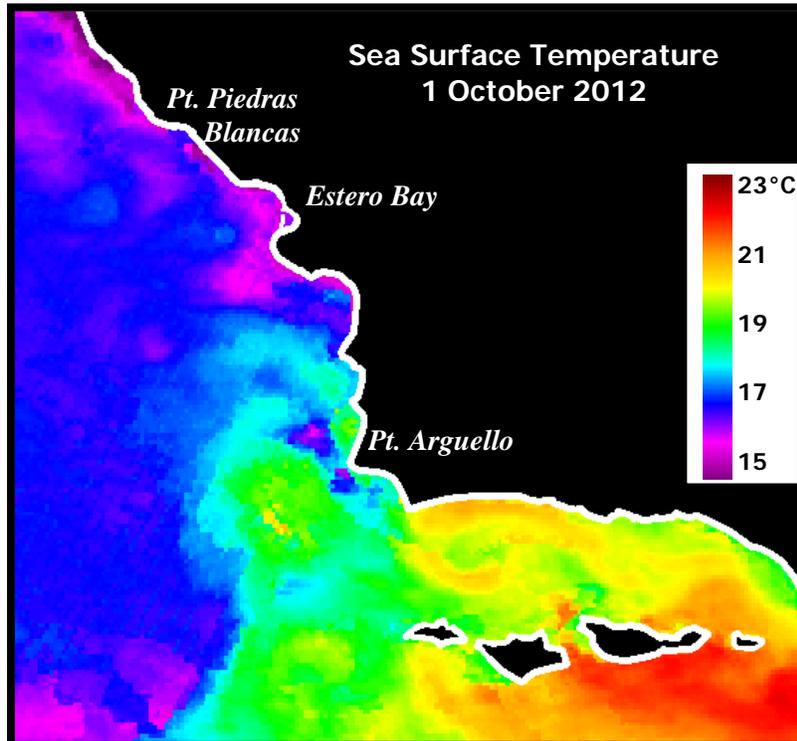


**City of Morro Bay and
Cayucos Sanitary District**

OFFSHORE MONITORING AND REPORTING PROGRAM

FOURTH QUARTER RECEIVING-WATER SURVEY

OCTOBER 2012



Marine Research Specialists

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

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

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Morro Bay, California 93442
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**OFFSHORE MONITORING
AND REPORTING PROGRAM**

**FOURTH QUARTER
RECEIVING–WATER SURVEY**

OCTOBER 2012

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January 2013

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

15 January 2013

Reference: Fourth Quarter Receiving-Water Survey Report – October 2013

Dear Mr. Keogh:

The attached report presents results from a quarterly receiving-water survey conducted on Tuesday, 2 October 2012. The survey was conducted in accordance with the requirements of the NPDES permit issued to the City and District for discharge of treated wastewater to Estero Bay. The report evaluated compliance with permit limitations and assessed the effectiveness of effluent dispersion. Quantitative analyses of continuous instrumental measurements and qualitative visual observations confirm that the wastewater discharge complied with the receiving-water limitations specified in the permit, and with the objectives of the California Ocean Plan.

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

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

Sincerely,



Bonnie Luke
Program Manager

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



Mr. Bruce Keogh
Wastewater Division Manager
City of Morro Bay

Date January 15, 2013

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INTRODUCTION

The City of Morro Bay and the Cayucos Sanitary District (MBCSD) jointly own the wastewater treatment plant operated by the City of Morro Bay. In March 1985, Region IX of the U.S. Environmental Protection Agency (USEPA) and the Central Coast California Regional Water Quality Control Board (RWQCB) issued the first National Pollutant Discharge Elimination System (NPDES) permit to the MBCSD. The permit incorporated partially modified secondary treatment requirements for the plant's ocean discharge. The permit has been re-issued three times, in March 1993 (RWQCB-USEPA 1993ab), December 1998 (RWQCB-USEPA 1998ab), and January 2009 (RWQCB-USEPA 2009). The October 2012 field survey described in this report was the fifteenth 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 2 October 2012. 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 CTD¹ 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.

¹ Conductivity, temperature, and depth (CTD)



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

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

SAMPLING LOCATIONS

As shown in Figure 2, the offshore sampling pattern consists of six fixed offshore stations located within 100 m of the outfall diffuser structure. The red ⊙ symbols in the Figure indicate the target locations of the sampling stations (Table 1). The stations are situated at three distances relative to the center of the diffuser structure and lie along a north-south axis at the same water depth (15.2 m) as the center of the diffuser. Depending on the direction of the local oceanic currents at the time of sampling, the discharge may influence one or more of these stations. The up-current stations on the opposite side of the diffuser then act as reference stations. Comparisons 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. 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 ± 15 m, a span equal to half the total width of the ZID itself. DGPS incorporates a second signal from a fixed, land-based beacon that continuously transmits position errors in standard GPS readings to the DGPS receiver onboard the survey vessel. Real-time correction for these position errors provides an extremely stable and accurate offshore navigational reading with position errors of less than 2 m.

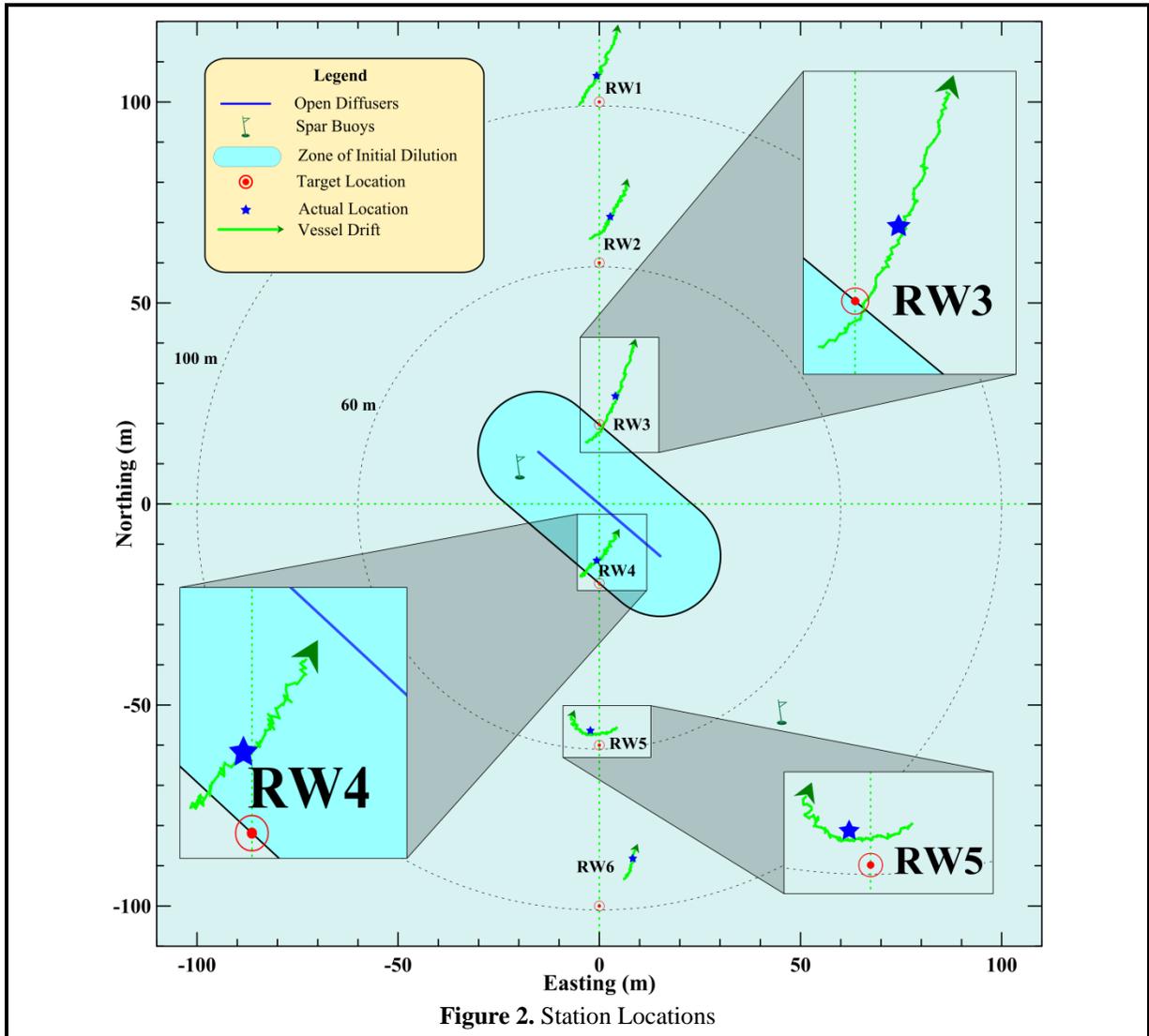


Figure 2. Station Locations

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

Station	Description	Latitude	Longitude	Center Distance ² (m)	Closest Approach Distance ³ (m)
RW1	Upcoast Midfield	35° 23.253' N	120° 52.504' W	100	88.4
RW2	Upcoast Nearfield	35° 23.231' N	120° 52.504' W	60	49.4
RW3	Upcoast ZID	35° 23.210' N	120° 52.504' W	20	15.0
RW4	Downcoast ZID	35° 23.188' N	120° 52.504' W	20	15.0
RW5	Downcoast Nearfield	35° 23.167' N	120° 52.504' W	60	49.4
RW6	Downcoast Midfield	35° 23.145' N	120° 52.504' W	100	88.4

² Distance to the center of the open diffuser section

³ Distance to the closest open diffuser port

During a diver survey in July 1998, the survey vessel's DGPS navigation system, consisting of a Furuno™ GPS 30 and FBX2 differential beacon receiver, was used to precisely determine the position of the open section of the diffuser structure (MRS 1998) and establish the target locations for the receiving-water monitoring stations shown in Figure 2 and listed in Table 1. 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 metocean⁴ 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.

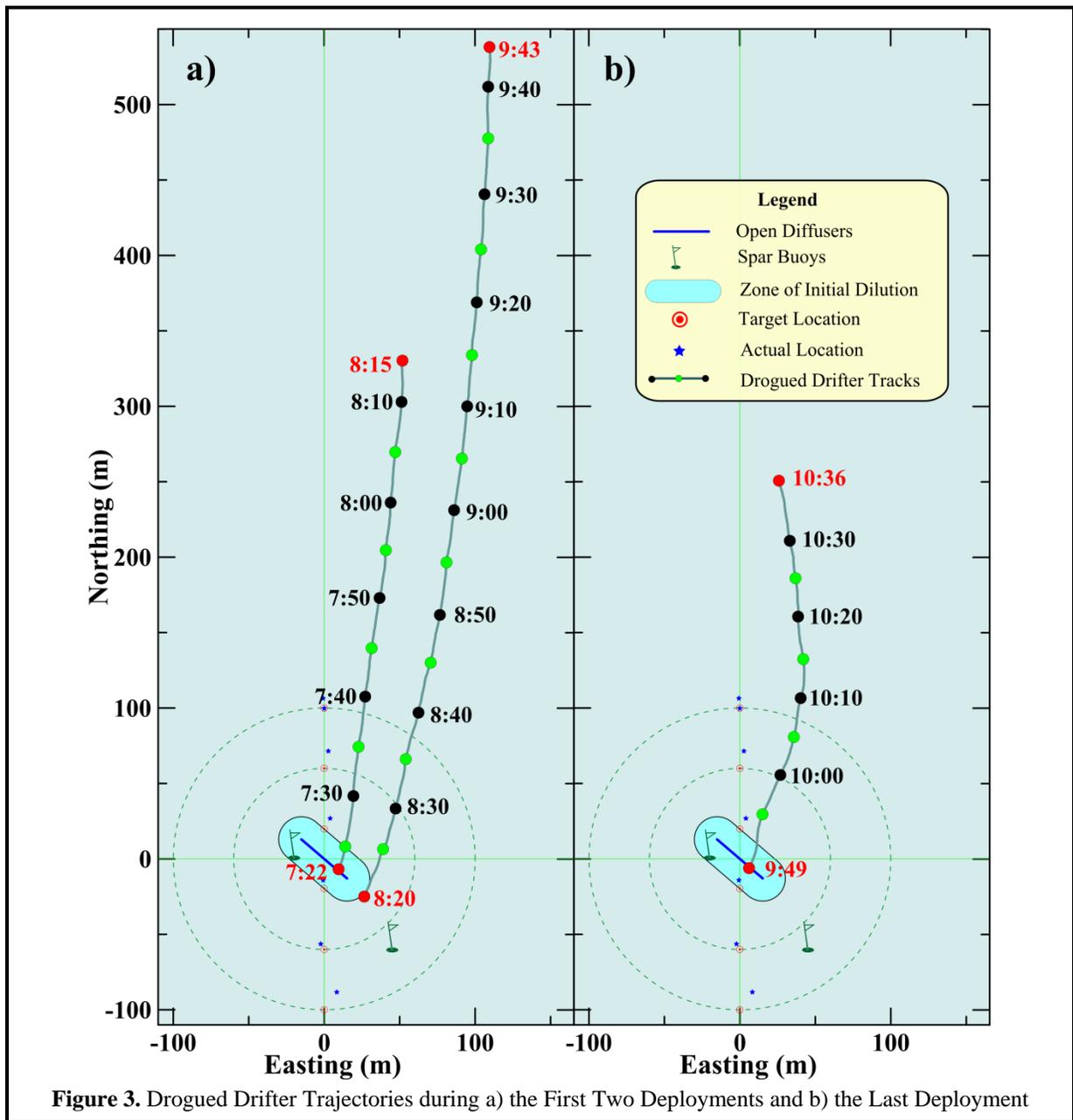
The magnitude of the drift at each of the six stations during the October 2012 survey is apparent from the length of the green tracklines in Figure 2. These tracklines trace the horizontal movement of the survey vessel as the CTD was lowered to the seafloor. Their lengths and offsets from the target locations reflect the overall station-keeping ability during the October 2012 survey. During the time it took the CTD to traverse the water column and reach the seafloor, which averaged two minutes, the instrument package moved an average of 16 m.

