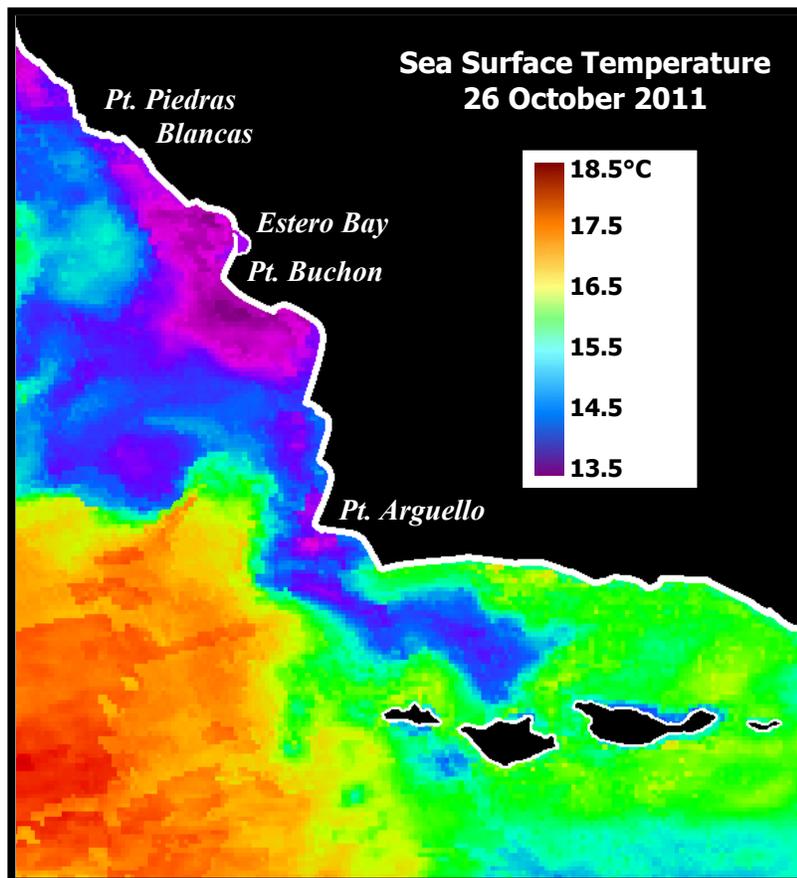


**City of Morro Bay and  
Cayucos Sanitary District**

# **OFFSHORE MONITORING AND REPORTING PROGRAM**

## **FOURTH QUARTER RECEIVING-WATER SURVEY**

**OCTOBER 2011**



**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**

**FOURTH QUARTER  
RECEIVING-WATER SURVEY**

**OCTOBER 2011**

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**December 2011**

# marine research specialists

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

22 December 2011

**Reference: Fourth Quarter Receiving-Water Survey Report – October 2011**

Dear Mr. Keogh:

The attached report presents results from a quarterly receiving-water survey conducted on Monday, 24 October 2011. 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

(Submitted Electronically)

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

---

Mr. Rob Livick  
Director of Public Services  
City of Morro Bay

Date \_\_\_\_\_

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## **INTRODUCTION**

The City of Morro Bay and the Cayucos Sanitary District (MBCSD) jointly own the wastewater treatment plant operated by the City of Morro Bay. In March 1985, Region IX of the U.S. Environmental Protection Agency (USEPA) and the Central Coast California Regional Water Quality Control Board (RWQCB) issued the first National Pollutant Discharge Elimination System (NPDES) permit to the MBCSD. The permit incorporated partially modified secondary treatment requirements for the plant's ocean discharge. The permit has been re-issued three times, in March 1993 (RWQCB-USEPA 1993ab), December 1998 (RWQCB-USEPA 1998ab), and January 2009 (RWQCB-USEPA 2009). The October 2011 field survey described in this report was the eleventh receiving-water survey conducted under the current permit.

The NPDES discharge permit requires seasonal monitoring of offshore receiving-water quality with quarterly surveys. This report summarizes the results of sampling conducted on 24 October 2011. Specifically, this fourth-quarter survey captured ambient oceanographic conditions along the central California coast during the autumn season. The survey's measurements were used to assess the discharge's compliance with the objectives of the California Ocean Plan (COP) and the Central Coast Basin Plan (RWQCB 1994) as promulgated by the receiving-water limitations specified in the NPDES discharge permit.

The monitoring objectives were achieved by evaluating empirical 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)



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

Near the diffuser, prevailing flow generally follows bathymetric contours that parallel the north-south trend of the adjacent coastline. Because of the rapid initial mixing achieved within 15 m of the diffuser structure, impingement of unmixed effluent onto the adjacent coastline, 827 m away, is highly unlikely. Nevertheless, in the event of a failure in the treatment plant's disinfection system, collection and analysis of water samples at the 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 of water properties at these antipodal stations quantify departures from ambient seawater properties that help determine compliance with the NPDES discharge permit.

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. Therefore, the "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.

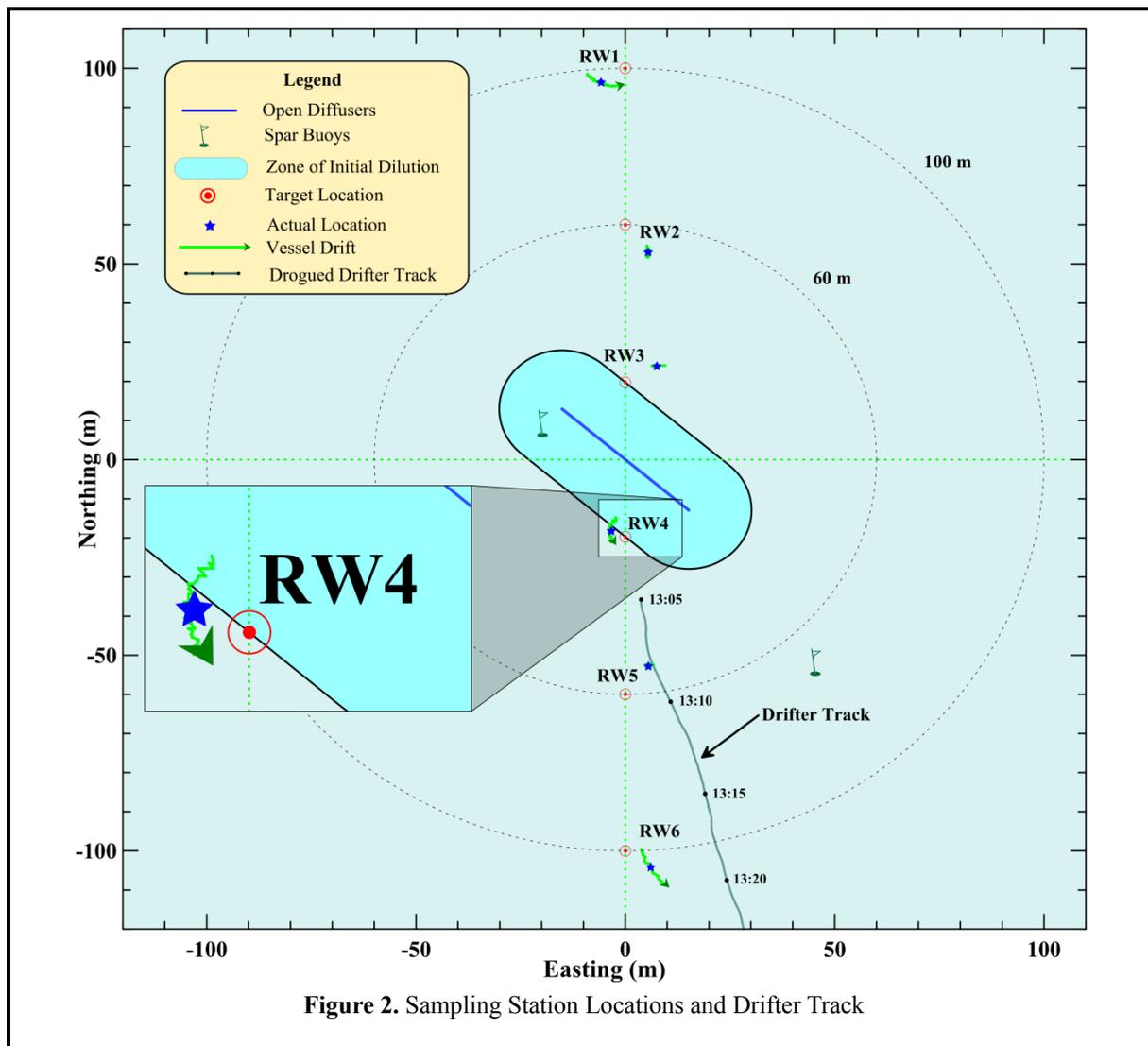


Figure 2. Sampling Station Locations and Drifter Track

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 October 2011 survey is apparent from the length of the green tracklines in Figure 2. These tracklines trace the horizontal movement of the CTD as it was lowered to the seafloor. Their length and offset from the target locations reflect the overall station-keeping ability during the October 2011 survey. During the time it took the CTD to traverse the water column and reach the seafloor, which averaged 59 seconds, the instrument package moved an average of 5.4 m. This amount of drift is comparable to that of most prior surveys conducted under similarly quiescent oceanographic conditions.

The CTD trajectories shown by the tracklines in Figure 2 reflect complex interactions between surface currents, wind forces, and any residual momentum of the survey vessel as it approached each station during the October 2011 survey. For example, stations with tangible movement had a southerly drift component,<sup>5</sup> which was consistent with south-southeast transport by the subsurface current measured by the drogue drifter.<sup>6</sup> Generally, winds affect the vessel's ability to maintain station to a greater degree than does current flow, however, this was not the case with the October survey because winds were light throughout the survey. Additionally, both the eastward drift at RW1 and the lack of drift at RW5 resulted from the residual momentum of the vessel as it approached these stations.

Compliance assessment can be complicated when the CTD drifts across the ZID boundary during vertical hydrocasts at stations close to the diffuser structure. This is because the receiving-water limitations specified in the COP only apply to measurements recorded beyond the ZID boundary, where initial mixing is assumed complete. For example, during the October survey, measurements acquired in the upper portion of the water column at Station RW4 were not subject to the limitations because the CTD was still within the ZID boundary. As the CTD descended further, however, it moved beyond the ZID where its measurements became subject to compliance evaluation.

