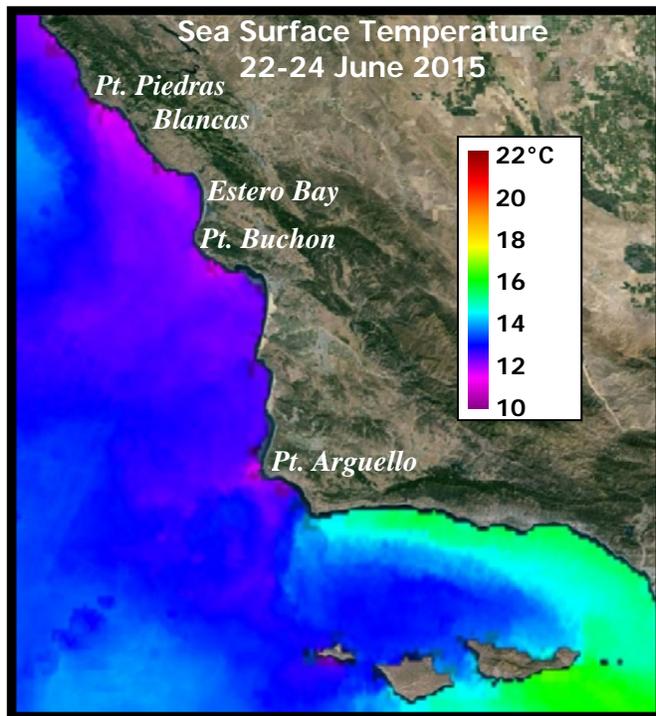


**City of Morro Bay and
Cayucos Sanitary District**

OFFSHORE MONITORING AND REPORTING PROGRAM

SECOND QUARTER RECEIVING-WATER SURVEY

JUNE 2015



Marine Research Specialists

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

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

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

**SECOND QUARTER
RECEIVING–WATER SURVEY**

JUNE 2015

**Prepared by
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July 2015

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

28 July 2015

Reference: Second Quarter Receiving-Water Survey Report – June 2015

Dear Mr. Keogh:

The attached report presents results from a quarterly receiving-water survey conducted on Tuesday, 30 June 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.

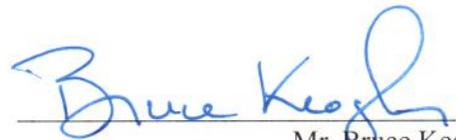
Please contact the undersigned if you have questions regarding the attached report.

Sincerely,

 **MA** RINE **RE** SEARCH **S** SPECIALISTS
Vice President

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.



Mr. Bruce Keogh
Wastewater Division Manager
City of Morro Bay

Date July 29, 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 June 2015 field survey described in this report was the twenty-sixth 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 30 June 2015. Specifically, this second-quarter survey captured ambient oceanographic conditions along the central California coast during the spring 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 CTD¹ 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)



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.

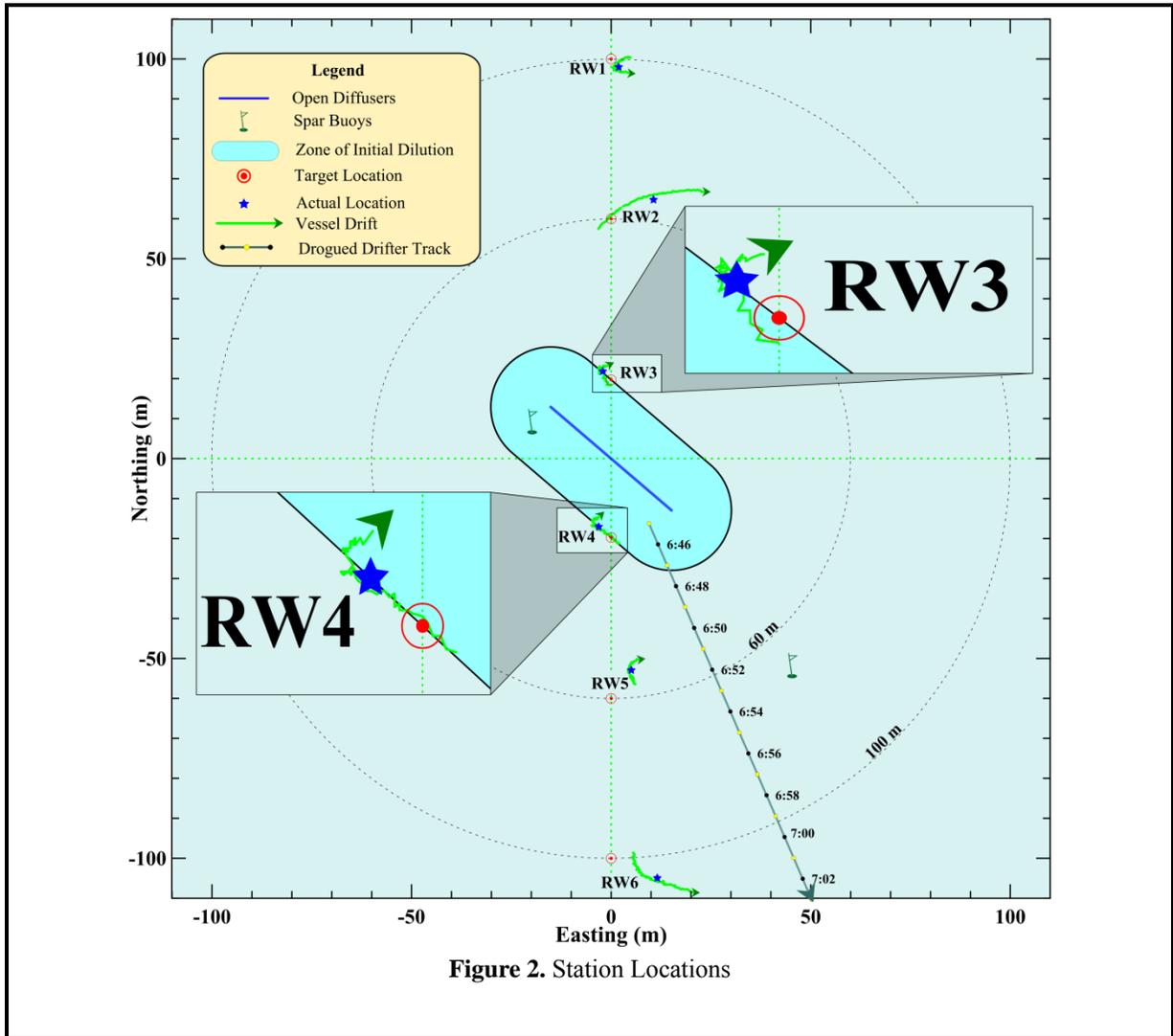


Figure 2. Station Locations

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 metocean⁴ conditions, the residual momentum of the survey vessel as it approaches the target locations can create perceptible offsets. Using DGPS however, these offsets can be quantified, and the vessel location can be precisely tracked throughout sampling at each station.

