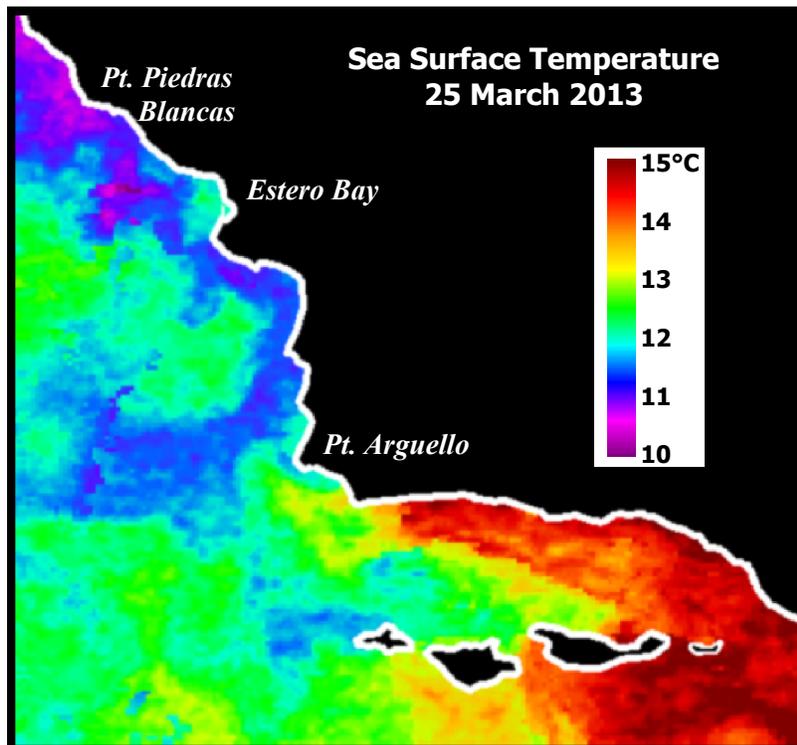


**City of Morro Bay and  
Cayucos Sanitary District**

**OFFSHORE MONITORING  
AND REPORTING PROGRAM**

**FIRST QUARTER  
RECEIVING-WATER SURVEY**

**MARCH 2013**



**Marine Research Specialists**

**3140 Telegraph Rd., Suite A  
Ventura, California 93003**

**Report to the  
City of Morro Bay and  
Cayucos Sanitary District**

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

**OFFSHORE MONITORING  
AND REPORTING PROGRAM**

**FIRST QUARTER  
RECEIVING–WATER SURVEY**

**MARCH 2013**

**Prepared by**

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**April 2013**

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

30 April 2013

**Reference: First Quarter Receiving-Water Survey Report – March 2013**

Dear Mr. Keogh:

The attached report presents results from a quarterly receiving-water survey conducted on Tuesday, 26 March 2013. The survey was conducted in accordance with the requirements of the NPDES permit issued to the City and District for discharge of treated wastewater to Estero Bay. The report evaluated compliance with permit limitations and assessed the effectiveness of effluent dispersion. Quantitative analyses of continuous instrumental measurements and qualitative visual observations confirm that the wastewater discharge complied with the receiving-water limitations specified in the permit, and with the objectives of the California Ocean Plan.

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

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

Sincerely,



Bonnie Luke  
Program Manager

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

A handwritten signature in blue ink that reads "Bruce Keogh". The signature is written in a cursive style with a large initial "B".

Mr. Bruce Keogh  
Wastewater Division Manager  
City of Morro Bay

Date April 30, 2013

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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 March 2013 field survey described in this report was the sixteenth 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 26 March 2013. Specifically, this first-quarter survey captured ambient oceanographic conditions along the central California coast during late winter. 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<sup>1</sup> instrument package repeatedly over the diffuser structure. This allowed for a more precise determination 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, define the extent of the discharge plume, and evaluate compliance with the NPDES permit limitations.

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<sup>1</sup> Conductivity, temperature, and depth (CTD)



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 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  $\pm 15$  m, a span equal to half the total width of the ZID itself. DGPS incorporates a second signal from a fixed, land-based beacon that continuously transmits position errors in standard GPS readings to the DGPS receiver onboard the survey vessel. Real-time correction for these position errors provides an extremely stable and accurate offshore navigational reading with position errors of less than 2 m.

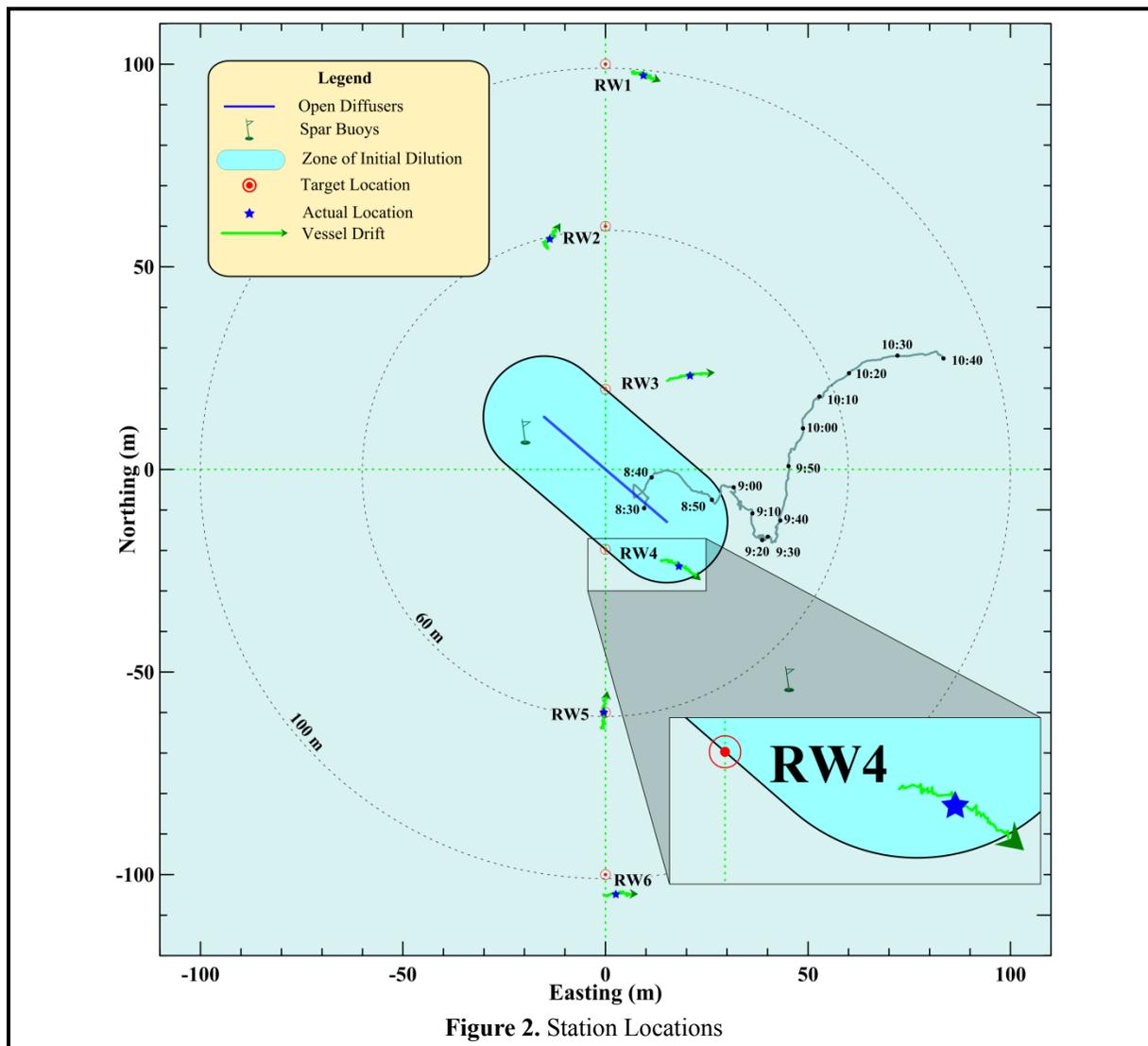


Figure 2. Station Locations

Table 1. Target Locations of the Receiving-Water Monitoring Stations

Station	Description	Latitude	Longitude	Center Distance <sup>2</sup> (m)	Closest Approach Distance <sup>3</sup> (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

<sup>2</sup> Distance to the center of the open diffuser section

<sup>3</sup> 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. Currently, use of two independent DGPS receivers on 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<sup>4</sup> conditions, the residual momentum of the survey vessel as it approaches the target locations can create perceptible offsets. Using DGPS however, these offsets can be quantified, and the vessel location can be precisely tracked throughout sampling at each station.

The magnitude of the drift at each of the six stations during the March 2013 survey is apparent from the length of the green tracklines in Figure 2. These tracklines trace the horizontal movement of the survey vessel as the CTD was lowered to the seafloor. Their lengths and offsets from the target locations reflect the overall station-keeping ability during the March 2013 survey. During the time it took the CTD to traverse the water column and reach the seafloor, which averaged a 1.5 minutes, the instrument package moved an average of 7.5 m.

This amount of drift is comparable to most recent surveys, where downcasts have typically been completed in 1 minute 30 seconds with lateral offsets of less than 10 m. During the March 2013 survey, however, an unusually weak oceanic current allowed the light winds out of the southeast to cause a general eastward drift during most of the downcasts. In contrast, the due northward trajectory at Station RW5 reflected the influence of the residual momentum of the survey vessel as it approached the station from the south. Regardless of the various processes that affect the location of the CTD during downcasts, knowledge of the CTD's location relative to the ZID is important for the compliance assessment.

Because the target locations for Stations RW3 and RW4 lie along the ZID boundary (red ⊙ symbols in Figure 2), detailed knowledge of the CTD's location during the downcasts at those stations is particularly important in the compliance evaluation. In addition, because those stations are closest (15.2 m) to the diffuser structure, where any potential discharge effects are expected to be largest, slight changes in measurement location can determine whether the discharge plume is encountered. Moreover, 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 March 2013 survey, the CTD traversed the ZID boundary at Station RW4 (green line in the inset in Figure 2). Although a majority of the measurements recorded by the CTD at Station RW4 were located inside the ZID and were not subject to the compliance analysis, a small portion of the deepest measurements were located outside the ZID.