Determining which measurements are subject to permit limits within hydrocasts near the ZID boundary only became possible after the advent of DGPS. Prior to 1999, CTD locations could not be determined with sufficient accuracy to establish whether a station was located within the ZID, much less how the CTD was moving laterally during the hydrocast. Because of these navigational limitations, sampling was presumed to occur at a single, imprecisely determined, horizontal location. Federal and State reporting of monitoring data still mandates identification of a single position for all of the CTD data collected at a

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

<sup>5</sup> RW1, RW4, and RW6

<sup>6</sup> A portion of the drifter track is shown in Figure 2 and the full track is shown in Figure 3

particular station. Thus, for regulatory reporting, and for consistency with past surveys, the October 2011 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 October 2011 Survey

Station	Time (PDT)		Latitude	Longitude	Closest Approach	
	Downcast	Upcast			Range <sup>7</sup> (m)	Bearing <sup>8</sup> (°T)
RW1	14:02:01	14:03:08	35° 23.251' N	120° 52.508' W	84.1	6
RW2	14:08:48	14:09:45	35° 23.228' N	120° 52.500' W	45.1	27
RW3	14:18:54	14:19:57	35° 23.212' N	120° 52.499' W	23.1	41
RW4	14:25:21	14:26:23	35° 23.189' N	120° 52.506' W	<b>16.0<sup>9</sup></b>	221
RW5	14:30:45	14:31:38	35° 23.170' N	120° 52.500' W	40.9	194
RW6	14:39:27	14:40:20	35° 23.143' N	120° 52.500' W	91.6	186

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 CTD 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 a steady south-southeastward flow throughout the October 2011 survey (Figure 3). Modeled after the curtain-shade design of Davis et al. (1982) and drogued at mid-depth (7 m), a drifter has typically 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.

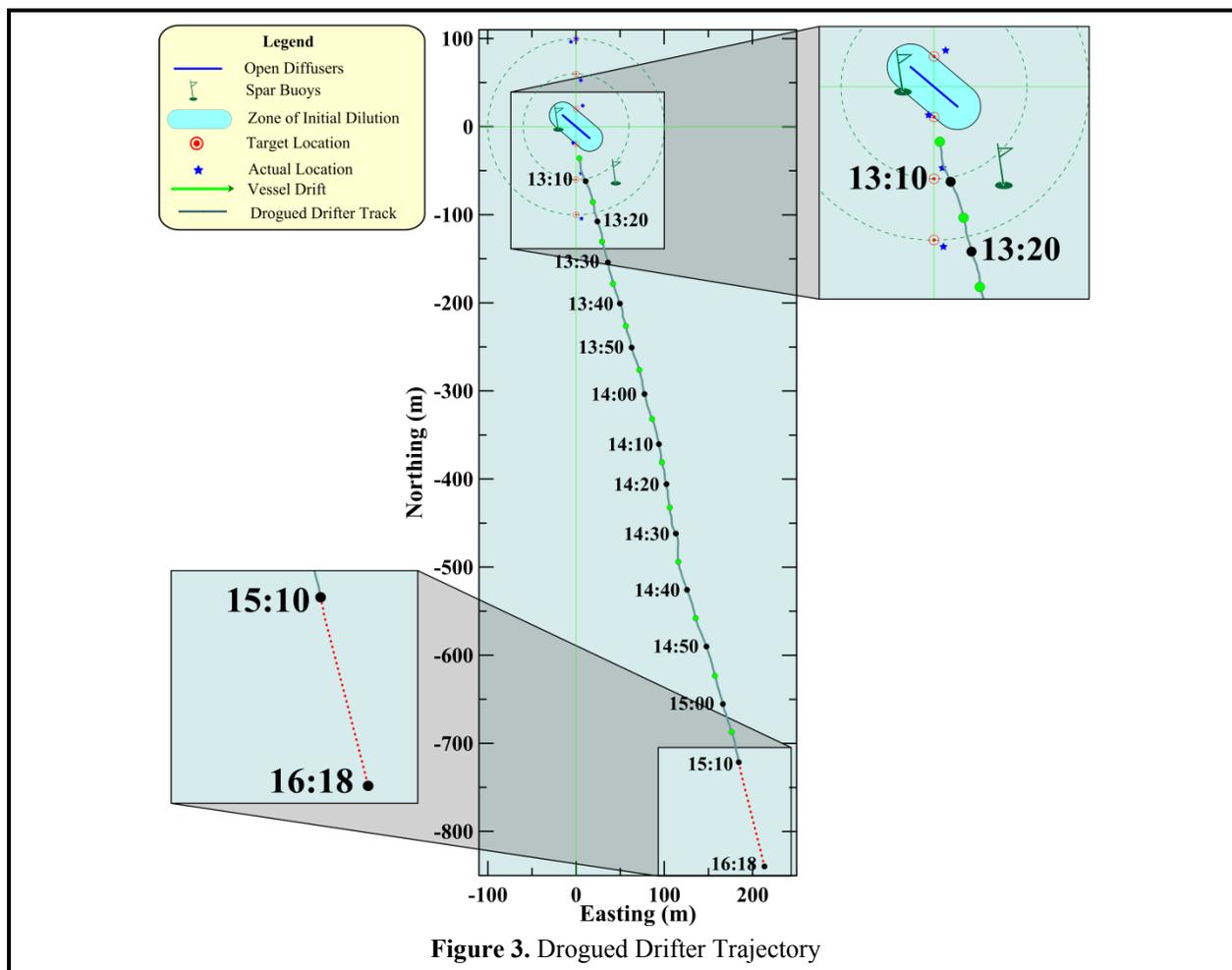
The drifter was deployed just south of the ZID at 13:05 PDT, and was recovered three hours later, at a location 830 m south-southeast of its initial location (Figure 3). The green and black dots in Figure 3 show the drifter’s progress at five-minute intervals during the first two hours of deployment. The alternating green dots represent 10-minute intervals, and their uniform spacing reflects the relatively constant speed of the drifter, which averaged 9.5 cm/s, or 0.18 knots. At this speed, the plume would have traversed the ZID in just over two-and-a-half minutes.

After 15:10 PDT, the memory in the drifter’s onboard GPS became filled, and additional detailed drifter positions ceased to be recorded. Therefore, Figure 3 shows the estimated drifter track during its final hour of deployment as a dotted red line.

<sup>7</sup> Distance from the closest open diffuser port to the average profile location.

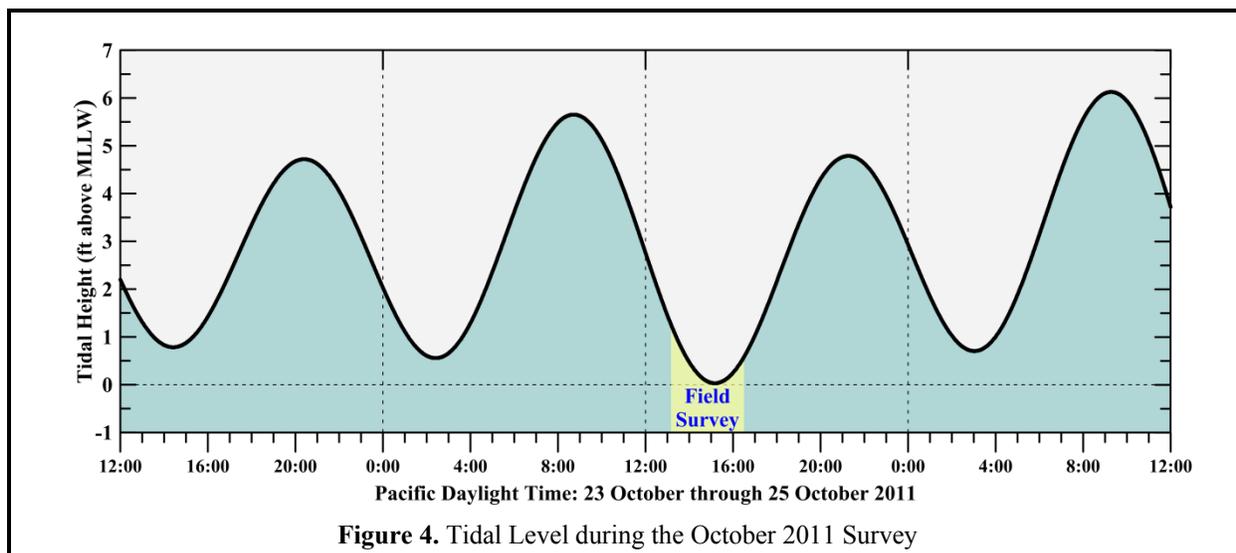
<sup>8</sup> Angle measured clockwise relative to true north from the closest diffuser port to the average profile location.

<sup>9</sup> The shallow CTD measurements at Station RW4 were located within the ZID boundary.



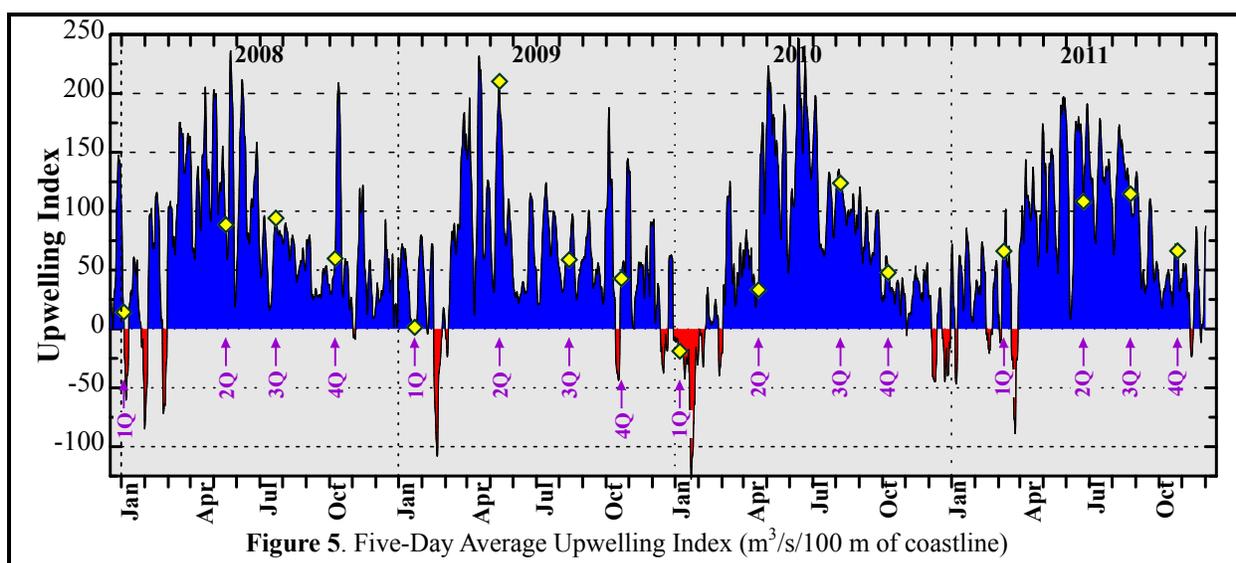
The relatively strong, southward oceanic flow measured by the drifter was consistent with the ebb tide that prevailed during the first portion of the survey. During the last hour of deployment, however, when the tow survey was underway, the strength of the oceanic flow noticeably decreased. During that time, the net speed of the drifter was only about a third of the speed measured during the prior two hours. This reduction in flow was consistent with reduced tidal forcing associated with the slack tide, which occurred just after 15:00 PDT (Figure 4). However, flow within Estero Bay is 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 also induce a southerly (offshore) flow in the upper water column, and a northerly (onshore) flow at depth.

