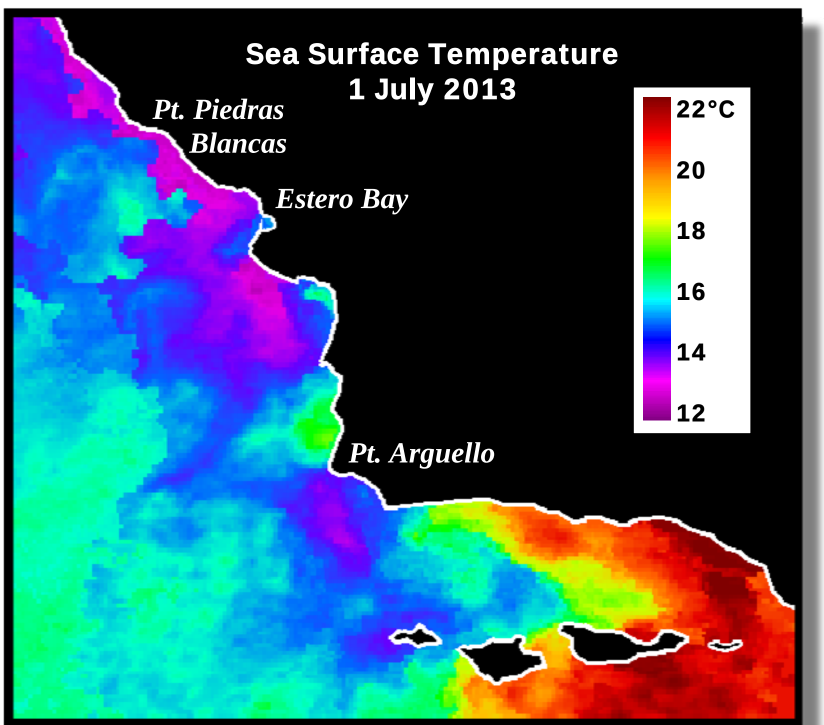
City of Morro Bay and
Cayucos Sanitary District

OFFSHORE MONITORING AND REPORTING PROGRAM

THIRD QUARTER RECEIVING–WATER SURVEY

JULY 2013



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Report to the

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THIRD QUARTER RECEIVING–WATER SURVEY

JULY 2013

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

17 September 2013

Reference: Third Quarter Receiving-Water Survey Report – July 2013

Dear Mr. Keogh:

The attached report presents results from a quarterly receiving-water survey conducted on Wednesday, 10 July 2013. The survey was conducted in accordance with the requirements of the NPDES permit issued to the City and District for discharge of treated wastewater to Estero Bay. The report evaluated compliance with permit limitations and assessed the effectiveness of effluent dispersion. Quantitative analyses of continuous instrumental measurements and qualitative visual observations confirm that the wastewater discharge complied with the receiving-water limitations specified in the permit, and with the objectives of the California Ocean Plan.

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

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

Sincerely,

Bonnie Luke
Program Manager

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

Bruce Keogh

Mr. Bruce Keogh
Wastewater Division Manager
City of Morro Bay

Date September 18, 2013

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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 July 2013 field survey described in this report was the eighteenth 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 10 July 2013. Specifically, this third-quarter survey captured ambient oceanographic conditions along the central California coast during the summer season. The survey's measurements were used to assess the discharge's compliance with the objectives of the California Ocean Plan (COP) and the Central Coast Basin Plan (RWQCB 1994) as promulgated by the receiving-water limitations specified in the NPDES discharge permit.

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

SURVEY SETTING

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

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

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

Figure 1. Location of the Receiving-Water Survey Area

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

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

SAMPLING LOCATIONS

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

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

Another important consideration for compliance evaluation is the ability to determine the actual location of the measurements. Discerning small spatial separations within the compact sampling pattern only became feasible after the advent of Differential Global Positioning Systems (DGPS). The accuracy of traditional navigation systems such as LORAN or standard GPS is typically ±15 m, a span equal to half the total width of the ZID itself. DGPS incorporates a second signal from a fixed, land-based beacon that continuously transmits position errors in standard GPS readings to the DGPS receiver onboard the survey vessel. Real-time correction for these position errors provides an extremely stable and accurate offshore navigational reading with position errors of less than 2 m.

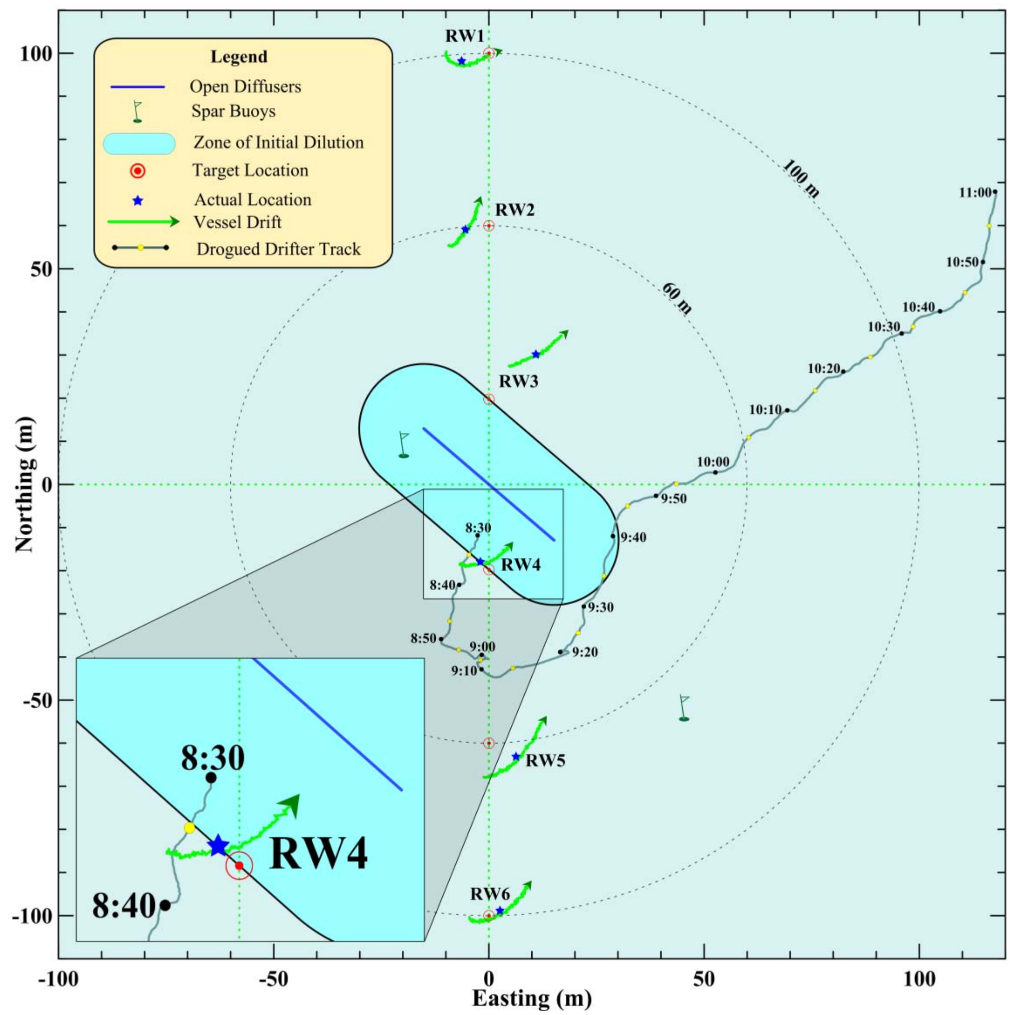

Figure 2. Station Locations

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. Presently, the use of two independent DGPS receivers onboard the survey vessel allows access to two separate land-based beacons for navigational comparison, ensuring extremely accurate and uninterrupted navigational reports.

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

The magnitude of the drift at each of the six stations during the July 2013 survey is apparent from the length of the green tracklines in Figure 2. These tracklines trace the horizontal movement of the CTD as it was lowered to the seafloor at each station. Their lengths and offsets from the target locations reflect the overall station-keeping ability during the July 2013 survey. As seen in Figure 2, drift distance and direction were generally consistent among the six downcasts. During the time it took the CTD to traverse the water column and reach the seafloor, which averaged a 01:24 (one minute 24 seconds), the instrument package moved an average of 13.6 m toward the northeast. This amount of drift is slightly greater than in most recent surveys, where lateral offsets were typically less than 10 m.

Because the target locations for Stations RW3 and RW4 lie along the ZID boundary (red ⊙ symbols in Figure 2), detailed knowledge of the CTD's location during the downcasts at those stations is particularly important in the compliance evaluation. This is because the receiving-water limitations specified in the COP only apply to measurements recorded along or beyond the ZID boundary, where initial mixing is assumed complete. During the July 2013 survey, the CTD traversed the ZID boundary at Station RW4 (green line in the inset in Figure 2). As a result, more than half of the measurements recorded by the CTD at Station RW4 were located inside the ZID and were not subject to the compliance analysis.

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 July 2013 survey also identifies a single sampling location for each station. These average station positions are shown by blue stars in Figure 2, and are listed in Table 2 along with their distances from the diffuser structure.

