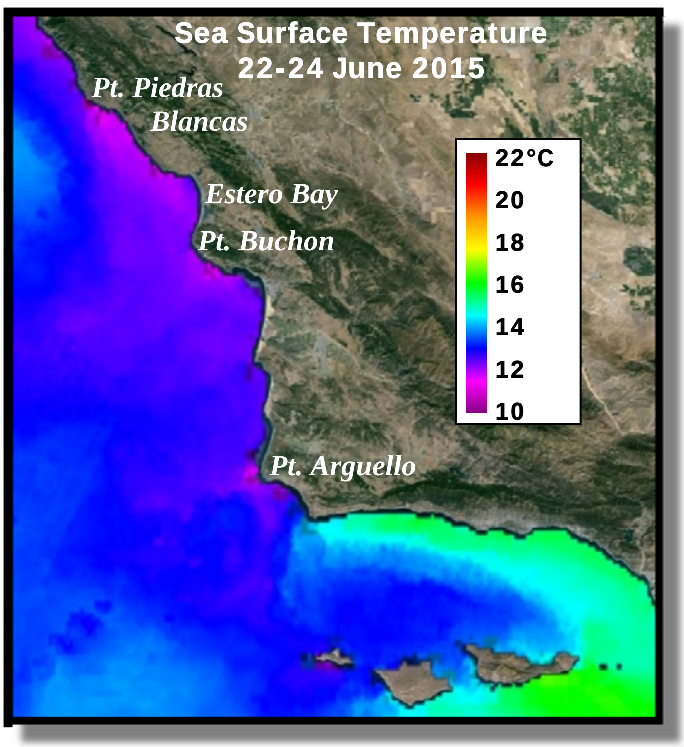
City of Morro Bay and
Cayucos Sanitary District

OFFSHORE MONITORING AND REPORTING PROGRAM

THIRD QUARTER RECEIVING–WATER SURVEY

JULY 2015



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Report to the

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THIRD QUARTER RECEIVING–WATER SURVEY

JULY 2015

Prepared by

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August 2015

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

13 August 2015

Reference: Third Quarter Receiving-Water Survey Report – July 2015

Dear Mr. Keogh:

The attached report presents results from a quarterly receiving-water survey conducted on Wednesday, 1 July 2015. The survey was conducted in accordance with the requirements of the NPDES permit issued to the City and District for discharge of treated wastewater to Estero Bay. The report evaluated compliance with permit limitations and assessed the effectiveness of effluent dispersion. Quantitative analyses of continuous instrumental measurements and qualitative visual observations confirm that the wastewater discharge complied with the receiving-water limitations specified in the permit, and with the objectives of the California Ocean Plan.

The offshore measurements confirmed that the diffuser structure and treatment plant continue 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,

Douglas A. Coats

Douglas A. Coats
Program Manager

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

Bruce Keogh

Mr. Bruce Keogh
Wastewater Division Manager
City of Morro Bay

Date Aug 13, 2015

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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 July 2015 field survey described in this report was the twenty-seventh 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 1 July 2015. 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.

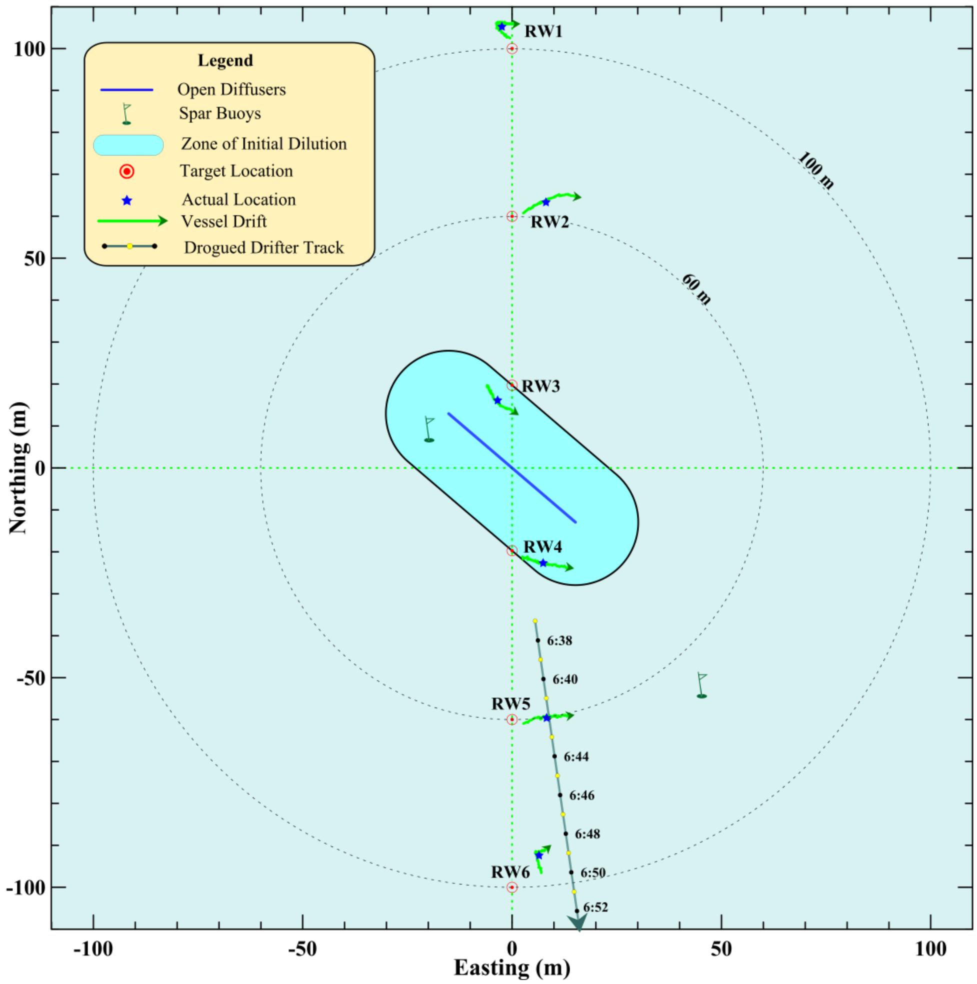

Figure 2. Station Locations

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 downcasts during the July survey were conducted progressing from south to north, beginning with Station RW6. The magnitude of the drift at each of the six stations during the July 2015 survey is apparent from the length of the green tracklines in Figure 2. The tracklines trace the horizontal movement of the CTD as it was lowered to the seafloor at each station. Their lengths and offsets from the target locations reflect the overall station-keeping ability during the July 2015 survey. Although the time it took the CTD to traverse the water column to the seafloor, which averaged 1 min 24 s, was consistent among stations, the lateral distance traversed by the instrument package varied considerably, from as little as 3.4 m at Station RW1, to 13.0 m at Station RW2. At 8.8 m, the average distance among all the stations was comparable to that of most prior surveys. Although the eastward component of CTD movement at most stations was consistent with transport by winds out of the west, variation in the vessel's residual momentum as it approached the stations introduced significant inconsistency among the CTD drift patterns during the downcasts.

Detailed knowledge of the CTD's location during downcasts is important for the interpretation of the water-quality measurements. Because the target locations for Stations RW3 and RW4 lie along the ZID boundary (red ⊙ symbols in Figure 2), knowledge of the CTD's location during the downcasts at those stations is especially important in the compliance evaluation. This is because the receiving-water limitations specified in the COP only apply to measurements recorded along or beyond the ZID boundary, where initial mixing is assumed complete. For example, during the July 2015 survey, all of measurements at both Stations RW3 and RW4 were located within the ZID boundary where receiving-water limitations do not apply. Consequently, the hydrocast data from these stations were excluded from the compliance evaluation.

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

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

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

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

	Time (PDT)				Closest Approach	
Station	**Downcast**	**Upcast**	**Latitude**	**Longitude**	**Range[5] (m)**	**Bearing[6] (ºT)**
RW1	8:14:41	8:16:02	35° 23.256' N	120° 52.506' W	93.2	8
RW2	8:10:32	8:12:05	35° 23.233' N	120° 52.499' W	55.6	25
RW3	8:06:29	8:07:48	35° 23.208' N	120° 52.506' W	**10.1**[7]	41
RW4	8:01:56	8:03:18	35° 23.187' N	120° 52.499' W	**12.4**[7]	219
RW5	7:57:29	7:58:49	35° 23.167' N	120° 52.499' W	47.1	188
RW6	7:53:50	7:55:19	35° 23.149' N	120° 52.500' W	79.8	186

OCEANOGRAPHIC PROCESSES

The trajectory of a satellite-tracked drogued drifter measured oceanic flow throughout the July 2015 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 two decades. In this configuration, the oceanic flow field rather than surface wind dictates the drifter's trajectory, providing a good assessment of the plume's movement after discharge.

During the July 2015 survey, the drifter was deployed near the diffuser structure at 6:37 AM, and was recovered at 8:38 AM at a location 562 m to the south-southeast (163ºT[8]) of its original release point. The direction and speed of the drifter was relatively uniform throughout its deployment. The rapid but steady flow speed is reflected by the uniform spacing between the dots in the drifter track of Figure 2, which show the drifter's progress at one-minute intervals. The drifter's average speed of 7.7 cm/s[9] was slightly greater than flow speeds measured during most prior surveys. At the transport rate measured during the July 2015 survey, effluent would have experienced only a brief, 3.3-minute residence time within the ZID.

