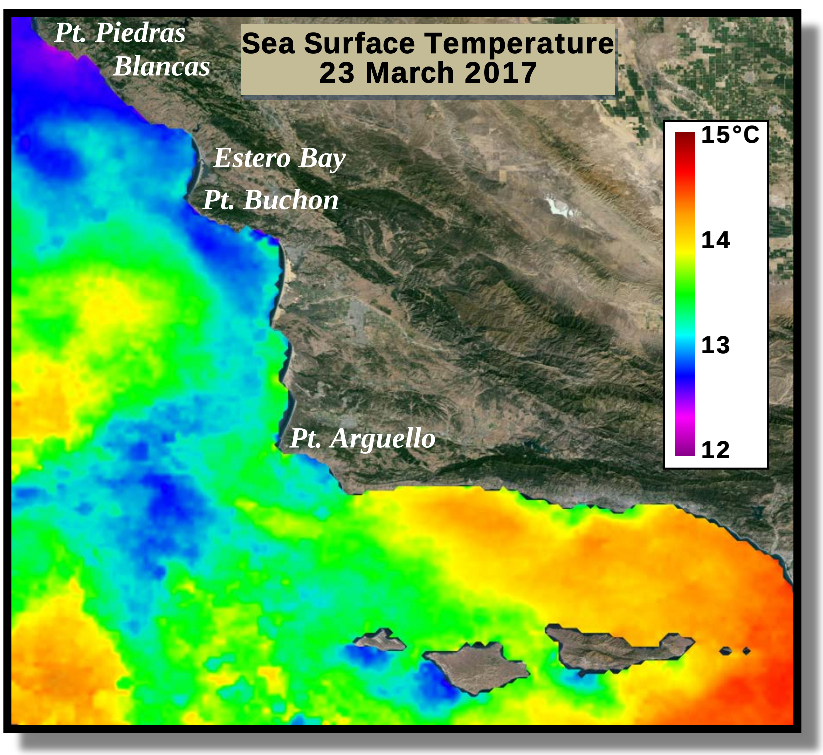
City of Morro Bay and
Cayucos Sanitary District

OFFSHORE MONITORING AND REPORTING PROGRAM

FIRST QUARTER RECEIVING–WATER SURVEY

MARCH 2017



Marine Research Specialists
4744 Telephone Rd., Suite 3-315
Ventura, California 93003

Report to the

City of Morro Bay and
Cayucos Sanitary District

955 Shasta Avenue
Morro Bay, California 93442
(805) 772-6272

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FIRST QUARTER RECEIVING–WATER SURVEY

MARCH 2017

Prepared by

Douglas A. Coats

Marine Research Specialists

4744 Telephone Rd., Suite 3-315
Ventura, California 93003

Telephone: (805) 644-1180
E-mail: Marine@Rain.org

April 2017

marine research specialists
4744 Telephone Rd., Suite 3-315 · Ventura, CA 93003 · 805-644-1180

John Gunderlock
Wastewater & Collection Systems Supervisor
City of Morro Bay
955 Shasta Avenue
Morro Bay, CA 93442

25 April 2017

Reference: First Quarter Receiving-Water Survey Report – March 2017

Dear Mr. Gunderlock:

The attached report presents results from a quarterly receiving-water survey conducted on Friday, 24 March 2017. 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 south 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/Collections System Supervisor
City of Morro Bay/Cayucos CSD Wastewater Treatment Plant

Date: 4/25/17

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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 March 2017 field survey described in this report was the thirty-third 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 March 2017. Specifically, this first-quarter survey captured ambient oceanographic conditions along the central California coast during the winter season. The survey's measurements were used to assess the discharge's compliance with the objectives of the California Ocean Plan (COP) and the Central Coast Basin Plan (RWQCB 1994) as promulgated by the receiving-water limitations specified in the NPDES discharge permit.

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

SURVEY SETTING

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

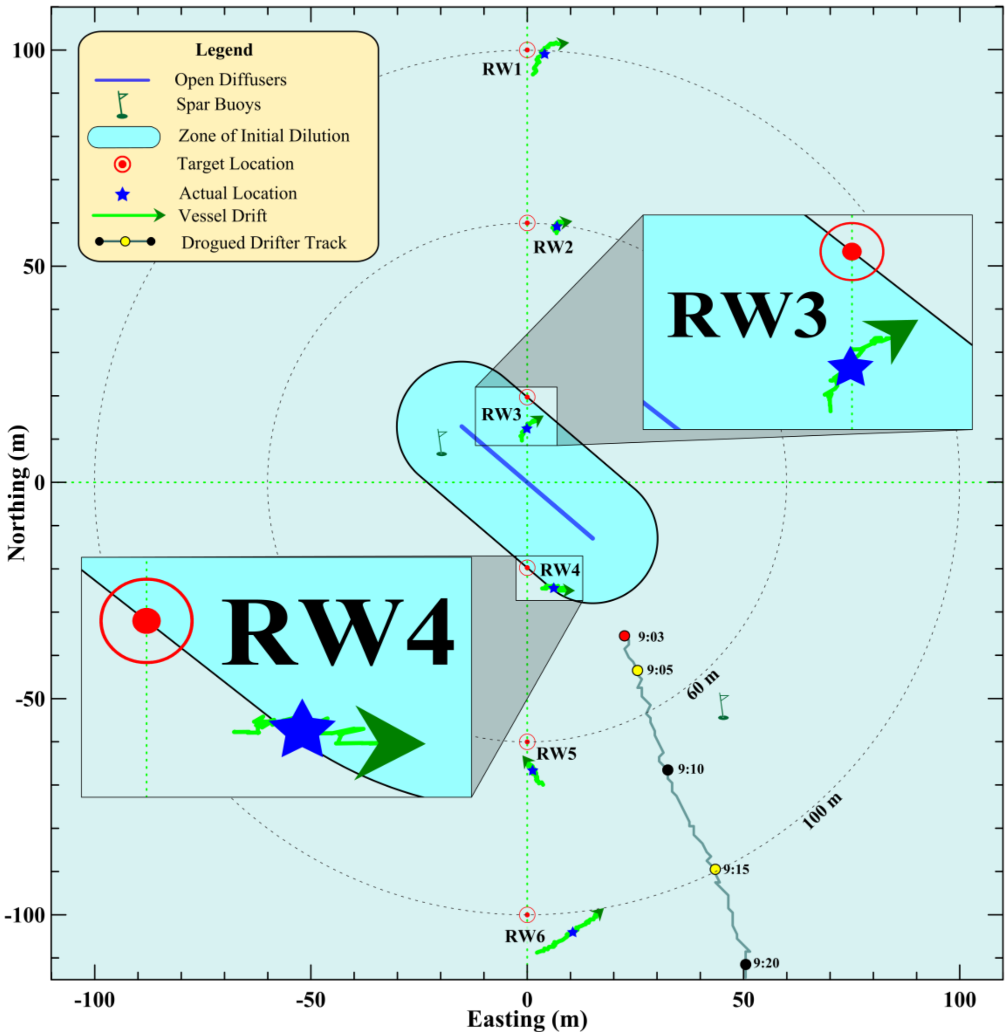

Figure 2. Station Locations

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 March 2017 hydrocasts were conducted progressing from south to north, beginning with Station RW6. The magnitude of the drift at each of the six stations during the March 2017 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 March 2017 survey.

The time it took the CTD to traverse the water column to the seafloor, which averaged 1 min 16 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 was less than 6 m at most stations, but at Stations RW1 and RW6, the CTD moved more than 9 m during the downcasts. The lateral movement of the CTD at any given time is determined by a 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 RW6 resulted from increased residual momentum as the vessel approached the stations from the southwest. The strong south-southeastward current flow delineated by the drogued-drifter trajectory in Figure 2[5] did not appear to dominate the CTD movement during any of the downcasts. Similarly, the onshore prevailing winds did not appear to control vessel movement during the downcasts even though wind speed was moderately strong 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.