It has not always been possible to determine which measurements were subject to permit limits within hydrocasts near the ZID boundary. 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

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<sup>4</sup> Meteorological and oceanographic conditions include winds, waves, tides, and currents.

for all of the CTD data collected at a particular station. Thus, for regulatory reporting, and for consistency with past surveys, the March 2013 survey also identifies a single sampling location for each station. These average station positions are shown by blue stars in Figure 2, and are listed in Table 2 along with their distances from the diffuser structure.

**Table 2.** Average Position of Vertical Profiles during the March 2013 Survey

Station	Time (PDT)		Latitude	Longitude	Closest Approach	
	Downcast	Upcast			Range <sup>5</sup> (m)	Bearing <sup>6</sup> (°T)
RW1	9:07:01	9:08:23	35° 23.252' N	120° 52.498' W	87.8	16
RW2	9:00:58	9:02:40	35° 23.230' N	120° 52.513' W	44.0	2
RW3	8:54:43	8:55:56	35° 23.212' N	120° 52.490' W	31.2	41
RW4	8:48:39	8:50:07	35° 23.186' N	120° 52.492' W	<b>11.3</b> <sup>7</sup>	165
RW5	8:42:51	8:44:16	35° 23.167' N	120° 52.504' W	49.4	198
RW6	8:36:58	8:38:25	35° 23.142' N	120° 52.502' W	92.7	188

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 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 vertical profiles collected during a given survey.

### OCEANOGRAPHIC PROCESSES

The trajectory of a satellite-tracked drogued drifter documented the oceanic flow during the March 2013 survey (Figure 2). 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 decade. In this configuration, the oceanic flow field rather than surface winds dictates the drifter’s trajectory, providing a good assessment of the plume’s movement after discharge.

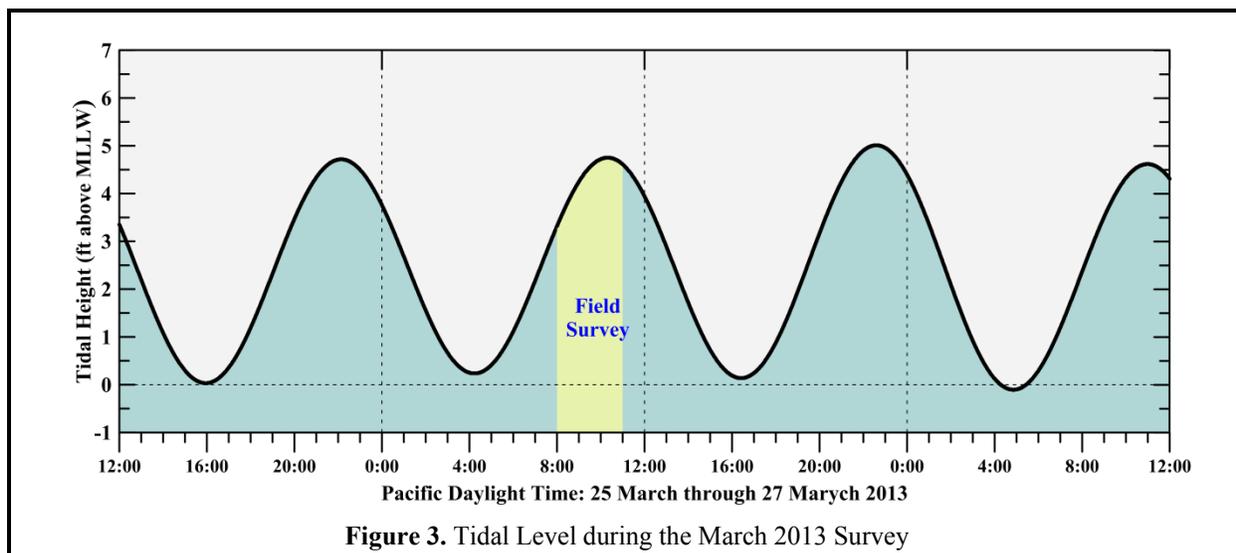
The drifter was deployed near the diffuser structure at 8:30 AM, and was recovered at 10:40 AM (Figure 2). During that time, the drifter slowly followed circuitous route toward the east. The prevailing flow speed can be discerned from the spacing of the black dots, which show the drifter’s location at ten-minute intervals. During the first 50 minutes, the relatively uniform spacing of the dots reflects an average flow speed of 1 cm/s, or 0.02 knots (kt) directed toward the east at 105°T.<sup>8</sup> This eastward (shoreward) flow direction was consistent with the flood tide that prevailed during most of the survey (Figure 3). At this very slow transport rate, effluent had a long, 25-minute residence time within the ZID and only traveled a net distance of 30 m in an hour. Additionally, for 10 minutes, between 9:20 and 9:30, flow was stagnant before the drifter began to move in an arc toward the northeast (46°T) at a speed of 1.6 cm/s (0.03 kt) before its recovery at 10:40, only 83 m from its deployment location. Even at this slightly increased transport speed, the 16-minute residence time within the ZID was still significantly longer than the transport times measured during most prior MBCSD surveys.

<sup>5</sup> Distance from the closest open diffuser port to the average profile location.

<sup>6</sup> Angle measured clockwise relative to true north from the closest diffuser port to the average profile location.

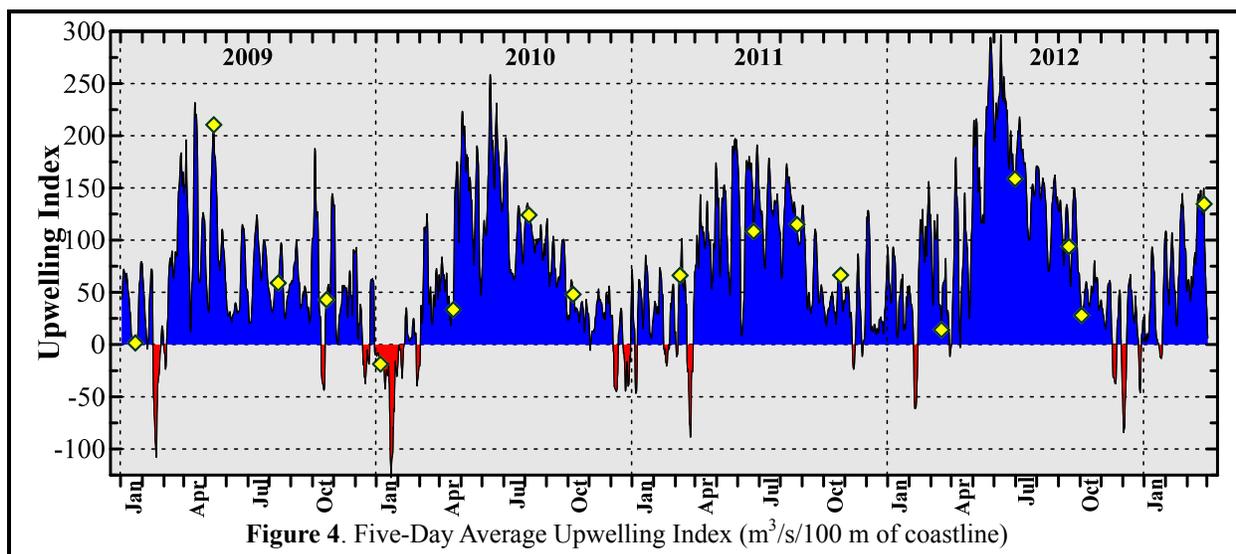
<sup>7</sup> Except for a few of the deepest measurements, CTD measurements at Station RW4 were located within the ZID boundary (refer to the inset in Figure 2).

<sup>8</sup> Eight degrees relative to true (rather than magnetic) north



Despite the general correspondence between flow direction and tides measured during the March 2013 survey, coastal currents within Estero Bay are also often strongly influenced by external processes, such as wind-generated upwelling, downwelling, or the passing of offshore eddies propagating along the coastline. Upwelling, for example, can induce a southerly (offshore) flow in the upper water column, and a northerly (shoreward) flow at depth. Figure 4 shows that persistent and intense upwelling conditions prevailed in the week prior to the March 2013 survey.

Upwelling season normally begins sometime during late March and or early April as shown by the positive (blue) upwelling indices in Figure 4. At the onset of upwelling season, there is a transition to more persistent southeastward winds along the central California coast that is initiated by the stabilization of a high-pressure field over the northeastern Pacific Ocean. Clockwise winds around this pressure field drive prevailing northwesterly winds along the central California coast. These winds move warmer surface waters southward and offshore, allowing deep, cool, nutrient-rich waters to move shoreward and upwell near the coast.



The nutrient-rich seawater that is brought to the sea surface near the coast by upwelling enables phytoplanktonic blooms that are the foundation of the productive marine fishery found along the central California coast. The cross-shore flow associated with persistent upwelling conditions also enhances vertical stratification of the water column. The presence of denser water at depth produces a shallow thermocline (<10 m) that is commonly maintained throughout summer and into fall.

In contrast, downwelling events, indicated by the negative (red shaded) indices in Figure 4, occur infrequently, and almost exclusively in winter, when passing storms temporarily reverse the normal wind pattern and drive surface waters shoreward. As the surface waters approach the coastline, they downwell, producing nearly uniform seawater properties throughout the water column.

The satellite image on the cover of this report documents the influence of upwelling on sea-surface temperatures immediately prior to the March 2013 survey. The image was recorded the day before the survey, when skies were clear enough for sea-surface temperatures to be measured by infrared sensors on one of NOAA's polar orbiting satellites. The distinctive thermal signature of upwelling is apparent in the cover image, with a band of cooler nearshore sea-surface temperatures shown in blue and purple (<12°C) along the central coast. As is common during upwelling, these cooler waters are typically transported offshore by the cross-shore flow that occurs at major promontories, such as Point Arguello.

## **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, 26 March 2013. Bonnie Luke of Marine Research Specialists (MRS) supervised deck operations as Chief Scientist, and collected auxiliary measurements of biological, meteorological, and oceanographic conditions. Dr. Douglas Coats, provided data-acquisition and navigational support during the survey. William Skok assisted with deployment and recovery of the CTD and drifter.

### *Auxiliary Measurements*

Auxiliary measurements and observations were collected during the vertical water-column profiling conducted at each of the six stations. Standard observations of weather and sea conditions, and beneficial uses, were augmented by visual inspection of the sea surface for floating particulates, oil sheens, and discoloration potentially related to the effluent discharge. Other auxiliary measurements collected at each station included wind speeds and air temperatures measured with a handheld Kestrel<sup>®</sup> 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 March 2013 survey. The six seawater properties used to assess receiving-water quality in this report were derived from the continuously recorded output from the CTD's probes and sensors. Although pressure-housing limitations confine the CTD to depths less than 680 m (Table 3), this is well beyond the maximum depth of the deepest station in the outfall survey.