This amount of drift is larger than that of most recent surveys, where downcasts have typically been completed in 1 minute 30 seconds with lateral offsets of less than 10 m. During the October 2012 survey, however, an extremely strong oceanic flow transported the CTD toward the north-northeast. Meanwhile, winds out of the northeast retarded the survey vessel's transport in that direction. As a result, the CTD became increasingly offset from the vessel position during its descent. Because the CTD cable is paid-out at approximately the same rate during all surveys, and because the CTD's lateral separation from the survey vessel was greater during the October 2012 survey, more line was paid-out and the CTD took an additional 30 seconds to traverse the water column.

The CTD tracklines shown light green in Figure 2 are determined from vessel position, so the actual lengths of the CTD trajectories may have extended up to an additional 14 m to the north-northeast. For example, as discussed later in this report, the trajectory of the CTD at Station RW4 (see the leftmost inset in Figure 2) actually crossed over the diffuser structure before reaching the seafloor. The CTD data measured at this station demonstrate that the CTD passed through an ejection jet emanating from a single diffuser port immediately prior to impinging on the seafloor. Such would not be the case if the CTD had reached the seafloor at the location of the dark green arrowhead shown in Figure 2, which is 3.4 m southwest of the diffuser structure at a location upstream of the transport direction of the discharge plume.

In addition to the complex interaction between surface currents and wind forces described above, the curved trajectory at Station RW5 (see lower right inset in Figure 2) reflected the influence of the residual momentum of the survey vessel as it approached the station from the northeast. Vessel trajectories at the other receiving-water stations were consistent with the north-northeastward transport of the drogued drifter by subsurface currents (Figure 3). However, the residual southwestward momentum of the survey vessel at Station RW5 was initially sufficient to counteract the influence of northeastward oceanic

⁴ Meteorological and oceanographic conditions include winds, waves, tides, and currents.



transport. As the CTD descended into the lower water column and vessel momentum dissipated, northeastward flow began to dominate the movement of the vessel and CTD.

Detailed knowledge of the CTD's location during downcasts at Station RW3 and RW4 is particularly important for compliance evaluations. The target locations for these stations (red \odot symbols in Figure 2) lie along the ZID boundary, and are closest (15.2 m) to the diffuser structure where any potential discharge effects are expected to be largest. However, receiving-water limitations specified in the COP only apply to measurements recorded along or beyond the ZID boundary, where initial mixing is assumed complete. During the October 2012 survey, the CTD traversed the ZID boundary at both stations (green

lines in the left and upper right insets in Figure 2), so only a portion of the measured data was subject to compliance analysis.

Specifically, most of the measurements recorded by the CTD at Station RW3 were located outside the ZID and were subject to the compliance analysis. However, the initial CTD measurements, which were collected at depths shallower than 4 m, were located within the ZID and were not subject to the compliance analysis. Conversely, only the shallowest CTD measurements at Station RW4, namely, those above 4.5 m, were subject to compliance analysis. During the initial portions of the hydrocasts at each station, the CTD was close to the survey vessel and its location was accurately reflected by the vessel locations shown in Figure 2. As described above, however, the deepest portions of the vessel trajectories at both stations underestimate the final north-northeastward location of the CTD because the CTD was carried by the strong north-northeastward current at a rate faster than that of the survey vessel. However, offsets between vessel and CTD positions were small during the shallow portions of hydrocasts, including the points at which the CTD was crossing the ZID boundary at Stations RW3 and RW4.

Except for the unusual metocean conditions during the October 2012 survey, where wind direction opposed a strong oceanic flow, CTD locations normally closely track the vessel trajectory. This is apparent because the length of cable that is paid out when CTD reaches the seafloor is normally close to the water depth. As described above, however, the October 2012 CTD measurements could also be accurately screened for compliance based on their position relative to the ZID because both the vessel and CTD crossed the ZID boundary during the shallow portion of the hydrocasts when their offset was minimal. Nevertheless, it has not always been possible to determine which measurements were subject to permit limits within hydrocasts near the ZID boundary. Prior to 1999 and before the advent of DGPS, CTD locations could not be determined with sufficient accuracy to establish whether the average station position was located within the ZID, much less how the CTD was moving laterally during the hydrocast. Because of these navigational limitations, sampling was presumed to occur at a single, imprecisely determined, horizontal location. Federal and state reporting of monitoring data still mandates identification of a single position for all of the CTD data collected at a particular station. Thus, for regulatory reporting, and for consistency with past surveys, the October 2012 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 2012 Survey

Station	Time (PDT)		Latitude	Longitude	Closest Approach	
	Downcast	Upcast			Range ⁵ (m)	Bearing ⁶ (°T)
RW1	7:29:48	7:31:41	35° 23.257' N	120° 52.504' W	94.8	9
RW2	7:40:43	7:42:59	35° 23.238' N	120° 52.502' W	61.3	17
RW3	7:46:10	7:48:14	35° 23.214' N	120° 52.501' W	23.1 ⁷	41
RW4	7:53:52	7:55:53	35° 23.191' N	120° 52.504' W	11.0 ⁸	221
RW5	8:00:31	8:02:44	35° 23.169' N	120° 52.505' W	46.7	202
RW6	8:09:11	8:10:43	35° 23.151' N	120° 52.499' W	75.5	185

⁵ Distance from the closest open diffuser port to the average profile location.

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

⁷ Some of the shallow CTD measurements at Station RW3 were located within the ZID boundary (refer to the rightmost inset in Figure 2).

⁸ Except for a few shallow measurements, CTD measurements at Station RW4 were located within the ZID boundary (refer to the other inset in Figure 2).

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

OCEANOGRAPHIC PROCESSES

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

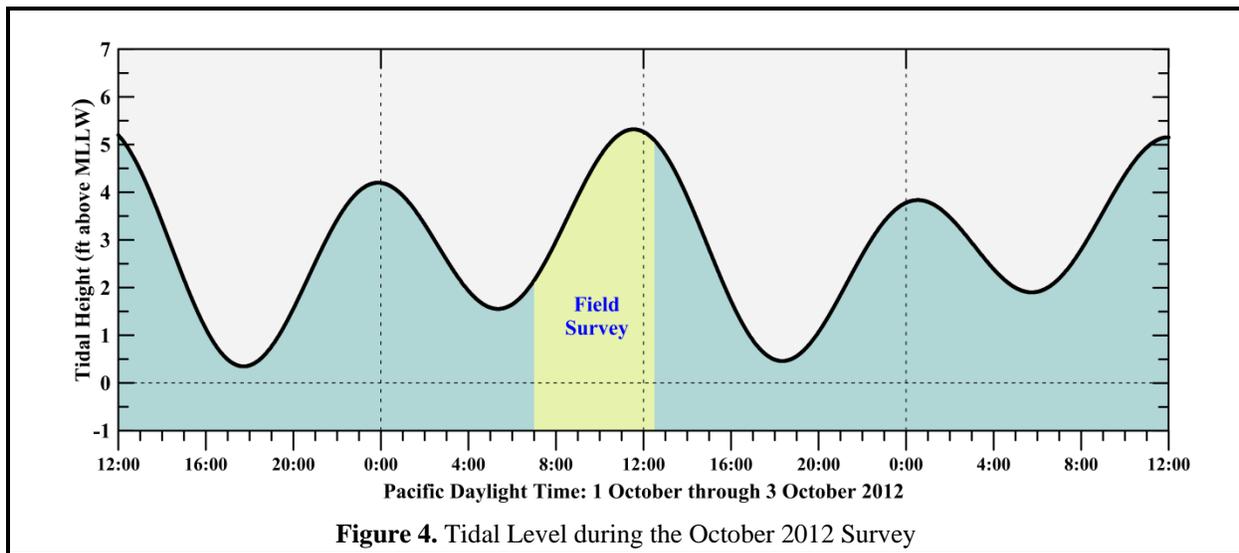
The drifter was deployed near the diffuser structure at 7:22 AM, and was recovered and redeployed two additional times during the survey, once at 8:20 AM, and again at 9:49 AM (Figure 3ab). Normally, the drifter is deployed only once during a survey, but the high flow speeds during the October 2012 necessitated repeated recovery and redeployment. This ensured that the drifter's movement reflected flow near the survey area throughout the survey, and that the drifter could be easily located and recovered after the survey was complete.

The first two drifter deployments measured a strong, steady oceanic flow that was sustained throughout the first two hours of the survey when vertical profiling was being conducted (Figure 3a). During the next hour of the survey, however, the flow speed decreased and direction began to change to a more northerly alignment (Figure 3b). During this last deployment, attempts to collect tow data were complicated by the widespread presence of drifting detached kelp that rapidly fouled the CTD as soon as tows were initiated. The drifter was retrieved and demobilized in anticipation of a return to port. However, patient persistence by the survey personnel was rewarded around 11:00 AM, when the tow survey was reinitiated because most of the drift kelp had been carried out the survey area by the strong oceanic current.

Prevailing flow can be quantified from the drifter trajectories shown in Figure 3. The black dots show the drifter's location at ten-minute intervals, with green dots indicating intervening 5-minute time stamps. The deployment and recovery times and locations are indicated in red. During the first two drifter deployments, the uniform spacing of the black and green dots reflects an average flow speed of 11 cm/s, or 0.21 knots directed toward the north-northeast at 8°T.⁹ This north-northeastward (onshore) flow direction was consistent with the flood tide that prevailed during most of the survey (Figure 4) while the flow speed was one of the highest measured during the past twenty years of conducting receiving-water surveys for the MBCSD. At this transport rate, effluent was carried beyond the ZID in less than 2 minutes 18 seconds after discharge.