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

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

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

Station	Time (PDT)		Latitude	Longitude	Closest Approach	
	Downcast	Upcast			Range[5](m)	Bearing[6](ºT)
RW1	8:45:02	8:46:26	35° 23.252' N	120° 52.508' W	85.8	6
RW2	8:52:55	8:54:05	35° 23.231' N	120° 52.508' W	47.3	12
RW3	9:01:14	9:02:34	35° 23.215' N	120° 52.497' W	30.1	41
RW4	9:08:27	9:09:54	35° 23.189' N	120° 52.505' W	**14.9**[7]	221
RW5	9:14:48	9:16:23	35° 23.165' N	120° 52.500' W	50.8	190
RW6	9:26:01	9:27:29	35° 23.146' N	120° 52.502' W	86.7	188

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 July 2013 survey (Figure 2). Modeled after the curtain-shade design of Davis et al. (1982) and drogued at mid-depth (7 m), a drifter has been deployed during each of the quarterly water column surveys conducted over the past decade. In this configuration, the oceanic flow field rather than surface wind dictates the drifter's trajectory, providing a good assessment of the plume's movement after discharge.

The drifter was deployed near the diffuser structure at 8:30 AM, and was recovered at 11:00 AM at a location 145 m from its original release point (Figure 2). The green and black dots in the figure show the drifter's progress at five- and ten-minute intervals throughout the survey. Over the entire course of the survey, the drifter measured an average flow speed of only 1.6 cm/s (0.03 kt). At this relatively slow transport rate, the effluent would have experienced a long, 16-minute residence time within the ZID. However, the speed and direction of oceanic flow changed significantly during the survey. Consequently, the average flow velocity determined from the drifter's release and recovery points does not necessarily reflect the plume transport at any given time during the survey.

Specifically, the drifter data indicates that flow was limited at the beginning of the survey, which took place shortly after low tide (Figure 3). Specifically, during the first 42 minutes of the survey, the drifter traveled a total of only 33 m along a circuitous path to the south (168ºT[8]), with a net transport speed of 1.3 cm/s (0.02 kt).

After 9:20 AM, however, the drifter's transport direction shifted toward the northeast (43ºT) and its speed increased to an average of 2.4 cm/s (0.05 kt). As shown by the uniform spacing between the time stamps in Figure 2, the current speed remained relatively constant during the remainder of the survey. The change in flow velocity coincided with the increasing influence of the flood tide. Normally, flood tides generate flow toward the northeast, which is consistent with the drifter's movement after 9:20 AM.

Typically, the drifter rapidly clears the survey area shortly after deployment. However, the low flow conditions that prevailed during the early part of July 2013 limited drifter transport away from the ZID. As a result, the paths of the drifter and survey vessel intersected during vertical profiling at Station RW5.

[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] The CTD measurements collected in the lower water column at Station RW4 were located within the ZID boundary (refer to the inset in Figure 2).
[8] Direction measured clockwise relative to true (rather than magnetic) north

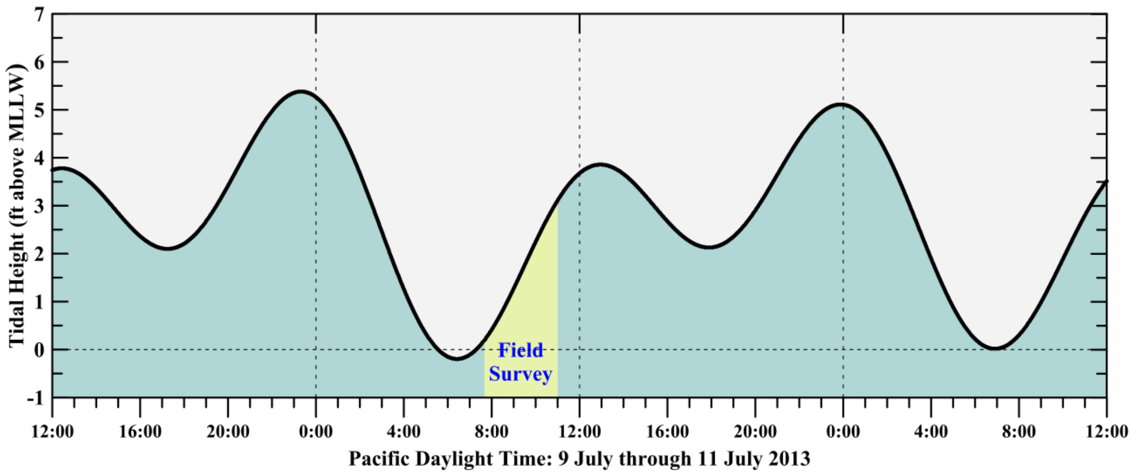

Figure 3. Tidal Level during the July 2013 Survey

The interaction between the drifter and vessel artificially altered the drifter trajectory between 9:10 and 9:20 AM. To avoid entanglement, the drifter was transported by hand along the length of the survey vessel and was redeployed slightly to the east of its original location at 9:17 AM.

Despite the general correspondence between flow direction and tides measured during the July 2013 survey, coastal currents within Estero Bay are often more-strongly influenced by external processes, such as wind-generated upwelling, downwelling, or the passing of offshore eddies propagating along the coastline. For example, in the absence of strong tidal forcing during the first portion of the July survey, it is likely that the initial southward movement of the drifter resulted from upwelling conditions. Upwelling tends to generate an offshore surface flow near the coastline, and the strong upwelling winds that prevailed around the time of the survey (last yellow diamond in Figure 4) probably induced the southerly (offshore) flow that was observed in the upper water column. Upwelling season normally begins sometime during late March and or early April as shown by the positive (blue) upwelling indices in Figure 4. At the onset of upwelling season, there is a transition to more persistent southeastward winds

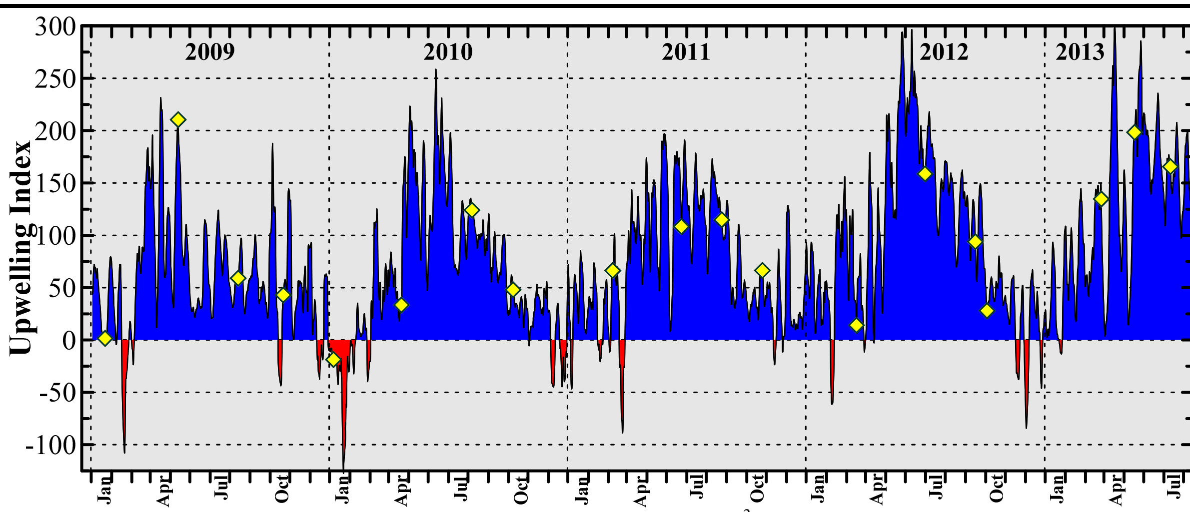

Figure 4. Five-Day Average Upwelling Index (m^3/s/100 m of coastline)

along the central California coast that is initiated by the stabilization of a high-pressure field over the northeastern Pacific Ocean. Clockwise winds around this pressure field drive prevailing northwesterly winds along the central California coast. These winds move warmer surface waters southward and offshore, allowing deep, cool, nutrient-rich waters to move shoreward and upwell near the coast.

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

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

The satellite image on the cover of this report documents the influence of upwelling on sea-surface temperatures at the beginning of July 2013. The image was recorded ten days before the survey, when skies were clear enough for sea-surface temperatures to be measured by infrared sensors on one of NOAA's polar orbiting satellites. The distinctive thermal signature of upwelling is apparent in the cover image, with a band of cooler nearshore sea-surface temperatures shown in purple (<13˚C) along the central coast. As is common during upwelling, these cooler waters are typically transported offshore by the cross-shore flow that occurs at major promontories, such as Point Arguello.

METHODS

The 38 ft F/V *Bonnie Marietta*, owned and operated by Captain Mark Tognazzini of Morro Bay, served as the survey vessel on Wednesday, 10 July 2013. Bonnie Luke of Marine Research Specialists (MRS) supervised deck operations as Chief Scientist, and collected auxiliary measurements of biological, meteorological, and oceanographic conditions. Dr. Douglas Coats, provided data-acquisition and navigational support during the survey. William Skok assisted with deployment and recovery of the CTD and drifter. The collections supervisor for the City of Morro Bay, Mr. Dave Zevely, was also onboard. He observed the survey activities and assisted in the CTD deployment and recovery.

Auxiliary Measurements

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

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

Instrumental Measurements

A Sea Bird Electronics SBE-19plusV2 Seacat CTD instrument package collected measurements of conductivity, temperature, light transmittance, dissolved oxygen (DO), pH, and pressure during the July 2013 survey. The six seawater properties used to assess receiving-water quality in this report were derived from the continuously recorded output from the CTD's probes and sensors. Although pressure-housing limitations confine the CTD to depths less than 680 m (Table 3), this is well beyond the maximum depth of the deepest station in the outfall survey.