**Table 3. CTD Specifications**

<b>Component</b>	<b>Units</b>	<b>Range</b>	<b>Accuracy</b>	<b>Resolution</b>
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	°C	-5 to 35	± 0.005	± 0.0001
Transmissivity (WETLabs C-Star) <sup>9</sup>	%	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 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%. However, the extraordinarily high mid-depth water clarity that was present during the March 2013 survey, resulted in measurements exceeding 92%.<sup>10</sup>

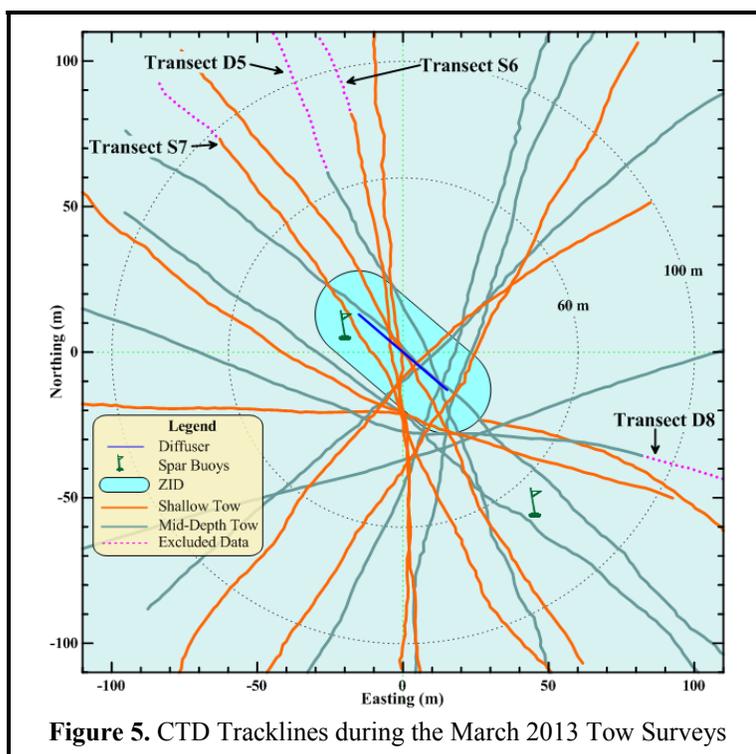
Before the first vertical hydrocast at Station RW6, the CTD was held below the sea surface for three minutes. Subsequently, the CTD was raised to within 0.5 m of the sea surface and profiling commenced. The CTD was lowered at a continuous rate of speed to the seafloor. Measurements at all six stations were collected during a single deployment of the CTD package by towing it below the water surface while transiting between adjacent stations.

<sup>9</sup> 25-cm path length of red (660 nm) light

<sup>10</sup> Refer to the light blue lines in Figure 6 and last columns of Table 5 later in this report

At 9:09 AM, following 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 at mid-depth below the thermocline and one within the surface mixed layer, in accordance with the monitoring requirements of the NPDES discharge permit (Figure 5).

Initially, the reconfigured CTD package was towed for 31 minutes at an average depth of 4.02 m, and an average speed of 1.79 m/s, passing over, or near the diffuser structure eight times. Subsequently, eight additional passes were made with the CTD at an average depth of 9.41 m. During this 33-minute mid-depth tow, vessel speed averaged 2.11 m/s. At the observed towing speeds and the 4 Hz sampling rate, at least 1.9 CTD measurements were collected for each meter traversed. This complies with the permit requirement for minimum horizontal resolution of at least one sample per meter. Contemporaneous navigation fixes recorded onboard the survey vessel were adjusted for CTD setback and aligned with time stamps on the internally recorded CTD data. The resulting data for the six seawater properties were then processed to produce horizontal maps within the upper and sub-thermocline portions of the water column.<sup>11</sup>



**Figure 5. CTD Tracklines during the March 2013 Tow Surveys**

### *Quality Control*

Upon retrieval of the CTD following the tow survey, water-quality data were examined for completeness and range acceptability. Although real-time monitoring indicated the recorded properties were complete and within acceptable coastal seawater ranges,<sup>12</sup> subsequent post-processing revealed several events that impacted portions of the data, resulting in the adjustment or exclusion of these data prior to initiation of the compliance analysis. For example, review of the tow data revealed that the CTD was tracking at a slightly different depth (>1 m offset) during the latter portions of the mid-depth tows along Transects D5 and D8, as well as during the shallow tows along Transects S6 and S7 (purple dotted lines in Figure 5).

These depth fluctuations were induced by changes in vessel speed that were instituted to prevent the CTD from colliding with the seafloor during the execution of the turns used to align the vessel between each transect. Because of the complex interaction between turn radius, vessel speed, and CTD depth, the CTD's target depth could not be precisely maintained at these times.

<sup>11</sup> Figures 7 and 8 later in this report

<sup>12</sup> Field sampling protocols employed during the March 2012 survey generally followed the field operations manual for the Southern California Bight Study (SCBFMC 2002), which includes CTD cast-acceptability ranges in Table 2 of the manual.

Because the discharge-related anomalies used in the compliance analysis are identified by comparing the amplitudes of measurements acquired at the same depth level, the ability to resolve anomalies with statistical certainty is compromised when data from different depth levels are combined in the horizontal maps. This is particularly true when the water column is stratified, as was the case during the March 2013 survey.

The exclusion of small portions of Transects S6, S7, D5, and D8 did not, however, adversely affect the compliance analysis because the remaining transects adequately covered the survey region. Specifically, the remaining data, shown by the solid orange and blue-green lines in Figure 5, met the permit monitoring requirement of at least five passes near the diffuser structure at each tow depth.

Quality-control screening of the vertical profile data was also required because the length of the CTD is close to the 0.5-m standard depth bins used to report the vertical profile data. Because of the CTD's physical dimensions, the ability to compute average values for seawater properties at locations very near the sea surface and seafloor varies depending on how the CTD's reported depth is influenced by temporal differences in sea-surface height. These height fluctuations are caused by wave and tidal-induced oscillations during its deployment at each station. For example, during the March 2013 survey, data on average seawater properties could not be reported within the deepest depth bin (17 m) except at Station RW5.<sup>13</sup> Because this isolated observation cannot quantify a horizontal trend, it was excluded from the subsequent compliance evaluation.

## RESULTS

The first-quarter receiving-water survey was conducted on the morning of Tuesday, 26 March 2013. The receiving-water survey commenced at 8:30 AM with the deployment of the drogued drifter. Over the following two hours, offshore observations and measurements were collected as required by the NPDES monitoring program. The survey ended at 10:40 AM with the retrieval of the CTD from the mid-depth tow survey. Collection of required visual observations of the sea surface was unencumbered throughout the survey.

### *Auxiliary Observations*

On the morning of 26 March 2013, skies were clear, with only light and variable southeasterly winds. Average wind speeds, calculated over one-minute intervals, ranged from 0.7 kt to 1.4 kt (Table 4). Similarly, peak wind speeds ranged from 1.4 kt to 2.2 kt. The swell was out of the northwest with a significant wave height of between 2 and 3 feet. Air temperatures remained fairly constant throughout the survey, averaging 12.2°C.

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

Station	Location <sup>14</sup>		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° 23.252' N	120° 52.491' W	91.2	9:10:03	12.8	5	0.7	1.4	SE	2-3 NW	6.0
RW2	35° 23.237' N	120° 52.505' W	57.9	9:04:11	12.4	5	1.1	2.1	SE	2-3 NW	6.5
RW3	35° 23.213' N	120° 52.483' W	40.6	8:57:26	12.0	5	1.1	1.5	SE	2-3 NW	6.0
RW4	35° 23.184' N	120° 52.487' W	18.5	8:51:41	12.0	5	1.3	1.8	SE	2-3 NW	6.0
RW5	35° 23.172' N	120° 52.505' W	39.6	8:45:37	12.0	5	1.0	1.7	SE	2-3 NW	5.5
RW6	35° 23.141' N	120° 52.502' W	93.8	8:40:00	11.8	5	1.4	2.2	SE	2-3 NW	6.0

<sup>13</sup> Refer to Table 5 later in this report.

<sup>14</sup> Locations are the vessel positions at the time the Secchi depths were measured. They may depart from the CTD profile locations listed in Table 2.

The 5.5 to 6.5 m Secchi depths recorded during the March 2013 survey reflected the presence of a euphotic zone that extended throughout most of the water column but did not extend to the seafloor at any station (Table 4). The highest water clarity during the survey was located at mid-depth, with reduced clarity near the sea surface due to increased planktonic densities that result from upwelling. During upwelling, nutrients carried upward into the euphotic zone are assimilated by phytoplankton, whose populations increase and, along with their associated zooplanktonic predators, their elevated densities can reduce the transmittance of ambient light. Even close to the sea surface, however, water clarity was high, and exceeded 83.2%.

Although there was no evidence of floating particulates, oil sheens, or any discoloration of the sea surface associated with wastewater constituents, the high water clarity allowed biofilm particulates suspended within the upper water column near the ZID to be visually apparent during portions of the March 2013 survey. Biofilm particulates are not present in wastewater prior to discharge at the treatment plant, but line the interior surface of the outfall pipe. Periodically, small pieces of biofilm detach from the outfall pipe and become entrained within the discharge plume. Depending on the ambient seawater clarity and the vertical extent of the plume within the water column, these particulates are occasionally observed during the water-quality surveys.

Communication with plant personnel and subsequent review of effluent discharge properties on the day of the survey, confirm that the treatment process was performing nominally at time of the survey. The 1.015 million gallons of effluent discharged on 26 March had a temperature of 18°C, a suspended-solids concentration of 41 mg/L, and a pH of 7.5. Biochemical oxygen demand (BOD) measured in an effluent sample collected three days before the survey was 73 mg/L.

During the March 2013 survey, visual observations demonstrated continued beneficial use of the coastal waters within Estero Bay by both wildlife and recreational users. Small numbers of Brandt's cormorants (*Phalacrocorax penicillatus*), pelagic cormorants (*Phalacrocorax pelagicus*), and western gulls (*Larus occidentalis*) were noted transiting the survey area. Additionally, over 15 southern sea otters (*Enhydra lutris nereis*) were observed near the dock and inside the mouth of Morro Bay during transit to and from the survey site. Pedestrians were visible along Atascadero State beach throughout the survey, and several small recreational fishing and sailing vessels were observed well offshore of the survey area.