Upwelling was occurring around the time of the October 2011 survey. Upwelling season normally begins sometime during late March and or early April as shown by the positive (blue) upwelling indices in Figure 5. At the onset of upwelling season, there is a spring transition to more persistent southeastward winds along the central California coast. This transition is initiated by the stabilization of a high-pressure field over the northeastern Pacific Ocean. Clockwise winds around this pressure field drive the prevailing northwesterly winds along the central California coast. These prevailing 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) indices in Figure 5, 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. Although mild southeastward winds prevailed during the October 2011 survey, strong southeastward winds prevailed along the central California coast throughout most of October, resulting in cooler sea surface temperatures close to the coastline at the time of the survey.



The satellite image on the cover of this report documents the upwelling that was present around the time of the survey. The image was recorded two days after 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. As is apparent in the cover image, the cool, nearshore sea-surface temperatures (~13.5°C) within Estero Bay were comparable to the near-surface temperatures measured by the CTD during the October 2011 survey.<sup>10</sup>

## METHODS

The 38 ft F/V *Bonnie Marietta*, owned and operated by Captain Mark Tognazzini of Morro Bay, served as the survey vessel on Monday, 24 October 2011. Bonnie Luke of Marine Research Specialists (MRS) was Chief Scientist and collected auxiliary measurements of biological, meteorological, and oceanographic conditions. Dr. Douglas Coats, also of MRS, provided 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 October 2011 survey. This new CTD instrument package was commissioned in May 2011 to replace an older model SBE-19 profiler that was retired from regular use following the June 2011 survey. The DO and pH probes on the older instrument package were repaired and calibrated at the factory in June 2011, and the instrument will be maintained and kept available as a backup unit.

The new CTD system offers many advantages over the older unit, which was in service for nearly two decades. The 4 Hz sampling rate<sup>11</sup> on the new instrument collects data at twice the rate of the older unit, allowing much higher spatial resolution for a given tow, or descent rate. In addition, the probes and sensors have a much faster response time, further enhancing the spatial resolution of seawater properties. Lastly, the probes and sensors on the new CTD are more stable and exhibit negligible long-term drift. As

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<sup>10</sup> Refer to Table 5 and Figure 7 for receiving-water properties recorded during the vertical hydrocasts.

<sup>11</sup> 0.25-s sampling interval

a result, and in accordance with the manufacturer's recommendations, the new CTD package does not require regular recalibration of the sensors prior to each field survey. Nevertheless, following receipt of the new CTD package, the accuracy of the pH and DO sensors was confirmed in the MRS laboratory.

The six seawater properties used to assess receiving-water quality in this report were derived from the continuously recorded output of the CTD's probes and sensors. Pressure housing limitations confine the CTD to depths less than 680 m (Table 3), which 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>12</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 also 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 ( $\sigma_t$ ).

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. Therefore, transmission in pure water is expected to be 91.3% of the reported values for this transmissometer.

Before initial deployment for the vertical hydrocasts, the CTD was held below the sea surface for a nine-minute equilibration period. 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>12</sup> 25-cm path length of red (660 nm) light

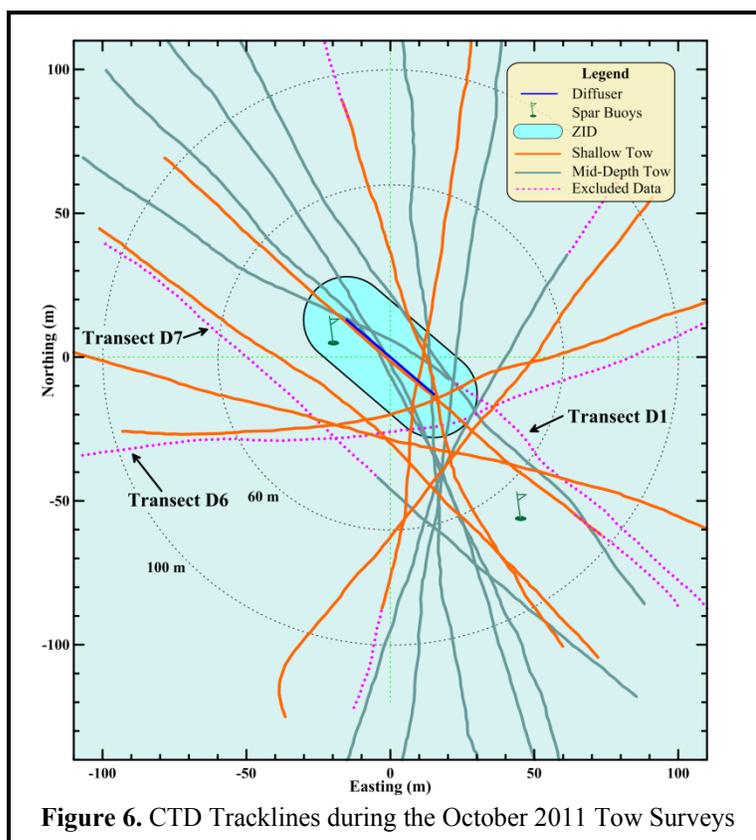
At 14:41 PDT, following the last vertical profile at RW6, the CTD instrument package was brought aboard the survey vessel and reconfigured for horizontal towing with uniform flow across forward-looking probes. The CTD was fitted with a horizontal stabilizer wing and a depth-suppression weight was added to the towline to achieve constant-depth tows. The CTD was subsequently towed around and across the ZID at two separate depths, one within the surface mixed layer and one below the thermocline, in accordance with the monitoring requirements of the NPDES discharge permit (Figure 6).

Initially, the reconfigured CTD package was towed for 22 minutes at an average depth of 3.94 m, and an average speed of 1.60 m/s, passing over, or near the diffuser structure seven times. Subsequently, nine additional passes were made with the CTD at an average depth of 7.02 m.<sup>13</sup>

During this 41-minute mid-depth-tow, vessel speed averaged 1.56 m/s. At the observed towing speeds and a 4 Hz sampling rate, 2.5 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 processed to produce horizontal maps within the upper and sub-thermocline portions of the water column.<sup>14</sup>

### *Quality Control*

Upon retrieval of the CTD following the tow survey, water-quality data were downloaded to a portable computer and examined for completeness and range acceptability. The CTD continuously recorded data from the time it was turned on prior to the vertical casts, to the time it was retrieved following the tow surveys. This included the time it was taken out of the water to be fitted with a depth suppressor wing after completion of the vertical casts and before initiating the tow survey. In the past, data was downloaded and reviewed for acceptability following the vertical casts. However, the new CTD supports continuous monitoring of the data as it is being recorded, obviating the need for periodic downloading and review. Real-time monitoring revealed that the recorded seawater properties were complete and



**Figure 6.** CTD Tracklines during the October 2011 Tow Surveys

<sup>13</sup> The tow depths during parts of shallow transects S2, S3, and S4; parts of deep transects D1, D5, and D7; and all of D6, as shown by the dashed lines in Figure 6, were removed from subsequent analysis due to their vertical offset as described in the *Quality Control* section.

<sup>14</sup> Figures 8 and 9 present the horizontal maps of seawater properties measured during the tow-survey portion of the field survey.

within acceptable coastal seawater ranges.<sup>15</sup> The only exceptions occurred when the CTD was out of the water, prior to the vertical casts, when it was fitted with the wing before to the tow survey, and for a brief period after it was retrieved from the tow survey prior to switch-off.

Subsequent post-processing of the data review 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 during portions of both the mid-depth and shallow tows (dashed lines in Figure 6). Specifically, slight increases in vessel speed during the final portions of Transects S2, S3, and S4 resulted in tow depths that were 0.36 m shallower than average. Similarly, increased speed during the first part of Transect D1 and last part of D5 resulted in a 1.7 m decrease in tow depth compared to the average tow depths of the other transects conducted at mid-depth. Conversely, decreased tow speed during all of Transect D6 and the first half of D7 resulted in unacceptably deep offsets (2.3 m deeper than average). While these depth offsets appear small, they created artificial horizontal differences in the combined data set because of vertical gradients associated with upwelling-induced stratification. Because discharge-related anomalies 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 levels are combined, particularly when the water column is highly stratified, as was the case during the October 2011 survey.

Because of their depth offsets, data collected during these portions of the tow surveys were incompatible with the rest of the tow data, and were excluded from the subsequent analysis to avoid introducing erroneous lateral differences in the horizontal property maps.<sup>16</sup> Exclusion of these transects, shown by the dotted purple lines in Figure 6, did not, however, adversely affect the compliance analysis because the remaining transects adequately covered the survey region. The remaining transects, shown by the solid orange and blue lines in Figure 6, also met the permit monitoring requirement of at least five passes near the diffuser structure at each tow depth.

Similarly, quality-control screening of the vertical profile data over the years has determined that because the overall length of the CTD is close to the 0.5-m standard depth bins used to report the vertical profile data, 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 depth is influenced by wave and tidal-induced oscillations during its deployment at each station. For example, during the October 2011 survey, data on average seawater properties was not recorded within the shallowest depth bin (0.5 m) at Stations RW2, RW3, RW4, and RW5.<sup>17</sup> Because the spatial coverage of the observations at the very shallowest depth level could not adequately quantify horizontal trends, the remaining observations were excluded from the subsequent compliance evaluation.

