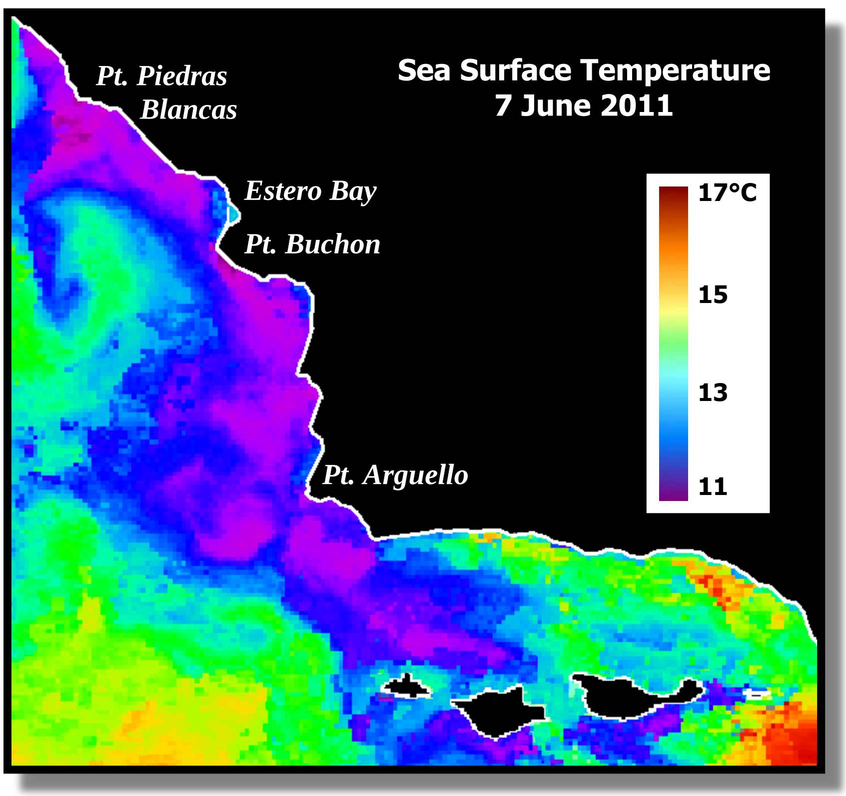
City of Morro Bay and
Cayucos Sanitary District

OFFSHORE MONITORING AND REPORTING PROGRAM

SECOND QUARTER RECEIVING–WATER SURVEY

JUNE 2011



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Report to the

City of Morro Bay and Cayucos Sanitary District

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SECOND QUARTER RECEIVING–WATER SURVEY

JUNE 2011

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

19 July 2011

Reference: Second Quarter Receiving-Water Survey Report – June 2011

Dear Mr. Keogh:

The attached report presents results from a quarterly receiving-water survey conducted on Wednesday, 22 June 2011. The survey was conducted in accordance with the requirements of the NPDES permit issued to the City and District for discharge of treated wastewater to Estero Bay. The report evaluated compliance with permit limitations and assessed the effectiveness of effluent dispersion. Quantitative analyses of continuous instrumental measurements and qualitative visual observations confirm that the wastewater discharge complied with the receiving-water limitations specified in the permit, and with the objectives of the California Ocean Plan.

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

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

Sincerely,

Bonnie Luke
Program Manager

(Submitted Electronically)

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

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

Date ______________________________

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INTRODUCTION

The City of Morro Bay and the Cayucos Sanitary District (MBCSD) jointly own the wastewater treatment plant operated by the City of Morro Bay. In March 1985, Region IX of the U.S. Environmental Protection Agency (USEPA) and the Central Coast California Regional Water Quality Control Board (RWQCB) issued the first National Pollutant Discharge Elimination System (NPDES) permit to the MBCSD. The permit incorporated partially modified secondary treatment requirements for the plant's ocean discharge. The permit has been re-issued three times, in March 1993 (RWQCB-USEPA 1993ab), December 1998 (RWQCB-USEPA 1998ab), and January 2009 (RWQCB-USEPA 2009). The June 2011 field survey described in this report was the ninth 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 22 June 2011. Specifically, this second-quarter survey captured ambient oceanographic conditions along the central California coast at the close of 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 evaluating empirical tabulations of instrumental measurements and standard field observations. In addition to the traditional, vertical water-column profiles, instrumental measurements were used to generate horizontal maps from high-resolution data gathered by towing a CTD[1] instrument package repeatedly over the diffuser structure. This allowed for a more precise determination of the plume's lateral extent.

SURVEY SETTING

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

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

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

Figure 1. Location of the Receiving-Water Survey Area

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

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

SAMPLING LOCATIONS

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

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

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

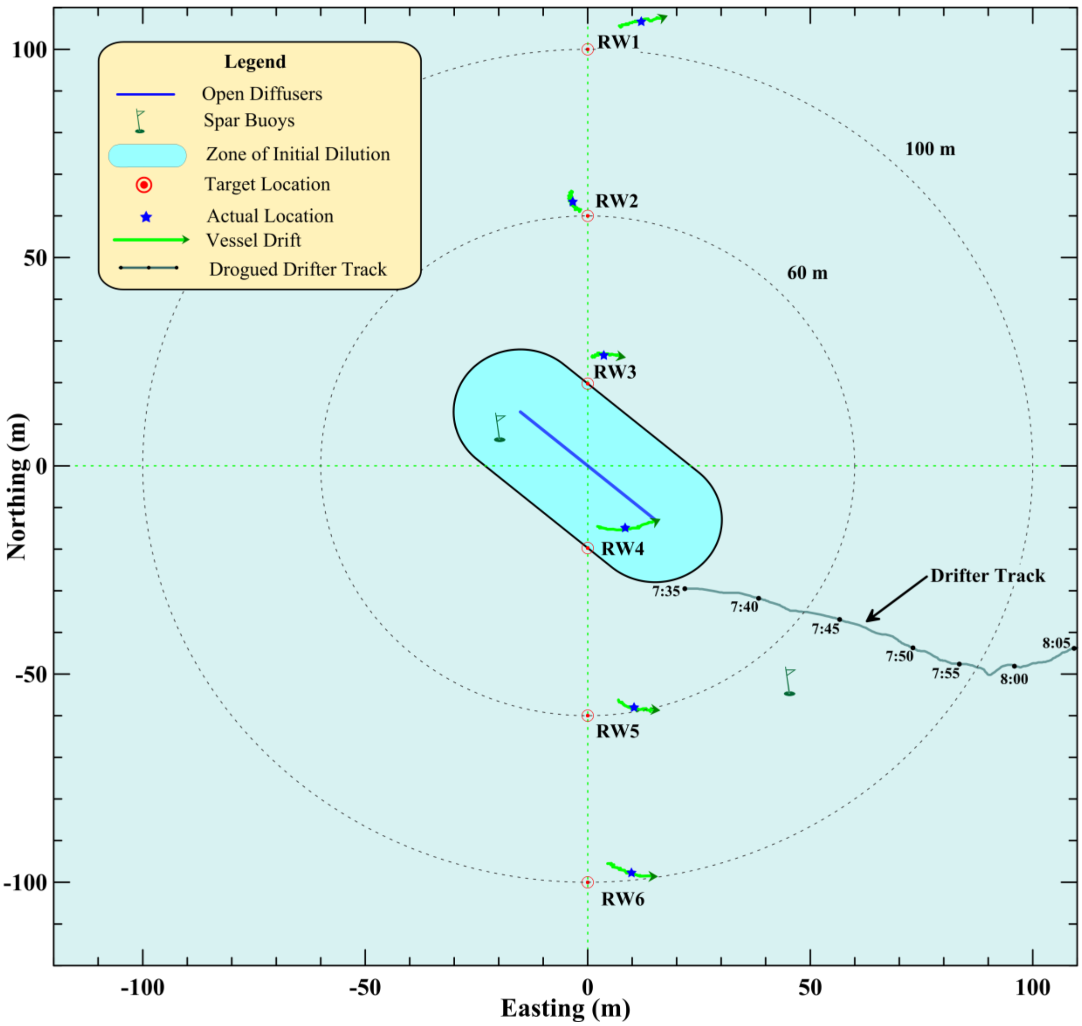

Figure 2. Sampling Station Locations and Drifter Track

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

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

[2] Distance to the center of the open diffuser section
[3] Distance to the closest open diffuser port

During a diver survey in July 1998, the survey vessel's DGPS navigation system, consisting of a Furuno™ GPS 30 and FBX2 differential beacon receiver, was used to precisely determine the position of the open section of the diffuser structure (MRS 1998) and establish the target locations for the receiving-water monitoring stations shown in Figure 2 and listed in Table 1. Currently, use of two independent DGPS receivers on the survey vessel allows access to two separate land-based beacons for navigational comparison, ensuring extremely accurate and uninterrupted navigational reports.

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

The magnitude of the drift at each of the six stations during the June 2011 survey is apparent from the length of the green tracklines in Figure 2. These tracklines trace the horizontal movement of the CTD as it was lowered to the seafloor. Their length and offset from the target locations reflect the overall station-keeping ability during the June 2011 survey. During the time it took the CTD to traverse the water column and reach the seafloor, which averaged 1 min 07 s, the instrument package moved an average of 8.8 m. This amount of drift is comparable to that of most prior surveys conducted under similarly quiescent oceanographic conditions.

The CTD trajectories shown by the tracklines in Figure 2 reflect complex interactions between surface currents, wind forces, and any residual momentum of the survey vessel as it approached each station during the June 2011 survey. For example, vessel drift at most stations was toward the east, in a direction consistent with subsurface current measured by the drogue drifter. Generally, winds affect the vessel's ability to maintain station to a greater degree than does current flow, however, this was not the case with during the June survey because winds were light throughout the survey.

Lateral drift of the CTD during the vertical hydrocasts frequently complicates the assessment of compliance with discharge limitations at stations close to the diffuser structure. This is because the receiving-water limitations specified in the COP only apply to measurements recorded beyond the ZID boundary, where initial mixing is assumed complete. For example, during the June 2011 survey, none of the measurements acquired at Station RW4 were subject to the limitations because the CTD was within the ZID boundary throughout the entire downcast.

Determining which measurements are subject to permit limits within hydrocasts near the ZID boundary only became possible after the advent of DGPS. Prior to 1999, CTD locations could not be determined with sufficient accuracy or precision to establish whether a station was located within the ZID, much less how the CTD was moving laterally during the hydrocast. Because of these navigational limitations, sampling was presumed to occur at a single, imprecisely determined, horizontal location. Federal and State reporting of monitoring data still mandates identification of a single position for all of the CTD data collected at a particular station. Thus, for regulatory reporting, and for consistency with past surveys, the June 2011 survey also identifies a single sampling location for each station. These average station positions are shown by blue stars in Figure 2, and are listed in Table 2 with their distances from the diffuser structure.

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

Compliance assessments notwithstanding, measurements acquired from 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.

