25.150	25.116	7.913	7.914	7.887	7.942	7.917	7.926
16.5			25.180	25.130	25.180	25.162			7.858	7.923	7.885	7.904
17.0						25.186						7.882

Table 5. Vertical Profile Data Collected on 24 October 2016 (continued)

Depth (m)	Dissolved Oxygen (mg/L)						Transmissivity (%)					
	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6
0.5	7.602	7.637	7.724	7.761	8.020	8.054	81.634	82.247	82.778	82.137	82.862	83.515
1.0	7.582	7.666	7.688	7.781	8.037	8.055	81.526	82.039	82.515	82.126	83.082	83.682
1.5	7.558	7.717	7.728	7.859	8.024	8.063	80.872	81.984	82.360	82.261	83.026	84.113
2.0	7.559	7.696	7.800	7.910	8.027	8.036	80.894	82.384	83.157	82.392	83.121	84.149
2.5	7.549	7.731	7.800	7.948	8.010	8.011	80.757	83.063	83.400	82.841	82.552	83.276
3.0	7.539	7.774	7.589	7.941	8.016	7.995	80.712	83.316	83.697	82.793	82.127	82.721
3.5	7.539	7.812	7.363	7.920	8.000	7.946	81.113	83.379	83.844	83.170	82.079	83.039
4.0	7.539	7.792	7.351	7.893	7.969	7.889	81.271	83.858	80.436	82.923	82.142	83.201
4.5	7.557	7.783	7.360	7.878	7.937	7.877	80.995	84.238	78.238	83.135	82.354	83.120
5.0	7.669	7.796	7.386	7.867	7.885	7.851	81.287	84.303	77.986	83.499	83.485	83.587
5.5	7.716	7.805	7.438	7.847	7.841	7.837	82.357	84.172	78.230	83.552	83.519	83.815
6.0	7.763	7.796	7.452	7.845	7.835	7.840	82.853	84.190	78.978	83.629	83.295	83.805
6.5	7.760	7.789	7.464	7.827	7.823	7.805	83.154	84.645	79.319	83.662	83.816	83.823
7.0	7.760	7.785	7.499	7.791	7.838	7.781	83.857	84.346	78.840	83.939	84.308	83.737
7.5	7.772	7.781	7.520	7.803	7.829	7.782	83.812	84.618	79.957	83.817	83.749	83.924
8.0	7.775	7.789	7.531	7.788	7.824	7.778	83.836	84.659	80.363	83.820	83.883	84.495
8.5	7.773	7.783	7.508	7.802	7.795	7.798	85.291	84.897	81.119	83.691	84.135	84.495
9.0	7.778	7.786	7.489	7.792	7.801	7.798	85.293	84.701	81.484	83.793	83.854	84.459
9.5	7.778	7.792	7.523	7.790	7.793	7.801	85.485	84.821	81.332	83.976	84.186	84.209
10.0	7.775	7.791	7.503	7.768	7.792	7.795	85.569	84.857	81.149	84.073	84.676	84.111
10.5	7.776	7.765	7.528	7.772	7.793	7.787	85.458	84.981	81.481	84.152	84.830	84.266
11.0	7.776	7.762	7.619	7.773	7.795	7.785	85.217	84.994	81.468	84.470	85.242	84.290
11.5	7.777	7.762	7.666	7.766	7.758	7.761	85.424	84.956	83.325	84.507	85.267	84.185
12.0	7.773	7.759	7.747	7.752	7.714	7.743	86.113	85.427	85.504	85.418	85.601	84.934
12.5	7.718	7.746	7.748	7.714	7.713	7.714	86.241	86.165	85.917	86.112	86.659	85.514
13.0	7.645	7.628	7.735	7.699	7.704	7.656	87.525	86.389	86.975	87.341	87.862	86.825
13.5	7.644	7.589	7.712	7.689	7.657	7.606	88.997	87.243	87.799	87.561	88.234	88.025
14.0	7.629	7.586	7.569	7.679	7.471	7.561	89.952	88.834	88.252	87.911	88.496	89.191
14.5	7.309	7.588	7.292	7.616	7.373	7.353	90.138	89.371	88.451	88.276	89.136	88.643
15.0	6.874	7.165	6.770	7.594	7.074	7.163	88.709	88.563	87.169	89.054	87.523	87.152
15.5	7.053	6.666	6.671	7.385	6.628	6.885	81.325	87.847	82.078	89.605	83.688	82.975
16.0	6.843	7.217	6.875	7.077	6.619	6.597	79.849	84.524	73.493	89.392	75.637	79.536
16.5			7.530	7.477	6.776	6.687			65.445	84.069	65.286	72.915
17.0						6.810						71.498

