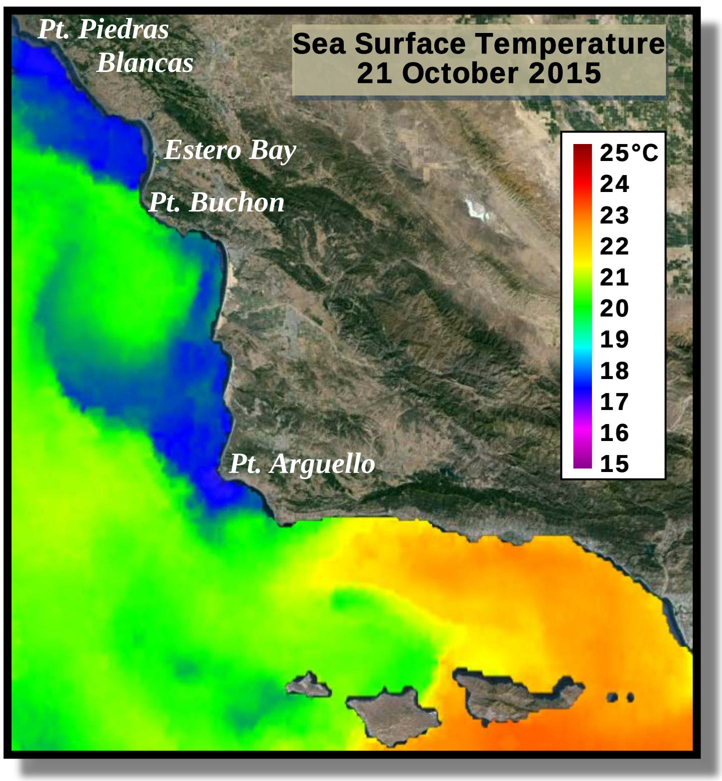
**City of Morro Bay and**
**Cayucos Sanitary District**

# OFFSHORE MONITORING AND REPORTING PROGRAM

# FOURTH QUARTER RECEIVING–WATER SURVEY

# OCTOBER 2015

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**Ventura, California 93003**

**Report to the**

## City of Morro Bay and
## Cayucos Sanitary District

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**Morro Bay, California 93442**
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# OCTOBER 2015

**Prepared by**

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**January 2016**

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11 January 2016

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

**Reference: Fourth Quarter Receiving-Water Survey Report – October 2015**

Dear Mr. Keogh:

The attached report presents results from a quarterly receiving-water survey conducted on Tuesday, 27 October 2015. The survey was conducted in accordance with the requirements of the NPDES permit issued to the City and District for discharge of treated wastewater to Estero Bay. The report evaluated compliance with permit limitations and assessed the effectiveness of effluent dispersion. Quantitative analyses of continuous instrumental measurements and qualitative visual observations confirm that the wastewater discharge complied with the receiving-water limitations specified in the permit, and with the objectives of the California Ocean Plan.

The offshore measurements confirmed that the diffuser structure and treatment plant continued to operate at a high level of performance. The measurements delineated a diffuse discharge plume containing low organic loads within a highly localized region north of the discharge point. Dilution within the plume exceeded expectations based on modeling and outfall design criteria.

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

Sincerely,

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.

Bruce Keogh

Mr. Bruce Keogh
Wastewater Division Manager
City of Morro Bay

Date January 11, 2016

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## INTRODUCTION

The City of Morro Bay and the Cayucos Sanitary District (MBCSD) jointly own the wastewater treatment plant operated by the City of Morro Bay. In March 1985, Region IX of the U.S. Environmental Protection Agency (USEPA) and the Central Coast California Regional Water Quality Control Board (RWQCB) issued the first National Pollutant Discharge Elimination System (NPDES) permit to the MBCSD. The permit incorporated partially modified secondary treatment requirements for the plant's ocean discharge. The permit has been re-issued three times, in March 1993 (RWQCB-USEPA 1993ab), December 1998 (RWQCB-USEPA 1998ab), and January 2009 (RWQCB-USEPA 2009). The October 2015 field survey described in this report was the twenty-eighth 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 27 October 2015. Specifically, this fourth-quarter survey captured ambient oceanographic conditions along the central California coast during the fall season. The survey's measurements were used to assess the discharge's compliance with the objectives of the California Ocean Plan (COP) and the Central Coast Basin Plan (RWQCB 1994) as promulgated by the receiving-water limitations specified in the NPDES discharge permit.

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

## SURVEY SETTING

The MBCSD treatment plant is located within the City of Morro Bay, which is situated along the central coast of California halfway between Los Angeles and San Francisco. Effluent is carried from the onshore treatment plant through a 1,450-m long outfall pipe, which terminates at a diffuser structure on the seafloor 827 m from the shoreline within Estero Bay (Figure 1). The diffuser structure extends an additional 52 m toward the northwest from the outfall terminus and consists of 34 ports that are hydraulically designed to create a turbulent ejection jet that rapidly mixes effluent with receiving seawater upon discharge. Currently, six of the diffuser ports are kept closed, thereby improving effluent dispersion by increasing the ejection velocity from the remaining 28 ports distributed along a 42-m section of the diffuser structure.

Following discharge from the diffuser ports, additional turbulent mixing occurs as the buoyant plume of dilute effluent rises through the water column. Most of this buoyancy-induced mixing occurs within a zone of initial dilution (ZID), whose lateral reach in modeling studies extends 15.2 m from the centerline of the diffuser structure. Beyond the ZID, energetic waves, tides, and coastal currents within Estero Bay further disperse the dilute effluent within the open-ocean receiving waters. Both vertical hydrocasts and horizontal tow surveys are conducted around the diffuser structure to assess the efficacy of the diffuser, to define the lateral extent of the discharge plume, and to evaluate compliance with the NPDES permit limitations.

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


**Figure 1.** Location of the Receiving-Water Survey Area

Near the diffuser, prevailing flow generally follows bathymetric contours that parallel the north-south trend of the adjacent coastline. Because of the rapid initial mixing achieved within 15 m of the diffuser structure, impingement of unmixed effluent onto the adjacent coastline, 827 m away, is highly unlikely. Nevertheless, in the event of a failure in the treatment plant's disinfection system, collection and analysis of water samples at the eight surfzone-sampling stations shown in Figure 1 would be conducted to monitor for potential shoreline impacts. These surfzone samples would be analyzed for total and fecal coliform, and enterococcus bacterial densities.

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

## SAMPLING LOCATIONS

As shown in Figure 2, the offshore sampling pattern consists of six fixed offshore stations located within 100 m of the outfall diffuser structure. The red ⊙ symbols in the Figure indicate the target locations of the sampling stations (Table 1). The stations are situated at three distances relative to the center of the diffuser structure, and lie along a north-south axis at the same water depth (15.2 m) as the center of the diffuser. Depending on the direction of the local oceanic currents at the time of sampling, the discharge may influence one or more of these stations. The up-current stations on the opposite side of the diffuser then act as reference stations. Comparisons between the water properties at these antipodal stations quantify departures from ambient seawater properties caused by the discharge and allow compliance with the NPDES discharge permit to be determined.

The finite size of the diffuser is an important consideration in the assessment of wastewater dispersion close to the discharge. Although the discharge is considered a "*point source*" for modeling and regulatory purposes, it does not occur at a point of infinitesimal size. Instead, the discharge is distributed along a 42 m section of the seafloor, and, ultimately, the amount of wastewater dispersion at a given point in the water column is dictated by its distance from the closest diffuser port, rather than its distance from the center of the diffuser structure. This "*closest approach*" distance can be considerably less than the centerpoint distance normally cited in modeling studies.

Another important consideration for compliance evaluation is the ability to determine the actual location of the measurements. Discerning small spatial separations within the compact sampling pattern only became feasible after the advent of Differential Global Positioning Systems (DGPS). The accuracy of traditional navigation systems such as LORAN or standard GPS is typically ±15 m, a span equal to half the total width of the ZID itself. DGPS incorporates a second signal from a fixed, land-based beacon that continuously transmits position errors in standard GPS readings to the DGPS receiver onboard the survey vessel. Real-time correction for these position errors provides an extremely stable and accurate offshore navigational reading with position errors of no more than 2 m, and often of sub-meter accuracy.

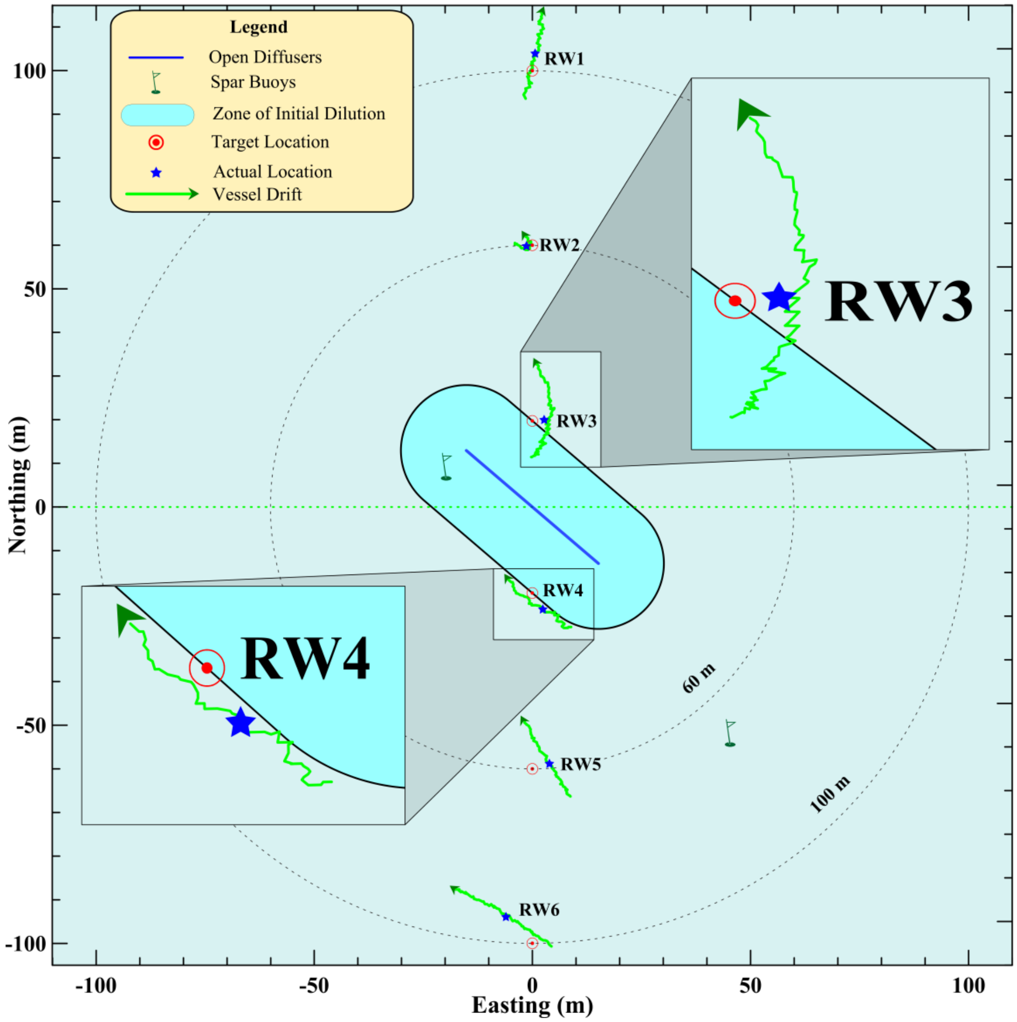


**Figure 2.** Station Locations

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

Recording of DGPS positions at one-second intervals allows precise determination of sampling locations throughout the vertical CTD profiling conducted at the six individual stations, as well as during the tow survey. Knowledge of the precise location of individual CTD measurements relative to the diffuser is critical for accurate interpretation of the water-property fields. During vertical-profile sampling, the actual measurement locations rarely coincide with the target coordinates listed in Table 1 because winds, waves, and currents induce unavoidable horizontal offsets (drift). Even during quiescent metocean[4] conditions, the residual momentum of the survey vessel as it approaches the target locations can create perceptible offsets. Using DGPS however, these offsets can be quantified, and the vessel location can be precisely tracked throughout sampling at each station.

The downcasts during the October 2015 survey were conducted progressing from south to north, beginning with Station RW6. The magnitude of the drift at each of the six stations during the October 2015 survey is apparent from the length of the green tracklines in Figure 2. The tracklines trace the horizontal movement of the CTD as it was lowered to the seafloor at each station. Their lengths and offsets from the target locations reflect the overall station-keeping ability during the October 2015 survey.