Table 2. Average Position of Vertical Profiles during the June 2011 Survey

Station	Time (PDT)		Latitude	Longitude	Closest Approach	
	Downcast	Upcast			Range[5] (m)	Bearing[6] (ºT)
RW1	7:45:58	7:47:06	35° 23.257' N	120° 52.496' W	97.7	16
RW2	7:50:02	7:51:10	35° 23.233' N	120° 52.506' W	51.9	13
RW3	7:53:57	7:55:05	35° 23.213' N	120° 52.502' W	22.6	41
RW4	7:57:29	7:58:43	35° 23.191' N	120° 52.498' W	**5.8**[7]	221
RW5	8:01:13	8:02:17	35° 23.168' N	120° 52.497' W	45.2	186
RW6	8:04:44	8:05:46	35° 23.146' N	120° 52.498' W	84.8	184

Analysis of the outfall's operation over the past two decades, however, suggests that it has maintained a high level of effectiveness in effluent dispersal. In fact, without the occasional measurements recorded within the ZID due to CTD drift, the extremely dilute discharge plume might remain undetected within all vertical profiles collected during a given survey.

OCEANOGRAPHIC PROCESSES

The trajectory of a satellite-tracked drogued drifter documented a weak eastward flow throughout much of the June 2011 survey (Figure 3). Modeled after the curtain-shade design of Davis et al. (1982) and drogued at mid-depth (7 m), a drifter has typically been deployed during each of the quarterly water column surveys conducted over the past decade. In this configuration, the oceanic flow field rather than surface winds dictates the drifter's trajectory, providing a good assessment of the plume's movement following discharge.

The drifter was deployed just south of the ZID at 07:34 PDT, and was recovered slightly more than two hours later, at a location 212 m east of its initial location. Figure 3 highlights the two distinct phases that characterized the drifter's movements during the survey: an initial, eastwardly steady-transport phase; and a second, stationary phase. The dots in Figure 3 show the drifter's progress at five-minute intervals, with the alternating green dots representing 10-minute intervals.

During the first hour and twenty minutes, the uniform spacing of the time stamps reflects the relatively constant speed of the drifter, which averaged 4.2 cm/s, or 0.08 knots. At this speed, the plume would have traversed the ZID in just under six minutes. However, as seen in Figure 3, the drifter's path during this time was not entirely unidirectional. Therefore, the actual drifter speed was slightly faster than 4.2 cm/s. Beginning at 09:00 PDT, at the start of the deep tow survey, the drifter's eastward movement suddenly stalled, and the drifter remained within the same limited area until its recovery at 09:46 PDT. The drifter stagnation coincided with the low-flow conditions during the slack tide that occurs with the approach of the tide changes, specifically, the low tide at 9:35 PDT (Figure 4).

[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 cast at Station RW4 was located within the ZID boundary.

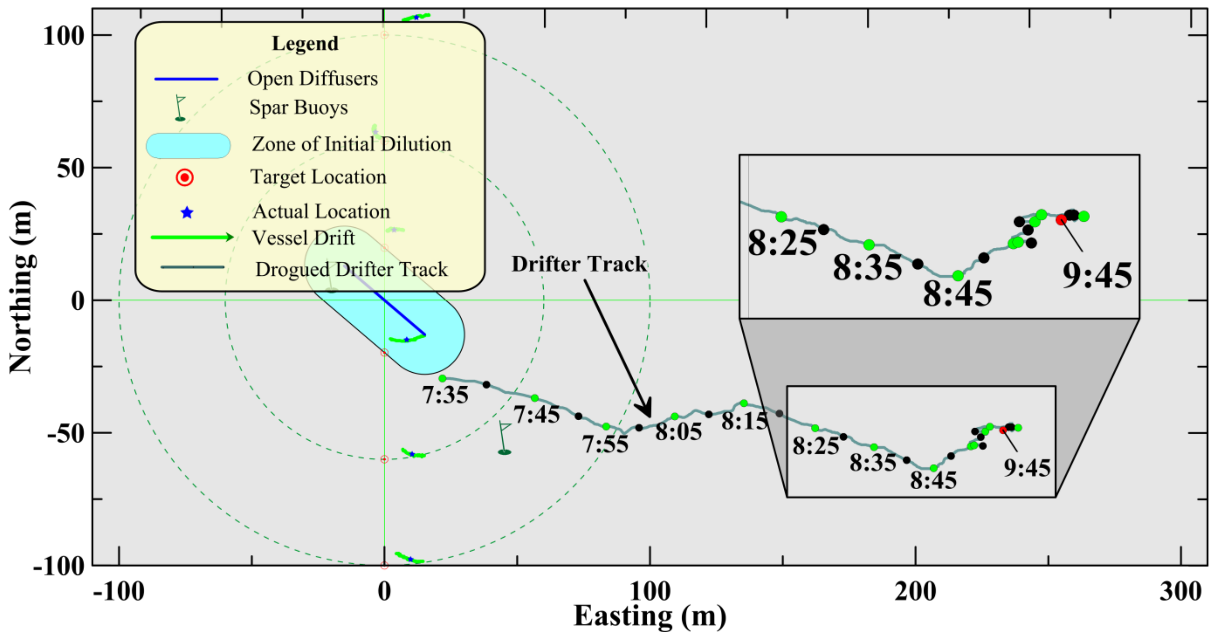

Figure 3. Drogued Drifter Trajectory

Although the initial portion of the drifter track had slight but intermittent southerly excursions, mid-level flow was predominately eastward (onshore). This movement was inconsistent with the outgoing (ebb) tide. In the absence of other influences, an ebb tide typically induces a weak soutwestward (offshore) flow in the survey region while an incoming (flood) tide results in a northeastward (onshore) flow. However, flow within Estero Bay is more-often dominated by external processes, such as wind-generated upwelling, downwelling, or the passing of offshore eddies propagating along the coastline. Upwelling, for example, induces a weak southwesterly (offshore) flow in the upper water column.

Upwelling season normally begins sometime during late March and or early April as shown by the positive (blue) upwelling indices in Figure 5. At the onset of upwelling season, there is a spring transition

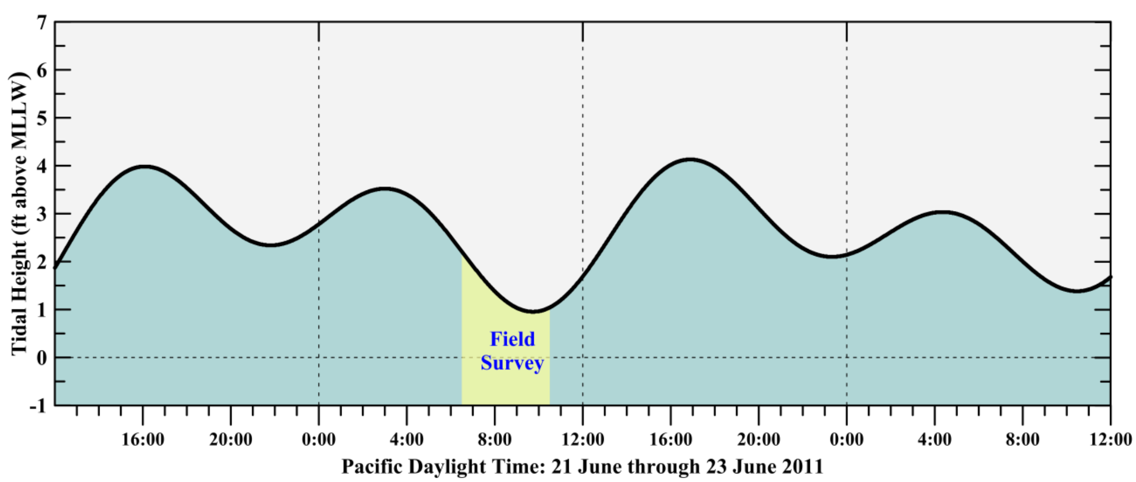

Figure 4. Tidal Level during the June 2011 Survey

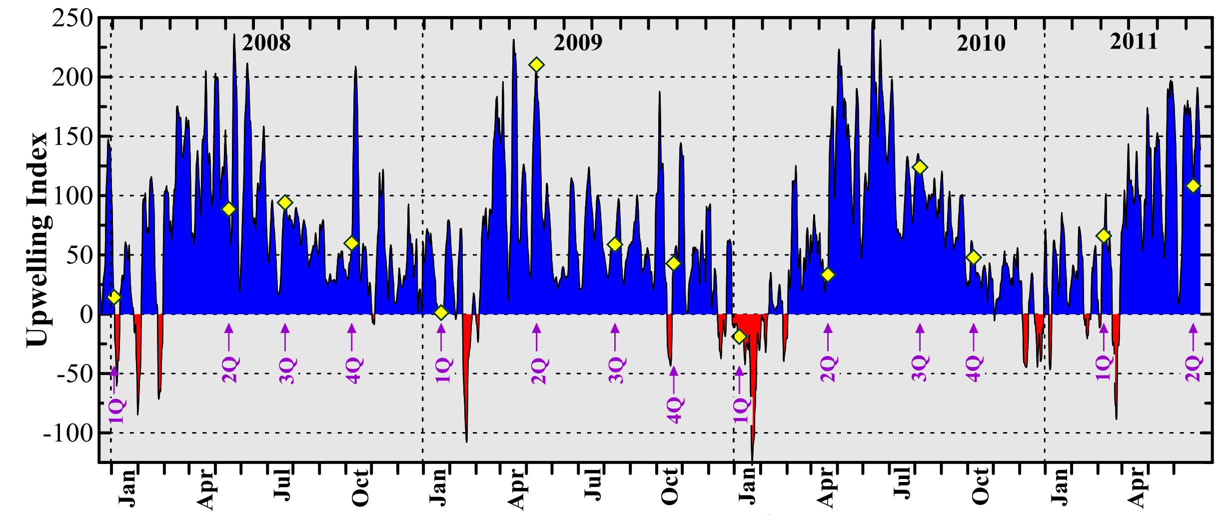

Figure 5. Five-Day Average Upwelling Index ($m^3/s/100m$ of coastline)

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

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

In contrast, downwelling events, indicated by the negative (red) indices in Figure 5, occur infrequently, and almost exclusively in winter, when passing storms temporarily reverse the normal wind pattern and drive surface waters shoreward. As the surface waters approach the coastline, they downwell, producing nearly uniform seawater properties throughout the water column.

The satellite image on the cover of this report documents the upwelling that was present two weeks prior to the survey, on 7 June 2011, when skies were clear enough for sea-surface temperatures to be measured by infrared sensors on one of NOAA's polar orbiting satellites. As is apparent in the cover image, the cool, nearshore sea-surface temperatures (~12˚C) within Estero Bay were slightly cooler than the near-surface temperatures measured by the CTD (13.5˚C) during the June 2011 survey.[8]

Although mild southward winds prevailed on the morning of the June 2011 survey, strong southeastward winds prevailed along the central California coast throughout most of the month of June, resulting in cooler sea surface temperatures close to the coastline, while farther offshore, surface water temperatures were several degrees warmer,

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

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, 22 June 2011. Bonnie Luke of Marine Research Specialists (MRS) was Chief Scientist and collected auxiliary measurements of biological, meteorological, and oceanographic conditions. Douglas Coats, also of MRS, provided navigational support during the survey. William Skok assisted with deployment and recovery of the CTD and drifter. Mr. Bruce Keogh, the MBCSD Wastewater Division Manager, monitored operations onboard the vessel as client inspector.

Auxiliary Measurements

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

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

Instrumental Measurements

A Sea Bird Electronics SBE-19 Seacat CTD instrument package collected measurements of conductivity, temperature, light transmittance, dissolved oxygen (DO), pH, and pressure at a sampling rate of 2 Hz (0.5-s intervals) at each of the six vertical sampling stations, as well as during the towed survey. A submersible pump on the CTD continuously flushed water through the conductivity cell and oxygen plenum at a constant rate, independent of the CTD’s motion through the water column.