Table 3. CTD Specifications

Component	Units	Range	Accuracy	Resolution
Housing (19p-1a; Acetron Plastic)	m	0 to 680	—	—
Pump (SBE 5P)	—	—	—	—
Pressure (19p-2h; Strain-Gauge)	dBar	0 to 680	±1.7	± 0.10
Conductivity	Siemens/m	0 to 9	± 0.0005	± 0.00005
Salinity	‰	0 to 58	± 0.004	± 0.0004
Temperature	ºC	–5 to 35	± 0.005	± 0.0001
Transmissivity (WETLabs C-Star)[9]	%	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, so the maximum theoretical transmission in (pure) water is expected to be 91.3%.

Before the first vertical hydrocast at Station RW1, the CTD was held below the sea surface for eight minutes. Subsequently, the CTD was raised to within 0.5 m of the sea surface and profiling commenced. The CTD was lowered at a continuous rate of speed to the seafloor. Measurements at all six stations were collected during a single deployment of the CTD package by towing it below the water surface while transiting between adjacent stations.

[9] 25-cm path length of red (660 nm) light

At 9:28 AM, following completion of 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 reconfigured CTD was deployed, it was towed around and across the ZID at two separate depths, one at mid-depth below the thermocline and one within the surface mixed layer, in accordance with the monitoring requirements of the NPDES discharge permit (Figure 5).

Initially, the reconfigured CTD package was towed for 34 minutes at an average depth of 3.68 m, and an average speed of 1.73 m/s, passing over, or near the diffuser structure eight times. Subsequently, eight additional passes were made with the CTD at an average depth of 9.69 m. During this 27-minute mid-depth tow, vessel speed averaged 1.67 m/s. At the observed towing speeds and the 4 Hz sampling rate, at least 2.3 CTD measurements were collected for each meter traversed. This complies with the 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.[10]

Quality Control

During the vertical-profiling and horizontal-towing phases of the survey, real-time data were monitored for completeness and range acceptability. Although real-time monitoring indicated the recorded properties were complete and within acceptable coastal seawater ranges,[11] 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 initial portion of the mid-depth tow along Transect D1, and during the latter portion of the mid-depth tows along Transects D1, D3, D4, and D5 (purple dotted lines in Figure 5).

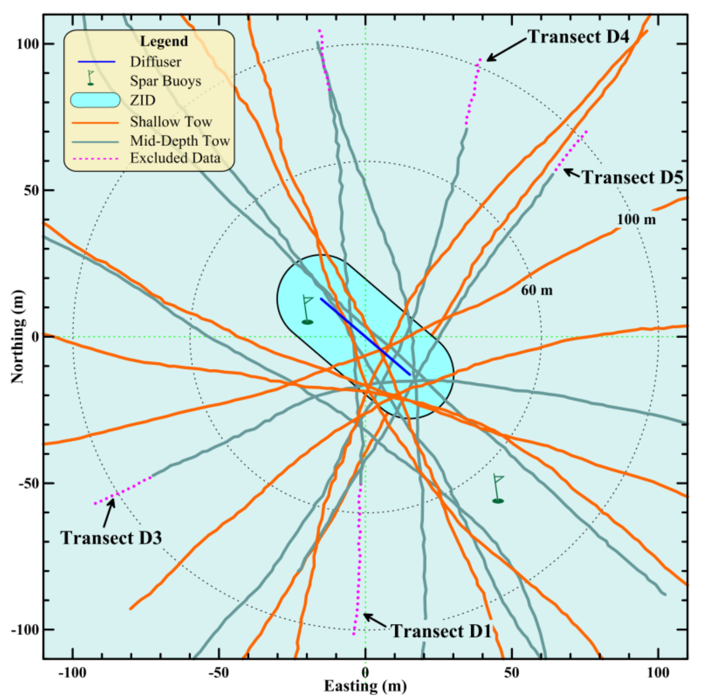

Figure 5. CTD Tracklines during the July 2013 Tow Surveys

Depth offsets are typically induced by changes in vessel speed that are instituted to prevent the CTD from colliding with the seafloor during the execution of the turns used to align the vessel between each

10 Figures 7 and 8 later in this report

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

transect. Because of the complex interaction between turn radius, vessel speed, and CTD depth, the CTD's target depth cannot always be precisely maintained. For example, the CTD was still in the process of descending from the shallow to the mid-depth tow at the beginning of Transect D1, rendering the first 50 m of data from Transect D1 unusable.

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

The exclusion of the small portions of Transects D1, D3, D4, and D6 did not, however, adversely affect the compliance analysis because the remaining data adequately covered the 100-m survey area surrounding the diffuser structure. Specifically, the remaining data, shown by the solid orange and blue-green lines in Figure 5, met the permit monitoring requirement of at least five passes near the diffuser structure at each tow depth.

RESULTS

The third-quarter receiving-water survey was conducted on the morning of Wednesday, 10 July 2013. The receiving-water survey commenced at 8:30 AM with the deployment of the drogued drifter. Over the following two and a half hours, offshore observations and measurements were collected as required by the NPDES monitoring program. The survey ended at 11:01 AM with the retrieval of the drogued drifter. Collection of required visual observations of the sea surface was unencumbered throughout the survey.

Auxiliary Observations

On the morning of 10 July 2013, the sky was overcast, and it remained so throughout the survey. Light but steady northwesterly winds prevailed during the morning. Average wind speeds, calculated over one-minute intervals, ranged from 2.1 kt to 3.8 kt (Table 4). Similarly, peak wind speeds ranged from 3.1 kt to 5.4 kt. The swell was out of the northwest with a significant wave height of between 2 and 3 feet. Air temperatures remained fairly constant throughout the survey, averaging 13.0°C.

Table 4. Standard Meteorological and Oceanographic Observations

Station	Location[12]		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° 23.264' N	120° 52.497' W	109.5	8:47:49	13.6	100	3.0	4.8	NW	2-3 NW	4.0
RW2	35° 23.241' N	120° 52.508' W	65.7	8:55:09	13.4	100	3.7	5.4	NW	2-3 NW	3.5
RW3	35° 23.220' N	120° 52.492' W	42.1	9:03:38	12.5	100	3.8	4.7	NW	2-3 NW	3.5
RW4	35° 23.201' N	120° 52.498' W	8.4	9:11:04	12.9	100	2.1	3.1	NW	2-3 NW	4.0
RW5	35° 23.178' N	120° 52.495' W	26.1	9:17:37	12.5	100	3.9	5.8	NW	2-3 NW	3.5
RW6	35° 23.157' N	120° 52.500' W	64.7	9:28:41	13.3	100	2.3	3.6	NW	2-3 NW	4.0

The 3.5-to-4.0 m Secchi depths recorded during the July 2013 survey reflected the presence of a restricted 8-m euphotic zone that extended only halfway through the water column (Table 4). Thus, although much less turbid seawater was present at depth, the Secchi measurements only captured the low water clarity that was present within the 4-m thick surface mixed layer. The reduced seawater clarity within the mixed

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

layer near the sea surface was caused by increased planktonic densities that arose because of upwelling. During upwelling, nutrients carried upward into the euphotic zone are assimilated by phytoplankton, whose populations increase and, along with their associated zooplanktonic predators, their elevated densities reduce the transmittance of ambient light.

Communication with plant personnel and subsequent review of effluent discharge properties on the day of the survey, confirm that the treatment process was performing nominally at time of the survey. The 1.025 million gallons of effluent discharged on 10 July had a temperature of 22°C, a suspended-solids concentration of 24.8 mg/L, and a pH of 7.6. Biochemical oxygen demand (BOD) measured in an effluent sample collected five days before the survey was 63.4 mg/L while a sample collected three days after the survey was 52 mg/L.

During the July 2013 survey, visual observations demonstrated continued beneficial use of the coastal waters within Estero Bay by both wildlife and recreational users. California brown pelicans (*Pelecanus occidentalis*), Brandt's cormorants (*Phalacrocorax penicillatus*), pelagic cormorants (*Phalacrocorax pelagicus*), and western gulls (*Larus occidentalis*) were all observed transiting the survey area. Additionally, a California sea lion (*Zalophus californianus*) was briefly sighted swimming near the outfall during the course of the survey. Small numbers of pedestrians were visible along Atascadero State beach throughout the survey. Additionally, several recreational and sport-fishing vessels were observed transiting the survey area in pursuit of salmon. One small boat of recreational fishermen remained in the survey area throughout most of the horizontal tow survey.

Instrumental Observations

Data collected during vertical profiling were processed in accordance with standard procedures (SCCWRP 2002), and are collated within 0.5-m depth intervals in Table 5. Data collected during the July 2013 survey reflect the presence of a highly stratified water column indicative of upwelling conditions within Estero Bay (Figure 4).

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

Although winds were mild on the morning of the survey, sustained northwesterly strong winds prevailed both in the days prior to the survey, and during the afternoon on the day of the survey (Figure 4), resulting in intense upwelling. As a result, the vertical profiles exhibit a sharply defined transition between the 5-m deep surface mixed layer and the nearly uniform seawater properties that were present at depths below 9 m (Figure 6a). In particular, all seawater properties except salinity exhibit steadily increasing or decreasing values throughout the subsurface transition zone. Additionally, at all of the stations except Station RW1, the uniform ambient seawater properties in the lower half of the water column were entrained in the rising effluent plume, and caused the vertical transition zone to be compressed (Figure 6bcdef).