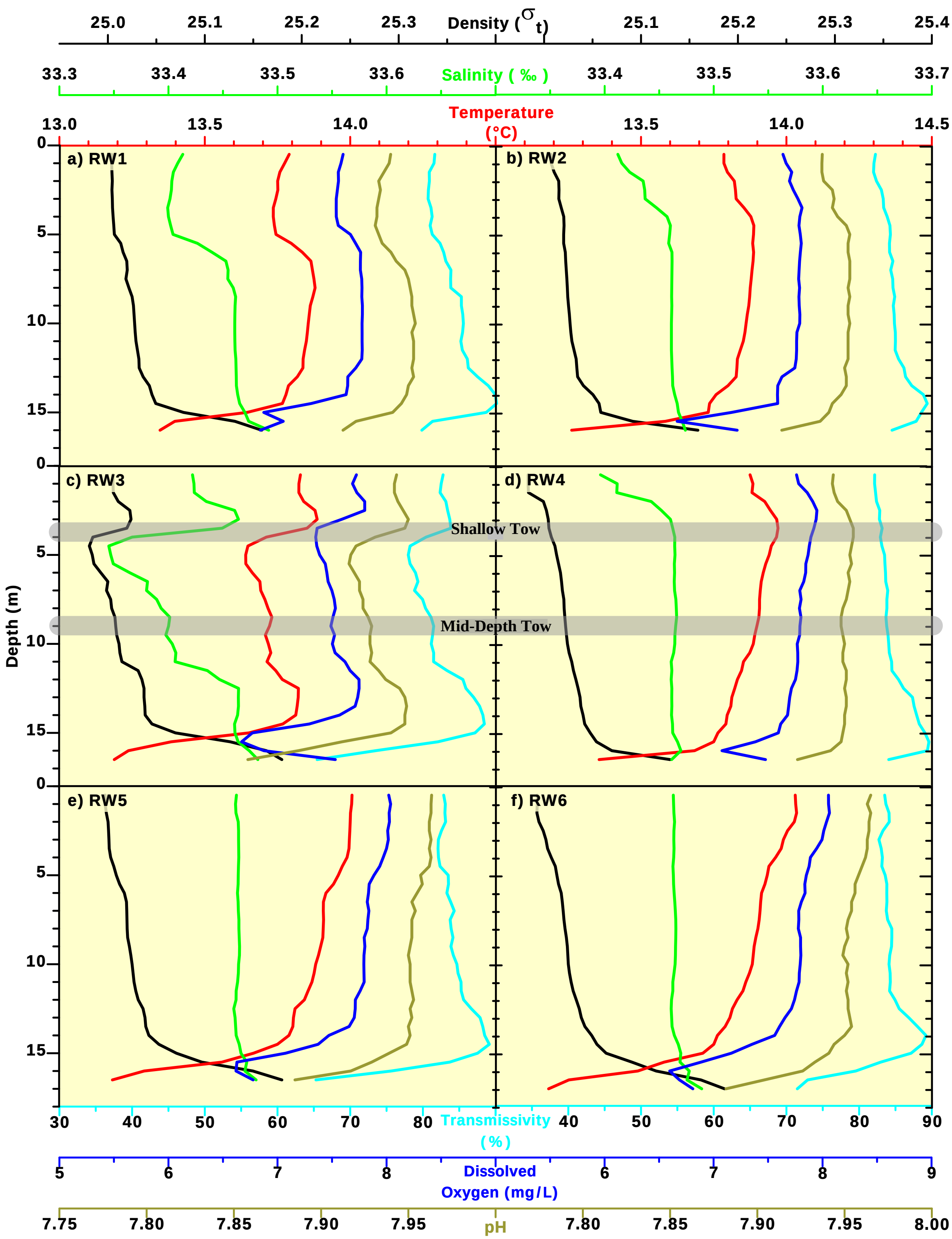

Figure 8. Vertical Profiles of Water-Quality Parameters

This regional upwelling event produced predicable changes in seawater properties within the vertical transition zone; namely, seawater properties exhibited steadily increasing or decreasing values with depth that were determined by well-established physicochemical processes within ocean waters (Figure 8). In particular, temperature (red lines), DO (dark blue lines), pH (olive-colored lines) steadily decreased with increasing depth below 15 m. These decreases were mirrored by a halocline and pycnocline, where salinity (green lines) and density (black lines) steadily increased with depth. Because the deep offshore watermass that was transported shoreward 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 reduction in pH (olive-colored lines).

Meanwhile, ongoing primary productivity within the euphotic zone produced oxygen, consumed carbon dioxide (increasing pH), and slightly decreased water clarity (light blue lines). In the absence of increased phytoplankton density, transmissivity increased to levels approaching pure seawater (90%) beneath the 11-m deep euphotic zone. This formed a localized maximum in water clarity near a depth of 14 m (and resulted in the different shape of the light blue lines at most stations). Beneath this localized maximum in transmissivity, water clarity sharply declined within the deep watermass due to naturally occurring resuspension processes associated with boundary layer flow along the seafloor. During upwelling, the shoreward transport of offshore waters along the seafloor occasionally generates increased turbulence and shear within a benthic nepheloid layer (BNL). These thin, transient, particle-rich layers form when lightweight flocs of detritus are resuspended by the turbulence generated from bottom currents. BNLs are a widespread phenomenon on continental shelves (Kuehl et al. 1996) and have been regularly documented in past surveys conducted within Estero Bay.