The time it took the CTD to traverse the water column to the seafloor, which averaged 1 min 28 s, was consistent among stations, as was the 21-m lateral distance traversed by the instrument package at all stations except Station RW2, where the CTD moved only 2.9 m (Figure 2). In contrast to the other stations, the vessel approached RW2 directly from the north, and retained some of its southward residual momentum at the beginning of the downcast. This southward motion counteracted the strong northward ocean current that prevailed at the time of the survey. Because of this strong current, the lateral movement at the other stations was approximately twice the distance traveled by the CTD in most prior surveys.

The lateral movement of the CTD movement at any given is typically determined by a complex interplay between the external influences of winds and currents, and the vessel's residual momentum immediately prior to each downcast. However, the light breeze out of the east that was present during the October survey[5] had little influence on vessel movement compared to the swift prevailing current.

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 (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. During the October 2015 survey, only the deep portion[6] of the data collected at Station RW3 was subject to a compliance assessment because the cast began within the ZID and traversed the ZID boundary as it was transported to the north (see the upper right inset in Figure 2). In contrast, the CTD downcast at Station RW4 (lower left

4 Meteorological and oceanographic conditions include winds, waves, tides, and currents.
5 Refer to the meteorological and oceanographic observations listed in Table 4 later in this report.
6 Below 7.5 m

inset) paralleled the ZID boundary, and only briefly crossed into the ZID. Thus, only the single CTD measurement[7] was not subject to a compliance evaluation.

Compliance assessments notwithstanding, measurements acquired within the ZID lend valuable insight into the outfall's effectiveness at dispersing wastewater. For example, low dilution rates and concentrated effluent throughout the ZID would indicate potentially damaged or broken diffuser ports. Analysis of the outfall's operation over the past two and a half decades, however, demonstrates that it has maintained a high level of effectiveness in effluent dispersal. In fact, without the occasional measurements recorded within the ZID due to vessel drift, the extremely dilute discharge plume might remain undetected within all the vertical profiles collected during a given survey.

It has not always been possible to determine which measurements were subject to permit limits among hydrocasts near the ZID boundary, however. For example, prior to 1999 and before the advent of DGPS, CTD locations could not be determined with sufficient accuracy to establish whether the average station position was located within the ZID, much less how the CTD was moving laterally during the hydrocast. Because of these navigational limitations, sampling was presumed to occur at a single, imprecisely determined, horizontal location. Federal and state reporting of monitoring data still mandates identification of a single position for all of the CTD data collected at a particular station. Thus, for regulatory reporting, and for consistency with past surveys, the October 2015 survey also identifies a single sampling location for each station. These average station positions are identified by the blue stars in Figure 2, and are listed in Table 2 along with their distances from the diffuser structure.

**Table 2.** Average Position of Vertical Profiles during the October 2015 Survey

| Station | Time (PDT) | | Latitude | Longitude | Closest Approach | |
|---|---|---|---|---|---|---|
| | Downcast | Upcast | | | Range[8] (m) | Bearing[9] (ºT) |
| RW1 | 8:19:18 | 8:20:37 | 35° 23.255' N | 120° 52.504' W | 92.4 | 10 |
| RW2 | 8:15:17 | 8:16:36 | 35° 23.231' N | 120° 52.505' W | 48.9 | 16 |
| RW3 | 8:09:45 | 8:11:07 | 35° 23.210' N | 120° 52.502' W | **17.0**[10] | 41 |
| RW4 | 8:04:01 | 8:05:23 | 35° 23.186' N | 120° 52.502' W | **16.2**[11] | 221 |
| RW5 | 7:57:50 | 7:59:15 | 35° 23.167' N | 120° 52.501' W | 47.2 | 194 |
| RW6 | 7:51:00 | 7:53:00 | 35° 23.148' N | 120° 52.508' W | 83.6 | 195 |

## OCEANOGRAPHIC PROCESSES

The trajectory of a satellite-tracked drogued drifter measured oceanic flow throughout the October 2015 survey (Figure 3). Modeled after the curtain-shade design of Davis et al. (1982) and drogued at mid-depth (7 m), a drifter has been deployed during each of the quarterly water column surveys conducted over the past two decades. In this configuration, the oceanic flow field rather than surface wind dictates the drifter's trajectory, providing a good assessment of the plume's movement after discharge.

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7 At 7.0 m
8 Distance from the closest open diffuser port to the average profile location
9 Angle measured clockwise relative to true north from the closest diffuser port to the average profile location
10 CTD measurements collected above 8 m at Station RW3 were located within the ZID boundary (refer to the upper-right inset in Figure 2).
11 A single CTD measurement collected at a depth of 7 m at Station RW4 was located 0.1 m within the ZID boundary (refer to the lower-left inset in Figure 2).

During the October 2015 survey, the drifter was deployed near the diffuser structure at 7:36 AM, and was recovered at 10:11 AM at a location 956 m almost due north (357ºT[12]) of its original release point (red dots in Figure 3). In contrast to most prior surveys, the direction and speed of the drifter was relatively uniform throughout its deployment. The steady flow speed is reflected by the uniform spacing of the green and black dots in Figure 3, which show the drifter's progress at five- and ten-minute intervals. Additionally, the drifter's average speed of 10.3 m/s[13] was double maximum speeds measured during most prior surveys. At this rapid transport rate, effluent would have experienced only a brief, two-and-a-half-minute residence time within the ZID.

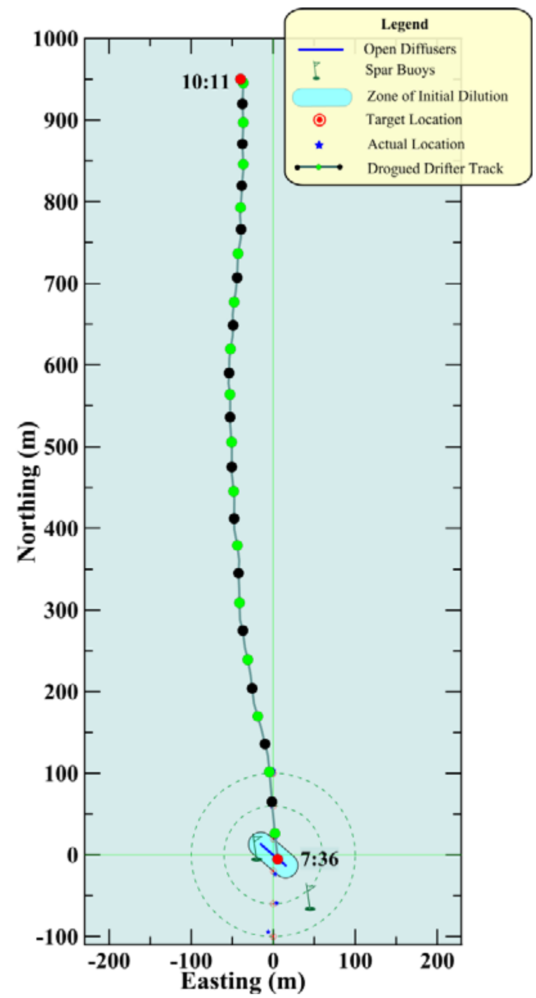


**Figure 3.** Drogued Drifter Trajectory

The overall flow direction measured by the drifter was consistent with the flood tide that prevailed during the October 2015 survey (Figure 4). Flood tides normally induce a weak northeastward (onshore) flow in the survey region. While tidal forcing may have contributed to the observed flow, currents within the survey area are often dominated by other processes, such as upwelling. Upwelling winds can also induce a northeastward flow at depth as offshore waters move shoreward and upwell to replace near-surface waters driven offshore by the winds.

The onset of upwelling-dominated processes begins with a rapid intensification of southeastward-directed winds along the central coast during late March and or early April as shown by the positive (blue) upwelling indices in Figure 5. This transition to more persistent southeastward winds is initiated by the stabilization of a high-pressure field over the northeastern Pacific Ocean. Clockwise winds around this pressure field drive prevailing northwesterly winds along the central California coast. These winds move warmer surface waters southwestward and offshore, allowing deep, cool, nutrient-rich waters to move shoreward and upwell near the coast.

The nutrient-rich seawater that is brought to the sea surface near the coast by upwelling enables phytoplanktonic blooms that are the foundation of the productive marine fishery found along the central California coast. The 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 shallow thermocline (<10 m) that is commonly maintained throughout summer and into fall. As a result, some degree of upwelling is almost always present during offshore surveys (yellow diamonds in Figure 5). During winter, upwelling is typically weak, and occasionally downwelling events, indicated by the negative (red shaded) indices in Figure 5, occur when passing storms temporarily reverse the normal wind

[12] Direction measured clockwise relative to true (rather than magnetic) north
[13] 0.200 kt

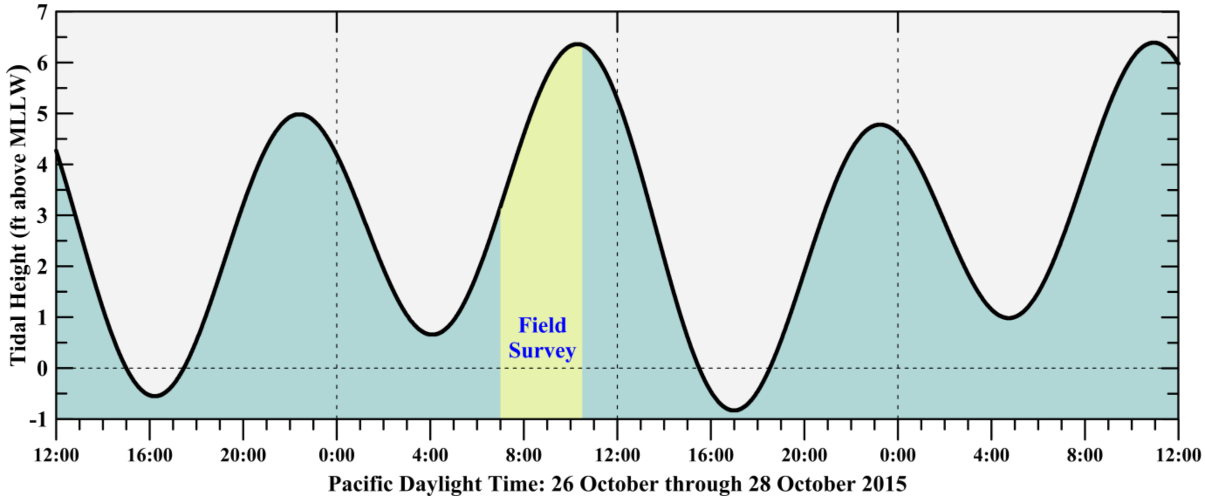


**Figure 4**. Tidal Level during the October 2015 Survey

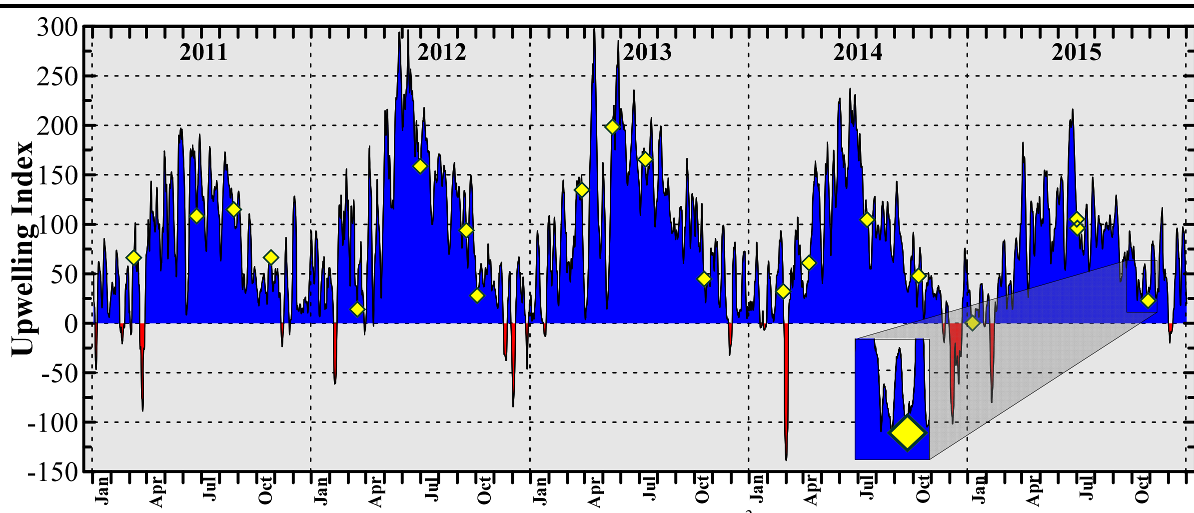


**Figure 5**. Five-Day Average Upwelling Index ($m^3/s/100$ m of coastline)

pattern and drive surface waters shoreward. As the surface waters approach the coastline, they downwell, producing nearly uniform seawater properties throughout the water column.