The downcasts during the June 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 June 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 June 2015 survey. Although the time it took the CTD to traverse the water column to the seafloor, which averaged 1 min 30 s, was consistent among stations, the lateral distance traversed by the instrument package varied considerably, from as little as 3.9 m at Station RW1, to 28.0 m at Station RW2. At 11.6 m, the average distance among all the stations was slightly greater than that of most prior surveys. Although the eastward component of CTD movement at depth was consistent with transport by winds out of the west, variation in the vessel's residual momentum as it approached the stations dictated the CTD's overall movement 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 June 2015 survey, only the deepest measurements at Station RW3 were located beyond the ZID boundary where receiving-water limitations are considered applicable (see the upper-right inset in Figure 2). In contrast, the deeper data collected during the hydrocast at Station RW4 were located within the ZID (see the lower-left inset in Figure 2), and were therefore 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 June 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 June 2015 Survey

Station	Time (PDT)		Latitude	Longitude	Closest Approach	
	Downcast	Upcast			Range ⁵ (m)	Bearing ⁶ (°T)
RW1	8:33:46	8:35:17	35° 23.252' N	120° 52.503' W	86.8	11
RW2	8:29:10	8:30:38	35° 23.234' N	120° 52.497' W	58.0	26
RW3	8:26:14	8:27:23	35° 23.211' N	120° 52.505' W	15.3⁷	41
RW4	8:22:50	8:24:25	35° 23.190' N	120° 52.506' W	14.9⁸	221
RW5	8:19:16	8:20:51	35° 23.170' N	120° 52.501' W	41.1	194
RW6	8:14:43	8:16:23	35° 23.142' N	120° 52.496' W	92.0	182

OCEANOGRAPHIC PROCESSES

The trajectory of a satellite-tracked drogued drifter measured oceanic flow throughout the June 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 June 2015 survey, the drifter was deployed near the diffuser structure at 6:45 AM, and was recovered at 8:54 AM at a location 740 m to the south-southeast (157°T⁹) 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 of 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 9.5 cm/s¹⁰ was somewhat greater than flow speeds measured during most prior surveys. At the rapid transport rate measured during the June 2015 survey, effluent would have experienced only a brief, 2.5-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 June 2015 survey (Figure 3). Flood tides normally induce a weak northward

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

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

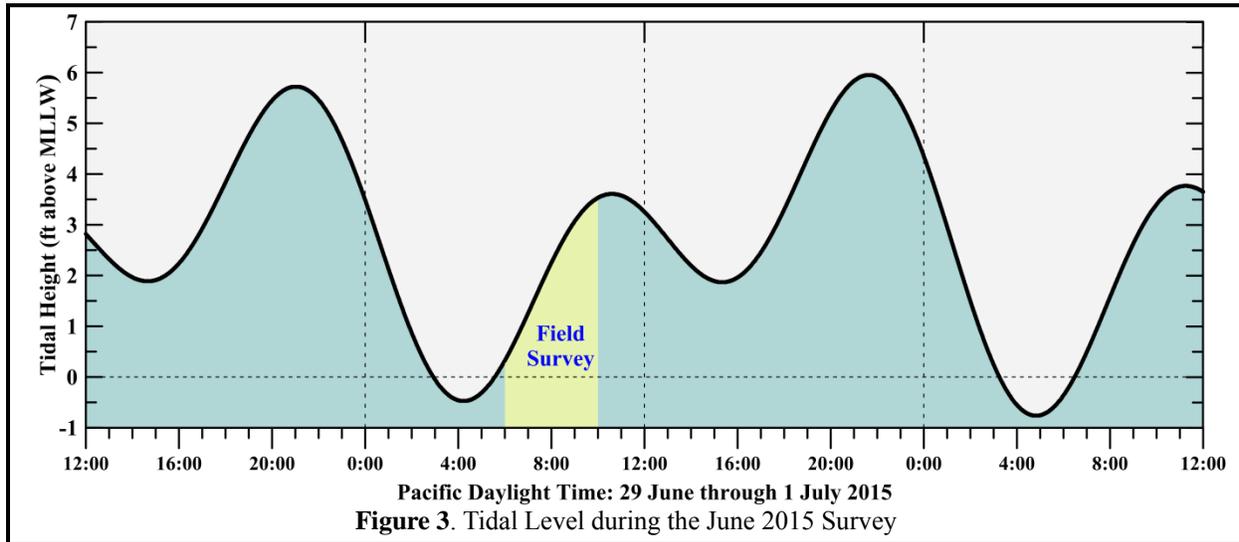
⁷ Some of the CTD measurements collected at Station RW3 were located within the ZID boundary (refer to the upper-right inset in Figure 2).

⁸ Some of the CTD measurements collected at Station RW4 were located within the ZID boundary (refer to the lower-left inset in Figure 2).

⁹ Direction measured clockwise relative to true (rather than magnetic) north

¹⁰ 0.1947 kt

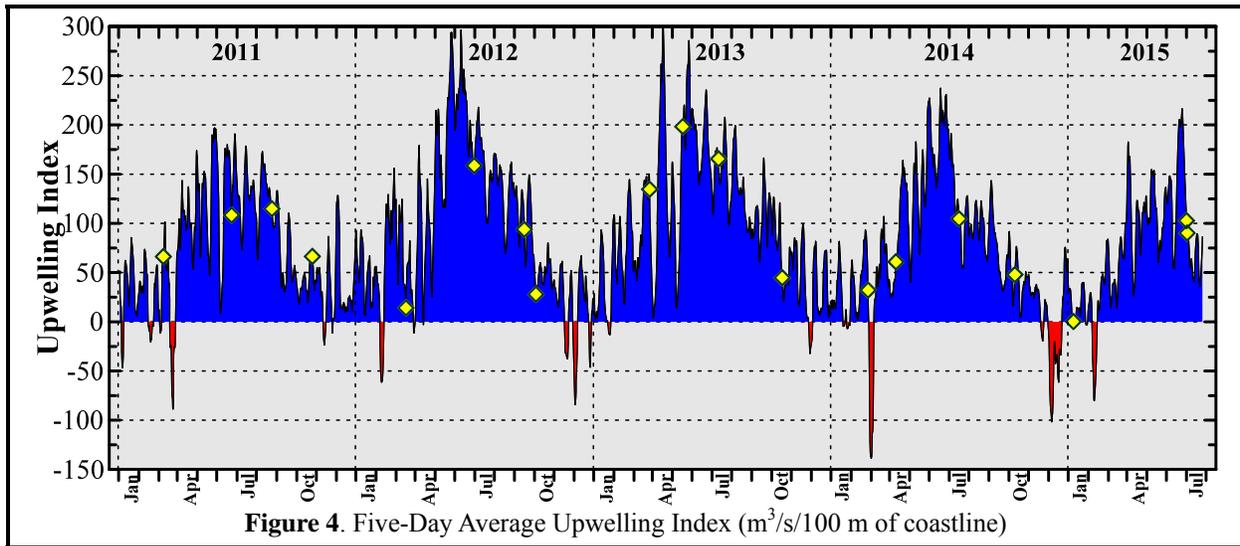
(onshore) flow in the survey region. However, flow within the survey area is often also affected by other processes, such as wind-generated upwelling, downwelling, or offshore eddies migrating past Estero Bay. These external flow influences are apparent in the complexity of sea-surface temperatures depicted in the 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 prevailed 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 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.

