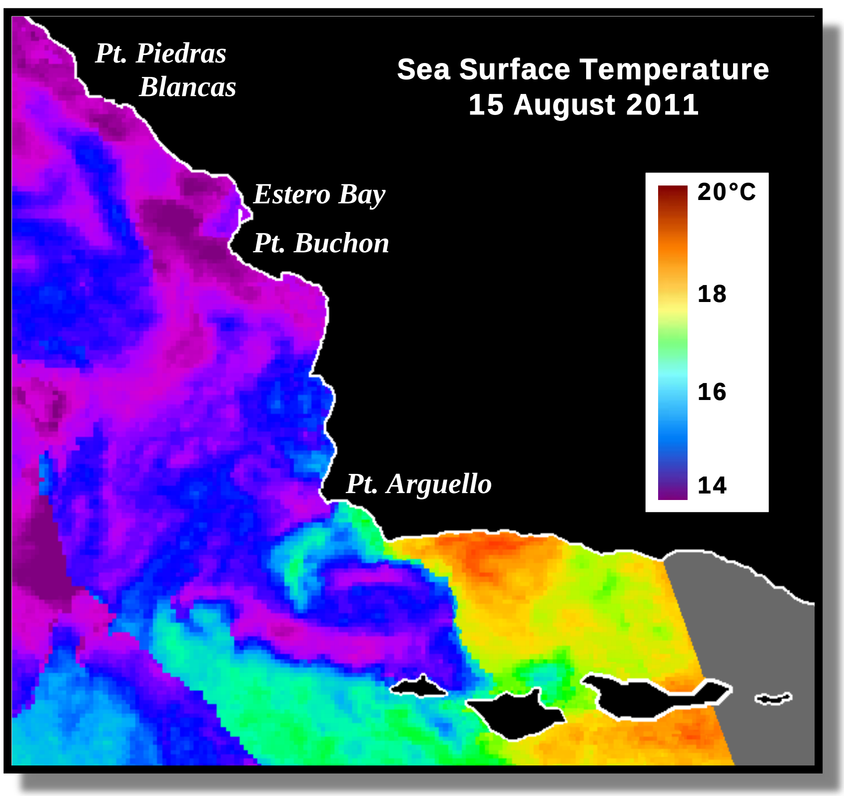
City of Morro Bay and
Cayucos Sanitary District

OFFSHORE MONITORING AND REPORTING PROGRAM

THIRD QUARTER RECEIVING–WATER SURVEY

AUGUST 2011



Marine Research Specialists

3140 Telegraph Rd., Suite A
Ventura, California 93003

Report to the

City of Morro Bay and Cayucos Sanitary District

955 Shasta Avenue
Morro Bay, California 93442
(805) 772-6272

OFFSHORE MONITORING AND REPORTING PROGRAM

THIRD QUARTER RECEIVING–WATER SURVEY

AUGUST 2011

Prepared by

Bonnie Luke
Douglas A. Coats

Marine Research Specialists

3140 Telegraph Rd., Suite A
Ventura, California 93003

Telephone: (805) 644-1180
Telefax: (805) 289-3935
E-mail: Marine@Rain.org

October 2011

marine research specialists
3140 Telegraph Road, Suite A • Ventura, CA 93003 • (805) 644-1180

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

31October 2011

Reference: Third Quarter Receiving-Water Survey Report – August 2011

Dear Mr. Keogh:

The attached report presents results from a quarterly receiving-water survey conducted on Tuesday, 23 August 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.

____

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

Date ______________________________

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The City of Morro Bay and the Cayucos Sanitary District (MBCSD) jointly own the wastewater treatment plant operated by the City of Morro Bay. In March 1985, Region IX of the U.S. Environmental Protection Agency (USEPA) and the Central Coast California Regional Water Quality Control Board (RWQCB) issued the first National Pollutant Discharge Elimination System (NPDES) permit to the MBCSD. The permit incorporated partially modified secondary treatment requirements for the plant's ocean discharge. The permit has been re-issued three times, in March 1993 (RWQCB-USEPA 1993ab), December 1998 (RWQCB-USEPA 1998ab), and January 2009 (RWQCB-USEPA 2009). The August 2011 field survey described in this report was the tenth 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 23 August 2011. Specifically, this third-quarter survey captured ambient oceanographic conditions along the central California coast during the summer season. The survey's measurements were used to assess the discharge's compliance with the objectives of the California Ocean Plan (COP) and the Central Coast Basin Plan (RWQCB 1994) as promulgated by the receiving-water limitations specified in the NPDES discharge permit.

The monitoring objectives were achieved by 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.