### *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 March 2013 survey reflect the presence of a moderately stratified water column indicating that upwelling conditions had recently prevailed within Estero Bay (Figure 4).

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. Upwelling results in an influx of dense, cold, saline water at depth and often leads to a sharp thermocline, halocline, and pycnocline where temperature, salinity, and density change rapidly over a small vertical distance. Under highly stratified conditions, isotherms crowd together to form a density interface that restricts the vertical transport of the effluent plume, inhibiting the vertical exchange of nutrients and other water properties, and reducing the initial dilution of the effluent plume.

When upwelling winds are not sustained, the sharp interface between the surface and deep water masses begins to erode, and eventually, the water column stratification appears as a more gradual vertical change in seawater properties that ultimately extends throughout the water column. This was the case during the March 2013 survey. Although winds were mild on the morning of the 26 March, sustained northwesterly

Table 5. Vertical Profile Data Collected on 26 March 2013

Depth (m)	Temperature (°C)						Salinity (‰)					
	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6
1.0	10.644	10.476		10.060	10.501	10.625	33.754	33.746		33.699	33.758	33.751
1.5	10.597	10.466	10.061	10.063	10.367	10.618	33.752	33.742	33.726	33.701	33.741	33.748
2.0	10.408	10.437	10.050	10.066	10.261	10.605	33.735	33.739	33.722	33.708	33.735	33.748
2.5	10.336	10.283	10.052	10.066	10.235	10.510	33.732	33.731	33.726	33.707	33.734	33.743
3.0	10.284	10.179	10.045	10.067	10.214	10.322	33.731	33.738	33.720	33.708	33.736	33.732
3.5	10.217	10.150	10.043	10.070	10.173	10.213	33.736	33.744	33.718	33.712	33.740	33.738
4.0	10.213	10.169	10.040	10.077	10.155	10.207	33.741	33.752	33.714	33.719	33.742	33.745
4.5	10.199	10.185	10.040	10.124	10.148	10.210	33.752	33.758	33.713	33.722	33.742	33.747
5.0	10.201	10.200	10.047	10.185	10.141	10.219	33.760	33.768	33.717	33.728	33.751	33.752
5.5	10.193	10.201	10.049	10.111	10.149	10.219	33.771	33.770	33.714	33.727	33.760	33.764
6.0	10.184	10.183	10.048	10.106	10.150	10.187	33.772	33.772	33.714	33.738	33.768	33.768
6.5	10.172	10.168	10.046	10.108	10.127	10.153	33.775	33.775	33.715	33.743	33.773	33.770
7.0	10.162	10.158	10.040	10.102	10.118	10.153	33.777	33.777	33.707	33.773	33.775	33.771
7.5	10.150	10.148	10.039	10.100	10.109	10.126	33.778	33.778	33.707	33.779	33.776	33.773
8.0	10.122	10.135	10.037	10.089	10.091	10.118	33.778	33.780	33.705	33.782	33.778	33.774
8.5	10.108	10.100	10.036	10.077	10.072	10.092	33.781	33.780	33.702	33.783	33.778	33.776
9.0	10.097	10.078	10.041	10.051	10.068	10.088	33.783	33.781	33.719	33.780	33.778	33.777
9.5	10.079	10.065	10.048	10.030	10.064	10.070	33.783	33.782	33.771	33.780	33.779	33.778
10.0	10.060	10.055	10.046	10.019	10.048	10.041	33.783	33.782	33.784	33.781	33.779	33.779
10.5	10.037	10.045	10.044	10.004	10.028	10.030	33.783	33.783	33.784	33.783	33.780	33.781
11.0	10.030	10.040	10.035	9.993	10.008	10.007	33.783	33.783	33.783	33.784	33.782	33.781
11.5	10.013	10.042	10.019	9.986	9.995	10.003	33.784	33.783	33.782	33.785	33.782	33.782
12.0	10.003	10.025	10.011	9.983	9.984	9.983	33.785	33.783	33.783	33.785	33.784	33.784
12.5	9.995	10.013	10.003	9.984	9.980	9.985	33.785	33.784	33.783	33.786	33.785	33.785
12.0	9.991	10.005	10.001	9.985	9.980	9.985	33.786	33.784	33.783	33.786	33.786	33.786
12.5	9.992	9.996	10.000	9.986	9.982	9.983	33.786	33.785	33.784	33.787	33.787	33.787
14.0	9.990	9.993	9.999	9.985	9.981	9.983	33.787	33.785	33.785	33.786	33.786	33.787
14.5	9.985	9.991	10.004	9.986	9.982	9.982	33.786	33.786	33.785	33.786	33.787	33.788
15.0	9.982	9.989	10.009	9.991	9.983	9.983	33.786	33.786	33.785	33.787	33.787	33.788
15.5	9.982	9.987	10.011	9.995	9.983	9.983	33.786	33.786	33.785	33.787	33.787	33.788
16.0	9.988	9.982	10.012	9.995	9.983	9.984	33.786	33.786	33.785	33.787	33.787	33.787
16.5		9.982	10.015	9.997	9.988	9.988		33.786	33.786	33.787	33.787	33.788
17.0					9.988					33.787		

Table 5. Vertical Profile Data Collected on 26 March 2013 (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
1.0	25.868	25.891		25.926	25.896	25.869	7.984	7.958		7.901	7.942	7.979
1.5	25.875	25.890	25.947	25.927	25.906	25.868	7.991	7.964	7.899	7.898	7.955	7.991
2.0	25.894	25.893	25.946	25.932	25.920	25.871	7.989	7.969	7.900	7.897	7.953	7.995
2.5	25.905	25.913	25.948	25.931	25.924	25.883	7.978	7.965	7.899	7.897	7.945	7.995
3.0	25.913	25.936	25.945	25.932	25.929	25.907	7.970	7.951	7.899	7.897	7.940	7.984
3.5	25.928	25.946	25.944	25.934	25.939	25.930	7.958	7.942	7.898	7.897	7.935	7.973
4.0	25.933	25.949	25.941	25.938	25.943	25.937	7.951	7.936	7.898	7.899	7.930	7.961
4.5	25.944	25.951	25.940	25.933	25.945	25.938	7.946	7.933	7.897	7.901	7.926	7.951
5.0	25.950	25.956	25.943	25.928	25.953	25.940	7.942	7.934	7.897	7.907	7.922	7.944
5.5	25.959	25.957	25.940	25.939	25.959	25.949	7.940	7.934	7.896	7.913	7.922	7.942
6.0	25.962	25.962	25.940	25.949	25.965	25.959	7.939	7.936	7.897	7.911	7.922	7.939
6.5	25.967	25.967	25.941	25.953	25.972	25.966	7.937	7.933	7.896	7.909	7.923	7.937
7.0	25.969	25.970	25.936	25.977	25.975	25.966	7.934	7.930	7.895	7.909	7.921	7.934
7.5	25.972	25.973	25.936	25.981	25.978	25.972	7.929	7.925	7.895	7.908	7.920	7.931
8.0	25.977	25.977	25.934	25.986	25.983	25.975	7.925	7.922	7.894	7.906	7.917	7.927
8.5	25.982	25.983	25.932	25.988	25.986	25.981	7.922	7.918	7.893	7.905	7.914	7.923
9.0	25.985	25.987	25.945	25.991	25.986	25.982	7.918	7.915	7.894	7.905	7.912	7.921
9.5	25.989	25.990	25.984	25.994	25.988	25.986	7.915	7.912	7.895	7.905	7.911	7.919
10.0	25.992	25.992	25.995	25.997	25.991	25.992	7.911	7.910	7.897	7.904	7.909	7.916
10.5	25.995	25.994	25.995	26.001	25.995	25.995	7.910	7.907	7.899	7.903	7.908	7.912
11.0	25.997	25.995	25.996	26.003	25.999	25.999	7.908	7.906	7.900	7.900	7.904	7.909
11.5	26.000	25.995	25.998	26.006	26.002	26.001	7.907	7.906	7.902	7.897	7.904	7.907
12.0	26.003	25.998	26.000	26.006	26.005	26.005	7.905	7.905	7.902	7.894	7.902	7.903
12.5	26.004	26.000	26.001	26.007	26.007	26.006	7.905	7.904	7.902	7.893	7.900	7.900
12.0	26.006	26.002	26.002	26.007	26.007	26.006	7.904	7.904	7.902	7.893	7.896	7.899
12.5	26.006	26.004	26.003	26.007	26.008	26.007	7.901	7.903	7.900	7.893	7.893	7.895
14.0	26.006	26.005	26.003	26.007	26.008	26.008	7.900	7.901	7.899	7.892	7.892	7.893
14.5	26.007	26.005	26.003	26.007	26.008	26.008	7.899	7.901	7.896	7.891	7.892	7.892
15.0	26.007	26.006	26.002	26.006	26.008	26.008	7.898	7.901	7.894	7.891	7.890	7.890
15.5	26.007	26.006	26.002	26.005	26.008	26.008	7.897	7.900	7.892	7.890	7.890	7.890
16.0	26.006	26.007	26.002	26.005	26.008	26.008	7.896	7.899	7.891	7.889	7.889	7.888
16.5		26.007	26.001	26.005	26.007	26.008		7.895	7.886	7.887	7.888	7.884
17.0					26.007						7.887	

Table 5. Vertical Profile Data Collected on 26 March 2013 (continued)