Table 5. Vertical Profile Data Collected on 10 July 2013

Depth (m)	Temperature (°C)						Salinity (‰)					
	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6
1.0			14.477	14.522	14.235	14.059			33.800	33.810	33.805	33.794
1.5	14.396	14.031	14.500	14.520	14.387	13.997	33.808	33.792	33.801	33.810	33.810	33.793
2.0	14.368	13.892	14.370	14.462	14.323	14.129	33.811	33.798	33.794	33.806	33.806	33.805
2.5	14.106	13.417	14.203	14.272	13.894	14.053	33.793	33.761	33.783	33.800	33.781	33.800
3.0	13.983	13.176	14.116	13.902	13.718	13.925	33.794	33.753	33.779	33.784	33.781	33.787
3.5	13.809	13.041	13.827	13.616	13.540	13.735	33.787	33.739	33.756	33.771	33.770	33.784
4.0	13.596	12.950	13.538	13.523	13.444	13.497	33.779	33.755	33.741	33.763	33.773	33.766
4.5	13.485	12.933	13.246	13.441	13.179	12.942	33.784	33.760	33.716	33.754	33.727	33.698
5.0	13.353	12.936	13.131	13.325	12.993	12.782	33.783	33.766	33.711	33.740	33.709	33.731
5.5	13.288	12.956	13.020	13.123	12.712	12.821	33.788	33.780	33.697	33.709	33.684	33.757
6.0	13.247	12.968	12.912	13.086	12.640	12.869	33.790	33.789	33.694	33.708	33.708	33.785
6.5	13.215	12.914	12.657	13.026	12.658	12.861	33.790	33.790	33.678	33.704	33.725	33.792
7.0	13.164	12.844	12.607	12.914	12.716	12.823	33.792	33.792	33.688	33.697	33.751	33.792
7.5	13.078	12.680	12.568	12.724	12.756	12.804	33.791	33.788	33.700	33.677	33.763	33.793
8.0	12.988	12.603	12.598	12.636	12.795	12.775	33.791	33.793	33.738	33.684	33.784	33.793
8.5	12.754	12.524	12.618	12.570	12.728	12.720	33.782	33.792	33.752	33.683	33.772	33.792
9.0	12.724	12.497	12.647	12.539	12.601	12.674	33.793	33.795	33.764	33.682	33.775	33.794
9.5	12.568	12.475	12.638	12.509	12.536	12.633	33.787	33.796	33.766	33.686	33.796	33.795
10.0	12.511	12.466	12.562	12.490	12.457	12.569	33.795	33.798	33.791	33.694	33.796	33.795
10.5	12.501	12.449	12.498	12.491	12.423	12.483	33.796	33.798	33.797	33.744	33.798	33.794
11.0	12.477	12.436	12.457	12.496	12.412	12.437	33.797	33.799	33.798	33.786	33.799	33.797
11.5	12.464	12.427	12.440	12.482	12.409	12.427	33.798	33.799	33.799	33.797	33.800	33.798
12.0	12.455	12.422	12.432	12.456	12.404	12.422	33.799	33.800	33.799	33.800	33.800	33.799
12.5	12.438	12.417	12.426	12.428	12.401	12.412	33.799	33.800	33.800	33.800	33.801	33.799
13.0	12.430	12.417	12.422	12.409	12.399	12.403	33.800	33.801	33.800	33.800	33.801	33.799
13.5	12.430	12.409	12.420	12.405	12.391	12.395	33.801	33.801	33.801	33.801	33.800	33.800
14.0	12.436	12.402	12.412	12.403	12.382	12.375	33.801	33.801	33.801	33.801	33.801	33.799
14.5	12.440	12.399	12.407	12.398	12.370	12.361	33.801	33.801	33.801	33.801	33.800	33.799
15.0	12.446	12.400	12.408	12.390	12.365	12.357	33.801	33.800	33.801	33.801	33.800	33.800
15.5	12.455	12.409	12.411	12.387	12.367	12.355	33.801	33.801	33.801	33.801	33.801	33.801
16.0				12.392	12.370	12.358				33.802	33.801	33.801

Table 5. Vertical Profile Data Collected on 10 July 2013 (continued)

Depth (m)	Density (σ_t)						pH					
	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6
1.0			25.159	25.158	25.214	25.243			8.223	8.232	8.208	8.195
1.5	25.183	25.247	25.155	25.158	25.186	25.255	8.214	8.199	8.220	8.231	8.213	8.191
2.0	25.191	25.281	25.177	25.167	25.197	25.237	8.211	8.195	8.220	8.231	8.217	8.193
2.5	25.232	25.349	25.204	25.203	25.267	25.248	8.205	8.190	8.215	8.229	8.213	8.197
3.0	25.259	25.392	25.219	25.267	25.304	25.266	8.194	8.170	8.206	8.212	8.191	8.199
3.5	25.289	25.408	25.261	25.317	25.332	25.302	8.184	8.151	8.199	8.191	8.175	8.183
4.0	25.327	25.438	25.310	25.330	25.353	25.337	8.178	8.130	8.191	8.170	8.165	8.165
4.5	25.353	25.446	25.349	25.339	25.371	25.396	8.168	8.113	8.173	8.156	8.140	8.127
5.0	25.379	25.450	25.369	25.352	25.394	25.453	8.155	8.099	8.146	8.142	8.114	8.090
5.5	25.396	25.457	25.380	25.368	25.430	25.465	8.142	8.091	8.123	8.121	8.086	8.078
6.0	25.406	25.462	25.399	25.375	25.463	25.478	8.128	8.087	8.104	8.105	8.054	8.073
6.5	25.413	25.473	25.437	25.384	25.473	25.484	8.114	8.085	8.086	8.092	8.043	8.073
7.0	25.424	25.488	25.454	25.400	25.482	25.492	8.110	8.081	8.061	8.078	8.037	8.072
7.5	25.441	25.517	25.471	25.423	25.483	25.497	8.103	8.075	8.044	8.060	8.039	8.070
8.0	25.459	25.536	25.495	25.445	25.492	25.502	8.095	8.061	8.035	8.045	8.048	8.067
8.5	25.498	25.551	25.501	25.457	25.495	25.512	8.081	8.048	8.030	8.030	8.053	8.065
9.0	25.512	25.558	25.505	25.462	25.523	25.523	8.065	8.032	8.031	8.019	8.044	8.061
9.5	25.538	25.563	25.508	25.471	25.551	25.531	8.046	8.024	8.031	8.008	8.038	8.055
10.0	25.555	25.566	25.542	25.481	25.567	25.544	8.030	8.018	8.032	8.005	8.027	8.047
10.5	25.558	25.570	25.560	25.520	25.575	25.560	8.019	8.013	8.029	8.004	8.018	8.039
11.0	25.564	25.573	25.568	25.551	25.578	25.571	8.014	8.009	8.024	8.007	8.012	8.028
11.5	25.567	25.575	25.572	25.563	25.579	25.574	8.010	8.005	8.019	8.009	8.007	8.019
12.0	25.570	25.577	25.574	25.570	25.580	25.576	8.007	8.004	8.014	8.010	8.005	8.014
12.5	25.573	25.578	25.576	25.575	25.581	25.577	8.004	8.002	8.010	8.009	8.003	8.010
13.0	25.575	25.578	25.577	25.579	25.582	25.580	8.002	8.001	8.007	8.005	8.002	8.007
13.5	25.575	25.580	25.577	25.580	25.583	25.581	8.000	8.002	8.004	8.003	8.001	8.007
14.0	25.575	25.581	25.579	25.581	25.585	25.585	7.998	8.000	8.004	8.000	8.000	8.005
14.5	25.574	25.582	25.580	25.582	25.587	25.588	7.997	7.998	8.003	7.999	7.997	8.002
15.0	25.573	25.580	25.580	25.584	25.588	25.589	7.996	7.998	8.001	7.997	7.995	7.999
15.5	25.571	25.580	25.580	25.584	25.588	25.590	7.996	7.997	7.999	7.997	7.994	7.996
16.0				25.584	25.587	25.590				7.995	7.990	7.994

Table 5. Vertical Profile Data Collected on 10 July 2013 (continued)

Depth (m)	Dissolved Oxygen (mg/L)						Transmissivity (%)					
	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6
1.0			9.112	9.323	9.215	8.712			72.536	72.009	71.643	72.537
1.5	8.955	8.590	8.987	9.291	9.098	8.828	72.089	72.421	72.730	71.688	72.202	72.463
2.0	8.877	7.748	8.837	9.104	8.604	8.830	72.136	72.925	72.748	71.817	72.232	72.813
2.5	8.730	7.670	8.760	8.597	8.501	8.671	72.382	73.013	72.595	71.754	71.986	72.798
3.0	8.742	7.439	8.333	8.404	8.510	8.314	72.454	74.095	73.062	72.128	72.032	72.521
3.5	8.568	7.460	7.862	8.428	8.326	7.911	72.676	75.382	73.189	72.263	72.286	72.627
4.0	8.404	7.490	7.462	8.295	7.497	6.915	72.748	77.240	73.694	72.177	72.473	73.048
4.5	8.103	7.556	7.426	7.891	7.328	7.197	72.727	78.070	75.044	72.405	73.533	74.353
5.0	8.040	7.623	7.256	7.401	6.757	7.369	72.440	78.485	76.518	73.033	75.042	76.850
5.5	7.907	7.597	7.133	7.500	6.887	7.454	73.401	78.264	77.255	75.212	77.180	79.239
6.0	7.898	7.456	6.702	7.286	7.015	7.371	74.412	78.448	77.754	76.404	79.794	79.735
6.5	7.785	7.321	6.800	7.114	7.162	7.342	74.777	78.476	78.578	76.643	80.353	79.919
7.0	7.718	6.981	6.805	6.798	7.240	7.339	75.983	78.509	79.206	76.992	80.166	79.718
7.5	7.565	6.896	6.942	6.709	7.350	7.300	76.438	79.839	80.441	78.716	80.475	79.984
8.0	7.156	6.662	6.972	6.677	7.106	7.175	77.641	81.166	80.585	79.431	80.187	79.927
8.5	7.229	6.691	7.034	6.646	6.840	7.129	79.026	82.106	81.073	79.993	80.234	80.294
9.0	6.816	6.653	6.938	6.629	6.837	7.012	81.317	82.183	81.254	79.961	80.831	80.841
9.5	6.686	6.651	6.765	6.605	6.610	6.869	82.139	82.146	81.094	80.353	81.281	81.878
10.0	6.709	6.621	6.645	6.707	6.608	6.655	82.151	82.652	81.626	80.516	82.855	82.352
10.5	6.660	6.601	6.608	6.755	6.577	6.618	82.232	82.976	82.472	80.890	84.292	83.025
11.0	6.645	6.615	6.605	6.725	6.588	6.618	82.438	82.988	82.983	81.643	84.511	84.329
11.5	6.634	6.617	6.575	6.662	6.567	6.625	82.650	83.305	83.427	82.466	84.073	84.199
12.0	6.589	6.585	6.563	6.597	6.557	6.589	82.771	83.247	83.469	83.317	83.985	84.116
12.5	6.552	6.577	6.576	6.541	6.557	6.570	82.567	83.555	83.564	83.923	84.096	84.270
13.0	6.561	6.564	6.569	6.548	6.522	6.561	82.660	83.700	83.102	83.837	83.674	84.902
13.5	6.550	6.510	6.550	6.540	6.513	6.532	82.720	83.662	83.137	83.273	83.802	84.452
14.0	6.537	6.533	6.543	6.531	6.474	6.486	82.571	83.578	83.682	82.925	84.133	85.104
14.5	6.531	6.517	6.527	6.519	6.470	6.452	82.323	83.771	83.751	82.624	84.223	85.496
15.0	6.527	6.504	6.526	6.504	6.453	6.446	82.208	83.626	83.584	82.425	83.588	85.488
15.5	6.510	6.502	6.540	6.505	6.443	6.412	81.315	83.477	83.185	82.817	83.226	84.389
16.0				6.509	6.460	6.431				82.142	82.211	83.438