[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 March 2017 survey, only the upper portion[7] of the data collected at Station RW4 was subject to the compliance assessment because the downcast began beyond the ZID but quickly traversed the ZID boundary as it approached the seafloor during its transport toward the east.[8] Thus, only the data recorded within 5.5 m of the sea surface at Station RW4 were subject to the compliance analysis. This was the case even though the average location of the CTD data (blue star in the lower-left inset in Figure 2) was only 70 cm from the ZID boundary. Similarly, none of the data collected at Station RW3 was subject to a compliance assessment because CTD remained entirely within ZID throughout the downcast (upper right 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 consistently 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 March 2017 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 March 2017 Survey

	Time (PDT)				Closest Approach	
Station	**Downcast**	**Upcast**	**Latitude**	**Longitude**	**Range[9](m)**	**Bearing[10](ºT)**
RW1	10:58:43	11:00:02	35° 23.253' N	120° 52.501' W	88.3	13
RW2	10:55:29	10:56:38	35° 23.231' N	120° 52.499' W	51.3	25
RW3	10:52:09	10:53:23	35° 23.206' N	120° 52.504' W	**9.5[11]**	41
RW4	10:48:36	10:49:49	35° 23.186' N	120° 52.500' W	**14.5[12]**	218
RW5	10:45:06	10:46:23	35° 23.163' N	120° 52.503' W	55.3	195
RW6	10:41:18	10:42:41	35° 23.143' N	120° 52.497' W	91.1	183

7 Above 5.5 m
8 Refer to the lower 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 All of the CTD measurements were located within the ZID boundary (refer to the upper right inset in Figure 2).
12 Some 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 March 2017 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.

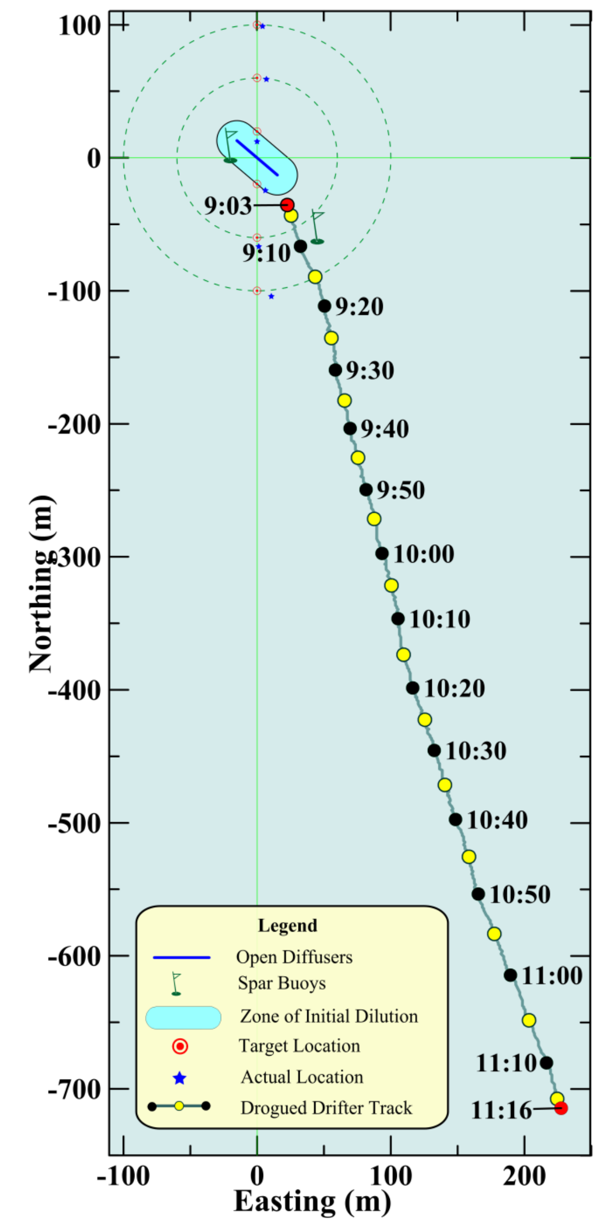

Figure 3. Drogued Drifter Trajectory

During the March 2017 survey, the drifter was deployed near the diffuser structure at 9:03 AM, and was recovered at 11:16 AM at a location 709 m south-southeast (163°T[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. The uniform spacing between the yellow and black dots in Figure 3, which show the drifter's progress at five- and ten-minute intervals, indicates that flow speed varied little from the average speed of 8.9 cm/s.[14] This flow speed was somewhat greater than that observed during most prior surveys. At the rapid transport rate measured during the March 2017 survey, effluent would have experienced only a brief, 2.9-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 south-southeasterly offset observed in the plume signature delineated during the tow surveys.[15] This consistency in directional offset, as well as the absence of a sharply defined thermocline within the water column,[16] suggests that vertical shear in the flow field was minimal.

[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 steady vertical change in seawater properties throughout the water column as shown in Figure 8 later in this report.

Barotropic (vertically uniform) flow is a hallmark of tidal forcing, and a southward component of flow is consistent with the ebb tide that prevailed throughout the survey (Figure 4). However, flow within the survey area is influenced by a variety of oceanographic processes in addition to tidal forcing, including upwelling and remote processes, such as large-scale along-shore pressure gradients and 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.

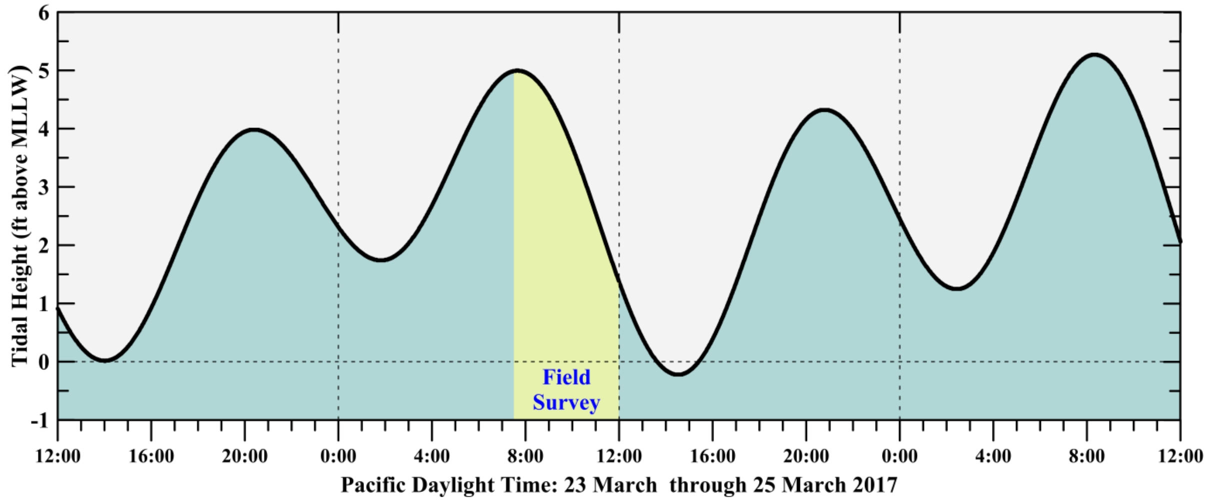

Figure 4. Tidal Level during the March 2017 Survey

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 vertical shear in the flow within the survey area.

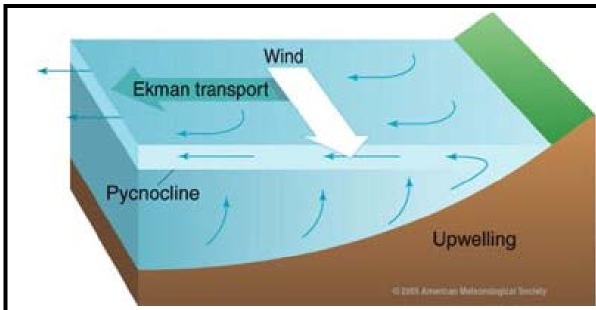

Figure 5. Schematic of Upwelling Processes

The onset of these upwelling-dominated processes normally 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 March 2017 survey was conducted shortly after an early upwelling event that preceded the normal onset of the full spring transition as shown by the last yellow diamond in Figure 6 (refer to the inset).