During the third and final drifter deployment, the flow speed decreased slightly to 9.3 cm/s (0.18 knots) and a westward shift in the drifter's trajectory became apparent (Figure 3b). The decrease in flow speed and change in flow direction both coincided with the slack tide that began at approximately 10:20 AM. Even at the slightly reduced flow speed, however, the plume's residence time within the ZID was less

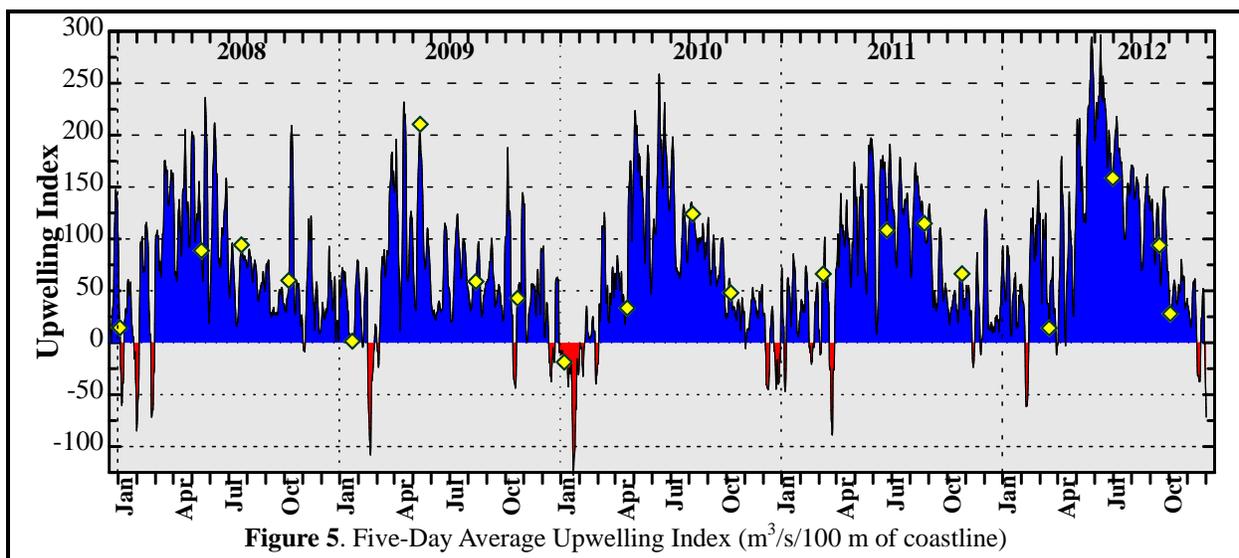
⁹ Eight degrees relative to true (rather than magnetic) north



than 2 minutes 45 seconds, which is still significantly shorter than transport times measured during most prior MBCSD surveys.

Despite the co-occurrence of changes in flow velocity and tides measured during the October 2012 survey, coastal currents within Estero Bay are also often strongly influenced by external processes, such as wind-generated upwelling, downwelling, or the passing of offshore eddies propagating along the coastline. Upwelling, for example, can induce a southerly (offshore) flow in the upper water column, and a northerly (onshore) flow at depth.

Figure 5 shows, however, that the unusually persistent and intense upwelling conditions that prevailed throughout most of 2012 declined markedly at the time of the October survey. Upwelling winds generally tend to be stronger and more persistent during the spring and summer compared to the fall. Just prior to the October survey, a strong ridge of high pressure began to build over the central California coast, which reduced the strength of the northwesterly winds that normally prevail throughout much of the year.



Accordingly, only limited amount of upwelling was produced at the time of the October 2012 survey, although strong upwelling had occurred in the weeks prior to the survey (Figure 5).

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 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.

The satellite image on the cover of this report documents the influence of upwelling on sea-surface temperatures prior to the October 2012 survey. The image was recorded the day before the survey, when skies were clear enough for sea-surface temperatures to be measured by infrared sensors on one of NOAA's polar orbiting satellites. As is apparent in the cover image, the cool, nearshore sea-surface temperatures (15.0°C) within Estero Bay were comparable to the near-surface temperatures measured by the CTD during the October 2012 survey.¹⁰

METHODS

The 38 ft F/V *Bonnie Marietta*, owned and operated by Captain Mark Tognazzini of Morro Bay, served as the survey vessel on Tuesday, 2 October 2012. Bonnie Luke of Marine Research Specialists (MRS) was Chief Scientist and collected auxiliary measurements of biological, meteorological, and oceanographic conditions. Michael Cassata and Dr. Douglas Coats, also of MRS, assisted with Secchi depth measurements and provided navigational support, respectively, 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® 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.

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

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 2012 survey. The six seawater properties used to assess receiving-water quality in this report were derived from the continuously recorded output from the CTD’s probes and sensors. Although pressure-housing limitations confine the CTD to depths less than 680 m (Table 3), this is well beyond the maximum depth of the deepest station in the outfall survey.

Table 3. CTD Specifications

Component	Units	Range	Accuracy	Resolution
Housing (19p-1a; Acetron Plastic)	m	0 to 680	—	—
Pump (SBE 5P)	—	—	—	—
Pressure (19p-2h; Strain-Gauge)	dBar	0 to 680	±1.7	± 0.10
Conductivity	Siemens/m	0 to 9	± 0.0005	± 0.00005
Salinity	‰	0 to 58	± 0.004	± 0.0004
Temperature	°C	-5 to 35	± 0.005	± 0.0001
Transmissivity (WETLabs C-Star) ¹¹	%	0 to 100	± 0.3	± 0.03
Oxygen (SBE 43)	% Saturation	0 to 120	± 2	—
pH (SBE 18)	pH	0 to 14	± 0.1	—

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

Assessments of all three of the physical parameters (salinity, temperature, and density) helped determine the lateral extent of the effluent plume during the 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 the first vertical hydrocast at Station RW1, the CTD was held below the sea surface for four minutes. Subsequently, the CTD was raised to within 0.5 m of the sea surface and profiling commenced.

¹¹ 25-cm path length of red (660 nm) light

The CTD was lowered at a continuous rate of speed to the seafloor. Measurements at all six stations were collected during a single deployment of the CTD package by towing it below the water surface while transiting between adjacent stations.

At 8:10 AM, following the last vertical profile at RW6, the CTD instrument package was brought aboard the survey vessel and reconfigured for horizontal towing with forward-looking probes. The CTD was fitted with a horizontal stabilizer wing and a depth-suppression weight was added to the towline to achieve constant-depth tows. After the CTD was deployed in this configuration, towing commenced but had to be repeatedly aborted due to fouling of the equipment by the dense patches of detached kelp that were floating throughout the survey area.

After an hour and a half of failed attempts at steering around kelp patches, and repeated clearing of kelp from the CTD, the CTD configuration was changed back to a vertical profiling mode. In this configuration, tow-yo's were conducted where the CTD was repeatedly raised and lowered as the survey vessel was slowly maneuvered around the diffuser structure. This method of obtaining high-resolution lateral data was attempted for another hour with little success. Because of the strong currents, floating kelp continued to be entrained as the CTD moved through the water column and enough usable data to satisfy the permit monitoring requirements were not obtained. At that point, options for repeating the survey on another day were discussed, and demobilization of the equipment, including drifter retrieval began. During this discussion and demobilization period, it was observed that much of the floating kelp was being carried out of the survey area by the strong northward current.

The CTD was reconfigured for towing and redeployed at 10:59 AM. Subsequently, the CTD was successfully towed around and across the ZID at two separate depths, one at mid-depth below the thermocline and one within the surface mixed layer, in accordance with the monitoring requirements of the NPDES discharge permit (Figure 6). Initially, the reconfigured CTD package was towed for 36 minutes at an average depth of 10.12 m, and an average speed of 1.92 m/s, passing over, or near the diffuser structure eight times. The CTD needed to be retrieved to clear kelp from the apparatus only once during this mid-depth tow. The presence of the attached kelp was readily apparent in the real-time data that was being monitoring onboard during the tow. At other times, reductions in data quality arose when pieces of floating kelp passed through the transmissometer beam, and the instrument exhibited brief but sharp reductions in transmissivity.

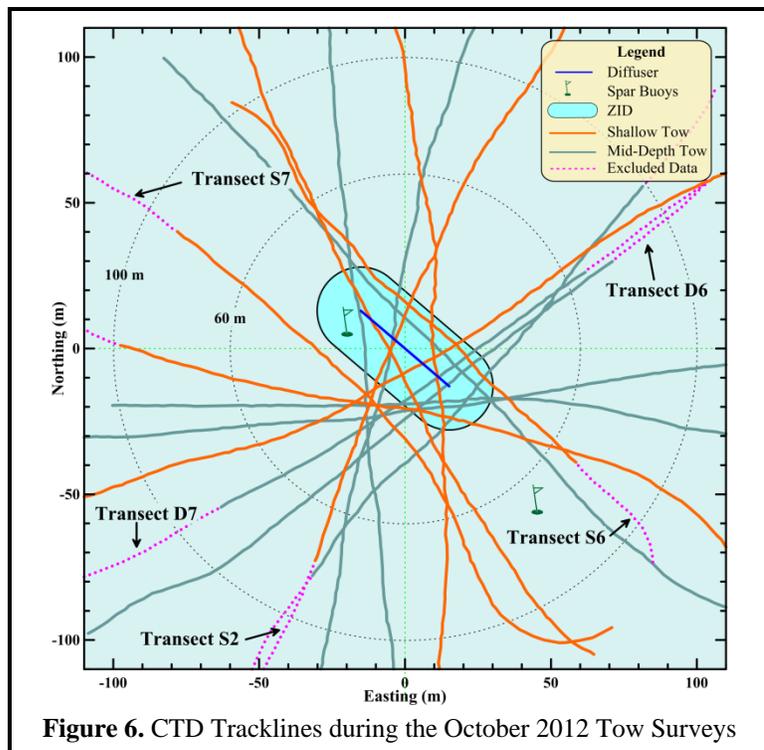


Figure 6. CTD Tracklines during the October 2012 Tow Surveys

Subsequently, seven additional passes were made with the CTD at an average depth of 7.13 m. During this 27-minute shallow tow, vessel speed averaged 1.77 m/s. At the observed towing speeds and a 4 Hz sampling rate, 2.3 CTD measurements were collected for each meter traversed. This complies with the permit requirement for minimum horizontal resolution of at least one sample per meter. Contemporaneous navigation fixes recorded onboard the survey vessel were adjusted for CTD setback and aligned with time stamps on the internally recorded CTD data. The resulting data for the six seawater properties were then processed to produce horizontal maps within the upper and sub-thermocline portions of the water column.¹²

Quality Control

Upon retrieval of the CTD following the tow survey, water-quality data were examined for completeness and range acceptability. Although real-time monitoring indicated the recorded properties except transmissivity were complete and within acceptable coastal seawater ranges,¹³ subsequent post-processing revealed several events that impacted portions of the data, resulting in the adjustment or exclusion of these data prior to initiation of the compliance analysis. For example, review of the tow data revealed that the CTD was tracking at a slightly different depth (>1 m offset) during the latter portions of the mid-depth tows along Transects D6 and D7, as well as during the shallow tows along Transects S2, S6, and S7 (purple dotted lines in Figure 6).

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

Because the discharge-related anomalies used in the compliance analysis are identified by comparing the amplitudes of measurements acquired at the same depth level, the ability to resolve anomalies with statistical certainty is compromised when data from different depth levels are combined. This is particularly true when the water column is stratified, as was the case during the October 2012 survey.

The exclusion of small portions of Transects S2, S6, S7, D6, and D7 did not, however, adversely affect the compliance analysis because the remaining transects adequately covered the survey region. Specifically, the remaining data, shown by the solid orange and blue-green lines in Figure 6, met the permit monitoring requirement of at least five passes near the diffuser structure at each tow depth.

In addition to the removal of all measured properties within limited sections of the tow survey, small portions of the transmissivity record were excised to remove extraneous reductions that arose during encounters with floating kelp. These encounters resulted in rapid, large (>10%), but short-lived (≤1 second) reductions in transmissivity. In contrast, when the plume signature is observed in the transmissivity record, the changes are gradual, of limited amplitude, and can be in either direction relative to average water clarity depending on whether the deep seawater entrained at depth is more or less turbid than mid-depth seawater. Occasionally, sharp reductions in DO also occurred when kelp temporarily clogged the intake to the plenum. Nevertheless, more than 92% of the transmissivity observations, and more than 99.6% of the DO observations remained even though 89 separate kelp encounters were addressed in this phase of the quality control process.

Quality-control screening of the vertical profile data was also required because the length of the CTD is close to the 0.5-m standard depth bins used to report the vertical profile data. Because of the CTD's

¹² Figures 8 and 9 later in this report

¹³ Field sampling protocols employed during the October 2012 survey generally followed the field operations manual for the Southern California Bight Study (SCBFMC 2002), which includes CTD cast-acceptability ranges in Table 2 of the manual.

physical dimensions, the ability to compute average values for seawater properties at locations very near the sea surface and seafloor varies depending on how the CTD's reported depth is influenced by temporal differences in sea-surface height. These height fluctuations are caused by wave and tidal-induced oscillations during its deployment at each station. For example, during the October 2012 survey, data on average seawater properties could not be reported within the deepest depth bin (17 m) except at Stations RW4 and RW5.¹⁴ Because these isolated observations cannot quantify a horizontal trend, they were excluded from the subsequent compliance evaluation.

RESULTS

The fourth-quarter receiving-water survey was conducted on the morning of Tuesday, 2 October 2012. The receiving-water survey commenced at 7:20 AM with the deployment of the drogued drifter. Over the following five hours, offshore observations and measurements were collected as required by the NPDES monitoring program. The survey ended at 12:20 PM with the retrieval of the CTD from the shallow tow survey. Collection of required visual observations of the sea surface was unencumbered throughout the survey.