Depth (m)	Dissolved Oxygen (mg/L)						Transmissivity (%)					
	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6
1.0	7.212	6.545		4.964	6.093	7.349	86.114	85.664		88.311	85.415	83.206
1.5	6.283	6.464	4.936	5.024	5.742	7.211	85.320	85.706	88.840	88.702	85.667	83.713
2.0	5.961	5.791	4.970	5.016	5.665	6.628	86.341	85.710	89.042	88.838	86.406	83.660
2.5	5.789	5.437	4.932	5.016	5.613	5.705	86.598	86.340	88.869	89.042	87.596	83.840
3.0	5.541	5.302	4.928	5.034	5.449	5.483	86.840	87.748	89.101	88.621	87.874	84.643
3.5	5.578	5.436	4.913	5.067	5.375	5.559	87.465	88.578	88.898	89.027	88.639	87.169
4.0	5.518	5.483	4.919	5.342	5.374	5.591	88.275	89.516	88.563	89.025	89.227	88.445
4.5	5.538	5.556	4.954	5.581	5.335	5.622	88.837	89.713	88.409	89.050	89.031	88.991
5.0	5.483	5.530	4.952	5.169	5.379	5.610	89.199	89.859	88.489	88.211	89.527	89.680
5.5	5.436	5.471	4.941	5.185	5.364	5.494	90.372	90.373	88.379	88.139	89.766	90.198
6.0	5.378	5.411	4.934	5.199	5.270	5.374	90.250	90.615	88.512	89.290	90.363	90.817
6.5	5.345	5.336	4.904	5.204	5.266	5.392	90.494	90.653	88.445	89.618	91.048	91.491
7.0	5.304	5.333	4.903	5.184	5.231	5.278	90.282	90.368	88.400	89.649	91.278	92.074
7.5	5.173	5.293	4.890	5.138	5.157	5.281	89.746	90.264	88.262	90.068	91.919	92.031
8.0	5.162	5.151	4.886	5.112	5.122	5.174	90.064	90.177	88.301	89.935	92.108	92.224
8.5	5.136	5.071	4.940	5.054	5.108	5.169	90.221	89.352	88.148	90.023	91.915	92.205
9.0	5.030	5.042	5.048	4.985	5.096	5.119	89.950	89.167	88.114	90.718	92.358	92.474
9.5	5.023	5.035	5.030	4.968	5.038	5.028	89.211	89.976	88.559	92.352	92.792	92.885
10.0	4.969	5.029	5.011	4.893	4.985	5.012	89.552	90.516	90.244	92.389	92.294	92.125
10.5	4.972	5.017	4.987	4.854	4.910	4.938	90.291	90.998	91.676	92.831	92.780	92.977
11.0	4.927	5.015	4.943	4.820	4.894	4.941	90.599	90.761	91.500	91.857	93.066	92.931
11.5	4.873	4.983	4.938	4.813	4.862	4.834	91.130	90.994	92.143	91.464	93.054	92.742
12.0	4.836	4.924	4.924	4.817	4.824	4.865	90.923	90.969	92.491	91.105	92.729	92.499
12.5	4.800	4.923	4.922	4.815	4.827	4.843	92.100	91.462	92.937	91.268	92.493	92.095
12.0	4.819	4.879	4.859	4.804	4.819	4.835	92.069	92.174	92.853	91.010	92.766	92.154
12.5	4.802	4.881	4.828	4.813	4.822	4.805	91.931	92.319	92.505	90.770	91.894	90.264
14.0	4.800	4.875	4.780	4.809	4.814	4.803	91.710	92.436	91.783	90.513	90.931	89.626
14.5	4.764	4.854	4.774	4.793	4.798	4.821	91.631	92.534	90.604	90.933	90.699	89.980
15.0	4.770	4.863	4.765	4.747	4.814	4.803	91.051	92.811	89.435	89.875	90.632	89.975
15.5	4.734	4.789	4.745	4.761	4.795	4.801	90.367	92.891	88.514	88.015	90.665	89.939
16.0	4.755	4.776	4.733	4.740	4.770	4.794	90.120	92.945	86.767	87.864	90.339	89.563
16.5		4.768	4.751	4.751	4.784	4.810		92.200	84.103	87.232	89.851	87.257
17.0					4.809						89.378	

winds prevailed in the days prior to the survey (Figure 4). As a result, a relict upwelling signature appears in the vertical profiles as moderate stratification that extends through most of the water column (Figure 6).

In particular, all seawater properties except transmissivity exhibit steadily increasing or decreasing values throughout the mid-depth range between 2 and 12 m. Large departures from these vertical trends apparent in the upper water column at Stations RW3 and RW4 (Figure 4cd) were caused by the discharge plume. For the most part however, steady decreases in temperature (red lines), DO (dark blue lines), and pH (olive-colored lines) with depth reflect the lingering effects of upwelling during the days prior to the survey. These decreases are mirrored by a pycnocline, where density (black lines) steadily increases with depth. These gradual vertical changes reflect the transition to colder, saltier, nutrient-rich but oxygen-poor watermass that migrated shoreward along the seafloor as part of the upwelling process. Departures from these gradual vertical trends occur within the near-surface mixed layer, which extends approximately 2 m below the sea surface, and within a 2-m benthic nepheloid layer (BNL) immediately above the seafloor. The sharp reduction in water clarity near the seafloor reflects the presence of a turbid BNL containing light flocs of detritus resuspended from the seafloor by boundary layer flow processes. The BNL lies within a thicker layer containing water properties that originated deep offshore. This offshore watermass was characterized by cold, dense seawater (red and black lines in Figure 6) that moved shoreward to replace nearshore surface waters that were driven offshore by prevailing winds. Because this deep offshore watermass had not been in recent direct contact with the atmosphere, biotic respiration and decomposition had depleted its DO levels (dark blue lines). Additionally, at depth, biotic respiration and decomposition produced carbon dioxide (CO<sub>2</sub>), and in its dissolved state, the increased concentration of carbonic acid appears as a concomitant decline in pH (olive-colored lines).

Meanwhile, within the surface mixed layer, nutrient-rich seawater brought to the sea surface by the recent upwelling facilitated phytoplankton blooms that produced oxygen, consumed carbon dioxide (CO<sub>2</sub>), and decreased water clarity (light blue lines). The presence of plankton within the surface mixed layer caused a perceptible 7% decrease in transmissivity at the sea surface compared to mid-depth. Within the BNL, the presence of resuspended surficial sediments and light flocs of detritus caused a smaller reduction in water clarity, decreasing transmissivity by an average of 3% compared to mid-depth.

The moderately deep deep Secchi depths (Table 3) and high transmissivities (Figure 6) measured during the March 2013 document a high level of water clarity throughout most of the water column. While the Secchi disk observations demonstrate that ambient light extended through the surface mixed layer and well into the water column, the measurements did not encompass the increases in turbidity that were captured by the transmissometer within the BNL. In fact, the Secchi depths demonstrate that the euphotic zone did not reach below 13 m, and that little ambient light penetrated into the turbid BNL and reached the seafloor.

The level of vertical stratification within the survey area is important for understanding the dynamics of the effluent plume dispersion at the time of the survey. For example, when the water column is strongly stratified during upwelling events, the rising plume can become trapped at depth within the water column, thereby limiting its full capacity for dilution. However, during the moderate stratification of the March 2013 survey, the plume's buoyancy was sufficient to carry it to the sea surface, where it achieved higher dilution levels.

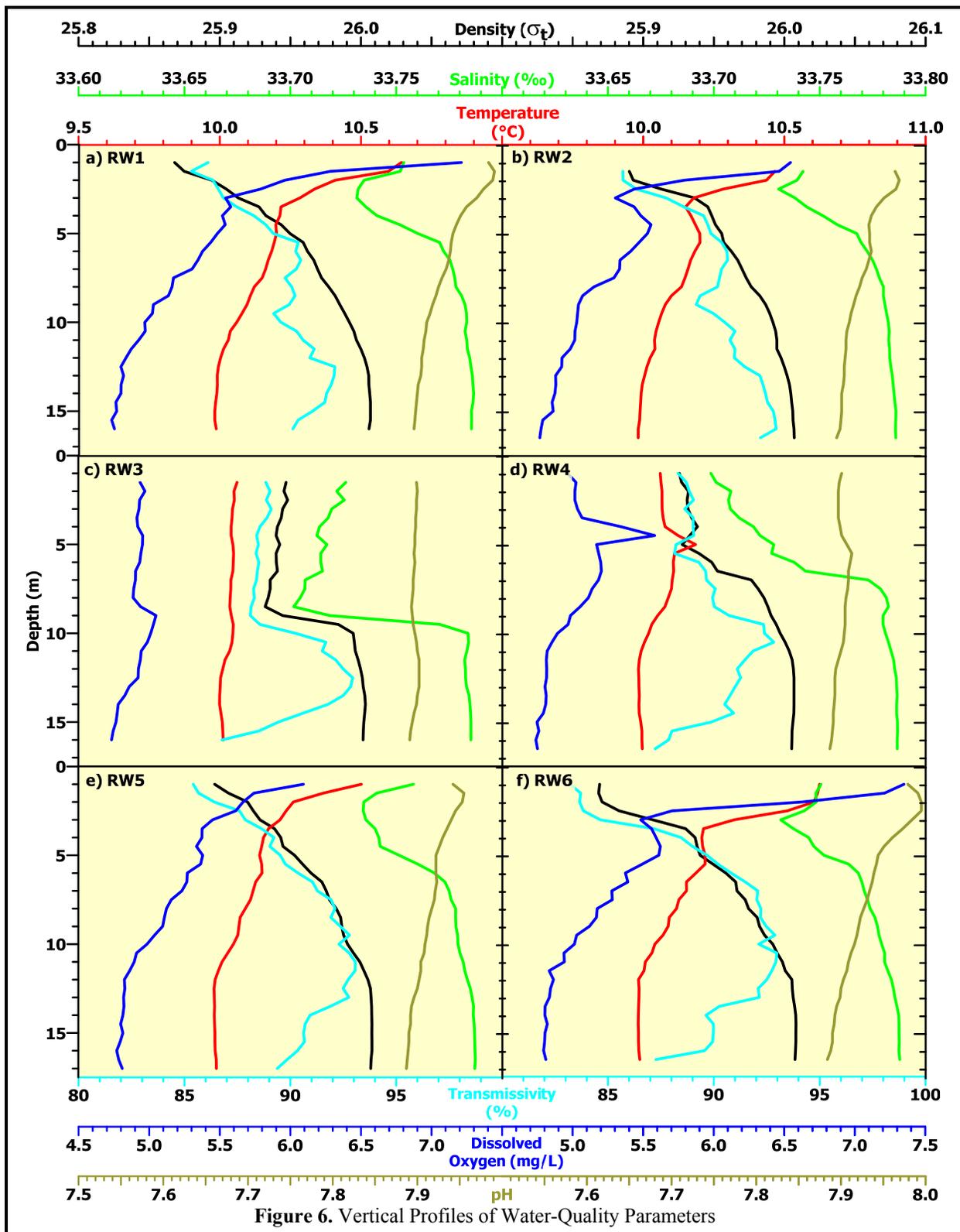


Figure 6. Vertical Profiles of Water-Quality Parameters

The signature of the surfacing effluent plume can be seen clearly in the vertical profiles at Station RW3 (Figure 6c). This station was situated north of the northern limit of the ZID and along the plume transport path (Figure 2). Sharp decreases in salinity (green lines), density (black lines), and transmissivity (light blue lines) above 11 m characterize the presence of the effluent plume. Similarly, the vertical profiles of temperature (red lines), DO (dark blue lines), and pH (gold lines) were nearly uniform throughout the water column at this station compared to the other stations (*cf.* Figure 6c with 6abef). This vertical uniformity was caused by the entrainment of cooler, oxygen-depleted, and acidic ambient seawater near the seafloor, which was subsequently carried upward by the rising effluent plume. Station RW4, whose measurements were located primarily within the ZID, exhibited a similar plume signature within the upper water column.