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

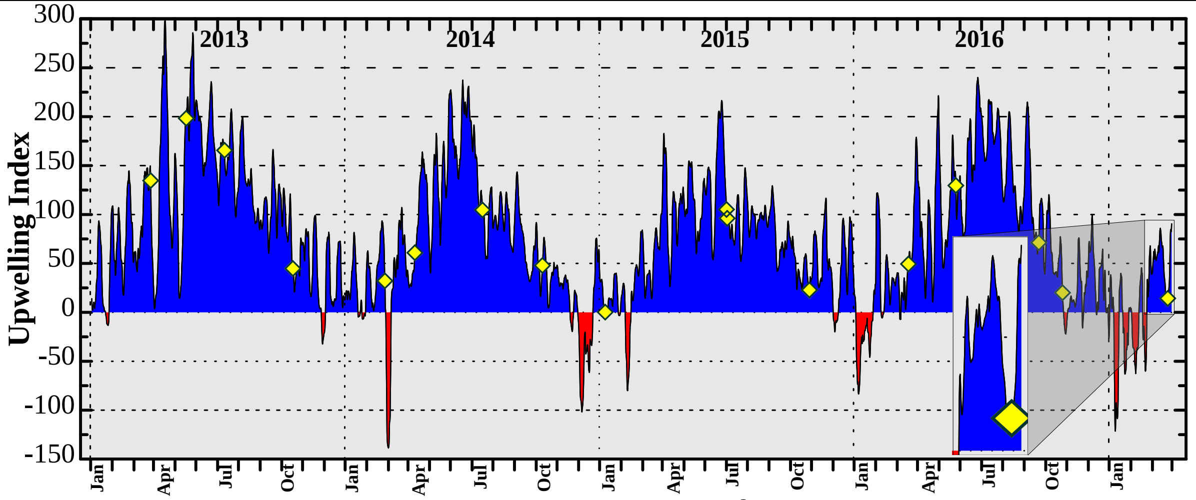

Figure 6. Five-Day Average Upwelling Index (m^3/s/100 m of coastline)

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. An unusual series of severe winter storms at the beginning of 2017 produced multiple downwelling events (refer to the red downward excursions in the upwelling index during January and February 2017 in Figure 6). Because of the associated harsh metocean conditions, the first quarter 2017 survey was delayed until March. By the time the survey could be conducted, an early upwelling event had occurred.

Although upwelling winds were negligible at the time of the March 2017 survey, winds during the weeks 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. Remnants of this pattern were captured by the satellite image shown on the cover of this report. The image was recorded by infrared sensors on one of NOAA's polar orbiting satellites during a period of relatively cloudless skies on the day prior to the survey. The presence of pools of cooler, upwelled water is visually apparent along the south-central coastline (dark -blue and magenta shading). However, the 2°C contrast between these sea-surface temperatures and temperatures farther offshore (in green and yellow) indicates that the upwelling event had largely dissipated at the time of the March 2017 survey.

As described below, the water column was only moderately stratified at the time of the March 2017 survey. The sharply defined thermocline normally indicative of the prior upwelling event had largely been eroded by mixing, leaving behind a gradual vertical gradient in seawater properties. Thus, the strong south-southeastward oceanic flow measured within northern Estero Bay during the survey was probably not solely due to 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 an eddy associated with the California Current.[18]

METHODS

The 38 ft F/V *Bonnie Marietta*, owned and operated by Captain Mark Tognazzini of Morro Bay, served as the survey vessel on Friday, 24 March 2017. 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. Dean Dusette, also of MRS, 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 March 2017 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

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	—

[18] Note the eddy-like feature delineated in light and dark blue in the upper left portion of the cover image
[19] 25-cm path length of red (650 nm) light

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.

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 9:15 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 10.51 m and an average speed of 1.70 m/s over the span of 36 minutes (blue-green lines in Figure 7). Subsequently, at 9:55 AM, eight additional passes were made with the CTD at an average depth of 2.16 m (orange lines). During this 33-minute shallow tow, vessel speed averaged 1.74 m/s. At the observed towing speeds and the 4 Hz sampling rate, at least 2.3 CTD measurements were collected for each meter traversed. This complies with the 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.

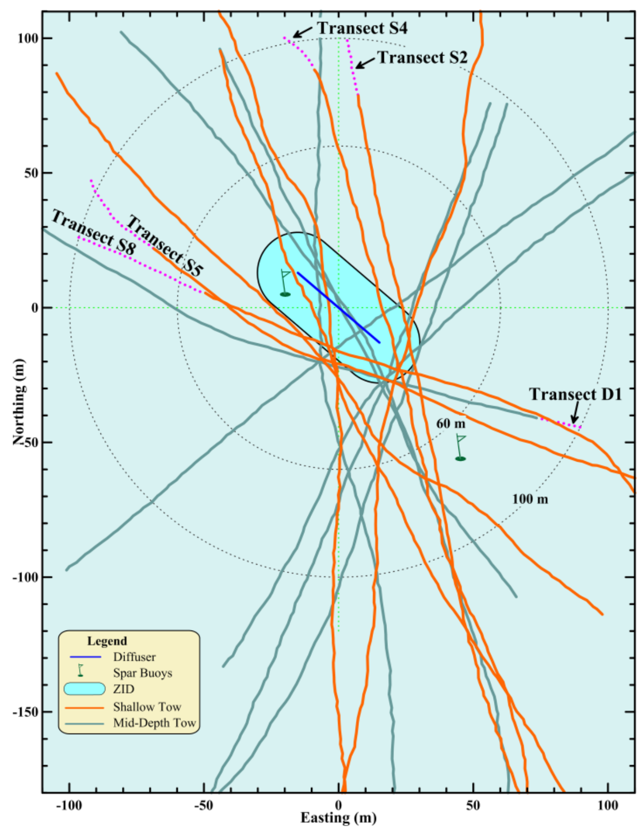

Figure 7. CTD Tracklines during the March 2017 Tow Surveys

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 10:29 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 10:38 AM, and was held beneath the surface for four minutes as the vessel was repositioned over Station RW6. 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 introduced 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 March 2017 survey.

However, the exclusion of portions of tow data did not adversely affect the compliance analysis. Only small portions of five transects (D1, S2, S4, S5, and S8) exhibited unacceptable depth offsets within the 100-m survey area (purple dotted lines in 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.

Additionally, the portions of the transects that were excluded because of depth offsets were located well outside of the plume footprint. Real-time monitoring of the CTD measurements during the initial portion of the tow survey revealed that the plume had been transported well south of the diffuser structure, and in a direction aligned with the drogued drifter movement. In response, the normal 100-m survey area, which is usually centered on the ZID, was extended well to the south in order to delineate the plume signature.

[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.

RESULTS

The first-quarter receiving-water survey was conducted on the morning of Friday, 24 March 2017. The receiving-water survey commenced at 9:03 AM with the deployment of the drogued drifter. Over the course of the ensuing two hours and fifteen minutes, offshore observations and measurements were collected as required by the NPDES monitoring program. The survey ended at 11:18 AM with the retrieval of the drogued drifter. Collection of required visual observations of the sea surface was generally unencumbered throughout the survey.

Auxiliary Observations

On the morning of 24 March 2017, skies were overcast, with a sustained moderate onshore wind out of the southwest (Table 4). Auxiliary observations were collected beginning at 11:06 AM, after completion of the vertical profiling phase of the survey. During the subsequent nine minutes, each station was re-occupied beginning with Station RW1, and sequentially progressing toward the south. During that time, wind speed and air temperature remained relatively constant. A swell out of the northwest had a significant wave height of three-to-four feet. Average air temperature (16.0°C) was somewhat warmer than the 13.1°C sea surface temperature.

Table 4. Standard Meteorological and Oceanographic Observations

	Location[22]		Diffuser Distance	Time	Air	Cloud Cover	Wind Avg	Wind Dir (from)	Swell Ht/Dir	Secchi Depth
Station	Latitude	Longitude	(m)	(PDT)	(°C)	(%)	(kt)	(°T)	(ft/°T)	(m)
RW1	35° 23.253' N	120° 52.488' W	94.5	11:06:43	16.0	70%	5.4	218	3-4 NW	4.0
RW2	35° 23.225' N	120° 52.491' W	48.7	11:09:01	15.9	70%	7.3	208	3-4 NW	4.0
RW3	35° 23.213' N	120° 52.510' W	13.7	11:10:52	16.0	70%	6.9	214	3-4 NW	4.0
RW4	35° 23.184' N	120° 52.492' W	14.9	11:12:27	15.9	70%	6.4	220	3-4 NW	4.0
RW5	35° 23.166' N	120° 52.502' W	49.7	11:13:55	16.0	70%	7.7	230	3-4 NW	4.0
RW6	35° 23.136' N	120° 52.497' W	102.6	11:15:46	16.1	70%	6.6	226	3-4 NW	4.0

There was no evidence of floating particulates, oil sheens, or any discoloration of the sea surface associated with the presence of wastewater constituents. There was no other visual indication of the presence of the discharge plume at or beneath the sea surface during the survey. Ambient light penetration through the water column was limited by an increased density of planktonic organisms within the upper water column. During upwelling, nutrients carried upward into the euphotic zone are assimilated by phytoplankton, whose populations increase and, along with their associated zooplanktonic herbivores; their elevated densities reduce the transmittance of ambient light. At stations unaffected by the discharge during the March 2017 survey, plankton-induced increases in turbidity extended to a depth of 3.5 m.