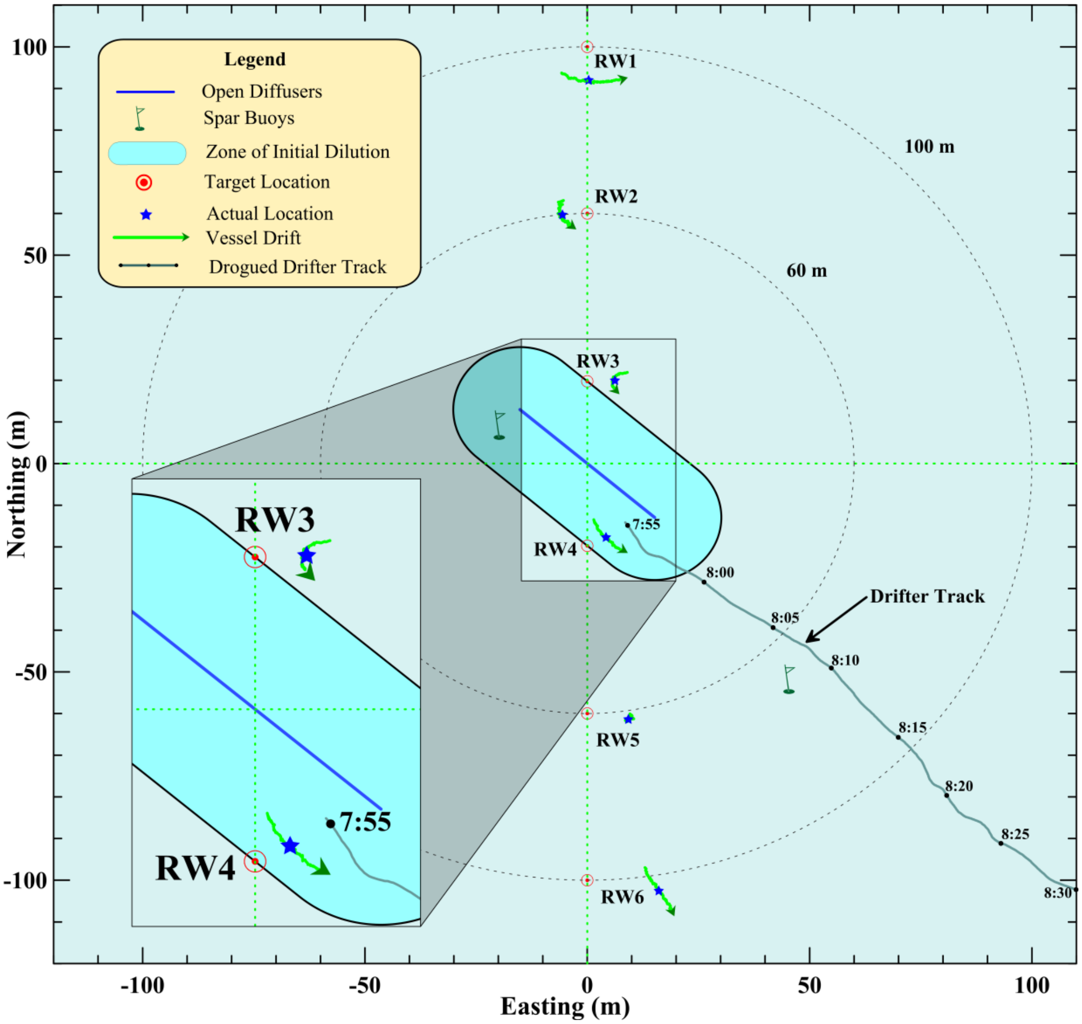


Figure 2. Sampling Station Locations and Drifter Track

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 August 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 August 2011 survey. During the time it took the CTD to traverse the water column and reach the seafloor, which averaged 1 min 18 s, the instrument package moved an average of 7.7 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 August 2011 survey. For example, vessel drift at most stations was toward the southeast,[5] in a direction consistent with transport by the subsurface current measured by the drogue drifter.[6] 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 the August survey because winds were light throughout the survey. Additionally, both the eastward drift at RW1 and the lack of drift at RW5 resulted from the residual momentum of the vessel as it approached these stations.

Compliance assessment can be complicated when the CTD drifts across the ZID boundary during a vertical hydrocasts 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 August 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 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 August 2011

[4] Meteorological and oceanographic conditions include winds, waves, tides, and currents.
[5] RW2, RW3, RW4, and RW6
[6] A portion of the drifter track is shown in Figure 2 and the full track is shown in Figure 3

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

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

Station	Time (PDT)		Latitude	Longitude	Closest Approach	
	Downcast	Upcast			Range[7] (m)	Bearing[8] (ºT)
RW1	8:09:42	8:11:01	35° 23.249' N	120° 52.504' W	80.6	11
RW2	8:15:51	8:17:16	35° 23.231' N	120° 52.508' W	47.8	12
RW3	8:23:28	8:24:46	35° 23.210' N	120° 52.500' W	19.3	41
RW4	8:28:37	8:29:47	35° 23.189' N	120° 52.501' W	**10.6**[9]	221
RW5	8:35:15	8:36:39	35° 23.166' N	120° 52.498' W	48.7	187
RW6	8:40:56	8:42:07	35° 23.144' N	120° 52.493' W	89.5	179

Compliance assessments notwithstanding, measurements acquired within the ZID lend valuable insight into the outfall’s effectiveness at dispersing wastewater. For example, low dilution rates and concentrated effluent throughout the ZID would indicate potentially damaged or broken diffuser ports. Analysis of the outfall’s operation over the past two decades, however, demonstrates that it has maintained a high level of effectiveness in effluent dispersal. In fact, without the occasional measurements recorded within the ZID due to 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 steady southeastward flow throughout the August 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 after discharge.