Auxiliary Observations

On the morning of 2 October 2012, skies were clear, with only light and variable northwesterly winds. Average wind speeds, calculated over one-minute intervals, ranged from 0.6 kt to 1.2 kt (Table 4). Similarly, peak wind speeds ranged from 1.9 kt to 2.8 kt. The swell was out of the northwest with a significant wave height of 2 feet. A southerly swell with a significant wave height of 1 to 2 feet was also present. Air temperatures remained fairly constant throughout the survey, averaging 19.9°C.

Table 4. Standard Meteorological and Oceanographic Observations

Station	Location ¹⁵		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° 23.282' N	120° 52.499' W	141.8	7:34:12	19.2	0	1.2	2.8	NE	2 NW	6.0
RW2	35° 23.237' N	120° 52.502' W	60.6	7:42:35	18.3	0	1.0	1.6	NE	2 NW	6.0
RW3	35° 23.231' N	120° 52.499' W	52.2	7:49:27	22.8	0	0.6	1.6	NE	2 NW	7.0
RW4	35° 23.198' N	120° 52.499' W	3.5	7:55:59	20.3	0	1.0	2.2	NE	2 NW	7.0
RW5	35° 23.180' N	120° 52.513' W	35.3	8:04:28	20.8	0	0.8	1.8	NE	2 NW	8.0
RW6	35° 23.150' N	120° 52.502' W	78.5	8:12:59	18.1	0	1.1	1.8	NE	2 NW	9.0

The 6 to 9 m Secchi depths recorded during the October 2012 survey reflected the presence of a deep euphotic zone that reached the seafloor at most stations (Table 4). The high water clarity during the survey was due in part to the limited amount of upwelling around the time of the survey. During strong upwelling events, nutrients carried upward into the euphotic zone are assimilated by phytoplankton, whose populations increase and, along with their associated zooplanktonic predators, their increased densities reduce the transmittance of ambient light. Despite the increased water clarity during the October 2012 survey, there was no evidence of floating particulates, oil sheens, or any discoloration of the sea surface associated with wastewater-related constituents during the survey.

¹⁴ Refer to Table 5 later in this report.

¹⁵ 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.

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 0.748 million gallons of effluent discharged on the day of the survey had a temperature of 23°C, a suspended-solids concentration of 30 mg/L, and a pH of 7.5. Biochemical oxygen demand (BOD) measured in an effluent sample collected four days before the survey was 43 mg/L.

During the October 2012 survey, visual observations demonstrated continued beneficial use of the coastal waters within Estero Bay by both wildlife and recreational users. Small numbers of Brandt's cormorants (*Phalacrocorax penicillatus*), pelagic cormorants (*Phalacrocorax pelagicus*), western gulls (*Larus occidentalis*), Heermann's gulls (*Larus heermanni*) and a lone southern sea otter (*Enhydra lutris nereis*) were noted transiting the survey area. Additionally, a pair of Elegant terns (*Thalasseus elegans*) was also present in the area. Pedestrians were visible along Atascadero State beach throughout the survey, and several small recreational fishing vessels were also observed offshore. During much of the survey, numerous rafts of floating giant kelp (*Macrocystis pyrifera*) and bull kelp (*Nereocystis luetkeana*) were present in the survey area. These rafts and patches of kelp were far more abundant than what is normally encountered during the receiving water surveys, which complicated both the completion of the tow portion of the survey and the quality control of the survey data.

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 2012 survey reflect the presence of a moderately stratified water column indicating that upwelling conditions had recently prevailed within Estero Bay (Figure 5).

Upwelling of varying intensity occurs most of the year along the central California coast, with the strongest upwelling winds beginning in March or April and extending through the summer. Upwelling results in an influx of dense, cold, saline water at depth and often leads to a sharp thermocline, halocline, and pycnocline where temperature, salinity, and density change rapidly over a small vertical distance. Under highly stratified conditions, isotherms crowd together to form a density interface that restricts the vertical transport of the effluent plume, inhibiting the vertical exchange of nutrients and other water properties, and reducing the initial dilution of the effluent plume.

If strong upwelling winds are not sustained, the sharp interface between the surface and deep water masses begins to erode, and eventually, the water column stratification appears as a more gradual vertical change in seawater properties that ultimately extends throughout the water column. This was the case during the October 2012 survey. Although winds were mild on the morning of the 2 October, sustained northwesterly winds prevailed in the days prior to the survey (Figure 5). As a result, a relict upwelling signature appears in the vertical profiles as moderate stratification that extends through most of the water column (Figure 7).

In particular, all seawater properties except transmissivity exhibit steadily increasing or decreasing values throughout the mid-depth range. Slight departures apparent near 10 m at Stations RW3 and RW4 (Figure 5bc) were caused by the discharge plume. For the most part however, steady decreases in temperature (red lines), DO (dark blue lines), and pH (olive-colored lines) with depth reflect the lingering effects of upwelling in the days prior to the survey. These decreases are mirrored by a pycnocline, where density (black lines) steadily increases with depth. These gradual vertical changes reflect the transition to colder, saltier, nutrient-rich but oxygen-poor water mass that migrated shoreward along the seafloor as part of the upwelling process.

Table 5. Vertical Profile Data Collected on 2 October 2012

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	15.070	15.146	15.253	15.217	15.273	15.030	33.464	33.469	33.469	33.474	33.471	33.465
1.5	15.097	15.105	15.258	15.025	15.189	15.016	33.466	33.466	33.469	33.463	33.466	33.463
2.0	15.100	15.030	15.185	14.962	15.112	14.999	33.465	33.462	33.466	33.461	33.462	33.462
2.5	15.019	14.984	15.015	14.915	14.920	14.881	33.462	33.461	33.459	33.458	33.454	33.455
3.0	15.002	14.977	14.945	14.885	14.856	14.839	33.462	33.461	33.457	33.457	33.453	33.454
3.5	14.997	14.955	14.884	14.852	14.813	14.818	33.462	33.460	33.455	33.456	33.452	33.453
4.0	14.981	14.918	14.847	14.809	14.785	14.788	33.461	33.458	33.455	33.454	33.452	33.452
4.5	14.947	14.872	14.782	14.775	14.752	14.764	33.459	33.455	33.452	33.454	33.452	33.452
5.0	14.902	14.857	14.748	14.763	14.728	14.753	33.458	33.456	33.452	33.454	33.452	33.452
5.5	14.864	14.844	14.738	14.748	14.719	14.735	33.456	33.456	33.453	33.453	33.452	33.452
6.0	14.782	14.829	14.733	14.732	14.713	14.726	33.452	33.455	33.453	33.453	33.452	33.452
6.5	14.748	14.811	14.727	14.716	14.703	14.719	33.453	33.455	33.453	33.453	33.452	33.452
7.0	14.732	14.790	14.724	14.710	14.698	14.709	33.454	33.454	33.453	33.453	33.452	33.452
7.5	14.694	14.778	14.710	14.703	14.694	14.710	33.455	33.453	33.452	33.453	33.453	33.452
8.0	14.631	14.763	14.654	14.695	14.683	14.711	33.452	33.451	33.441	33.453	33.453	33.452
8.5	14.589	14.734	14.564	14.668	14.671	14.713	33.448	33.447	33.412	33.454	33.454	33.453
9.0	14.578	14.724	14.563	14.661	14.657	14.702	33.447	33.446	33.411	33.454	33.454	33.453
9.5	14.571	14.684	14.529	14.636	14.640	14.678	33.449	33.439	33.403	33.456	33.455	33.453
10.0	14.570	14.584	14.523	14.622	14.625	14.664	33.450	33.428	33.401	33.456	33.456	33.453
10.5	14.567	14.572	14.518	14.609	14.601	14.636	33.452	33.435	33.397	33.457	33.457	33.454
11.0	14.565	14.567	14.570	14.600	14.580	14.623	33.455	33.441	33.417	33.458	33.459	33.456
11.5	14.561	14.568	14.585	14.591	14.575	14.614	33.457	33.452	33.428	33.459	33.459	33.457
12.0	14.561	14.557	14.600	14.576	14.575	14.589	33.457	33.457	33.440	33.460	33.460	33.458
12.5	14.550	14.549	14.605	14.575	14.568	14.591	33.460	33.460	33.442	33.461	33.460	33.459
12.0	14.533	14.540	14.594	14.571	14.566	14.605	33.460	33.461	33.438	33.461	33.461	33.458
12.5	14.472	14.528	14.597	14.562	14.563	14.578	33.461	33.462	33.452	33.462	33.461	33.459
14.0	14.370	14.447	14.578	14.554	14.551	14.552	33.460	33.462	33.460	33.462	33.461	33.461
14.5	14.275	14.325	14.501	14.546	14.527	14.534	33.461	33.459	33.460	33.462	33.462	33.461
15.0	14.049	14.123	14.401	14.537	14.519	14.485	33.454	33.455	33.460	33.462	33.463	33.461
15.5	13.899	13.991	14.221	14.518	14.412	14.389	33.453	33.455	33.458	33.408	33.461	33.460
16.0	13.876	13.912	14.056	14.438	14.230	14.262	33.457	33.455	33.457	33.345	33.459	33.458
16.5				14.201	14.213	14.188				33.447	33.461	33.459
17.0				14.160	14.220					33.437	33.463	

Table 5. Vertical Profile Data Collected on 2 October 2012 (continued)

Depth (m)	Density (σ_t)						pH					
	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6
1.0	24.773	24.760	24.737	24.748	24.734	24.782	8.127	8.124	8.116	8.117	8.118	8.130
1.5	24.768	24.767	24.736	24.782	24.748	24.784	8.124	8.122	8.113	8.124	8.114	8.129
2.0	24.767	24.780	24.749	24.794	24.762	24.786	8.123	8.124	8.111	8.128	8.117	8.130
2.5	24.782	24.789	24.781	24.802	24.797	24.806	8.127	8.129	8.117	8.131	8.128	8.133
3.0	24.786	24.791	24.794	24.807	24.811	24.815	8.131	8.132	8.125	8.133	8.132	8.134
3.5	24.787	24.794	24.806	24.813	24.819	24.819	8.133	8.133	8.130	8.133	8.134	8.134
4.0	24.790	24.801	24.814	24.821	24.825	24.825	8.134	8.134	8.130	8.133	8.134	8.135
4.5	24.795	24.809	24.826	24.829	24.832	24.829	8.134	8.134	8.132	8.132	8.133	8.134
5.0	24.804	24.812	24.833	24.831	24.837	24.832	8.135	8.134	8.131	8.132	8.133	8.135
5.5	24.811	24.815	24.836	24.834	24.839	24.836	8.135	8.133	8.130	8.132	8.133	8.134
6.0	24.826	24.818	24.837	24.837	24.841	24.838	8.134	8.133	8.129	8.131	8.132	8.135
6.5	24.834	24.822	24.838	24.840	24.843	24.839	8.131	8.132	8.130	8.130	8.132	8.135
7.0	24.838	24.825	24.839	24.842	24.844	24.841	8.131	8.131	8.129	8.131	8.132	8.135
7.5	24.847	24.827	24.841	24.843	24.845	24.841	8.130	8.132	8.129	8.130	8.131	8.134
8.0	24.858	24.829	24.845	24.845	24.848	24.841	8.129	8.131	8.128	8.129	8.131	8.135
8.5	24.864	24.832	24.841	24.852	24.851	24.841	8.128	8.130	8.126	8.129	8.131	8.134
9.0	24.866	24.833	24.841	24.854	24.854	24.844	8.125	8.128	8.120	8.128	8.130	8.135
9.5	24.869	24.837	24.842	24.860	24.858	24.848	8.124	8.128	8.118	8.127	8.130	8.134
10.0	24.869	24.850	24.842	24.863	24.862	24.852	8.123	8.125	8.116	8.127	8.129	8.134
10.5	24.871	24.857	24.840	24.867	24.868	24.859	8.122	8.122	8.113	8.126	8.128	8.132
11.0	24.875	24.863	24.844	24.869	24.874	24.863	8.122	8.118	8.113	8.126	8.128	8.132
11.5	24.877	24.871	24.849	24.872	24.876	24.865	8.122	8.120	8.114	8.124	8.126	8.131
12.0	24.877	24.877	24.855	24.876	24.876	24.872	8.122	8.119	8.117	8.124	8.126	8.131
12.5	24.882	24.882	24.856	24.877	24.878	24.872	8.122	8.119	8.119	8.124	8.124	8.129
12.0	24.885	24.885	24.855	24.878	24.879	24.869	8.120	8.119	8.119	8.124	8.125	8.128
12.5	24.899	24.887	24.866	24.880	24.879	24.875	8.118	8.119	8.120	8.122	8.124	8.128
14.0	24.920	24.905	24.875	24.882	24.882	24.882	8.112	8.116	8.120	8.121	8.124	8.128
14.5	24.940	24.928	24.892	24.884	24.888	24.886	8.105	8.109	8.121	8.121	8.123	8.127
15.0	24.982	24.967	24.913	24.886	24.890	24.896	8.095	8.096	8.117	8.120	8.123	8.125
15.5	25.013	24.995	24.950	24.848	24.912	24.915	8.086	8.080	8.114	8.120	8.117	8.120
16.0	25.020	25.011	24.983	24.816	24.949	24.941	8.076	8.065	8.098	8.115	8.102	8.114
16.5				24.946	24.954	24.958				8.106	8.091	8.099
17.0				24.946	24.953					8.091	8.086	