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 Tuesday, 30 June 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. William Skok served as deckhand and assisted with the deployment and recovery of the CTD and drifter.

Auxiliary Measurements

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

Additionally, at all six stations, a Secchi disk was lowered through the water column to determine its depth of disappearance. Secchi depths provide a visual measure of near-surface turbidity or water clarity. 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 June 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.

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).

Table 3. CTD Specifications

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

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 6:56 AM, the CTD was deployed beneath the sea surface for seven 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.

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

Eight transects of shallow data were collected at an average depth of 3.5 m, and an average speed of 1.71 m/s over the span of 29 minutes (Figure 5). Subsequently, eight additional passes were made with the CTD at an average depth of 7.5 m. During this 29-minute mid-depth tow, vessel speed averaged 1.65 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 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.

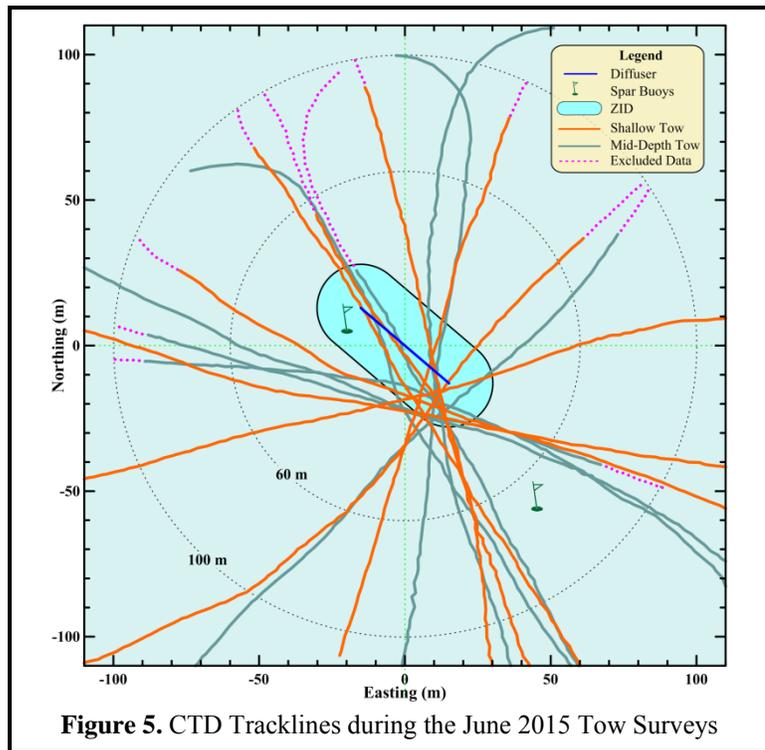


Figure 5. CTD Tracklines during the June 2015 Tow Surveys

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.¹²

At 7:59AM, 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 8:07 AM, and was held beneath the surface for eight minutes 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,¹³ 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

¹² Figures 7 and 8 later in this report

¹³ 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 June 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.

RESULTS

The second-quarter receiving-water survey was conducted on the morning of Tuesday, 30 June 2015. The receiving-water survey commenced at 6:45 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 8:45 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 30 June 2015, skies were clear, with a light west-northeasterly breeze.¹⁴ Average wind speeds, calculated over one-minute intervals, ranged from 3.1 kt to 5.6 kt (Table 4). Similarly, peak wind speeds ranged from 4.2 kt to 7.3 kt. The swell was out of the northwest with a significant wave height of one-to-two feet. Air temperatures remained nearly constant throughout the survey, averaging 15°C, and were one degree warmer than the 14.0°C sea-surface temperatures.

Table 4. Standard Meteorological and Oceanographic Observations

Station	Location ¹⁵		Diffuser	Time (PDT)	Air (°C)	Cloud Cover (%)	Wind Avg (kt)	Wind Max (kt)	Wind Dir (°T)	Swell Ht/Dir (ft/°T)	Secchi Depth (m)
	Latitude	Longitude	Distance (m)								
RW1	35° 23.254' N	120° 52.499' W	91.2	8:39:42	15.1	5	3.3	4.2	WNW	1-2 NW	4.0
RW2	35° 23.234' N	120° 52.506' W	51.9	8:41:52	15.0	5	3.1	4.4	WNW	1-2 NW	4.0
RW3	35° 23.210' N	120° 52.513' W	7.0	8:43:44	14.9	5	4.6	6.0	WNW	1-2 NW	4.5
RW4	35° 23.189' N	120° 52.502' W	11.9	8:45:46	15.1	10	3.7	5.1	WNW	1-2 NW	6.0
RW5	35° 23.166' N	120° 52.502' W	49.5	8:48:19	15.2	10	3.5	5.4	WNW	1-2 NW	5.0
RW6	35° 23.146' N	120° 52.503' W	86.5	8:50:26	14.6	30	5.6	7.3	WNW	1-2 NW	4.0

The ≥4 m Secchi depths recorded during the June 2015 survey reflected the presence of a 8-m euphotic zone that was projected to extend through about 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

¹⁴ [Beaufort Scale](#)

¹⁵ 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.

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.

The increased Secchi depths measured at the stations immediately south of the diffuser structure resulted from the upward transport of relatively clear deeper water by the rising effluent plume. However, 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 0.975 million gallons of effluent discharged on 30 June had a temperature of 22°C, a suspended-solids concentration of 32 mg/L, and a pH of 7.6. The biochemical oxygen demand (BOD) of the effluent measured five days prior to the survey on 25 June was 39 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 June 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 small vertical distance. Under highly stratified conditions, isotherms crowd together to form a density interface that inhibits the vertical exchange of nutrients and other ambient water properties; and restricts the vertical movement of the effluent plume thereby reducing the initial dilution of the effluent plume.

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. As a result, the vertical profiles exhibit a sharply defined transition between the 3-m deep surface mixed layer and the nearly uniform seawater properties that were present at depths below 5 m (Figure 6). In particular, all seawater properties except salinity and transmissivity exhibit steadily increasing or decreasing values throughout this thin subsurface transition zone. At the southern stations of RW4, RW5, and RW6 (Figure 6def), the upward displacement of deeper ambient seawater that was entrained within the rising effluent plume further compressed this vertical transition zone.

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 during the days prior to the survey. These decreases are mirrored by a pycnocline, where density (black lines) steadily increases with depth. 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 (CO₂), and in its dissolved state, the increased concentration of carbonic acid appears as a concomitant decline in pH (olive-colored lines).