## RESULTS

The fourth-quarter receiving-water survey was conducted on the afternoon of Monday, 24 October 2011, following the completion of the annual benthic monitoring survey. The receiving-water survey commenced at 13:05 PDT with the deployment of the drogued drifter. Over the following three hours, offshore observations and measurements were collected as required by the NPDES monitoring program. The survey ended just after 16:18 PDT with the retrieval of the CTD from its mid-depth-tow configuration and the recovery of the drifter. Observations of beneficial use and the collection of required visual observations of the sea surface were unencumbered throughout the survey.

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<sup>15</sup> Field sampling protocols employed during the October 2011 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.

<sup>16</sup> Shown in Figures 8 and 9 on Pages 20 and 21

<sup>17</sup> Refer to Table 5 on Page 14

*Auxiliary Observations*

On the afternoon of 24 October 2011, skies were cloudy, with light southerly winds. Average wind speeds, calculated over one-minute intervals, ranged from 0.9 kt to 2.8 kt (Table 4). Similarly, peak wind speeds ranged from 1.6 kt to 3.8 kt. The swell was out of the northwest with a significant wave height of two-to-three feet. Air temperatures, which varied from 15.2°C to 15.8°C, were several degrees warmer than the average sea-surface temperatures.

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

Station	Location <sup>18</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° 23.248' N	120° 52.485' W	88.7	14:05:15	15.4	100	1.9	2.9	SE	2-3/NW	6.0
RW2	35° 23.247' N	120° 52.499' W	79.2	14:12:24	15.8	100	1.5	2.3	SE	2-3/NW	6.0
RW3	35° 23.210' N	120° 52.491' W	28.0	14:21:25	15.7	100	0.9	1.6	SE	2-3/NW	4.0
RW4	35° 23.183' N	120° 52.501' W	20.0	14:27:51	15.7	100	1.3	1.9	SE	2-3/NW	5.0
RW5	35° 23.166' N	120° 52.492' W	48.5	14:33:32	15.2	100	2.0	3.2	SE	2-3/NW	5.5
RW6	35° 23.134' N	120° 52.485' W	107.6	14:41:48	15.4	100	2.8	3.8	SE	2-3/NW	6.0

The 4-to-6 m Secchi depths recorded during the October 2011 survey indicated a moderate level of ambient water clarity (Table 4). The Secchi depths reflected the presence of an 8-to-12 m euphotic zone that spanned more than half of the 15.5-m water column. There was no evidence during the survey of floating particulates, oil sheens, or any discoloration of the sea surface associated with wastewater-related constituents. Communication with plant personnel during the survey, and subsequent review of effluent discharge properties, confirm that the treatment process was performing nominally at the time of the survey. The 1.01 million gallons of effluent discharged on the day of the survey had a temperature of 21°C, a suspended-solids concentration of 35 mg/L, an oil-and-grease concentration of 3.8 mg/L, and a pH of 7.6. Biochemical oxygen demand (BOD) measured in a sample collected four days prior to the survey was 38 mg/L.

During the October 2011 survey, visual observations demonstrated continued beneficial use of the coastal waters within Estero Bay by both wildlife and recreational users. Brandt's cormorants (*Phalacrocorax penicillatus*), pelagic cormorants (*Phalacrocorax pelagicus*), western gulls (*Larus occidentalis*), and California brown pelicans (*Pelecanus occidentalis californicus*) were all noted transiting the survey area. California sea lions (*Zalophus californianus*), detached bull kelp (*nereocystis luetkeana*) holdfasts and one southern sea otter (*Enhydra lutris nereis*) were also noted within the survey area. Finally, pedestrians and stand-up paddle boarders were documented utilizing the adjacent beach and nearshore waters during the October 2011 survey.

*Instrumental Observations*

Data collected during vertical profiling were processed in accordance with standard procedures (SCCWRP 2002), and are collated within 0.5-m depth intervals in Table 5. Data collected during the October 2011 survey reflect the presence of a stratified water column indicative of upwelling conditions. Upwelling conditions prevail most of the year along the central California coast, generally beginning in March or April, and extend through the fall months. 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 short vertical distances.

<sup>18</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.

Table 5. Vertical Profile Data Collected on 24 October 2011

Depth (m)	Temperature (°C)						Salinity (‰)					
	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6
1.0	13.957					13.591	33.379					33.376
1.5	13.957	13.773	13.816	13.771	13.888	13.689	33.377	33.375	33.374	33.375	33.373	33.375
2.0	13.786	13.708	13.803	13.742	13.751	13.702	33.367	33.370	33.372	33.370	33.365	33.373
2.5	13.566	13.771	13.786	13.704	13.690	13.693	33.362	33.376	33.372	33.371	33.368	33.374
3.0	13.420	13.775	13.779	13.671	13.651	13.661	33.364	33.373	33.372	33.370	33.367	33.371
3.5	13.351	13.645	13.767	13.644	13.623	13.625	33.368	33.369	33.371	33.369	33.369	33.373
4.0	13.330	13.574	13.750	13.600	13.588	13.529	33.372	33.370	33.372	33.369	33.370	33.369
4.5	13.320	13.529	13.742	13.522	13.481	13.427	33.374	33.369	33.372	33.367	33.369	33.370
5.0	13.285	13.385	13.733	13.484	13.364	13.452	33.375	33.364	33.371	33.371	33.366	33.375
5.5	13.249	13.337	13.726	13.414	13.325	13.446	33.377	33.370	33.371	33.371	33.372	33.372
6.0	13.230	13.307	13.721	13.350	13.307	13.396	33.380	33.373	33.371	33.372	33.374	33.373
6.5	13.206	13.278	13.650	13.336	13.299	13.334	33.381	33.375	33.367	33.375	33.375	33.363
7.0	13.171	13.211	13.559	13.314	13.280	13.267	33.383	33.377	33.369	33.376	33.376	33.362
7.5	13.135	13.159	13.541	13.284	13.246	13.228	33.384	33.380	33.370	33.377	33.375	33.358
8.0	13.035	13.080	13.517	13.248	13.135	13.196	33.385	33.381	33.370	33.378	33.347	33.353
8.5	12.992	13.013	13.451	13.220	13.012	13.196	33.387	33.385	33.370	33.381	33.324	33.360
9.0	12.996	12.962	13.351	13.178	12.985	13.151	33.389	33.384	33.368	33.376	33.326	33.353
9.5	12.940	12.931	13.310	12.938	12.869	13.076	33.386	33.385	33.373	33.311	33.303	33.339
10.0	12.893	12.886	13.283	12.892	12.852	13.050	33.386	33.384	33.376	33.329	33.307	33.338
10.5	12.870	12.874	13.210	12.914	12.886	13.031	33.388	33.388	33.378	33.342	33.313	33.338
11.0	12.850	12.849	13.114	12.930	12.901	12.929	33.390	33.389	33.381	33.357	33.318	33.328
11.5	12.795	12.808	13.007	12.946	12.909	12.882	33.394	33.391	33.379	33.363	33.323	33.344
12.0	12.752	12.766	12.930	12.973	12.906	12.899	33.400	33.397	33.384	33.369	33.320	33.368
12.5	12.735	12.713	12.876	12.919	12.900	12.895	33.402	33.400	33.385	33.312	33.320	33.387
13.0	12.729	12.639	12.848	12.913	12.877	12.862	33.403	33.402	33.390	33.334	33.322	33.391
13.5	12.697	12.626	12.772	12.859	12.834	12.758	33.403	33.405	33.395	33.280	33.334	33.395
14.0	12.672	12.627	12.711	12.822	12.795	12.699	33.405	33.406	33.399	33.233	33.373	33.400
14.5	12.632	12.621	12.668	12.806	12.749	12.685	33.405	33.407	33.402	33.270	33.395	33.403
15.0	12.588	12.606	12.629	12.753	12.687	12.688	33.408	33.407	33.404	33.312	33.401	33.404
15.5			12.609	12.738	12.651	12.687			33.408	33.322	33.407	33.404

Table 5. Vertical Profile Data Collected on 24 October 2011 (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	24.944					25.016	8.139					8.147
1.5	24.942	24.978	24.969	24.978	24.953	24.996	8.139	8.137	8.139	8.142	8.148	8.146
2.0	24.969	24.988	24.970	24.981	24.975	24.991	8.141	8.133	8.138	8.142	8.148	8.146
2.5	25.011	24.979	24.973	24.989	24.990	24.994	8.139	8.136	8.138	8.143	8.146	8.148
3.0	25.042	24.977	24.975	24.995	24.997	24.998	8.141	8.139	8.138	8.142	8.142	8.148
3.5	25.059	25.000	24.977	25.000	25.004	25.007	8.144	8.138	8.139	8.142	8.141	8.149
4.0	25.066	25.015	24.981	25.009	25.012	25.024	8.146	8.139	8.137	8.140	8.140	8.150
4.5	25.069	25.024	24.982	25.023	25.033	25.045	8.149	8.141	8.137	8.139	8.138	8.153
5.0	25.077	25.049	24.983	25.034	25.055	25.044	8.152	8.141	8.137	8.139	8.136	8.152
5.5	25.086	25.063	24.985	25.048	25.067	25.043	8.151	8.143	8.137	8.138	8.136	8.153
6.0	25.092	25.071	24.986	25.062	25.072	25.053	8.150	8.144	8.136	8.138	8.137	8.153
6.5	25.098	25.079	24.997	25.067	25.075	25.058	8.146	8.147	8.136	8.139	8.138	8.149
7.0	25.106	25.094	25.018	25.072	25.079	25.071	8.141	8.145	8.136	8.138	8.138	8.139
7.5	25.114	25.106	25.022	25.079	25.085	25.076	8.138	8.137	8.136	8.139	8.136	8.133
8.0	25.135	25.123	25.027	25.087	25.086	25.078	8.131	8.130	8.136	8.139	8.130	8.127
8.5	25.145	25.139	25.040	25.095	25.092	25.084	8.118	8.121	8.137	8.137	8.114	8.123
9.0	25.146	25.149	25.059	25.099	25.100	25.087	8.112	8.106	8.137	8.132	8.107	8.124
9.5	25.155	25.155	25.071	25.097	25.104	25.091	8.108	8.106	8.138	8.112	8.098	8.124
10.0	25.164	25.164	25.078	25.120	25.111	25.096	8.107	8.104	8.138	8.098	8.086	8.117
10.5	25.170	25.169	25.095	25.126	25.108	25.099	8.106	8.104	8.136	8.094	8.086	8.112
11.0	25.175	25.175	25.116	25.134	25.110	25.111	8.106	8.104	8.129	8.093	8.088	8.108
11.5	25.190	25.185	25.136	25.135	25.112	25.133	8.101	8.103	8.118	8.093	8.087	8.099
12.0	25.202	25.197	25.155	25.135	25.110	25.149	8.095	8.092	8.107	8.098	8.089	8.092
12.5	25.207	25.210	25.166	25.102	25.111	25.164	8.091	8.085	8.100	8.100	8.088	8.090
13.0	25.209	25.226	25.176	25.120	25.117	25.174	8.091	8.078	8.097	8.093	8.086	8.092
13.5	25.215	25.231	25.194	25.088	25.135	25.197	8.086	8.072	8.093	8.089	8.083	8.088
14.0	25.222	25.231	25.209	25.059	25.173	25.213	8.083	8.070	8.088	8.080	8.081	8.078
14.5	25.230	25.233	25.220	25.091	25.199	25.217	8.077	8.067	8.083	8.079	8.081	8.068
15.0	25.240	25.237	25.229	25.134	25.216	25.218	8.069	8.065	8.071	8.077	8.077	8.065
15.5			25.236	25.145	25.227	25.218			8.066	8.074	8.058	8.063