Because of this near-surface layer of increased turbidity, the Secchi disk faded from view at a relatively shallow depth of 4 m as it was lowered through the upper water column at each station (Table 4). The measured Secchi depth indicates that an 8-m euphotic zone was present during the survey, and that ambient light only penetrated through the upper half of the water column and did not extend to the 10.5-m level where the mid-depth tow was conducted.

[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.

Because the Secchi depths were constant among all the stations, near-surface water clarity did not appear to be significantly impacted by the presence of the plume, at least at the locations where the Secchi depth was measured. As discussed below, the rising effluent plume carried relatively clear deep seawater into the shallow more-turbid mixed layer where the shallow tow was conducted, and consequently, Secchi depth measurements within the near-surface plume signature would be expected to be larger than those outside the plume. However, because Secchi depths were consistent at all stations, they either did not encounter the plume, or did not detect the weak transmissivity signature. No visual evidence of the plume at the sea surface was observed at any time during the survey, which is consistent with the marginal transmissivity increase delineated by the CTD measurements within the surfacing plume. Similarly, no evidence of floating particulates, oil sheens, or any discoloration of the sea surface was visually apparent that might be related to the presence of wastewater constituents.

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 1.032 million gallons of effluent discharged on 24 March had a temperature of 18°C, a suspended-solids concentration of 32 mg/L, and a pH of 7.5. The 1.5 mg/L oil and grease concentration measured within effluent discharged three days prior to the survey was below the method quantification threshold. The biochemical oxygen demand (BOD) within an effluent sample collected two days after the survey on 26 March was 48 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 March 2017 survey reflect moderately stratified conditions within Estero Bay indicative of a relaxation in coastal upwelling following a month-long pulse of moderate upwelling winds that ended three days prior to the March 2017 survey (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 the case during the March 2017 survey when seawater properties characteristic of the surface mixed layer steadily changed with increasing depth until they reached ambient seawater conditions more representative of a deep watermass that migrated shoreward along the seafloor during upwelling (Figure 8). This gradual vertical transition was interrupted by the rising effluent plume that was captured by the hydrocast at Station RW4 (Figure 8d). Additionally, the transmissivity profiles, shown in light blue, exhibited a complex vertical structure at stations unaffected by the discharge that departed from the steadily increasing or decreasing trends seen in other seawater properties (Figure 8abc).

Table 5. Vertical Profile Data Collected on 24 March 2017

Depth (m)	Temperature (°C)						Salinity (‰)					
	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6
1.0	13.144	13.315	13.321	13.121	12.978	12.789	33.362	33.371	33.371	33.374	33.363	33.362
1.5	13.106	13.252	13.202	13.118	12.872	12.779	33.360	33.364	33.361	33.368	33.354	33.363
2.0	13.045	13.114	13.131	13.021	12.833	12.754	33.364	33.358	33.360	33.378	33.355	33.364
2.5	12.951	13.042	13.081	12.855	12.800	12.690	33.384	33.367	33.361	33.398	33.356	33.369
3.0	12.877	12.959	13.060	12.805	12.752	12.681	33.399	33.382	33.363	33.407	33.360	33.376
3.5	12.852	12.885	13.017	12.790	12.700	12.674	33.402	33.396	33.368	33.410	33.369	33.378
4.0	12.822	12.835	12.927	12.780	12.657	12.677	33.405	33.403	33.387	33.412	33.374	33.372
4.5	12.799	12.793	12.834	12.738	12.660	12.665	33.409	33.408	33.401	33.406	33.376	33.374
5.0	12.785	12.786	12.808	12.659	12.647	12.664	33.412	33.411	33.406	33.366	33.380	33.375
5.5	12.769	12.774	12.794	12.575	12.621	12.662	33.413	33.413	33.410	33.301	33.385	33.384
6.0	12.761	12.742	12.781	12.547	12.619	12.656	33.415	33.411	33.412	33.297	33.388	33.395
6.5	12.742	12.719	12.752	12.545	12.619	12.668	33.415	33.411	33.411	33.294	33.396	33.407
7.0	12.724	12.703	12.709	12.529	12.620	12.666	33.415	33.410	33.408	33.287	33.405	33.405
7.5	12.722	12.698	12.688	12.525	12.618	12.668	33.418	33.411	33.408	33.292	33.410	33.406
8.0	12.721	12.699	12.681	12.498	12.585	12.661	33.419	33.414	33.409	33.317	33.419	33.407
8.5	12.705	12.692	12.680	12.452	12.567	12.646	33.422	33.418	33.410	33.339	33.425	33.413
9.0	12.692	12.683	12.679	12.448	12.556	12.626	33.423	33.422	33.411	33.324	33.428	33.412
9.5	12.674	12.665	12.679	12.422	12.549	12.599	33.424	33.425	33.411	33.321	33.429	33.410
10.0	12.641	12.633	12.680	12.450	12.500	12.578	33.426	33.426	33.412	33.336	33.434	33.414
10.5	12.602	12.593	12.683	12.461	12.458	12.577	33.429	33.430	33.417	33.381	33.440	33.413
11.0	12.546	12.505	12.665	12.472	12.410	12.528	33.431	33.434	33.424	33.372	33.445	33.424
11.5	12.470	12.404	12.628	12.457	12.346	12.455	33.438	33.443	33.428	33.332	33.450	33.438
12.0	12.409	12.371	12.626	12.458	12.238	12.416	33.445	33.449	33.429	33.353	33.458	33.443
12.5	12.401	12.364	12.560	12.462	12.136	12.423	33.446	33.450	33.432	33.362	33.469	33.444
13.0	12.395	12.332	12.495	12.400	12.109	12.386	33.447	33.452	33.437	33.409	33.475	33.447
13.5	12.374	12.322	12.450	12.325	12.092	12.343	33.450	33.455	33.441	33.441	33.477	33.450
14.0	12.365	12.295	12.418	12.291	12.099	12.331	33.451	33.457	33.444	33.455	33.477	33.453
14.5	12.312	12.267	12.368	12.296	12.105	12.303	33.456	33.460	33.448	33.452	33.478	33.456
15.0	12.216	12.232	12.302	12.303	12.126	12.216	33.464	33.464	33.454	33.448	33.477	33.463
15.5	12.191	12.209	12.253	12.279	12.140	12.137	33.468	33.467	33.458	33.452	33.475	33.471
16.0		12.210	12.227	12.192	12.145	12.128		33.471	33.463	33.466	33.475	33.474
16.5			12.178		12.145				33.467		33.475	

Table 5. Vertical Profile Data Collected on 24 March 2017 (continued)