The drifter was deployed just south of the ZID at 07:54 PDT, and was recovered two hours later, at a location 492 m southeast of its initial location. The dots in Figure 3 show the drifter’s progress at five-minute intervals, with the alternating green dots representing 10-minute intervals. The uniform spacing of the time stamps reflects the relatively constant speed of the drifter, which averaged 6.8 cm/s, or 0.13 knots. At this speed, the plume would have traversed the ZID in just under four minutes.

The relatively strong and unidirectional oceanic flow was not tidally driven because there was little change in tidal elevation throughout the survey (Figure 4). In the absence of tidal influence, flow within Estero Bay is dominated by external processes, such as wind-generated upwelling, downwelling, or the passing of offshore eddies propagating along the coastline. Upwelling, for example, can induce a southerly (offshore) flow in the upper water column, and a northerly (onshore) flow at depth.

7 Distance from the closest open diffuser port to the average profile location.
8 Angle measured clockwise relative to true north from the closest diffuser port to the average profile location.
9 All of the CTD cast at Station RW4 was located within the ZID boundary.

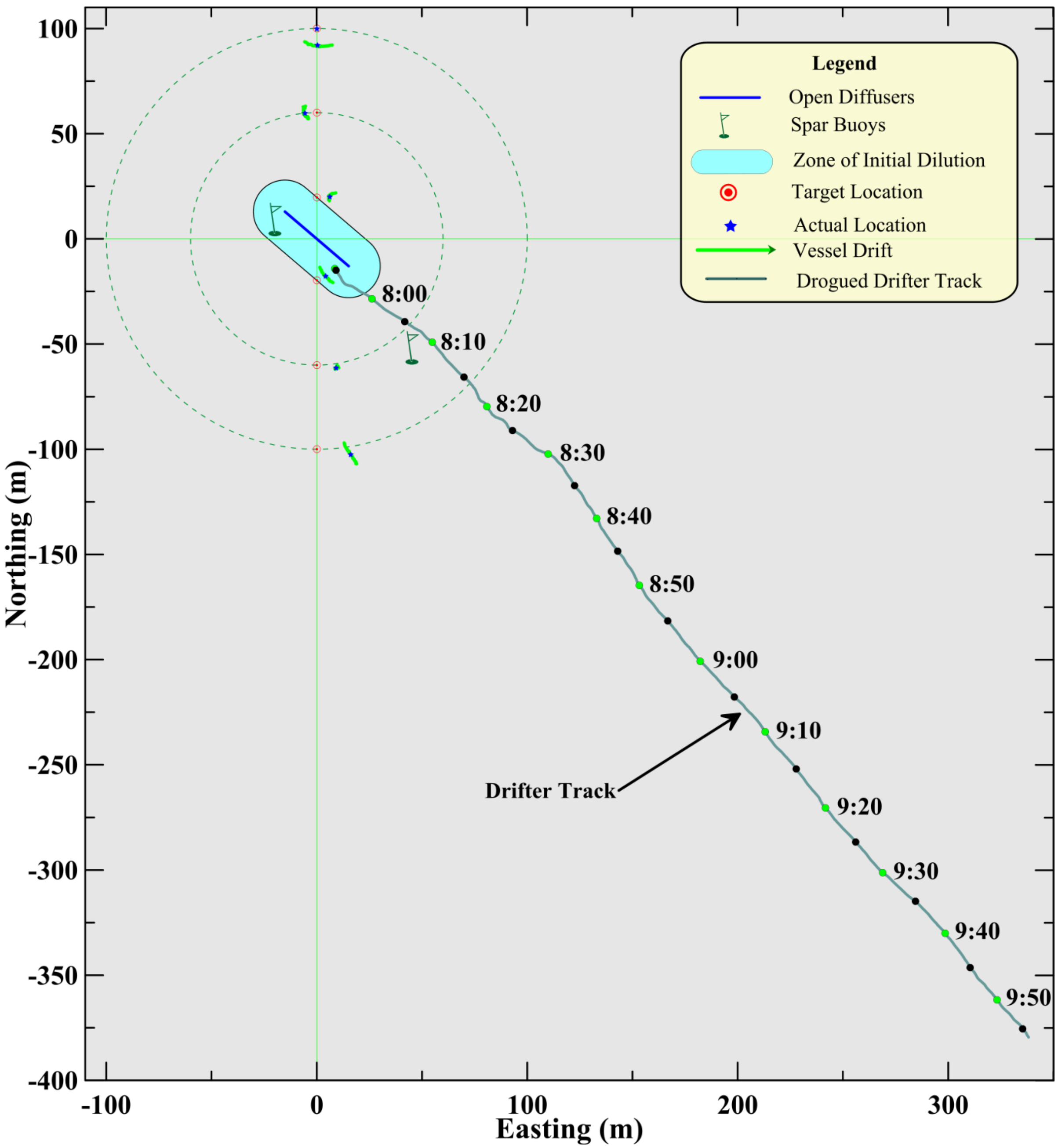


Figure 3. Drogued Drifter Trajectory

Upwelling was occurring around the time of the August 2011 survey. Upwelling season normally begins sometime during late March and or early April as shown by the positive (blue) upwelling indices in Figure 5. At the onset of upwelling season, there is a spring transition to more persistent southeastward winds along the central California coast. This transition is initiated by the stabilization of a high-pressure field over the northeastern Pacific Ocean. Clockwise winds around this pressure field drive the prevailing northwesterly winds along the central California coast. These prevailing winds move warmer surface