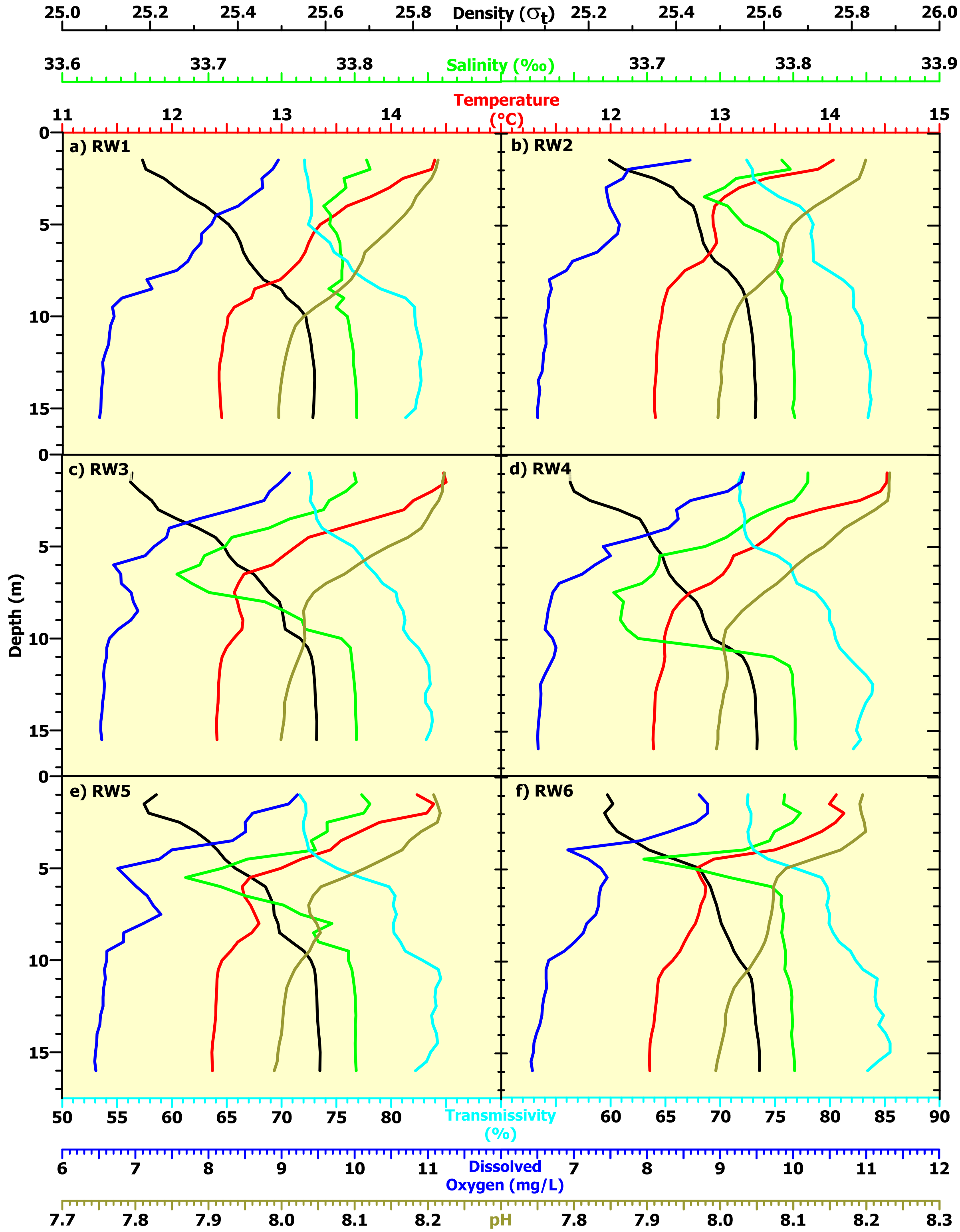

Figure 6. Vertical Profiles of Water-Quality Parameters

Within the transition zone, temperature (red lines), DO (dark blue lines), and pH (olive-colored lines) decrease with depth and reflect the effects of upwelling. These decreases are mirrored by a pycnocline, where density (black lines) steadily increase with depth. These vertical changes reflect the transition to a colder, nutrient-rich but oxygen-poor water mass that originated offshore. This offshore water mass migrated shoreward along the seafloor to replace nearshore surface waters that were driven offshore by the prevailing northwesterly winds. Because this deep, offshore water mass had not been in recent direct contact with the atmosphere, biotic respiration and decomposition had depleted its DO levels (dark blue lines). Additionally, at depth, biotic respiration and decomposition produced carbon dioxide (CO_2), and in its dissolved state, the increased concentration of carbonic acid appears as a concomitant decline in pH (olive-colored lines).

Meanwhile, within the surface mixed layer, nutrient-rich seawater brought to the sea surface by the recent upwelling facilitated phytoplankton blooms that produced oxygen, consumed carbon dioxide (CO_2), and decreased water clarity (light blue lines). The presence of plankton within the surface mixed layer caused a large, 10% decrease in transmissivity at the sea surface compared to mid-depth.

The degree of vertical stratification within the survey area is important for understanding the dynamics of the effluent dispersion at the time of the survey. For example, when the water column is strongly stratified by upwelling, the rising plume can become trapped at depth within the water column, thereby limiting its full capacity for dilution. The stratification present at the time of the July 2013 survey was strong enough to prevent the plume from reaching the sea surface within the survey area. The plume's subsurface signature is apparent as a marked reduction in salinity over a limited depth range at Stations RW2 through RW6 (green lines in Figure 6bcdef).

Additionally, the plume signature was asymmetrical about the diffuser. As expected from their proximity to the discharge, with the thickest and deepest plume signature was captured at the two ZID stations (RW3 and RW4; Figure 6cd). As the plume collapsed around its subsurface equilibrium depth, it spread laterally, creating thinner, low-salinity anomalies at the surrounding stations (RW2, RW5 and RW6; Figure 6bef). The plume signature was slightly weaker to the north and was imperceptible at the northernmost station (RW1; Figure 6a). This north-south asymmetry in plume spreading was consistent with the weak southerly flow that prevailed during the majority of the vertical profiling phase of the survey (*cf.,* the drifter track prior to 9:10 AM in Figure 2). Normally, dilute effluent is rarely observed on both sides of the diffuser structure, but the oceanic current flow at that time was so weak that gravitational spreading processes dominated, allowing the plume to spread upstream as far as Station RW2.

Although the presence of dilute effluent was delineated by sharp reductions in salinity, changes observed in other water properties within the plume were not caused by the presence of wastewater constituents. Instead, they reflect the presence of ambient seawater that was entrained within the rising effluent plume shortly after its discharge near the seafloor. As these deep seawater properties were carried into the upper water column by the rising plume, they expanded the vertical extent of the deep watermass, and vertically compressed the thermocline (*cf.,* the red, blue, black, gold, and light blue lines at Stations RW2 through RW6 with those at Station RW1).

The effluent plume acquires deep watermass properties because it rapidly entrains bottom seawater shortly after discharge. Close to the seafloor, intense mixing is driven by the momentum of the effluent's ejection from the individual diffuser ports. Subsequent turbulent mixing caused by rise of the plume through the water column is less intense, and as a result, the dilute effluent plume tends to retain the ambient seawater properties it acquired at the seafloor. These deep seawater properties become apparent as a signature of the buoyant effluent plume when they are juxtaposed against the ambient seawater characteristics in the upper water column.

It is clear that the anomalies in seawater properties in the upper water column at Stations RW2 through RW6 were caused by entrainment rather than the presence of wastewater constituents because the offsets in their properties were consistent with the vertical differences in ambient seawater. For example, the increased transmissivity, and decreased temperature, pH, and DO measured within the anomalies were comparable to the ambient seawater properties found near the seafloor at all stations (Figure 6).