Depth (m)	Density (σ_t)						pH					
	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6
1.0	25.096	25.068	25.067	25.109	25.129	25.166	8.057	8.054	8.054	8.043	8.040	8.025
1.5	25.101	25.076	25.083	25.105	25.143	25.169	8.058	8.054	8.056	8.049	8.040	8.024
2.0	25.117	25.098	25.097	25.132	25.151	25.174	8.058	8.056	8.055	8.051	8.034	8.024
2.5	25.151	25.120	25.108	25.181	25.159	25.190	8.055	8.055	8.055	8.048	8.031	8.022
3.0	25.177	25.148	25.113	25.197	25.172	25.198	8.049	8.053	8.055	8.042	8.028	8.019
3.5	25.184	25.173	25.125	25.203	25.189	25.200	8.045	8.048	8.053	8.036	8.025	8.019
4.0	25.193	25.188	25.158	25.206	25.200	25.196	8.042	8.043	8.049	8.032	8.021	8.020
4.5	25.200	25.201	25.187	25.210	25.202	25.199	8.040	8.040	8.042	8.030	8.018	8.018
5.0	25.205	25.204	25.196	25.195	25.207	25.200	8.034	8.035	8.039	8.029	8.018	8.017
5.5	25.209	25.208	25.202	25.160	25.216	25.207	8.033	8.034	8.038	8.022	8.017	8.018
6.0	25.212	25.213	25.206	25.162	25.219	25.217	8.030	8.032	8.033	8.010	8.015	8.018
6.5	25.216	25.217	25.211	25.161	25.225	25.224	8.028	8.032	8.033	8.005	8.015	8.022
7.0	25.219	25.220	25.217	25.158	25.232	25.223	8.028	8.032	8.033	8.002	8.015	8.023
7.5	25.222	25.221	25.221	25.163	25.236	25.223	8.030	8.033	8.033	7.999	8.016	8.024
8.0	25.223	25.224	25.223	25.187	25.249	25.226	8.026	8.032	8.034	7.996	8.016	8.024
8.5	25.228	25.228	25.224	25.213	25.257	25.233	8.024	8.031	8.033	7.996	8.015	8.023
9.0	25.232	25.233	25.225	25.202	25.262	25.236	8.020	8.028	8.033	7.994	8.012	8.021
9.5	25.236	25.238	25.225	25.205	25.265	25.240	8.019	8.024	8.032	7.990	8.012	8.017
10.0	25.244	25.246	25.226	25.212	25.278	25.247	8.019	8.020	8.031	7.988	8.009	8.016
10.5	25.254	25.256	25.229	25.244	25.290	25.247	8.020	8.019	8.030	7.990	8.008	8.013
11.0	25.267	25.277	25.238	25.235	25.304	25.264	8.017	8.018	8.027	7.992	8.004	8.011
11.5	25.287	25.303	25.248	25.207	25.320	25.289	8.014	8.013	8.022	7.994	8.000	8.008
12.0	25.304	25.314	25.250	25.223	25.347	25.301	8.005	8.001	8.018	7.995	7.999	8.004
12.5	25.306	25.316	25.265	25.229	25.374	25.300	7.997	7.994	8.015	7.993	7.991	8.001
13.0	25.308	25.324	25.281	25.278	25.384	25.310	7.995	7.990	8.012	7.992	7.979	8.000
13.5	25.314	25.328	25.293	25.316	25.389	25.320	7.991	7.988	8.008	7.990	7.975	7.997
14.0	25.317	25.335	25.301	25.334	25.388	25.325	7.989	7.985	8.003	7.988	7.971	7.995
14.5	25.331	25.343	25.314	25.331	25.387	25.332	7.986	7.984	7.997	7.986	7.969	7.994
15.0	25.355	25.352	25.331	25.326	25.382	25.355	7.981	7.983	7.994	7.984	7.966	7.987
15.5	25.363	25.359	25.344	25.334	25.379	25.376	7.969	7.977	7.991	7.984	7.966	7.979
16.0		25.362	25.352	25.362	25.377	25.380		7.974	7.987	7.977	7.965	7.970
16.5			25.365		25.377				7.979		7.965	

Table 5. Vertical Profile Data Collected on 24 March 2017 (continued)

Depth (m)	Dissolved Oxygen (mg/L)						Transmissivity (%)					
	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6
1.0	8.628	8.556	8.560	8.626	8.249	8.170	81.505	81.782	82.760	83.402	83.976	86.225
1.5	8.542	8.559	8.564	8.388	8.216	8.119	81.589	81.835	82.706	83.215	83.774	85.869
2.0	8.401	8.498	8.571	8.270	8.181	8.072	81.620	81.581	82.491	83.271	83.739	85.749
2.5	8.379	8.401	8.562	8.302	8.114	8.074	82.460	81.902	82.258	86.912	83.841	85.155
3.0	8.344	8.349	8.523	8.258	8.074	8.070	85.576	82.595	82.738	89.916	83.952	85.474
3.5	8.304	8.307	8.364	8.221	8.035	8.063	90.117	87.857	82.631	89.396	83.912	85.656
4.0	8.265	8.284	8.328	8.166	8.048	8.031	90.323	89.931	83.914	88.514	83.563	85.258
4.5	8.264	8.282	8.305	8.002	8.014	8.056	90.044	89.242	89.227	87.825	83.478	85.154
5.0	8.245	8.240	8.271	7.858	8.007	8.052	89.128	88.350	89.702	84.482	83.927	85.033
5.5	8.209	8.210	8.247	7.850	8.015	8.076	84.507	87.167	89.309	82.227	83.927	85.432
6.0	8.172	8.214	8.205	7.850	8.016	8.105	70.158	83.097	88.794	80.590	84.294	86.261
6.5	8.144	8.193	8.196	7.801	8.031	8.087	75.928	78.822	88.511	81.261	83.953	87.531
7.0	8.128	8.176	8.183	7.813	8.018	8.094	85.869	83.370	86.969	77.750	84.863	88.074
7.5	8.113	8.151	8.183	7.759	7.963	8.074	87.699	86.744	84.875	78.098	85.200	88.056
8.0	8.094	8.112	8.175	7.718	7.935	8.061	85.676	86.677	84.110	77.085	85.089	88.731
8.5	8.102	8.096	8.140	7.694	7.936	8.017	83.237	87.051	87.692	76.186	84.802	88.434
9.0	8.084	8.079	8.149	7.682	7.907	7.973	86.812	87.592	90.127	76.067	83.843	88.082
9.5	8.076	8.060	8.149	7.756	7.829	7.949	87.339	87.321	90.785	75.233	83.769	87.186
10.0	8.034	7.949	8.097	7.775	7.760	7.942	87.074	86.668	90.711	74.935	83.212	86.379
10.5	7.905	7.724	8.037	7.759	7.720	7.856	85.960	85.735	90.395	75.650	82.067	85.852
11.0	7.676	7.588	8.028	7.713	7.604	7.773	82.354	82.449	89.088	76.414	81.232	84.081
11.5	7.628	7.581	8.010	7.734	7.400	7.755	78.043	79.131	86.946	76.713	79.932	83.247
12.0	7.627	7.560	7.863	7.719	7.327	7.770	69.938	76.344	86.825	76.544	78.046	81.010
12.5	7.615	7.537	7.765	7.578	7.319	7.689	68.810	70.044	83.720	77.110	77.419	80.717
13.0	7.584	7.510	7.702	7.525	7.292	7.654	69.198	69.476	80.316	76.465	77.202	80.110
13.5	7.546	7.500	7.661	7.541	7.297	7.649	69.023	69.834	77.504	76.074	76.637	79.438
14.0	7.406	7.447	7.556	7.554	7.302	7.585	68.171	70.341	75.475	75.148	75.663	78.857
14.5	7.219	7.330	7.454	7.548	7.282	7.434	67.733	70.589	73.838	75.998	75.378	78.511
15.0	7.202	7.257	7.421	7.487	7.248	7.295	65.869	70.644	72.742	75.279	73.351	78.066
15.5	7.283	7.302	7.357	7.341	7.242	7.293	61.160	67.200	72.575	74.352	69.167	77.303
16.0		7.236	7.298	7.354	7.241	7.358		66.377	71.617	67.336	68.278	76.321
16.5			7.350		7.258				65.137		70.158	