Table 5. Vertical Profile Data Collected on 24 October 2011 (continued)

Depth (m)	Dissolved Oxygen (mg/L)						Transmissivity (%)					
	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6
1.0	8.607					8.814	81.089					80.113
1.5	8.408	8.471	8.547	8.634	8.681	8.786	80.971	81.340	80.724	80.471	78.593	80.287
2.0	8.426	8.540	8.568	8.628	8.631	8.787	81.050	81.559	80.840	80.351	78.758	79.679
2.5	8.449	8.461	8.565	8.597	8.635	8.782	81.518	82.064	80.954	80.488	79.644	79.977
3.0	8.514	8.449	8.553	8.596	8.628	8.769	82.342	81.606	80.940	80.711	80.788	80.188
3.5	8.581	8.489	8.544	8.544	8.530	8.806	83.037	81.391	81.107	81.190	81.105	80.425
4.0	8.574	8.480	8.551	8.539	8.490	8.855	82.520	82.040	81.151	81.493	81.216	80.204
4.5	8.532	8.506	8.538	8.532	8.540	8.800	82.548	82.509	81.207	81.860	81.642	80.804
5.0	8.494	8.531	8.535	8.537	8.583	8.766	82.814	82.678	81.372	82.161	82.618	80.707
5.5	8.452	8.560	8.508	8.563	8.602	8.605	82.928	82.795	81.453	82.363	83.396	81.254
6.0	8.339	8.504	8.495	8.558	8.575	8.467	83.675	82.960	81.475	83.144	83.584	81.169
6.5	8.302	8.319	8.516	8.555	8.511	8.448	83.759	82.907	81.685	83.157	83.568	81.614
7.0	8.233	8.206	8.540	8.524	8.276	8.412	84.232	83.619	82.072	83.180	83.185	82.572
7.5	7.951	8.027	8.521	8.463	8.030	8.407	84.838	84.374	82.381	83.349	83.588	83.201
8.0	7.933	7.956	8.499	8.422	8.004	8.384	85.885	84.843	82.156	83.839	84.254	84.169
8.5	7.992	7.951	8.497	8.189	7.945	8.222	85.431	85.693	82.459	84.010	84.869	83.902
9.0	7.950	7.959	8.533	7.835	7.801	8.159	86.528	86.896	82.750	84.496	85.010	84.228
9.5	7.941	7.954	8.517	7.903	7.899	8.162	86.692	86.200	83.100	85.312	85.407	84.341
10.0	7.957	7.945	8.306	7.961	7.950	8.001	86.730	86.516	83.319	85.440	85.451	84.619
10.5	7.918	7.876	8.128	7.981	7.963	7.835	87.036	86.510	83.444	85.934	85.447	84.540
11.0	7.716	7.732	7.962	8.007	7.948	7.932	86.825	86.785	84.147	85.888	85.171	84.873
11.5	7.655	7.631	7.930	7.954	7.927	7.970	86.838	86.883	85.888	86.070	85.073	85.462
12.0	7.684	7.405	7.930	7.886	7.891	7.960	87.044	87.219	86.521	86.026	85.216	85.943
12.5	7.654	7.385	7.908	7.884	7.809	7.783	86.862	87.228	87.013	85.681	85.647	86.172
13.0	7.540	7.415	7.746	7.706	7.767	7.563	87.014	87.184	86.818	85.823	85.535	86.968
13.5	7.483	7.412	7.589	7.749	7.648	7.516	87.203	87.743	86.116	86.208	85.637	86.681
14.0	7.377	7.385	7.491	7.710	7.510	7.542	87.277	88.231	86.386	85.861	86.098	86.993
14.5	7.317	7.352	7.379	7.658	7.443	7.534	87.560	88.202	86.787	84.503	86.402	86.996
15.0	7.353	7.371	7.377	7.662	7.473	7.547	88.154	88.081	87.541	84.873	86.921	87.023
15.5			7.459	7.693	7.569	7.556			87.845	85.856	87.676	87.224

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.

Although the thermocline was not sharply defined during the October 2011 survey, upwelling-induced gradients extending throughout the water column are evident in the vertical profiles of each of the seawater properties (Figure 7). They appear as decreases in temperature (red lines), DO (dark blue lines), and pH (gold lines) with increasing depth throughout the entire water column. These decreases are mirrored by a pycnocline and halocline where density (black lines) and salinity (green line) steadily increase with depth. Specifically, the profiles exhibit a gradual vertical transition between a relatively uniform, near-surface mixed layer and a colder, saltier, nutrient-rich but oxygen-poor water mass at depth.

At the time of the October 2011 survey, the vertical structure of seawater characteristics was comparable to that of other upwelling periods. Near the seafloor, upwelling had transported cold, dense seawater (red and black lines in Figure 7) onshore to replace nearshore surface waters that were driven offshore by prevailing winds. These deep offshore waters had not been in recent direct contact with the atmosphere, and biotic respiration and decomposition had depleted their DO levels (dark blue lines).

Additionally, in contrast to the relatively fresh surface waters associated with the southward-flowing California Current, the slightly elevated salinity at depth at Stations RW1, RW2, and RW3 (green lines in Figure 7abc) was indicative of waters that originated in the Southern California Bight and had been carried northward by the Davidson Undercurrent.

Nutrient-rich seawater brought to the sea surface by upwelling facilitates phytoplankton blooms that produce oxygen, consume carbon dioxide (CO<sub>2</sub>), and decrease water clarity. With increasing depth, the ratio of respiration to photosynthesis increases, resulting in a corresponding increase in dissolved CO<sub>2</sub> (carbonic acid) and a concomitant decline in pH (olive-colored lines). Steadily increasing respiration with increasing depth also depleted DO concentrations near the seafloor relative to the sea surface (dark-blue lines). The reduced presence of phytoplankton below the euphotic zone resulted in an increased water clarity (transmissivity) at depth (light-blue lines).

The influence of the effluent discharge can be seen in the vertical profiles of salinity recorded at Stations RW4, RW5, and RW6 (green lines in Figure 7def). Typically, and as was the case during the October 2011 survey, the presence of dilute wastewater appears as one or more sharp reductions in salinity within the lower water column. Discharge-related anomalies in other seawater properties are rare, and usually related to upward transport of deep ambient water that has mixed into the rising plume. Occasionally, density anomalies associated with strong salinity fluctuations are apparent, as was the case in the density profile at RW4 (black line in Figure 7d). The density signature associated with the low-salinity plume was much weaker at RW5 and RW6 as the plume dissipated during its southward transport (black line in Figures 7ef). These vertical profiles indicate that the effluent plume had lost its buoyancy and become trapped below 7 m as it was transported rapidly to the south.