Additionally, for some properties the offsets were opposite of the changes that would be caused by wastewater particulates. For example, wastewater discharged on the day of the survey was much warmer (22°C) than the receiving seawater (<15°C). Entrainment of cool bottom seawater is the only mechanism that could have created a plume that was cooler than the surrounding ambient seawater within the upper water column. Similarly, the increased transmissivity (water clarity) that coincided with the salinity anomalies could not have been generated by the increased particulate loads associated with effluent. Instead, they reflect the upward transport of the deep watermass, which had higher water clarity than the ambient seawater in the mixed layer (light blue line in at Station RW1 in Figure 6a).

The legacies of entrainment anomalies can be particularly long-lived, remaining apparent within the water column well after completion of the initial dilution process. However, 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. Nevertheless, these anomalies provide useful tracers of the diffuse effluent plume after the completion of the initial dilution process.

The post-ZID disposition of the effluent plume is also apparent in the horizontal maps created from the horizontal tow data (Figures 7 and 8). However, it is important to note that the oceanic flow changed substantially between the time the vertical and horizontal tow surveys were conducted. Specifically, during the majority of the vertical tow portion of the survey, flow speed was minimal, resulting in a drifter track that led slightly toward the south. In contrast, by the time the horizontal tow survey began, the flow had intensified and was directed toward the northeast (*cf.,* the drifter track after 9:20 AM in Figure 2).

During the tow survey, the presence of wastewater constituents, as indicated by slightly reduced salinity, was generally limited to a small area near the diffuser structure (Figures 7b and 8b). These anomalies reflect the characteristics of the plume shortly after discharge. Other, much smaller reductions in salinity, which are apparent as isolated patches of dark blue and green shading in the Figures, probably resulted from random fluctuations in the CTD depth as it was being towed.

As with the vertical profiles, the seawater properties measured near the ZID during the tow survey were consistent with entrainment processes rather than the influence of wastewater constituents. During the July 2013 survey, the presence of a vertically uniform, deep watermass that extended through more than half of the water column above the seafloor resulted in little contrast between the properties of deep seawater entrained within the plume, and the properties of the mid-depth ambient seawater surrounding the plume. Therefore, at mid-depth, fluctuations detected in temperature, transmissivity, DO, and pH were exceedingly small, and generally distributed throughout the survey area rather than only over the diffuser structure (Figure 7adef).

Additionally, at mid-depth, the plume was still undergoing rapid initial dilution as it continued to rise through the water column. This is apparent from the negative density anomaly that was measured in conjunction with the salinity reductions near the diffuser structure (Figure 7c). At that location, the plume was lighter than the surrounding waters, indicating that buoyancy forces were still acting on the plume.

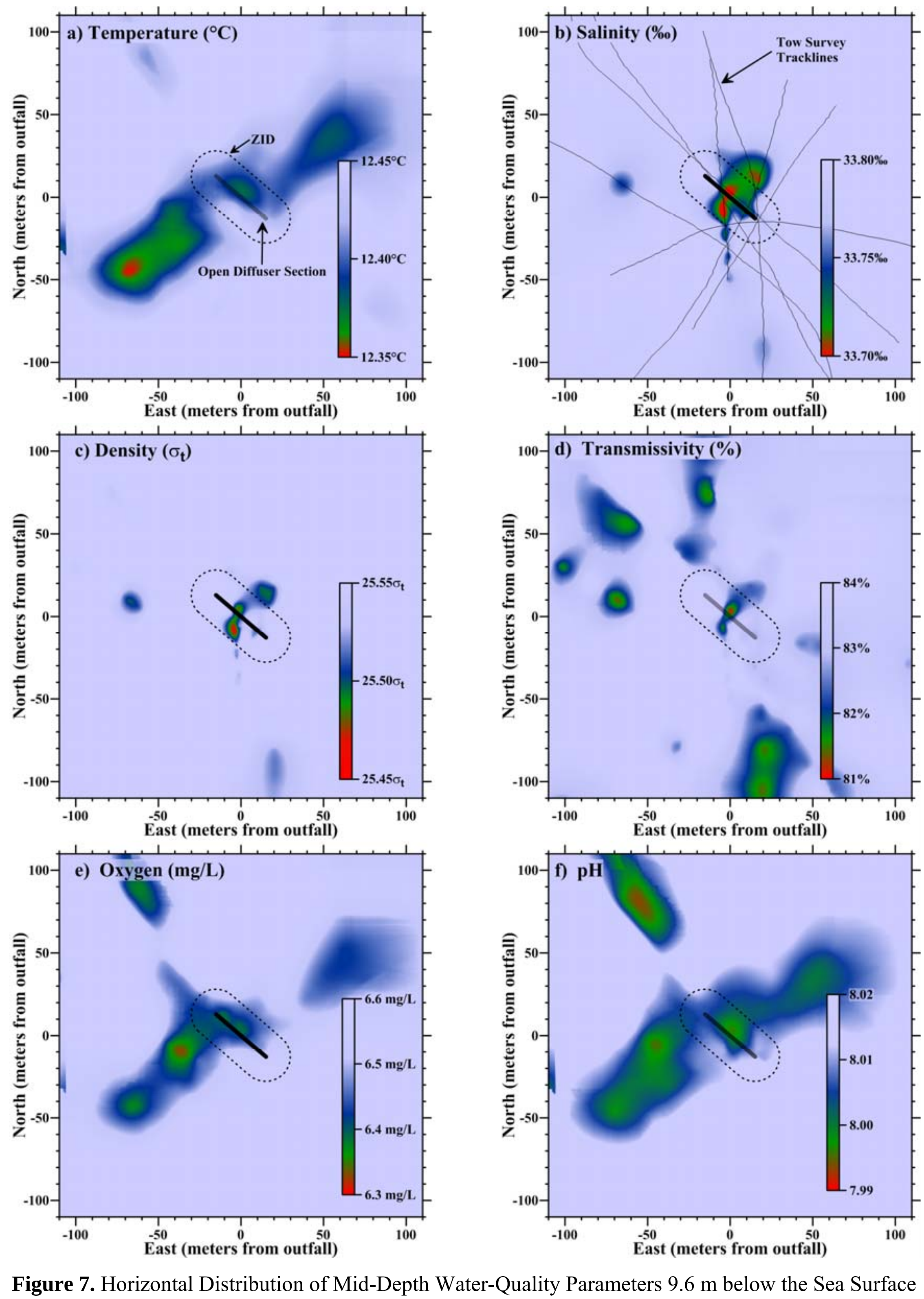

Figure 7. Horizontal Distribution of Mid-Depth Water-Quality Parameters 9.6 m below the Sea Surface

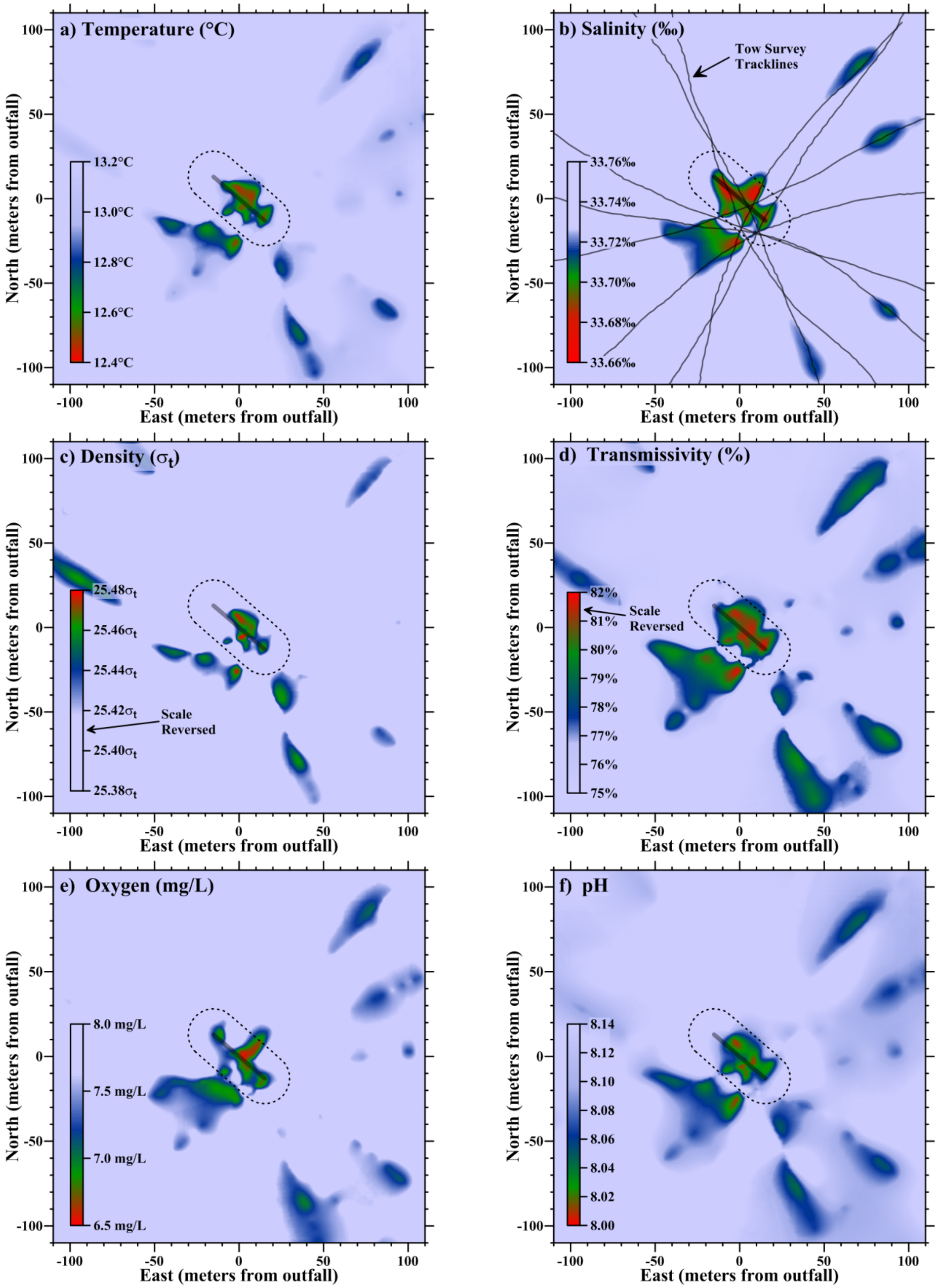

Figure 8. Horizontal Distribution of Shallow Water-Quality Parameters 3.7 m below the Sea Surface