In addition to the aforementioned influence of natural processes on the vertical trends at depth in Figure 8, the downcasts at Stations RW1 through RW4 (Figure 8abcd) encountered the effluent plume within the upper water column. Against the backdrop of relatively uniform ambient seawater conditions measured at the two southernmost stations (RW5 and RW6 in Figure 8ef), localized decreases in all six of the seawater properties clearly delineate the buoyant effluent plume as it approached and impinged on the sea surface.

Salinity reductions (light green lines) were the most diagnostic of the presence of dilute effluent constituents. Slight salinity reductions extending from the sea surface to a depth of at least 3 m were apparent at all four northernmost stations. The vertical extent of the plume signature at Station RW1 was somewhat greater and reached 8 m (Figure 8a). Additionally, the amplitude of the subsurface salinity reduction at Station RW3, immediately north of the discharge, was twice as large as at the other stations, and spanned a depth range from 3.5 to 12.5 m (Figure 8c). The low density associated with this salinity anomaly (black line in Figure 8c) demonstrates that the plume was buoyant throughout this subsurface depth range. As a result, it would be expected to continue to rise within the water column and further mix with ambient seawater before reaching the sea surface. The final stage of the initial mixing process was captured by the near surface measurements at Stations RW1 through RW4 as the plume spread laterally at the sea surface.

In contrast to the reductions in salinity and density, which resulted from the presence of dilute effluent constituents, the co-occurring reductions in the other four seawater properties were caused by the upward transport of ambient seawater within the deep watermass that was entrained shortly after discharge. This cold turbid seawater with reduced DO and pH was present near the seafloor and was mixed rapidly with effluent shortly after discharge. It is important to distinguish plume signatures that are caused by the presence of effluent constituents, exemplified by marked reductions in salinity and density, from those caused by the upward transport of ambient seawater, embodied by the lateral anomalies in all the other seawater properties associated with the plume within the upper water column.

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 the plume's ascent 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. During the October 2016 survey, these deep seawater properties became apparent as a signature of the buoyant effluent plume when they were 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 the shallow and deep ambient seawater properties.

The legacies of entrainment anomalies can be particularly long-lived, remaining apparent within the water column well after completion of the initial dilution process. As such, these anomalies provide useful tracers of the diffuse effluent plume during and after the 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 by a simple relocation of ambient seawater.

In addition to the vertical hydrocasts, the tow surveys also captured the signature of the plume as it rose within the mid and upper water column, and was transported toward the northeast (Figures 9 and 10). Both tow surveys delineated the plume signature with localized reductions in all six seawater properties that began immediately northeast of the diffuser structure and extended in a direction along the trajectory of the drogued drifter (Figure 3).

Outfall Performance

The efficacy of the outfall can be evaluated through a comparison of dilution levels measured at the time of the October 2016 survey, and dilutions anticipated from modeling studies that were codified in the discharge permit through limits imposed on effluent constituents. Specifically, the critical initial dilution applicable to the MBCSD outfall was conservatively estimated to be 133:1 (Tetra Tech 1992). That is, dispersion modeling estimated that, at the conclusion of the minimum expected initial mixing, 133 parts of ambient seawater would have mixed with each part of wastewater.

The 133:1 dilution estimate was based on worst-case modeling under highly stratified conditions, where trapping of the plume below a strong thermocline would curtail the additional buoyant mixing normally experienced during the plume's ascent through the entire 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 ascend further in the water column. At that point, the plume would spread laterally with dilution occurring at a much-reduced rate. A 9-m ascent at the MBCSD outfall translates into a trapping depth that is 6.4 m below the sea surface. As described below, however, the dilution levels observed during the October 2016 survey were much higher than the 133:1 predicted by the modeling, even though they were measured within the ZID and prior to the completion of the initial dilution process.