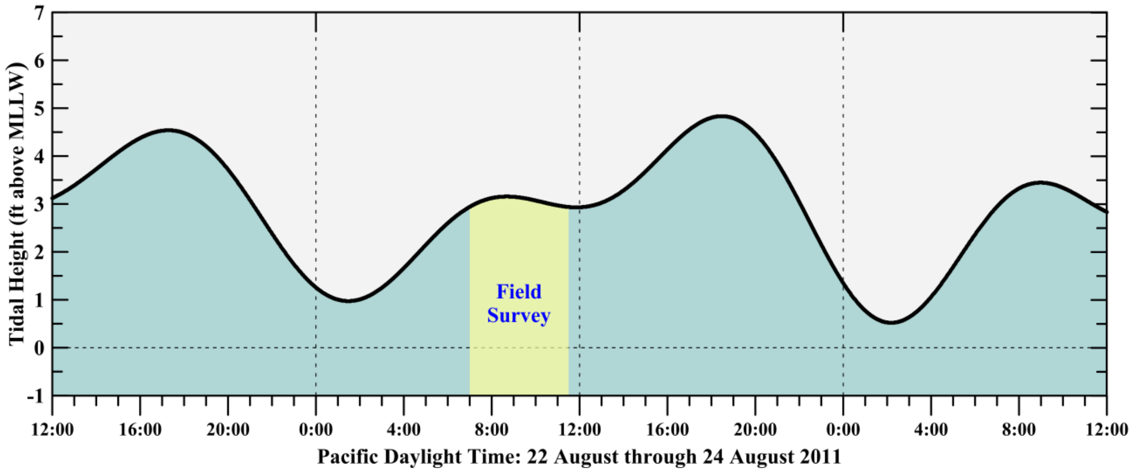


Figure 4. Tidal Level during the August 2011 Survey

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. Although mild southeastward winds prevailed on the morning of the August 2011 survey, strong southeastward winds prevailed along the

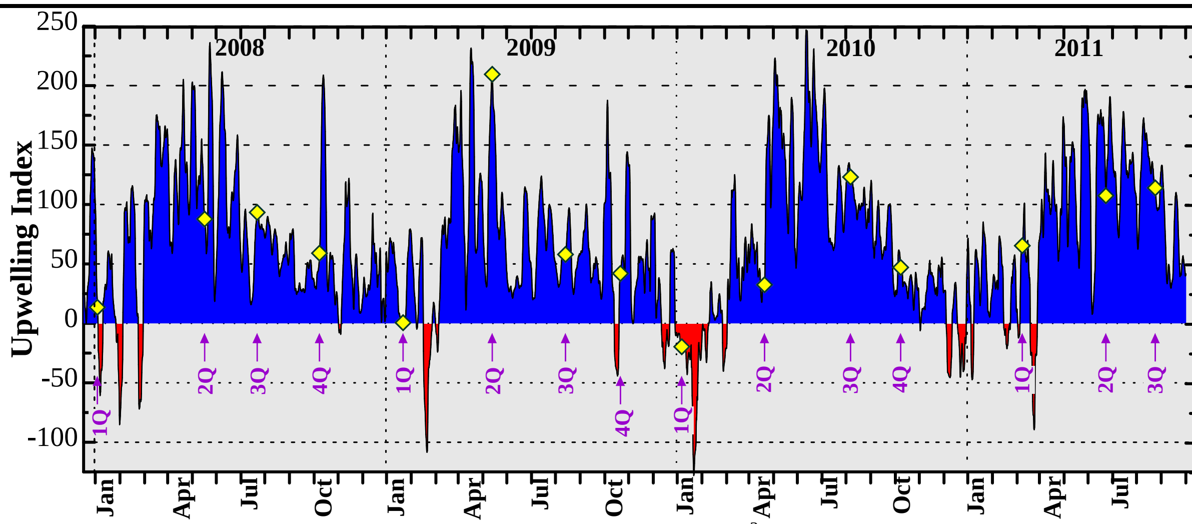


Figure 5. Five-Day Average Upwelling Index ($m^3/s/100m$ of coastline)

central California coast throughout most of the month of August, resulting in cooler sea surface temperatures close to the coastline.