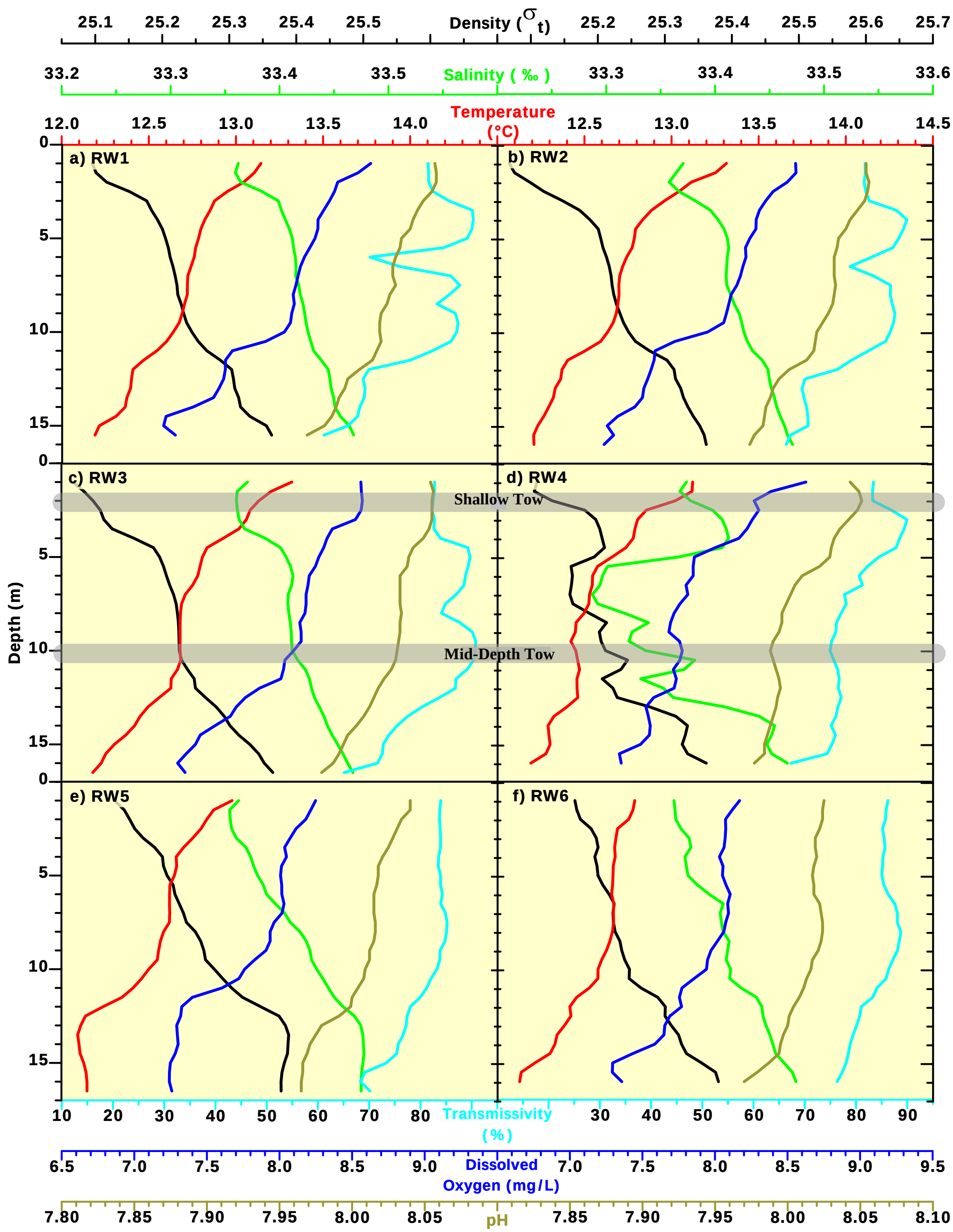

Figure 8. Vertical Profiles of Water-Quality Parameters

For the most part, however, the vertical changes in seawater properties reflected a gradual transition from shallow conditions established locally by nearshore processes 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.

Thus, upwelling in the weeks prior to the survey 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. 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, primary productivity within the 3-m thick surface mixed layer 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 (90.7%) approaching that of pure seawater (91.3%) beneath the 8-m deep euphotic zone. These processes formed a pair of localized maxima in water clarity near depths of 4 m and 9.5 m at the northernmost stations that were unaffected by the discharge (Figure 8abc). Beneath these localized maxima in transmissivity, water clarity declined rapidly as the influence of the deep offshore watermass began to prevail. Seawater turbidity increases at depth because of 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 in seawater properties, the downcasts at Stations RW4 through RW6 (Figure 8def) encountered the effluent plume, which perceptibly altered the vertical distribution of ambient seawater properties. Not surprisingly, the most pronounced plume effect is apparent in the profiles at Station RW4 (Figure 8d) which was located immediately down-current of the diffuser structure. The obvious declines in salinity (green) and density (black) between 5.5 m and 12.5 m are highly diagnostic of the presence of dilute wastewater constituents within a buoyant plume. The low density associated with the low salinity anomaly (black line in Figure 8d) demonstrates that the plume was buoyant throughout this subsurface depth range. As a result, it would be expected to continue to ascend through the water column and further mix with ambient seawater before reaching the sea surface.

Accordingly, this final stage of the initial mixing process was captured by the near surface measurements to the south, at Stations RW5 and RW6 (Figure 8ef). As the plume was transported farther downstream, it impinged on the sea surface and began to spread laterally. There, the mid-depth salinity and density signatures associated with the presence of buoyant wastewater constituents at Station RW4 had largely dissipated (black and green lines). Instead, the subtle and long-lived influence of ambient seawater that had been displaced upward within the rising effluent plume became apparent. For example, sea surface temperature at Station RW6 (top of the red line in Figure 8f) was 0.5ºC colder than that of the three northernmost stations (Figure 8abc). Similarly, surface transmissivity (light blue lines) was as much as 4.7% higher at Station RW6 (Figure 8f) and the complex vertical structure in transmissivity introduced by primary productivity at the northernmost stations (Figure 8abc) had been mixed to uniformity (Figure 8ef) by the plume's ascent through the water column. These observations demonstrate that the rising effluent plume reached the sea surface within 55 m of the discharge point as it was transported southward by the prevailing oceanic flow.

The southward migration of the rising effluent plume that was revealed in the vertical hydrocasts was also captured by the tow surveys (Figures 9 and 10). Both tow surveys delineated the lateral extent of the plume signature with localized reductions in all six seawater properties. At mid-depth (Figure 9), the plume signature was largely limited to a narrow region along the southern boundary of the ZID although weak but perceptible anomalies extended 100 m farther south. At that depth, the large and localized density reduction delineated the core of the highly buoyant effluent-seawater mixture (Figure 9c).

In contrast, the shallow tow (Figure 10) captured a more-diffuse plume signature centered 30 m farther south and stretching at least 100 m toward the south-southeast.[23] Notably, the plume at this near-surface depth was denser than the surrounding seawater,[24] indicating that the plume's upward momentum had caused it to overshoot its equilibrium level, and that it would subsequently sink. Thus, as the plume was transported south, it executed a damped oscillation about its equilibrium depth that resulted in the somewhat patchy character seen especially in the salinity (Figure 10b) and transmissivity (Figure 10d) distributions. Also notable was the increased transmissivity associated with the plume at that depth level (Figure 10d), which indicates that the very high transmissivity ambient seawater at mid-depth had been entrained in the rising effluent plume and became apparent as a localized reduction in turbidity within the naturally turbid surface mixed layer. Clearly, reduced turbidity within the shallow plume signature could not have been caused by the increased presence of wastewater particulates.

In fact, the signatures seen in temperature, transmissivity, DO, and pH at both depth levels (Figure 9adef and 10adef) were caused by the entrainment and upward transport of ambient seawater. 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. 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 March 2017 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.

[23] Note that the shallow maps (Figure 10) are shifted 30 m to the south to encompass more of the plume signature.
[24] Note that the scales are reversed in Figure 10cd as compared to Figure 9cd.