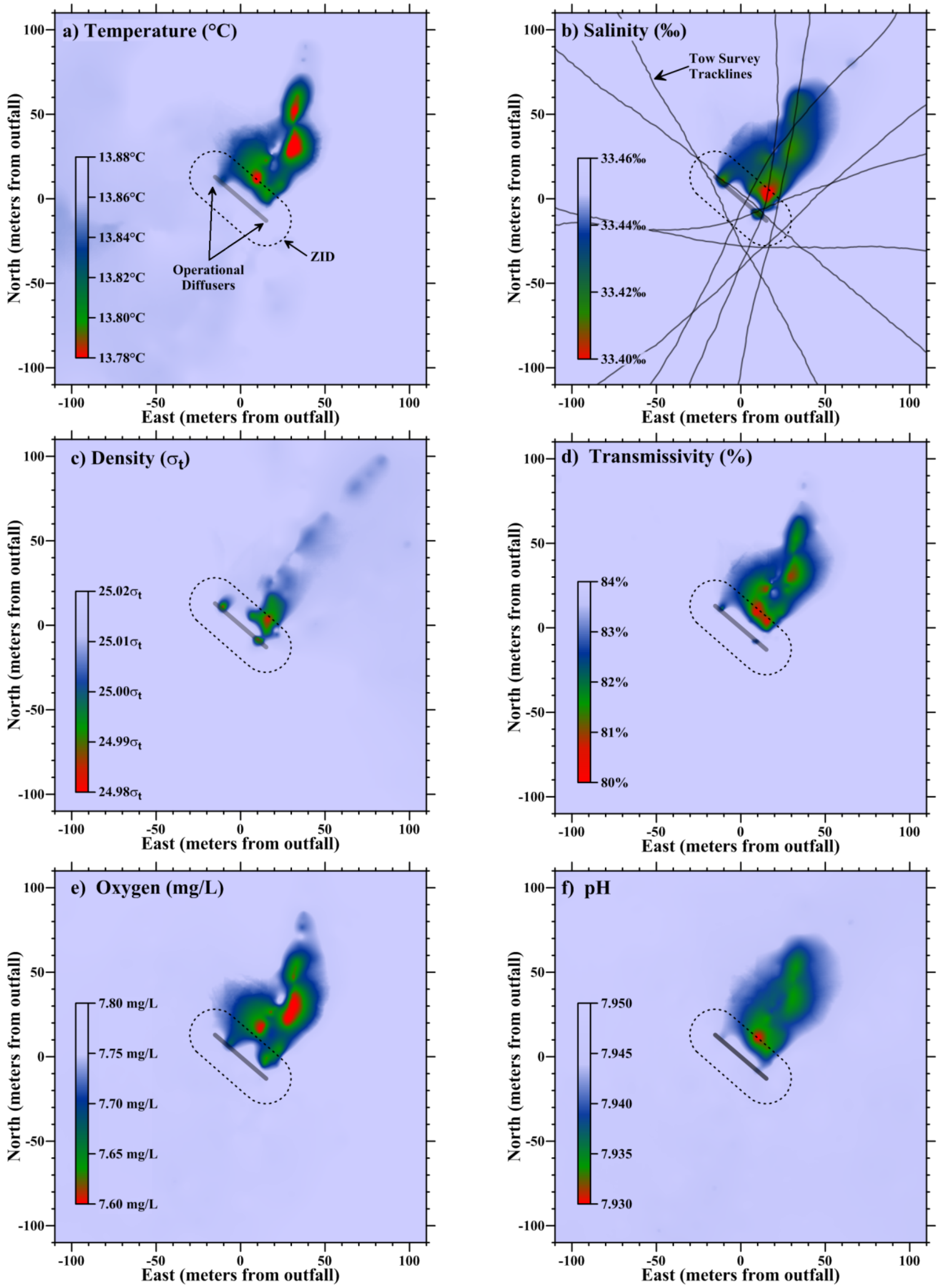

Figure 9. Horizontal Distribution of Mid-Depth Water-Quality Parameters 8.8 m below the Sea Surface