The CTD instrument package receives regular maintenance and calibration. After the January 2001 survey, the CTD was returned to the factory for comprehensive testing, repair, and calibration. The DO and pH sensors were returned to the factory in May 2003, June 2006, and May 2011 for testing and calibration. Because of increasing temporal drift associated with aging DO probes, the DO probe was replaced on each occasion. The CTD system was then recalibrated at the MRS laboratory prior to the June 2011 survey. The upper-bound DO calibration point at full saturation was established by immersing the CTD in an aerated, temperature-controlled calibration tank. Similarly, a zero-oxygen calibration point was determined by filling the oxygen-sensor plenum with an 8% solution of sodium sulfite (Na_2SO_3). Oxygen calibration coefficients were established through regression analysis of sensor-membrane current and temperature, as recommended by the manufacturer (SBE 1993). As in previous surveys, the calibration coefficients determined by MRS closely corresponded with prior factory calibrations.

Table 3. CTD Specifications

Component	Depth[9]	Units	Range	Accuracy	Resolution
Housing	600	—	—	—	—
Pump	3400	—	—	—	—
Pressure	680	Psia	0 to 1000	± 5.0	± 0.5
Depth	—	Meters	0 to 690	± 3.0	± 0.3
Conductivity	600	Siemens/m	0 to 6.5	± 0.001	± 0.0001
Salinity	600	‰	0 to 38	± 0.006	± 0.0006
Temperature	600	ºC	–5 to 35	± 0.01	± 0.001
Transmissivity	2000	%	0 to 100	± 0.1	± 0.025
Dissolved Oxygen	200	mg/L	0 to 21.5	± 0.14	± 0.014
Acidity/Alkalinity	200	pH	0 to 14	± 0.1	± 0.006

The six seawater properties used to assess receiving-water quality in this report were derived from the continuously recorded output of the CTD's probes and sensors. Pressure housing limitations on the combination oxygen/pH sensor confine the CTD to depths less than 200 m (Table 3), which 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 also listed in the table. 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).

All three of the physical parameters (salinity, temperature, and density) helped determine the lateral extent of the effluent plume during the towing phase of the survey. Additionally, during the vertical-profiling phase, they quantified layering, or vertical stratification and stability of the water column, which determines the behavior and dynamics of the effluent as it mixes with seawater within the ZID. Data on the three remaining seawater properties, light transmittance (water clarity), hydrogen-ion concentration (acidity/alkalinity – pH), and dissolved oxygen (DO), further characterized the receiving waters and were used to assess compliance with water-quality criteria. Light transmittance was measured as a percentage of the initial intensity of a transmitted beam of light detected at the opposite end of a 0.25-m path. Transmissivity readings are reported relative to 100% transmission in air. Therefore, transmission in pure water is 91.3% of the reported values for this transmissometer. Increased transmittance indicates increased water clarity and decreased turbidity.

During the calibration of the CTD, coefficients for the pH (alkalinity) sensor were determined from a linear regression of output voltage after immersion in four separate buffered solutions of known pH. Buffering solutions with a pH of 4±0.01, 6±0.01, 7±0.01, 8±0.01 and 9±0.02 were used to bracket the range of in situ measurements. The SeaTech transmissometer was air calibrated by fitting the voltages recorded with and without blocking of the light transmission path in air, as recommended by the manufacturer (SBE 1989). Algorithms that converted sensor voltage to engineering units during processing of the field data relied on calibration coefficients determined before the survey.

Comparison with the factory calibration of the entire CTD package conducted in December 2001, and the more recent May 2011 replacement and calibration of the DO probe, confirmed the continued accuracy and stability of the temperature, pressure, and conductivity sensors, as well as the operational integrity of the oxygen and pH probes. To correct for a slight drift in the pressure strain gauge since its calibration in 2001, a +0.25 Psia offset was incorporated in the conversion to depth measurements. In addition, a slight (0.044) temporal increase pH measurements arose from the sensor's ongoing equilibration between the vertical-profile and tow-survey deployments. This offset was removed prior to analysis of the time series.

9 Maximum depth limit in meters

Before initial deployment for the vertical hydrocasts, the CTD was held below the sea surface for a nine-minute equilibration period. Subsequently, the CTD was raised to within 0.5 m of the sea surface and profiling commenced. The CTD was lowered at a continuous rate of speed to the seafloor. Measurements at all six stations were collected during a single deployment of the CTD package by towing it below the water surface while transiting between adjacent stations.

At 08:06 PDT, following the last vertical profile at RW6, the CTD instrument package was brought onboard the survey vessel and fitted with a depth-suppressor wing and horizontal stabilizer. Ducting from the DO plenum to the pump was also disconnected. This configuration allowed the CTD to achieve constant-depth tows with uniform flow across forward-looking probes. The CTD was then towed continuously around and across the ZID at two separate depths in accordance with the receiving-water monitoring requirements of the NPDES discharge permit (Figure 6).

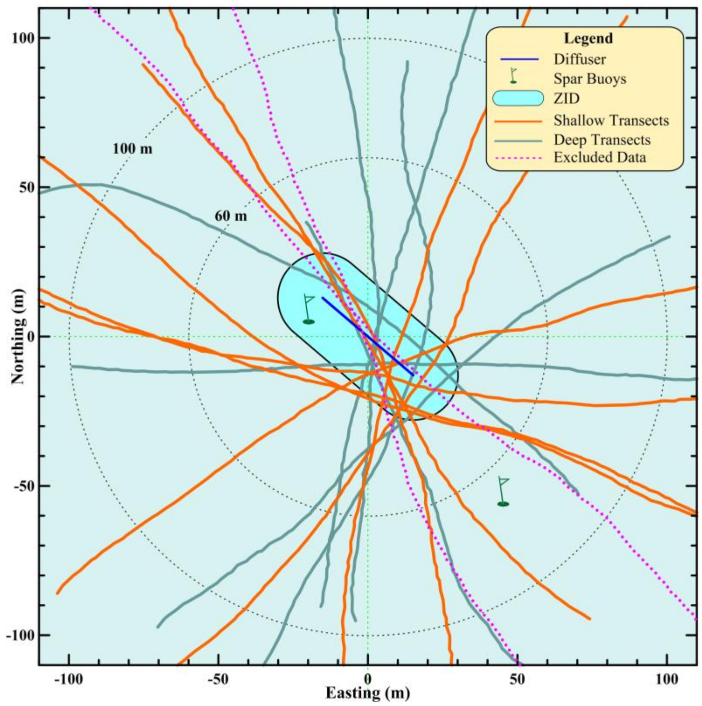

Figure 6. CTD Tracklines during the Tow Surveys

Initially, the reconfigured CTD package was towed for 29 min at an average depth of 5.44 m, and an average speed of 1.59 m/s, passing near the diffuser structure eight times. Subsequently, nine additional passes were made with the CTD at an average depth of 8.63 m.[10] During this 23-minute mid-depth-tow, vessel speed averaged 1.56 m/s. At the observed towing speeds and 2 Hz sampling rate, 1.3 CTD measurements were collected for each meter traversed, which complies with the permit requirement for at least one sample per meter. Contemporaneous navigation fixes recorded onboard the survey vessel were adjusted for CTD setback and aligned with time stamps on the internally recorded CTD data. The resulting data for the six seawater properties were processed to produce horizontal maps within the mid-depth and upper portions of the water column.[11]

Quality Control

Upon retrieval of the CTD following both the vertical casts and the horizontal tows, the data were downloaded to a portable computer and examined for completeness and range acceptability. Preliminary review revealed several events that impacted portions of the data, resulting in the adjustment or exclusion of these data prior to initiation of the compliance analysis.

[10] Average depth of the seven mid-depth tow transects evaluated in the compliance analysis. The first two transects, shown by the dashed lines in Figure 6, were removed from consideration due to a vertical offset in tow depth as described in the *Quality Control* section.

[11] Figures 8 and 9 present the horizontal maps of seawater properties measured during the tow-survey portion of the field survey.

For example, review of the tow survey data determined that the depths of the first and second transects of the mid-depth tow were offset from the remainder of tow data. Specifically, slightly increased vessel speeds during the first transect resulted in tow depths that were 0.5 m shallower than average, while slower speeds during the second transect resulted in a 0.5 m increase in tow depth compared to the average tow depths of the other transects. While these depth offsets appear small, the mid-depth tow was conducted within a region of sharp vertical gradients associated with upwelling-induced stratification. As a result, the slight depth offsets created artificial horizontal differences in the combined mid-depth data set. Because discharge-related anomalies are identified by comparing the amplitudes of measurements acquired at the same depth level, the ability to resolve anomalies with statistical certainty is compromised when data from different levels are combined, particularly when the water column is highly stratified as was the case during the June 2011 survey. Because of their depth offsets, data collected during Transects D1 and D2 were incompatible with the rest of the mid-depth tow data, and were excluded from the subsequent analysis to avoid introducing erroneous lateral differences in the horizontal property maps.[12] Exclusion of these transects, shown by the dotted purple lines in Figure 6, did not, however, adversely affect the compliance analysis because the remaining transects adequately covered the survey region. The remaining transects, shown by the solid orange and blue lines in Figure 6, also met the permit monitoring requirement of at least five passes near the diffuser structure at each tow depth.

Additional quality-control screening of the vertical profile data found that variation in total water depth due to passing waves, along with differences in how long the CTD is allowed to pause within the deepest bin, created differences in the maximum depth measured at individual stations. For example, during the June 2011 survey, data on average seawater properties were not recorded the below 15 m at any station except RW4 and RW5, while Station RW1 only had reliable data down to 14.5 m (Table 5). Although the bin-averages at the remaining five stations were sufficient to determine lateral variation from 14.5 m to 15 m, the inconsistent spatial coverage of the observations at 15.5 m could not adequately quantify horizontal trends, and the observations at this deepest depth were excluded from the subsequent compliance evaluation.

Further quality-control screening eliminated erroneous "salinity spikes." When the CTD crosses a sharp thermocline, the mismatch between the locations of the conductivity and the temperature probes on the CTD results in the sensors sampling parcels of water with entirely different properties, thereby creating erroneous spikes in computed salinity. This is particularly common with data obtained at shallow depths, where entrainment of ambient waters by the rising effluent plume has 'squeezed' the thermocline, making it sharper. Low-pass filtering of the time series of tow data and vertical smoothing of the profile data effectively mitigated the influence of salinity spikes that resulted from the significant vertical stratification present during the June 2011 survey.

Lastly, small jellyfish were prevalent throughout the water column during the June 2011 survey. Occasionally during the tow surveys, these jellyfish passed across the light path of the transmissometer, resulting in brief and large decreases in transmissivity. Because the vertical profiles spanned a relatively short period, no erroneous transmissivity measurements occurred from jellyfish encounters during that portion of the survey. However, out of the 3,970 tow measurements, 36 encounters with jellyfish resulted in the elimination of 49 erroneously low transmissivity measurements from the data set. The erroneous data were easily identified because the transmissivity reductions were both large in amplitude and very brief (generally $\leq$1 second) in duration, characteristics that are atypical of reductions in water clarity associated with encounters with dilute effluent particulates. Moreover, the erroneous data were distributed randomly throughout the survey area, with only four erroneous observations found within the area that coincided with the low-salinity signature of the dilute plume beyond ZID.