Only weak upwelling winds prevailed at the time of the October 2015 survey (see the inset showing the last yellow diamond in Figure 5). Nevertheless, slightly stronger winds in the week prior to the survey produced a pattern of sea surface temperatures indicative of mild upwelling processes within the central-coast region. This pattern was captured by the satellite image shown on the cover of this report. The image was recorded by infrared sensors on one of NOAA's polar orbiting satellites during a period of relatively cloudless skies five days prior to the survey. The presence of a pool of cooler, upwelled water is visually apparent along the south-central coastline (dark-blue shading), although the 3°C contrast between these sea-surface temperatures and temperatures farther offshore (in green) indicates that the upwelling event was weaker than those of the spring and summer seasons.

Moreover, the upwelling index on the day of the survey (inset in Figure 5) demonstrates that the upwelling induced by winds at the time of the survey were negligible. Consequently, as described below, the water column was only weakly stratified at the time of the survey. This weak stratification was probably a relic of the prior week's upwelling event. The stratification did not result from strong upwelling-induced vertical counterflow at the sea surface and seafloor at the time of the October 2015 survey. Thus, while the strong northward oceanic flow measured within northern Estero Bay during the survey is representative of either tidal or upwelling forcing, it is likely that it was caused by other external oceanographic processes, such as large-scale along-shore pressure gradients, or the passing of a large eddy associated with the California Current.[14]

## METHODS

The 38 ft F/V *Bonnie Marietta*, owned and operated by Captain Mark Tognazzini of Morro Bay, served as the survey vessel on Tuesday, 27 October 2015. Douglas Coats of Marine Research Specialists (MRS) supervised scientific operations as Chief Scientist, and provided data-acquisition and navigational support during the survey. Dean Dusette, also of MRS, assisted with the deployment and recovery of the CTD and drifter in conjunction with crewmembers William Skok and Marc Tognazzini. Marc Tognazzini also collected auxiliary measurements of biological, meteorological, and oceanographic conditions.

### *Auxiliary Measurements*

Auxiliary measurements and observations were collected during the vertical water-column profiling conducted at each of the six stations. Standard observations of weather and sea conditions, and beneficial uses, were augmented by visual inspection of the sea surface for floating particulates, oil sheens, and discoloration potentially related to the effluent discharge. Other auxiliary measurements collected at each station included wind speeds and air temperatures measured with a handheld Kestrel® 2000 Thermo-Anemometer, and oceanic flow measurements made throughout the survey using a drogued drifter.

Additionally, at all six stations, a Secchi disk was lowered through the water column to determine its depth of disappearance. Secchi depths provide a visual measure of near-surface turbidity or water clarity. The depth of disappearance is inversely proportional to the average amount of organic and inorganic suspended material along a line of sight in the upper water column. As such, Secchi depths measure natural light penetration, which can be limited by increased suspended particulate loads from plankton blooms, onshore runoff, seafloor sediment resuspension, and wastewater discharge. They are also biologically meaningful because the depth of the euphotic zone, where most oceanic photosynthesis occurs, extends to approximately twice the Secchi depth.

### *Instrumental Measurements*

A Sea Bird Electronics SBE-19plusV2 Seacat CTD instrument package collected measurements of conductivity, temperature, light transmittance, dissolved oxygen (DO), pH, and pressure during the October 2015 survey. The six seawater properties used to assess receiving-water quality in this report were derived from the continuously recorded output from the CTD's probes and sensors. Although pressure-housing limitations confine the CTD to depths less than 680 m (Table 3), this is well beyond the maximum depth of the deepest station in the outfall survey.

[14] See the large eddy-like feature delineated in dark blue offshore Point Buchon in the cover image

**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)[15] | % | 0 to 100 | ± 0.3 | ± 0.03 |
| Oxygen (SBE 43) | % Saturation | 0 to 120 | ± 2 | — |
| pH (SBE 18) | pH | 0 to 14 | ± 0.1 | — |

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

Assessments of all three of the physical parameters (salinity, temperature, and density) helped determine the lateral extent of the effluent plume during the tow phase of the survey. Additionally, during the vertical-profiling phase, they quantified layering, or vertical stratification and stability of the water column, which determines the behavior and dynamics of the effluent as it mixes with seawater within 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 the first vertical hydrocast at Station RW6, the CTD was held below the sea surface for seven minutes. Subsequently, the CTD was raised to within 0.5 m of the sea surface and profiling commenced. The CTD was lowered at a continuous rate of speed to the seafloor. Measurements at all six stations were collected during a single deployment of the CTD package by towing it below the water surface while transiting between adjacent stations.

At 8:25 AM, following completion of the last vertical profile at RW1, the CTD instrument package was brought aboard the survey vessel and reconfigured for horizontal towing with forward-looking probes. The CTD was fitted with a horizontal stabilizer wing and a depth-suppression weight was added to the towline to achieve constant-depth tows. After the reconfigured CTD was deployed, it was towed around and across the ZID at two separate depths, one within the surface mixed layer and one at mid-depth within the thermocline, in accordance with the monitoring requirements of the NPDES discharge permit (Figure 6).

Eight transects of shallow data were collected at an average depth near 3.5 m, and an average speed of 1.64 m/s over the span of 33 minutes (Figure 6). Subsequently, eight additional passes were made with the CTD at an average depth near 9.8 m. During this 42-minute mid-depth tow, vessel speed averaged 1.61 m/s. At the observed towing speeds and the 4 Hz sampling rate, at least 2.4 CTD measurements were collected for each meter traversed. This complies with the NPDES discharge permit requirement for minimum horizontal resolution of at least one sample per meter during at least five passes around and

[15] 25-cm path length of red (660 nm) light

across the ZID at two separate depths, one within the surface mixed layer and one at mid-depth within the thermocline.

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.[16]

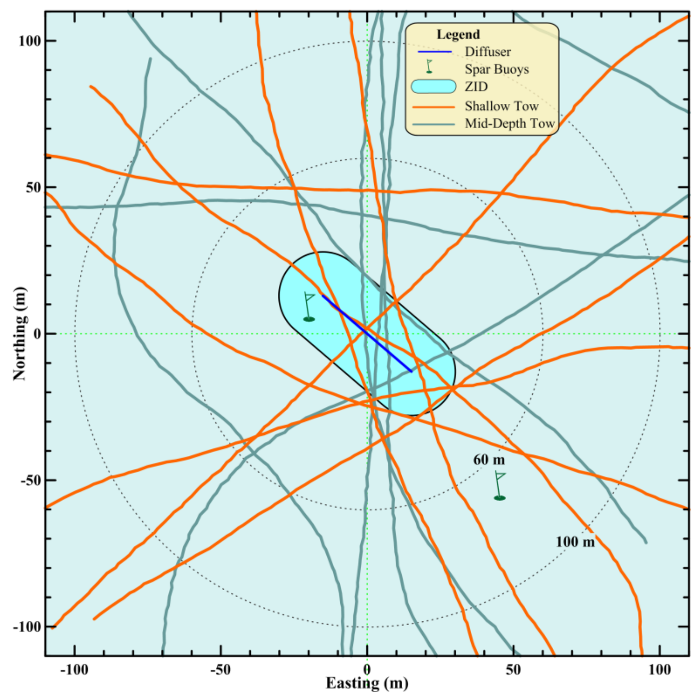


**Figure 6.** CTD Tracklines during the October 2015 Tow Surveys

## *Quality Control*

During the vertical-profiling and horizontal-towing phases of the survey, real-time data were monitored for completeness and range acceptability. Although real-time monitoring indicated the recorded properties were complete and within acceptable coastal seawater ranges,[17] subsequent post-processing revealed several events that impacted portions of the data, resulting in the adjustment or exclusion of these data prior to initiating the compliance analysis. For example, review of the tow data revealed that the CTD changed depth when the vessel executed a turn at the beginning and end of each transect. The offsets in CTD depth are induced by changes in vessel speed and direction that are instituted to realign the vessel between each transect. Because of the complex interaction between turn radius, vessel speed, and CTD depth, the CTD's target depth cannot always be precisely maintained at these times.

Because the discharge-related anomalies used in the compliance analysis are identified by comparing the amplitudes of measurements acquired at the same depth level, the ability to resolve anomalies with statistical certainty is compromised when data from different depth levels are combined in the horizontal maps. This is true whenever the water column is stratified, even slightly, as was the case during the October 2015 survey.

The exclusion of small portions of tow data during turns did not, however, adversely affect the compliance analysis because all 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 6, met the permit monitoring requirement of at least five passes near the diffuser structure at each tow depth.

Additionally, a slightly increased transmissometer response time was observed in the October 2015 dataset. The increased lag, which ranged between 0.75 and 1.25 s, was first noticed during the initial stage of post-processing, when the CTD data was synchronized with the navigational dataset. Synchronization

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16 Figures 8 and 9 later in this report

17 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.

is made possible by precisely logging multiple times when the transmissometer's light path was manually blocked and unblocked on-deck prior to, and after CTD deployment. During post-processing, aligning the measured transmissometer response with the associated blocking events recorded in the navigation file results in temporally compatible datasets, with offsets generally less than 0.25 s. However, during the October 2015 survey, the transmissometer did not immediately drop to zero when its path was blocked, or return to 100% transmissivity when it was unblocked. Although the small observed reduction in transmissometer response time did not materially affect the analysis in this report, it is an indication that water vapor within the sealed instrument was condensing on the lenses; a condition that will worsen over time. Upon discovery of the degradation in instrument response, the transmissometer was immediately returned to the manufacturer for servicing and repair.

## RESULTS

The fourth-quarter receiving-water survey was conducted on the morning of Tuesday, 27 October 2015. The receiving-water survey commenced at 7:36 AM with the deployment of the drogued drifter. Over the course of the ensuing 2.5 hours, offshore observations and measurements were collected as required by the NPDES monitoring program. The survey ended at 10:11 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 27 October 2015, skies were overcast, with light easterly winds that shifted from the southeast to northeast as the survey progressed from Station RW6 in the south to the northernmost station (RW1). Average wind speeds, calculated over one-minute intervals, decreased from 4.1 kt to 1.4 kt as the survey progressed and skies cleared (Table 4). Similarly, peak wind speeds declined from 6.0 kt to 1.4 kt. A swell out of the northwest had a significant wave height of three-to-four feet. Air temperatures remained fairly constant throughout the survey, averaging 15.25°C; a temperature somewhat lower than that of the sea surface.

**Table 4.** Standard Meteorological and Oceanographic Observations

| Station | Location[18] | | Diffuser Distance (m) | Time (PDT) | Air (°C) | Cloud Cover (%) | Wind Avg (kt) | Wind Max (kt) | Wind Dir (from) (°T) | Swell Ht/Dir (ft/°T) | Secchi Depth (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Latitude | Longitude | | | | | | | | | |
| RW1 | 35° 23.266' N | 120° 52.502' W | 111.6 | 8:20:51 | 15.2 | 50 | 1.4 | 1.4 | ENE | 3-4 NW | 11.0 |
| RW2 | 35° 23.230' N | 120° 52.500' W | 49.3 | 8:16:18 | 15.1 | 40 | 2.3 | 3.0 | ENE | 3-4 NW | 11.0 |
| RW3 | 35° 23.213' N | 120° 52.505' W | 18.2 | 8:10:47 | 15.8 | 60 | 2.2 | 2.8 | ESE | 3-4 NW | 13.0 |
| RW4 | 35° 23.191' N | 120° 52.507' W | 13.8 | 8:05:02 | 15.5 | 60 | 2.2 | 2.9 | ESE | 3-4 NW | 13.0 |
| RW5 | 35° 23.172' N | 120° 52.506' W | 41.2 | 7:58:48 | 14.8 | 60 | 2.4 | 3.0 | ESE | 3-4 NW | 13.0 |
| RW6 | 35° 23.148' N | 120° 52.515' W | 86.3 | 7:52:19 | 15.1 | 60 | 4.1 | 6.0 | SE | 3-4 NW | 13.0 |

At stations unaffected by the plume in the upper water column, the 13-m Secchi depths reflected the presence of a 26-m euphotic zone, indicating that ambient light easily penetrated to the seafloor. Even at the northernmost stations (RW1 and RW2), where more-turbid deep seawater was carried upward in the water column by the rising plume and caused 2-m reduction in Secchi depth, ambient light still easily extended to the seafloor.

[18] Locations are the vessel positions at the time the Secchi depths were measured. These typically depart slightly from the CTD profile locations listed in Table 2.

The unusually high ambient seawater clarity throughout the water column at the time of the survey was also reflected in the elevated transmissivities that were recorded throughout the survey. Transmissivity exceeded 90% at depths above 10 m at all stations. This extraordinarily high water clarity within the upper water column reflects the weak upwelling winds that prevailed at the time of the survey. During most surveys, upwelling-induced planktonic blooms markedly reduce seawater clarity within the upper water column, and limit the euphotic zone to the surface mixed layer. During upwelling, nutrients carried into the upper water column are assimilated by phytoplankton, whose populations increase. Along with their associated zooplanktonic predators, these elevated plankton densities reduce the penetration of ambient light thru the water column.