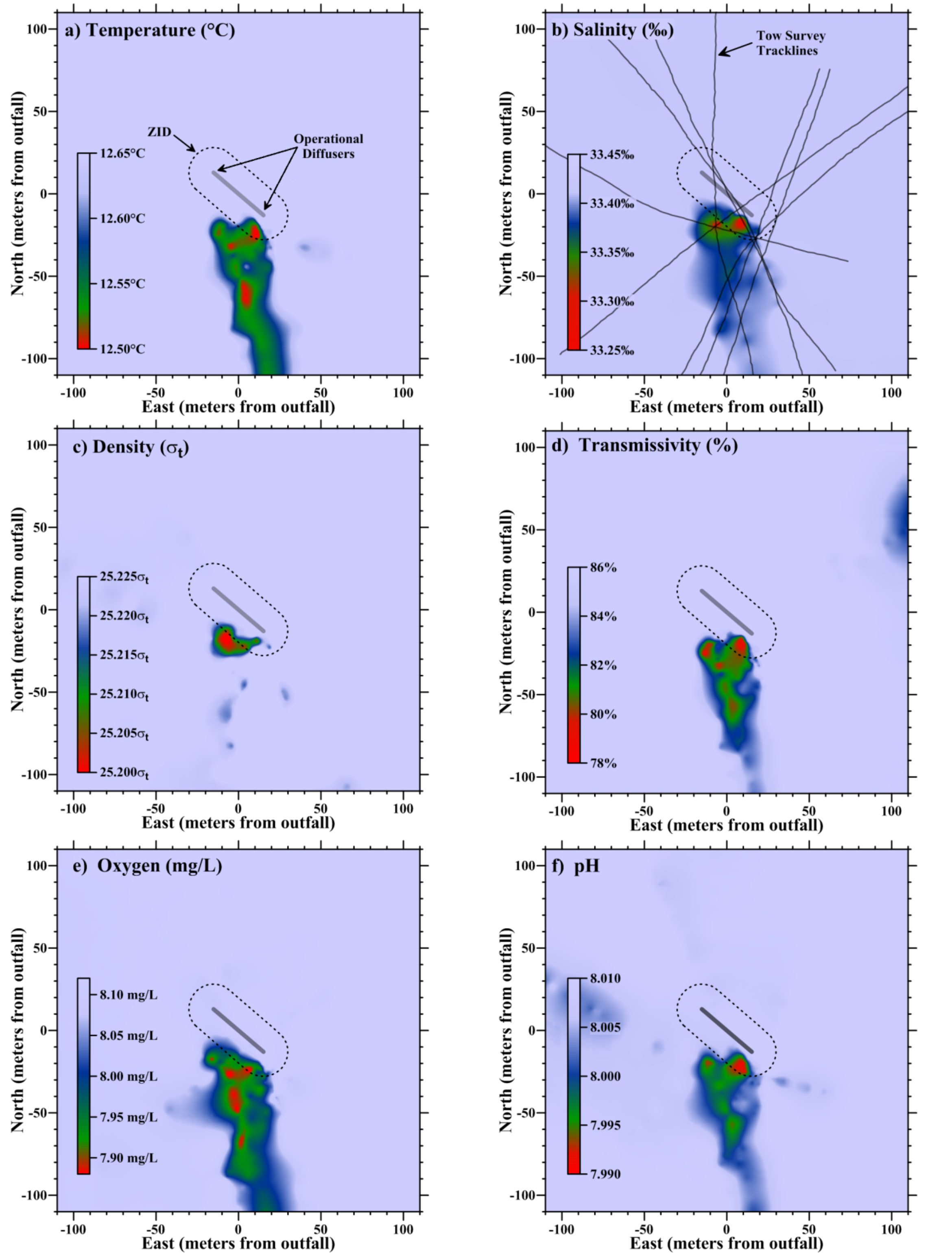

Figure 9. Horizontal Distribution of Mid-Depth Water-Quality Parameters 10.5 m below the Sea Surface

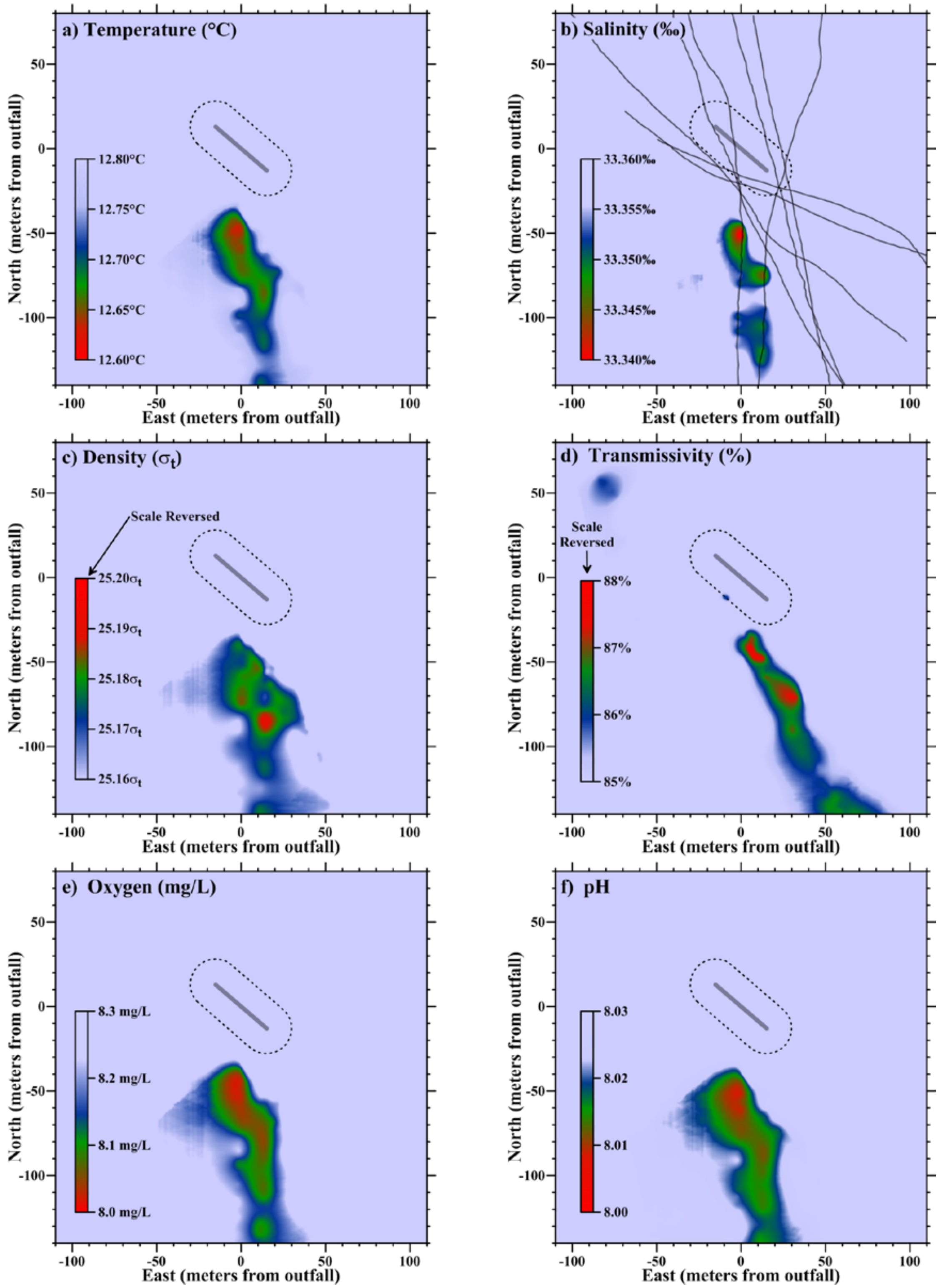

Figure 10. Horizontal Distribution of Shallow Water-Quality Parameters 2.2 m below the Sea Surface

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.

Outfall Performance

The efficacy of the outfall can be evaluated through a comparison of dilution levels measured at the time of the March 2017 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 March 2017 survey were much higher than the 133:1 predicted by the modeling, even though they were measured within the ZID and well before the completion of the initial dilution process.

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 south of the outfall in both tow-survey maps (Figures 9b and 10b), and in the vertical profiles measured at the southern ZID Station RW4 (Figure 8d) 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:

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

The salinity concentration within MBCSD effluent (C_e)[25] 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.

Among the 12,691 CTD measurements collected during the March 2017 survey, the greatest reduction in salinity (-0.185‰) was recorded during the second transect of the mid-depth tow survey when a salinity of 33.234‰ was encountered only 7 m from the southeastern end of the diffuser structure (red shading in Figure 9b). From Equation 2, this salinity anomaly corresponds to a dilution of 174-fold (Figure 11). The salinity reduction seen in the vertical profile at Station RW4 (Figure 8d) at a slightly shallower depth (7 m) and a location 5 m farther south corresponded to a slightly higher dilution factor (259:1). 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 increased levels of dilution would be achieved as the buoyant plume continued to rise to the sea surface. Accordingly, the lowest dilution measured near the sea surface was 732:1 during the shallow tow survey.

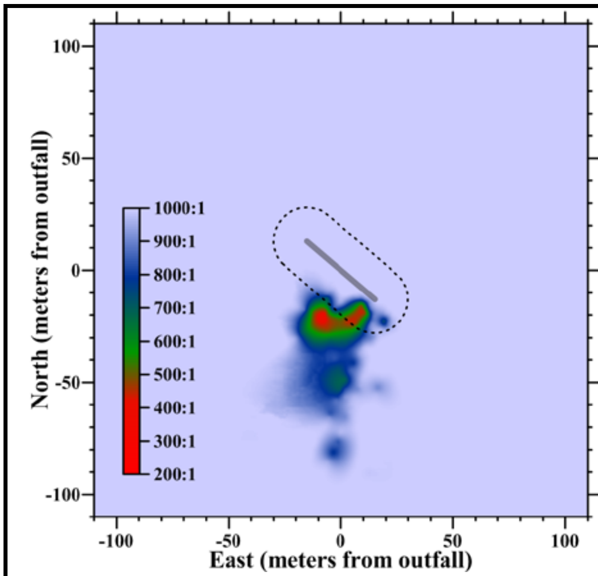

Figure 11. Plume Dilution Computed from Salinity Anomalies in Figure 9b

Overall, the dilution computations show that, during the March 2017 survey, the outfall was performing better than designed and was rapidly entraining seawater shortly after discharge. This resulted in dilution levels exceeding 174-fold within the ZID and long before the initial mixing process was complete. Upon completion of initial mixing at the sea surface, effluent dilution was more than five-times higher than the

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

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 March 2017 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 the analyses performed on the March 2017 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 March 2017 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 March 2017 survey through visual inspection of the sea surface that documented 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 within 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 temperature, transmissivity, DO, and pH within the receiving waters surrounding the outfall.