The southward component of flow measured by the drifter was inconsistent with the flood tide that prevailed during the July 2015 survey (Figure 3). Flood tides normally induce a weak northward (onshore) flow in the survey region. However, flow within the survey area is often also affected by other processes, such as wind-generated upwelling, downwelling, or offshore eddies migrating past Estero Bay. These external flow influences are apparent in the complexity of sea-surface temperatures depicted in the

[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] All of the CTD measurements collected at Stations RW3 and RW4 were located within the ZID boundary.
[8] Direction measured clockwise relative to true (rather than magnetic) north
[9] 0.1502 kt

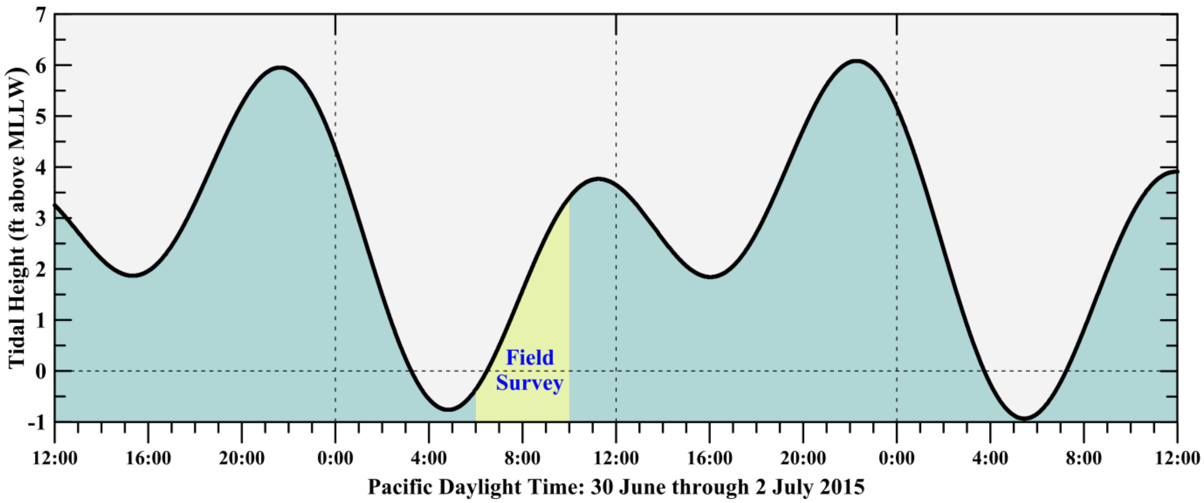

Figure 3. Tidal Level during the July 2015 Survey

satellite image on the cover of this report. The cover image is a composite of sea-surface temperatures measured by infrared sensors on NOAA's polar orbiting satellites from 22 thru 24 June, when skies were clear enough for measurements to be collected in the region.

The satellite image reveals a pattern of sea surface temperatures indicative of recent upwelling processes within the region where cooler, upwelled water is visually apparent along the south-central California coastline (purple and dark blue shading). As is typical of upwelling, jets of cold (light purple) water can be seen extending offshore at major promontories, such as Point Buchon and Arguello. Some of this upwelled water (dark blue) can be seen extending into the southern Santa Barbara Channel, where a counterclockwise circulation within the Channel created a 3°C north-south contrast.

This pattern of sea-surface temperatures demonstrates that a strong upwelling event occurred immediately prior to the survey. The onset of upwelling-dominated processes normally begins with a rapid intensification of southeastward-directed winds along the central coast during late March and or early April as shown by the positive (blue) upwelling indices in Figure 4. This transition to more persistent southeastward winds is initiated by the stabilization of a high-pressure field over the northeastern Pacific Ocean. Clockwise winds around this pressure field drive prevailing northwesterly winds along the central California coast. These winds move warmer surface waters southwestward and offshore, allowing deep, cool, nutrient-rich waters to move shoreward and upwell near the coast.

The nutrient-rich seawater that is brought to the sea surface near the coast by upwelling enables phytoplanktonic blooms that are the foundation of the productive marine fishery found along the central California coast. The cross-shore flow associated with persistent upwelling conditions also enhances vertical stratification of the water column. The presence of denser cooler water at depth produces a shallow thermocline (<10 m) that is commonly maintained throughout summer and into fall. As a result, some degree of upwelling is almost always present during offshore surveys (yellow diamonds in Figure 4). Upwelling winds were relatively strong immediately prior to the June and July 2015 surveys (last two yellow diamonds in Figure 4). The sustained afternoon upwelling winds immediately prior to the surveys generated a pattern of cross-shore counter-flows at the sea surface and seafloor, and as a result, the water column was well stratified at the time of the surveys.

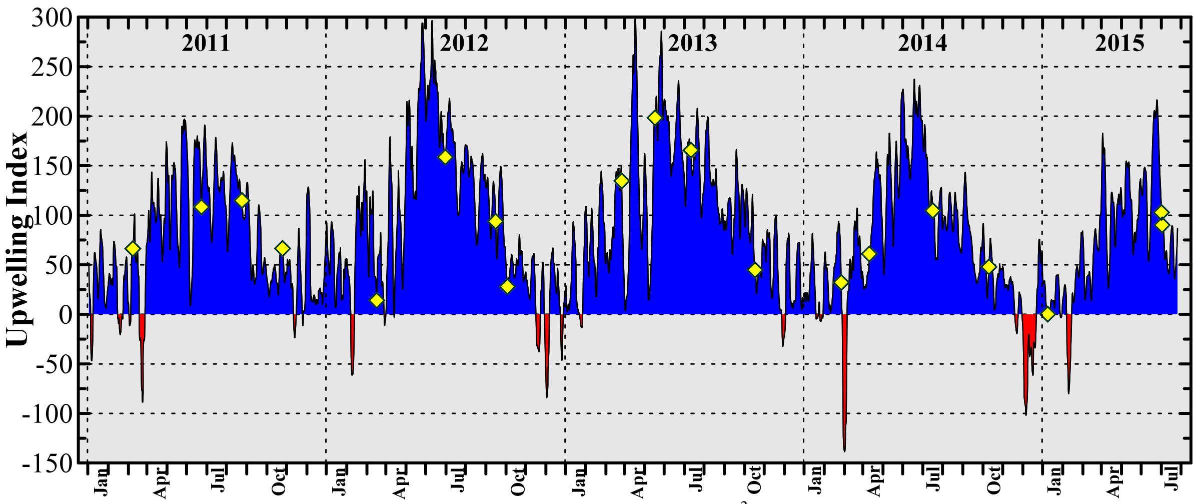

Figure 4. Five-Day Average Upwelling Index ($m^3/s/100$ m of coastline)

This contrasts with the flow patterns observed during winter surveys, when upwelling is typically weak, and occasionally downwelling events, indicated by the negative (red shaded) indices, occur 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.

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, 1 July 2015. Dr. Douglas Coats of Marine Research Specialists (MRS) supervised deck operations as Chief Scientist, collected auxiliary measurements of biological, meteorological, and oceanographic conditions, and provided data-acquisition and navigational support during the survey. Mr. Marc Tognazzini served as deckhand and assisted with the deployment and recovery of the CTD and drifter.

Auxiliary Measurements

Auxiliary measurements and observations were collected at each of the six stations where vertical hydrocasts were conducted. 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 suspended particulates generated by 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 2015 survey. The six seawater properties used to assess receiving-water quality in this report were derived from the continuously recorded output from the CTD's probes and sensors. Although pressure-housing limitations confine the CTD to depths less than 680 m (Table 3), this is well beyond the maximum depth of the deepest station in the outfall survey.

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)[10]	%	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 beginning the shallow tow survey at 6:48 AM, the CTD was deployed beneath the sea surface for 3.5 minutes as the vessel was positioned to begin the first transect. Prior to deployment, the CTD package had been configured for horizontal towing with forward-looking probes. The protective cage around the CTD was fitted with a horizontal stabilizer wing and a depth-suppression weight was added to the towline to achieve nearly constant-depth tows.

[10] 25-cm path length of red (660 nm) light

Eight transects of shallow data were collected at an average depth of 3.3 m, and an average speed of 1.59 m/s over the span of 25 minutes (Figure 5). Subsequently, eight additional passes were made with the CTD at an average depth of 6.4 m. During this 26-minute mid-depth tow, vessel speed averaged 1.64 m/s. At the observed towing speeds and the 4 Hz sampling rate, at least 2.4 CTD measurements were collected for each meter traversed. This complies with the NPDES discharge permit requirement for minimum horizontal resolution of at least one sample per meter during at least five passes around and across the ZID at two separate depths, one within the surface mixed layer and one at mid-depth within the thermocline.