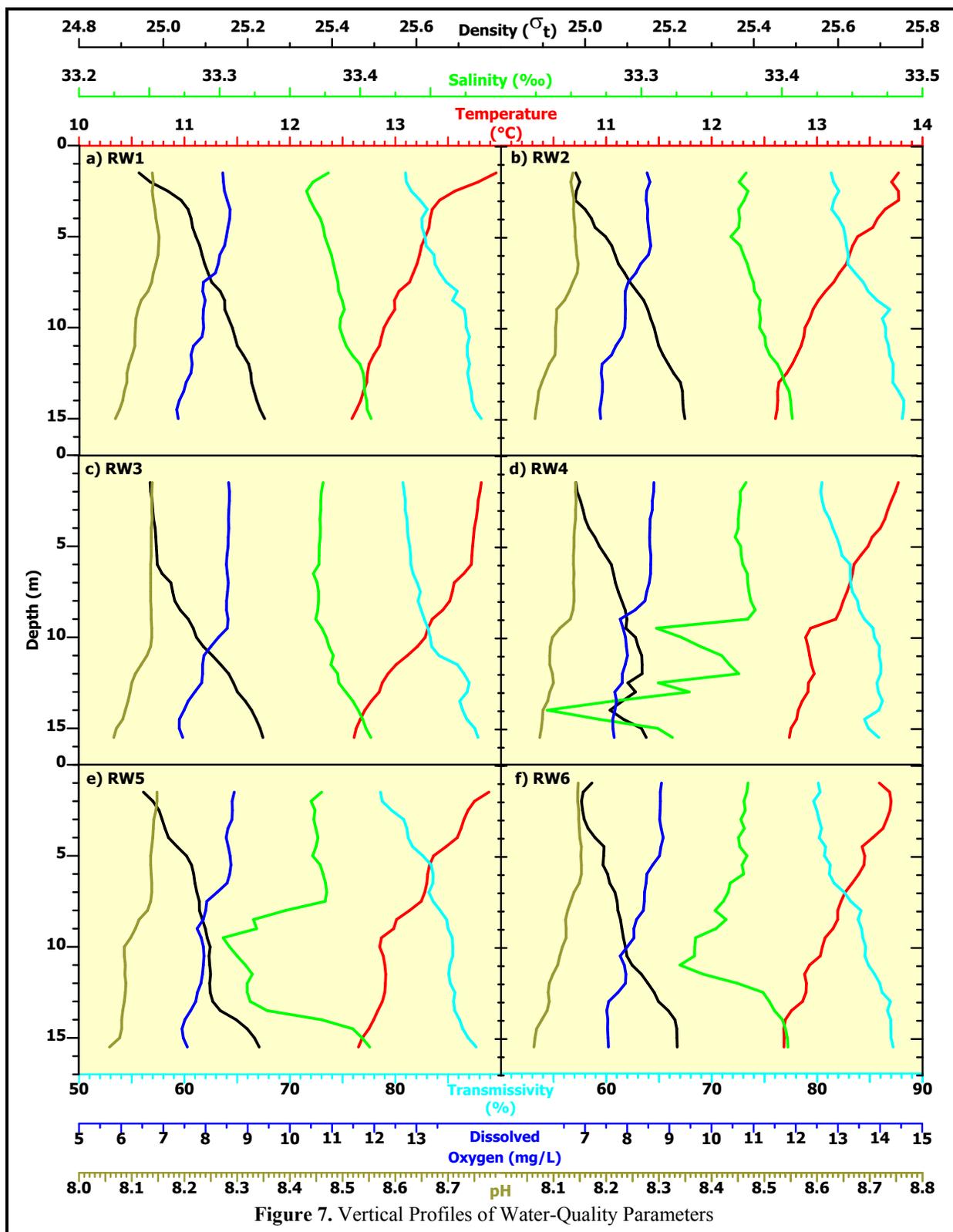


Figure 7. Vertical Profiles of Water-Quality Parameters

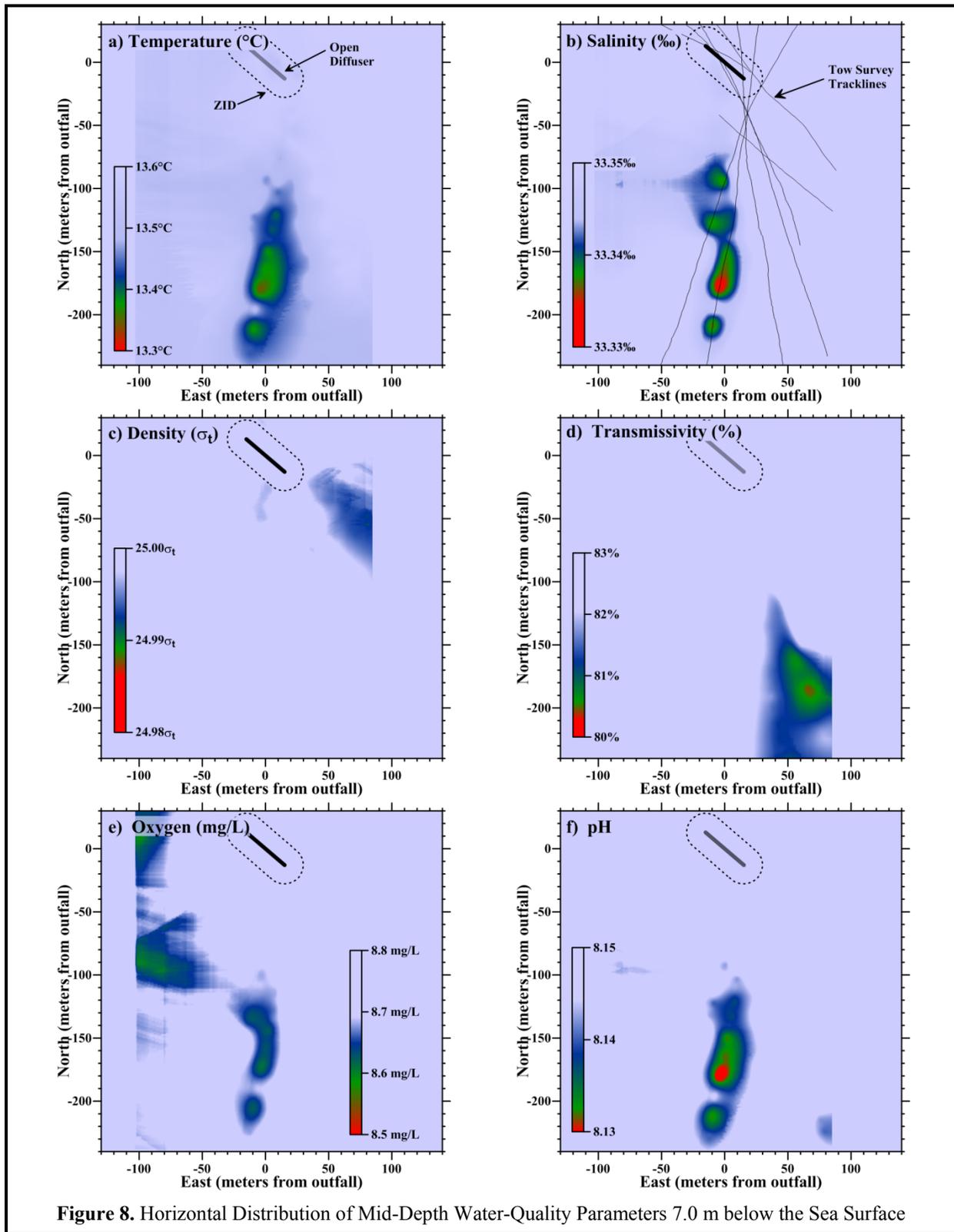
Because the plume was trapped at depth, there was no visual or instrumental evidence of the plume signature within the upper water column. In fact, the horizontal maps generated by the mid-depth tow (7 m in Figure 8), and the Secchi depths (<6 m in Table 4) were all well above the plume signature (below 7 m) measured by the vertical profiles. Therefore, variations in transmissivity, as well as most other properties in the upper water column, resulted entirely from the patchy distribution of ambient seawater properties within the mixed layer during the October 2011 survey, and lacked any apparent relationship to outfall proximity (Figure 9). Instead, the maps document the intrusion of a slightly cooler, lower salinity, more turbid, and lower DO watermass into the western portion of the survey area. Additionally, the shallowest Secchi depth (4.0 m) was measured upstream (north) at Station RW3, in the opposite direction from where any influence from wastewater particulates would be expected given the prevailing strong southerly flow measured by the drogue drifter.

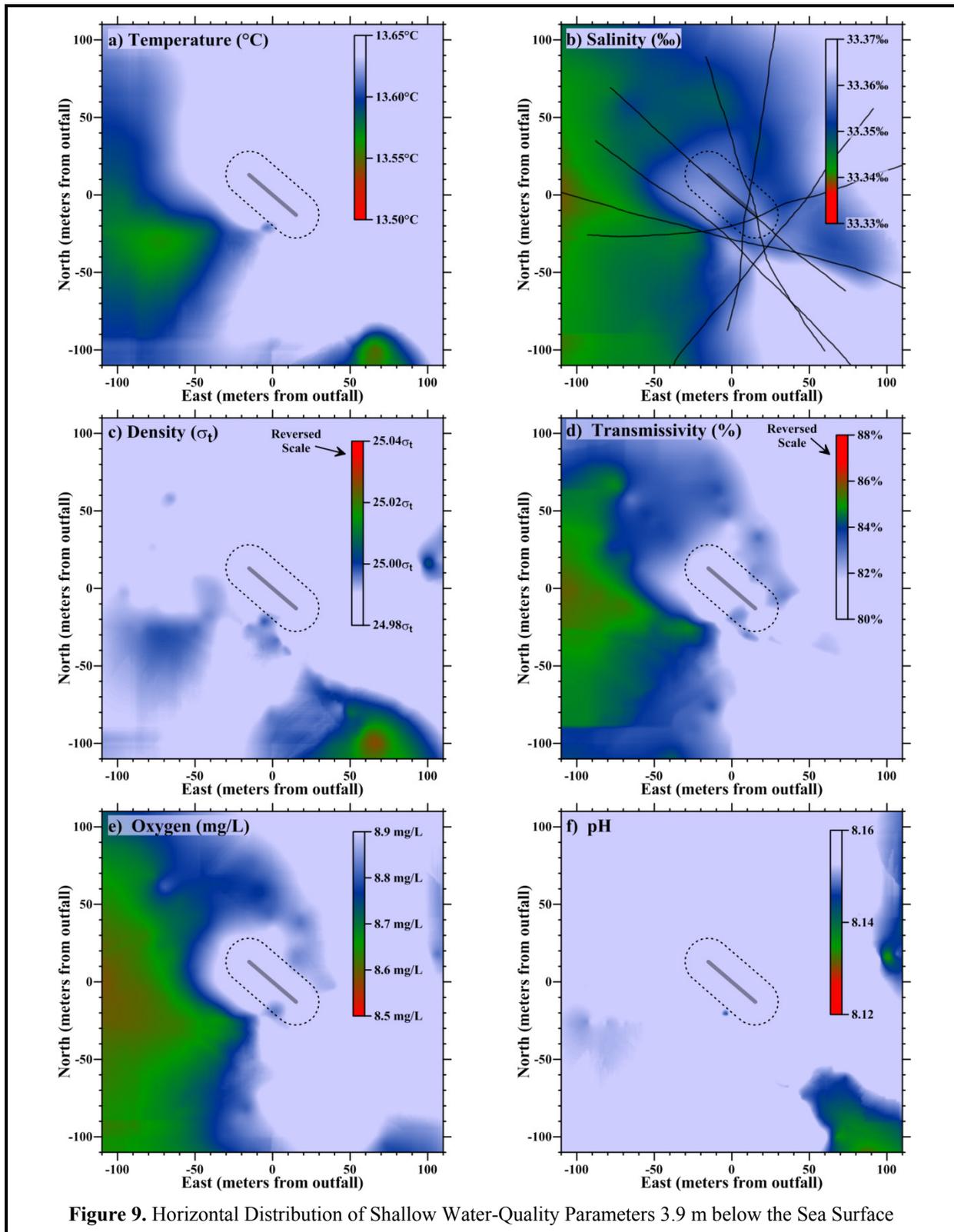
The only evidence of a plume signature in the horizontal tow data was well south of the survey area (Figure 8abfe). Note that these mid-depth maps extend much farther south than survey area normally of interest, which is shown in Figures 2, 6, and 9. Vertical mixing of the deep effluent plume as it was rapidly transported to the south eventually led to a detectable signature within the mid-depth tow data. The absence of a overlapping density anomaly (Figure 8c) is diagnostic of a plume that has reached buoyancy equilibrium, and has begun to spread laterally. With the exception of density, anomalies in other seawater properties coincided with the plume's salinity anomaly. However, in contrast to the salinity anomaly, they were all generated by entrainment and the upward transport of ambient seawater from near the seafloor rather than the presence of dilute wastewater constituents.