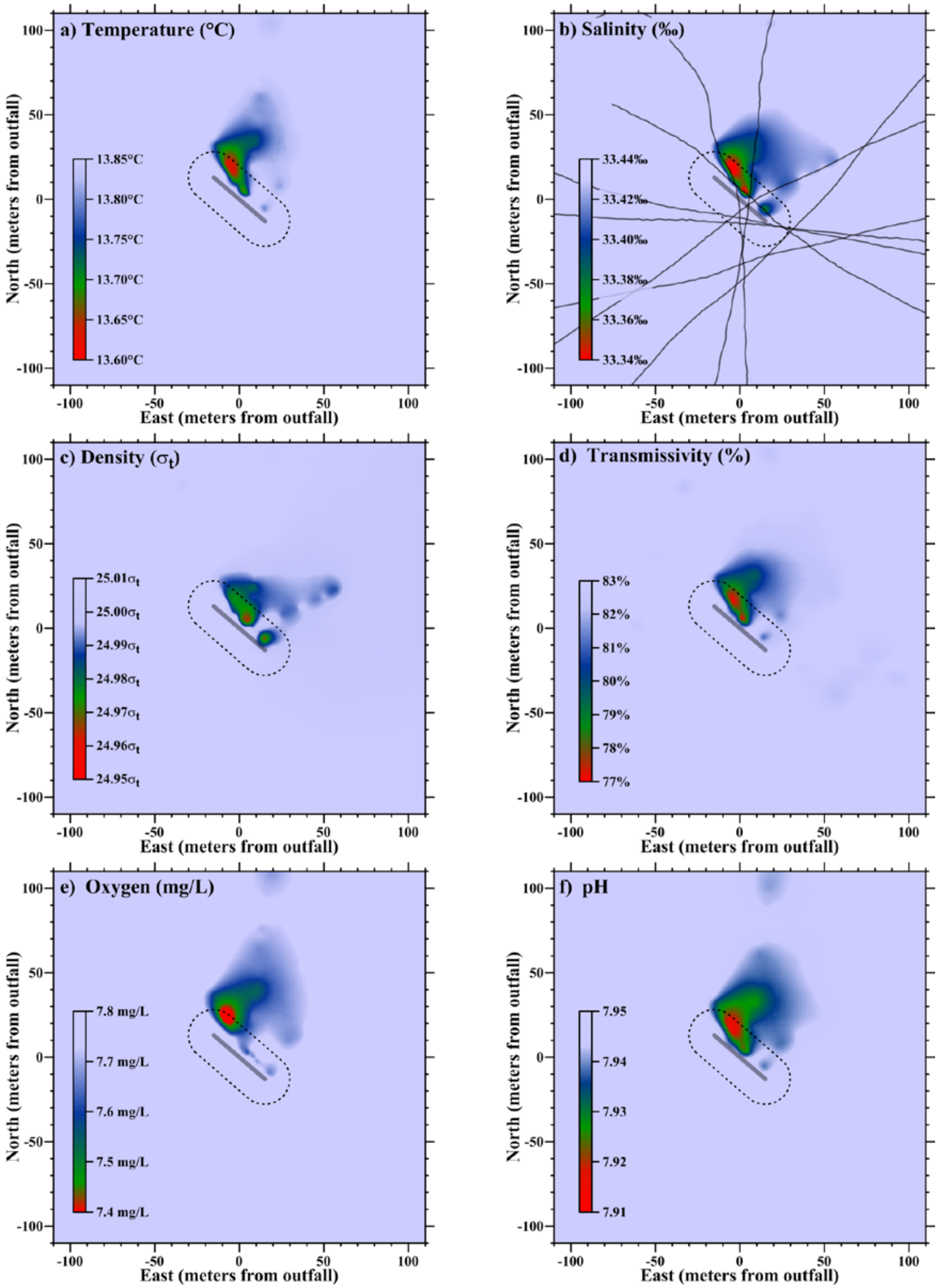

Figure 10. Horizontal Distribution of Shallow Water-Quality Parameters 3.7 m below the Sea Surface

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 within 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. The regions of slightly lower salinity apparent northeast of the diffuser structure in both tow-survey maps (Figures 9b and 10b), and in the vertical profiles measured at the first four stations (Figure 8abcd) were induced by the presence of dilute wastewater. These salinity anomalies document-mixing processes within the effluent plume shortly after discharge, and as it rose through the water column and spread along the sea surface.

The amplitudes of these salinity anomalies quantify the magnitude of wastewater dilution at the 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:

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

The salinity concentration within MBCSD effluent (C_e)[23] is 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 effluent plume is directly mirrored by a larger reduction in the measured salinity relative to that of the surrounding seawater.

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

Among the 13,919 CTD measurements collected during the October 2016 survey, the greatest reduction in salinity (-0.147‰) was recorded during the seventh transect of the shallow tow survey when a salinity of 33.315‰ was encountered only 5.4 m from the northeastern end of the diffuser structure (red shading in Figure 10b). From Equation 2, this salinity anomaly corresponds to a dilution of 220-fold (Figure 11). The salinity reduction seen at nearly the same depth (4.5 m) and location in the vertical profile at Station RW3 (Figure 8c) corresponded to a slightly higher dilution factor (275:1). Both of these subsurface salinity anomalies were associated with negative density anomalies, indicating that the initial mixing dilution process was ongoing at that point, and that additional increased levels of dilution would be achieved as the buoyant plume continued to rise to the sea surface. Accordingly, the lowest dilution measured at the sea surface during the survey was 489:1 at Station RW4. All three of these measurements were collected within the ZID where the initial mixing process is assumed to occur.