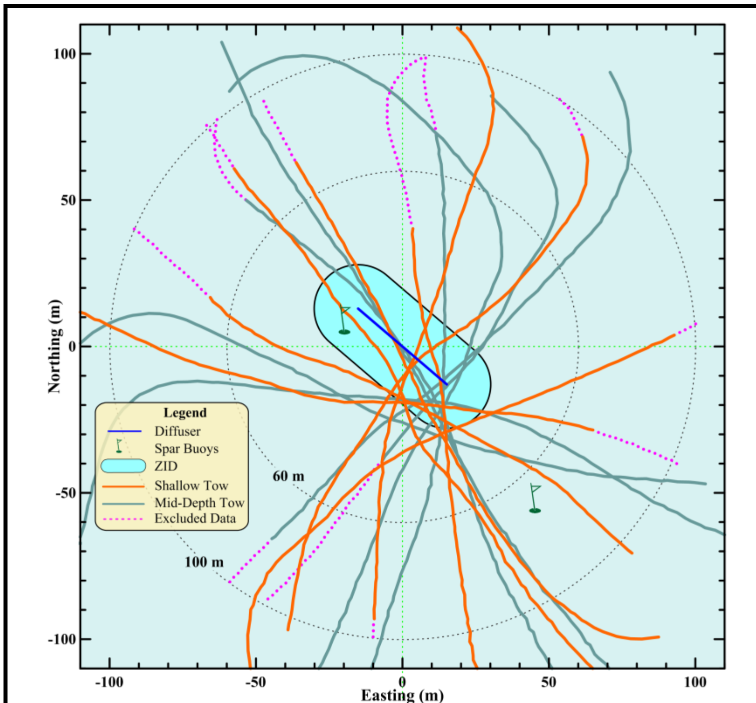

Figure 5. CTD Tracklines during the July 2015 Tow Surveys

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.[11]

At 7:44AM, following completion of the last mid-depth tow, the CTD package was brought aboard the survey vessel and reconfigured for vertical profiling. The CTD was redeployed at 7:53 AM, and was held beneath the surface for one minute as the vessel was repositioned over Station RW6. 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.

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,[12] subsequent post-processing revealed several events that impacted portions of the data, resulting in the adjustment or exclusion of these data prior to initiating the compliance analysis. For example, review of the tow data revealed that the CTD was tracking at a slightly different depth (>1 m offset) during the initial and final portions of several of the tows (purple dotted lines in Figure 5). 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

[11] Figures 7 and 8 later in this report

[12] 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.

realign the vessel between each transect. Because of the complex interaction between turn radius, vessel speed, and CTD depth, the CTD's target depth cannot always be precisely maintained at these times.

Because the discharge-related anomalies used in the compliance analysis are identified by comparing the amplitudes of measurements acquired at the same depth level, the ability to resolve anomalies with statistical certainty is compromised when data from different depth levels are combined in the horizontal maps. This is particularly true when the water column is highly stratified, as was the case during the July 2015 survey. Nevertheless, exclusion of portions of the tow surveys did not adversely affect the compliance analysis. The remaining data adequately covered the 100-m survey area surrounding the diffuser structure, and the eliminated data were largely located well away from the discharge plume.

In addition to the depth-induced fluctuations during the tow surveys, salinity data collected during the initial (shallow) portion of the vertical profile at Station RW6 may have been impacted by the unusually brief one-minute soak time after the CTD was deployed. Normally, the CTD is left to equilibrate for several minutes after it is re-introduced into seawater, and before vertical profiling begins. However, while the CTD was equilibrating during the July survey, the vessel drifted directly over the Station-RW6 target position and the hydrocast was quickly initiated to capture data proximal to the target. The resulting inadvertently brief soak time caused a series of high salinity spikes above 5 m,[13] but did not appear to affect the data from the other sensors. Because salinity increases are opposite of changes expected from the presence of a low-salinity wastewater constituents, the high-salinity spikes at Station RW6 did not directly affect the compliance assessment. However, because these spikes would artificially increase ambient salinity variability, they were excluded from the determinations of natural variability at the time of the survey.[14]

RESULTS

The third-quarter receiving-water survey was conducted on the morning of Wednesday, 1 July 2015. The receiving-water survey commenced at 6:37 AM with the deployment of the drogued drifter. Over the following two hours, offshore observations and measurements were collected as required by the NPDES monitoring program. The survey ended at 8:38 AM with the retrieval of the drogued drifter. Collection of the required visual observations of the sea surface was unencumbered throughout the survey.

Auxiliary Observations

On the morning of 1 July 2015, skies were overcast, with a light westerly breeze.[15] Average wind speeds, calculated over one-minute intervals, ranged from 3.9 kt to 6.0 kt (Table 4). Similarly, peak wind speeds ranged from 5.3 kt to 7.7 kt. Winds took on a southerly component as the collection of the auxiliary observations progressed from north to south. The swell was consistently out of the northwest with a significant wave height of one-to-two feet. Air temperatures remained nearly constant throughout the survey, averaging 14.4°C, and were comparable to the highest sea-surface temperature (14.35°C) measured during vertical profiling.

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[13] Refer to the green line in Figure 6f later in this report.
[14] Refer to the "*Natural Variability Threshold*" in Table 8 later in this report.
[15] Beaufort Scale

Table 4. Standard Meteorological and Oceanographic Observations

Station	Location[16] Latitude	Location[16] Longitude	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)
RW1	35° 23.254' N	120° 52.504' W	89.9	8:21:46	14.4	70	4.6	5.3	W	1-2 NW	4.5
RW2	35° 23.232' N	120° 52.503' W	50.8	8:24:20	14.7	70	5.3	6.1	W	1-2 NW	4.5
RW3	35° 23.210' N	120° 52.506' W	14.0	8:27:00	13.9	70	5.7	7.7	W	1-2 NW	4.5
RW4	35° 23.194' N	120° 52.503' W	5.5	8:29:20	14.3	70	6.0	6.8	SW	1-2 NW	4.5
RW5	35° 23.163' N	120° 52.501' W	54.8	8:31:41	15.0	70	3.9	5.6	SW	1-2 NW	4.5
RW6	35° 23.146' N	120° 52.502' W	86.3	8:34:13	14.0	70	4.7	5.4	SW	1-2 NW	4.5

The 4.5 m Secchi depths recorded during the July 2015 survey reflected the presence of a 9-m euphotic zone that was projected to extend through a little more than half of the water column (Table 4). In reality, the reduced water clarity was largely restricted to the shallow mixed layer that extended to the base of a sharp, shallow thermocline at 4 m. 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 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.

Because the measured Secchi depth was the same at all the stations, near-surface water clarity was not impacted by the presence of the plume, at least at the locations where the measurements were collected. If anything, shallow measurements within the plume would be expected to increase Secchi depth because the rising effluent plume carried relatively clear deeper water into the shallow more-turbid mixed layer. Consistent with the invariant Secchi depths, there was no visual evidence of the plume signature at the sea surface at any time during the survey. Similarly, no evidence of floating particulates, oil sheens, or any discoloration of the sea surface was visually apparent that might be related to the presence of wastewater constituents.

Communication with plant personnel and subsequent review of effluent discharge properties on the day of the survey, confirmed that the treatment process was performing well at time of the survey. The 1.013 million gallons of effluent discharged on 1 July had a temperature of 22°C, a suspended-solids concentration of 33.8 mg/L, and a pH of 7.6. The biochemical oxygen demand (BOD) of the effluent measured two days after the survey on 3 July was 42.6 mg/L.

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 2015 survey reflect the presence of a highly stratified water column indicative of upwelling conditions within Estero Bay (Figure 6). 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 limited vertical extent. Under highly stratified conditions, isotherms crowd together to form a density

[16] 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.