The satellite image on the cover of this report documents the upwelling that was present one week prior to the survey, on 15 August 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 (~14˚C) within Estero Bay were comparable to the near-surface temperatures measured by the CTD during the August 2011 survey.[10]

METHODS

The 38 ft F/V *Bonnie Marietta*, owned and operated by Captain Mark Tognazzini of Morro Bay, served as the survey vessel on Tuesday, 23 August 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-19plusV2 Seacat CTD instrument package collected measurements of conductivity, temperature, light transmittance, dissolved oxygen (DO), pH, and pressure during the August 2011 survey. This new CTD instrument package was commissioned in May 2011 to replace an older model SBE-19 profiler that was retired from regular use following the June 2011 survey. The DO and pH probes on the older instrument package were repaired and calibrated at the factory in June 2011, and the instrument will be maintained and kept available as a backup unit.

The new CTD system offers many advantages over the older unit, which was in service for nearly two decades. The 4 Hz sampling rate[11] on the new instrument collects data at twice the rate of the older unit, allowing much higher spatial resolution for a given tow, or descent rate. In addition, the probes and

[10] Refer to Table 5 and Figure 7 for receiving-water properties recorded during the vertical hydrocasts.
[11] 0.25-s sampling interval

sensors have a much faster response time, further enhancing the spatial resolution of seawater properties. Lastly, the probes and sensors on the new CTD are more stable and exhibit negligible long-term drift. As a result, and in accordance with the manufacturer's recommendations, the new CTD package does not require regular recalibration of the sensors prior to each field survey. Nevertheless, following receipt of the new CTD package, the accuracy of the pH and DO sensors was confirmed in the MRS laboratory prior to its deployment in the August 2011 survey.

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 confine the CTD to depths less than 600 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 Table 3. Salinity (‰) was calculated from conductivity measurements reported in units of Siemens/m. Density was derived from contemporaneous temperature (°C) and salinity data, and was expressed as 1000 times the specific gravity minus one, which is a unit of sigma-T (σ_t).

Table 3. CTD Specifications

Component	Units	Range	Accuracy	Resolution
Housing (19p-1a; Acetron Plastic)	m	0 to 680	—	—
Pump (SBE 5P)	—	—	—	—
Pressure (19p-2h; Strain-Gauge)	dBar	0 to 680	±1.7	± 0.10
Conductivity	Siemens/m	0 to 9	± 0.0005	± 0.00005
Salinity	‰	0 to 58	± 0.004	± 0.0004
Temperature	ºC	–5 to 35	± 0.005	± 0.0001
Transmissivity (WETLabs C-Star)[12]	%	0 to 100	± 0.3	± 0.03
Oxygen (SBE 43)	% Saturation	0 to 120	± 2	—
pH (SBE 18)	pH	0 to 14	± 0.1	—

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

Before 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.

[12] 25-cm path length of red (660 nm) light

At 08:43 PDT, following the last vertical profile at RW6, the CTD instrument package was brought aboard the survey vessel. Data was downloaded and inspected for overall quality and the presence of a thermocline was noted below 6 m. The CTD was then reconfigured for horizontal towing with uniform flow across forward-looking probes. The CTD was fitted with a horizontal stabilizer wing and a depth-suppression weight was added to the towline to achieve constant- depth tows. The CTD was subsequently towed around and across the ZID at two separate depths, one within the surface mixed layer and one below the thermocline, in accordance with the receiving-water monitoring require-ments of the NPDES discharge permit (Figure 6).

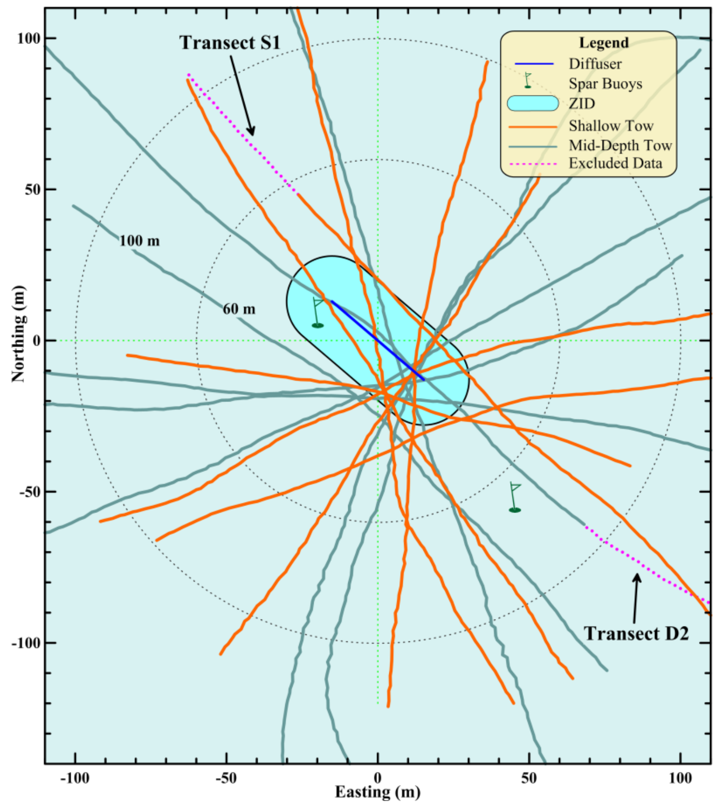


Figure 6. CTD Tracklines during the August 2011 Tow Surveys

Initially, the reconfigured CTD package was towed for 23 min at an average depth of 3.67 m, and an average speed of 1.91 m/s, passing over, or near the diffuser structure eight times. After completion of the shallow tow survey, the CTD was brought aboard to facilitate the retrieval of the drogued drifter which had steadily been moving beyond the survey area.