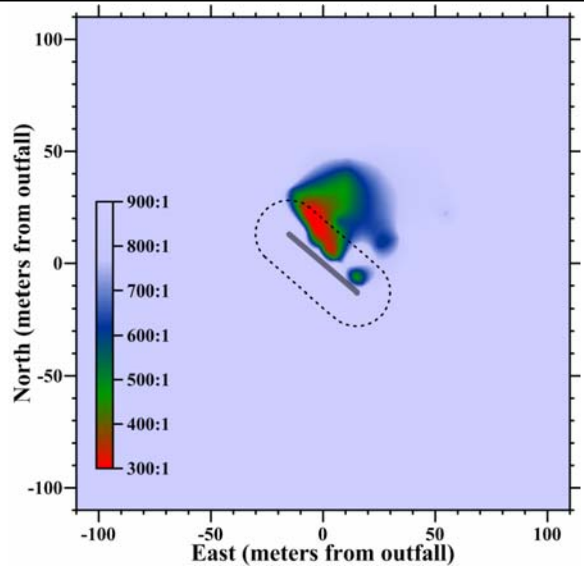

Figure 11. Plume Dilution Computed from Salinity Anomalies in Figure 10b

Overall, the dilution computations show that, during the October 2016 survey, the outfall was performing better than designed and was rapidly entraining seawater shortly after discharge. This resulted in dilution levels exceeding 220-fold within the ZID and before the initial mixing process was complete. Upon completion of initial mixing at the sea surface, effluent dilution was more than three-times higher than the 133:1 critical initial dilution used to establish end-of-pipe permit limitations on contaminant concentrations within wastewater discharged from the MBCSD treatment plant. This demonstrates that, during the October 2016 survey, the COP receiving-water objectives were being easily met by the limits on chemical concentrations within discharged wastewater that are promulgated by the NPDES discharge permit issued to the MBCSD.

COMPLIANCE

This section evaluates 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 October 2016 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 met the prescribed limits because actual dilution levels routinely exceeded the conservative design specifications assumed in the discharge permit. Thus, the quantitative evaluation described in this section documents an outfall and treatment process that was performing at a high level during the October 2016 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 during the October 2016 survey through visual inspection of the sea surface that found an absence of floating wastewater materials, oil, grease, and discoloration of the sea surface.

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 in terms of "*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 13,919 CTD measurements collected during the October 2016 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 completing the screening process 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[24]	*Parameter*
Location	1. Was the measurement collected beyond the 15.2-m ZID boundary where modeling assumes that initial dilution is complete?	*1,405*	*12,514*	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?	*12,452*	*62*	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?	*62*	*0*	Temperature
		62	*0*	Transmissivity
		62	*0*	DO
		62	*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 identifying observations suitable for further compliance analysis is presented in the following descriptions 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 ascent through the water column.

Although currents often transport the plume well 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.

[24] Number of remaining CTD observations of potential compliance interest based on sequential application of each successive screening question

Application of this initial screening question to the October 2016 dataset eliminated 1,405 of the original 13,919 receiving-water observations from further consideration because they were collected within the ZID (Table 7, Question 1). The remaining 12,514 observations were carried forward in the screening 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 upward movement of ambient seawater entrained within the buoyant effluent plume. Analyses conducted on quarterly receiving-water surveys over the last decade have demonstrated that the direct influence of dilute wastewater is almost never observed in any seawater property other than salinity, except very close (<1 m) to a diffuser port and within its ejection jet.

In fact, negative salinity anomalies are the only consistent indicator of the presence of wastewater constituents within receiving waters. Wastewater salinity is negligible compared to that of the receiving seawater, so the presence of a distinct salinity minimum provides *de facto* evidence of the presence of wastewater constituents. Because of the large contrast between the nearly fresh wastewater and the salty receiving water, salinity provides a powerful tracer of dilute wastewater that is unrivaled by other seawater properties. Other properties do not exhibit such a large contrast and, as such, their wastewater signatures dissipate rapidly upon discharge with very little mixing. Wastewater's lack of salinity, however, provides a 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 in Equation 2. 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 discussed previously, the greatest salinity reductions observed during the October survey were recorded northeast of the diffuser structure during the shallow tow survey and during vertical profiling at Station RW3. These subsurface observations were measured in close proximity to one another and well within the ZID boundary. A smaller salinity reduction was measured near the sea surface after the completion of the initial mixing process. Additional smaller salinity anomalies were found within the dilute effluent plume as it was transported farther to the northeast and beyond the 15-m-wide ZID. However, only sixty-two of these salinity reductions were large enough to be reliably determined against the backdrop of natural variability (Table 7). Other salinity measurements corresponded to dilutions less than 550:1. In particular, 12,452 observations that were measured outside the ZID during the October 2016 survey did not have salinity reductions that were greater than the 0.062‰ plume-detection threshold.

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 at the time of the survey is necessary for determining whether a particular observation warrants comparison with the numeric permit limits.

A statistical analysis of receiving-water data collected around the outfall was used to establish the range in natural conditions surrounding the outfall (first three data columns of Table 8). These ambient-variability ranges were used to identify significant departures from natural conditions that could be indicative of adverse discharge-related effects on water quality. The same five-year database used to establish the within-survey salinity variation discussed previously, was also used to establish one-sided 95% confidence bounds on transmissivity (-10.2%), temperature (+0.82°C), DO (-1.38 mg/L), and pH (± 0.094). These were combined with 95th percentiles determined from the October 2016 ambient seawater data, to establish time-specific natural-variability thresholds in a manner analogous to COP Appendix VI. The percentiles were largely determined from October 2016 vertical profile data collected at Stations RW5 and RW6, and excluded measurements potentially affected by the discharge.