Table 5. Vertical Profile Data Collected on 1 July 2015

Depth (m)	Temperature (°C)						Salinity (‰)					
	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6
0.5	14.348	14.080		13.913			33.650	33.621		33.611		
1.0	13.900	14.082	13.725	13.869	13.490	13.339	33.595	33.597	33.586	33.598	33.581	33.615
1.5	13.397	13.850	13.232	13.697	13.286	13.218	33.568	33.586	33.563	33.586	33.567	33.662
2.0	12.907	13.634	12.940	12.871	13.062	13.155	33.550	33.575	33.553	33.538	33.561	33.677
2.5	12.550	13.173	12.697	12.458	12.897	13.101	33.540	33.554	33.543	33.544	33.557	33.604
3.0	12.371	12.663	12.504	12.251	12.696	12.993	33.543	33.535	33.545	33.543	33.554	33.628
3.5	12.222	12.334	12.258	12.069	12.330	12.608	33.545	33.542	33.541	33.542	33.538	33.717
4.0	12.097	12.134	12.155	11.954	12.277	12.418	33.549	33.544	33.549	33.548	33.552	33.615
4.5	12.013	12.049	12.103	11.908	12.207	12.074	33.553	33.550	33.551	33.554	33.552	33.524
5.0	11.923	11.947	12.033	11.864	12.013	11.998	33.554	33.554	33.553	33.558	33.547	33.553
5.5	11.897	11.896	11.938	11.817	11.899	11.852	33.559	33.558	33.555	33.559	33.556	33.550
6.0	11.861	11.876	11.910	11.806	11.753	11.765	33.562	33.562	33.559	33.564	33.552	33.556
6.5	11.785	11.851	11.890	11.773	11.632	11.635	33.563	33.564	33.562	33.565	33.545	33.545
7.0	11.695	11.818	11.856	11.734	11.550	11.530	33.564	33.566	33.563	33.566	33.543	33.532
7.5	11.626	11.706	11.824	11.675	11.537	11.477	33.567	33.564	33.565	33.567	33.545	33.528
8.0	11.593	11.630	11.726	11.650	11.495	11.437	33.570	33.568	33.563	33.568	33.540	33.525
8.5	11.570	11.588	11.617	11.633	11.425	11.424	33.571	33.571	33.566	33.570	33.531	33.526
9.0	11.528	11.563	11.580	11.612	11.394	11.406	33.572	33.572	33.570	33.571	33.534	33.533
9.5	11.492	11.550	11.566	11.594	11.398	11.390	33.574	33.574	33.572	33.572	33.545	33.540
10.0	11.439	11.484	11.501	11.567	11.378	11.391	33.576	33.574	33.571	33.573	33.550	33.541
10.5	11.428	11.425	11.433	11.511	11.392	11.374	33.579	33.576	33.570	33.572	33.552	33.548
11.0	11.416	11.414	11.391	11.452	11.402	11.372	33.578	33.579	33.573	33.573	33.555	33.555
11.5	11.392	11.389	11.379	11.415	11.368	11.368	33.583	33.582	33.576	33.573	33.577	33.553
12.0	11.362	11.365	11.364	11.402	11.351	11.366	33.584	33.584	33.580	33.576	33.585	33.549
12.5	11.321	11.345	11.345	11.393	11.341	11.374	33.586	33.585	33.583	33.578	33.586	33.552
13.0	11.305	11.320	11.330	11.390	11.325	11.381	33.587	33.587	33.586	33.580	33.587	33.564
13.5	11.285	11.302	11.321	11.377	11.268	11.359	33.589	33.588	33.587	33.582	33.588	33.573
14.0	11.270	11.274	11.305	11.342	11.243	11.336	33.590	33.589	33.588	33.584	33.590	33.581
14.5	11.235	11.238	11.298	11.326	11.236	11.308	33.591	33.591	33.589	33.587	33.590	33.585
15.0	11.212	11.218	11.259	11.295	11.238	11.286	33.593	33.592	33.590	33.588	33.591	33.586
15.5	11.212	11.215	11.204	11.249	11.234	11.278	33.594	33.594	33.592	33.590	33.592	33.587
16.0			11.196	11.228		11.275			33.594	33.592		33.588

Table 5. Vertical Profile Data Collected on 1 July 2015 (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
0.5	25.071	25.105		25.132			8.085	8.100		8.079		
1.0	25.122	25.086	25.151	25.131	25.195	25.269	8.117	8.113	8.109	8.092	8.096	8.094
1.5	25.205	25.125	25.233	25.157	25.226	25.332	8.120	8.117	8.109	8.098	8.097	8.093
2.0	25.288	25.161	25.284	25.286	25.266	25.334	8.115	8.117	8.105	8.097	8.094	8.091
2.5	25.350	25.238	25.324	25.371	25.296	25.307	8.105	8.115	8.100	8.090	8.090	8.088
3.0	25.387	25.324	25.363	25.410	25.333	25.332	8.091	8.106	8.092	8.075	8.086	8.083
3.5	25.417	25.393	25.407	25.444	25.391	25.488	8.079	8.095	8.082	8.061	8.077	8.071
4.0	25.444	25.433	25.433	25.470	25.412	25.475	8.068	8.076	8.071	8.049	8.070	8.057
4.5	25.463	25.454	25.445	25.483	25.425	25.447	8.054	8.063	8.063	8.038	8.061	8.048
5.0	25.480	25.476	25.459	25.495	25.458	25.466	8.043	8.051	8.055	8.030	8.053	8.044
5.5	25.490	25.489	25.479	25.505	25.487	25.491	8.036	8.039	8.049	8.022	8.041	8.037
6.0	25.498	25.496	25.487	25.510	25.511	25.512	8.029	8.030	8.039	8.016	8.031	8.024
6.5	25.513	25.502	25.493	25.517	25.528	25.527	8.022	8.021	8.033	8.011	8.018	8.013
7.0	25.531	25.510	25.500	25.526	25.541	25.536	8.014	8.016	8.028	8.005	8.002	7.998
7.5	25.546	25.529	25.507	25.537	25.546	25.543	8.006	8.011	8.022	8.001	7.994	7.980
8.0	25.554	25.546	25.525	25.543	25.549	25.548	7.995	8.002	8.018	7.997	7.981	7.970
8.5	25.560	25.556	25.547	25.547	25.555	25.551	7.986	7.992	8.010	7.992	7.969	7.961
9.0	25.568	25.561	25.556	25.552	25.563	25.560	7.978	7.984	8.001	7.986	7.962	7.954
9.5	25.576	25.565	25.561	25.556	25.571	25.568	7.969	7.975	7.992	7.982	7.951	7.948
10.0	25.588	25.577	25.572	25.562	25.579	25.569	7.961	7.970	7.985	7.976	7.946	7.943
10.5	25.591	25.590	25.584	25.571	25.577	25.577	7.956	7.962	7.975	7.972	7.942	7.941
11.0	25.593	25.594	25.594	25.582	25.578	25.583	7.952	7.955	7.965	7.965	7.941	7.939
11.5	25.601	25.601	25.599	25.589	25.601	25.582	7.947	7.951	7.960	7.955	7.940	7.937
12.0	25.608	25.607	25.604	25.594	25.610	25.580	7.943	7.946	7.956	7.951	7.938	7.935
12.5	25.616	25.612	25.610	25.597	25.613	25.580	7.939	7.941	7.950	7.945	7.935	7.932
13.0	25.621	25.617	25.615	25.599	25.617	25.589	7.933	7.938	7.944	7.944	7.932	7.932
13.5	25.625	25.622	25.617	25.603	25.628	25.600	7.928	7.932	7.939	7.940	7.928	7.932
14.0	25.629	25.628	25.621	25.612	25.634	25.610	7.922	7.927	7.935	7.938	7.921	7.931
14.5	25.636	25.636	25.623	25.616	25.635	25.619	7.917	7.922	7.929	7.934	7.914	7.927
15.0	25.642	25.640	25.631	25.623	25.636	25.623	7.910	7.914	7.926	7.929	7.908	7.924
15.5	25.643	25.642	25.643	25.633	25.637	25.625	7.902	7.906	7.922	7.920	7.902	7.920
16.0			25.646	25.638		25.627			7.914	7.909		7.921

Table 5. Vertical Profile Data Collected on 1 July 2015 (continued)

Depth (m)	Dissolved Oxygen (mg/L)						Transmissivity (%)					
	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6
0.5	8.954	8.782		8.512			77.129	75.883		76.724		
1.0	8.493	8.620	8.331	8.380	8.340	7.003	76.701	75.840	75.800	76.545	76.743	78.147
1.5	8.300	8.600	8.300	8.047	8.312	7.284	77.742	76.260	76.945	77.073	77.697	78.647
2.0	8.182	8.424	8.222	7.888	8.253	7.472	79.463	76.619	79.129	78.985	78.592	79.656
2.5	8.006	8.093	8.104	7.739	8.136	7.406	80.953	79.010	80.466	80.280	79.912	79.338
3.0	7.753	7.878	7.783	7.516	7.773	7.372	81.216	81.181	81.064	81.816	80.553	79.813
3.5	7.601	7.700	7.702	7.363	7.803	7.310	81.399	81.059	81.450	82.833	81.604	81.165
4.0	7.499	7.594	7.636	7.286	7.704	7.466	81.593	81.875	81.955	82.912	82.481	82.336
4.5	7.324	7.380	7.491	7.197	7.406	7.391	82.108	83.305	83.037	83.263	82.686	82.696
5.0	7.295	7.295	7.314	7.111	7.147	7.105	83.889	82.976	83.180	84.060	82.562	82.868
5.5	7.228	7.250	7.291	7.095	6.802	7.016	83.707	83.911	83.497	84.435	82.996	83.086
6.0	7.062	7.201	7.257	7.028	6.628	6.728	83.745	83.753	83.276	84.062	84.369	84.283
6.5	6.891	7.155	7.170	6.960	6.515	6.383	84.355	83.873	83.529	85.466	84.945	85.039
7.0	6.705	6.912	7.127	6.865	6.468	6.324	84.604	83.673	84.015	84.770	85.797	85.493
7.5	6.633	6.729	6.870	6.797	6.367	6.202	85.139	84.381	83.961	85.183	86.001	86.110
8.0	6.549	6.629	6.612	6.745	6.177	6.177	86.165	84.703	84.255	85.558	86.392	86.179
8.5	6.432	6.546	6.588	6.674	6.099	6.142	86.152	85.476	84.853	85.775	86.566	86.457
9.0	6.382	6.519	6.560	6.631	6.131	6.093	85.657	86.280	85.580	85.489	86.929	86.478
9.5	6.254	6.335	6.319	6.540	6.100	6.090	86.139	86.230	85.666	86.060	87.212	86.450
10.0	6.254	6.230	6.227	6.387	6.139	6.064	86.998	85.998	86.013	86.240	87.065	86.933
10.5	6.232	6.227	6.174	6.291	6.152	6.057	87.438	87.645	86.113	86.531	87.583	87.080
11.0	6.161	6.145	6.143	6.219	6.079	6.059	87.311	87.774	86.781	87.025	87.614	87.483
11.5	6.060	6.099	6.094	6.189	6.065	6.034	87.510	88.047	87.783	88.274	87.796	87.623
12.0	5.963	6.058	6.054	6.170	6.032	6.058	88.314	88.428	88.551	88.642	88.347	87.668
12.5	5.884	5.949	6.003	6.164	5.947	6.094	88.440	88.279	88.832	88.459	88.628	87.164
13.0	5.832	5.900	5.976	6.135	5.745	6.045	88.628	88.809	88.458	88.392	88.698	87.317
13.5	5.771	5.782	5.906	6.040	5.645	5.978	88.746	88.975	88.599	88.322	88.933	87.605
14.0	5.610	5.634	5.907	5.955	5.618	5.909	88.702	89.105	88.655	88.606	88.409	88.038
14.5	5.481	5.549	5.700	5.826	5.627	5.790	88.541	88.454	88.702	88.771	88.207	88.193
15.0	5.483	5.513	5.505	5.636	5.605	5.768	87.414	87.148	88.866	88.797	88.091	88.406
15.5	5.487	5.500	5.470	5.633	5.650	5.777	87.002	86.603	88.532	88.573	87.821	88.544
16.0			5.482	5.705		5.788			87.740	88.670		88.729