Specifically, the lower temperature, pH, and DO concentration of the near-bottom seawater created lateral anomalies when they were displaced upward, and became juxtaposed against the ambient seawater at 7 m. For example, wastewater was much warmer than the receiving seawater, yet the thermal signature of the plume (Figure 8a) was negative (cooler) than the surrounding seawater. Similarly, increased transmissivity (water clarity) within ambient seawater near the seafloor (light blue lines in Figure 7) created significant anomalies when contrasted with the murkier waters in the mid and upper water column. This increased transmissivity was associated with the plume signature observed during the mid-depth tow (Figure 8d). Both of these anomalies associated with the trapped plume could only have been generated by the upward displacement of cooler, clearer seawater within the rising effluent plume. The observed anomalies were opposite of those that would have been generated by the presence of warm wastewater particulates.

### *Outfall Performance*

The efficacy of the outfall can be evaluated through a comparison of dilution levels measured at the time of the October 2011 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 with 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, spread laterally, and cease to rise in the water column and dilute further. 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 were higher than the conservative model prediction, at depths greater than the trapping depth predicted by modeling 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. Use 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 are apparent to the south of the survey area in the mid-depth tow-survey map (Figure 8b) and in the vertical profiles measured at Stations RW4, RW5, and RW6 (green lines in Figure 7def). These localized salinity anomalies reflect the presence of dilute wastewater within the effluent plume as it rose and spread within the water column.

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>19</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, reduced effluent dilution at a given location within receiving waters is directly reflected by a larger amplitude salinity anomaly.

The lowest salinity (33.233‰) measured during the October 2011 survey was recorded just beyond the ZID at a depth of 14 m at Station RW4 (green line in Figure 7d). This measured salinity corresponds to a 0.168‰ reduction below the mean ambient salinity of 33.401‰ that was measured at the same depth level, but well beyond the influence of the discharge. It documents the presence of wastewater that has been diluted 193-fold. This is higher than the 133:1 critical initial dilution used to establish limits on contaminant concentrations in wastewater. In addition, the measurement was recorded well below the 6.4-m trapping depth assumed in modeling studies.

The plume further dispersed as it was transported to the south; steadily smaller salinity reductions were observed at Station RW5 (0.080‰) and RW6 (0.061‰), corresponding to respective dilution levels of 405- and 535-fold. The bulk of the plume was located below the 7 m mid-depth tow. Consequently, the horizontal maps only reflect a very diffuse plume signature extending well south of the survey area (Figure 8abdef). At that location, vertical mixing had dispersed the plume sufficiently to allow the plume signature to be identified at the 7-m tow depth. However, the salinity anomalies were small (0.061‰), corresponding to a dilution exceeding 700-fold (Figure 10). Although weak, the presence of an identifiable plume signature 200 m from the ZID boundary was unusual. It arose because the plume was trapped close to the seafloor, resulting in reduced dilution, and because the plume signature was rapidly transported by a strong ocean current. Nevertheless, dilution levels still far exceeded those predicted by the modeling.

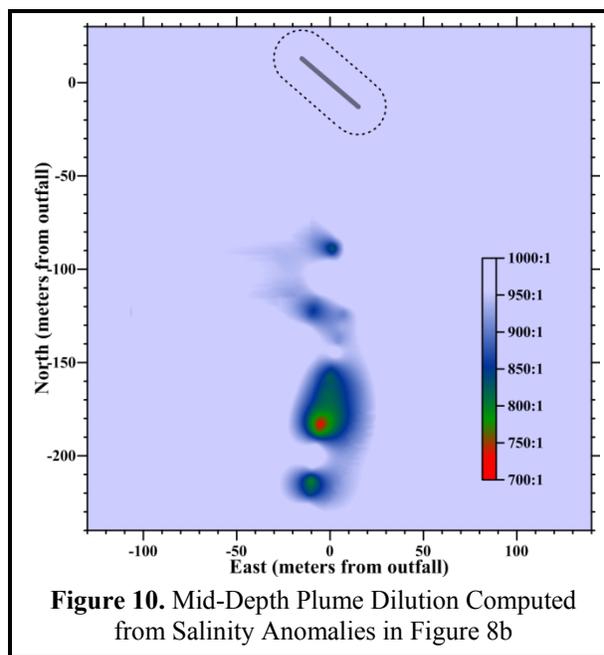


Figure 10. Mid-Depth Plume Dilution Computed from Salinity Anomalies in Figure 8b

<sup>19</sup> Wastewater samples collected during September 2011 had an average salinity of 0.779‰.

Although a weak plume signature was observed at depth, the shallow tow survey revealed no evidence of the effluent plume (Figure 9). The absence of a shallow signature is consistent with the vertical distribution of the plume's salinity signature, which was largely confined to depths below 7 m. Because the observed trapping depth was greater than the 6.4-m trapping depth predicted by modeling, dilutions below 133-fold could potentially be expected. Instead, dilutions exceeded the model predictions even close to the ZID boundary, and at a depth (14 m) much deeper than the trapping depth assessed in the modeling. Near the ZID, and well before completion of initial dilution, observed dilutions exceeded 193-fold. At that location, the plume was continuing to disperse vertically as it spread laterally to the south, where observed dilution levels exceeded 400-fold, triple the dilution level predicted by modeling to establish end-of-pipe limits on effluent constituents in the MBCSD permit.

The dilution computations demonstrate that, during the October 2011 survey, the outfall was performing better than designed and was rapidly diluting effluent more than 193-fold shortly after discharge, and well before completion of the initial-dilution process. This dilution level exceeds the 133:1 critical dilution used to establish end-of-pipe permit limitations on contaminant concentrations within wastewater discharged from the MBCSD treatment plant. Consequently, during the October 2011 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**

<b>Limit #</b>	<b>Limit</b>
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 October 2011 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 dilution levels 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 October 2011 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 October 2011 survey.

Compliance with the remaining four receiving-water limitations is quantitatively evaluated through a comparison of instrumental measurements and the specific 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. 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. An accurate characterization of stratification helps distinguish discharge-related changes that arise from the presence of wastewater constituents, which are subject to a compliance evaluation, from changes that arise because of the upward movement of ambient seawater, which are specifically excluded from the compliance evaluation.

### *Screening of Measurements*

Evaluating whether any of the 10,933 CTD measurements collected during the October 2011 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 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 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

Table 7. Receiving-Water Measurements Screened for Compliance Evaluation

Topic Addressed	Screening Question	Answer		Parameter
		No	Yes <sup>20</sup>	
Location	1. Was the measurement collected beyond the 15.2-m ZID boundary where modeling assumes that initial dilution is complete?	1,218	9,715	All
Wastewater Constituents	2. Did the beyond-ZID measurement coincide with a quantifiable salinity anomaly ( $\leq 550:1$ dilution level) indicating the presence of detectable wastewater constituents?	9,697	18	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?	18	0	Temperature
		18	0	Transmissivity
		18	0	DO
		18	0	pH

independent of the screening process. However, the screening process described in this section unequivocally eliminated all of the CTD measurements collected during the October 2011 survey from further consideration. 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, as was the case during the October 2011 survey, the COP states that dilution estimates shall be based on “the assumption that no currents, of sufficient strength to influence the initial dilution process, flow across the discharge structure.” Because of this, the regulatory mixing distance, which is equal to the 15.2-m water depth of the discharge, provides a conservative boundary to screen receiving-water data for subsequent compliance evaluation. Application of this initial screening question to the October 2011 dataset eliminated 1,218 of the original 10,933 receiving-water observations from further consideration because they were collected within the ZID (Table 7, Question 1). The remaining 9,715 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 water. 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

<sup>20</sup> Number of remaining CTD observations of potential compliance interest based on this screening question

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 reliably detected within receiving waters is 0.062‰. This represents a dilution level of 542-fold. Reductions that are smaller than 0.062‰, cannot be reliably discerned against the backdrop of natural variation and would not result in discernable changes in other seawater properties. Eliminating those measurements from further compliance evaluation restricts attention to excursions in temperature, light transmittance, DO, and pH that are potentially related to the presence of wastewater constituents. Of the 9,715 observations that were measured outside the ZID during the October 2011 survey, only 18 had reductions in salinity that were greater than 0.062‰ (Table 7).

**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 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 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 used to establish the natural 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 (-1.4 mg/L), and pH ( $\pm 0.094$ ). These were combined with 95<sup>th</sup> percentiles determined from the October 2011 ambient seawater data, to establish time-specific natural-variability thresholds in a manner analogous to COP Appendix VI. The percentiles were determined from October 2011 vertical profile data, excluding measurements potentially affected by the discharge.

Temperature, transmissivity, and DO concentrations associated with the 18 measurements of potential compliance interest all remained within their respective ranges of natural variability (Table 7, Question 3). 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 of strong stratification, such as during the October 2011 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 at mid-depth. All of the anomalies in seawater properties that coincided with salinity anomalies in Figures 7 and 8 were consistent with the upward displacement of ambient bottom water rather than with the presence of the effluent plume.

Table 8. Compliance Thresholds

Water Quality Property	95% Confidence Bound <sup>21</sup>	95 <sup>th</sup> Percentile <sup>22,23</sup>	Natural Variability Threshold <sup>24</sup>	COP Allowance <sup>25</sup>	Basin Plan Limit <sup>26</sup>	Extremum <sup>27</sup>
Temperature (°C)	0.82	13.78	>14.60	—	—	≤13.96
Transmissivity (%)	-10.2	80.3	<70.0	—	—	≥76.9
DO (mg/L)	-1.38	7.39	<6.01	<5.40	<5.00	≥7.32
pH (minimum)	-0.094	8.070	<7.975	<7.775	<7.000	≥8.058
pH (maximum)	0.094	8.149	>8.244	>8.444	>8.300	≤8.172

For example, because effluent is warmer than receiving waters, the cold thermal anomalies in Figures 8a and 9a could only be generated by entrainment and upward displacement of the colder bottom waters. Similarly, the increased transmissivity observed in Figure 8a would not result from the presence of wastewater particulates. Ambient transmissivity was less than 85% above 7 m while water clarity reached 87% near the seafloor (light-blue lines in Figure 7). Entrainment of the clearer bottom water within the rising plume often results in positive transmissivity anomalies within the plume signature rather than the transmissivity decrease that might be expected from the presence of wastewater particulates.