Communication with plant personnel and subsequent review of effluent discharge properties on the day of the survey, confirmed that the treatment process was performing well at time of the survey. The 0.778 million gallons of effluent discharged on 27 October had a temperature of 22°C, a suspended-solids concentration of 28 mg/L, and a pH of 7.6. No quantifiable amounts of oil and grease were present in the effluent discharged on that day. The biochemical oxygen demand (BOD) of the effluent measured four days prior to the survey, on 23 October, was 33 mg/L; while the demand measured four days after the survey, on 31 October, was 35 mg/L.

During the October 2015 survey, visual observations demonstrated continued beneficial use of the coastal waters within Estero Bay by both wildlife and recreational users. Six vessels were observed actively fishing the area approximately 1 km outside of the entrance to Morro Bay. Small numbers of pelagic and coastal birds were observed transiting the survey area. Additionally, the visual observations did not reveal aesthetic impacts on the sea surface from the discharge of effluent offshore. 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. However, an area of reduced capillary wave formation was briefly observed north of the ZID during the downcast at Station RW1. This surface-boil feature was a physical manifestation of the surfacing effluent plume and was a clear indication that the plume has risen to the surface rather than being trapped at depth. Its location and presence at the sea surface was consistent with the northward flowing current and weak stratification that prevailed at the time of the survey.

### *Instrumental Observations*

Data collected during vertical profiling were processed in accordance with standard procedures (SCCWRP 2002), and are collated within 0.5-m depth intervals in Table 5. Data collected during the October 2015 survey reflect weakly stratified conditions within Estero Bay indicative of a minor upwelling event in the week prior to the survey (Figure 5).

Upwelling of varying intensity occurs most of the year along the central California coast, with the strongest upwelling winds beginning in March or April and extending through the summer. The intensity of upwelling tends to decline into fall, although pulses of sustained northwesterly winds still occur. 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.

**Table 5. Vertical Profile Data Collected on 27 October 2015**

| Depth (m) | Temperature (°C) | | | | | | Salinity ( ‰ ) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | RW-1 | RW-2 | RW-3 | RW-4 | RW-5 | RW-6 | RW-1 | RW-2 | RW-3 | RW-4 | RW-5 | RW-6 |
| 0.5 | 16.939 | | 16.958 | 16.968 | | | 33.242 | | 33.266 | 33.266 | | |
| 1.0 | 16.938 | 16.954 | 16.961 | 16.968 | 16.966 | 16.967 | 33.241 | 33.250 | 33.266 | 33.266 | 33.266 | 33.266 |
| 1.5 | 16.931 | 16.956 | 16.965 | 16.971 | 16.971 | 16.970 | 33.240 | 33.250 | 33.266 | 33.266 | 33.266 | 33.266 |
| 2.0 | 16.937 | 16.957 | 16.967 | 16.975 | 16.972 | 16.975 | 33.246 | 33.251 | 33.266 | 33.266 | 33.266 | 33.266 |
| 2.5 | 16.946 | 16.957 | 16.968 | 16.975 | 16.973 | 16.975 | 33.254 | 33.250 | 33.266 | 33.266 | 33.266 | 33.266 |
| 3.0 | 16.942 | 16.958 | 16.969 | 16.973 | 16.973 | 16.975 | 33.254 | 33.251 | 33.266 | 33.266 | 33.266 | 33.266 |
| 3.5 | 16.943 | 16.958 | 16.969 | 16.972 | 16.973 | 16.975 | 33.253 | 33.250 | 33.266 | 33.266 | 33.266 | 33.266 |
| 4.0 | 16.947 | 16.963 | 16.968 | 16.972 | 16.974 | 16.974 | 33.254 | 33.257 | 33.266 | 33.265 | 33.265 | 33.266 |
| 4.5 | 16.940 | 16.966 | 16.968 | 16.972 | 16.974 | 16.977 | 33.251 | 33.263 | 33.266 | 33.265 | 33.265 | 33.266 |
| 5.0 | 16.920 | 16.966 | 16.969 | 16.972 | 16.975 | 16.976 | 33.246 | 33.265 | 33.266 | 33.265 | 33.265 | 33.265 |
| 5.5 | 16.919 | 16.967 | 16.969 | 16.972 | 16.975 | 16.975 | 33.247 | 33.265 | 33.266 | 33.265 | 33.265 | 33.265 |
| 6.0 | 16.918 | 16.965 | 16.969 | 16.972 | 16.974 | 16.976 | 33.246 | 33.261 | 33.266 | 33.265 | 33.265 | 33.265 |
| 6.5 | 16.923 | 16.962 | 16.970 | 16.970 | 16.974 | 16.976 | 33.249 | 33.258 | 33.266 | 33.265 | 33.265 | 33.265 |
| 7.0 | 16.927 | 16.955 | 16.969 | 16.960 | 16.973 | 16.976 | 33.250 | 33.250 | 33.266 | 33.264 | 33.265 | 33.265 |
| 7.5 | 16.932 | 16.936 | 16.966 | 16.953 | 16.973 | 16.976 | 33.252 | 33.236 | 33.265 | 33.264 | 33.265 | 33.265 |
| 8.0 | 16.938 | 16.926 | 16.964 | 16.952 | 16.965 | 16.972 | 33.254 | 33.231 | 33.258 | 33.264 | 33.264 | 33.265 |
| 8.5 | 16.937 | 16.925 | 16.966 | 16.953 | 16.953 | 16.961 | 33.254 | 33.231 | 33.255 | 33.264 | 33.263 | 33.264 |
| 9.0 | 16.934 | 16.925 | 16.952 | 16.954 | 16.948 | 16.959 | 33.254 | 33.233 | 33.221 | 33.264 | 33.263 | 33.264 |
| 9.5 | 16.919 | 16.927 | 16.932 | 16.951 | 16.950 | 16.959 | 33.253 | 33.235 | 33.167 | 33.264 | 33.264 | 33.264 |
| 10.0 | 16.915 | 16.927 | 16.926 | 16.951 | 16.950 | 16.952 | 33.254 | 33.237 | 33.160 | 33.264 | 33.264 | 33.264 |
| 10.5 | 16.913 | 16.937 | 16.923 | 16.955 | 16.940 | 16.937 | 33.255 | 33.237 | 33.163 | 33.264 | 33.263 | 33.263 |
| 11.0 | 16.912 | 16.940 | 16.924 | 16.947 | 16.934 | 16.929 | 33.255 | 33.237 | 33.188 | 33.264 | 33.263 | 33.263 |
| 11.5 | 16.910 | 16.936 | 16.925 | 16.923 | 16.927 | 16.920 | 33.257 | 33.239 | 33.196 | 33.262 | 33.263 | 33.262 |
| 12.0 | 16.911 | 16.919 | 16.920 | 16.916 | 16.919 | 16.912 | 33.258 | 33.250 | 33.200 | 33.262 | 33.262 | 33.262 |
| 12.5 | 16.911 | 16.911 | 16.922 | 16.916 | 16.911 | 16.907 | 33.259 | 33.255 | 33.209 | 33.262 | 33.262 | 33.262 |
| 13.0 | 16.910 | 16.908 | 16.921 | 16.906 | 16.909 | 16.902 | 33.260 | 33.259 | 33.209 | 33.262 | 33.262 | 33.262 |
| 13.5 | 16.908 | 16.907 | 16.919 | 16.902 | 16.907 | 16.898 | 33.260 | 33.260 | 33.213 | 33.262 | 33.262 | 33.262 |
| 14.0 | 16.906 | 16.905 | 16.920 | 16.897 | 16.902 | 16.895 | 33.260 | 33.262 | 33.210 | 33.262 | 33.262 | 33.262 |
| 14.5 | 16.905 | 16.904 | 16.915 | 16.894 | 16.895 | 16.891 | 33.261 | 33.262 | 33.211 | 33.262 | 33.262 | 33.262 |
| 15.0 | 16.904 | 16.904 | 16.915 | 16.895 | 16.891 | 16.890 | 33.261 | 33.262 | 33.216 | 33.262 | 33.262 | 33.262 |
| 15.5 | 16.904 | 16.903 | 16.915 | 16.896 | 16.889 | 16.886 | 33.261 | 33.262 | 33.217 | 33.262 | 33.262 | 33.262 |
| 16.0 | 16.902 | 16.902 | 16.916 | 16.894 | 16.890 | 16.886 | 33.261 | 33.262 | 33.219 | 33.262 | 33.262 | 33.262 |
| 16.5 | 16.901 | 16.900 | 16.914 | 16.891 | 16.890 | 16.885 | 33.262 | 33.262 | 33.222 | 33.262 | 33.262 | 33.262 |
| 17.0 | 16.900 | 16.901 | 16.915 | 16.890 | 16.890 | 16.885 | 33.261 | 33.262 | 33.218 | 33.262 | 33.262 | 33.262 |
| 17.5 | | | | 16.888 | | 16.883 | | | | 33.262 | | 33.262 |

**Table 5. Vertical Profile Data Collected on 27 October 2015** (continued)

| Depth (m) | Density ($\sigma_t$) | | | | | | pH | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | RW-1 | RW-2 | RW-3 | RW-4 | RW-5 | RW-6 | RW-1 | RW-2 | RW-3 | RW-4 | RW-5 | RW-6 |
| 0.5 | 24.179 | | 24.193 | 24.191 | | | 8.087 | | 8.090 | 8.090 | | |
| 1.0 | 24.179 | 24.182 | 24.193 | 24.191 | 24.191 | 24.192 | 8.086 | 8.086 | 8.090 | 8.090 | 8.092 | 8.089 |
| 1.5 | 24.180 | 24.182 | 24.192 | 24.190 | 24.191 | 24.191 | 8.087 | 8.087 | 8.090 | 8.091 | 8.092 | 8.089 |
| 2.0 | 24.184 | 24.182 | 24.192 | 24.190 | 24.190 | 24.189 | 8.086 | 8.088 | 8.090 | 8.090 | 8.091 | 8.089 |
| 2.5 | 24.187 | 24.182 | 24.191 | 24.189 | 24.190 | 24.189 | 8.087 | 8.088 | 8.090 | 8.090 | 8.092 | 8.090 |
| 3.0 | 24.188 | 24.182 | 24.191 | 24.190 | 24.190 | 24.189 | 8.087 | 8.089 | 8.090 | 8.090 | 8.092 | 8.090 |
| 3.5 | 24.187 | 24.182 | 24.191 | 24.190 | 24.190 | 24.189 | 8.087 | 8.089 | 8.090 | 8.090 | 8.092 | 8.090 |
| 4.0 | 24.187 | 24.186 | 24.191 | 24.190 | 24.189 | 24.190 | 8.089 | 8.089 | 8.090 | 8.091 | 8.092 | 8.090 |
| 4.5 | 24.186 | 24.190 | 24.191 | 24.190 | 24.189 | 24.189 | 8.089 | 8.089 | 8.090 | 8.090 | 8.093 | 8.091 |
| 5.0 | 24.187 | 24.191 | 24.191 | 24.190 | 24.189 | 24.189 | 8.088 | 8.090 | 8.091 | 8.090 | 8.092 | 8.090 |
| 5.5 | 24.188 | 24.191 | 24.191 | 24.190 | 24.189 | 24.189 | 8.088 | 8.090 | 8.091 | 8.091 | 8.093 | 8.090 |
| 6.0 | 24.188 | 24.188 | 24.191 | 24.190 | 24.189 | 24.189 | 8.087 | 8.091 | 8.091 | 8.090 | 8.092 | 8.090 |
| 6.5 | 24.189 | 24.186 | 24.191 | 24.190 | 24.189 | 24.189 | 8.087 | 8.090 | 8.091 | 8.090 | 8.092 | 8.090 |
| 7.0 | 24.189 | 24.182 | 24.191 | 24.192 | 24.190 | 24.189 | 8.086 | 8.091 | 8.091 | 8.091 | 8.093 | 8.090 |
| 7.5 | 24.189 | 24.176 | 24.191 | 24.193 | 24.190 | 24.189 | 8.085 | 8.090 | 8.091 | 8.090 | 8.092 | 8.091 |
| 8.0 | 24.189 | 24.174 | 24.186 | 24.193 | 24.191 | 24.189 | 8.085 | 8.089 | 8.091 | 8.090 | 8.091 | 8.091 |
| 8.5 | 24.190 | 24.175 | 24.183 | 24.193 | 24.193 | 24.191 | 8.087 | 8.088 | 8.089 | 8.088 | 8.091 | 8.090 |
| 9.0 | 24.190 | 24.176 | 24.160 | 24.193 | 24.194 | 24.192 | 8.087 | 8.086 | 8.088 | 8.089 | 8.091 | 8.090 |
| 9.5 | 24.193 | 24.177 | 24.124 | 24.194 | 24.194 | 24.192 | 8.087 | 8.085 | 8.086 | 8.089 | 8.091 | 8.090 |
| 10.0 | 24.194 | 24.179 | 24.120 | 24.194 | 24.194 | 24.193 | 8.086 | 8.085 | 8.085 | 8.089 | 8.089 | 8.090 |
| 10.5 | 24.196 | 24.177 | 24.123 | 24.193 | 24.195 | 24.196 | 8.086 | 8.084 | 8.083 | 8.090 | 8.090 | 8.089 |
| 11.0 | 24.196 | 24.176 | 24.141 | 24.194 | 24.197 | 24.198 | 8.084 | 8.085 | 8.080 | 8.089 | 8.090 | 8.089 |
| 11.5 | 24.198 | 24.179 | 24.147 | 24.198 | 24.199 | 24.200 | 8.084 | 8.084 | 8.079 | 8.089 | 8.089 | 8.088 |
| 12.0 | 24.199 | 24.190 | 24.151 | 24.201 | 24.200 | 24.202 | 8.084 | 8.085 | 8.080 | 8.088 | 8.088 | 8.087 |
| 12.5 | 24.199 | 24.196 | 24.158 | 24.201 | 24.202 | 24.203 | 8.084 | 8.085 | 8.079 | 8.087 | 8.088 | 8.086 |
| 13.0 | 24.200 | 24.200 | 24.159 | 24.203 | 24.202 | 24.204 | 8.083 | 8.083 | 8.078 | 8.085 | 8.087 | 8.086 |
| 13.5 | 24.201 | 24.201 | 24.162 | 24.204 | 24.203 | 24.205 | 8.084 | 8.083 | 8.078 | 8.084 | 8.086 | 8.085 |
| 14.0 | 24.202 | 24.203 | 24.159 | 24.205 | 24.204 | 24.205 | 8.083 | 8.082 | 8.079 | 8.083 | 8.085 | 8.084 |
| 14.5 | 24.202 | 24.203 | 24.162 | 24.205 | 24.205 | 24.206 | 8.083 | 8.083 | 8.078 | 8.082 | 8.085 | 8.084 |
| 15.0 | 24.203 | 24.203 | 24.165 | 24.205 | 24.206 | 24.207 | 8.083 | 8.083 | 8.078 | 8.081 | 8.084 | 8.082 |
| 15.5 | 24.203 | 24.204 | 24.166 | 24.205 | 24.206 | 24.207 | 8.083 | 8.082 | 8.077 | 8.080 | 8.083 | 8.082 |
| 16.0 | 24.203 | 24.204 | 24.167 | 24.205 | 24.206 | 24.207 | 8.082 | 8.082 | 8.079 | 8.081 | 8.082 | 8.081 |
| 16.5 | 24.204 | 24.204 | 24.170 | 24.206 | 24.206 | 24.208 | 8.081 | 8.081 | 8.079 | 8.079 | 8.081 | 8.080 |
| 17.0 | 24.204 | 24.204 | 24.167 | 24.206 | 24.206 | 24.208 | 8.082 | 8.081 | 8.078 | 8.078 | 8.080 | 8.078 |
| 17.5 | | | | 24.207 | | 24.208 | | | | 8.077 | | 8.079 |