Table 5. Vertical Profile Data Collected on 30 June 2015

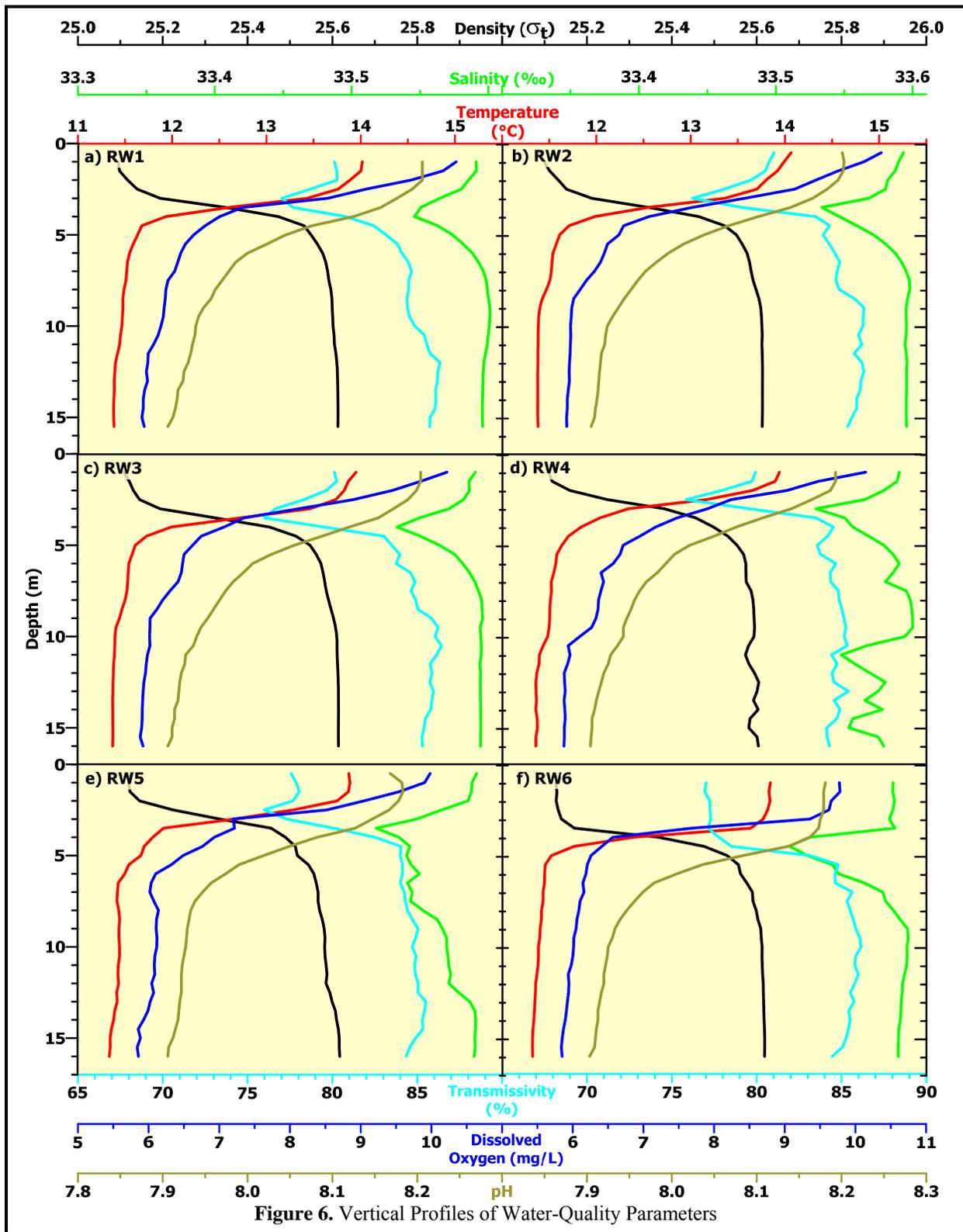
Depth (m)	Temperature (°C)						Salinity (‰)					
	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6
0.5		14.066			13.873			33.593			33.591	
1.0	14.018	13.991	13.951	13.942	13.886	13.846	33.591	33.590	33.591	33.590	33.588	33.586
1.5	14.001	13.920	13.870	13.897	13.869	13.831	33.591	33.587	33.586	33.589	33.588	33.586
2.0	13.888	13.801	13.824	13.657	13.750	13.843	33.586	33.582	33.586	33.579	33.585	33.587
2.5	13.759	13.701	13.737	13.166	13.287	13.817	33.580	33.580	33.582	33.565	33.566	33.586
3.0	13.433	13.362	13.461	12.339	12.663	13.770	33.565	33.568	33.571	33.529	33.548	33.583
3.5	12.600	12.548	12.723	12.037	11.909	13.637	33.551	33.534	33.550	33.550	33.518	33.587
4.0	11.933	11.983	11.992	11.838	11.795	12.392	33.546	33.546	33.533	33.556	33.535	33.524
4.5	11.678	11.710	11.728	11.705	11.703	11.763	33.563	33.559	33.550	33.568	33.543	33.510
5.0	11.634	11.610	11.608	11.634	11.670	11.524	33.574	33.571	33.564	33.579	33.540	33.523
5.5	11.587	11.575	11.576	11.580	11.541	11.458	33.582	33.580	33.575	33.586	33.543	33.542
6.0	11.548	11.540	11.540	11.570	11.497	11.450	33.588	33.587	33.581	33.590	33.550	33.546
6.5	11.527	11.529	11.534	11.549	11.428	11.449	33.593	33.592	33.586	33.586	33.541	33.565
7.0	11.518	11.522	11.528	11.521	11.420	11.435	33.596	33.595	33.590	33.580	33.544	33.578
7.5	11.510	11.507	11.520	11.524	11.415	11.435	33.598	33.598	33.593	33.595	33.543	33.580
8.0	11.489	11.470	11.501	11.512	11.434	11.418	33.599	33.598	33.595	33.598	33.552	33.586
8.5	11.477	11.427	11.468	11.507	11.444	11.416	33.600	33.596	33.595	33.599	33.563	33.591
9.0	11.479	11.399	11.441	11.504	11.436	11.404	33.601	33.595	33.596	33.600	33.566	33.596
9.5	11.473	11.389	11.404	11.498	11.436	11.399	33.601	33.595	33.594	33.600	33.569	33.597
10.0	11.467	11.385	11.394	11.483	11.442	11.385	33.601	33.596	33.594	33.594	33.570	33.596
10.5	11.451	11.380	11.391	11.435	11.442	11.385	33.600	33.595	33.595	33.566	33.570	33.596
11.0	11.443	11.381	11.388	11.395	11.430	11.381	33.599	33.595	33.595	33.548	33.571	33.596
11.5	11.422	11.379	11.380	11.392	11.425	11.369	33.598	33.595	33.594	33.558	33.573	33.594
12.0	11.399	11.380	11.376	11.368	11.432	11.356	33.597	33.596	33.594	33.569	33.571	33.593
12.5	11.393	11.377	11.373	11.359	11.413	11.354	33.596	33.596	33.594	33.580	33.578	33.592
13.0	11.386	11.378	11.371	11.360	11.418	11.346	33.596	33.596	33.594	33.575	33.586	33.592
13.5	11.387	11.378	11.369	11.364	11.391	11.343	33.596	33.596	33.594	33.565	33.590	33.591
14.0	11.381	11.377	11.370	11.358	11.379	11.337	33.596	33.595	33.594	33.578	33.591	33.591
14.5	11.380	11.377	11.370	11.371	11.356	11.327	33.596	33.595	33.594	33.556	33.591	33.590
15.0	11.381	11.378	11.371	11.374	11.342	11.323	33.596	33.595	33.594	33.553	33.590	33.590
15.5	11.383	11.381	11.372	11.359	11.344	11.322	33.596	33.596	33.594	33.575	33.590	33.589
16.0			11.369	11.358	11.333	11.324			33.594	33.579	33.590	33.590