As described in prior sections, 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 12,691 CTD measurements collected during the March 2017 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 water 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 even 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[26]	*Parameter*
Location	1. Was the measurement collected beyond the 15.2-m ZID boundary where modeling assumes that initial dilution is complete?	*1,249*	*11,442*	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?	*11,345*	*97*	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?	*97*	*0*	Temperature
		97	*0*	Transmissivity
		97	*0*	DO
		97	*0*	pH

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

The subsection following this one 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. Application of this initial screening question to the March 2017 dataset eliminated 1,249 of the original 12,691 receiving-water observations from further consideration because they were collected within the ZID (Table 7, Question 1). The remaining 11,442 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 March survey were recorded immediately south of the outfall during the mid-depth tow survey and during vertical profiling at Station RW4. These subsurface observations were measured in close proximity to one another and within the ZID. However, because of the strong oceanic flow, the plume was carried well beyond the ZID before the initial dilution process was complete. As a result, an unusually large number of quantifiable salinity reductions were measured at the same depth level only a few meters south of the ZID boundary. Even though these 97 salinity anomalies were clearly measured prior to completion of the initial dilution process, they were reliably associated with the presence of wastewater constituents (Table 7). The remaining 11,345 salinity measurements collected beyond the ZID during the March 2017 survey did not have salinity reductions that were greater than the 0.062‰ plume-detection threshold, and therefore corresponded to dilutions less than 550:1.

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 March 2017 ambient seawater data, to establish time-specific natural-variability thresholds in a manner analogous to COP Appendix VI. The percentiles were largely determined from March 2017 vertical profile data collected at Stations RW1, RW2, and RW3, and excluded measurements potentially affected by the discharge.

Temperature, transmissivity, pH, and DO concentrations associated with the 97 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 March 2017 survey from further consideration in the compliance analysis. In fact, all of the documented excursions in these properties were the result of physical processes unrelated to the presence of wastewater constituents, namely, entrainment of near-bottom seawater within the rising effluent plume.

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.

Table 8. Compliance Thresholds

Water Quality Property	95% Confidence Bound[27]	95th Percentile[28,29]	Natural Variability Threshold[30]	COP Allowance[31]	Basin Plan Limit[32]	Extremum[33]
Temperature (ºC)	0.82	13.12	>13.94	>16.14	—	≤13.32
Transmissivity (%)	-10.2	68.2	<58.0	—	—	≥61.2
DO (mg/L)	-1.38	7.28	<5.90	<5.31	<5.00	≥7.20
pH (minimum)	-0.094	7.979	<7.885	<7.685	<7.000	≥7.965
pH (maximum)	0.094	8.055	>8.149	>8.349	>8.300	≤8.061

Other Lines of Evidence

Several additional lines of evidence further support the conclusion that all the CTD measurements collected during the March 2017 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 March 2017 survey.

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 March 2017 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 12,691 temperature, DO, and pH observations exceeded the thresholds of natural variability specified in Table 8.

[27] 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.

[28] 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*."

[29] The 95th-percentile quantified natural variability in seawater properties during the March 2017 survey itself, and was determined from vertical-profiles data unaffected by the discharge.

[30] 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 March 2017 survey. They do not include the COP allowances specified in the column to the right.

[31] 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.*" The California Thermal Plan is incorporated into the COP by reference, and restricts temperature increases to less than 2.2ºC.

[32] 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.

[33] Maximum or minimum value measured during the March 2017 survey, regardless of location within or beyond the ZID

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. For example, temperatures are expected to range as high as 13.94ºC, but the highest measured temperature was 13.32ºC. Similarly natural excursions in transmissivity are expected to range as low as 58%, while the lowest measured transmissivity was 61.2%.

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 7.685 for the March 2017 survey (fourth data column of Table 8). This limiting value is significantly less than the lowest pH measurement of 7.965 recorded during the March 2017 survey. In fact, the entire range in measured pH during the survey was only about half of the COP allowance (0.096 difference in pH extrema in the last column of Table 8).[34] Similarly, the lowest DO concentration measured during the survey (7.20 mg/L) was well above the lower bound in expected natural variability (5.90 mg/L) and even more so for the less-stringent 10% compliance threshold promulgated by the COP (5.31 mg/L).

Limited Ambient Light Penetration: Although there are no explicit numerical objectives for discharge-related reductions in transmissivity, a numerical limit can be established from the COP requirement that the discharge not result in significant reductions in the transmission of natural light (P4 in Table 6). Because the COP does not specify an allowance beyond natural conditions, the 58% threshold on ambient transmissivity variations listed in third data column of Table 8 can be interpreted to constitute a numerical limit.

However, 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 March 2017 survey only applies to measurements recorded above 8 m (twice the average Secchi depth listed in Table 4). This immediately eliminates about half of the transmissivity measurements from further compliance consideration, even though they were included in the screening analysis. Specifically, even if the discharge of wastewater particulates had caused transmissivity measurements collected below the euphotic zone to drop below the numeric compliance threshold, it would not have been of regulatory concern because the penetration of ambient light would not have been affected. This includes measurements collected shortly after discharge near a diffuser port, or those within the naturally turbid BNL above the seafloor because virtually no natural light was present near the seafloor during the March 2017 survey.

Insignificant Thermal Impact: As with transmissivity, there are no explicit numerical objectives for discharge-related increases in temperature. Nevertheless, 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). Although the COP remains silent regarding allowable temperature changes, it incorporates the California Thermal Plan requirements by reference (COP Introduction §C.3). The Thermal Plan (SWRCB 1972) restricts temperature increases caused by new discharges to coastal water to be less than 2.2°C (4°F). As

[34] Compliance with COP maximum pH allowance (8.349) 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 (7.965). Consequently, the presence of effluent constituents could not have induced an increase in pH within receiving waters.

with DO and pH, a quantitative permit limit on temperature increases can be established by combining the Thermal Plan allowance with the natural variability threshold listed in the third data column of Table 8. Accordingly, increases in temperature caused by the discharge of warm wastewater during the March 2017 survey could be deemed to adversely affect beneficial uses if they exceeded 16.14°C (fourth data column of Table 8). However, none of the 12,691 CTD measurements collected during the survey exceeded 13.32°C (last column in Table 8). As a result, all the measurements remained within the natural variability thermal threshold (13.94°C), and thus, also easily complied with the numerical limit derived from the Thermal Plan. In reality, temperatures measured within the rising effluent plume were uniformly below that of the surrounding seawater because cooler seawater near the seafloor had been entrained in the plume shortly after discharge. Consequently, any potential thermal impact resulting from the discharge of warm wastewater was almost immediately eliminated upon discharge because the effluent entrained much colder seawater near the seafloor.

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, 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, they were produced because the plume entrained cooler bottom water shortly after discharge. Similarly, the increased transmissivity observed within the plume during the shallow tow (Figure 10d) could not have been generated by an unacceptably high particulate load within wastewater. In both cases, the directional offsets were opposite of receiving-water impacts expected from the presence of wastewater constituents.

Insignificant Wastewater Particulate Loads: Another independent line of evidence demonstrates that the discharge of wastewater particulates could not have contributed materially to turbidity within the dilute effluent plume, 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 March 2017 was 32 mg/L. After dilution by at least 174-fold, the effluent suspended-solids concentration would have the reduced ambient transmissivity by no more than 0.8%. This small potential decrease in transmissivity is overwhelmed by the large 23% 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 48-mg/L BOD measured within the plant's effluent two days after 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 a 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.

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 less restrictive than the 5.31 mg/L minimum allowable DO concentration established for the March 2017 survey under COP objectives. Because all of the DO measurements complied with the more conservative COP objective on DO reductions, they also easily complied with the Basin-Plan limit. Similarly, the minimum allowable pH (7.0) specified in the Basin Plan was less restrictive than the COP limit (7.685) specified for the March 2017 Survey, so all the pH observations again complied with both regulations.

CONCLUSIONS

The quantitative screening analysis demonstrated that all measurements recorded during the March 2017 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 March 2017 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).

Early in the initial mixing dilution process, effluent was being diluted to levels in excess of 174-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 732-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 March 2017 survey demonstrated that the discharge complied with the narrative receiving-water limits in the discharge permit and the COP. Together; these observations demonstrate that the treatment process, diffuser structure, and the outfall continue to surpass design expectations.

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