**Table 5. Vertical Profile Data Collected on 27 October 2015** (continued)

| Depth (m) | Dissolved Oxygen (mg/L) | | | | | | Transmissivity (%) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | RW-1 | RW-2 | RW-3 | RW-4 | RW-5 | RW-6 | RW-1 | RW-2 | RW-3 | RW-4 | RW-5 | RW-6 |
| **0.5** | 7.745 | | 7.782 | 7.765 | | | 94.061 | | 97.561 | 97.383 | | |
| **1.0** | 7.735 | 7.766 | 7.786 | 7.750 | 7.790 | 7.789 | 93.851 | 95.815 | 97.564 | 97.510 | 97.561 | 97.636 |
| **1.5** | 7.743 | 7.775 | 7.779 | 7.765 | 7.807 | 7.784 | 93.751 | 96.029 | 97.626 | 97.600 | 97.637 | 97.682 |
| **2.0** | 7.771 | 7.779 | 7.790 | 7.760 | 7.792 | 7.792 | 94.224 | 96.133 | 97.622 | 97.501 | 97.504 | 97.719 |
| **2.5** | 7.751 | 7.762 | 7.784 | 7.756 | 7.785 | 7.786 | 95.489 | 96.260 | 97.566 | 97.402 | 97.706 | 97.681 |
| **3.0** | 7.761 | 7.778 | 7.798 | 7.775 | 7.796 | 7.788 | 95.826 | 96.451 | 97.534 | 97.509 | 97.585 | 97.680 |
| **3.5** | 7.742 | 7.778 | 7.788 | 7.775 | 7.798 | 7.792 | 95.255 | 96.059 | 97.520 | 97.442 | 97.692 | 97.663 |
| **4.0** | 7.730 | 7.778 | 7.793 | 7.761 | 7.792 | 7.784 | 95.634 | 96.479 | 97.544 | 97.466 | 97.683 | 97.694 |
| **4.5** | 7.719 | 7.783 | 7.796 | 7.774 | 7.798 | 7.784 | 95.849 | 97.010 | 97.522 | 97.370 | 97.600 | 97.682 |
| **5.0** | 7.729 | 7.786 | 7.794 | 7.788 | 7.792 | 7.793 | 95.510 | 97.037 | 97.444 | 97.480 | 97.627 | 97.648 |
| **5.5** | 7.729 | 7.766 | 7.786 | 7.777 | 7.799 | 7.793 | 93.203 | 97.412 | 97.448 | 97.514 | 97.597 | 97.629 |
| **6.0** | 7.743 | 7.768 | 7.797 | 7.753 | 7.786 | 7.781 | 93.329 | 97.437 | 97.567 | 97.533 | 97.594 | 97.565 |
| **6.5** | 7.740 | 7.767 | 7.782 | 7.753 | 7.796 | 7.792 | 93.234 | 97.259 | 97.517 | 97.477 | 97.620 | 97.493 |
| **7.0** | 7.751 | 7.737 | 7.789 | 7.759 | 7.794 | 7.786 | 93.600 | 96.813 | 97.510 | 97.478 | 97.585 | 97.452 |
| **7.5** | 7.749 | 7.725 | 7.767 | 7.759 | 7.779 | 7.781 | 93.695 | 95.385 | 97.185 | 96.980 | 97.639 | 97.550 |
| **8.0** | 7.750 | 7.729 | 7.785 | 7.762 | 7.781 | 7.775 | 94.243 | 93.124 | 96.402 | 96.461 | 97.354 | 97.519 |
| **8.5** | 7.741 | 7.731 | 7.719 | 7.763 | 7.770 | 7.784 | 94.356 | 92.776 | 96.553 | 96.216 | 96.494 | 97.138 |
| **9.0** | 7.716 | 7.729 | 7.694 | 7.771 | 7.780 | 7.783 | 94.088 | 92.415 | 96.293 | 96.312 | 96.159 | 96.718 |
| **9.5** | 7.725 | 7.733 | 7.687 | 7.764 | 7.759 | 7.775 | 92.747 | 92.678 | 92.013 | 96.401 | 96.041 | 96.564 |
| **10.0** | 7.722 | 7.739 | 7.699 | 7.768 | 7.751 | 7.763 | 92.074 | 92.930 | 90.390 | 96.281 | 96.337 | 96.465 |
| **10.5** | 7.716 | 7.725 | 7.704 | 7.746 | 7.752 | 7.751 | 92.260 | 92.695 | 88.576 | 96.239 | 95.898 | 95.422 |
| **11.0** | 7.711 | 7.725 | 7.693 | 7.729 | 7.743 | 7.750 | 92.092 | 92.764 | 89.541 | 96.256 | 95.318 | 94.717 |
| **11.5** | 7.719 | 7.719 | 7.706 | 7.738 | 7.734 | 7.743 | 92.088 | 93.322 | 90.410 | 95.013 | 94.428 | 94.022 |
| **12.0** | 7.714 | 7.716 | 7.720 | 7.721 | 7.737 | 7.733 | 91.788 | 93.521 | 90.409 | 94.800 | 93.805 | 93.843 |
| **12.5** | 7.720 | 7.713 | 7.703 | 7.715 | 7.734 | 7.722 | 91.961 | 92.310 | 90.505 | 93.817 | 93.495 | 93.128 |
| **13.0** | 7.715 | 7.709 | 7.711 | 7.711 | 7.730 | 7.714 | 92.430 | 92.060 | 90.699 | 93.718 | 92.913 | 93.110 |
| **13.5** | 7.697 | 7.691 | 7.706 | 7.688 | 7.705 | 7.718 | 91.683 | 92.071 | 91.170 | 92.713 | 92.720 | 92.189 |
| **14.0** | 7.692 | 7.702 | 7.695 | 7.692 | 7.698 | 7.718 | 91.416 | 91.625 | 91.187 | 91.575 | 92.429 | 91.729 |
| **14.5** | 7.712 | 7.703 | 7.696 | 7.696 | 7.698 | 7.697 | 91.123 | 91.493 | 91.038 | 91.295 | 91.023 | 91.496 |
| **15.0** | 7.702 | 7.695 | 7.703 | 7.705 | 7.693 | 7.695 | 90.976 | 91.353 | 90.675 | 90.558 | 90.460 | 90.727 |
| **15.5** | 7.701 | 7.687 | 7.705 | 7.689 | 7.699 | 7.690 | 90.826 | 91.280 | 90.800 | 90.302 | 89.390 | 90.110 |
| **16.0** | 7.695 | 7.669 | 7.687 | 7.674 | 7.685 | 7.692 | 90.688 | 91.112 | 90.789 | 90.352 | 89.244 | 89.704 |
| **16.5** | 7.688 | 7.684 | 7.696 | 7.660 | 7.686 | 7.706 | 90.595 | 90.595 | 91.199 | 90.021 | 89.097 | 89.676 |
| **17.0** | 7.692 | 7.679 | 7.661 | 7.671 | 7.685 | 7.684 | 90.639 | 90.697 | 91.173 | 89.549 | 89.104 | 89.676 |
| **17.5** | | | | 7.667 | | 7.705 | | | | 89.282 | | 89.666 |

If the upwelling winds are weak, occur only briefly, or have not occurred recently; the contrast between the surface and deep watermasses is reduced, and stratification appears as a more gradual vertical change in seawater properties below the surface mixed layer. This was the case during the October 2015 survey where the upwelling signatures in the vertical profiles unaffected by the discharge appear as a steady change with depth (below 10 m in Figure 7def). Absent are sharply defined interfaces where large changes in seawater properties occur over a limited vertical extent; signatures that are normally indicative of strong, recent upwelling conditions. In contrast, the thermocline that was present during the October 2015 survey extended across most of the bottom half of the water column.

This gradual transition zone separated a relatively uniform mixed layer, which extended down to 10 m, from a 2-m-thick seawater mass situated immediately above the sea floor. Within this weak thermocline, seawater properties exhibited steadily increasing or decreasing values that were determined by well-defined oceanographic processes. In particular, temperature (red lines), transmissivity (light blue lines), DO (dark blue lines), and pH (olive-colored lines) steadily decrease with increasing depth between 10 and 15 m. These decreases are mirrored by a pycnocline, where density (black lines) steadily increases with depth. These gradual vertical changes reflect the lingering effects of weak upwelling in the days prior to the survey. The transition zone separates a surface mixed layer from a turbid, colder, nutrient-rich but oxygen-poor watermass that migrated shoreward along the seafloor as part of the upwelling process.

The seawater properties of this deep watermass originate within the northward-flowing Davidson undercurrent that carries warmer, more saline, and less oxygenated waters out of the Southern California Bight and northward along the central California coast. Because this deep, offshore watermass had not been in recent direct contact with the atmosphere, biotic respiration and decomposition depleted its DO levels (dark blue lines) and produced carbon dioxide ($CO_2$). In its dissolved state, the increased concentration of carbonic acid appears as a concomitant decline in pH (olive-colored lines).

The degree of vertical stratification within the receiving seawater is important for understanding the dynamics of the effluent dispersion at the time of the survey. For example, when the water column is strongly stratified by upwelling, the rising plume can become trapped at depth within the water column, thereby limiting its full capacity for dilution. However, this was not the case during the October 2015 survey. At that time, the water column was only weakly stratified, and as mentioned before, a visual manifestation of the discharge plume was observed near the sea surface at Station RW1.