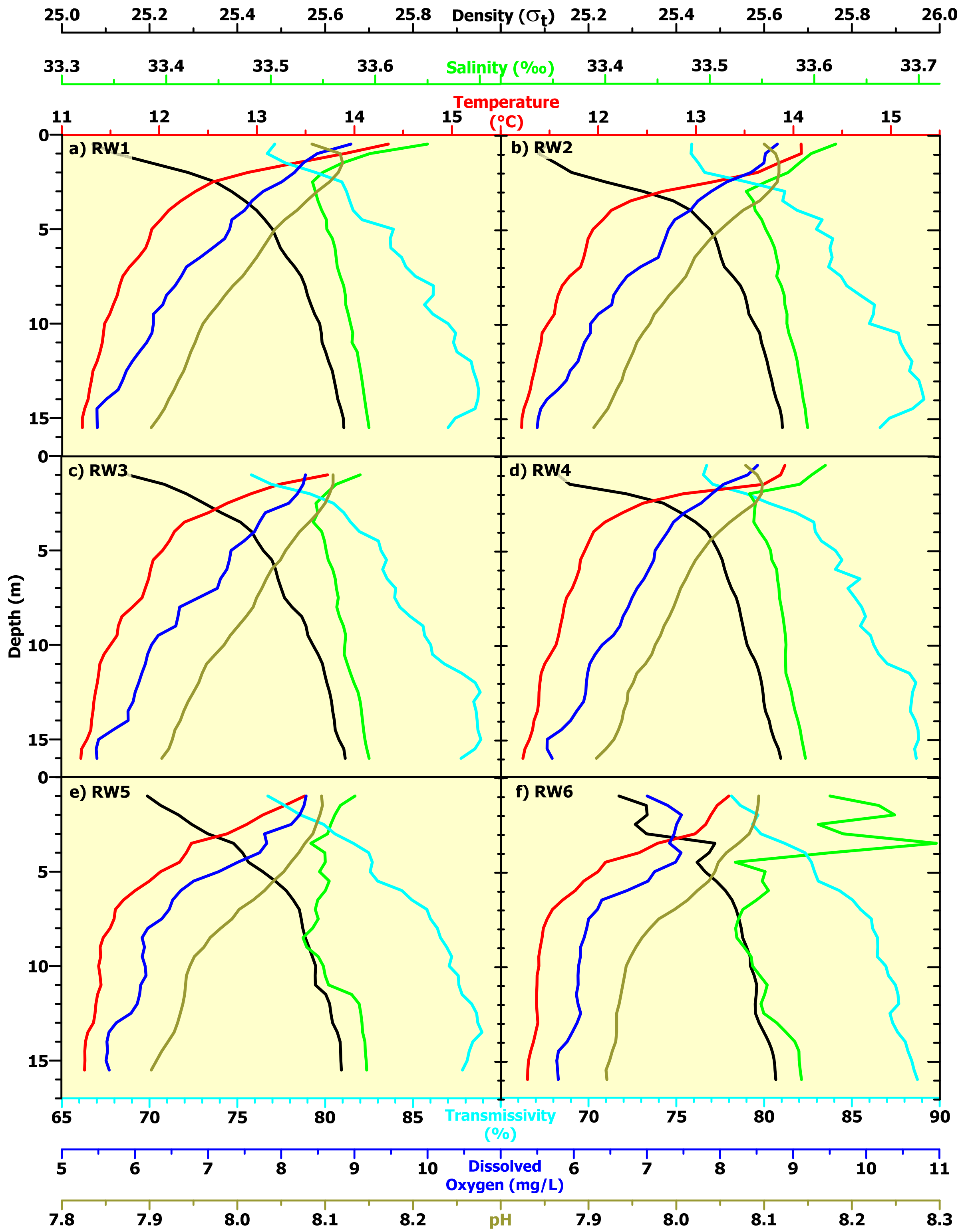

Figure 6. Vertical Profiles of Water-Quality Parameters

interface that inhibits the vertical exchange of nutrients and other ambient water properties; and that restricts the vertical movement of the effluent plume thereby reducing the amount of initial dilution that would have been achieved had the plume reached the sea surface.

Although winds were light on the day of the survey, strong sustained northwesterly winds prevailed in the days prior to the survey, resulting in intense upwelling. Consequently, vertical profiles temperature, and density exhibit a rapid transition between the sea surface and depth of approximately 4 m, below which these physical properties were more uniform (Figure 6). Other seawater properties generally exhibit steadily increasing or decreasing values throughout the water column. At the southern ZID station (RW4), upward displacement of deeper ambient seawater that was entrained within the rising effluent plume appears to have compressed the near-surface transition zone (Figure 6d).

Throughout the water column, temperature (red lines), DO (dark blue lines), and pH (olive-colored lines) generally decrease with depth, reflecting the effects of upwelling during the days prior to the survey. These decreases are mirrored by a pycnocline, where density (black lines) steadily increases with depth, as does transmissivity (light blue line) to a lesser extent. These vertical changes reflect the transition to colder, saltier, nutrient-rich but oxygen-poor watermass that migrated shoreward along the seafloor as part of the upwelling process. This offshore watermass moved shoreward to replace nearshore surface waters that were driven offshore by the prevailing northwesterly winds. Because this deep offshore watermass had not been in recent direct contact with the atmosphere, biotic respiration and decomposition had depleted its DO levels (dark blue lines). Additionally, at depth, biotic respiration and decomposition produced carbon dioxide (CO_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 transition zone (thermocline) caused a 12% decrease in transmissivity compared to the deeper water mass.

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 during and immediately after strong upwelling events, the rising plume can become trapped at depth within the water column, thereby limiting its full capacity for dilution.

During the July 2015 survey, the strongest signature of the effluent plume remained at mid-depth as it was carried south. Its presence is apparent between 6 m and 12 m in the salinity profile at Station RW5 (green line in Figure 6e), and between 6 m and 14 m at Station RW6 (Figure 6f). The mid-depth tow (Figure 7b) also captured the upper portion of this subsurface plume as its low-salinity signature spread southward near a depth of 6.43 m, which is just beneath the plume's 6-m trapping depth. We know the plume had reached buoyant equilibrium at this depth because it did not exhibit a negative density anomaly that was spatially coincident with the salinity anomaly (*cf.* Figure 7b and 7c). Normally, ongoing initial dilution processes associated with the rising plume are characterized in horizontal maps by an area of reduced density that indicates the plume is lighter than surrounding seawater and is therefore still buoyant.