Upon returning to the survey area, eight additional passes were made with the CTD at an average depth of 8.31 m.[13] During this 40-minute mid-depth-tow, vessel speed averaged 1.91 m/s. At the observed towing speeds and a 4 Hz sampling rate, 2.1 CTD measurements were collected for each meter traversed. This complies with the permit requirement for minimum horizontal resolution of at least one sample per meter. Contemporaneous navigation fixes recorded onboard the survey vessel were adjusted for CTD setback and aligned with time stamps on the internally recorded CTD data. The resulting data for the six seawater properties were processed to produce horizontal maps within the upper and sub-thermocline portions of the water column.[14]

Quality Control

Upon retrieval of the CTD following the vertical casts water-quality data were downloaded to a portable computer and examined for completeness and range acceptability. Data acquired during the tow surveys were monitored continuously as the data was logged. Subsequent review of the tow data revealed that the

[13] The tow depths during parts of the first shallow transect (S1) and the second deep transect (D2), as shown by the dashed lines in Figure 6, were removed from subsequent analysis due to their vertical offset as described in the *Quality Control* section.

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

CTD was tracking at a slightly different depth during small portions of both the mid-depth and shallow tows (dashed lines in Figure 6). Specifically, slightly increased vessel speeds during the first part of Transect S1 resulted in tow depths that were 0.4 m shallower than average, while increased speed during the last part of Transect D2 resulted in a 1.7 m decrease in tow depth compared to the average tow depths of the other transects. While these depth offsets appear small, the tows were conducted near the region of sharp vertical gradients associated with upwelling-induced stratification. As a result, the slight depth offsets created artificial horizontal differences in the combined 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 August 2011 survey. Because of their depth offsets, data collected during these portions of Transects S1 and D2 were incompatible with the rest of the tow data, and were excluded from the subsequent analysis to avoid introducing erroneous lateral differences in the horizontal property maps.[15] 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.

RESULTS

The second-quarter receiving-water survey began on Tuesday, 23 August 2011, at 07:53 PDT with the deployment of the drogued drifter. Over the following three hours, offshore observations and measurements were collected as required by the NPDES monitoring program. The survey ended at 10:52 PDT with the retrieval of the CTD at the completion of the mid-depth tow. Although 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 23 August 2011, skies were overcast, with light but steady winds. Average wind speeds, calculated over one-minute intervals, ranged from 0.7 kt to 3.2 kt (Table 4). Similarly, peak wind speeds averaged from 1.3 kt to 3.9 kt. The swell was out of the northwest with a significant wave height of 2 feet. Air temperatures, which varied from 12.6°C to 14.8°C, were slightly cooler than the average sea-surface temperatures.

Table 4. Standard Meteorological and Oceanographic Observations

Station	Location[16] Latitude	Location[16] Longitude	Diffuser Distance (m)	Time (PDT)	Air (°C)	Cloud Cover (%)	Wind Avg (kt)	Wind Max (kt)	Wind Dir (from) (°T)	Swell Ht/Dir (ft/°T)	Secchi Depth (m)
RW1	35° 23.257' N	120° 52.488' W	102.2	8:12:47	13.7	100	2.6	3.7	NW	2/NW	3.0
RW2	35° 23.225' N	120° 52.501' W	40.2	8:18:37	13.4	100	2.3	3.6	NW	2/NW	3.0
RW3	35° 23.205' N	120° 52.498' W	13.5	8:26:08	14.8	100	0.7	1.3	NW	2/NW	3.0
RW4	35° 23.188' N	120° 52.496' W	7.2	8:31:04	12.6	100	3.2	4.1	NW	2/NW	3.0
RW5	35° 23.167' N	120° 52.498' W	46.3	8:38:01	12.6	100	3.2	3.9	NW	2/NW	3.0
RW6	35° 23.138' N	120° 52.486' W	99.9	8:43:51	12.8	100	2.3	3.1	NW	2/NW	3.0

[15] Shown in Figures 8 and 9 on Pages 19 and 20

[16] 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.

The 3-m Secchi depths recorded at most stations during the August 2011 survey indicated a low level of ambient water clarity (Table 4). The Secchi depths reflected the presence of a 6-m euphotic zone that spanned only the top third of the 16.5-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. The 1.21 million gallons of effluent discharged on the day of the survey had a temperature of 21°C, a suspended-solids concentration of 34 mg/L, an oil-and-grease concentration of 5 mg/L, and a pH of 7.7. Biochemical oxygen demand (BOD) measured in a sample collected two days after the survey was 56 mg/L.

During the August 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.