The signature of the rising plume was also captured in the vertical profile data as it steadily dispersed and was carried northward by the prevailing current. The strongest signature was captured at mid depth in the profile collected at Station RW3, immediately north of the diffuser structure (Figure 7c). Markedly reduced salinity associated with the presence of dilute effluent is readily apparent at 10 m (green profile). Additionally, below 11 m, the profiles of DO, ph, transmissivity, and temperature were relatively uniform (dark blue, olive green, light blue, and red profiles in Figure 7c) compared to the steadily decreasing profiles at southern stations unaffected by the plume (Stations RW4, RW5, and RW6 in Figure 7def). The vertical uniformity in these properties at Station RW3 resulted from the upward transport of seawater within the deep watermass that was entrained within the buoyant effluent plume shortly after discharge. In addition, and as a result of upward transport, the gradual vertical transition observed in deep ambient waters to the south was compressed, producing a sharper thermocline near 10 m at Station RW3.

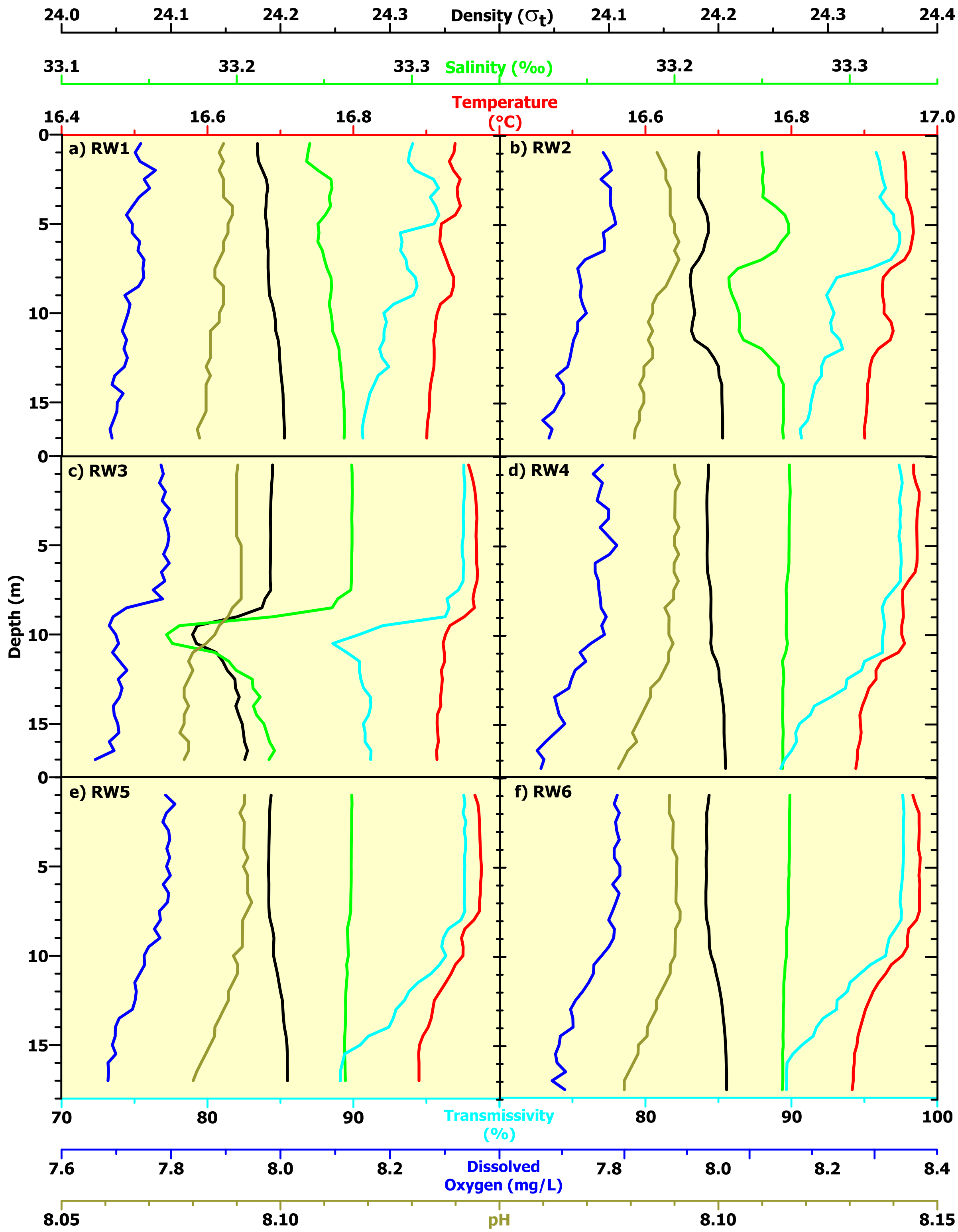


**Figure 7.** Vertical Profiles of Water-Quality Parameters

Moreover, the density profile at Station RW3 (black line in Figure 7c) exhibits a distinct minimum that coincides with the negative salinity anomaly. This indicates that, at that point, the plume was much less dense than the surrounding seawater, and buoyancy forces were continuing to mix and transport the plume upward as it was carried to the north. Accordingly, at Station RW2, which is located immediately to the north, the negative salinity (green) and density (black) signatures were weaker, shallower, and spread across a wider depth range (7 to 12 m in Figure 7b). Finally, when the plume reached the sea surface at the northernmost Station RW1, its signature had largely dissipated throughout the entire water column, and surface waters only exhibited very slight reductions in salinity and density (*cf.,* black and green profiles in Figures 7a and 7e). Based on the measured northward current speed, the plume reached the sea surface and completed the initial dilution process in only 15 minutes.

The tow surveys also captured the signature of the plume as it was transported northward. The mid-depth tow delineated the limited lateral extent of the plume near the northern boundary of the ZID (Figure 8). Observed reductions in temperature, density, DO and pH were highly localized in the vicinity of Station RW3, where reductions in these properties were also apparent in the vertical profiles near the 10-m tow depth (Figure 7c). Data collected at the shallow tow depth, near 3.5 m, revealed a plume signature farther to the north with a somewhat larger lateral extent and smaller-amplitude reductions in seawater properties (Figure 9).

It is important to distinguish plume signatures that are caused by the presence of effluent constituents, exemplified by sharp reductions in salinity and density, from those caused by the upward transport of ambient seawater entrained near the seafloor shortly after discharge. Close to the seafloor, intense mixing is driven by the momentum of the effluent's ejection from the individual diffuser ports. Subsequent turbulent mixing caused by rise of the plume through the water column is less intense, and as a result, the dilute effluent plume tends to retain the ambient seawater properties it acquired at the seafloor. These deep seawater properties can become apparent as a signature of the buoyant effluent plume when they are juxtaposed against the ambient seawater characteristics in the mid and upper water column. These entrainment-generated anomalies are only apparent, however, when the water column is sufficiently stratified to cause a perceptible contrast between the shallow and deep ambient seawater properties.

The legacies of entrainment anomalies can be particularly long-lived, remaining apparent within the water column well after completion of the initial dilution process. As such, these anomalies provide useful tracers of the diffuse effluent plume during and after the completion of the initial dilution process. However, such anomalies are irrelevant to the receiving-water compliance assessment because the permit restricts attention to water-quality changes caused solely by the presence of wastewater constituents rather than a simple relocation of ambient seawater. The observed reductions in seawater temperature within the plume in Figures 8a and 9a, for example, could not have been generated by the presence of warmer effluent. Wastewater discharged on the day of the survey was much warmer (22ºC) than the receiving seawater (17°C). Therefore, entrainment of bottom seawater is the only mechanism that could have created a plume that was cooler than the surrounding ambient seawater within the upper water column.

### *Outfall Performance*

The efficacy of the outfall can be evaluated through a comparison of dilution levels measured at the time of the October 2015 survey, and dilutions anticipated from modeling studies that were codified in the discharge permit through limits imposed on effluent constituents. Specifically, the critical initial dilution applicable to the MBCSD outfall was conservatively estimated to be 133:1 (Tetra Tech 1992). That is, dispersion modeling estimated that, at the conclusion of the minimum expected initial mixing, 133 parts of ambient seawater would have mixed with each part of wastewater.