In contrast to the mid-depth tow data, only extremely small and highly localized salinity reductions are apparent immediately south of the diffuser structure in the shallow-tow map (Figure 8b). This shallow plume signature arose because the upward momentum of the rising plume caused it to briefly overshoot its equilibrium depth, before descending again under gravitational forces. Accordingly, the density map

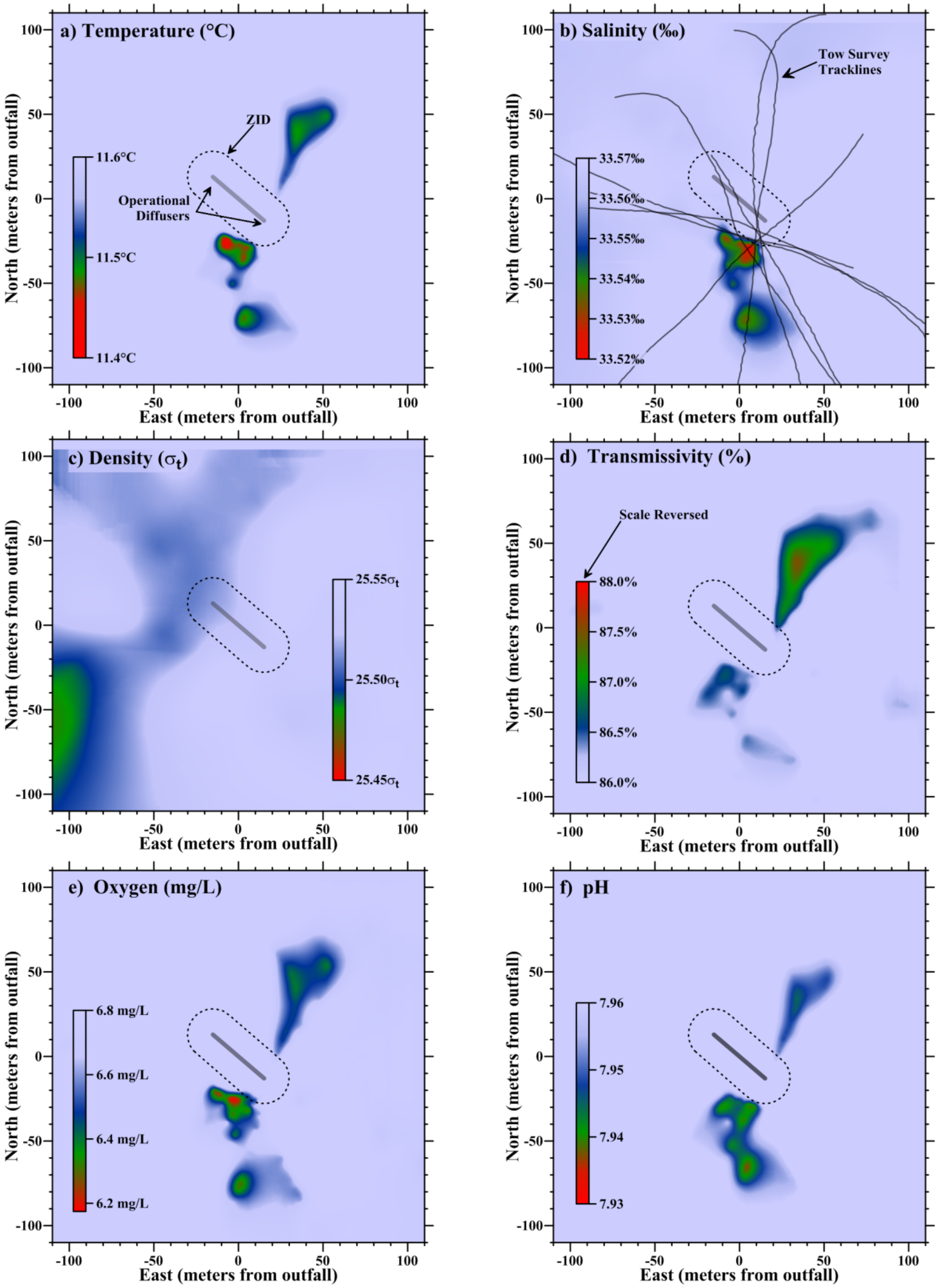

Figure 7. Horizontal Distribution of Mid-Depth Water-Quality Parameters 6.43 m below the Sea Surface

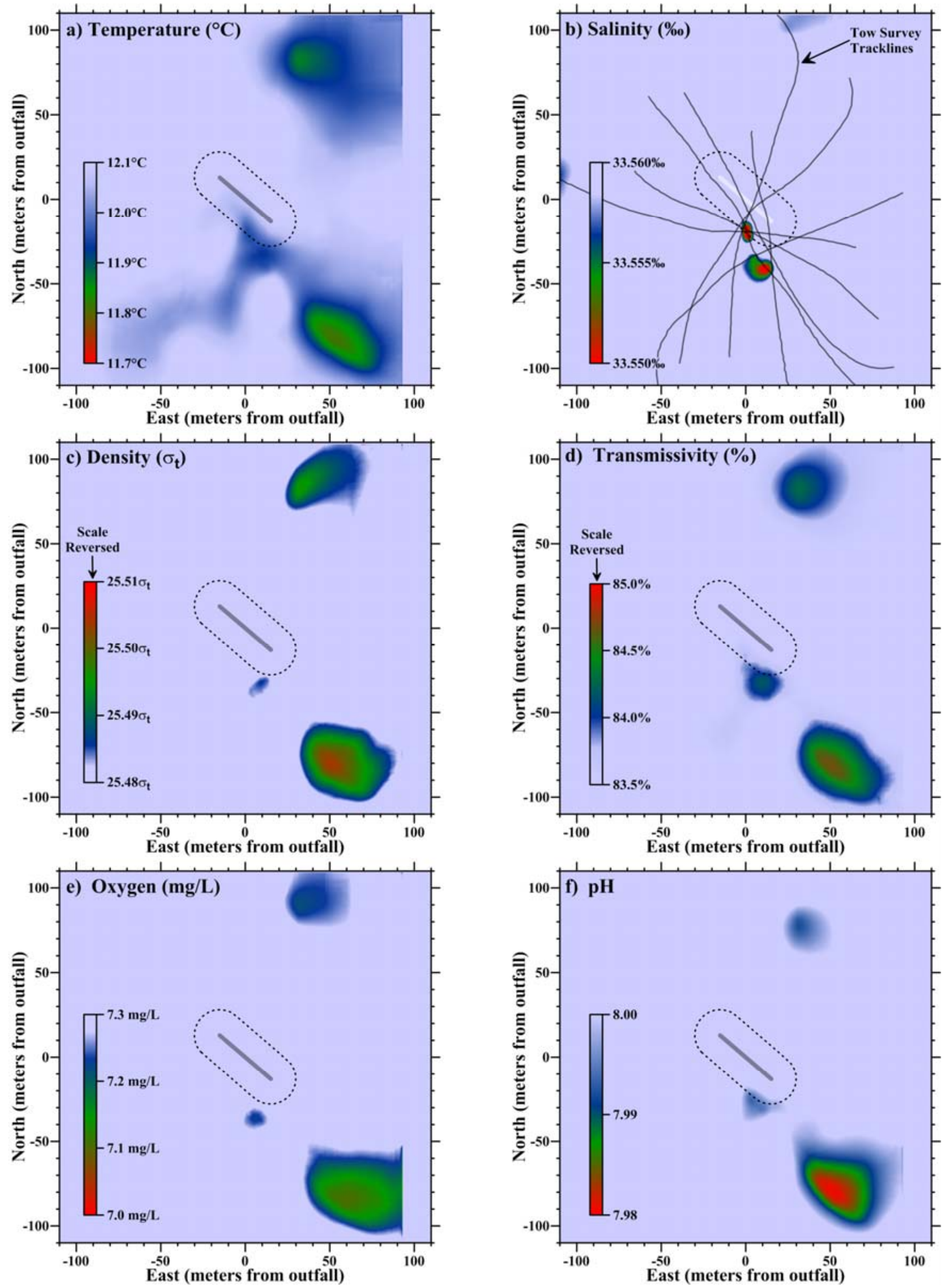

Figure 8. Horizontal Distribution of Shallow Water-Quality Parameters 3.31 m below the Sea Surface

(Figure 8c) shows a very slightly increased density at the location of the shallow salinity signature,[17] indicating that the plume was heavier than most of the surrounding seawater and would begin to sink. These types of buoyancy-induced vertical excursions are commonplace when the effluent plume is trapped at depth.

Nevertheless, the amplitude of the density anomaly associated with the plume's buoyancy oscillation is much smaller than the density excursions apparent in the northeast and southeast quadrants of the tow map. These, and the coincidental excursions in temperature, transmissivity, DO, and pH (Figure 8adef), were caused by slight increases in tow depth as the vessel was completing a turn at the outer reaches of the survey area. These patches resulted because the 3.31 m average depth of the tow was directly within the thermocline where strong vertical gradients in seawater properties were present (Figure 6). The patchy variations in the shallow horizontal maps were caused by slight changes in tow depth that resulted in large excursions in measured properties. Most changes in tow depth occur at the beginning of a transect, after the vessel executes a turn and before the CTD's depth has fully stabilized. Thus, the patches tend to occur at the outer reaches of the survey area. In most past surveys, similar excursions in tow depth did not result in this patchiness because the tows were not conducted within such an unusually sharp thermocline.

Artifacts resulting from tow-depth differences are also visually apparent extending northeast of the ZID in the mid-depth map (Figure 7adef). Despite the presence of these artifacts, anomalies related to the discharge can still be discerned in many of the seawater properties. Although small in amplitude, they extend south of the diffuser structure and coincide spatially with the salinity anomalies the mid-depth and shallow maps (Figure 7b and 8b). However, in contrast to salinity, the anomalies observed in other water properties 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.

Close to the seafloor, intense mixing is driven by the momentum of the effluent's ejection from the individual diffuser ports. Subsequent turbulent mixing caused by rise of the plume through the water column is less intense, and as a result, the dilute effluent plume tends to retain the ambient seawater properties it acquired at the seafloor. These deep seawater properties can become apparent as a signature of the buoyant effluent plume when they are juxtaposed against the ambient seawater characteristics in the mid and upper water column. These entrainment-generated anomalies are only apparent, however, when the water column is sufficiently stratified to cause a perceptible contrast between shallow and deep ambient seawater properties.