However, as the plume continued to rise within the water column, it eventually reached and extended above its buoyant equilibrium depth to a depth of at least 3.7 m. This is apparent in the shallow-tow data from the positive density anomalies located near the diffuser structure (red areas in Figure 8c). As the plume's momentum dissipated, however, it would be expected to subsequently sink slowly within the water column. Thus, the measurements collected within the ZID during the shallow tow captured the plume during and shortly after the completion of the initial dilution process.

Additionally, in contrast to the deep-tow data, anomalies in other seawater properties measured over the diffuser structure during the shallow tow were clearly generated by the upward displacement of ambient seawater under stratified conditions. For example, the pools of reduced temperature, DO, and pH, and of increased transmissivity, that are apparent in Figure 8adef are consistent with the vertical contrast that existed between the deep and shallow seawater properties at the time of the July 2013 survey. These anomalies exhibit the signature of deep seawater properties that were entrained within the rising plume.

Outfall Performance

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

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

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

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

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

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

By rearranging Equation 1, the actual dilution achieved by the outfall can be determined from measured seawater anomalies. This measured dilution can then be compared with the critical dilution factor determined from modeling. Salinity is an especially useful tracer because it directly reflects the magnitude of ongoing dilution. Wastewater-induced patches of lower salinity were apparent in the vertical profiles measured at all the stations except RW1 (green lines in Figure 6bcdef), and near the diffuser structure in both tow-survey maps (Figures 7b and 8b). These localized salinity anomalies document mixing processes within the effluent plume shortly after it emanated from a diffuser port and rose through the water column.

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

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

The salinity concentration within MBCSD effluent (C_e)[13] is generally small compared to that of the receiving seawater and, after dilution by more than 133-fold, the salinity of the effluent-seawater mixture is close to ambient salinity. Consequently, to a close approximation, dilution levels are inversely proportional to the amplitude of the salinity anomaly. Thus, lower effluent dilution at a given location within receiving waters is directly mirrored by a larger salinity reduction.

Some of the lowest salinities (<33.68‰) measured during the July 2013 survey were recorded within 10 m of the diffuser structure at a depth of 8.2 m during the first transect of the mid-depth tow survey (red shading southwest of the diffuser structure in Figure 7b). This measured salinity corresponds to a 0.12‰ reduction below the mean ambient salinity of 33.80‰ that was measured at the same depth level, but well beyond the influence of the discharge. From Equation 2, that salinity anomaly corresponds to a dilution of 274-fold (Figure 9).

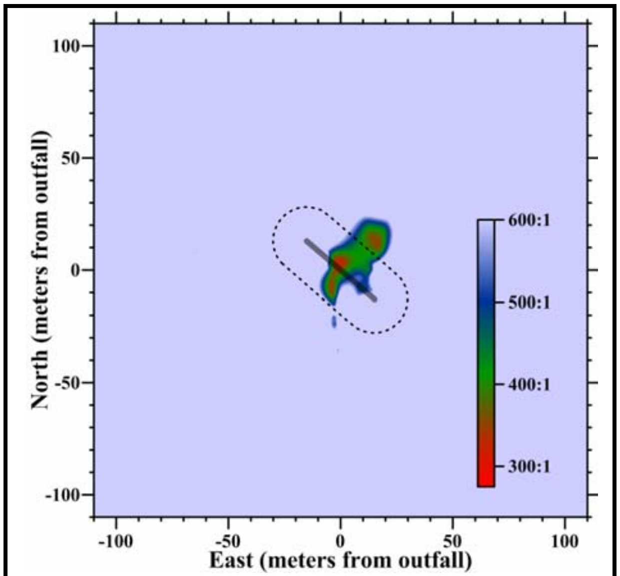

Figure 9. Mid-Depth Plume Dilution Computed from Salinity Anomalies in Figure 7b

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

This is double the 133:1 critical initial dilution used to establish limits on contaminant concentrations in wastewater.

In addition, the lowest dilution was measured at an 8.2-m depth, which was 1.8 m below the 6.4-m trapping depth identified in the modeling that established the 133:1 minimum dilution ratio. According to the conservative modeling results, dilution levels would be expected to be less than 133:1 at that depth level. Instead, the much higher dilutions measured during the mid-depth tow indicate that the diffuser structure was dispersing the effluent far more efficiently than predicted by the modeling, even before the completion of the initial dilution process.

As expected, dilution levels measured during the shallow tow were substantially higher (Figure 10). The lowest dilution was measured 5 m to the northeast of the diffuser structure and demonstrated that effluent had been diluted at least 311-fold at the completion of the initial dilution process when the plume had reached its trapping depth and completed most of its buoyancy-induced mixing.

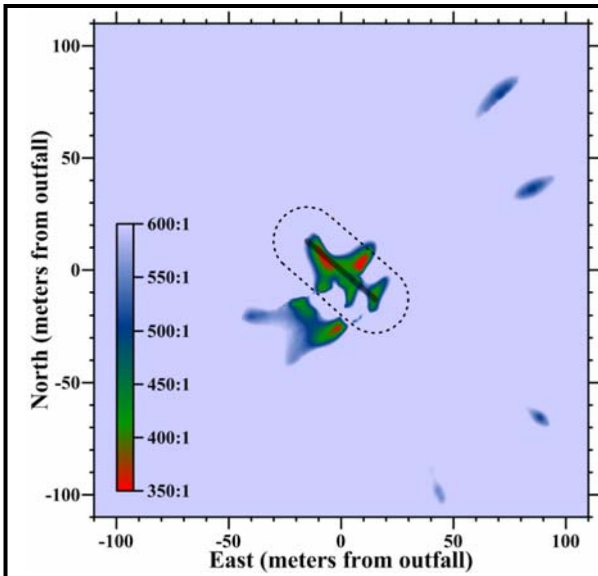

Figure 10. Shallow Plume Dilution Computed from Salinity Anomalies in Figure 8b

The dilution computations demonstrate that, during the July 2013 survey, the outfall was performing better than designed and was rapidly diluting effluent more than 274-fold immediately after discharge, and well before completion of the initial-dilution process. After initial dilution was complete, effluent had been diluted at least 311-fold. The dilution levels measured 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. This demonstrates that, during the July 2013 survey, the COP receiving-water objectives were being met by the limits on chemical concentrations within discharged wastewater that are promulgated by the NPDES discharge permit issued to the MBCSD.

COMPLIANCE

This section evaluates compliance with the water-quality limits listed in the NPDES permit (Table 6). The limitations themselves are based on criteria in the COP, the Central Coast Basin Plan, and other state and federal policies that were designed to protect marine life and beneficial uses of ocean waters. Because the

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

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.

The results of these analyses applied to the July 2013 data demonstrate that the MBCSD discharge complied with the NPDES discharge permit. Moreover, although observations within the ZID are not subject to compliance evaluations, they often met the prescribed limits because actual dilution levels routinely exceeded the conservative design specifications assumed in the discharge permit. Thus, the quantitative evaluation described in this section documents an outfall and treatment process that was performing at a high level during the July 2013 survey.

Permit Provisions

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

The first two receiving-water limits, P1 and P2, rely on qualitative visual observations for compliance evaluation. As described previously, no floating wastewater materials, oil, grease, or discoloration of the sea surface were observed during the July 2013 survey.

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

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

Screening of Measurements

Evaluating whether any of the 10,845 CTD measurements collected during the July 2013 survey exceeded a permit limit can be a complex process. For example, although apparently significant excursions in an individual seawater property may be related to the presence of wastewater constituents, they may also result from instrumental errors, natural processes, entrainment of ambient bottom waters in the rising effluent plume, statistical uncertainty, ongoing initial mixing within and beyond the ZID, or other anthropogenic influences (e.g., dredging discharges or oil spills).

Because of this complexity, measurements were first screened to determine whether numerical limits on individual seawater properties apply (Table 7). The screening procedure sequentially applies three questions to restrict attention to: 1) the oceanic area where permit provisions apply; 2) changes due to the presence of wastewater particulates; and 3) changes large enough to be reliably detected against the backdrop of natural variation. The measurements that make it through the screening process, if any, can 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 No	Answer Yes[14]	*Parameter*
Location	1. Was the measurement collected beyond the 15.2-m ZID boundary where modeling assumes that initial dilution is complete?	*1,481*	*9,364*	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?	*8,855*	*509*	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?	*509*	*0*	Temperature
		509	*0*	Transmissivity
		509	*0*	DO
		509	*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 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 July 2013 dataset eliminated 1,481 of the original 10,845 receiving-water observations from further consideration because they were collected within the ZID (Table 7, Question 1). The remaining 9,364 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

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

in the COP, rather than anomalies that arise from the movement of ambient seawater entrained in the effluent plume. Analyses conducted on quarterly receiving-water surveys over the last decade have demonstrated that the direct influence of dilute wastewater is almost never observed in any seawater property other than salinity, except very close (<1 m) to a diffuser port and within its ejection jet.