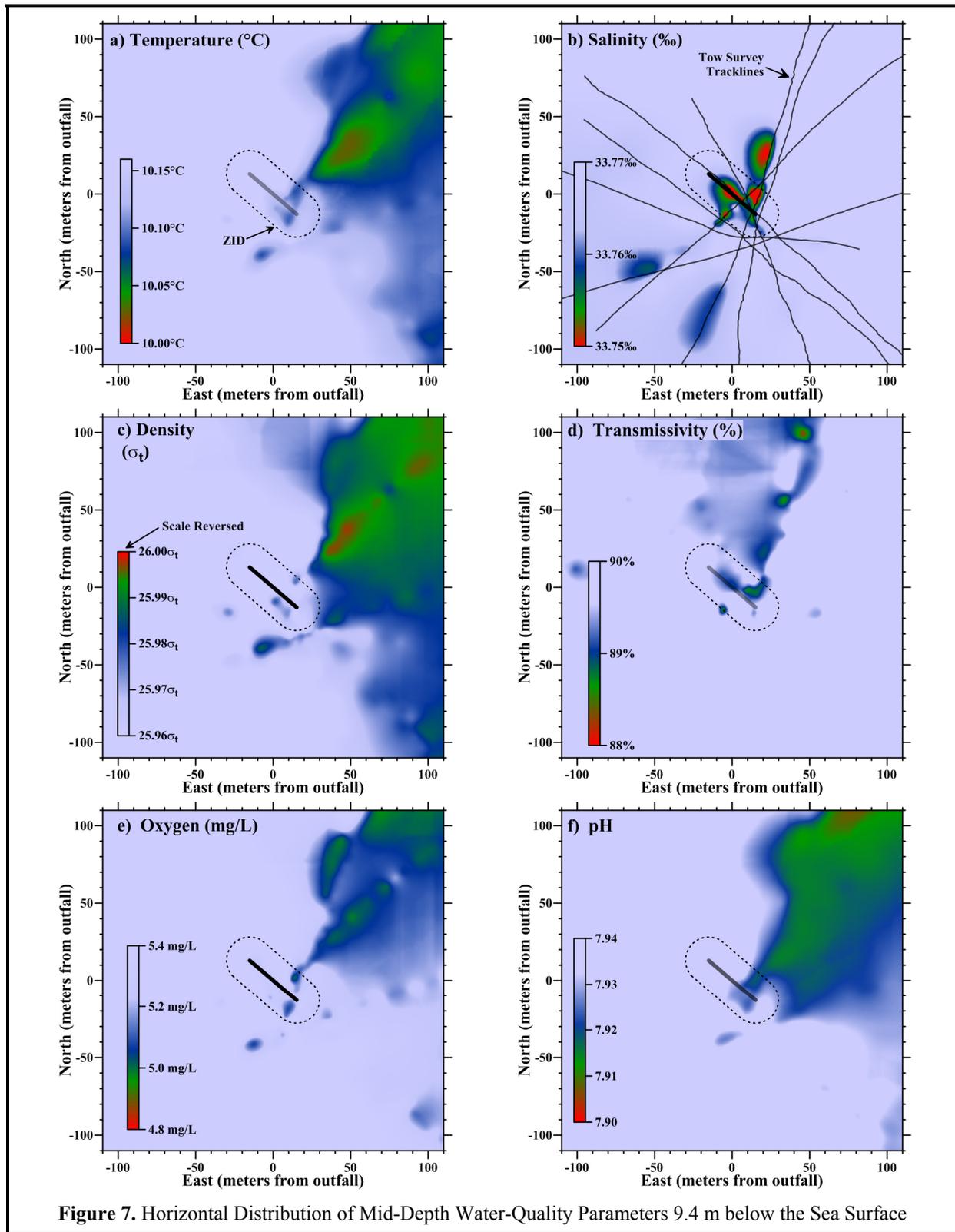
Nevertheless, the amplitudes of the variations in seawater properties that identify the presence of the plume signature at Stations RW3 and RW4 were generally small. This is because ambient seawater properties were comparatively uniform during the survey. For example, the temperature range spanned only 0.7°C over the entire dataset, and essentially all of this difference was due to vertical stratification (red lines in Figure 6abef). Within the plume signature in the upper water column at Station RW3 (Figure 6c), the uniformly reduced temperature, DO, pH, and transmissivity values were comparable to those of ambient seawater immediately above the seafloor. The plume acquired deep watermass properties when it entrained bottom seawater shortly after discharge. At that location, intense mixing was driven by the momentum of the effluent's ejection from the individual diffuser ports. These deep seawater properties became apparent as a signature of the buoyant effluent plume after they were carried upward in the water column and juxtaposed against the ambient seawater characteristics in the upper water column.

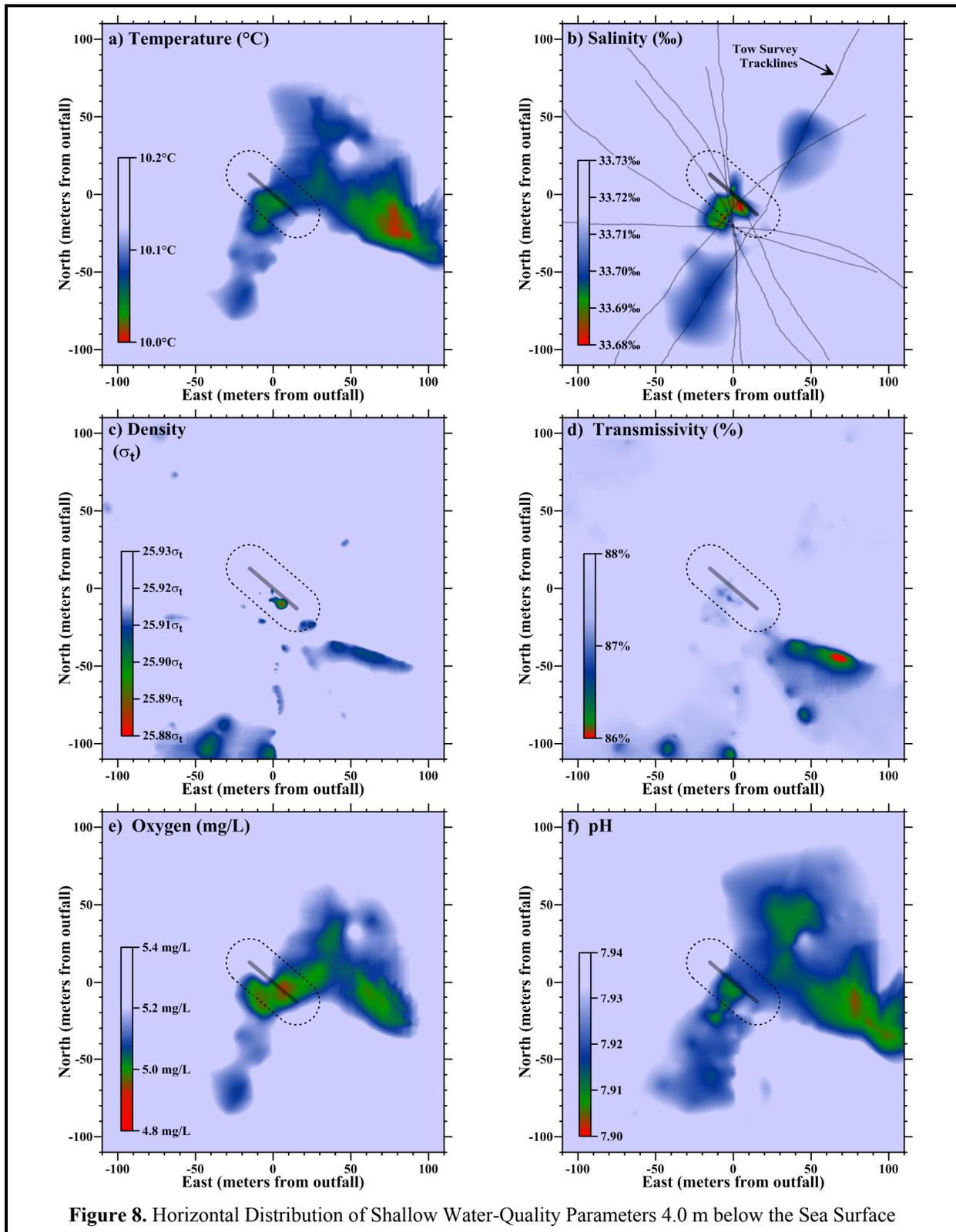
In contrast, the reduced salinity that characterized the discharge plume in the upper water column at Station RW3 (green line in Figure 6c) was caused by the presence wastewater constituents. Ambient seawater near the seafloor was higher than the surface seawater, and thus, upward transport of entrained seawater could not account for the observed reduction in salinity. In fact, the salinities measured near 11 m at Station RW3 were the lowest among the 11,115 measurements collected during the survey, although their -0.077‰ departure from ambient salinity at the same depth level was exceedingly small.

It is clear that the anomalies in other seawater properties at Station RW3 were not caused by the presence of wastewater constituents because the offsets in their properties were consistent with the vertical differences in ambient seawater and, for some properties, the offsets were opposite of the changes that would be expected to be caused by wastewater. For example, wastewater discharged on the day of the survey was much warmer (18°C) than receiving seawater (<10.7°C), and thus the presence of warmer wastewater constituents could not have induced the negative thermal signature observed above 11 m at that station. Entrainment of cool bottom seawater is the only mechanism that could have created a dilute effluent plume that was cooler than the ambient seawater in the upper water column. Additionally, the decreased transmissivity, temperature, pH, and DO measured within the entrainment anomalies above 11 m at Station RW3 were comparable to the ambient seawater properties found near the seafloor (Figure 6cd).

The legacies of such entrainment anomalies can be particularly long-lived, remaining apparent within the water column well after completion of the initial dilution process when wastewater constituents have been dispersed beyond recognition. Regardless, such anomalies are irrelevant to the receiving-water compliance assessment because the permit requirements restrict attention to water-quality changes caused solely by the presence of wastewater constituents.