Table 5. Vertical Profile Data Collected on 2 October 2012 (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	8.007	7.960	7.904	7.967	7.929	7.941	87.191	85.379	85.171	86.242	86.588	88.904
1.5	7.974	8.016	7.910	8.010	7.910	7.953	86.948	86.526	85.222	86.421	86.135	88.883
2.0	8.033	8.058	7.979	8.009	7.958	7.970	87.148	86.955	85.105	87.513	86.443	88.921
2.5	8.065	8.061	8.013	8.002	7.984	7.947	87.344	88.282	85.899	88.730	87.007	89.174
3.0	8.071	8.059	7.999	7.980	7.960	7.950	88.325	88.610	87.624	89.767	88.909	90.165
3.5	8.047	8.038	7.975	7.953	7.940	7.946	88.576	88.881	89.610	90.184	90.792	91.210
4.0	8.029	8.002	7.948	7.951	7.944	7.938	88.633	89.345	90.604	91.806	91.710	92.023
4.5	7.998	7.997	7.939	7.931	7.920	7.948	88.912	90.795	91.642	91.871	92.342	92.340
5.0	7.990	7.989	7.937	7.932	7.909	7.936	89.598	91.869	92.290	92.427	92.767	92.736
5.5	7.936	7.987	7.944	7.931	7.933	7.929	90.370	91.953	92.740	92.700	93.116	93.279
6.0	7.934	7.981	7.922	7.922	7.920	7.930	90.974	92.098	93.035	93.061	93.134	93.356
6.5	7.934	7.959	7.944	7.915	7.906	7.930	91.967	92.217	93.142	93.024	93.228	93.544
7.0	7.916	7.959	7.926	7.912	7.917	7.931	92.662	92.477	93.107	93.044	93.308	93.541
7.5	7.895	7.946	7.868	7.919	7.906	7.918	92.797	92.671	93.287	93.090	93.420	93.465
8.0	7.866	7.921	7.777	7.904	7.900	7.930	92.136	92.809	92.865	93.027	93.321	93.452
8.5	7.872	7.915	7.794	7.905	7.890	7.913	91.171	92.757	89.888	93.121	93.350	91.857
9.0	7.864	7.905	7.757	7.886	7.902	7.890	90.275	92.323	87.881	92.992	93.193	91.019
9.5	7.857	7.809	7.748	7.884	7.879	7.900	90.227	92.092	87.716	92.552	93.033	93.348
10.0	7.862	7.815	7.735	7.859	7.865	7.886	90.138	90.340	87.315	92.054	92.767	93.404
10.5	7.870	7.825	7.807	7.872	7.858	7.867	90.101	89.049	87.629	91.940	92.627	93.141
11.0	7.856	7.840	7.817	7.875	7.866	7.863	90.019	89.126	89.402	91.741	91.863	92.745
11.5	7.862	7.834	7.858	7.859	7.853	7.845	89.872	89.642	89.952	91.489	91.377	92.614
12.0	7.835	7.845	7.858	7.845	7.841	7.861	89.756	89.909	90.373	90.897	91.161	91.666
12.5	7.813	7.832	7.850	7.859	7.845	7.868	89.749	89.911	90.262	90.798	90.963	91.348
12.0	7.733	7.838	7.857	7.837	7.853	7.819	89.839	89.904	90.255	90.560	90.627	91.005
12.5	7.516	7.715	7.864	7.833	7.826	7.818	89.280	89.816	89.642	90.469	90.543	91.601
14.0	7.485	7.528	7.797	7.807	7.795	7.794	87.756	89.166	90.501	90.004	90.494	90.935
14.5	7.158	7.356	7.697	7.811	7.794	7.656	86.724	88.639	90.086	89.735	90.297	90.047
15.0	6.974	7.083	7.396	7.798	7.644	7.462	83.453	85.673	88.597	89.562	89.937	89.610
15.5	6.991	7.050	7.145	7.557	7.263	7.309	76.502	81.125	86.399	89.214	89.605	87.336
16.0	6.981	7.045	7.243	7.288	7.327	7.280	70.702	75.837	80.098	83.007	86.983	83.815
16.5				7.250	7.325	7.384				83.426	84.770	75.967
17.0				7.281	7.313					72.991	82.190	

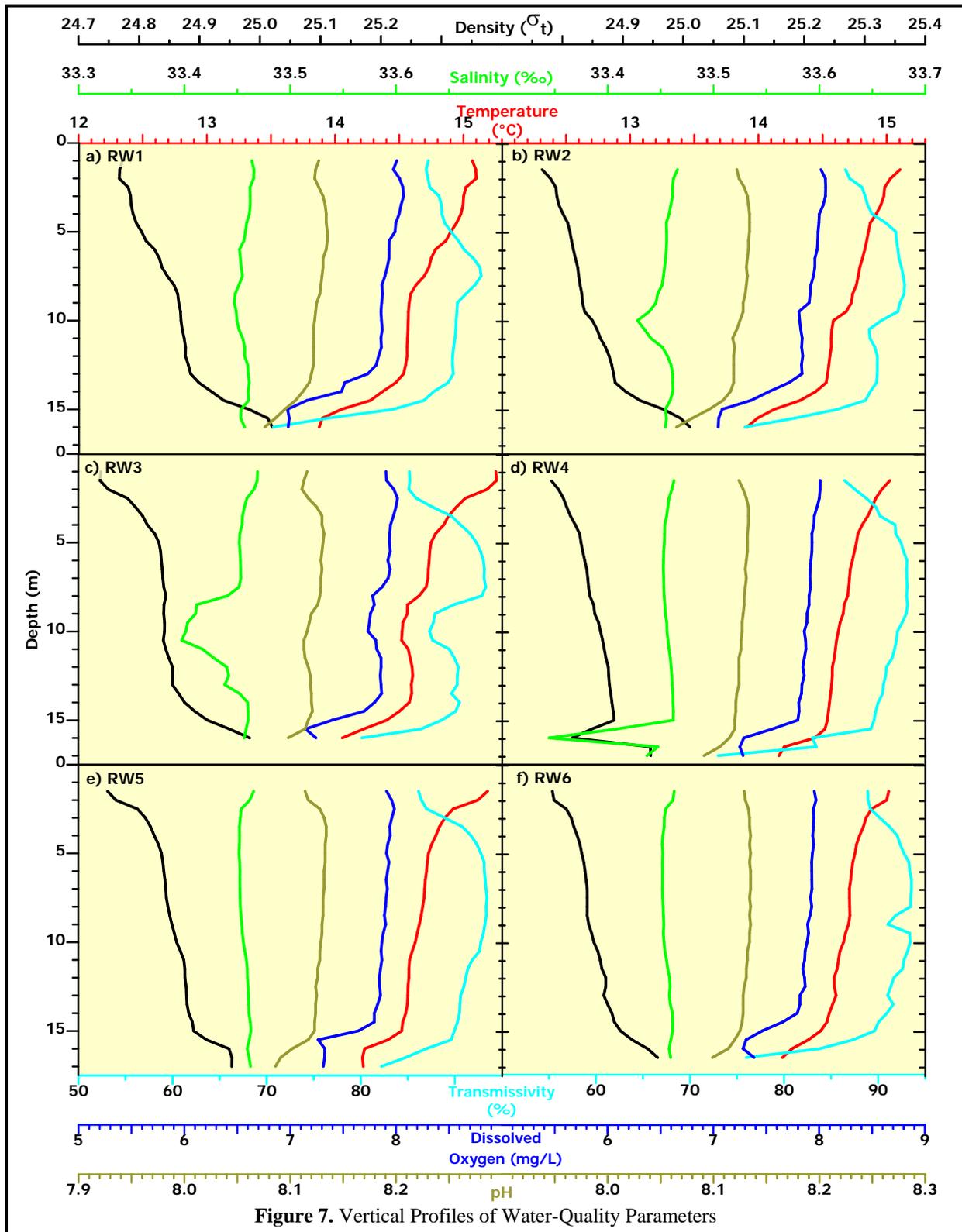


Figure 7. Vertical Profiles of Water-Quality Parameters

Departures from these gradual vertical trends occur within the near-surface mixed layer, which extends approximately 2 m below the sea surface, and within a 2-m benthic nepheloid layer (BNL) immediately above the seafloor. The sharper gradients in seawater properties near the seafloor reflect a more-recent pulse in upwelling winds that initiated the onshore movement of a deep watermass within a thin turbid BNL. This offshore watermass was characterized by cold, dense seawater (red and black lines in Figure 7) that moved shoreward to replace nearshore surface waters that were driven offshore by prevailing winds. Because this deep offshore watermass had not been in recent direct contact with the atmosphere, biotic respiration and decomposition had depleted its DO levels (dark blue lines). Additionally, at depth, biotic respiration and decomposition produced carbon dioxide (CO₂), and in its dissolved state, the increased concentration of carbonic acid appears as a concomitant decline in pH (olive-colored lines).

Meanwhile, within the surface mixed layer, nutrient-rich seawater brought to the sea surface by the recent upwelling facilitated phytoplankton blooms that produced oxygen, consumed carbon dioxide (CO₂), and decreased water clarity (light blue lines). The presence of plankton within the surface mixed layer cause a small but perceptible 5% decrease in transmissivity at the sea surface. Within the BNL, however, the presence of resuspended surficial sediments and light flocs of detritus caused a much sharper reduction in water clarity, decreasing transmissivity by an average of 13%.

As discussed previously, the relatively deep Secchi depths (Table 3) and high transmissivities (Figure 7) measured during the October 2012 document a high level of water clarity throughout most of the water column. However, the Secchi disk observations did not encompass the sharp increase in turbidity that was captured by the transmissometer within the BNL. Because of the presence of this turbid BNL, however, it is unlikely that the euphotic zone, which is normally estimated as twice the Secchi depth, actually reached the seafloor.

The level of vertical stratification within the survey area is important for understanding the dynamics of the effluent plume dispersion at the time of the survey. For example, when the water column is moderately stratified, as was the case during the October 2012 survey, the rising plume becomes trapped at depth within the water column, thereby limiting its full capacity for dilution.

The signature of the trapped effluent plume of the effluent discharge can be seen clearly as large decrease in salinity between 8 and 13 m in the vertical profile of salinity recorded at Stations RW3 (cf. green lines in Figure 7c with 7adf). This station was situated along the northern margin of the ZID (Figure 2), and along the plume transport path (Figure 3a). A Station RW2, which was situated farther north along the plume trajectory, a much weaker salinity signature was apparent in the vertical salinity profile (Figure 7b). That small salinity anomaly reflected the presence of very dilute effluent that was trapped 10 m below the sea surface.

The plume signature at Stations RW2 and RW3 is also apparent as a decrease in water clarity in the transmissivity profiles (light blue lines in Figure 7bc), and to a lesser extent in temperature (red lines) and DO (dark blue lines). The absence of a corresponding anomaly in the density profile (black lines) demonstrates that the plume had reached buoyant equilibrium near a depth of 10 m along the northern ZID boundary, and was no longer rising through water column. This indicates that the initial dilution process had been completed at that location.

Another much-larger discharge-related anomaly is apparent at a depth of 16 m in the vertical profiles at Station RW4 (Figure 7d). In contrast to the anomalies at Stations RW2 and RW3, the anomalies at Station RW4 captured the plume signature shortly after discharge, and well before the initial dilution process was complete. This is apparent from the large density decrease (black line) associated with the signature. It indicates that, at that location, the diluted effluent was much less dense than the surrounding seawater and that the buoyant plume was continuing to rise within the water column.