Table 8. Compliance Thresholds

Water Quality Property	95% Confidence Bound[25]	95th Percentile[26,27]	Natural Variability Threshold[28]	COP Allowance[29]	Basin Plan Limit[30]	Extremum[31]
Temperature (ºC)	0.82	14.00	>14.82	—	—	≤14.04
Transmissivity (%)	-10.2	81.4	<71.2	—	—	≥65.3
DO (mg/L)	-1.38	6.78	<5.40	<4.86	<5.00	≥6.60
pH (minimum)	-0.094	7.917	<7.823	<7.623	<7.000	≥7.858
pH (maximum)	0.094	7.963	>8.057	>8.257	>8.300	≤7.965

Temperature, transmissivity, pH, and DO concentrations associated with the 62 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 measurements collected during the October 2016 survey from further consideration in the compliance analysis. In fact, all of the

25 The one-sided confidence bound measures the ability to reliably determine ambient seawater properties 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.

26 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*."

27 The 95th-percentile quantified natural variability in seawater properties during the October 2016 survey itself, and was determined from vertical-profiles data unaffected by the discharge.

28 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 October 2016 survey. They do not include the COP allowances specified in the column to the right.

29 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.*"

30 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.

31 Maximum or minimum value measured during the October 2016 survey, regardless of location within or beyond the ZID

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.

As described previously, anomalies in seawater properties clearly delineated the plume, but those entrainment-generated excursions were not caused by the presence of wastewater constituents. During periods when the water column is even slightly stratified, 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 observed decreases in DO and pH within the upper water column, their influence would still have been well within the natural range of the ambient seawater properties at the time of the survey. Consequently, their influence on water quality would not be considered environmentally significant.

Other Lines of Evidence

Several additional lines of evidence further support the conclusion that all the CTD measurements collected during the October 2016 survey complied with the quantitative 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 to provide a more robust compliance assessment. Together, these lines of evidence significantly strengthen the conclusion that the discharge fully complied with the permit at the time of the October 2016 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 could be deemed to affect beneficial uses adversely if they exceeded the natural temperature range observed at the time of the survey (i.e. exceeded 14.82°C listed in the third data column of Table 8). However, none of the 13,919 CTD measurements collected during the October 2016 survey exceeded 14.04°C (last column in Table 8).

Directional Offset: Analysis of the directional offset of CTD measurements is useful because wastewater and receiving-seawater properties depart from one another in several predictable ways. Specifically, upon discharge, wastewater is fresher, warmer, more turbid, and less dense than the ambient receiving waters of Estero Bay. 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). Therefore, as discussed previously, the reduced temperatures observed in conjunction with the effluent plume during the tow surveys (Figures 9a and 10a) could not have been generated by the presence of warmer wastewater constituents. Instead, the directional offset was opposite of receiving-water impacts expected from the presence of wastewater constituents because the plume entrained cooler bottom water shortly after discharge. As a result, the rising plume actually exhibited a lower temperature than the surrounding seawater within the upper water column (Figures 9a and 10a).

Natural Variability within and beyond the ZID: Although the permit limits only apply to changes in DO, pH, temperature, and transmissivity beyond the ZID, examination of measurements acquired within the ZID frequently provides additional insight into the potential for adverse effects on water quality. However, among all the data collected during the October 2016 survey, salinity was the only seawater property that exhibited a perceptible difference from ambient conditions. Regardless of their association with the plume's effluent salinity signature or their proximity to the diffuser structure, none of the 13,919 temperature, DO, and pH observations exceeded the thresholds of natural variability, or the Basin-Plan limits specified in Table 8. This is apparent from a comparison between the extrema listed in the last data column in Table 8, and the corresponding natural-variability thresholds listed in third data column.

However, the October-2016 database also contained two rare observations that ranged beyond the calculated natural variability threshold. Specifically, two very low transmissivity observations, near 65.3%, were measured at the seafloor at Stations RW3 and RW5 (Figure 8ce). These measurements ranged well below the 71.2% natural variability threshold determined from a statistical analysis of the entire October-2016 database (third data column of Table 8). These unusually low transmissivities captured the strikingly higher turbidity that was present within the thin BNL immediately above the seafloor at the time of the survey. Both measurements were eliminated in the screening analysis because they were not associated with low salinities that would identify them as part of the dilute effluent plume. Thus, because they arose from naturally occurring sediment resuspension processes rather than from the presence of wastewater particulates; they did not represent an exception to the permit provisions.

Instead, they ranged below the natural variability threshold for transmissivity because that threshold is a statistical construct specifically designed to identify highly unusual measurements within the entire database of observations measured at the time of a given survey. Ostensibly, if these highly unusual observations resulted from poorly dispersed effluent beyond the ZID, they could constitute a violation of receiving-water limits because they departed significantly from natural conditions at the time of the survey. Thus, identification of these two unusually low transmissivity observations as statistically significant excursions within the October-2016 database demonstrates that the statistical construct was performing as expected; namely, identifying excursions in seawater properties of potential compliance concern. Because the BNL was very thin, and because its water clarity was much reduced compared to the rest of the water column, the low BNL transmissivities were under-represented in the database. As a result, they ranged beyond the 95% confidence bounds that were used to establish the threshold in Table 8. Moreover, occasional excursions beyond variability thresholds are expected because when a 95% threshold is cast in terms of the definition of a null hypothesis test, one-in-twenty apparently "significant" excursions would be expected to could occur by chance alone.