Additionally, these anomalies provide useful tracers of the diffuse effluent plume after the completion of initial dilution. The post-ZID disposition of the effluent plume is particularly apparent in the horizontal maps created from the tow data (Figures 7 and 8). At mid-depth, the presence of wastewater constituents,





as indicated by the lower salinities, are generally clustered around the diffuser structure, and within a limited area just beyond the northeast boundary of the ZID (Figure 7b). The entrainment anomalies, however, are apparent in all the other water properties, and extend well to the northeast of the more compact salinity footprint (Figure 7acdef), in a direction consistent with the drifter trajectory. It is also important to note that the amplitudes of both the salinity and the entrainment anomalies are exceedingly small, as shown by the scales within each plot. The ability to resolve minute lateral differences in temperature (0.15°C), salinity (0.02‰), density (0.04σ<sub>t</sub>), transmissivity (2%), DO (0.6 mg/L), and pH (0.04) within the unusually uniform distribution of ambient seawater properties that prevailed at the time of the survey attests to the high precision of the CTD measurements.

Closer to the sea surface (Figure 8), the lateral extent of the plume entrainment signature was comparatively limited. This is because the initial momentum of the rising effluent plume caused it to overshoot its subsurface buoyant equilibrium level, briefly rising to the sea surface within the ZID before descending again within the water column beyond the ZID. This is apparent from the positive density anomaly that was associated with the entrainment signature at mid-depth (shading in the northeast quadrant of Figure 7c). This indicates that the plume was heavier than the surrounding seawater at 9.4 m, and was slowly descending through the water column as it was being transported toward the northeast. The absence of a diffuse entrainment signature near the sea surface (Figure 9), however, indicates that the plume was largely located below the 4-m tow depth.

### *Outfall Performance*

The efficacy of the outfall can be evaluated through a comparison of dilution levels measured at the time of the March 2013 survey, and dilutions anticipated from modeling studies that were codified in the discharge permit through limits imposed on effluent constituents. Specifically, the critical initial dilution applicable to the MBCSD outfall was conservatively estimated to be 133:1 (Tetra Tech 1992). That is, dispersion modeling estimated that, at the conclusion of the minimum expected initial mixing, 133 parts of ambient seawater would have mixed with each part of wastewater.

The 133:1 dilution estimate was based on worst-case modeling under highly stratified conditions, where trapping of the plume below a strong thermocline would curtail the additional buoyant mixing normally experienced during the plume's rise through the water column. Additionally, the modeling assumed quiescent oceanic flow conditions, thereby restricting initial mixing processes to the ZID. Under those conditions, the modeling predicted that a 133:1 dilution would be achieved after the plume rose only 9 m from the seafloor, whereupon it would become trapped, ceasing to rise further in the water column, and spread laterally with no further dilution occurring. A 9-m rise at the MBCSD outfall translates into a trapping depth that is 6.4 m below the sea surface. As described below, observed dilution levels during the March 2013 survey were higher than the conservative model prediction, at depths greater than the trapping depth predicted by modeling, and where measured initial-dilution levels would be expected to be much lower than the 133:1 of 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.

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

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. Wastewater-induced patches of lower salinity were apparent in the upper water column in the vertical profiles measured at Stations RW3 and RW4 (green lines in Figure 6cd), and near the diffuser structure in the tow-survey maps (Figures 7b and 8b). These localized salinity anomalies document mixing processes within the effluent plume shortly after it emanated from a diffuser port and rose through the water column.

These salinity anomalies measure the magnitude of wastewater dilution at these various stages of the initial mixing process. By rearranging Equation 1, the dilution ratio ( $D$ ) can be computed from the salinity anomaly ( $A = C_o - C_s$ ) as:

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

The salinity concentration within MBCSD effluent ( $C_e$ )<sup>15</sup> is generally small compared to that of the receiving seawater and, after dilution by more than 100-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, lower effluent dilution at a given location within receiving waters is directly mirrored by a larger salinity reduction.

The lowest salinity (33.677‰) measured during the March 2013 survey was recorded during the shallow tow at a location that was almost directly over the diffuser structure (red shading in Figure 8b). This low salinity was well within the ZID at a lateral distance of only 2 m from the diffuser structure. Although this was the lowest salinity measured during the survey, it corresponded to only a 0.053‰ reduction below the mean ambient salinity of 33.730‰ that was measured at that tow depth, but well beyond the influence of the discharge. From Equation 2, that salinity anomaly corresponds to a dilution of 614-fold (Figure 9). The distribution of the dilution levels computed from the low salinities measured during the shallow tow were highly localized within a region directly over the diffuser structure.

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<sup>15</sup> Wastewater samples have an average salinity of 0.995‰.

The small amplitudes of the discharge-related salinity anomalies at that depth level resulted from the comparatively low salinity of the ambient seawater that was present just below the sea surface during the March 2013 survey. Vertical profiles of salinity at Stations RW1, RW2, RW5, and RW6 all exhibited a distinct sub-surface salinity minimum immediately below the sea surface, and near the depth where shallow tow took place (green lines in Figure 6abef). As a result, the contrast between the wastewater-induced salinity reduction and the ambient salinity was smaller at that depth level.

Larger salinity contrasts (0.077‰) were apparent between 6 and 9 m in the vertical profile collected at Station RW3, even though the associated salinity (33.702‰) was not the lowest measured during the March 2013 survey (green line in Figure 6c). However, because it was located below the salinity minimum of ambient seawater, the difference between the ambient salinity and the wastewater-induced reduction in salinity was larger. The largest difference occurred at a depth of 8.5 m at Station RW3 and corresponded to a plume dilution of 425-fold.

At the slightly greater depth level of the mid-depth tow (9.4 m), there was little evidence of wastewater constituents. The very small salinity reductions (-0.025‰) that were apparent in the horizontal map shown in Figure 7b, translated into very high computed dilutions (<900-fold in Figure 10). As with the shallow tow, the highly dilute wastewater constituents were only apparent very close to the diffuser structure and where the initial dilution process was not yet complete.

The lowest dilution of 425:1 measured during the March 2013 survey was three-times greater than the 133:1 critical initial dilution used to establish limits on contaminant concentrations in wastewater after the initial-dilution process is complete. In addition, it was measured at depth level (8.5 m) that was below the 6.4-m trapping depth determined in the worst-case initial dilution modeling. At that depth, the plume was still buoyant and undergoing additional initial dilution. Thus, during the March 2013 survey, the diffuser was diluting wastewater at least three-times more efficiently than predicted by modeling.

The dilution computations demonstrate that, during the March 2013 survey, the outfall was performing better than designed and was rapidly diluting effluent more than 425-fold immediately after discharge,

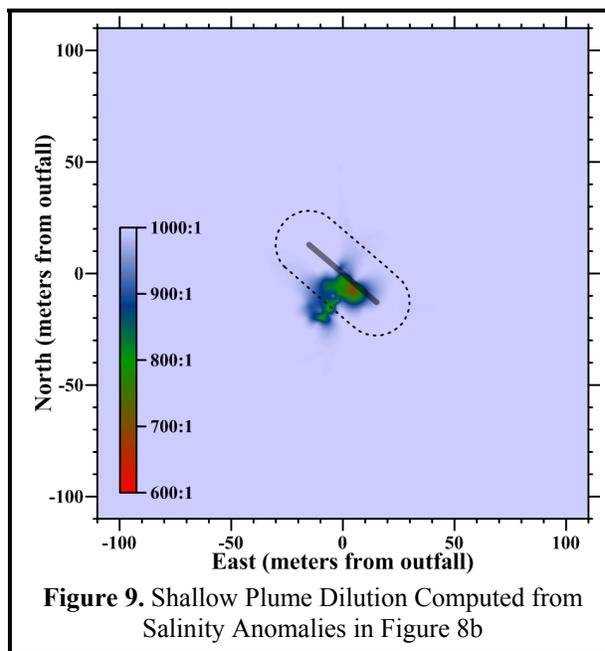


Figure 9. Shallow Plume Dilution Computed from Salinity Anomalies in Figure 8b

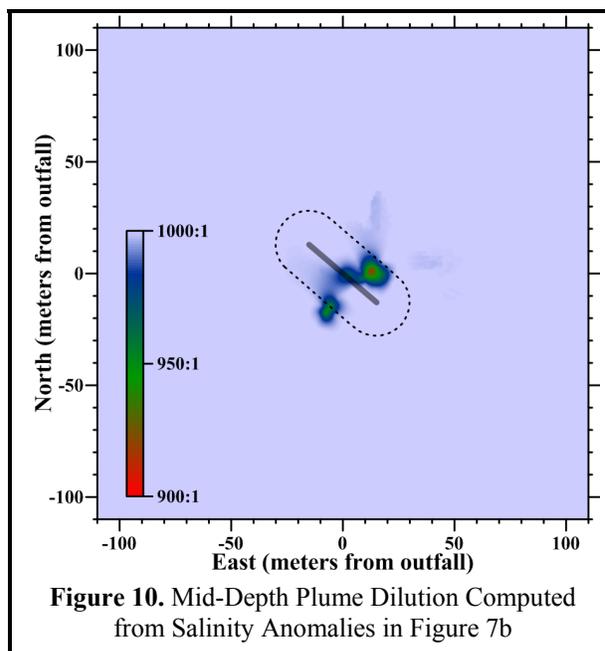


Figure 10. Mid-Depth Plume Dilution Computed from Salinity Anomalies in Figure 7b

and well before completion of the initial-dilution process. The measured dilution levels throughout the survey easily exceeded the 133:1 critical initial dilution used to establish end-of-pipe permit limitations on contaminant concentrations within wastewater discharged from the MBCSD treatment plant. Consequently, during the March 2013 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 limits listed in the NPDES permit (Table 6). The limitations 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 applied to the March 2013 data demonstrate that the MBCSD discharge complied with the NPDES discharge permit. Moreover, although observations within the ZID are not subject to compliance evaluations, they often meet the prescribed limits because actual dilution levels routinely exceed the conservative design specifications assumed in the discharge permit. Thus, the quantitative evaluation described in this section documents an outfall and treatment process that was performing at a high level during the March 2013 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. As described previously, no floating wastewater materials, oil, grease, or discoloration of the sea surface were observed during the March 2013 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.