It is clear that the anomalies in these seawater properties within the upper water column were caused by entrainment rather than wastewater loading because for some properties, the offsets were opposite of the changes that would be expected if they were caused by the presence of wastewater particulates. For example, wastewater discharged on the day of the survey was much warmer (22°C) than the receiving seawater at depth (11.2°C). Therefore, entrainment of bottom seawater is the only mechanism that could have created a plume that was cooler than the surrounding ambient seawater within the upper water column (Figure 7a).

Similarly, the increased particulate load associated with dilute wastewater would be expected to decrease transmissivity, yet the anomalies associated with the plume indicate transmissivity was higher[18] than the surrounding seawater in both the mid-depth and shallow maps (Figure 7d and 8d). These anomalies arose because transmissivity was higher in the ambient seawater near the seafloor (light blue lines in Figure 6). As it was entrained in the rising plume, the higher ambient transmissivity became apparent after

[17] Note that the shading is reversed in the density map's scale.
[18] Note that the shading is reversed in the transmissivity scales.

juxtaposition with the more-turbid plankton-laden seawater within the euphotic zone. Similar entrainment-generated anomalies are apparent in the pools of reduced DO (Figure 7e and 8e) and pH (Figure 7f and 8f) that co-occur with the mid-depth and shallow salinity anomalies. As with the other seawater properties, ambient DO and pH declined with depth (dark blue and olive lines in Figure 6), so it is not surprising that slight reductions in these properties become apparent when deep seawater is carried upward.

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 restricts attention to water-quality changes caused solely by the presence of wastewater constituents rather than a simple relocation of ambient seawater. Nevertheless, these anomalies provide useful tracers of the diffuse effluent plume after the completion of the initial dilution process.

Outfall Performance

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

The 133:1 dilution estimate was based on worst-case modeling under highly stratified conditions, where trapping of the plume below a strong thermocline would curtail the additional buoyant mixing normally experienced during the plume's rise through the entire water column. Additionally, the modeling assumed quiescent oceanic flow conditions, thereby restricting initial mixing processes to the ZID. Under those conditions, the modeling predicted that a 133:1 dilution would be achieved after the plume rose only 9 m from the seafloor, whereupon it would become trapped and cease to rise further in the water column. There it would begin to spread laterally with much diminished dispersion rates. A 9-m rise at the MBCSD outfall translates into a trapping depth that is 6.4 m below the sea surface, and close to the trapping depth observed during the July 2015 survey. As described below, however, the dilution levels observed during the July 2015 survey were much higher than the 133:1 predicted by the modeling, and were measured at depths greater than the trapping depth predicted by the modeling.

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

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

$$C_e \equiv C_o + D(C_o - C_s)$$ 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 predicted by modeling. Salinity is an especially useful tracer because it directly reflects the magnitude of ongoing dilution. The regions of slightly lower salinity apparent south of the diffuser structure in the mid-depth and shallow tow-survey maps (Figures 7b and 8b) were induced by the presence of very dilute wastewater. As discussed previously, the localized shallow salinity anomalies arose from buoyancy-induced oscillations before the plume settled on its equilibrium depth and spread to the south. The deep salinity anomaly documented mixing processes within the effluent plume near its trapping depth when the initial dilution process was considered complete.

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:

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

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

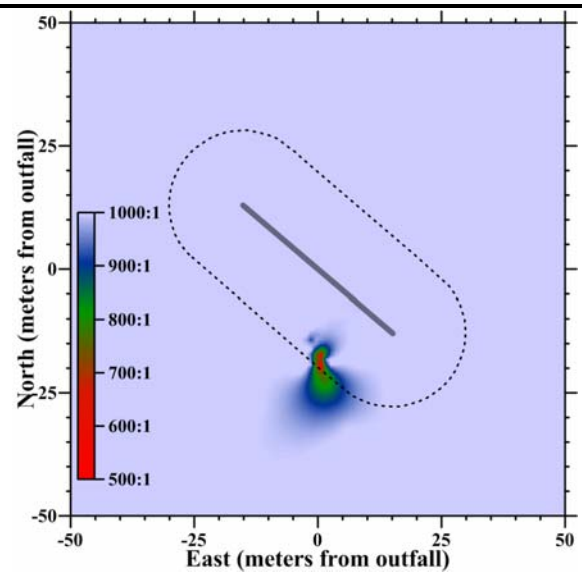

Figure 9 Shallow Plume Dilution Computed from Salinity Anomalies in Figure 8b

The lowest salinity (33.501‰) measured during the July 2015 survey was recorded within the ZID, 14.2 m south of the diffuser structure at a depth of 3.4 m during the sixth transect of the shallow tow survey (red shading in Figure 8b). This measured salinity corresponds to a 0.063‰ reduction below the mean ambient salinity of 33.564‰ 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 513-fold (Figure 9). This is nearly four-times

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

higher than 133:1 critical initial dilution used to establish limits on contaminant concentrations in wastewater. Strictly speaking, the effluent had yet to complete the initial dilution process at this location and according to the conservative modeling results, dilution levels would be expected to be less than 133:1 there. After drifting south and descending to its trapping level near the depth of the mid-depth tow, a slightly higher dilution (522:1) was recorded 19.2 m south of the diffuser structure (Figure 10). The high dilutions measured during the tow surveys indicate that the diffuser structure was dispersing the effluent far more efficiently than predicted by the modeling.

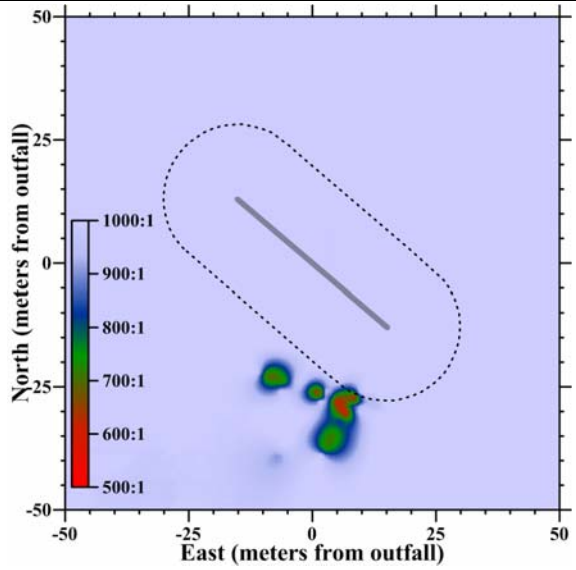

Figure 10. Mid-Depth Plume Dilution Computed from Salinity Anomalies in Figure 7b

These dilution computations demonstrate that, during the July 2015 survey, the outfall was performing better than designed and was rapidly diluting effluent more than 513-fold shortly after discharge, and before completion of the initial-dilution process. All 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. Consequently, during the July 2015 survey, the COP receiving-water objectives were being met by the limits on chemical concentrations within discharged wastewater that are promulgated by the NPDES discharge permit issued to the MBCSD.

COMPLIANCE

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

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

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

The results of these analyses of the July 2015 data demonstrate that the MBCSD discharge complied with the NPDES discharge permit. Moreover, although observations within the ZID are not subject to compliance evaluations, they easily met the prescribed limits because all the measured dilution levels significantly 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 2015 survey.

Permit Provisions

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

The first two receiving-water limits, P1 and P2, rely on qualitative visual observations for compliance evaluation. Compliance was demonstrated by the absence of floating wastewater materials, oil, grease, or discoloration of the sea surface during the July 2015 survey. Compliance with the remaining four receiving-water limitations is quantitatively evaluated through a comparison between instrumental measurements and numerical limits listed in the NPDES permit. For example, in P5 and P6, the fixed numeric limits on absolute values of DO (>5 mg/L) and pH (7.0 to 8.3) can be directly compared with field measurements within the dilute wastewater plume beyond the ZID. However, both P5 and P6 also contain narrative limits, which originate in the COP, and define unacceptable water-quality impacts as "*significant*" excursions beyond those that occur "*naturally*." Quantitative evaluation of these limits requires a further comparison of field measurements with numerical thresholds that reflect the natural variation in transmissivity, DO, and pH within the receiving waters surrounding the outfall.

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

Screening of Measurements

Evaluating whether any of the 9,228 CTD measurements collected during the July 2015 survey exceeded a permit limit can be a complex process. For example, although apparently significant excursions in an individual seawater property may be related to the presence of wastewater constituents, they may also result from instrumental errors, natural processes, entrainment of ambient bottom waters in the rising effluent plume, statistical uncertainty, ongoing initial mixing within and beyond the ZID, or other anthropogenic influences (e.g., dredging discharges or oil spills).

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

Table 7. Receiving-Water Measurements Screened for Compliance Evaluation

Topic Addressed	Screening Question	Answer: No	Answer: Yes[20]	*Parameter*
Location	1. Was the measurement collected beyond the 15.2-m ZID boundary where modeling assumes that initial dilution is complete?	*1,387*	*7,841*	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?	*7,835*	*6*	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?	*6*	*0*	Temperature
		6	*0*	Transmissivity
		6	*0*	DO
		6	*0*	pH

The last subsection of this section 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 presented in the following description of the three screening steps.