[12] Shown in Figures 8 and 9 on Pages 20 and 21

RESULTS

The second-quarter receiving-water survey began on Wednesday, 22 June 2011, at 07:34 PDT with the deployment of the drogued drifter. Over the following two hours and eleven minutes, offshore observations and measurements were collected as required by the NPDES monitoring program. The survey ended just after 09:46 PDT with the retrieval of the drogue drifter. Although heavily overcast, observations of beneficial use and the collection of required visual observations of the sea surface were unencumbered throughout the survey.

Auxiliary Observations

On the morning of 22 June 2011, skies were heavily overcast, with light but steady winds. Average wind speeds, calculated over one-minute intervals, ranged from 1.3 kt to 2.7 kt (Table 4). Similarly, peak wind speeds averaged from 1.6 kt to 3.3 kt. The swell was out of the northwest with a significant wave height of 2 to 3 feet. Air temperatures, which varied from 12.0°C to 12.3°C, were slightly cooler than the average sea-surface temperatures.

The 6-m Secchi depths recorded at most stations during the June 2011 survey indicated a moderate level of ambient water clarity (Table 4). The Secchi depths reflected the presence of a 12-m euphotic zone that spanned most of the 15-m water column. There was no evidence during the survey of floating particulates, oil sheens, or any discoloration of the sea surface associated with wastewater-related constituents. Communication with plant personnel during the survey and subsequent review of effluent discharge properties, confirm that the treatment process was performing nominally at the time of the survey.

During the June 2011 survey, visual observations demonstrated continued beneficial use of the coastal waters within Estero Bay by both wildlife and recreational users. Brandt’s cormorants (*Phalacrocorax penicillatus*), pelagic cormorants (*Phalacrocorax pelagicus*), western gulls (*Larus occidentalis*), and California brown pelicans (*Pelecanus occidentalis californicus*) were noted transiting the survey area. Marine mammal observations included one southern sea otter (*Enhydra lutris nereis*) near the outfall site, and a mother and pup within the mouth of the harbor. Also, several strands of bull kelp (*Nereocystis luetkeana*) were present in the survey area.

Moderate beach usage by pedestrians was observed during the June 2011 survey. Additionally, surfers were seen in the water offshore Cayucos and several small fishing vessels were observed in the offshore waters.

Table 4. Standard Meteorological and Oceanographic Observations

	Location[13]		Diffuser Distance	Time	Air	Cloud Cover	Wind Avg	Wind Max	Wind Dir (from)	Swell Ht/Dir	Secchi Depth
Station	Latitude	Longitude	(m)	(PDT)	(°C)	(%)	(kt)	(kt)	(°T)	(ft/°T)	(m)
RW1	35° 23.254' N	120° 52.493' W	93.8	7:46:55	12.1	100	1.8	2.8	NE	2-3/NW	6.0
RW2	35° 23.230' N	120° 52.505' W	46.5	7:50:41	12.0	100	1.3	1.6	NE	2-3/NW	6.0
RW3	35° 23.212' N	120° 52.504' W	18.0	7:54:39	12.3	100	1.3	2.6	NE	2-3/NW	5.0
RW4	35° 23.188' N	120° 52.498' W	9.6	7:58:10	12.2	100	2.5	3.3	N	2-3/NW	6.0
RW5	35° 23.165' N	120° 52.499' W	49.9	8:02:08	12.2	100	2.3	3.3	N	2-3/NW	6.0
RW6	35° 23.143' N	120° 52.497' W	91.3	8:05:34	12.2	100	2.7	3.2	N	2-3/NW	6.0

[13] Locations are the vessel positions at the time the Secchi depths were measured. They may depart from the CTD profile locations listed in Table 2.

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 2011 survey reflect the presence of a strongly stratified water column indicative of upwelling conditions. Upwelling conditions prevail most of the year along the central California coast, generally beginning in March or April, and extend through the fall months. Upwelling results in an influx of dense, cold, saline water at depth and often leads to a sharp thermocline, halocline, and pycnocline where temperature, salinity, and density change rapidly over short vertical distances. Under highly stratified conditions, isotherms crowd together to form a density interface that restricts the vertical transport of the effluent plume, inhibiting the vertical exchange of nutrients and other water properties, and reducing the initial dilution of the effluent plume.

Upwelling-induced gradients are evident in the vertical profiles of seawater properties shown in Figure 7 as decreases in temperature (red lines), DO (dark blue lines), and pH (gold lines) with increasing depth. These decreases are mirrored by a pycnocline and halocline where density (black lines) and salinity (green line) steadily increase with depth. Specifically, the profiles exhibit a vertical transition zone between a relatively uniform, near-surface mixed layer and a colder, saltier, nutrient-rich but oxygen-poor water mass at depth.

At the time of the June 2011 survey, the vertical structure of seawater characteristics was comparable to that of other upwelling periods. Near the seafloor, upwelling had transported cold, dense seawater (red and black lines in Figure 7) onshore to replace nearshore surface waters that were driven offshore by prevailing winds. These deep offshore waters had not been in recent direct contact with the atmosphere, and biotic respiration and decomposition had depleted their DO levels (dark blue lines). Additionally, in contrast to the relatively fresh surface waters associated with the southward-flowing California Current, the slightly elevated salinity (green lines in Figure 7) within 5 m of the seafloor was indicative of waters that originated in the Southern California Bight, which had been carried northward by the Davidson Undercurrent.

Nutrient-rich seawater brought to the sea surface by upwelling facilitates phytoplankton blooms that produced oxygen and consumed carbon dioxide (CO_2). With depth, the rate of respiration to photosynthesis increases, resulting in a corresponding increase in dissolved CO_2 (carbonic acid) and a concomitant decline in pH (olive-colored lines). Additionally, the decreased water clarity observed between 11 and 14 m clarity at the base of the thermocline (light-blue lines), reflects the accumulation of detritus and other particulates that were trapped by the limited vertical exchange within the thermocline.

The influence of the discharge can be seen in the vertical profile recorded at Station RW3 (Figure 7c). Typically, the presence of dilute wastewater appears as a sharp reduction in salinity and density at depth. During the June 2011 survey, however, the density signature associated with the low-salinity plume was very weak, indicating that effluent plume had lost its buoyancy and become trapped at depth. Through intense mixing with dense bottom waters, the buoyancy of the dilute effluent plume was incapable of carrying it through the strong thermocline to the sea surface. Nevertheless, as the effluent plume rose from the seafloor it carried ambient seafloor water properties upward, resulting in a compressed thermocline and reduced DO concentrations near 9-m.