The near-bottom plume signature at Station RW4 provides a rare glimpse into effluent mixing dynamics immediately after discharge and within the turbulent ejection jet emanating from a single diffuser port. CTD data is not normally collected this close to the diffuser structure, but the strong north-northeasterly current that prevailed during the October 2012 survey had carried the survey vessel well northeast of the RW4 target location during the downcast at that station (left inset in Figure 4). Although the location of the CTD's seafloor impingement (dark green arrow in the inset) appears to be upstream (southwest) of the diffuser structure (shown by the blue line), the CTD had actually crossed the structure during its descent, and had encountered the seafloor downstream of plume transport. As discussed previously, the hydrocast tracklines shown in the Figure were based on vessel location, but the strong north-northeasterly current began carrying the CTD progressively farther ahead of the vessel as the downcast progressed. At Station RW4, the plume signature captured at 16 m clearly demonstrates that the CTD had passed through an effluent ejection jet before reaching the seafloor at a depth of 17 m. The signature is elevated 1 m above the seafloor both because the buoyant jet rapidly carries the plume upward in the water column shortly after discharge, and because the diffuser ports themselves are elevated above the seabed.

Discharge-related anomalies in seawater properties other than salinity are rare, and usually related to upward transport of deep ambient water that is entrained within the rising plume shortly after discharge. Although the observed temperature, transmissivity, and DO anomalies identified near 10 m within the profiles recorded at Stations RW2 and RW3 (Figure 7bc) were clearly related to the plume mixing process, they were not associated with stressors caused by the presence of wastewater constituents. Instead, the lateral anomalies in these three seawater properties were created when near-bottom seawater was entrained within the rising effluent plume shortly after discharge. At that point, the diluted wastewater plume acquired the ambient seawater characteristics within the BNL, namely, their low temperature, DO, and water clarity. As these seawater properties were carried upward through the water column by the rising effluent plume, they became juxtaposed against the differing seawater properties within the rest of the water column.

It is clear that these entrainment anomalies were not caused by the presence of wastewater constituents because the offsets in their properties were consistent with the vertical differences in ambient seawater and, for some properties, the offsets were opposite of the changes that would be expected to be caused by wastewater. For example, wastewater discharged on the day of the survey was much warmer (23°C) than receiving seawater (<15.3°C), and thus the presence of warmer wastewater constituents could not have induced the negative thermal signature observed at 10 m. Entrainment of cold bottom water is the only mechanism that could have created a dilute effluent plume that was cooler than the ambient seawater at 10 m. Additionally, the decreased transmissivity, temperature, and DO measured within the entrainment anomalies at 10 m were comparable to the ambient seawater properties found near the seafloor (Figure 7bc).

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

Because of delays caused by the presence of floating kelp, the tow survey was completed over three hours after the profile data were collected. This contrasts with prior surveys when the two data sets were able to provide a nearly synoptic view of the vertical and horizontal distribution of the plume. Unfortunately, as plume dynamics can change substantially over a span of several hours, the plume anomalies that were apparent in the vertical profiles at 10 m, were no longer evident by the time the mid-depth tow was conducted (Figure 8acdef). Although a very small salinity anomaly was marginally apparent northeast of the diffuser structure (Figure 8b), along the plume transport path (Figure 3b), anomalies in other water

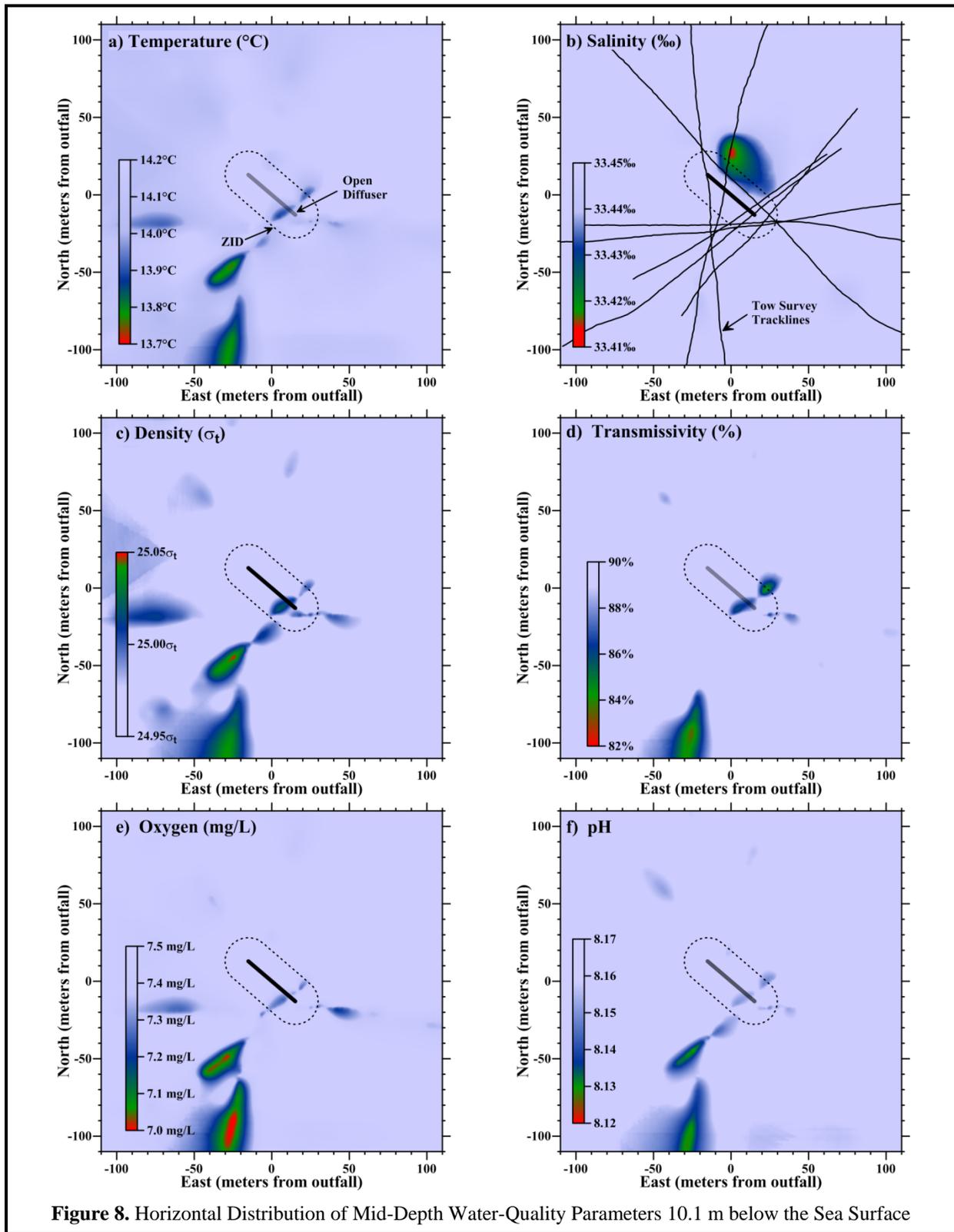


Figure 8. Horizontal Distribution of Mid-Depth Water-Quality Parameters 10.1 m below the Sea Surface

properties did not coincide with the plume location at that depth (Figure 8acdef). Instead, their mid-depth horizontal maps exhibit a random distribution of small fluctuations in seawater properties that were probably associated with small differences in tow depth.

In contrast, the shallow tow data captured a distinct plume signature northeast of the diffuser structure that was apparent in all six seawater properties (Figure 9). The 7.1-m tow depth was above the shallowest extent (8 m) of the anomaly captured in the vertical profiles (Figure 7c). The plume's density within the shallow-tow signature was greater than the surrounding seawater (Figure 9c), indicating the plume was negatively buoyant. Thus, the anomalies within the shallow tow data captured the signature of a plume whose upward momentum had caused it to overshoot its buoyant equilibrium depth and reach to within 7.1 m of the sea surface. The other seawater properties within the plume signature, namely, lower temperature, transmissivity, DO, and pH (Figure 9adef), were all consistent with the upward transport of ambient seawater within the BNL. Only the very slight salinity anomaly (Figure 9b) indicated the presence of extremely dilute wastewater constituents.

The buoyancy oscillations described above, help explain the reduced 6-m Secchi depth observed at the northern (downstream) stations compared to the 8-m Secchi depths found at the southernmost (upstream) stations (Table 4). If the plume had remained trapped at a depth of 10 m, it could not have influenced the Secchi disk observations. However, it is possible that turbid BNL waters entrained within the plume could have reduced Secchi depths at the northern locations where the plume had overshoot its equilibrium depth. Regardless, as discussed below, the apparent reduction in ambient light penetration measured by the Secchi depths does not constitute an exception to permit requirements because it was caused by entrainment of turbid ambient seawater rather than the presence of wastewater constituents.

Outfall Performance

The efficacy of the outfall can be evaluated through a comparison of dilution levels measured at the time of the October 2012 survey, and dilutions anticipated from modeling studies that were codified in the discharge permit through limits imposed on effluent constituents. Specifically, the critical initial dilution applicable to the MBCSD outfall was conservatively estimated to be 133:1 (Tetra Tech 1992). That is, dispersion modeling estimated that, at the conclusion of the minimum expected initial mixing, 133 parts of ambient seawater would have mixed with each part of wastewater.

The 133:1 dilution estimate was based on worst-case modeling under highly stratified conditions, where trapping of the plume below a strong thermocline would curtail the additional buoyant mixing normally experienced during the plume's rise through the water column. Additionally, the modeling assumed quiescent oceanic flow conditions, thereby restricting initial mixing processes to the ZID. Under those conditions, the modeling predicted that a 133:1 dilution would be achieved after the plume rose only 9 m from the seafloor, whereupon it would become trapped, spread laterally, cease to rise in the water column, and not 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, and where measured initial-dilution levels would be expected to be much lower than the 133:1 of the modeling.

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

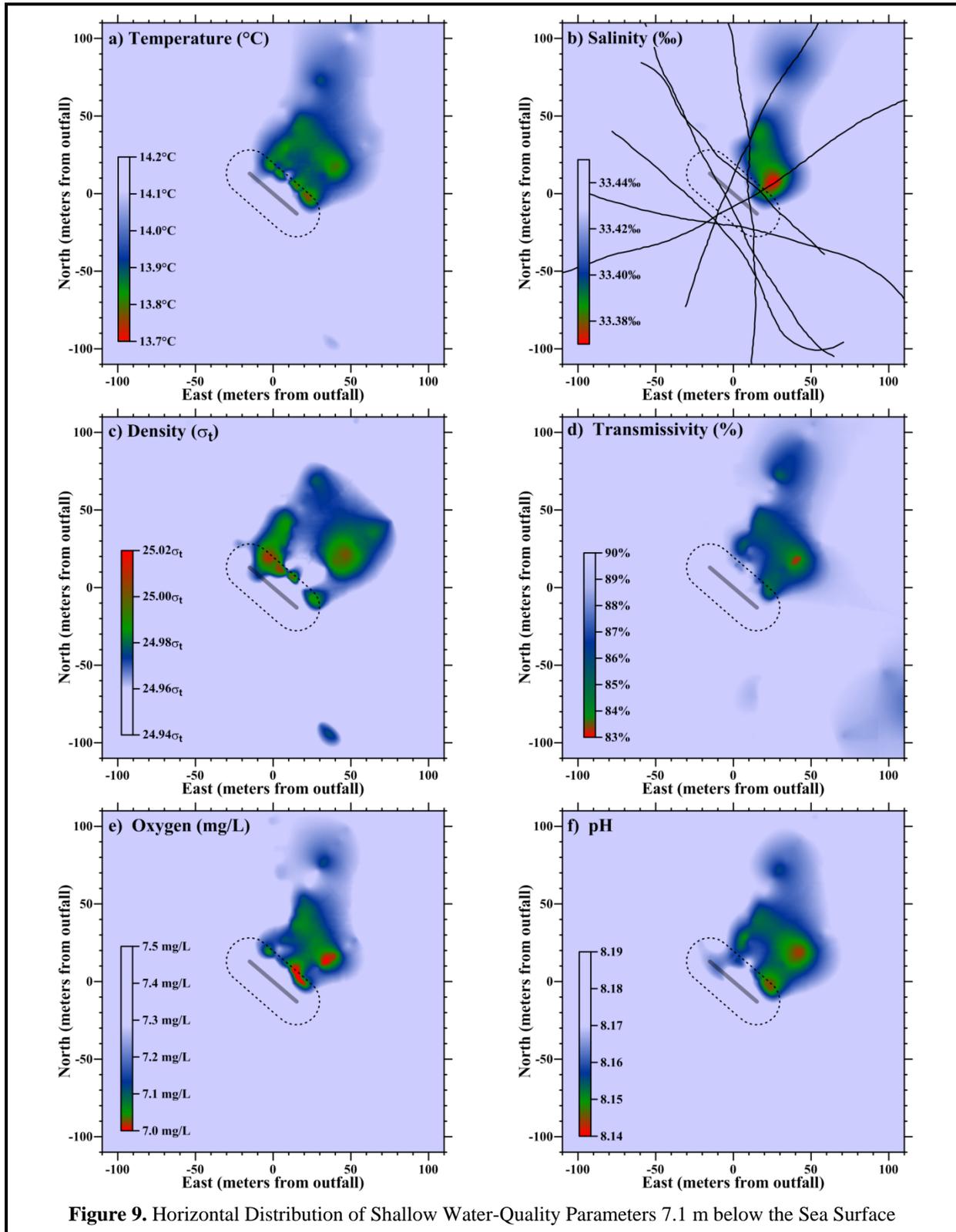


Figure 9. Horizontal Distribution of Shallow Water-Quality Parameters 7.1 m below the Sea Surface

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_o) can be determined from Equation 1.