Natural variation in seawater properties is driven by a variety of oceanographic processes. These processes determine 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 11,115 CTD measurements collected during the March 2013 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 apply; 2) changes due to the presence of wastewater particulates; and 3) changes large enough to be reliably detected against the backdrop of natural variation. The measurements that make it through the screening process, if any, can

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

Topic Addressed	Screening Question	Answer		Parameter
		No	Yes <sup>16</sup>	
Location	1. Was the measurement collected beyond the 15.2-m ZID boundary where modeling assumes that initial dilution is complete?	1,344	9,771	All
Wastewater Constituents	2. Did the beyond-ZID measurement coincide with a quantifiable salinity anomaly (≤550:1 dilution level) indicating the presence of detectable wastewater constituents?	9,766	5	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?	5	0	Temperature
		5	0	Transmissivity
		5	0	DO
		5	0	pH

<sup>16</sup> Number of remaining CTD observations of potential compliance interest based on this screening question

then be compared with Basin-Plan numerical limits and COP allowances. The following subsection provides additional lines-of-evidence that demonstrate compliance with numerical permit limits independent of the screening process. The rationale for evaluating observations for compliance analysis is provided in the following description of the three screening steps.

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

Although currents often transport the plume beyond the ZID before the initial dilution process is complete, the COP states that dilution estimates shall be based on “*the assumption that no currents, of sufficient strength to influence the initial dilution process, flow across the discharge structure.*” Because of this, the regulatory mixing distance, which is equal to the 15.2-m water depth of the discharge, provides a conservative boundary to screen receiving-water data for subsequent compliance evaluation. Application of this initial screening question to the March 2013 dataset eliminated 1,344 of the original 11,115 receiving-water observations from further consideration because they were collected within the ZID (Table 7, Question 1). The remaining 9,771 observations were carried forward in the compliance analysis.

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

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

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

As shown in Figures 7b and 8b, discharge-related salinity anomalies measured during the tow surveys were largely located within the ZID boundary due to the low current speeds that prevailed at the time of the March 2013 survey. Most of these observations were eliminated in the prior screening step. In fact, beyond the ZID, only five measurements had reductions in salinity that were greater than the 0.062‰ detection threshold (Table 7) where wastewater-induced salinity reductions can be reliably discerned.

**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 of variability in natural conditions surrounding the outfall (first three columns of Table 8). These ranges in natural variability were used to identify significant departures from ambient conditions that could be indicative of adverse discharge-related effects on water quality. The same five-year database

**Table 8. Compliance Thresholds**

<b>Water Quality Property</b>	<b>95% Confidence Bound<sup>17</sup></b>	<b>95<sup>th</sup> Percentile<sup>18,19</sup></b>	<b>Natural Variability Threshold<sup>20</sup></b>	<b>COP Allowance<sup>21</sup></b>	<b>Basin Plan Limit<sup>22</sup></b>	<b>Extremum<sup>23</sup></b>
Temperature (°C)	0.82	10.49	>11.31	—	—	≤10.64
Transmissivity (%)	-10.2	85.5	<75.3	—	—	≥83.2
DO (mg/L)	-1.38	4.78	<3.40	<3.06	<5.00	≥4.73
pH (minimum)	-0.094	7.890	<7.796	<7.596	<7.000	≥7.884
pH (maximum)	0.094	7.982	>8.076	>8.276	>8.300	≤7.997

<sup>17</sup> 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.

<sup>18</sup> 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.”

<sup>19</sup> The 95<sup>th</sup>-percentile quantifies natural variability in seawater properties during the March 2013 survey, and was determined from vertical-profiles data unaffected by the discharge.

<sup>20</sup> Thresholds represent limits on wastewater-induced changes to receiving-water properties that significantly exceed natural conditions as specified in the discharge permit and COP. They are determined from the sum of columns to the left and are specific to the March 2013 survey. They do not include the COP allowances specified in the column to the right.

<sup>21</sup> 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.”

<sup>22</sup> 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 the upper-bound objective 8.3, which applies to most beneficial uses was implemented in the MBCSD discharge permit.

<sup>23</sup> Maximum or minimum value measured during this survey

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 ( $\pm 0.094$ ). These were combined with 95<sup>th</sup> percentiles determined from the March 2013 ambient seawater data, to establish time-specific natural-variability thresholds in a manner analogous to COP Appendix VI. The percentiles were determined from March 2013 vertical profile data, excluding measurements potentially affected by the discharge.

Temperature, transmissivity, and DO concentrations associated with the five remaining measurements of potential compliance interest all remained within their respective ranges of natural variability (Table 7, Question 3). As such, the screening process unequivocally eliminated all of the CTD measurements collected during the March 2013 survey from further consideration. In fact, all of the documented excursions in these properties were the result of physical processes unrelated to the presence of wastewater constituents, namely, entrainment of near-bottom seawater within the rising effluent plume. During periods when the water column is stratified, such as during the March 2013 survey, ambient seawater properties near the seafloor differ from those within the rest of the water column, and their juxtaposition within the rising plume appears as lateral anomalies within the upper water column. As discussed previously, all of the anomalies in seawater properties that coincided with the salinity anomalies in Figures 6, 7 and 8 were consistent with the upward displacement of ambient bottom water rather than with the presence of the effluent plume. Additionally, even if the presence of wastewater particulates had contributed to the measured decreases in DO and pH, their influence would 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*

In addition to the analysis provided above, several additional lines of evidence support the conclusion that all the CTD measurements collected during the March 2013 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 March 2013 survey.

***Insignificant Thermal Impact:*** Although there are no explicit numerical objectives for discharge-related decreases 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 11.31°C in Table 8). However, none of the 11,115 CTD measurements collected during the March 2013 survey exceeded 10.64°C (last column in Table 8). In fact, as mentioned previously, because the effluent entrained cooler bottom water shortly after discharge, the rising plume actually had a lower temperature than most of the surrounding seawater (Figures 7a and 8a).

***Insignificant Wastewater Particulate Loads:*** The discharge of wastewater particulates on 26 March 2013 did not contribute materially to turbidity within the dilute effluent plume. The suspended-solids concentration measured onshore within the effluent prior to discharge from the WWTP was 41 mg/L.

After dilution by 425-fold, which was the lowest dilution measured during the survey, the effluent suspended-solids concentration would have the reduced ambient transmissivity by only 0.8%.

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, 73-mg/L BOD measured within the plant's effluent several days prior to 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.

**COP Allowances:** The COP does not explicitly require that wastewater-induced changes remain within the ranges in natural variation listed in the third column of Table 8, even though these ranges were conservatively used in the data screening process described in the previous subsection. 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 7.596 during the March 2013 survey (fourth column of Table 8). This value is well below the lowest pH measurement of 7.884 recorded during the March 2013 survey (last column of Table 8). Similarly, the lowest DO concentration measured during the survey (4.73 mg/L) was well above both the lower range in natural variation (3.40 mg/L) and the 10% compliance threshold promulgated by the COP (3.06 mg/L).

**Natural Variability within and beyond the ZID:** Although the permit limits only apply to changes in DO, pH, temperature, and transmissivity beyond the ZID, examination of measurements within the ZID frequently provides additional valuable insight into the potential for adverse effects on water quality beyond the ZID. However, during the March 2013 survey, salinity was the only seawater property that consistently exhibited a perceptible difference from ambient conditions. Regardless of their association with the effluent salinity signature or their proximity to the diffuser structure, none of the 11,115 temperature, DO, and pH observations exceeded the thresholds of natural variability specified in Table 8.

**Non-Discharge-Related Exceedances of 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. The COP requires that DO concentrations outside the ZID not be depressed more than 10% from that which occurs naturally, and restricts pH measurements to those within 0.2 units of that which occurs naturally. In contrast, the Basin-Plan's fixed numerical limits do not provide specific guidance as to how they might change in response to widespread changes in oceanographic conditions unrelated to the discharge. Specifically, the fixed numerical limits restrict DO concentrations outside the ZID to no less than 5 mg/L (P5 in Table 6), and pH levels to the 7.0-to-8.3 range (P6). While all 11,115 pH values measured during the March 2013 survey remained well within the Basin Plan's acceptable range, the same was not true for the DO measurements. Although all of the observed DO concentrations were within the ambient range measured at the time of the survey, and therefore complied with the COP portion of the permit provision, more than half (865 or 8%) of the observations were below the 5 mg/L Basin-Plan threshold.

These low DO concentrations arose because the deep watermass that was transported shoreward and into the survey area by upwelling was naturally depleted in oxygen. Accordingly, all of the DO concentrations measured below a depth of 11.5 m were below the 5-mg/L Basin Plan threshold (dark blue lines in Figure 6). Where the rising plume carried these naturally low DO concentrations upward, sub-5-mg/L concentrations were also observed throughout the water column and even near the sea surface in localized areas (Figures 6c, 7e, and 8e). DO concentrations below 5 mg/L have been observed in a number of past water-quality surveys in conjunction with prolonged upwelling events (MRS 2011, 2012, and 2013).

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

Naturally occurring DO concentrations below 5 mg/L were simply not envisioned within coastal waters when the Basin Plan was promulgated in 1972. The fixed Basin Plan limits were largely designed for discharges to onshore surface waters, where there is little natural variation in pH and DO within the receiving waters. Conversely, natural oceanographic processes, such as upwelling, regularly cause the DO and pH of the ambient receiving water surrounding the MBCSD outfall to range beyond the Basin Plan limits. In contrast to the Basin Plan limits, the COP recognizes the potential for inherent variation in the receiving-water characteristics and specifies limits on excursions in these two water properties relative to background levels present at the time of the survey. Because the COP receiving-water objectives are designed to be adequately protective of the marine environment, application of the fixed Basin Plan limits to the same receiving-water characteristics already covered by the COP is not only redundant but inappropriate. For these reasons, the Basin Plan limits have been recommended for removal from future MBCSD discharge permits (MRS 2011, 2012, and 2013).

## CONCLUSIONS

The quantitative screening analysis demonstrated that all measurements recorded during the March 2013 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. Although the presence of dilute wastewater constituents was delineated from salinity anomalies within the discharge plume, all the associated seawater properties were within the natural range of variability that prevailed at the time of the survey.

Shortly after discharge, the outfall was achieving dilution levels in excess of 425-fold, which substantially exceeds the critical dilution levels predicted by design modeling. This lowest dilution level was observed within the buoyant discharge plume, and before the initial dilution process was complete. As the plume continued to rise through the water column, it was transported slowly northeastward, achieving dilution levels exceeding 614-fold. Lastly, all of the auxiliary observations collected during the March 2013 survey demonstrated that the discharge complied with the narrative receiving-water limits in the discharge permit and the COP. Together, these observations demonstrated that the treatment process, diffuser structure, and the outfall continue to perform at levels exceeding design expectations.

Although discharge-related changes in seawater properties were observed during the March 2013 survey, the changes were either not of significant magnitude, 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.

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