Minimal beach usage by pedestrians was documented during the August 2011 survey, likely due to the heavily overcast conditions at the time of the survey. However, numerous small fishing vessels were observed in the offshore waters; the lower transmissivities associated with highly productive, heavily stratified, upwelled waters created ideal conditions, commonly referred to as "salmon water", for trolling for sea bass and halibut.

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 August 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 August 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).

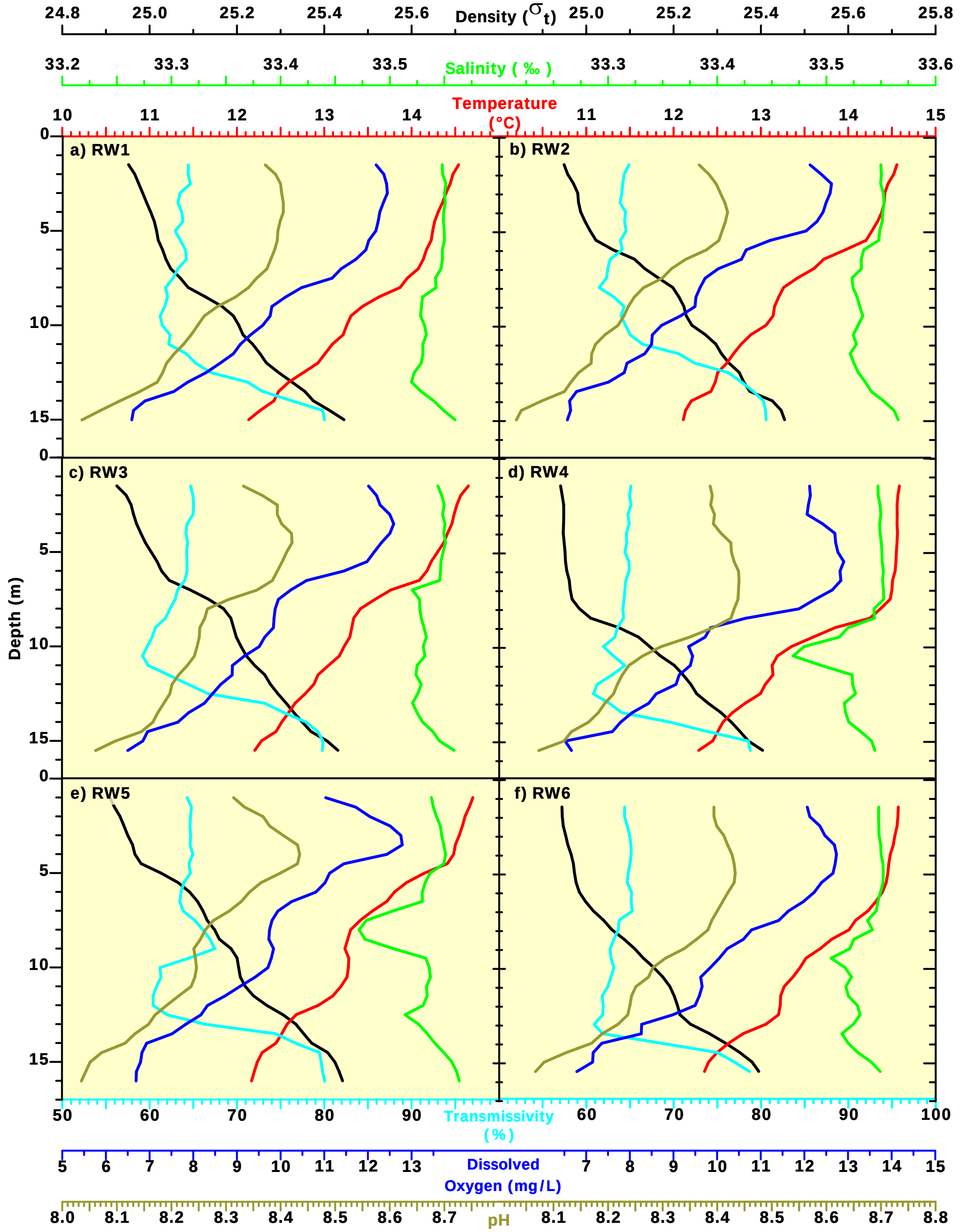


Figure 7. Vertical Profiles of Water-Quality Parameters

Table 5. Vertical Profile Data Collected on 23 August 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		14.603	14.671		14.703			33.551	33.543		33.538	
1.5	14.539	14.557	14.651	14.586	14.661	14.573	33.548	33.550	33.544	33.547	33.540	33.548
2.0	14.474	14.521	14.563	14.569	14.612	14.569	33.549	33.550	33.548	33.547	33.543	33.548
2.5	14.443	14.456	14.519	14.560	14.583	14.560	33.552	33.550	33.550	33.549	33.546	33.548
3.0	14.394	14.419	14.487	14.561	14.546	14.535	33.550	33.552	33.548	33.550	33.548	33.548
3.5	14.355	14.413	14.463	14.559	14.501	14.517	33.551	33.553	33.551	33.549	33.550	33.550
4.0	14.305	14.386	14.412	14.564	14.482	14.483	33.549	33.552	33.550	33.549	33.551	33.550
4.5	14.264	14.336	14.369	14.559	14.409	14.465	33.549	33.551	33.551	33.550	33.550	33.552
5.0	14.242	14.272	14.298	14.551	14.147	14.454	33.550	33.549	33.549	33.551	33.537	33.552
5.5	14.225	14.205	14.226	14.547	13.943	14.435	33.550	33.548	33.547	33.551	33.533	33.552
6.0	14.170	13.969	14.176	14.537	13.804	14.393	33.548	33.534	33.547	33.552	33.530	33.550
6.5	14.135	13.721	14.088	14.508	13.716	14.318	33.548	33.532	33.546	33.552	33.530	33.547
7.0	14.078	13.607	13.766	14.500	13.554	14.226	33.547	33.532	33.521	33.552	33.503	33.546
7.5	13.952	13.418	13.583	14.481	13.413	14.084	33.542	33.524	33.527	33.553	33.479	33.538
8.0	13.868	13.259	13.415	14.370	13.302	14.010	33.543	33.524	33.528	33.544	33.472	33.542
8.5	13.627	13.204	13.337	14.249	13.269	13.812	33.530	33.528	33.529	33.544	33.477	33.525
9.0	13.438	13.156	13.316	13.852	13.236	13.679	33.529	33.531	33.531	33.520	33.504	33.521
9.5	13.306	13.140	13.293	13.600	13.281	13.517	33.528	33.533	33.534	33.512	33.533	33.504