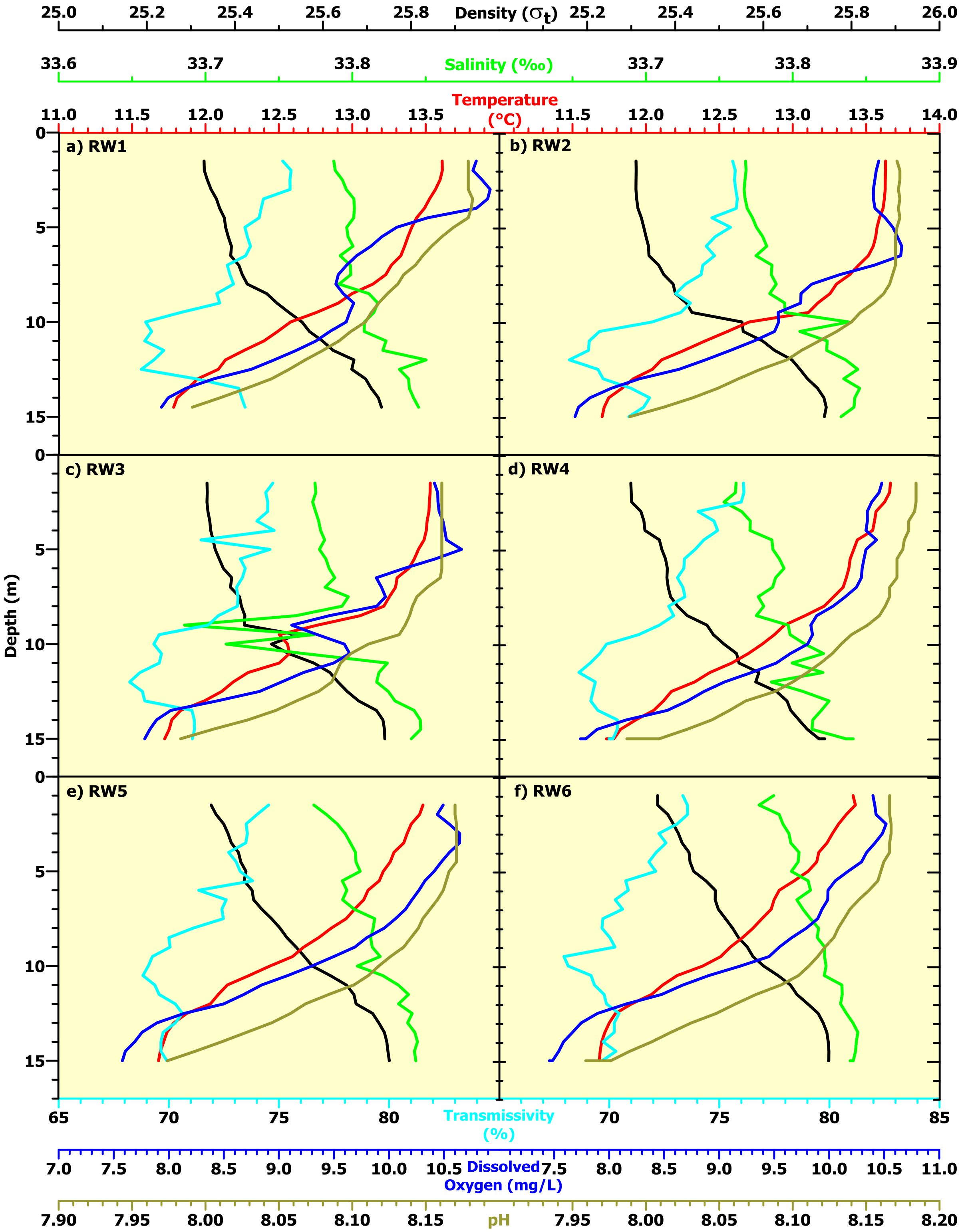

Figure 7. Vertical Profiles of Water-Quality Parameters

Table 5. Vertical Profile Data Collected on 22 June 2011

Depth (m)	Temperature (°C)						Salinity (‰)					
	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6
1.0	13.617	13.634	13.533	13.664		13.411	33.785	33.765	33.776	33.761		33.787
1.5	13.612	13.632	13.531	13.666	13.482	13.427	33.787	33.768	33.775	33.761	33.774	33.777
2.0	13.613	13.632	13.530	13.660	13.458	13.365	33.788	33.768	33.775	33.761	33.782	33.791
2.5	13.598	13.631	13.525	13.626	13.402	13.313	33.793	33.768	33.773	33.753	33.790	33.793
3.0	13.567	13.630	13.522	13.568	13.374	13.271	33.796	33.767	33.775	33.765	33.795	33.797
3.5	13.526	13.624	13.510	13.557	13.351	13.234	33.801	33.768	33.777	33.771	33.799	33.799
4.0	13.491	13.616	13.504	13.545	13.284	13.178	33.801	33.769	33.778	33.771	33.802	33.804
4.5	13.438	13.591	13.489	13.440	13.259	13.164	33.801	33.773	33.781	33.786	33.803	33.804
5.0	13.405	13.574	13.451	13.416	13.211	13.105	33.796	33.775	33.778	33.787	33.805	33.799
5.5	13.379	13.565	13.423	13.391	13.184	13.010	33.797	33.780	33.782	33.791	33.793	33.811
6.0	13.356	13.549	13.386	13.383	13.107	12.908	33.801	33.782	33.784	33.794	33.796	33.812
6.5	13.331	13.515	13.305	13.365	13.078	12.873	33.792	33.775	33.788	33.788	33.793	33.803
7.0	13.266	13.449	13.295	13.343	13.015	12.854	33.799	33.786	33.782	33.786	33.801	33.807
7.5	13.228	13.389	13.253	13.279	12.958	12.790	33.799	33.785	33.797	33.777	33.815	33.812
8.0	13.141	13.298	13.215	13.214	12.857	12.730	33.791	33.789	33.793	33.780	33.814	33.818
8.5	12.999	13.254	13.055	13.084	12.771	12.658	33.811	33.784	33.762	33.775	33.813	33.817
9.0	12.906	13.170	12.762	12.944	12.669	12.575	33.817	33.795	33.686	33.797	33.814	33.822
9.5	12.755	13.107	12.503	12.876	12.593	12.510	33.815	33.795	33.774	33.798	33.819	33.822
10.0	12.579	12.703	12.559	12.793	12.439	12.387	33.808	33.838	33.714	33.808	33.803	33.823
10.5	12.492	12.556	12.572	12.698	12.297	12.213	33.808	33.805	33.767	33.821	33.821	33.822
11.0	12.399	12.404	12.503	12.585	12.149	12.115	33.823	33.824	33.824	33.800	33.831	33.834
11.5	12.263	12.260	12.291	12.436	12.088	12.038	33.821	33.823	33.818	33.821	33.838	33.834
12.0	12.136	12.107	12.189	12.332	12.033	11.902	33.850	33.836	33.817	33.785	33.832	33.833
12.5	12.087	12.044	12.111	12.174	11.873	11.793	33.832	33.844	33.825	33.807	33.841	33.837
13.0	11.947	11.914	11.993	12.120	11.784	11.751	33.838	33.835	33.829	33.825	33.838	33.841
13.5	11.882	11.837	11.832	12.053	11.737	11.720	33.839	33.846	33.842	33.820	33.843	33.844
14.0	11.807	11.747	11.771	11.932	11.715	11.699	33.842	33.842	33.846	33.814	33.844	33.843
14.5	11.783	11.716	11.753	11.827	11.693	11.688	33.845	33.842	33.847	33.813	33.842	33.843
15.0		11.702	11.722	11.782	11.680	11.683		33.833	33.840	33.836	33.843	33.841
15.5				11.731		11.680				33.841		33.839

Table 5. Vertical Profile Data Collected on 22 June 2011 (continued)

Depth (m)	Density (σ_t)						pH					
	RW-1	**RW-2**	**RW-3**	**RW-4**	**RW-5**	**RW-6**	**RW-1**	**RW-2**	**RW-3**	**RW-4**	**RW-5**	**RW-6**
1.0	25.328	25.309	25.338	25.299		25.360	8.175	8.170	8.161	8.184		8.166
1.5	25.330	25.311	25.337	25.299	25.346	25.360	8.179	8.171	8.161	8.184	8.170	8.166
2.0	25.331	25.311	25.337	25.300	25.358	25.383	8.179	8.173	8.161	8.184	8.170	8.166
2.5	25.338	25.311	25.337	25.301	25.375	25.396	8.179	8.173	8.161	8.184	8.171	8.167
3.0	25.346	25.311	25.339	25.322	25.385	25.407	8.179	8.172	8.161	8.183	8.171	8.167
3.5	25.358	25.312	25.343	25.329	25.392	25.416	8.182	8.173	8.161	8.179	8.171	8.166
4.0	25.366	25.315	25.345	25.331	25.408	25.431	8.181	8.172	8.161	8.179	8.171	8.166
4.5	25.376	25.323	25.351	25.364	25.414	25.434	8.179	8.173	8.161	8.176	8.171	8.162
5.0	25.379	25.329	25.355	25.369	25.425	25.442	8.169	8.171	8.161	8.175	8.166	8.160
5.5	25.385	25.334	25.365	25.378	25.421	25.469	8.161	8.170	8.161	8.171	8.164	8.158
6.0	25.392	25.339	25.374	25.382	25.439	25.491	8.154	8.170	8.161	8.171	8.162	8.152
6.5	25.391	25.340	25.393	25.381	25.443	25.491	8.148	8.170	8.160	8.171	8.158	8.145
7.0	25.409	25.362	25.390	25.384	25.461	25.498	8.143	8.170	8.151	8.166	8.153	8.139
7.5	25.417	25.374	25.411	25.389	25.483	25.514	8.135	8.168	8.144	8.166	8.148	8.135
8.0	25.428	25.395	25.415	25.405	25.503	25.530	8.131	8.166	8.141	8.163	8.145	8.131
8.5	25.472	25.400	25.423	25.427	25.518	25.544	8.124	8.162	8.139	8.159	8.140	8.128
9.0	25.496	25.425	25.422	25.472	25.539	25.564	8.118	8.155	8.136	8.151	8.135	8.122
9.5	25.523	25.438	25.541	25.487	25.558	25.576	8.113	8.146	8.132	8.140	8.126	8.117
10.0	25.553	25.551	25.483	25.511	25.576	25.601	8.109	8.140	8.111	8.133	8.118	8.111
10.5	25.569	25.554	25.522	25.539	25.617	25.633	8.099	8.130	8.099	8.127	8.111	8.104
11.0	25.599	25.598	25.579	25.545	25.653	25.661	8.091	8.118	8.092	8.119	8.101	8.092
11.5	25.623	25.626	25.616	25.590	25.670	25.676	8.080	8.106	8.089	8.110	8.084	8.075
12.0	25.670	25.665	25.634	25.583	25.675	25.701	8.068	8.096	8.086	8.100	8.068	8.061
12.5	25.666	25.683	25.655	25.630	25.713	25.725	8.057	8.078	8.077	8.088	8.058	8.048
13.0	25.697	25.700	25.681	25.654	25.727	25.736	8.045	8.063	8.062	8.068	8.045	8.031
13.5	25.710	25.723	25.722	25.662	25.740	25.744	8.028	8.049	8.048	8.057	8.028	8.017
14.0	25.726	25.738	25.736	25.681	25.745	25.747	8.010	8.032	8.029	8.045	8.011	8.004
14.5	25.733	25.743	25.740	25.700	25.748	25.749	7.991	8.012	8.005	8.028	7.993	7.989
15.0		25.739	25.741	25.726	25.751	25.749		7.989	7.983	8.009	7.974	7.976
15.5				25.740		25.748				7.987		7.959

Table 5. Vertical Profile Data Collected on 22 June 2011 (continued)

Depth (m)	Dissolved Oxygen (mg/L)						Transmissivity (%)					
	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6
1.0	10.681	10.466	10.413	10.467		10.397	75.186	75.706	74.777	75.674		73.342
1.5	10.793	10.450	10.413	10.478	10.492	10.414	75.174	75.606	74.728	76.098	74.536	73.553
2.0	10.762	10.427	10.442	10.453	10.438	10.426	75.554	75.723	74.402	76.116	74.006	73.557
2.5	10.846	10.415	10.445	10.386	10.546	10.517	75.503	75.689	74.496	75.997	73.515	73.081
3.0	10.919	10.401	10.456	10.346	10.642	10.483	75.511	75.747	74.492	74.032	73.570	72.255
3.5	10.896	10.401	10.490	10.347	10.641	10.416	74.303	75.818	73.997	74.756	73.497	72.581
4.0	10.793	10.416	10.507	10.334	10.549	10.340	74.193	75.772	74.785	74.926	72.715	72.133
4.5	10.351	10.508	10.522	10.430	10.475	10.294	74.107	74.660	71.465	74.297	73.064	71.802
5.0	10.070	10.578	10.659	10.334	10.410	10.171	73.457	75.509	74.594	73.902	73.242	72.115
5.5	9.935	10.620	10.422	10.316	10.326	10.055	73.569	74.806	73.248	73.418	73.803	70.749
6.0	9.836	10.660	10.139	10.299	10.272	9.989	73.712	74.404	73.471	73.389	71.356	70.865
6.5	9.706	10.650	9.885	10.292	10.209	9.987	73.492	74.785	73.341	73.095	72.609	70.273
7.0	9.615	10.410	9.932	10.247	10.151	9.935	72.656	74.251	73.075	73.347	72.411	70.607
7.5	9.539	10.096	9.968	10.147	10.059	9.895	72.781	74.177	73.142	73.443	72.479	69.712
8.0	9.517	9.841	9.889	10.035	9.956	9.792	72.941	73.464	73.120	72.700	71.104	69.672
8.5	9.584	9.744	9.459	9.886	9.799	9.660	72.180	73.020	72.251	72.930	70.004	70.033
9.0	9.680	9.741	9.116	9.833	9.689	9.546	72.315	73.689	71.780	72.278	70.060	70.262
9.5	9.642	9.536	9.349	9.848	9.498	9.454	70.537	73.244	69.565	71.343	69.257	67.946
10.0	9.612	9.541	9.595	9.804	9.299	9.193	68.946	71.949	69.322	69.882	69.069	68.139
10.5	9.463	9.503	9.642	9.647	9.081	8.906	69.222	69.560	69.668	69.570	68.827	69.177
11.0	9.338	9.317	9.497	9.519	8.843	8.671	68.909	69.095	69.570	69.141	69.365	69.331
11.5	9.158	9.102	9.224	9.295	8.682	8.477	69.775	69.059	68.695	68.623	69.563	69.768
12.0	8.958	8.875	9.024	9.048	8.498	8.156	69.328	68.186	68.223	69.370	70.296	69.877
12.5	8.748	8.634	8.824	8.862	8.140	7.894	68.750	69.488	68.803	69.266	70.622	70.449
13.0	8.410	8.275	8.438	8.713	7.892	7.746	71.239	69.723	68.913	69.162	70.297	70.228
13.5	8.156	8.020	8.019	8.529	7.757	7.667	73.176	70.993	71.054	69.483	69.745	70.227
14.0	7.995	7.827	7.889	8.159	7.691	7.585	73.309	71.835	71.157	70.369	69.645	69.725
14.5	7.934	7.721	7.829	7.891	7.606	7.542	73.466	71.562	71.169	70.368	69.645	70.306
15.0		7.690	7.781	7.788	7.579	7.485		70.891	71.071	70.171	69.916	69.680
15.5				7.739		7.457				69.991		69.829

As a result of trapping at depth, there was little evidence of the plume signature in the upper water column at Station RW3. Nevertheless, the 1-m reduction in Secchi depth measured at Station RW3 (Table 4), may have been related to the isolated reduction in transmissivity measured by the CTD at 4.5 m ((light-blue line in Figure 7c). This shallow signature may have reflected a portion of the effluent plume that overshot its equilibrium depth as described for the shallow tow data below. However, because the Secchi depths only reached 6 m, they did not fully reflect the influence of the dilute effluent plume, most of which extended to greater depths. Additionally, Secchi depth readings throughout the survey were complicated by the variation in reflective glare from the overcast skies.