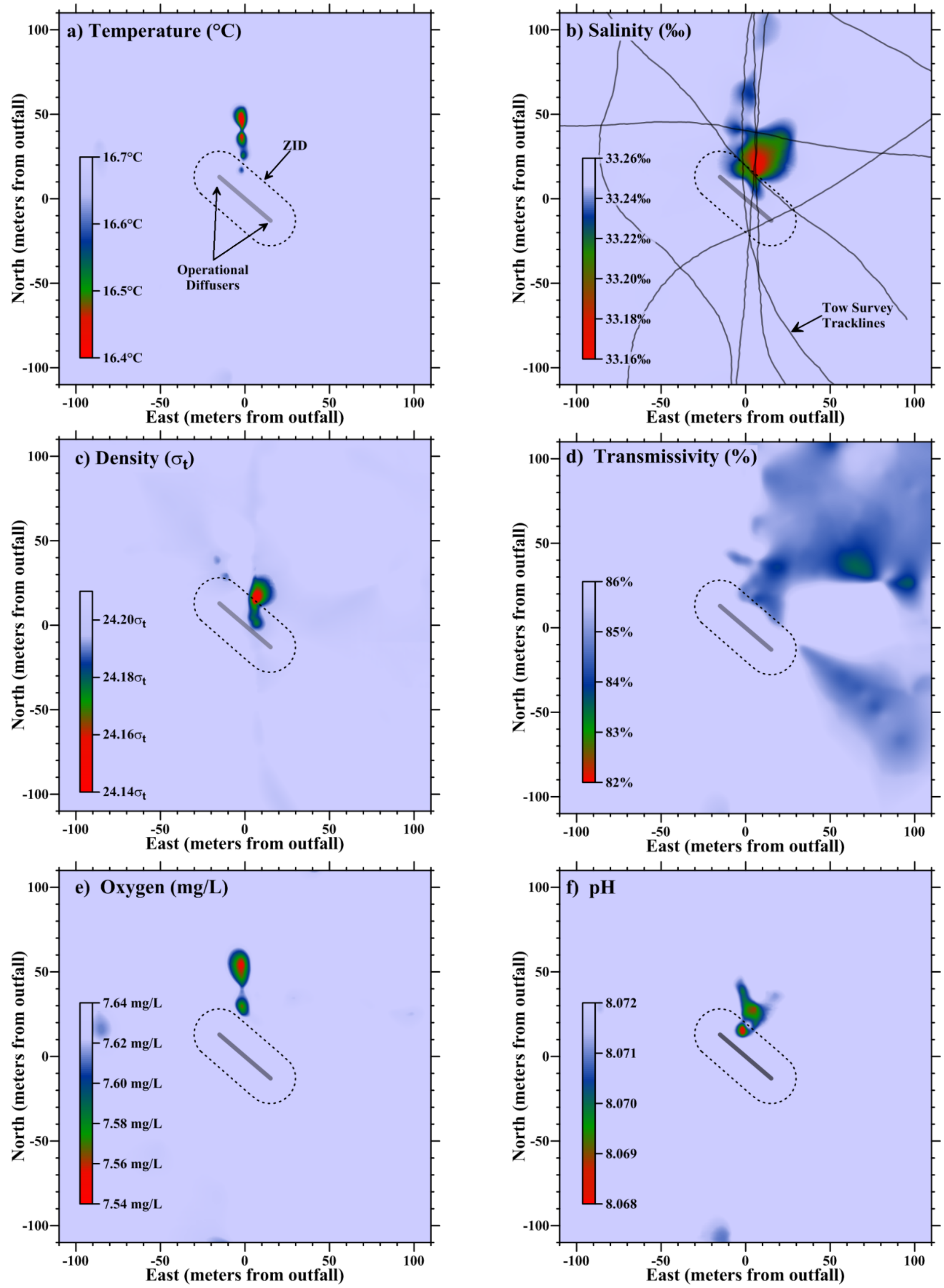


**Figure 8.** Horizontal Distribution of Mid-Depth Water-Quality Parameters 9.84 m below the Sea Surface

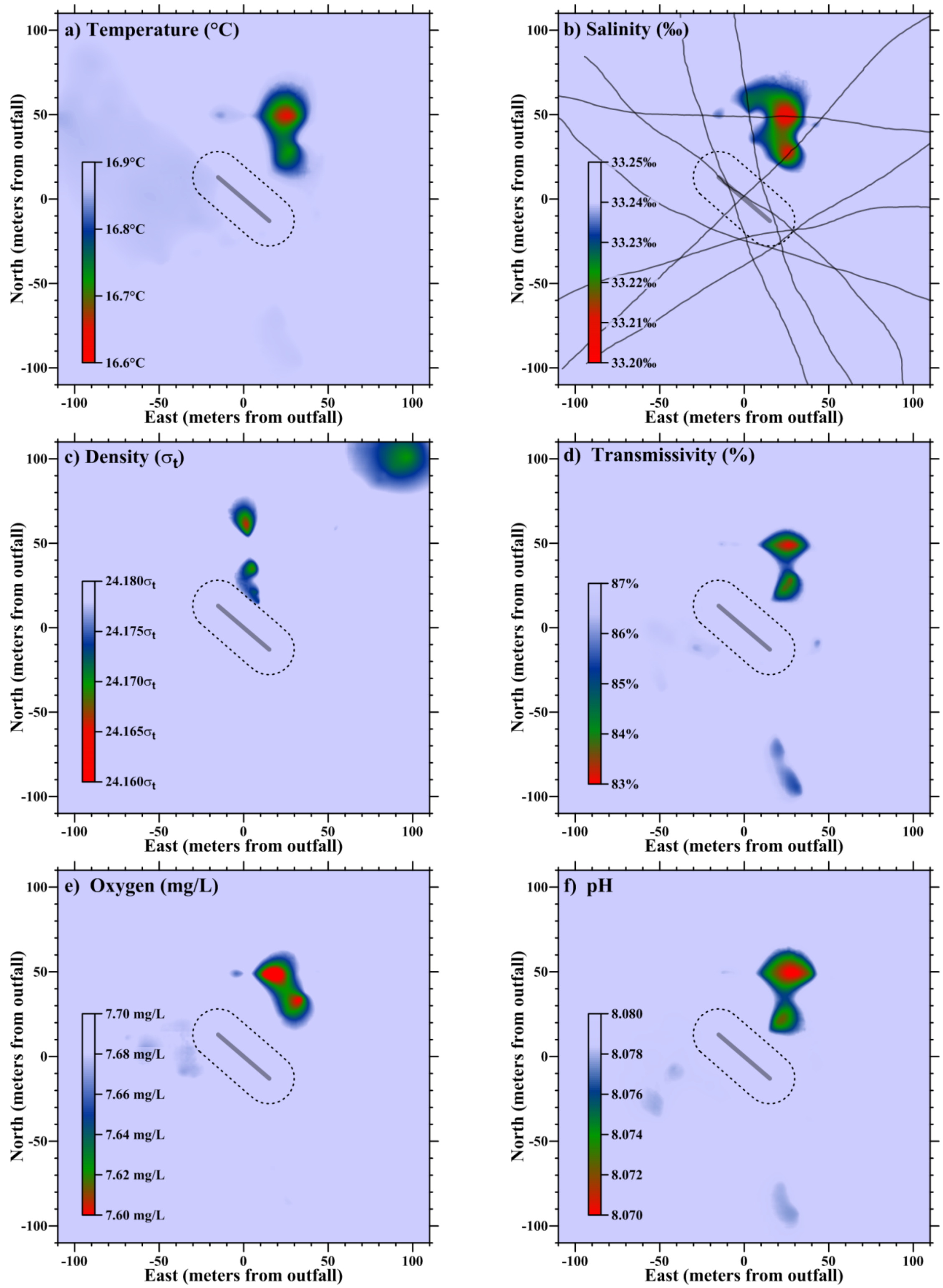


**Figure 9.** Horizontal Distribution of Shallow Water-Quality Parameters 3.49 m below the Sea Surface

The 133:1 dilution estimate was based on worst-case modeling under highly stratified conditions, where trapping of the plume below a strong thermocline would curtail the additional buoyant mixing normally experienced during the plume's rise through the 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 rise further in the water column, and spread laterally with no further dilution occurring. A 9-m rise at the MBCSD outfall translates into a trapping depth that is 6.4 m below the sea surface. As described below, however, the dilution levels observed during the October 2015 survey were much higher than the 133:1 predicted by the modeling, and were measured at depths greater than the trapping depth predicted by the modeling.

The conservative nature of the critical initial dilution determined from the modeling is an important consideration because it was used to specify permit limitations on chemical concentrations in wastewater discharged from the treatment plant. These end-of-pipe effluent limitations were back calculated from the receiving-water objectives in the COP (SWRCB 2005) using the projected 133-fold dilution determined from the modeling. Application of a higher critical dilution would relax the stringent end-of-pipe effluent limitations thought necessary to meet COP objectives after initial dilution is complete.

End-of-pipe limitations on contaminant concentrations within discharged wastewater were based on the definition of dilution (Fischer et al. 1979). From the mass-balance of a conservative tracer, the concentration of a particular chemical constituent within effluent before discharge ($C_e$) can be determined from Equation 1.

$$C_e \equiv C_o + D\left(C_o - C_s\right) \qquad \text{Equation 1}$$

where: $C_e$ = the concentration of a constituent in the effluent,
$C_o$ = the concentration of the constituent in the ocean after dilution by $D$ (i.e., the COP receiving-water objective),
$D$ = the dilution expressed as the volumetric ratio of seawater mixed with effluent, and
$C_s$ = the background concentration of the constituent in ambient seawater.

By rearranging Equation 1, the actual dilution achieved by the outfall can be determined from measured seawater anomalies. This measured dilution can then be compared with the critical dilution factor determined from modeling. Salinity is an especially useful tracer because it directly reflects the magnitude of ongoing dilution. The regions of slightly lower salinity apparent north of the diffuser structure in both of the tow-survey maps (Figures 8b and 9b) were induced by the presence of dilute wastewater. These salinity anomalies document mixing processes within the effluent plume shortly after discharge, and as it subsequently rose through the water column and approached the sea surface.

These 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:

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

The salinity concentration within MBCSD effluent ($C_e$)[19] is generally small compared to that of the receiving seawater and, after dilution by more than 133-fold, the salinity of the effluent-seawater mixture is close to ambient salinity. Consequently, to a close approximation, dilution levels are inversely proportional to the amplitude of the salinity anomaly. Thus, a lower effluent dilution at a given location within the receiving waters is directly mirrored by a larger salinity reduction.

The lowest salinities (<33.16‰) measured during the October 2015 survey were recorded along the northern boundary of the ZID during the third and forth transects of the mid-depth tow survey (red shading in Figure 8b). The lowest of these measured salinities corresponded to a reduction of 0.117‰ below the mean ambient salinity (33.260‰) measured at depth well beyond the influence of the discharge.

From Equation 2, that salinity anomaly corresponds to a dilution of 274-fold (Figure 10), which is double the 133:1 critical initial dilution used to establish limits on contaminant concentrations in wastewater. In addition, this dilution was measured at a depth of 9.7 m, which was 3 m deeper than the 6.4-m trapping depth identified in the modeling that established the 133:1 minimum dilution ratio. According to the conservative modeling results, dilution levels would be expected to be much less than 133:1 at that depth level. Instead, the much higher dilutions measured during the mid-depth tow indicate that the diffuser structure was dispersing the effluent far more efficiently than predicted by the modeling, even shortly after discharge and well before the completion of the initial dilution process.

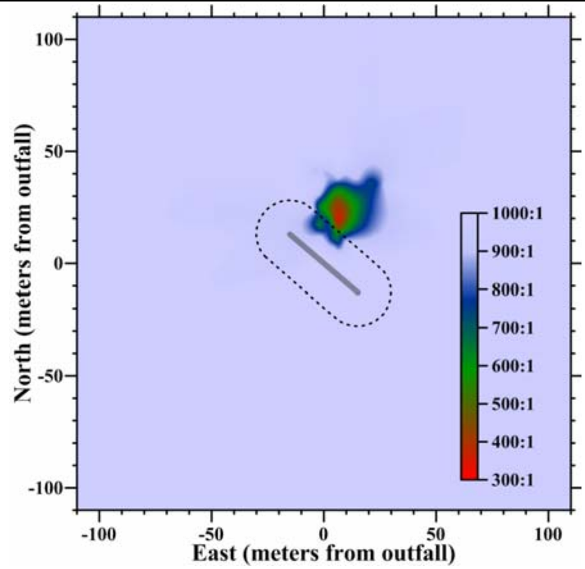


**Figure 10.** Mid-Depth Plume Dilution Computed from Salinity Anomalies in Figure 8b

As the buoyant plume rose within the water column and was carried farther northward by the prevailing current, turbulent mixing continued to dilute the wastewater. Accordingly, salinity data collected during the shallow tow demonstrated that the wastewater had been diluted by at least 550-fold by the time the dilute wastewater rose and additional 6.1 m to a depth level of 3.6 m (Figure 11).

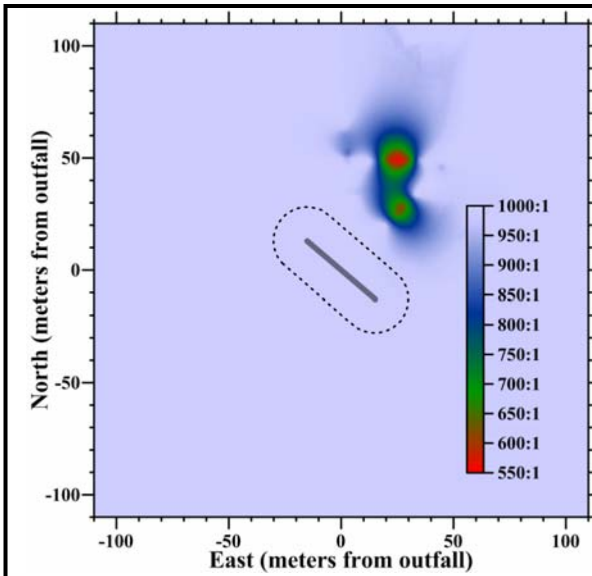


**Figure 11.** Shallow Plume Dilution Computed from Salinity Anomalies in Figure 9b

Overall, the dilution computations show that, during the October 2015 survey, the outfall was performing better than designed and was rapidly diluting effluent more than 274-fold almost immediately after discharge, and well before completion of the initial-dilution process. As the

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

initial dilution process was nearing completion, effluent had been diluted at least 550-fold, easily exceeding the 133:1 critical initial dilution used to establish end-of-pipe permit limitations on contaminant concentrations within wastewater discharged from the MBCSD treatment plant. This demonstrates that, during the October 2015 survey, the COP receiving-water objectives were being met by the limits on chemical concentrations within discharged wastewater that are promulgated by the NPDES discharge permit issued to the MBCSD.

## COMPLIANCE

This section evaluates compliance with the water-quality limitations listed in the NPDES permit (Table 6). The limits themselves are based on criteria in the COP, the Central Coast Basin Plan, and other state and federal policies that were designed to protect marine life and beneficial uses of ocean waters. Because the limits only pertain to changes in water properties that are caused by the presence of wastewater constituents beyond the ZID, instrumental measurements undergo a series of screening procedures prior to numeric comparison with the permit thresholds. Specifically, the quantitative analyses described in this section focus on water-property excursions caused by the presence of wastewater constituents beyond the ZID, whose amplitudes can be reliably discerned against the backdrop of ambient fluctuations. A detailed understanding of ambient seawater properties, and their natural variability within the region surrounding the outfall, is therefore an integral part of the compliance evaluation presented in this section.

**Table 6. Permit Provisions Addressed by the Offshore Receiving-Water Surveys**

| Limit # | Limit |
|---|---|
| P1 | Floating particles or oil and grease to be visible on the ocean surface |
| P2 | Aesthetically undesirable discoloration of the ocean surface |
| P3 | Temperature of the receiving water to adversely affect beneficial uses |
| P4 | Significant reduction in the transmittance of natural light at any point outside the ZID |
| P5 | The DO concentration outside the zone of initial dilution to fall below 5.0 mg/L or to be depressed more than 10% from that which occurs naturally |
| P6 | The pH outside the zone of initial dilution to be depressed below 7.0, raised above 8.3, or changed more than 0.2 units from that which occurs naturally |

The results of these analyses of the October 2015 data demonstrate that the MBCSD discharge complied with the NPDES discharge permit. Moreover, although observations within the ZID are not subject to compliance evaluations, they met the prescribed limits because actual dilution levels routinely exceeded the conservative design specifications assumed in the discharge permit. Thus, the quantitative evaluation described in this section documents an outfall and treatment process that was performing at a high level during the October 2015 survey.

### *Permit Provisions*

The offshore receiving-water surveys are designed to assess compliance with objectives dealing with undesirable alterations to six physical and chemical characteristics of seawater. Specifically, the permit states that wastewater constituents within the discharge shall not cause the limits listed in Table 6 to be exceeded.

The first two receiving-water limits, P1 and P2, rely on qualitative visual observations for compliance evaluation. Compliance was demonstrated by the visual absence of floating wastewater materials, oil, grease, or discoloration of the sea surface during the October 2015 survey.

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

As described previously, natural variation in seawater properties can result from a variety of oceanographic processes. These processes establish the range in ambient seawater properties caused by natural spatial variation within the survey region at a given time (e.g., vertical stratification), and by temporal variations caused by seasonal and interannual influences (e.g., El Niño and La Niña). Of particular interest are upwelling and downwelling processes that not only determine average properties at a given time, but also the degree of water-column stratification, or spatial variability, present during any given survey.

### *Screening of Measurements*

Evaluating whether any of the 13,139 CTD measurements collected during the October 2015 survey exceeded a permit limit can be a complex process. For example, although apparently significant excursions in an individual seawater property may be related to the presence of wastewater constituents, they may also result from instrumental errors, natural processes, entrainment of ambient bottom waters in the rising effluent plume, statistical uncertainty, ongoing initial mixing within and beyond the ZID, or other anthropogenic influences (e.g., dredging discharges or oil spills).