Table 5. Vertical Profile Data Collected on 30 June 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		25.087			25.125			8.201			8.168	
1.0	25.095	25.099	25.108	25.110	25.120	25.126	8.206	8.203	8.204	8.193	8.182	8.181
1.5	25.098	25.112	25.121	25.118	25.123	25.129	8.206	8.202	8.204	8.193	8.183	8.179
2.0	25.117	25.133	25.131	25.160	25.145	25.128	8.206	8.196	8.199	8.187	8.178	8.179
2.5	25.140	25.152	25.145	25.248	25.225	25.132	8.194	8.183	8.189	8.165	8.167	8.179
3.0	25.194	25.211	25.194	25.383	25.334	25.140	8.176	8.166	8.172	8.141	8.147	8.175
3.5	25.349	25.346	25.324	25.456	25.455	25.170	8.157	8.140	8.154	8.107	8.127	8.173
4.0	25.473	25.464	25.452	25.498	25.489	25.369	8.125	8.102	8.120	8.076	8.082	8.163
4.5	25.533	25.524	25.514	25.532	25.513	25.476	8.076	8.067	8.088	8.050	8.049	8.137
5.0	25.550	25.552	25.547	25.554	25.517	25.531	8.045	8.038	8.055	8.021	8.019	8.084
5.5	25.564	25.566	25.562	25.569	25.543	25.557	8.023	8.014	8.028	8.003	7.990	8.036
6.0	25.577	25.578	25.573	25.574	25.556	25.562	8.000	7.996	8.006	7.993	7.974	8.006
6.5	25.584	25.583	25.578	25.575	25.562	25.577	7.986	7.982	7.995	7.983	7.957	7.979
7.0	25.589	25.587	25.582	25.576	25.566	25.590	7.978	7.969	7.983	7.970	7.947	7.966
7.5	25.592	25.592	25.585	25.587	25.566	25.591	7.970	7.960	7.974	7.962	7.938	7.956
8.0	25.596	25.599	25.591	25.591	25.570	25.599	7.962	7.952	7.967	7.956	7.933	7.947
8.5	25.599	25.605	25.597	25.593	25.576	25.603	7.957	7.944	7.960	7.952	7.931	7.939
9.0	25.599	25.610	25.602	25.594	25.581	25.610	7.948	7.937	7.953	7.947	7.929	7.933
9.5	25.601	25.612	25.608	25.595	25.583	25.611	7.942	7.930	7.945	7.943	7.928	7.930
10.0	25.602	25.612	25.610	25.594	25.582	25.613	7.939	7.924	7.940	7.943	7.927	7.925
10.5	25.604	25.613	25.611	25.581	25.583	25.613	7.938	7.922	7.936	7.936	7.925	7.924
11.0	25.605	25.612	25.611	25.574	25.585	25.613	7.935	7.921	7.927	7.928	7.923	7.922
11.5	25.608	25.613	25.612	25.582	25.587	25.614	7.933	7.917	7.926	7.925	7.922	7.920
12.0	25.611	25.614	25.613	25.595	25.585	25.616	7.930	7.916	7.922	7.920	7.922	7.920
12.5	25.612	25.614	25.614	25.605	25.594	25.616	7.925	7.915	7.920	7.917	7.922	7.917
13.0	25.613	25.614	25.614	25.601	25.599	25.617	7.924	7.914	7.919	7.914	7.920	7.915
13.5	25.612	25.614	25.614	25.593	25.607	25.617	7.918	7.913	7.918	7.911	7.919	7.913
14.0	25.613	25.614	25.614	25.604	25.610	25.618	7.917	7.912	7.914	7.909	7.918	7.913
14.5	25.613	25.614	25.614	25.584	25.614	25.619	7.915	7.910	7.914	7.906	7.915	7.911
15.0	25.613	25.614	25.614	25.582	25.616	25.619	7.912	7.909	7.911	7.906	7.912	7.910
15.5	25.613	25.613	25.614	25.601	25.616	25.619	7.906	7.905	7.911	7.905	7.907	7.909
16.0			25.614	25.604	25.617	25.619			7.906	7.904	7.906	7.903

Table 5. Vertical Profile Data Collected on 30 June 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		10.365			9.983			81.031			77.559	
1.0	10.352	10.121	10.221	10.146	9.904	9.772	80.116	80.740	80.121	79.935	77.870	77.024
1.5	10.164	9.756	9.848	9.475	9.542	9.782	80.260	80.518	80.249	79.725	78.050	76.946
2.0	9.715	9.443	9.446	9.030	9.046	9.657	80.270	79.664	79.645	77.944	77.670	77.234
2.5	9.072	9.139	8.896	8.242	8.522	9.626	78.703	78.094	78.324	75.833	75.978	77.254
3.0	8.532	8.432	8.121	7.907	7.193	9.357	77.014	76.215	76.641	79.573	77.289	77.294
3.5	7.328	7.689	7.349	7.475	7.217	7.687	77.677	79.140	75.999	83.499	80.056	77.142
4.0	7.005	7.079	7.068	7.172	6.928	6.567	80.781	83.486	79.487	84.514	82.507	77.768
4.5	6.801	6.721	6.745	6.952	6.761	6.410	82.437	84.299	83.030	84.192	84.046	78.514
5.0	6.637	6.653	6.622	6.713	6.489	6.258	83.154	83.921	83.503	83.572	83.999	83.144
5.5	6.520	6.493	6.502	6.669	6.322	6.206	83.832	84.274	83.974	83.758	84.130	84.819
6.0	6.454	6.447	6.480	6.572	6.100	6.186	84.093	84.610	83.758	84.664	84.132	84.616
6.5	6.413	6.393	6.463	6.401	6.037	6.143	84.475	84.900	84.603	84.333	84.009	84.634
7.0	6.369	6.307	6.417	6.437	6.018	6.158	84.670	84.744	84.864	84.360	84.242	85.641
7.5	6.274	6.193	6.302	6.398	6.075	6.103	84.500	84.660	84.632	84.823	84.297	85.325
8.0	6.245	6.104	6.199	6.365	6.141	6.087	84.496	84.867	84.910	84.858	84.438	85.517
8.5	6.236	6.013	6.119	6.359	6.112	6.058	84.391	85.765	85.041	85.023	84.706	85.686
9.0	6.220	5.986	6.022	6.328	6.107	6.047	84.429	86.325	85.845	85.144	85.048	85.839
9.5	6.208	5.979	6.020	6.267	6.119	6.015	84.548	86.275	86.224	85.256	84.910	86.083
10.0	6.174	5.967	6.014	6.097	6.116	6.012	84.858	86.267	86.052	85.167	84.701	86.150
10.5	6.136	5.971	6.020	5.935	6.090	6.002	85.420	85.995	86.428	85.333	84.930	85.838
11.0	6.072	5.967	5.984	5.960	6.080	5.979	85.566	86.207	86.139	84.406	84.841	85.781
11.5	5.994	5.962	5.968	5.928	6.088	5.937	85.755	85.748	85.768	84.740	84.887	85.984
12.0	5.989	5.954	5.957	5.880	6.043	5.945	86.347	86.213	85.866	84.447	85.055	85.782
12.5	5.969	5.948	5.934	5.885	6.071	5.940	86.212	86.314	85.736	84.554	85.040	85.524
13.0	5.986	5.952	5.924	5.893	6.023	5.924	86.190	86.140	85.959	85.409	85.507	85.737
13.5	5.944	5.936	5.916	5.877	5.991	5.910	86.091	86.104	85.860	84.564	85.430	85.421
14.0	5.925	5.923	5.911	5.887	5.929	5.895	86.095	85.885	85.795	84.912	85.297	85.509
14.5	5.925	5.923	5.909	5.892	5.854	5.869	86.055	85.897	85.474	84.717	85.336	85.407
15.0	5.906	5.911	5.903	5.880	5.884	5.852	85.761	85.607	85.407	84.133	84.899	85.274
15.5	5.939	5.916	5.881	5.880	5.839	5.838	85.738	85.367	85.278	84.153	84.557	85.047
16.0			5.921	5.876	5.857	5.849			85.310	84.293	84.353	84.451