The presence of the plume at Station RW3 is also consistent with the northeasterly location of the plume signature delineated by the mid-depth tow (Figure 8b). The mid-depth tow was conducted just below 8-m between 08:58 and 09:29 PDT, when the drifter movement had stalled during the slack tide (Figure 3). With little flow, the trapped plume spread laterally beneath within thermocline, which accounts for the unusually large lateral extent of the deep plume signature observed in Figure 8b. The absence of a density signature at that location (Figure 8c) is also diagnostic of a plume that has reached buoyancy equilibrium, and has begun to spread laterally. With the exception of transmissivity, anomalies in other seawater properties coincided with the plume's salinity anomaly. However, in contrast to the salinity anomaly, they were generated by entrainment and the upward transport of ambient seawater from near the seafloor rather than the presence of dilute effluent constituents. Specifically, the lower temperature, pH, and DO concentration of the near-bottom seawater created lateral anomalies when they were displaced upward, and juxtaposed against the ambient seawater at 8.6 m.

Although the plume reached buoyant equilibrium near 8.6 m, the momentum of the rising plume carried it farther upward in the water column. As a result, a very weak plume signature was also apparent within the ZID during the shallow tow survey at 5.5 m (Figure 9b). In contrast to the signature at depth (Figure 8), however, all of the seawater properties exhibited anomalies coincident with the salinity anomaly. In particular, density within the plume was greater than the surrounding seawater, indicating that it was negatively buoyant, and would eventually descend in the water column, only to continue to oscillate vertically in a damped fashion. The anomalies in the other seawater properties (Figure 9adef), including the reduction in transmissivity, are consistent with the upward transport of ambient seawater within the rising plume. The slight, 1% reduction in transmissivity is consistent with the upward transport of the slightly more turbid seawater below 9 m that is apparent in the vertical profiles (Figure 7).

Outfall Performance

The efficacy of the outfall can be evaluated through a comparison of dilution levels measured at the time of the June 2011 survey, and dilutions anticipated from modeling studies that were codified in the discharge permit through limits imposed on effluent constituents. Specifically, the critical initial dilution applicable to the MBCSD outfall was conservatively estimated to be 133:1 (Tetra Tech 1992). That is, dispersion modeling estimated that, at the conclusion of the minimum expected initial mixing, 133 parts of ambient seawater would have mixed with each part of wastewater.

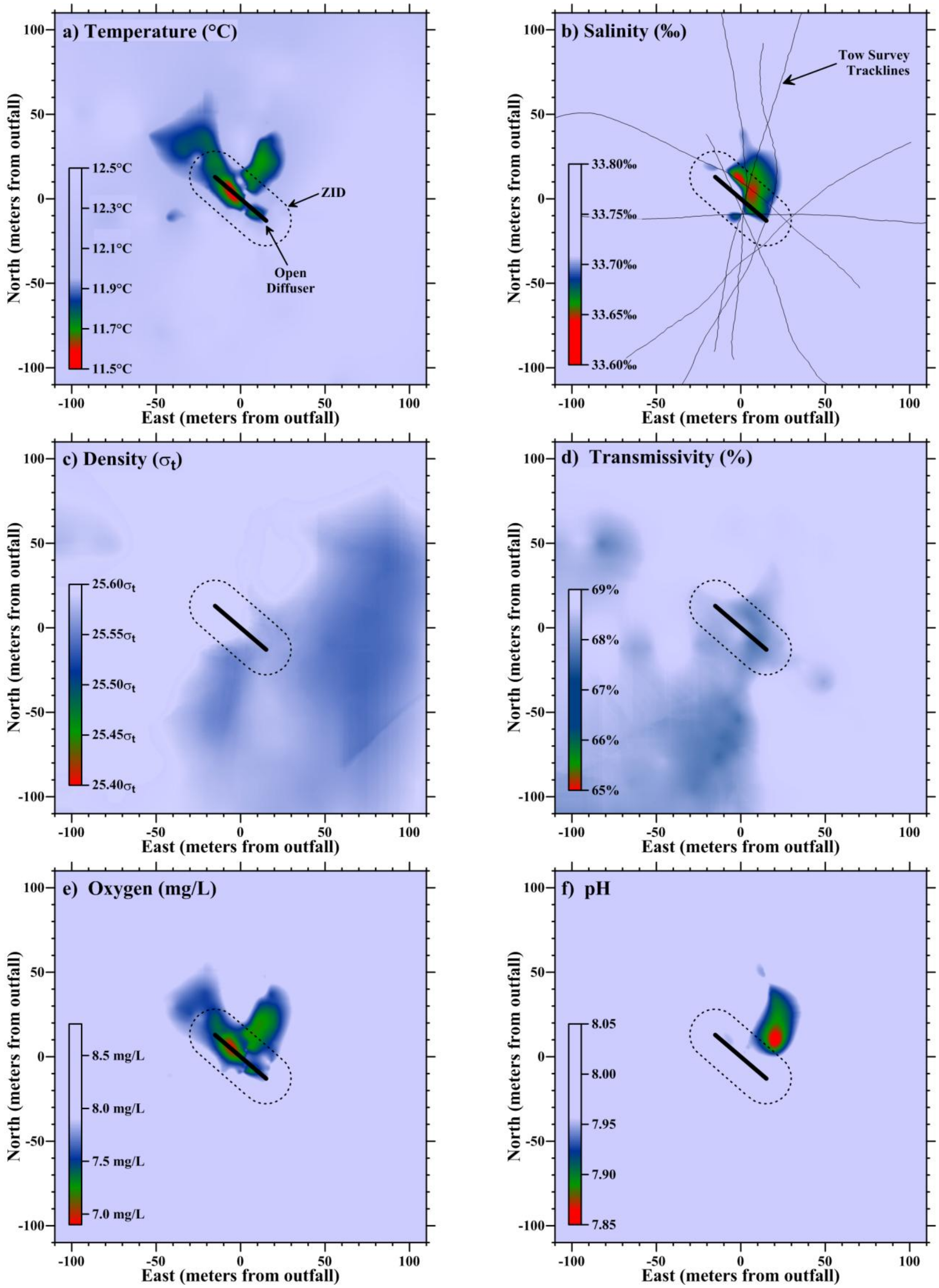

Figure 8. Horizontal Distribution of Mid-Depth Water-Quality Parameters 8.6 m below the Sea Surface

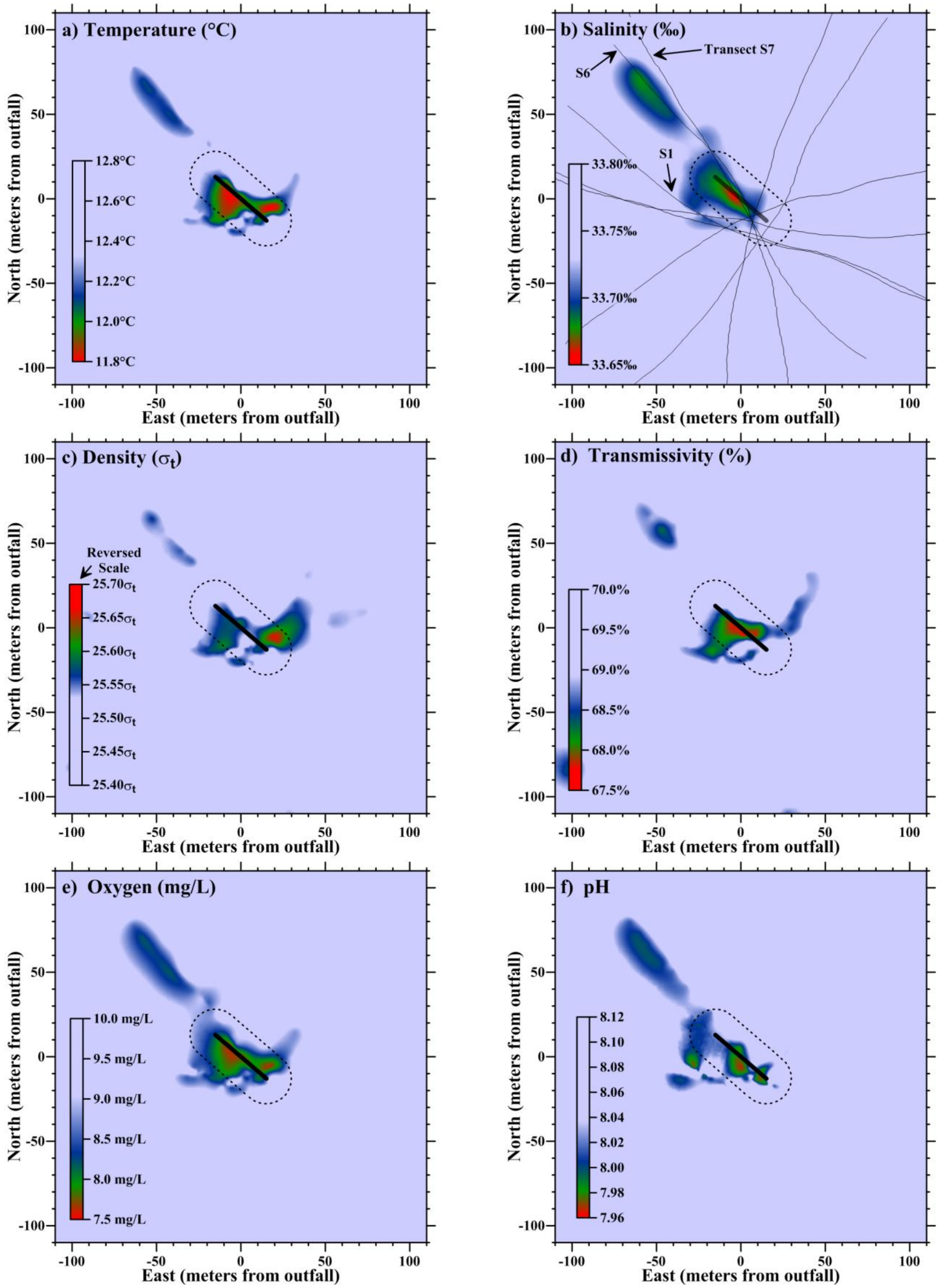

Figure 9. Horizontal Distribution of Shallow Water-Quality Parameters 5.5 m below the Sea Surface

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 buoyant mixing normally associated with turbulence generated by the plume's rise through the water column. Additionally, the modeling assumed quiescent oceanic flow conditions, thereby restricting initial mixing processes to the ZID. Under those conditions, the modeling predicted that a 133:1 dilution would be achieved after the plume rose only 9 m from the seafloor, whereupon it would become trapped, spread laterally, and cease to rise in the water column and dilute further. A 9-m rise at the MBCSD outfall translates into a trapping depth that is 6.4 m below the sea surface. As described below, observed dilution levels were far higher than the conservative model prediction, even at depths greater than the trapping depth predicted by modeling where measured initial dilution levels would be expected to be much lower than the 133:1 of the modeling.

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

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

$$C_e \equiv C_o + D\left(C_o - C_s\right)$$ Equation 1

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

By rearranging Equation 1, the actual dilution achieved by the outfall can be determined from measured seawater anomalies. This measured dilution can then be compared with the critical dilution factor determined from modeling. Salinity is an especially useful tracer because it directly reflects the magnitude of ongoing dilution. Wastewater-induced patches of lower salinity are apparent near the diffuser structure in the tow-survey maps (Figures 8b and 9b) and in the vertical profile measured at Station RW3 (Figure 7c). These localized salinity anomalies reflect the presence of dilute wastewater within the effluent plume as it rose and spread within the water column.