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

**Table 7. Receiving-Water Measurements Screened for Compliance Evaluation**

| Topic Addressed | Screening Question | Answer No | Answer Yes[20] | *Parameter* |
|---|---|---|---|---|
| Location | 1. Was the measurement collected beyond the 15.2-m ZID boundary where modeling assumes that initial dilution is complete? | *1,068* | *12,071* | 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? | *11,972* | *99* | 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? | *99* | *0* | Temperature |
| | | *99* | *0* | Transmissivity |
| | | *99* | *0* | DO |
| | | *99* | *0* | pH |

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

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

***1. Measurement Location:*** The COP states that compliance with its receiving-water objectives "*shall be determined from samples collected at stations representative of the area within the waste field where initial dilution is completed.*" Initial dilution includes the mixing that occurs from the turbulence associated with both the ejection jet, and the buoyant plume's subsequent rise through the water column.

Although currents often transport the plume 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 October 2015 dataset eliminated 1,068 of the original 13,139 receiving-water observations from further consideration because they were collected within the ZID (Table 7, Question 1). The remaining 12,071 observations were carried forward in the compliance analysis.

***2. Presence of Wastewater Constituents:*** The MBCSD discharge permit restricts application of the numerical receiving-water limits to excursions caused by the presence of wastewater constituents. This confines the compliance analysis to changes caused "*as the result of the discharge of waste*," as specified in the COP, rather than anomalies that arise from the movement of ambient seawater entrained in the effluent plume. Analyses conducted on quarterly receiving-water surveys over the last decade have demonstrated that the direct influence of dilute wastewater is almost never observed in any seawater property other than salinity, except very close (<1 m) to a diffuser port and within its ejection jet.

In fact, negative salinity anomalies are the only consistent indicator of the presence of wastewater constituents within receiving waters. Wastewater salinity is negligible compared to that of the receiving seawater, so the presence of a distinct salinity minimum provides *de facto* evidence of the presence of wastewater constituents. Because of the large contrast between the nearly fresh wastewater and the salty receiving water, salinity provides a powerful tracer of dilute wastewater that is unrivaled by other seawater properties. Other properties do not exhibit such a large contrast and, as such, their wastewater signatures dissipate rapidly upon discharge with very little mixing. Wastewater's lack of salinity, however, provides a definitive tracer that allows the presence of effluent constituents to be identified even after dilution many times greater than the 133-fold critical initial dilution assumed in the discharge permit.

As described in the previous section, wastewater-induced reductions in salinity can be used to determine the amount of dilution achieved by initial mixing. Based on statistical analyses of the natural variability in salinity readings measured near the outfall over a five-year period between 2004 and 2008, the smallest reduction in salinity that can be reliability detected within receiving waters is 0.062‰. This represents a dilution level of 542-fold. Salinity reductions that are smaller than 0.062‰ cannot be reliably discerned against the backdrop of natural variation and would not result in discernible changes in other seawater properties. Eliminating those measurements from further evaluation restricts attention to excursions in temperature, light transmittance, DO, and pH that are potentially related to the presence of wastewater constituents.

As discussed previously, the lowest salinities measured during the October survey were recorded north of the diffuser structure during the deep tow survey. Numerous other detectable reductions in salinity unequivocally identified the presence of dilute wastewater constituents in close spatial proximity to these minima. About two-thirds (99) of these measurements were located beyond the ZID boundary. The 99 salinity reductions measured beyond the ZID had dilutions less than 550:1 (Table 7). The remaining 11,972 observations that were measured outside the ZID during the October 2015 survey did not have salinity reductions that were greater than the 0.062‰ detection level.

***3. Natural Variation:*** An integral part of the compliance analysis is determining whether a particular anomalous measurement resulted from the presence of wastewater constituents, or whether it simply became apparent because ambient seawater was relocated (upward) by the plume. If the measurement does not significantly depart from the natural range in ambient seawater properties at the time of the survey, then it is difficult to ascribe the departure to the presence of wastewater constituents. Thus, quantifying the natural variability around the outfall is necessary for determining whether a particular observation warrants comparison with the numeric permit limits.

A statistical analysis of receiving-water data previously collected around the outfall was used to establish the range in natural conditions surrounding the outfall (first three 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 95$^{th}$ percentiles determined from the October 2015 ambient seawater data, to establish time-specific natural-variability thresholds in a manner analogous to COP Appendix VI. The percentiles were determined from October 2015 vertical profile data collected at Stations RW4, RW5, and RW6, thereby excluding measurements potentially affected by the discharge.

**Table 8. Compliance Thresholds**

| Water Quality Property | 95% Confidence Bound[21] | 95$^{th}$ Percentile[22,23] | Natural Variability Threshold[24] | COP Allowance[25] | Basin Plan Limit[26] | Extremum[27] |
|---|---|---|---|---|---|---|
| Temperature (ºC) | 0.82 | 16.98 | >17.80 | — | — | ≤17.01 |
| Transmissivity (%) | -10.2 | 89.7 | <79.5 | — | — | ≥82.7 |
| DO (mg/L) | -1.38 | 7.68 | <6.30 | <5.67 | <5.00 | ≥7.52 |
| pH (minimum) | -0.094 | 8.080 | <7.986 | <7.786 | <7.000 | ≥8.063 |
| pH (maximum) | 0.094 | 8.092 | >8.186 | >8.386 | >8.300 | ≤8.098 |

21 The one-sided confidence bound is used to measure the ability to reliably estimate percentiles within surveys as a whole. They were determined from an analysis of the variability in ambient water-quality data collected during 20 quarterly surveys conducted between 2004 and 2008. Although water-quality observations potentially affected by the presence of wastewater constituents were excluded from the analysis, more than 9,200 remaining observations for each of the six seawater properties accurately quantified the inherent uncertainty in defining the range in natural conditions.

22 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*."

23 The 95$^{th}$-percentile quantifies natural variability in seawater properties during the October 2015 survey, and was determined from vertical-profiles data unaffected by the discharge.

24 Thresholds represent limits on wastewater-induced changes to receiving-water properties that significantly exceed natural conditions as specified in the discharge permit and COP. They are determined from the sum of columns to the left and are specific to the October 2015 survey. They do not include the COP allowances specified in the column to the right.

25 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.*"

26 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.

27 Maximum or minimum value measured during the October 2015 survey

Temperature, transmissivity, pH, and DO concentrations associated with the 99 remaining measurements of potential compliance interest were all well within their respective ranges of natural variability (Table 7, Question 3). As such, the screening process unequivocally eliminated all of the remaining CTD measurements collected during the October 2015 survey from further consideration. In fact, all of the documented excursions in these properties were the result of physical processes unrelated to the presence of wastewater constituents, namely, entrainment of near-bottom seawater within the rising effluent plume.

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, as it was during the October 2015 survey, ambient seawater properties near the seafloor differ from those within the rest of the water column, and their juxtaposition within the rising effluent plume appears as lateral anomalies within the upper water column. Regardless, if the presence of wastewater particulates had contributed to the measured decreases in DO and pH, their influence would still have been well within the natural range of the ambient seawater properties at the time of the survey. Consequently, their influence on water quality would not be considered environmentally significant.

### *Other Lines of Evidence*

Several additional lines of evidence further support the conclusion that all the CTD measurements collected during the October 2015 survey complied with permit limits P3 through P6 in Table 6. In combination, these lines of evidence provide the "best explanation" of the origin and significance of individual measurements using abductive inference (Suter 2007). This process, which has been used to implement sediment-quality guidelines for California estuaries (SWRCB 2009), emphasizes a pattern of reasoning that accounts for both discrepancies and concurrences among multiple lines of evidence. A best explanation approach serves to limit the uncertainty associated with each individual CTD measurement and provide a more robust compliance assessment. Together, these lines of evidence significantly strengthen the conclusion that the discharge fully complied with the permit at the time of the October 2015 survey.

***Insignificant Thermal Impact:*** Although there are no explicit numerical objectives for discharge-related increases in temperature, a numerical limit can be established for thermal excursions that is based on the requirement that they not adversely affect beneficial uses (P3 in Table 6). Increases in temperature caused by the discharge of warm wastewater constituents could be deemed to adversely affect beneficial uses if they exceeded the natural temperature range observed at the time of the survey (i.e. exceeded 17.80°C in Table 8). However, none of the 13,139 CTD measurements collected during the October 2015 survey exceeded 17.01°C (last column in Table 8). Additionally, as mentioned previously, because the effluent entrained cooler bottom water shortly after discharge, the rising plume actually exhibited a lower temperature than most of the surrounding seawater (Figures 8a and 9a).

***Full Ambient Light Penetration:*** As with temperature, there are no explicit numerical objectives for discharge-related decreases in transmissivity. However, the COP narrative objective (P4) limiting significant reductions in the transmission of natural light can also be translated into a numerical objective. Specifically, because the COP does not specify an allowance beyond natural conditions, the same threshold on ambient transmissivity variations listed in Table 8 can be interpreted to constitute a numerical limit. However, none of the transmissivity measurements collected during the October 2015 survey fell below the 79.5% minimum compliance threshold. In fact, the lowest transmissivity measured during the survey was 82.7%. Even when the rising plume carried turbid bottom water into the upper water column near Stations RW1 and RW2, and reduced Secchi depths by 2 m (Table 4), the euphotic zone still significantly exceeded the water depth, indicating ambient light was easily reaching the seafloor.

***Directional Offset:*** Analysis of the directional offset of CTD measurements is useful because wastewater and receiving-seawater properties vary from one another in several predictable ways. For example, upon discharge, wastewater is fresher, warmer, and lighter than the ambient receiving waters of Estero Bay. Under most conditions, wastewater is also more turbid than the receiving waters. As such, the presence of wastewater constituents will reduce the salinity, density, and transmissivity of the receiving seawater (negative offset), while temperature will be increased (positive offset). Therefore, as discussed previously, the reduced temperatures observed in conjunction with the effluent plume (Figures 8a and 9a) could not have been generated by the presence of warmer wastewater constituents.

***Insignificant Wastewater Particulate Loads:*** Another independent line of evidence demonstrates that the discharge of wastewater particulates could not have contributed materially to turbidity within the dilute effluent plume. The suspended-solids concentration measured onshore, within the effluent, and immediately prior to discharge from the WWTP on 27 October 2015 was 28 mg/L. After dilution by 274-fold, the effluent suspended-solids concentration would have the reduced ambient transmissivity by only 0.9% within the plume. This small potential decrease in transmissivity was insignificant compared to the naturally-occurring 8% reduction in transmissivity observed within the watermass near the seafloor.

Similarly, the MBCSD discharge could not have contributed materially to the observed DO fluctuations. The MBCSD treatment process routinely removes 80% or more of the organic material, as demonstrated by the low, 35-mg/L BOD measured within the plant's effluent four 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 tangible BOD influence, wastewater discharge would actually be expected to increase DO within subsurface receiving waters, rather than decrease it. This is because effluent is oxygenated by recent contact with the atmosphere during the treatment process, whereas receiving waters at depth are typically depleted in DO due to the lack of atmospheric equilibration in the deep offshore watermass.

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

For pH, the COP and the discharge permit allow changes up to 0.2 pH units from natural conditions, bringing the minimum allowed pH to 7.786 during the October 2015 survey (fourth data column of Table 8). This limiting value is significantly less than the lowest pH measurement of 8.063 recorded during the October 2015 survey (last column of Table 8). Similarly, the lowest DO concentration measured during the survey (7.52 mg/L) was well above both the lower range in natural variation (6.3 mg/L) and the 10% compliance threshold promulgated by the COP (5.67 mg/L).

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

## CONCLUSIONS

The quantitative screening analysis demonstrated that all measurements recorded during the October 2015 survey complied with the receiving-water limitations specified in the NPDES discharge permit. This conclusion was further strengthened by other lines of evidence supporting compliance with the discharge permit. Specifically, although discharge-related changes in seawater properties were observed during the October 2015 survey, the changes were either not of significant magnitude (i.e., they were within the natural range of variability that prevailed at the time of the survey), were measured within the boundary of the ZID where initial mixing is still expected to occur, or were not directly caused by the presence of wastewater constituents within the water column.

Shortly after discharge, and well before the initial dilution process was complete, the effluent was achieving dilution levels in excess of 274-fold, which is more than double the critical dilution levels predicted by design modeling. As the plume rose through the water column and approached the sea surface, near the completion of the initial mixing process, dilution levels exceeded 550-fold. All of the measured dilution levels far exceeded levels that were predicted by modeling and that were incorporated in the discharge permit as limits on contaminant concentrations within effluent prior to discharge. Lastly, all of the auxiliary observations collected during the October 2015 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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