Meanwhile, within the surface mixed layer, nutrient-rich seawater brought to the sea surface by the recent upwelling facilitated phytoplankton blooms that produced oxygen, consumed carbon dioxide (CO₂), and decreased water clarity (light blue lines). The presence of plankton within the transition zone (thermocline) caused an 8% 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 June 2015 survey, the plume rose through the water column as it was carried south. The sequence of events was captured by the successive salinity profiles at Stations RW4, RW5, and RW6 (green lines in Figure 6def). Close to the diffuser, and shortly after discharge, reduced salinity associated with the rising plume can be seen extending above the seafloor up to a depth of 11 m (Figure 6d). Farther south, at Station RW5 (Figure 6e), the low salinity signature associated with the plume had risen in the water column, and its upper portion had reached the 4-m trapping depth. Finally, as the lower portion of the plume continued to rise and reach the trapping depth, the plume began to spread laterally at Station RW6 (Figure 6f). At that point, the trapped plume had vertically compressed the ambient transition zone, and the thermocline (red line), halocline (black line), and DO vertical gradient (dark blue line) had become much sharper.

During most surveys, the water column exhibits some degree of gradual stratification below the thermocline. As ambient seawater at depth is entrained within the rising plume, its properties differ from the properties of the surrounding shallower seawater. As a result, the plume's entrainment signature is almost always apparent in the horizontal maps of all water properties generated by the tow surveys. However, during the June 2015 survey, the vertical profiles of ambient seawater properties exhibit surprisingly little variation between the seafloor and the sharp shallow thermocline (Figure 6abc). Consequently, at mid-depth, there is no entrainment signature of the plume in the lateral distributions of temperature (Figure 7a), DO (Figure 7e), and pH (Figure 7f). In contrast, the plume's low-salinity signature is readily apparent extending south of the diffuser structure in Figure 7b. The effluent's reduced density is also marginally visible at the same location in Figure 7c. These signatures also coincide with a very slight reduction in transmissivity in Figure 7d. This could have resulted from the increased particulate load associated with dilute effluent, but its amplitude is no larger than the variability in ambient transmissivity at that depth level (green shading to east of the discharge structure in Figure 7d).

The map of water properties produced by the shallow tow is even more unusual (Figure 8). There is virtually no convincing signature of the plume in any of the seawater properties, not even salinity (Figure 8b). In nearly all of the past surveys, the plume's presence in the survey area has been well delineated by its low salinity in both the shallow and mid-depth tow maps. The only conclusion is that the plume was not present at the 3.5 m depth of the shallow tow during the June 2015 survey. In fact, as discussed previously, the plume signature was not evident in the shallow tow data because it had been trapped at a depth of 4 m (*cf.* the sharp reduction shown by the green profile shown in Figure 6f).