Limited Ambient Light Penetration: Even if the two unusually low transmissivity measurements had been measured beyond the ZID, and had been directly caused by the presence of effluent particulates, they would not have represented a violation of the receiving-water limitations. As with temperature, there are no explicit numerical objectives for discharge-related decreases in transmissivity, although the COP narrative objective (P4) limiting significant reductions in the transmission of natural light may be inappropriately construed as a numerical objective on transmissivity.

On the contrary, the COP objective for light penetration only applies to a portion of the transmissivity measurements. Because little natural light is present beneath the euphotic zone, which extends to approximately twice the Secchi depth, the limit on transmissivity reductions during the October 2016 survey only applies to measurements recorded above 11 m (twice the maximum Secchi depth listed in Table 4). Consequently, even if the discharge of wastewater particulates had caused any of the transmissivity measurements collected below the euphotic zone to drop below the numeric compliance threshold, they would not have been of regulatory concern because the penetration of ambient light would not have been affected. This includes measurements collected within the naturally turbid BNL above the seafloor where virtually no ambient light was present during the October 2016 survey.

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, even before completion of the initial mixing process. The suspended-solids concentration measured onshore, within the effluent, and immediately prior to discharge from the WWTP on 24 October 2016 was 69 mg/L. After dilution by at least 220-fold, the effluent suspended-solids concentration would have the reduced ambient transmissivity by no more than 1.7%. This small potential decrease in transmissivity is overwhelmed by the large 20% decrease in ambient transmissivity caused by the increased resuspension of seafloor sediments within the BNL.

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 76-mg/L BOD measured within the plant's effluent a week before the survey. That small amount of BOD would have induced a DO depression of no more than 0.022 mg/L after dilution (MRS 2002). In fact, in the absence of tangible BOD influence, wastewater discharge would actually be expected to increase DO within subsurface receiving waters, rather than decrease it. This is because effluent is oxygenated by recent contact with the atmosphere during the treatment process, whereas receiving waters at depth are typically depleted in DO due to the long absence of atmospheric equilibration within the deep offshore watermass.

COP Allowances: The COP does not explicitly require that wastewater-induced changes remain within the ranges in natural variation listed in the third data column of Table 8, even though these ranges were conservatively used in the data screening process described in previous subsections. Consideration of these COP allowances for receiving-water limits provides an additional safety factor 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 down to 7.623 during the October 2016 survey (fourth data column of Table 8). This limiting value is significantly less than the lowest pH measurement of 7.858 recorded during the October 2016 survey, given that the entire range in measured pH was only 0.107 pH units (last column of Table 8).[32] Similarly, the lowest DO concentration measured during the survey (6.60 mg/L) was well above both the lower range in natural variation (5.40 mg/L) and the 10% compliance threshold promulgated by the COP (4.86 mg/L).

Excursions remained within the fixed 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 limits. 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). As such, the fixed Basin-Plan limit on DO is slightly more restrictive than the 4.86 mg/L minimum allowable DO concentration established for the October 2016 survey under COP objectives; yet the all of the DO measurements also easily complied with the more conservative Basin-Plan limit on DO reductions. In contrast, the minimum allowable pH (7.0) specified in the Basin Plan was less restrictive than the COP limit (7.623) specified for the October 2016 Survey, so all the pH observations again complied with both regulations.

[32] Compliance with COP maximum pH allowance (8.257) is irrelevant because effluent on the day of the survey had a pH of 7.5, which is much lower than the lowest pH measured within the receiving seawater (7.858). Consequently, the presence of effluent constituents could not have induced an increase in pH within receiving waters.

CONCLUSIONS

The quantitative screening analysis demonstrated that all measurements recorded during the October 2016 survey complied with the receiving-water limitations specified in the NPDES discharge permit. This conclusion was further strengthened by other lines of evidence supporting compliance with the discharge permit. Specifically, although discharge-related changes in seawater properties were observed during the October 2016 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 (i.e., were entrainment generated).

Prior to completion of the initial dilution process, effluent was being diluted to levels in excess of 220-fold, which is markedly higher than the critical dilution levels predicted by design modeling after completion of the mixing process. As the plume rose through the water column and approached the sea surface, near the completion of the initial mixing process, dilution levels reached 489-fold. All of the 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 October 2016 survey demonstrated that the discharge complied with the narrative receiving-water limits in the discharge permit and the COP. Together; these observations demonstrate that the treatment process, diffuser structure, and the outfall continue to surpass design expectations.

REFERENCES

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

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

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

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

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

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

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

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

Marine Research Specialists (MRS). 2014. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 2013 Annual Report. Prepared for the City of Morro Bay, California. March 2014.

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

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

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

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

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

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

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

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

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

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

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

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

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

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