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

Although currents often transport the plume well beyond the ZID before the initial dilution process is complete, the COP states that dilution estimates shall be based on "*the assumption that no currents, of sufficient strength to influence the initial dilution process, flow across the discharge structure.*" Because of this, the regulatory mixing distance, which is equal to the 15.2-m water depth of the discharge, provides a conservative boundary to screen receiving-water data for subsequent compliance evaluation. Application of this initial screening question to the July 2015 dataset eliminated 1,387 of the original 9,228 receiving-water observations from further consideration because they were collected within the ZID (Table 7, Question 1). The remaining 7,841 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 rarely 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,

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

however, provides a definitive tracer that allows the presence of effluent constituents to be identified even after dilution many times greater than the 133-fold critical initial dilution assumed in the discharge permit.

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

As shown in Figures 7b and 8b, discharge-related salinity anomalies measured during the survey were largely restricted to a localized area along the southern boundary of the ZID. Only six of these had significant reductions in salinity that unequivocally identified the presence of dilute wastewater constituents beyond the ZID. The remaining 7,835 observations that were measured outside the ZID during the July 2015 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 the numerical permit limits.

A statistical analysis of receiving-water data previously collected around the outfall was used to establish the range in natural conditions within the survey area (first three data columns of Table 8). These ambient-variability ranges were used to identify significant departures from natural conditions that could be indicative of adverse discharge-related effects on water quality. The same five-year database used to establish the within-survey salinity variation discussed previously, was also used to establish one-sided 95% confidence bounds on transmissivity (-10.2%), temperature (+0.82°C), DO (-1.38 mg/L), and pH (± 0.094). These were combined with 95th percentiles determined from the July 2015 ambient seawater data, to establish time-specific natural-variability thresholds in a manner analogous to COP Appendix VI. The percentiles were determined from July 2015 vertical profile data collected at upstream Stations RW1, RW2, and RW3, thereby excluding measurements potentially affected by the discharge.

Temperature, transmissivity, pH, and DO concentrations associated with the six remaining measurements of potential compliance interest were all well within their respective ranges of natural variability (Table 7, Question 3). As such, the screening process unequivocally eliminated all of the remaining CTD measurements collected during the July 2015 survey from further consideration.

In fact, excursions in these properties for all 9,228 measurements collected during the July 2015 survey were within the range that arises from physical processes unrelated to the discharge of effluent, namely, entrainment of near-bottom seawater within the rising effluent plume. Even if the presence of wastewater particulates had contributed to the measured excursions in these properties, their influence remained 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.

Table 8. Compliance Thresholds

Water Quality Property	95% Confidence Bound[21]	95th Percentile[22,23]	Natural Variability Threshold[24]	COP Allowance[25]	Basin Plan Limit[26]	Extremum[27]
Temperature (ºC)	0.82	13.72	>14.54	—	—	≤14.35
Transmissivity (%)	-10.2	76.7	<66.5	—	—	≥75.8
DO (mg/L)	-1.38	5.52	<4.14	<3.73	<5.00	≥5.47
pH (minimum)	-0.094	7.914	<7.820	<7.620	<7.000	≥7.902
pH (maximum)	0.094	8.109	>8.203	>8.403	>8.300	≤8.120

Other Lines of Evidence

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

Insignificant Thermal Impact: Although there are no explicit numerical objectives for discharge-related increases in temperature, a numerical limit can be established for thermal excursions that is based on the requirement that they not adversely affect beneficial uses (P3 in Table 6). Increases in temperature caused by the discharge of warm wastewater constituents could be deemed to adversely affect beneficial uses if they exceeded the natural temperature range observed at the time of the survey (i.e. exceeded 14.54°C in Table 8). However, none of the 9,228 CTD measurements collected during the July 2015 survey exceeded 14.35°C (last column in Table 8). Additionally, as mentioned previously, because the effluent entrained

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

[22] The COP (Appendix I, Page 27, SWRCB 2005) defines a “*significant*” difference as “*a statistically significant difference in the means of two distributions of sampling results at the 95% confidence level*.” Accordingly, COP effluent analyses (Step 9 in Appendix VI, Page 42, Ibid.) are based “*the one-sided, upper 95% confidence bound for the 95th percentile*.”

[23] The 95th-percentile quantifies natural variability in seawater properties during the July 2015 survey, and was determined from vertical-profiles data unaffected by the discharge.

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

[25] The discharge permit, in accordance with the COP, allows excursions in seawater properties that depart from natural conditions by specified amounts. DO cannot be “*depressed more than 10% from that which occurs naturally*,” and pH cannot be “*changed more than 0.2 units from that which occurs naturally.*”

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

[27] Maximum or minimum value measured during this survey

cooler bottom water shortly after discharge, the rising plume actually exhibited a lower temperature than most of the surrounding seawater in the upper water column (Figure 7a).

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. However, none of the transmissivity measurements collected during the July 2015 survey fell below the 66.5% minimum compliance threshold. The lowest transmissivity measured during the survey was 75.8% and was recorded at the sea surface at Station RW2. As described previously, increased turbidity within the upper water column was a natural consequence of upwelling, namely, enhancement of primary production by the upward transport of nutrients into the euphotic zone.

Moreover, the COP objective for light penetration only applies to a portion of the transmissivity measurements. Because little natural light is present below the euphotic zone, which extends to approximately twice the Secchi depth, the limit on transmissivity reductions during the July 2015 survey only applies to measurements recorded above 9 m (twice the Secchi depth listed in Table 4). Consequently, even if the discharge of wastewater particulates had caused one or more of the 119 transmissivity measurements collected below the euphotic zone to drop below the numeric compliance threshold, it would not have been of regulatory concern because the penetration of ambient light would not have been impacted.

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) could not have been generated by the presence of warmer wastewater constituents. Similarly, the increased transmissivity observed within the discharge plume during both tows (Figures 7d and 9d) 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 effluent suspended-solids concentration measured onshore prior to discharge from the WWTP on 1 July 2015 was only 33.8 mg/L. After dilution by 513-fold, which was the lowest dilution measured during the survey, the effluent suspended-solids concentration would have reduced ambient transmissivity by only 0.4%. This small potential decrease in transmissivity would have been overwhelmed by the large 12% decrease in ambient transmissivity caused by the increased presence of plankton within the thermocline during upwelling.

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, 42.6-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 data column of Table 8, even though these ranges were conservatively used in the data screening process described in the previous subsection. Consideration of these COP allowances in the receiving-water limits provides an additional level of confidence in the compliance evaluation.

For pH, the COP and the discharge permit allow changes up to 0.2 pH units from natural conditions, bringing the minimum allowed pH to 7.620 during the July 2015 survey (fourth data column of Table 8). This limiting value is significantly less than the lowest pH measurement of 7.902 recorded during the July 2015 survey (last column of Table 8). Similarly, the lowest DO concentration measured during the survey (5.47 mg/L) was well above both the lower range in natural variation (4.14 mg/L) and the 10% compliance threshold promulgated by the COP (3.73 mg/L).

Excursions remained within the fixed Basin-Plan Limits: Permit provisions P5 and P6 (Table 6) combine receiving-water objectives from both the COP and the Basin Plan with respect to DO and pH limitations. As described previously, the COP requires that DO concentrations outside the ZID not be depressed more than 10% from that which occurs naturally, and restricts pH measurements to those within 0.2 units of that which occurs naturally. In contrast, the Basin-Plan's fixed numerical limits do not provide specific guidance as to how they might change in response to widespread changes in oceanographic conditions unrelated to the discharge. Specifically, the fixed numerical limits restrict DO concentrations outside the ZID to no less than 5 mg/L (P5 in Table 6), and pH levels to the 7.0-to-8.3 range (P6). As such, the fixed Basin-Plan limit on DO is far more restrictive than the 3.73 mg/L minimum allowable DO concentration established for the July 2015 survey under COP objectives; yet the all of the DO measurements also complied with the much more conservative Basin-Plan limit on DO reductions. Similarly, the maximum allowable pH (8.3) specified in the Basin Plan was more restrictive than the COP limit (8.403) specified for the July 2015 Survey, yet all the measurements again complied with both regulations.

Natural Variability within and beyond the ZID: Although the permit limits only apply to changes in DO, pH, temperature, and transmissivity beyond the ZID, the examination of measurements acquired within the ZID frequently provides additional insight into the potential for adverse effects on water quality. However, during the July 2015 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 9,228 temperature, DO, pH, and transmissivity observations exceeded the thresholds of natural variability specified in Table 8.

CONCLUSIONS

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

Even though the initial dilution process was curtailed by subsurface trapping, measured dilutions levels exceeded 513-fold. This measured dilution level far exceeds levels that were predicted by modeling and that were incorporated in the discharge permit as limits on contaminant concentrations within effluent prior to discharge. Additionally, all of the auxiliary observations collected during the July 2015 survey demonstrated that the discharge complied with the narrative receiving-water limits in the discharge permit and the COP. Together, these observations demonstrate that the treatment process, diffuser structure, and the outfall continue to surpass design expectations.

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