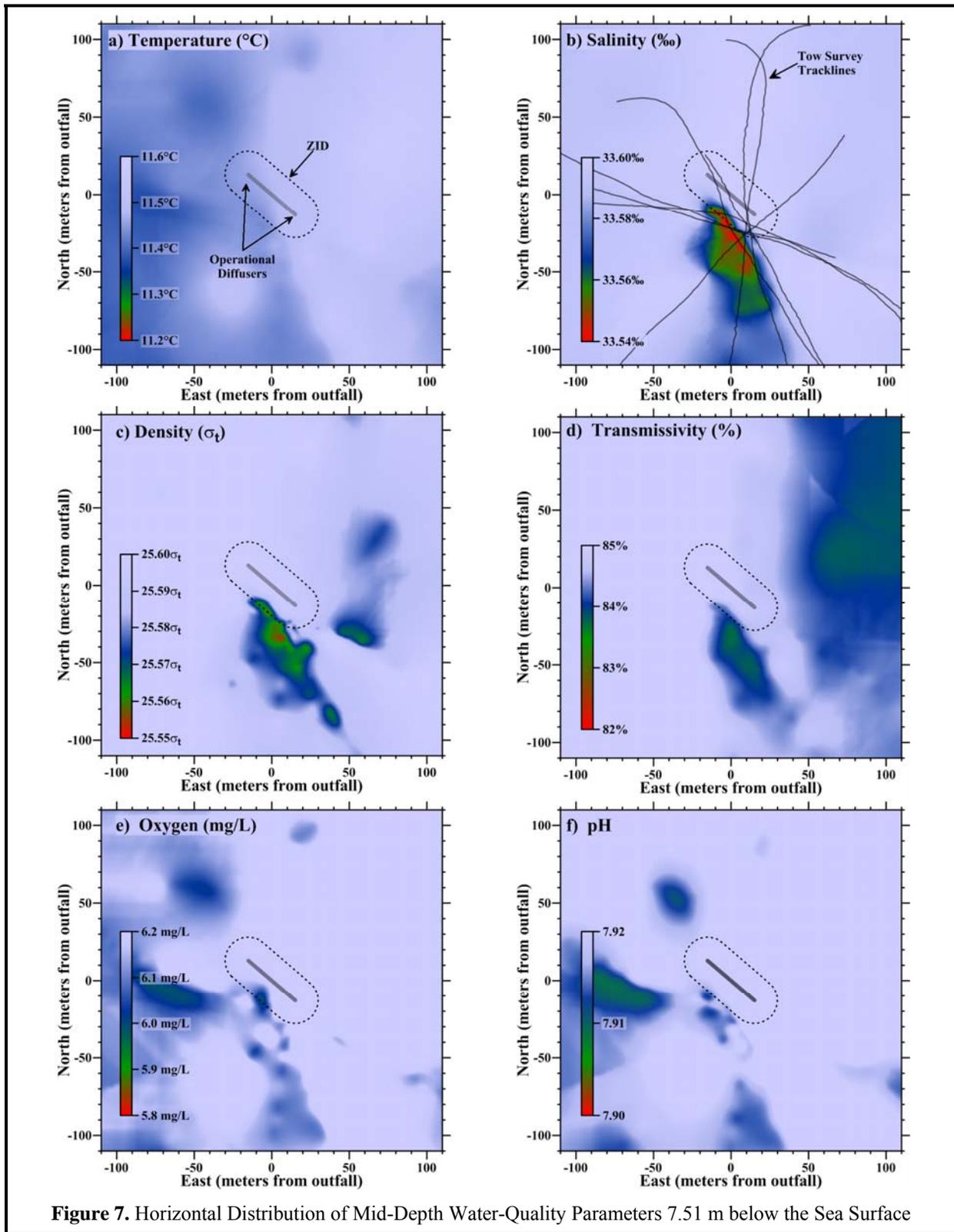


Figure 7. Horizontal Distribution of Mid-Depth Water-Quality Parameters 7.51 m below the Sea Surface

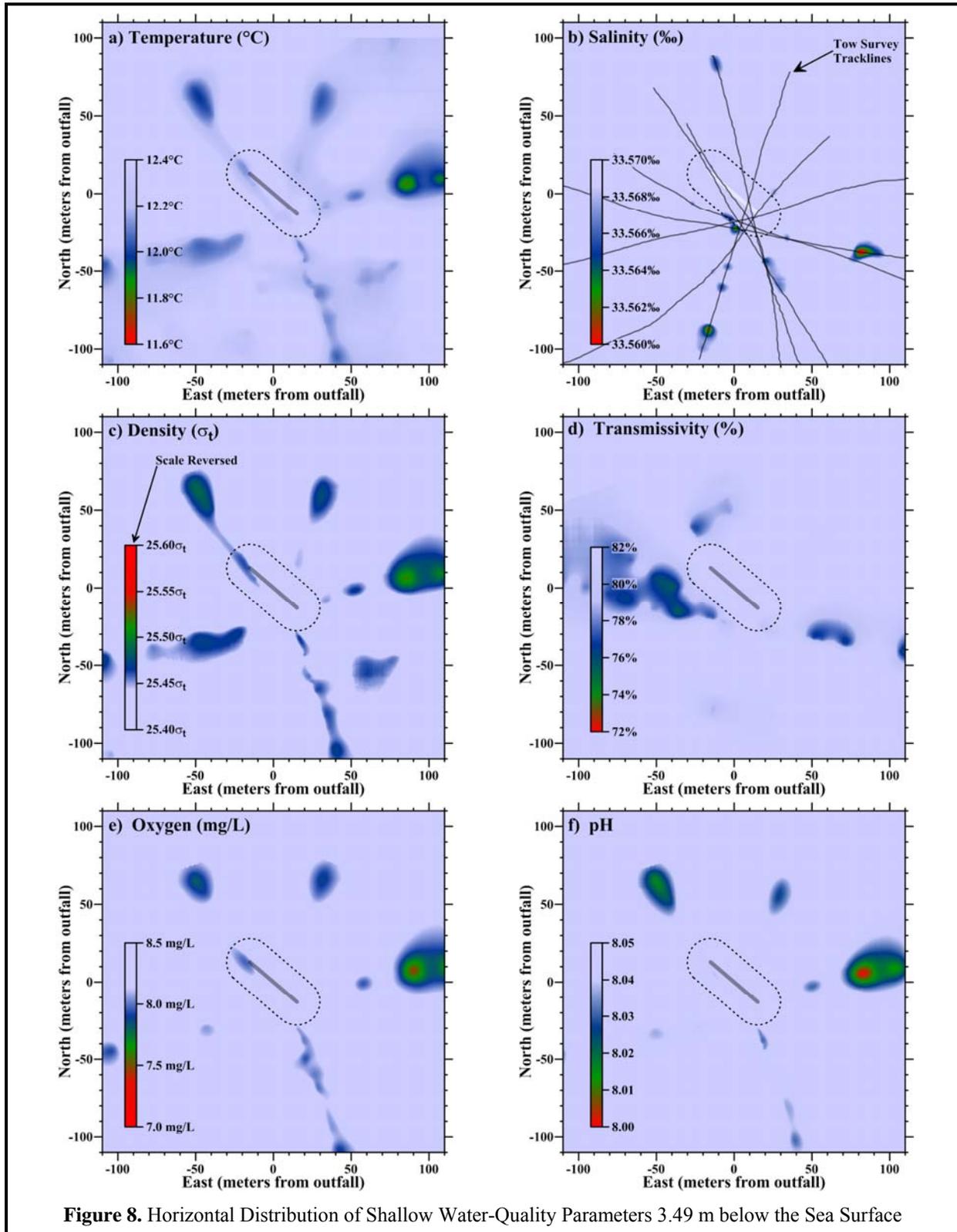


Figure 8. Horizontal Distribution of Shallow Water-Quality Parameters 3.49 m below the Sea Surface

The appearance of the shallow tow maps is unusual in another way. Most of the property maps exhibit similar patterns of collinear patchiness, especially at locations distant from the diffuser structure. These patches resulted because the 3.5 m average depth of the tow was directly within the thermocline where strong vertical gradients in most seawater properties were present (Figure 6). The patchy variations in the shallow horizontal maps were caused by very slight changes in tow depth that amplified into 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 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.

Outfall Performance

The efficacy of the outfall can be evaluated through a comparison of dilution levels measured at the time of the June 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 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, however, the dilution levels observed during the June 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.

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

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

By rearranging Equation 1, the actual dilution achieved by the outfall can be determined from measured seawater anomalies. This measured dilution can then be compared with the critical dilution determined from 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 tow-survey map (Figure 7b) were induced by the presence of very dilute wastewater. This salinity anomaly documented mixing processes within the effluent plume after it had risen 8.5 m through the water column and before it had completed the initial dilution process. As described previously, the plume continued to rise another 3.5 m before becoming trapped at a depth of 4 m.

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

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

The salinity concentration within MBCSD effluent (C_e)¹⁶ is generally small compared to that of the receiving seawater and, after dilution by more than 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.