By rearranging Equation 1, the dilution ratio (D) can be computed from the salinity anomaly ($A = C_o - C_s$) as:

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

The salinity concentration within MBCSD effluent (C_e)[14] is generally small compared to that of the receiving seawater and, after dilution by more than 100-fold, the salinity of the effluent-seawater mixture is close to ambient salinity. Consequently, to a close approximation, dilution levels are inversely proportional to the amplitude of the salinity anomaly. Thus, reduced effluent dilution at a given location within receiving waters directly reflected by a larger amplitude salinity anomaly.

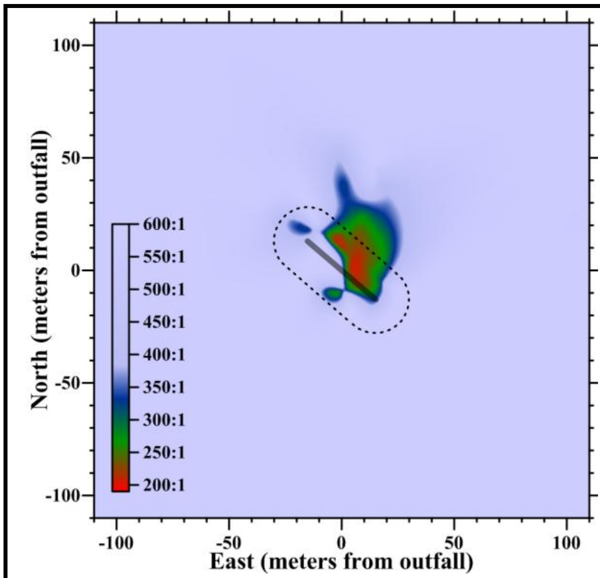

Figure 10. Mid-Depth Plume Dilution Computed from Salinity Anomalies in Figure 8b

The lowest salinity (33.631‰) measured during the June 2011 survey was recorded within the ZID at a depth of 8.6 m during Transect D8 of the deep tow survey (red shading in Figure 8b). The measured salinity corresponds to a 0.170‰ reduction below the mean ambient salinity of 33.801‰ that was measured at the same depth level, but well beyond the influence of the discharge. It documents the presence of wastewater that has been diluted 193-fold (Figure 10). This is nearly 50% higher than the 133:1 critical initial dilution used to establish limits on contaminant concentrations in wastewater. In addition, the measurement was recorded well within the ZID, only 7.7 m from the diffuser structure, and well below the 6.4-m trapping depth determined from modeling studies.

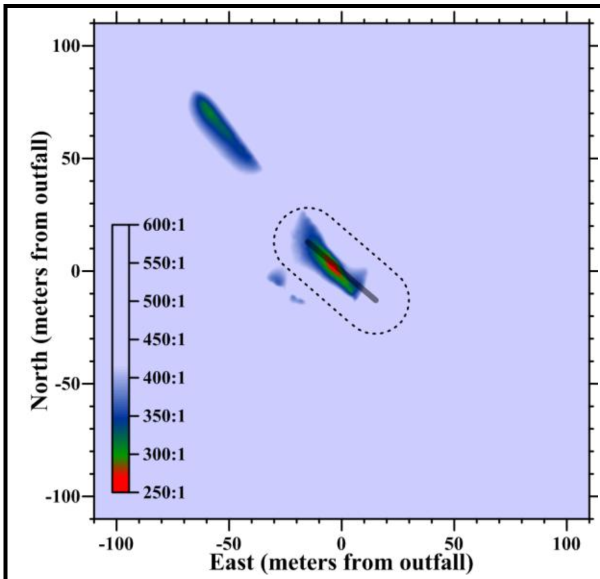

Figure 11. Shallow Plume Dilution Computed from Salinity Anomalies in Figure 9b

Slightly smaller salinity reductions (0.137‰), corresponding to dilution levels exceeding 239-fold, were measured directly over the diffuser structure at a depth 3.6 m above mid-depth plume signature (Figure 9b and Figure 11). The measurements collected near the diffuser structure within that 5-to-9 m depth range captured the plume as it spread within the upper thermocline and continued to mix as a result of turbulence generated by buoyancy-induced oscillations around the equilibrium depth.

The corresponding dilution levels beyond the ZID were high, and exceeded 220 fold along the northern ZID margin at mid-depth (Figure 10) and 300-fold in the upper water column, well away from the ZID (Figure 11). Salinities, reduced by as much as 0.109‰ were measured northwest of the diffuser structure at distances between 30 and 90 m from the northwestern terminus of the diffuser structure (Figure 9b). Although the presence of an isolated plume signature in the upper water column, well

[14] Wastewater grab samples collected on 22 June 2011 had a salinity of 0.868‰.

away from the ZID, was unusual, the presence of dilute wastewater constituents at that distant location was confirmed by entrainment anomalies in all the other water properties that coincided with the salinity anomaly (Figure 9acdef).

At that location, the plume signature occupied a very thin layer. As is apparent from the tracklines in Figure 9b, the salinity reductions were recorded only along Transect S6, while no salinity anomalies were observed in this area along Transect S7, which was immediately adjacent to Transect S6. Transect S6 detected the weak plume signature because the CTD was towed at a slightly deeper level within the water column, 5.73 m compared to 5.32 m for Transect S7. Thus, the depth of plume signature was sharply defined within the upper thermocline at this location, although it disappeared within as little as 0.41 m of depth.

The northwesterly location of this isolated plume signature was also unusual. During the shallow tow survey, which ended at 08:55 PDT, the prevailing flow measured by the drogued drifter had been primarily eastward. However, flow measured by the drifter was exceptionally weak and stagnated at the conclusion of the shallow tow survey. Although strong vertical counter currents commonly occur when the water column is highly stratified, the northwestern location of the distant plume signature likely arose because lateral transport by oceanic flow was negligible and dilute wastewater was spreading uniformly within a very thin layer produced by the gravitational collapse after completion of initial dilution within the ZID. This uniform spreading hypothesis is supported by the presence of a very weak plume signature just to the southwest of the southwestern ZID boundary (Figure 11). As with Transect S6, the 5.71-m depth level of the CTD along Transect S1 at that location was slightly deeper than the rest of the shallow tow data.

Regardless of the mechanism, data from the shallow tow survey indicates that the trapping depth ultimately achieved by the plume was close to 5.7 m. After completion of initial dilution at that depth level, dilutions exceeded 300-fold beyond the ZID. This is more than twice the 133:1 dilution level predicted by modeling that was used to establish end-of-pipe limits on effluent constituents in the MBCSD permit. Within the ZID, and well before completion of initial dilution, observed dilutions exceeded 193-fold at a depth of 8.6 m; again, significantly exceeding model predictions even though the plume had yet to reach the 6.4-m trapping depth predicted in the model. At 8.6 m, the plume had also already begun to spread laterally beyond the ZID, where observed dilution levels exceeded 223:1.

The dilution computations demonstrate that, during the June 2011 survey, the outfall was performing better than designed and was rapidly diluting effluent more than 193-fold shortly after discharge and well before completion of the initial-dilution process. This dilution level exceeds the 133:1 critical dilution used to establish end-of-pipe permit limitations on contaminant concentrations within wastewater discharged from the MBCSD treatment plant. Consequently, during the June 2011 survey, the COP receiving-water objectives were being easily 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 permit limits listed in the NPDES permit (Table 6). The limitations themselves are based on criteria in the COP, the Central Coast Basin Plan, and other state and federal policies that were designed to protect marine life and beneficial uses of ocean waters. Because the limits only pertain to changes in water properties that are caused by the presence of wastewater constituents beyond the ZID, instrumental measurements undergo a series of screening procedures prior to numeric comparison with the permit thresholds. Specifically, the quantitative analyses described in this section focus on water-property excursions caused by the presence of wastewater constituents beyond the ZID whose amplitudes can be reliably discerned against the backdrop of ambient

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

fluctuations. A detailed understanding of ambient seawater properties, and their natural variability within the region surrounding the outfall, is therefore, an integral part of the compliance evaluation presented in this section.

The results of these analyses applied to the June 2011 data demonstrate that the MBCSD discharge complied with the NPDES discharge permit. Moreover, although observations within the ZID are not subject to compliance evaluations, they often meet the prescribed limits because dilution levels exceed the conservative design specifications assumed in the discharge permit. Thus, the quantitative evaluation described in this section documents an outfall and treatment process that was performing at a high level during the survey.

Permit Provisions

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

The first two receiving-water limits, P1 and P2, rely on qualitative visual observations for compliance evaluation. As described previously, no floating wastewater materials, oil, grease, or discoloration of the sea surface were observed during the June 2011 survey.

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

Natural variation in seawater properties is driven by a variety of oceanographic processes. These processes determine the range in ambient seawater properties caused by natural spatial variation within the survey region at a given time (e.g., vertical stratification), and by temporal variations caused by seasonal and interannual influences (e.g. El Niño and La Niña). Of particular interest are upwelling and downwelling processes that not only determine average properties at a given time, but also the degree of water-column stratification, or spatial variability, present during any given survey. An accurate characterization of stratification helps distinguish discharge-related changes that arise from the presence of wastewater constituents, which are subject to a compliance evaluation, from changes that arise because of the upward movement of ambient seawater, which are specifically excluded from the compliance evaluation.

Screening of Measurements

Evaluating whether any of the 5,144 CTD measurements collected during the June 2011 survey exceeded a permit limit can be a complex process. For example, although apparently significant excursions in an individual seawater property may be related to the presence of wastewater constituents, they may also result from instrumental errors, natural processes, entrainment of ambient bottom waters in the rising effluent plume, statistical uncertainty, ongoing initial mixing within and beyond the ZID, or other anthropogenic influences (e.g. dredging or oil spills).

Because of this complexity, measurements were first screened to determine whether numerical limits on individual seawater properties apply (Table 7). The screening procedure sequentially applies four questions to restrict attention to: 1) the oceanic area where permit provisions apply; 2) changes due to the presence of wastewater particulates; 3) changes large enough to be reliably detected against the backdrop of natural variation; and 4) changes that exceed Basin-Plan numerical limits or COP allowances. The following subsection provides additional lines-of-evidence that demonstrate compliance with numerical permit limits independent of the screening process. However, the screening process described in this section unequivocally eliminated all of the CTD measurements collected during the June 2011 survey from exceedance of permit limits. The rationale for evaluating observations for compliance analysis is provided in the following four screening steps.

1. Measurement Location: The COP states that compliance with its receiving-water objectives "*shall be determined from samples collected at stations representative of the area within the waste field where initial dilution is completed.*" Initial dilution includes the mixing that occurs from the turbulence associated with both the ejection jet, and the buoyant plume's subsequent rise through the water column. Although currents often transport the plume beyond the ZID before the initial dilution process is complete, as was the case during the June 2011 survey, the COP states that dilution estimates shall be based on "*the assumption that no currents, of sufficient strength to influence the initial dilution process,*

Table 7. Receiving-Water Measurements Screened for Compliance Evaluation

Topic Addressed	Screening Question	Answer No	Answer Yes[15]	*Parameter*
Location	1. Was the measurement collected beyond the 15.2-m ZID boundary where modeling assumes that initial dilution is complete?	*806*	*4,338*	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?	*3,975*	*363*	All
Natural Variation	3. Did seawater properties associated with any measurement depart significantly from the expected range in ambient seawater properties at the time of the survey?	*363*	*0*	Temperature
		363	*0*	Transmissivity
		363	*0*	DO
		316	*47*	pH
Compliance Thresholds	4. Did the anomalous measurements exceed numeric thresholds identified in the discharge permit?	*47*	*0*	pH

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

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 2011 dataset eliminated 806 of the original 5,144 receiving-water observations from further consideration because they were collected within the ZID (Table 7, Question 1). As described previously, some of the remaining 4,338 observations were collected within the dilute effluent plume as it continued mixing beyond the ZID; however, for initial screening purposes, all of these measurements were carried forward in the compliance analysis.