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

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

As shown in Figures 7b, 8b, 9, and 10, discharge-related salinity anomalies measured during the survey were restricted to a localized area within and just outside the ZID boundary. Five-hundred-nine measurements had significant reductions in salinity that unequivocally identified the presence of dilute wastewater constituents beyond the ZID. The remaining 8,868 observations that were measured outside the ZID during the July 2013 survey did not have salinity reductions that were greater than the 0.062‰ detection level (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 the numeric permit limits.

A statistical analysis of receiving-water data previously collected around the outfall was used to establish the range in natural conditions surrounding the outfall (first three columns of Table 8). These natural-variability ranges 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 July 2013 ambient seawater data, to establish time-specific natural-variability thresholds in a manner analogous to COP Appendix VI. The percentiles were determined from July 2013 vertical profile data, excluding measurements potentially affected by the discharge.

Table 8. Compliance Thresholds

Water Quality Property	95% Confidence Bound[15]	95th Percentile[16,17]	Natural Variability Threshold[18]	COP Allowance[19]	Basin Plan Limit[20]	Extremum[21]
Temperature (ºC)	0.82	13.93	>14.75	—	—	≤14.61
Transmissivity (%)	-10.2	72.4	<62.2	—	—	≥70.6
DO (mg/L)	-1.38	6.46	<5.08	<4.57	<5.00	≥6.21
pH (minimum)	-0.094	7.996	<7.902	<7.702	<7.000	≥7.986
pH (maximum)	0.094	8.191	>8.285	>8.485	>8.300	≤8.247

Temperature, transmissivity, and DO concentrations associated with the 640 remaining measurements of potential compliance interest were all well within their respective ranges of natural variability (Table 7, Question 3). As such, the screening process unequivocally eliminated all of the CTD measurements collected during the July 2013 survey from further consideration. In fact, all of the documented excursions in these properties were the result of physical processes unrelated to the presence of wastewater constituents, namely, entrainment of near-bottom seawater within the rising effluent plume. During periods when the water column is stratified, such as during the July 2013 survey, ambient seawater properties near the seafloor differ from those within the rest of the water column, and their juxtaposition within the rising plume appears as lateral anomalies within the upper water column.

As discussed previously, all of the anomalies in seawater properties that coincided with the salinity anomalies in Figures 7 and 8 were consistent with the upward displacement of ambient bottom water rather than with the presence of the effluent plume. Additionally, even if the presence of wastewater particulates had contributed to the measured decreases in DO and pH, their influence would still have been well within the natural range of the ambient seawater properties at the time of the survey. Consequently, their influence on water quality would not be considered environmentally significant.

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15 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.

16 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*."

17 The 95th-percentile quantifies natural variability in seawater properties during the July 2013 survey, and was determined from vertical-profiles data unaffected by the discharge.

18 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 July 2013 survey. They do not include the COP allowances specified in the column to the right.

19 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.*"

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

21 Maximum or minimum value measured during this survey

Other Lines of Evidence

Several additional lines of evidence further support the conclusion that all the CTD measurements collected during the July 2013 survey complied with permit limits P3 through P6 in Table 6. In combination, these lines of evidence provide the "best explanation" of the origin and significance of individual measurements using abductive inference (Suter 2007). This process, which has been used to implement sediment-quality guidelines for California estuaries (SWRCB 2009), emphasizes a pattern of reasoning that accounts for both discrepancies and concurrences among multiple lines of evidence. A best explanation approach serves to limit the uncertainty associated with each individual CTD measurement and provide a more robust compliance assessment. Together, these lines of evidence significantly strengthen the conclusion that the discharge fully complied with the permit at the time of the July 2013 survey.

Insignificant Thermal Impact: Although there are no explicit numerical objectives for discharge-related decreases in temperature, a numerical limit can be established for thermal excursions that is based on the requirement that they not adversely affect beneficial uses (P3 in Table 6). Increases in temperature caused by the discharge of warm wastewater constituents could be deemed to adversely affect beneficial uses if they exceeded the natural temperature range observed at the time of the survey (i.e. exceeded 14.75°C in Table 8). However, none of the 10,845 CTD measurements collected during the July 2013 survey exceeded 14.61°C (last column in Table 8). In fact, as mentioned previously, because the effluent entrained cooler bottom water shortly after discharge, the rising plume actually had a lower temperature than most of the surrounding seawater (Figures 7a and 8a).

Limited Ambient Light Penetration: As with temperature, there are no explicit numerical objectives for discharge-related decreases in transmissivity. However, the COP narrative objective (P4) limiting significant reductions in the transmission of natural light can also be translated into a numerical objective. Specifically, because the COP does not specify an allowance beyond natural conditions, the same threshold on ambient transmissivity variations listed in Table 8 can be interpreted to constitute a numerical limit. As with temperature, none of the transmissivity measurements collected during the July 2013 survey ranged below the 62.2% minimum compliance threshold (Table 8).

Moreover, the COP objective for light penetration only applies to a limited number of transmissivity measurements. Because natural light is restricted to the euphotic zone, which extends to approximately twice the Secchi depth, the limit on transmissivity reductions during the July 2013 survey only applied to measurements recorded above 8 m (twice the maximum ambient Secchi depth listed in Table 4). Consequently, even if the discharge of wastewater particulates had caused one or more of the 4,466 transmissivity measurements collected below the euphotic zone to drop below the numeric compliance threshold, it would not have been of regulatory concern because increased turbidity below the euphotic zone does not materially impact the penetration of ambient light.

Directional Offset: Analysis of the directional offset of CTD measurements is useful because wastewater and receiving-seawater properties vary from one another in several predictable ways. For example, upon discharge, wastewater is fresher, warmer, and lighter than the ambient receiving waters of Estero Bay. Under most conditions, wastewater is also more turbid than the receiving waters. As such, the presence of wastewater constituents will reduce the salinity, density, and transmissivity of the receiving seawater (negative offset), while temperature will be increased (positive offset). As discussed previously, the reduced temperatures observed in conjunction with the effluent plume (Figures 7a and 8a) could not have been generated by the presence of warmer wastewater constituents. Similarly, the increased transmissivity observed within the discharge plume during the shallow tow (Figure 8d) could not have been generated by an increased wastewater particulate load. In both cases, the directional offsets were opposite of receiving-water impacts expected from the presence of wastewater constituents.

Insignificant Wastewater Particulate Loads: Another, independent line of evidence demonstrates that the discharge of wastewater particulates could not have contributed materially to turbidity within the dilute effluent plume. The suspended-solids concentration measured onshore, within the effluent, prior to discharge from the WWTP on 10 July 2013 was 24.8 mg/L. After dilution by 274-fold, which was the lowest dilution measured during the survey, the effluent suspended-solids concentration would have the reduced ambient transmissivity by only 0.6%. This small potential decrease in transmissivity would have been overwhelmed by the 7% increase caused by the entrainment and upward displacement of relatively clear ambient seawater near the seafloor (Figure 8d).

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, 63.4-mg/L BOD measured within the plant's effluent several days prior to the survey. That small amount of BOD would have induced a DO depression of no more than 0.022 mg/L after dilution (MRS 2002). In fact, in the absence of tangible BOD influence, wastewater discharge would actually be expected to increase DO within subsurface receiving waters, rather than decrease it. This is because effluent is oxygenated by recent contact with the atmosphere during the treatment process, whereas receiving waters at depth are typically depleted in DO.

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

For pH, the COP and the discharge permit allow changes up to 0.2 pH units from natural conditions, bringing the minimum allowed pH to 7.702 during the July 2013 survey (fourth column of Table 8). This value is well below the lowest pH measurement of 7.986 recorded during the July 2013 survey (last column of Table 8). Similarly, the lowest DO concentration measured during the survey (6.21 mg/L) was well above both the lower range in natural variation (5.08 mg/L) and the 10% compliance threshold promulgated by the COP (4.57 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. However, during the July 2013 survey, salinity was the only seawater property that exhibited a perceptible difference from ambient conditions. Regardless of their association with the effluent salinity signature or their proximity to the diffuser structure, none of the 10,845 temperature, DO, and pH observations exceeded the thresholds of natural variability specified in Table 8.

CONCLUSIONS

The quantitative screening analysis demonstrated that all measurements recorded during the July 2013 survey complied with the receiving-water limitations specified in the NPDES discharge permit. This conclusion was further strengthened by other lines of evidence supporting compliance with the discharge permit. Specifically, although discharge-related changes in seawater properties were observed during the July 2013 survey, the changes were either not of significant magnitude (i.e., they were within the natural range of variability that prevailed at the time of the survey), were measured within the boundary of the ZID where initial mixing is still expected to occur, or were not directly caused by the presence of wastewater constituents within the water column.

Shortly after discharge, the outfall was achieving dilution levels in excess of 274-fold, which substantially exceeds the critical dilution levels predicted by design modeling. This lowest dilution level was observed within the submerged discharge plume, and before the initial dilution process was complete. As the plume continued to rise through the water column, it achieved dilution levels exceeding 311-fold. Lastly, all of the auxiliary observations collected during the July 2013 survey demonstrated that the discharge complied with the narrative receiving-water limits in the discharge permit and the COP. Together, these observations demonstrate that the treatment process, diffuser structure, and the outfall continue to perform at levels exceeding design expectations.

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