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

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

By rearranging Equation 1, the actual dilution achieved by the outfall can be determined from measured seawater anomalies. This measured dilution can then be compared with the critical dilution factor determined from modeling. Salinity is an especially useful tracer because it directly reflects the magnitude of ongoing dilution. Wastewater-induced patches of lower salinity were apparent near the seafloor in the vertical profile measured at Station RW4 (Figure 7d), near 10 m in the vertical profiles measured at Stations RW2 and RW3 (green lines in Figure 7bc), and along the northern boundary of the ZID in the tow-survey maps (Figures 8b and 9b). These localized salinity anomalies document mixing processes within the effluent plume shortly after it emanated from a diffuser port, while it rose through the water column and became trapped near its buoyant equilibrium depth below the sea surface, and while it experienced buoyancy oscillations around the equilibrium depth.

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

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

The salinity concentration within MBCSD effluent (C_e)¹⁶ is generally small compared to that of the receiving seawater and, after dilution by more than 100-fold, the salinity of the effluent-seawater mixture is close to ambient salinity. Consequently, to a close approximation, dilution levels are inversely proportional to the amplitude of the salinity anomaly. Thus, lower effluent dilution at a given location within receiving waters is directly mirrored by a larger salinity reduction.

The lowest salinity (33.345‰) measured during the October 2012 survey was recorded within the wastewater ejection jet emanating from a single diffuser port at a depth of 16 m during the vertical

¹⁶ Wastewater samples have an average salinity of 0.995‰.

profiling at Station RW4 (Figure 7d). This measured salinity corresponded to a 0.115‰ reduction below the mean ambient salinity of 33.460‰ that was measured at the same depth level, but well beyond the influence of the discharge. This unusually close-in measurement indicated that wastewater was being diluted 281-fold shortly after discharge, and well before the initial-dilution process was complete. Nevertheless, the measured dilution at that point was more than double the 133:1 critical initial dilution used to establish limits on contaminant concentrations in wastewater after the initial-dilution process was complete.

The next lowest salinity (33.368‰) was only 0.083‰ below the salinity of the surrounding waters, and was recorded at the southern end of the diffuser structure, just northeast of the ZID boundary during the first shallow tow transect (Figure 9b). This salinity anomaly documented the presence of wastewater that had been diluted 390-fold (Figure 10). As discussed previously, the associated negative density anomaly indicated that the initial dilution process was complete at that point, and that the diffuser was diluting wastewater three-times more efficiently than predicted by modeling. This was the case even though the plume had been trapped at a depth greater than the 6.4 m trapping depth assumed in the worst-case initial dilution modeling.

As discussed previously, the vertical profiles at Stations RW2 and RW3 (Figure 7bc) and the deep tow survey (Figure 8b) also delineated a weak salinity anomaly northeast of the diffuser structure. In those cases, however, the corresponding dilution levels were only marginally resolved, and exceeded 600-fold (Figure 11).

The dilution computations demonstrate that, during the October 2012 survey, the outfall was performing better than designed and was rapidly diluting effluent more than 281-fold immediately after discharge, and well before completion of the initial-dilution process. The measured dilution levels throughout the survey easily exceeded the 133:1 critical initial dilution used to establish end-of-pipe permit limitations on contaminant concentrations within wastewater discharged from the MBCSD treatment plant. Consequently, during the October 2012 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.

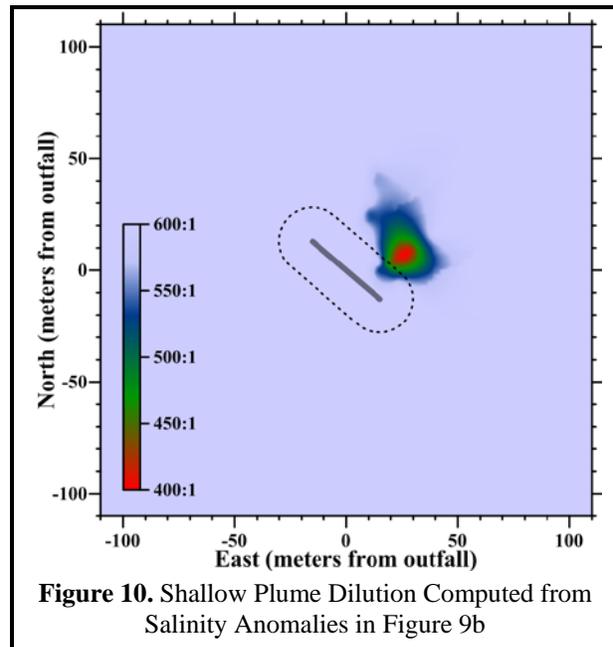


Figure 10. Shallow Plume Dilution Computed from Salinity Anomalies in Figure 9b

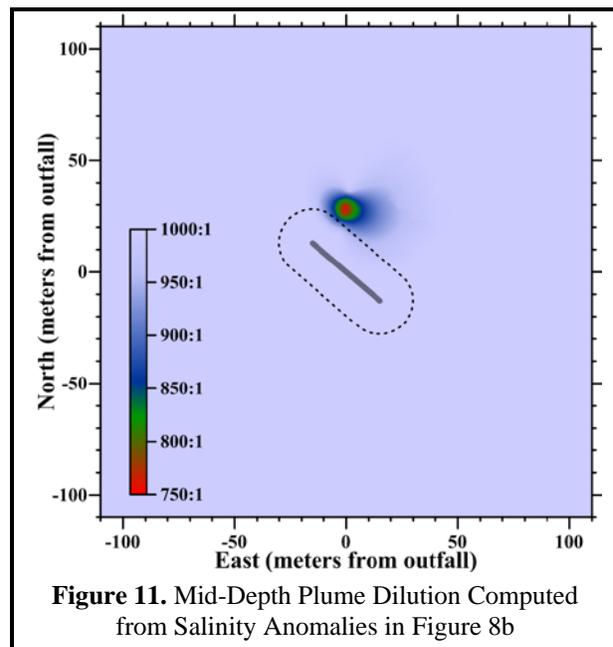


Figure 11. Mid-Depth Plume Dilution Computed from Salinity Anomalies in Figure 8b

COMPLIANCE

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

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

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

The results of these analyses applied to the October 2012 data demonstrate that the MBCSD discharge complied with the NPDES discharge permit. Moreover, although observations within the ZID are not subject to compliance evaluations, they often meet the prescribed limits because actual dilution levels routinely exceed the conservative design specifications assumed in the discharge permit. Thus, the quantitative evaluation described in this section documents an outfall and treatment process that was performing at a high level during the October 2012 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 2012 survey.

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

numerical thresholds that reflect the natural variation in transmissivity, DO, and pH within the receiving waters surrounding the outfall.

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

Screening of Measurements

Evaluating whether any of the 10,001 CTD measurements collected during the October 2012 survey exceeded a permit limit can be a complex process. For example, although apparently significant excursions in an individual seawater property may be related to the presence of wastewater constituents, they may also result from instrumental errors, natural processes, entrainment of ambient bottom waters in the rising effluent plume, statistical uncertainty, ongoing initial mixing within and beyond the ZID, or other anthropogenic influences (e.g., dredging discharges or oil spills).

Because of this complexity, measurements were first screened to determine whether numerical limits on individual seawater properties apply (Table 7). The screening procedure sequentially applies three questions to restrict attention to: 1) the oceanic area where permit provisions apply; 2) changes due to the presence of wastewater particulates; and 3) changes large enough to be reliably detected against the backdrop of natural variation. The measurements that make it through the screening process, if any, can then be compared with Basin-Plan numerical limits and COP allowances. The following subsection provides additional lines-of-evidence that demonstrate compliance with numerical permit limits independent of the screening process. The rationale for evaluating observations for compliance analysis is provided in the following description of the three screening steps.

Table 7. Receiving-Water Measurements Screened for Compliance Evaluation

Topic Addressed	Screening Question	Answer		Parameter
		No	Yes ¹⁷	
Location	1. Was the measurement collected beyond the 15.2-m ZID boundary where modeling assumes that initial dilution is complete?	1,389	8,612	All
Wastewater Constituents	2. Did the beyond-ZID measurement coincide with a quantifiable salinity anomaly (≤550:1 dilution level) indicating the presence of detectable wastewater constituents?	8,556	56	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?	56	0	Temperature
		56	0	Transmissivity
		56	0	DO
		56	0	pH

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

¹⁷ Number of remaining CTD observations of potential compliance interest based on this screening question

initial dilution is completed.” Initial dilution includes the mixing that occurs from the turbulence associated with both the ejection jet, and the buoyant plume’s subsequent rise through the water column.

Although currents often transport the plume beyond the ZID before the initial dilution process is complete, the COP states that dilution estimates shall be based on “*the assumption that no currents, of sufficient strength to influence the initial dilution process, flow across the discharge structure.*” Because of this, the regulatory mixing distance, which is equal to the 15.2-m water depth of the discharge, provides a conservative boundary to screen receiving-water data for subsequent compliance evaluation. Application of this initial screening question to the October 2012 dataset eliminated 1,389 of the original 10,001 receiving-water observations from further consideration because they were collected within the ZID (Table 7, Question 1). The remaining 8,612 observations were carried forward in the compliance analysis.

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

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

As described in the previous section, wastewater-induced reductions in salinity can be used to determine the amount of dilution achieved by initial mixing. Based on statistical analyses of the natural variability in salinity readings measured near the outfall over a five-year period between 2004 and 2008, the smallest reduction in salinity that can be 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 discernible changes in other seawater properties. Eliminating those measurements from further evaluation restricts attention to excursions in temperature, light transmittance, DO, and pH that are potentially related to the presence of wastewater constituents. As shown in Figures 7bc, 8b and 9b, discharge-related salinity anomalies were largely located well beyond the ZID boundary due to the high current speeds that prevailed at the time of the October 2012 survey. Consequently, the prior screening step only eliminated one wastewater-induced anomaly within the ZID, namely, the measurement collected very close to a diffuser port and shortly after discharge (the 16-m measurement in Figure 7d).

Beyond the ZID, 56 measurements had perceptible reductions in salinity that unequivocally identified the presence of dilute wastewater constituents beyond the ZID. The remaining 8,556 observations that were

measured outside the ZID during the October 2012 survey did not have salinity reductions 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 (upward) by the plume. If the measurement does not significantly depart from the natural range in ambient seawater properties at the time of the survey, then it is difficult to ascribe the departure to the presence of wastewater constituents. Thus, quantifying the natural variability around the outfall is necessary for determining whether a particular observation warrants comparison with 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 within-survey salinity variation discussed previously, was also used to establish one-sided 95% confidence bounds on transmissivity (-10.2%), temperature (+0.82°C), DO (-1.38 mg/L), and pH (± 0.094). These were combined with 95th percentiles determined from the October 2012 ambient

Table 8. Compliance Thresholds

Water Quality Property	95% Confidence Bound ¹⁸	95 th Percentile ^{19,20}	Natural Variability Threshold ²¹	COP Allowance ²²	Basin Plan Limit ²³	Extremum ²⁴
Temperature (°C)	0.82	15.11	>15.93	—	—	≤15.27
Transmissivity (%)	-10.2	85.2	<74.9	—	—	≥70.7
DO (mg/L)	-1.38	7.31	<5.93	<5.34	<5.00	≥6.93
pH (minimum)	-0.094	8.109	<8.014	<7.814	<7.000	≥8.065
pH (maximum)	0.094	8.135	>8.229	>8.429	>8.300	≤8.204

¹⁸ The one-sided confidence bound is used to measure the ability to reliably estimate percentiles within surveys as a whole. They were determined from an analysis of the variability in ambient water-quality data collected during 20 quarterly surveys conducted between 2004 and 2008. Although water-quality observations potentially affected by the presence of wastewater constituents were excluded from the analysis, more than 9,200 remaining observations for each of the six seawater properties accurately quantified the inherent uncertainty in defining the range in natural conditions.