The lowest salinity (33.51‰) measured during the June 2015 survey was recorded 15.2 m south of the diffuser structure at a depth of 7.4 m during the seventh transect of the mid-depth tow survey (red shading in Figure 7b). This measured salinity corresponds to a 0.086‰ reduction below the mean ambient salinity of 33.596‰ 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 379-fold (Figure 9). This is nearly three-times higher than 133:1 critical initial dilution used to establish limits on contaminant concentrations in wastewater.

In addition, the lowest dilution was measured at a depth one meter 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.

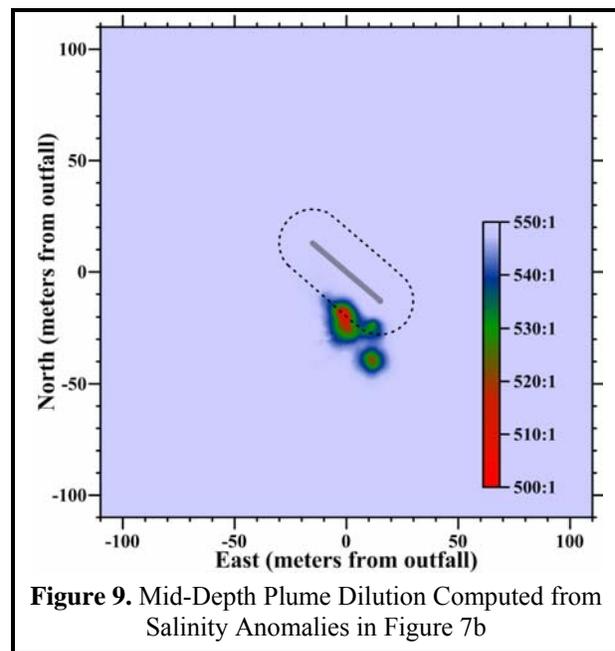


Figure 9. Mid-Depth Plume Dilution Computed from Salinity Anomalies in Figure 7b

¹⁶ Wastewater samples have an average salinity of 0.995‰.

The dilution computations demonstrate that, during the June 2015 survey, the outfall was performing better than designed and was rapidly diluting effluent more than 379-fold shortly after discharge, and well before completion of the initial-dilution process. The measured dilution levels throughout the survey easily exceeded the 133:1 critical initial dilution used to establish end-of-pipe permit limitations on contaminant concentrations within wastewater discharged from the MBCSD treatment plant. Consequently, during the June 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 June 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 June 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 June 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 10,253 CTD measurements collected during the June 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		Parameter
		No	Yes ¹⁷	
Location	1. Was the measurement collected beyond the 15.2-m ZID boundary where modeling assumes that initial dilution is complete?	1,474	8,779	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?	8,729	50	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?	50	0	Temperature
		50	0	Transmissivity
		50	0	DO
		50	0	pH

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

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 June 2015 dataset eliminated 1,474 of the original 10,253 receiving-water observations from further consideration because they were collected within the ZID (Table 7, Question 1). The remaining 8,779 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, 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 9, discharge-related salinity anomalies measured during the survey were largely restricted to a localized area along the southern boundary of the ZID. Only fifty of these had significant reductions in salinity that unequivocally identified the presence of dilute wastewater

constituents beyond the ZID. The remaining 8,729 observations that were measured outside the ZID during the June 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 surrounding the outfall (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 (\pm 0.094). These were combined with 95th percentiles determined from the June 2015 ambient seawater data, to establish time-specific natural-variability thresholds in a manner analogous to COP Appendix VI. The percentiles were determined from June 2015 vertical profile data collected at upstream Stations RW1, RW2, and RW3, thereby excluding measurements potentially affected by the discharge.

Table 8. Compliance Thresholds

Water Quality Property	95% Confidence Bound ¹⁸	95 th Percentile ^{19,20}	Natural Variability Threshold ²¹	COP Allowance ²²	Basin Plan Limit ²³	Extremum ²⁴
Temperature (°C)	0.82	13.91	>14.73	—	—	≤14.07
Transmissivity (%)	-10.2	77.8	<67.5	—	—	≥73.9
DO (mg/L)	-1.38	5.87	<4.49	<4.04	<5.00	≥5.84
pH (minimum)	-0.094	7.909	<7.815	<7.615	<7.000	≥7.903
pH (maximum)	0.094	8.202	>8.296	>8.496	>8.300	≤8.206

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

¹⁹ The COP (Appendix I, Page 27, SWRCB 2005) defines a “significant” difference as “a statistically significant difference in the means of two distributions of sampling results at the 95% confidence level.” Accordingly, COP effluent analyses (Step 9 in Appendix VI, Page 42, Ibid.) are based “the one-sided, upper 95% confidence bound for the 95th percentile.”

²⁰ The 95th-percentile quantifies natural variability in seawater properties during the June 2015 survey, and was determined from vertical-profiles data unaffected by the discharge.

²¹ Thresholds represent limits on wastewater-induced changes to receiving-water properties that significantly exceed natural conditions as specified in the discharge permit and COP. They are determined from the sum of columns to the left and are specific to the June 2015 survey. They do not include the COP allowances specified in the column to the right.

²² The discharge permit, in accordance with the COP, allows excursions in seawater properties that depart from natural conditions by specified amounts. DO cannot be “depressed more than 10% from that which occurs naturally,” and pH cannot be “changed more than 0.2 units from that which occurs naturally.”

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

²⁴ Maximum or minimum value measured during this survey

Temperature, transmissivity, pH, and DO concentrations associated with the 50 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 June 2015 survey from further consideration.

In fact, excursions in these properties for all 10,253 measurements collected during the June 2015 survey were within the range that arises from physical processes unrelated to the discharge of effluent. 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.

Other Lines of Evidence

Several additional lines of evidence further support the conclusion that all the CTD measurements collected during the June 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 June 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 14.73°C in Table 8). However, none of the 10,253 CTD measurements collected during the June 2015 survey exceeded 14.07°C (last column in Table 8). Additionally, because effluent entrains cooler bottom water shortly after discharge, the rising plume usually exhibits slightly lower temperature than the surrounding seawater in the upper water column.

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 June 2015 survey fell below the 67.5% minimum compliance threshold. The lowest transmissivity measured during the survey was 73.9%.

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 30 June 2015 was only 32 mg/L. After dilution by 379-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 was

overwhelmed by the large 8% 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, 39-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 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 7.615 during the June 2015 survey (fourth data column of Table 8). This limiting value is significantly less than the lowest pH measurement of 7.903 recorded during the June 2015 survey (last column of Table 8). Similarly, the lowest DO concentration measured during the survey (5.84 mg/L) was well above both the lower range in natural variation (4.49 mg/L) and the 10% compliance threshold promulgated by the COP (4.04 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 regard 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). Nevertheless, all of the June 2015 survey measurements complied with the Basin-Plan limits, including the more-restrictive limit on maximum pH.

CONCLUSIONS

The quantitative screening analysis demonstrated that all measurements recorded during the June 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 June 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.

As the dilute effluent plume rose through the water column and well before completion of the initial dilution process at a trapping depth of 4 m, measured dilutions levels reached 378-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. Lastly, all of

the auxiliary observations collected during the June 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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