Although the reductions in DO and pH that were observed within the plume (Figures 8ef) could be ascribed to the presence of acidic, oxygen-demanding wastewater constituents, entrainment of ambient seawater at depth is more plausible. As with temperature and transmissivity, the DO concentrations below 8.7 mg/L, and pH concentrations below 8.14, that were observed within the plume (Figure 8ef) were similar to that of ambient seawater near the seafloor. The DO and pH anomalies could easily be explained by the entrainment and upward movement of bottom seawater. Even if the presence of wastewater particulates decreased DO and pH within the plume, their influence was well within the natural range in ambient seawater properties at the time of the survey. Consequently, their influence on water quality cannot 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 October 2011 survey complied with permit limits P3 through P6 in Table 6. In combination, these lines of evidence provide the “best explanation” of the origin

<sup>21</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 observations for each of the six seawater properties accurately quantify the inherent uncertainty in defining the range in natural conditions.

<sup>22</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>23</sup> The 95<sup>th</sup>-percentile quantifies natural variability in seawater properties during the October 2010 survey, and was determined from vertical profiles excluding RW3 and RW4 where there were possible influences from the discharge.

<sup>24</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 right and are specific to the October 2010 survey. They do not include the COP allowances specified in the column to the left.

<sup>25</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>26</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.

<sup>27</sup> Maximum or minimum value measured during this survey

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 which accounts for both the discrepancies among multiple lines of evidence as well as concurrences. 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 during the October 2011 survey.

***Natural Variability in other Seawater Properties:*** Although the permit limits only apply to changes in DO, pH, temperature and transmissivity, a comparative evaluation of changes in the remaining seawater properties (salinity and density) frequently provides additional valuable insight into the origins of any variations observed during a particular survey. For example, during the October 2011 survey, salinity was the only seawater property that exhibited a perceptible difference from ambient conditions. However, regardless of their association with the effluent salinity signature, none of the 10,933 temperature, DO, pH, or transmissivity observations exceeded the thresholds of natural variability specified in Table 8. This includes measurements collected within the ZID that were eliminated from further compliance consideration by the first screening question in Table 7.

***Insignificant Thermal Impact:*** Although there are no explicit numerical objectives for discharge-related decreases in temperature, a numerical limit can also be established for thermal excursions, which are not allowed to adversely affect beneficial uses (P3 in Table 6). Increases in temperature caused by the discharge of warm wastewater constituents would not be deemed to adversely affect beneficial uses if they remained within the natural temperature range at the time of the survey (less than 14.6°C in Table 8). Such was the case for all 10,933 CTD measurements collected during the October 2011 survey; none of the measured temperatures exceeded 14°C. In fact, as mentioned previously, because the effluent entrained cooler bottom water shortly after discharge, the rising plume actually had a lower temperature than the surrounding water (Figure 8a).

***Light Penetration:*** As with temperature, there are no explicit numerical objectives for discharge-related decreases in transmissivity. However, the COP narrative objective (P4) limiting significant reductions in the transmission of natural light can also be translated into a numerical objective. Specifically, because the COP does not specify an allowance beyond natural conditions, the same threshold on ambient transmissivity variations listed in Table 8 can be interpreted to constitute a numerical limit. However, because natural light is restricted to the euphotic zone, which extends to approximately twice the Secchi depth, the limit on transmissivity reductions during the October 2011 survey only applied to measurements recorded above 12 m (twice the maximum ambient Secchi depth listed in Table 4). As stated previously, no exceedance occurred during the October 2011 survey. Additionally, the presence of a restricted euphotic zone resulting from upwelling processes means that even if the presence of wastewater particulates had caused a substantial reduction in transmissivity near the seafloor, it would not have been a violation of permit conditions because turbidity at that depth had no effect on natural light levels.

***Insignificant Wastewater Particulate Loads:*** The discharge of wastewater particulates on 24 October 2011 did not contribute materially to turbidity within the dilute effluent plume. The suspended-solids concentration measured onshore within effluent prior to discharge was 35 mg/L. After dilution by 193-fold, which was the lowest dilution measured during the survey, the effluent TSS concentration would have the reduced ambient transmissivity by only 1.3%. 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, 38-mg/L BOD measured within the plant's effluent around the time of the survey. That small amount of BOD would have induced a DO depression of no more than 0.023 mg/L after dilution (MRS 2003). In fact, in the absence of tangible

BOD influence, wastewater constituents 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, particularly during periods of pronounced upwelling such as during the October 2011 survey.

**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 subsections. 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 7.775 during the October 2011 survey. This value is well below the lowest pH measurement of 8.058 recorded during the October 2011 survey. Similarly, the lowest DO concentration measured during the survey (7.3 mg/L) was well above both the lower range in natural variation (6.01 mg/L) and the 10% compliance threshold promulgated by the COP (5.00 mg/L).

### CONCLUSIONS

The statistical screening analysis quantitatively demonstrated that all measurements recorded during the October 2011 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 a discharge plume, all the associated seawater properties were within the natural variability that prevailed at the time of the survey.

Immediately after discharge, the outfall was achieving dilution levels in excess of 193-fold, which exceeded the critical dilution levels predicted by design modeling. As the plume was transported rapidly south, and rose in the water column, dilution levels exceeded 400-fold throughout the water column. Lastly, all of the auxiliary observations collected during the October 2011 survey demonstrated that the discharge complied with the narrative receiving-water limits in the discharge permit and COP. All of 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 October 2011 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.

### REFERENCES

- Davis, R.E., J.E. Dufour, G.J. Parks, and M.R. Perkins. 1982. Two Inexpensive Current-Following Drifters. Scripps Institution of Oceanography, University of California, San Diego, La Jolla, California. SIO Reference No. 82-28. December 1982.
- Fischer, H.B., E.J. List, R.C.Y. Koh, J. Imberger, and N.H. Brooks. 1979. Mixing in Inland and Coastal Waters. New York: Academic Press, 483 p.
- Kuehl, S.A., C.A. Nittrouer, M.A. Allison, L. Ercilio, C. Faria, D.A. Dukat, J.M. Jaeger, T.D. Pacioni, A.G. Figueiredo, and E.C. Underkoffler 1996. Sediment deposition, accumulation, and seabed dynamics in an energetic fine-grained coastal environment. *Continental Shelf Research*, 16: 787-816.

- Marine Research Specialists (MRS). 1998. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, Semiannual Benthic Sampling Report, April 1998 Survey. Prepared for the City of Morro Bay, CA. July 1998.
- Marine Research Specialists (MRS). 2003. City of Morro Bay and Cayucos Sanitary District, Supplement to the 2003 Renewal Application For Ocean Discharge Under NPDES Permit No. Prepared for the City of Morro Bay and Cayucos Sanitary District, Morro Bay, CA. July 2003.
- [Marine Research Specialists \(MRS\). 2011. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 2010 Annual Report. Prepared for the City of Morro Bay, California. March 2011.](#)
- [City of] Morro Bay and Cayucos Sanitary District (MBCSD). 2010. The City of Morro Bay-Cayucos Wastewater Treatment Plant Monthly Operations Summary, March 2011.
- Regional Water Quality Control Board (RWQCB) - Central Coast Region. 1994. Water Quality Control Plan (Basin Plan) Central Coast Region. Available from the RWQCB at 81 Higuera Street, Suite 200, San Luis Obispo, California. 148p. + Appendices.
- Regional Water Quality Control Board (RWQCB) - Central Coast Region and the Environmental Protection Agency (USEPA) – Region IX. 1993a. Waste Discharge Requirements (Order No. 92-67) and Authorization to Discharge under the National Pollutant Discharge Elimination System (Permit No. CA0047881) for City of Morro Bay and Cayucos Sanitary District, San Luis Obispo County.
- Regional Water Quality Control Board (RWQCB) - Central Coast Region and the Environmental Protection Agency (USEPA) – Region IX. 1993b. Monitoring and Reporting Program No. 92-67 for City of Morro Bay and Cayucos Sanitary District, San Luis Obispo County (Permit No. CA0047881).
- Regional Water Quality Control Board (RWQCB) - Central Coast Region and the Environmental Protection Agency (USEPA) – Region IX. 1998a. Waste Discharge Requirements (Order No. 98-15) and National Pollutant Discharge Elimination System (Permit No. CA0047881) for City of Morro Bay and Cayucos Sanitary District, San Luis Obispo County. 11 December 1998.
- Regional Water Quality Control Board (RWQCB) - Central Coast Region and the Environmental Protection Agency (USEPA) – Region IX. 1998b. Monitoring and Reporting Program No. 98-15 for City of Morro Bay and Cayucos Sanitary District, San Luis Obispo County. 11 December 1998.
- Regional Water Quality Control Board (RWQCB) - Central Coast Region and the Environmental Protection Agency (EPA) – Region IX. 2009. Waste Discharge Requirements (Order No. R3-2008-0065) and National Pollutant Discharge Elimination System (Permit No. CA0047881) for the Morro Bay and Cayucos Wastewater Treatment Plant Discharges to the Pacific Ocean, Morro Bay, San Luis Obispo County. Effective 1 March 2009.
- Sea-Bird Electronics, Inc. (SBE) 1989. Calculation of M and B Coefficients for the Sea-Tech Transmissometer. Application Note No. 7, Revised September 1989.
- Sea-Bird Electronics, Inc. (SBE) 1993. SBE 13/22/23/30 Dissolved Oxygen Sensor Calibration and Deployment. Application Note No. 13-1, rev B, Revised April 1993.

- Southern California Bight Field Methods Committee (SCBFMC). 2002. Field Operation Manual for Marine Water-Column, Benthic, and Trawl monitoring in Southern California. Technical Report 359. Southern California Coastal Water Research Project. Westminster, CA. March 2002.
- State Water Resources Control Board (SWRCB). 2005. Water Quality Control Plan, Ocean Waters of California, California Ocean Plan. California Environmental Protection Agency. Effective February 14, 2006.
- State Water Resources Control Board (SWRCB). 2009. Water Quality Control Plan for Enclosed Bays and Estuaries – Part 1 Sediment Quality. California Environmental Protection Agency. Effective August 23, 2009. [sed\\_qlty\\_part1.pdf](#) [Accessed 03/26/10].
- Suter II, Glenn, W. 2007. Ecological risk assessment, 2nd edition. U. S. Environmental Protection Agency, Cincinnati, Ohio. CRC.
- Tetra Tech. 1992. Technical Review City of Morro Bay, CA Section 301(h) Application for Modification of Secondary Treatment Requirements for a Discharge into Marine Waters. Prepared for the U.S. Environmental Protection Agency, Region IX, San Francisco, CA by Tetra Tech, Inc., Lafayette, CA. February 1992.