¹⁹ 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.”

²⁰ The 95th-percentile quantifies natural variability in seawater properties during the October 2012 survey, and was determined from vertical-profiles data unaffected by the discharge.

²¹ Thresholds represent limits on wastewater-induced changes to receiving-water properties that significantly exceed natural conditions as specified in the discharge permit and COP. They are determined from the sum of columns to the left and are specific to the October 2012 survey. They do not include the COP allowances specified in the column to the right.

²² 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.”

²³ Permit limits P5 and P6 (Table 6) include specific numerical values promulgated in the RWQCB Basin Plan (1994) in addition to changes relative to natural conditions specified in the COP. The Basin Plan upper-bound pH objective for ocean waters is 8.5, but the upper-bound objective 8.3, which applies to most beneficial uses was implemented in the MBCSD discharge permit.

²⁴ Maximum or minimum value measured during this survey

seawater data, to establish time-specific natural-variability thresholds in a manner analogous to COP Appendix VI. The percentiles were determined from October 2012 vertical profile data, excluding measurements potentially affected by the discharge.

Temperature, transmissivity, and DO concentrations associated with the 56 remaining measurements of potential compliance interest all remained within their respective ranges of natural variability (Table 7, Question 3). As such, the screening process unequivocally eliminated all of the CTD measurements collected during the October 2012 survey from further consideration. In fact, all of the documented excursions in these properties were the result of physical processes unrelated to the presence of wastewater constituents, namely, entrainment of near-bottom seawater within the rising effluent plume. During periods when the water column is stratified, such as during the October 2012 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 in the upper water column. As discussed previously, all of the anomalies in seawater properties that coincided with the salinity anomalies in Figures 7, 8 and 9 were consistent with the upward displacement of ambient bottom water rather than with the presence of the effluent plume. Additionally, even if the presence of wastewater particulates had contributed to the measured decreases in DO and pH, their influence would have been well within the natural range 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 2012 survey complied with permit limits P3 through P6 in Table 6. In combination, these lines of evidence provide the “best explanation” of the origin and significance of individual measurements using abductive inference (Suter 2007). This process, which has been used to implement sediment-quality guidelines for California estuaries (SWRCB 2009), emphasizes a pattern of reasoning that accounts for both discrepancies and concurrences among multiple lines of evidence. A best explanation approach serves to limit the uncertainty associated with each individual CTD measurement and provide a more robust compliance assessment. Together, these lines of evidence significantly strengthen the conclusion that the discharge fully complied with the permit at the time of the October 2012 survey.

Insignificant Thermal Impact: Although there are no explicit numerical objectives for discharge-related decreases in temperature, a numerical limit can be established for thermal excursions that is based on the requirement that they not adversely affect beneficial uses (P3 in Table 6). Increases in temperature caused by the discharge of warm wastewater constituents could be deemed to adversely affect beneficial uses if they exceeded the natural temperature range observed at the time of the survey (i.e. exceeded 15.93°C in Table 8). However, none of the 10,001 CTD measurements collected during the October 2012 survey exceeded 15.27°C (last column in Table 8). In fact, as mentioned previously, because the effluent entrained cooler bottom water shortly after discharge, the rising plume actually had a lower temperature than most of the surrounding seawater (Figure 9a).

Insignificant Wastewater Particulate Loads: The discharge of wastewater particulates on 2 October 2012 did not contribute materially to turbidity within the dilute effluent plume. The suspended-solids concentration measured onshore within the effluent prior to discharge from the WWTP was 30 mg/L. After dilution by 281-fold, which was the lowest dilution measured during the survey, the effluent suspended-solids concentration would have the reduced ambient transmissivity by only 2.1%.

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, 43-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 0.022 mg/L after dilution (MRS 2002). In fact, in the absence of tangible BOD influence, wastewater discharge would actually be expected to increase DO within subsurface receiving waters, rather than decrease it. This is because effluent is oxygenated by recent contact with the atmosphere during the treatment process, whereas receiving waters at depth are typically depleted in DO.

COP Allowances: The COP does not explicitly require that wastewater-induced changes remain within the ranges in natural variation listed in the third column of Table 8, even though these ranges were conservatively used in the data screening process described in the previous subsection. For pH, the COP and the discharge permit allow changes up to 0.2 pH units from natural conditions, bringing the minimum allowed pH to 7.814 during the October 2012 survey (fourth column of Table 8). This value is well below the lowest pH measurement of 8.065 recorded during the October 2012 survey (last column of Table 8). Similarly, the lowest DO concentration measured during the survey (6.93 mg/L) was well above both the lower range in natural variation (5.93 mg/L) and the 10% compliance threshold promulgated by the COP (5.34 mg/L).

Natural Variability within and beyond the ZID: Although the permit limits only apply to changes in DO, pH, temperature, and transmissivity beyond the ZID, examination of measurements within the ZID frequently provides additional valuable insight into the potential for adverse effects on water quality beyond the ZID. However, during the October 2012 survey, salinity was the only seawater property that consistently exhibited a perceptible difference from ambient conditions. Regardless of their association with the effluent salinity signature, none of the 10,001 temperature, DO, and pH observations exceeded the thresholds of natural variability specified in Table 8.

Although two isolated transmissivity observations extended below the 74.9% threshold for natural variation during the October 2012 survey (Table 8), this is because the limit is a statistical construct that considers the scatter in measurements of ambient seawater properties around the survey average (95th percentile in Table 8). The construct failed to adequately capture the large natural declines in water clarity within the BNL that was present during the October 2012 survey. Because the BNL was very thin, and because water clarity within the BNL was much lower than in the rest of the water column, the low BNL transmissivities were under-represented in the database. Both of the anomalous measurements were collected just above the seafloor within the BNL. A transmissivity of 70.7% was measured at a depth of 16 m during vertical profiling at Station RW1, and a 73.0% transmissivity was measured at the bottom of the vertical profile at Station RW4 (last page of Table 5, and Figure 7ad). However, neither measurement was associated with a significant salinity anomaly that would indicate the presence of wastewater particulates, and thus both were eliminated from compliance consideration in Step 2 of the screening process.

Natural excursions beyond the 95% confidence bounds are not that unusual because, by the very definition of the 95% hypothesis test, one-in-twenty apparently "significant" excursions will occur by chance alone. Nevertheless, these measurements could not have contributed to a significant reduction of ambient light (Permit Provision P4 in Table 6) because, as discussed previously, due to the presence of the BNL itself, little if any ambient light was reaching the seafloor at the time of the survey.

CONCLUSIONS

The quantitative screening analysis demonstrated that all measurements recorded during the October 2012 survey complied with the receiving-water limitations specified in the NPDES discharge permit. This conclusion was further strengthened by other lines of evidence supporting compliance with the discharge permit. Although the presence of dilute wastewater constituents was delineated from salinity anomalies

within the discharge plume, all the associated seawater properties were within the natural range of variability that prevailed at the time of the survey.

Shortly after discharge, the outfall was achieving dilution levels in excess of 281-fold, which substantially exceeds the critical dilution levels predicted by design modeling. This lowest dilution level was observed within a discharge jet, and well before the initial dilution process was complete. As the plume continued to rise through the water column, it was transported rapidly north-northeastward, quickly achieving dilution levels exceeding 390-fold and becoming ever more diffuse even though the moderate stratification that was present in the water column trapped the plume at depth and inhibited its dilution. Lastly, all of the auxiliary observations collected during the October 2012 survey demonstrated that the discharge complied with the narrative receiving-water limits in the discharge permit and the COP. Together, these observations demonstrated that the treatment process, diffuser structure, and the outfall continue to perform at levels exceeding design expectations.

Although discharge-related changes in seawater properties were observed during the October 2012 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, 482 p.
- Kuehl, S.A., C.A. Nittrouer, M.A. Allison, L. Ercilio, C. Faria, D.A. Dukat, J.M. Jaeger, T.D. Pacioni, A.G. Figueiredo, and E.C. Underkoffler 1996. Sediment deposition, accumulation, and seabed dynamics in an energetic fine-grained coastal environment. *Continental Shelf Research*, 16: 787-816.
- Marine Research Specialists (MRS). 1998. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, Semiannual Benthic Sampling Report, April 1998 Survey. Prepared for the City of Morro Bay, CA. July 1998.
- Marine Research Specialists (MRS). 2002. City of Morro Bay and Cayucos Sanitary District, Supplement to the 2002 Renewal Application For Ocean Discharge Under NPDES Permit No. Prepared for the City of Morro Bay and Cayucos Sanitary District, Morro Bay, CA. July 2002.
- [Marine Research Specialists \(MRS\). 2011. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 2010 Annual Report. Prepared for the City of Morro Bay, California. March 2011.](#)
- [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. 1992a. Waste Discharge Requirements (Order No. 92-67) and Authorization to Discharge under the National Pollutant Discharge Elimination System (Permit No. CA0047881) for City of Morro Bay and Cayucos Sanitary District, San Luis Obispo County.
- Regional Water Quality Control Board (RWQCB) - Central Coast Region and the Environmental Protection Agency (USEPA) – Region IX. 1992b. Monitoring and Reporting Program No. 92-67 for City of Morro Bay and Cayucos Sanitary District, San Luis Obispo County (Permit No. CA0047881).
- Regional Water Quality Control Board (RWQCB) - Central Coast Region and the Environmental Protection Agency (USEPA) – Region IX. 1998a. Waste Discharge Requirements (Order No. 98-15) and National Pollutant Discharge Elimination System (Permit No. CA0047881) for City of Morro Bay and Cayucos Sanitary District, San Luis Obispo County. 11 December 1998.
- Regional Water Quality Control Board (RWQCB) - Central Coast Region and the Environmental Protection Agency (USEPA) – Region IX. 1998b. Monitoring and Reporting Program No. 98-15 for City of Morro Bay and Cayucos Sanitary District, San Luis Obispo County. 11 December 1998.
- Regional Water Quality Control Board (RWQCB) - Central Coast Region and the Environmental Protection Agency (EPA) – Region IX. 2009. Waste Discharge Requirements (Order No. R2-2008-0065) and National Pollutant Discharge Elimination System (Permit No. CA0047881) for the Morro Bay and Cayucos Wastewater Treatment Plant Discharges to the Pacific Ocean, Morro Bay, San Luis Obispo County. Effective 1 March 2009.
- Sea-Bird Electronics, Inc. (SBE) 1989. Calculation of M and B Coefficients for the Sea-Tech Transmissometer. Application Note No. 7, Revised September 1989.
- Sea-Bird Electronics, Inc. (SBE) 1992. SBE 12/22/22/20 Dissolved Oxygen Sensor Calibration and Deployment. Application Note No. 12-1, rev B, Revised April 1992.
- Southern California Bight Field Methods Committee (SCBFMC). 2002. Field Operation Manual for Marine Water-Column, Benthic, and Trawl monitoring in Southern California. Technical Report 259. Southern California Coastal Water Research Project. Westminster, CA. March 2002.
- State Water Resources Control Board (SWRCB). 2005. Water Quality Control Plan, Ocean Waters of California, California Ocean Plan. California Environmental Protection Agency. Effective February 14, 2006.
- State Water Resources Control Board (SWRCB). 2009. Water Quality Control Plan for Enclosed Bays and Estuaries – Part 1 Sediment Quality. California Environmental Protection Agency. Effective August 22, 2009. [sed_qlty_part1.pdf](#) [Accessed 02/26/10].
- Suter II, Glenn, W. 2007. Ecological risk assessment, 2nd edition. U. S. Environmental Protection Agency, Cincinnati, Ohio. CRC.
- Tetra Tech. 1992. Technical Review City of Morro Bay, CA Section 201(h) Application for Modification of Secondary Treatment Requirements for a Discharge into Marine Waters. Prepared for the U.S. Environmental Protection Agency, Region IX, San Francisco, CA by Tetra Tech, Inc., Lafayette, CA. February 1992.