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

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

As described in the previous section, wastewater-induced reductions in salinity can be used to directly determine the amount of dilution achieved by initial mixing. Wastewater's lack of salinity allows the presence of effluent constituents to be identified within receiving seawater well beyond the 133-fold critical initial dilution assumed in the discharge permit. 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. Reductions that are smaller than 0.062‰, cannot be reliably discerned against the backdrop of natural variation and would not result in discernable changes in other seawater properties. Eliminating those measurements from further compliance evaluation restricts attention to excursions in temperature, light transmittance, DO, and pH that are potentially related to the presence of wastewater constituents. During the June 2011 survey, only 817 low-salinity observations were identified as potentially being caused by the presence of wastewater constituents. However, 454 of these were recorded within the ZID where receiving-water limits do not apply because initial mixing was still taking place. Of the 4,338 observations that were measured outside the ZID during the June 2011 survey, only 363 had reductions in salinity that were greater than 0.062‰ (Table 7).

3. Natural Variation: An integral part of the compliance analysis is determining whether a particular anomalous measurement resulted from the presence of wastewater constituents, or whether it simply became apparent because ambient seawater was relocated by the plume. If the measurement does not significantly depart from the natural range in ambient seawater properties at the time of the survey, then it is difficult to ascribe the departure to the presence of wastewater constituents. Thus, quantifying the natural variability around the outfall is necessary for determining whether a particular observation warrants comparison with numeric permit limits.

A statistical analysis of receiving-water data previously collected around the outfall was used to establish the range of variability in natural conditions surrounding the outfall (first three columns of Table 8).

Table 8. Compliance Thresholds

Water Quality Property	95% Confidence Bound[16]	95th Percentile[17,18]	Natural Variability Threshold[19]	COP Allowance[20]	Basin Plan Limit[21]
Temperature (ºC)	0.82	13.63	>14.45	—	—
Transmissivity (%)	-10.2	68.9	<58.6	—	—
DO (mg/L)	-1.38	7.75	<6.37	<5.73	<5.0
pH (minimum)	-0.094	8.009	<7.915	<7.715	<7.0
pH (maximum)	0.094	8.179	>8.273	>8.473	>8.3

These ranges in natural variability were used to identify significant departures from ambient conditions that could be indicative of adverse discharge-related effects on water quality.

The same five-year database used to establish the natural within-survey salinity variation discussed previously was also used to establish one-sided 95% confidence bounds on transmissivity (-10.2%), temperature (+0.82°C), DO (-1.4 mg/L), and pH (± 0.094). These were combined with 95th percentiles determined from the June 2011 ambient seawater data, to establish time-specific natural-variability thresholds in a manner analogous to COP Appendix VI. The percentiles were determined from June 2011 vertical profile data, excluding measurements potentially affected by the discharge. Specifically, the measurements recorded at Stations RW3 and RW4 were excluded because they were acquired within the ZID and near its boundary where ongoing mixing is expected.

Temperature, transmissivity, and DO concentrations associated with the 363 measurements of potential compliance interest all remained within their respective ranges of natural variability (Table 7, Question 3). In fact, all of the documented excursions in these properties were the result of physical processes unrelated to the presence of wastewater constituents, namely, entrainment of near-bottom seawater within the rising effluent plume. During periods of strong stratification, such as during the June 2011 survey, ambient seawater properties near the seafloor differ from those within the rest of the water column, and their juxtaposition within the rising plume appear as lateral anomalies at mid-depth. All of the anomalies in seawater properties that coincided with salinity anomalies in Figures 8 and 9 were consistent with the

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

[17] 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*."

[18] The 95th-percentile quantifies natural variability in seawater properties during the August 2010 survey, and was determined from vertical profiles excluding RW3 and RW4 where there were possible influences from the discharge.

[19] Thresholds represent limits on wastewater-induced changes to receiving-water properties that significantly exceed natural conditions as specified in the discharge permit and COP. They are determined from the sum of columns to the right and are specific to the August 2010 survey. They do not include the COP allowances specified in the column to the left.

[20] 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.*"

[21] 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.

upward displacement of ambient bottom water, with the exception of mid-depth pH, as described below. For example, because effluent is warmer than receiving waters, the cold thermal anomalies in Figures 8a and 9a could only be generated by entrainment and upward displacement of the colder bottom waters. Similarly, the DO reductions observed at mid- and shallow levels (7.5 mg/L in Figures 8e and 9e) were consistent with the naturally depleted DO levels measured nearer the seafloor (dark blue lines in Figure 7).

The only exceptions to the entrainment origin were the 47 low pH measurements located just northeast of ZID boundary in Figure 8f. With pH levels between 7.839 and 7.915, the anomaly could not have been generated by the upward movement of the deeper seawater, which had a pH of greater than 7.915 (Table 8). Because the treatment plant's effluent had a pH of 7.8 on the day of the survey, it is conceivable that it was partially responsible for the observed mid-depth reductions within the plume. However, with dilution levels exceeding 200-fold at that location (Figure 10), effluent constituents are not the likely cause of the low pH. Nevertheless, the 47 low-pH measurements were carried forward in the compliance analysis (Table 7).

4. Permit Limits: The COP does not explicitly require that wastewater-induced changes remain within the ranges in natural variation listed in the third column of Table 8, even though they were conservatively used in the data screening process described in the previous subsections. Instead, the COP allows discharge-related changes in DO and pH to extend beyond these natural conditions. When combined with the variability thresholds, explicit numerical limits on allowed changes to seawater properties can be established (fourth column of Table 8). 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 7.715 during the June 2011 survey. As such, none of the 5,144 pH measurements collected during the June 2011 survey fell below the permitted limit.

In contrast to the narrative limits implemented in the COP, fixed Basin-Plan numerical limits are incorporated in the NPDES permit without specific guidance as to how they might change in response to widespread changes in ambient oceanographic conditions. The fixed Basin-Plan limits are listed in the fifth column of Table 8, and in the case of the June 2011 survey, the minimum Basin-Plan limits on DO and pH are less stringent than the COP limits. However, at 8.3, the maximum allowed pH is slightly more restrictive. Nevertheless, the highest pH measured during the June 2011 survey was 8.18, so all measurements collected during the survey complied with the receiving-water limits specified in the MBCSD discharge permit, including the 47 anomalous observations that were left after the previous steps in the screening process.

Other Lines of Evidence

In addition to the analysis provided above, several additional lines of evidence support the conclusion that all the CTD measurements collected during the June 2011 survey complied with permit limits P3 through P6 in Table 6. In combination, these lines of evidence provide the "best explanation" of the origin and significance of individual measurements using abductive inference (Suter 2007). This process, which has been used to implement sediment-quality guidelines for California estuaries (SWRCB 2009), emphasizes a pattern of reasoning which accounts for both the discrepancies among multiple lines of evidence as well as concurrences. A best explanation approach serves to limit the uncertainty associated with each individual CTD measurement and provide a more robust compliance assessment. Together, these lines of evidence significantly strengthen the conclusion that the discharge fully complied with the permit during the June 2011 survey.

Natural Variability in other Seawater Properties: Although the permit limits only apply to changes in DO, pH, temperature and transmissivity, a comparative evaluation of changes in the remaining seawater properties (salinity, density) frequently provides additional valuable insight into the origins of any variations observed during a particular survey. For example, during the June 2011 survey, salinity and pH were the only seawater properties that exhibited a perceptible difference from ambient conditions. As discussed previously, however, none of the 5,144 temperature, DO, or transmissivity observations exceeded the thresholds of natural variability specified in Table 8. This includes measurements collected within the ZID and close to the outfall that were eliminated from further compliance consideration by the first screening question in Table 7. Additionally, given the high dilution levels measured throughout the survey, and the lack of perceptible influence from the presence of dilute wastewater constituents on temperature, DO, or transmissivity, it is highly unlikely that the presence of slightly more acidic wastewater was responsible for the 47 anomalously low pH measurements.

Insignificant Thermal Impact: Although there are no explicit numerical objectives for discharge-related decreases in temperature, a numerical limit can also be established for thermal excursions, which are not allowed to adversely affect beneficial uses (P3 in Table 6). Increases in temperature caused by the discharge of warm wastewater constituents would not adversely affect beneficial uses as long as they remain within the natural temperature range at the time of the survey (14.45°C in Table 8). Such was the case for all 5,144 CTD measurements collected during the June 2011 survey. In fact, because effluent entrained cooler bottom water shortly after discharge, the rising plume actually had a lower temperature than the surrounding water (Figures 8a and 9a).

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. Because natural light is restricted to the euphotic zone, which extends to approximately twice the Secchi depth, the limit on transmissivity reductions applied to measurements above 12 m during the June 2011 survey (twice the ambient Secchi depth listed in Table 4). Regardless, the lowest transmissivity measurement (65.16%) was well above the limit on natural variability 58.6%, therefore, the June 2011 survey data met the requirement of the COP narrative objective (P4) that there be no significant reduction in the transmittance of natural light at any point outside the ZID (Table 8).

Insignificant Wastewater Particulate Loads: The discharge of wastewater particulates on 22 June 2011 did not contribute materially to turbidity within the dilute effluent plume. The suspended-solids concentration measured onshore within effluent prior to discharge was 20.6 mg/L. After dilution by 193-fold, which was the lowest dilution measured during the survey, the effluent TSS concentration would have the reduced ambient transmissivity by only 0.6%. 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, 41.1-mg/L biochemical oxygen demand (BOD) measured within the plant's effluent on the day of the survey. That small amount of BOD would have induced a DO depression of no more than 0.023 mg/L after dilution (MRS 2003). In fact, in the absence of tangible BOD influence, wastewater constituents would actually be expected to increase DO within subsurface receiving waters, rather than decrease it. This is because effluent is oxygenated by recent contact with the atmosphere during the treatment process, whereas receiving waters at depth are typically depleted in DO, particularly during periods of pronounced upwelling such as during the June 2011 survey.

CONCLUSIONS

The statistical screening analysis quantitatively demonstrated that all measurements recorded during the June 2011 survey complied with the receiving-water limitations specified in the NPDES discharge permit. This conclusion was further strengthened by other lines of evidence supporting compliance with the discharge permit. Although the presence of dilute wastewater constituents was delineated from salinity anomalies within a discharge plume, all the associated seawater properties except pH were within natural variability that prevailed at the time of the survey. Although the origin of the low pH measurements is unclear, they remained within permitted limits.

Immediately after discharge, the outfall was achieving dilution levels in excess of 193-fold, which exceeded the critical dilution levels predicted by design modeling. Additionally, throughout the water column, computed dilution levels outside the ZID typically achieved dilutions in excess of 220-fold. Lastly, all of the auxiliary observations collected during the June 2011 survey demonstrated that the discharge complied with the narrative receiving-water limits in the discharge permit and COP. All of these observations demonstrated that the treatment process, diffuser structure, and the outfall continue to perform at levels exceeding design expectations.

Although discharge-related changes in seawater properties were observed during the June 2011 survey, the changes were either not of significant magnitude, were measured within the boundary of the ZID where initial mixing is still expected to occur, or were not directly caused by the presence of wastewater constituents within the water column.

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