10.0	13.258	13.058	13.228	13.351	13.276	13.448	33.532	33.529	33.531	33.480	33.536	33.517
10.5	13.217	12.885	13.173	13.189	13.262	13.367	33.534	33.525	33.532	33.470	33.537	33.523
11.0	13.093	12.774	13.050	13.129	13.191	13.267	33.530	33.528	33.525	33.495	33.534	33.518
11.5	13.009	12.687	12.929	13.138	13.099	13.227	33.530	33.522	33.524	33.524	33.534	33.520
12.0	12.927	12.611	12.882	13.052	12.932	13.222	33.529	33.525	33.529	33.524	33.531	33.528
12.5	12.762	12.505	12.782	12.994	12.677	13.202	33.523	33.529	33.526	33.527	33.514	33.531
13.0	12.596	12.478	12.666	12.821	12.575	13.058	33.520	33.536	33.521	33.516	33.527	33.525
13.5	12.478	12.428	12.592	12.675	12.514	12.796	33.529	33.541	33.525	33.518	33.534	33.514
14.0	12.424	12.205	12.513	12.566	12.447	12.633	33.540	33.552	33.530	33.521	33.541	33.520
14.5	12.268	12.138	12.449	12.506	12.289	12.497	33.549	33.562	33.540	33.531	33.550	33.529
15.0	12.135	12.112	12.281	12.448	12.234	12.401	33.560	33.566	33.546	33.541	33.557	33.541
15.5	12.109	12.092	12.204	12.288	12.200	12.354	33.565	33.568	33.559	33.544	33.561	33.549
16.0	12.097	12.076	12.118	12.176	12.168	12.225	33.570	33.571	33.563	33.558	33.564	33.550
16.5			12.111	12.085	12.155				33.570	33.566	33.566	

Table 5. Vertical Profile Data Collected on 23 August 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		24.941	24.920		24.909			8.363	8.329		8.314	
1.5	24.952	24.949	24.925	24.941	24.919	24.944	8.372	8.367	8.332	8.387	8.334	8.394
2.0	24.966	24.957	24.946	24.945	24.932	24.945	8.391	8.385	8.367	8.391	8.368	8.394
2.5	24.975	24.971	24.958	24.948	24.941	24.947	8.400	8.398	8.394	8.388	8.380	8.399
3.0	24.984	24.981	24.963	24.949	24.950	24.953	8.402	8.406	8.394	8.395	8.405	8.412
3.5	24.993	24.982	24.970	24.948	24.961	24.958	8.405	8.414	8.402	8.393	8.431	8.419
4.0	25.002	24.987	24.980	24.947	24.966	24.965	8.405	8.419	8.420	8.407	8.435	8.427
4.5	25.011	24.997	24.990	24.949	24.981	24.971	8.399	8.415	8.421	8.425	8.431	8.431
5.0	25.016	25.009	25.004	24.951	25.026	24.973	8.395	8.409	8.411	8.426	8.399	8.433
5.5	25.020	25.022	25.017	24.953	25.065	24.977	8.394	8.403	8.403	8.431	8.364	8.431
6.0	25.030	25.061	25.027	24.955	25.092	24.984	8.389	8.380	8.394	8.439	8.343	8.420
6.5	25.037	25.110	25.045	24.961	25.110	24.998	8.382	8.342	8.385	8.440	8.328	8.410
7.0	25.048	25.134	25.092	24.963	25.122	25.016	8.375	8.316	8.357	8.439	8.306	8.400
7.5	25.070	25.166	25.135	24.968	25.132	25.040	8.356	8.299	8.305	8.438	8.277	8.390
8.0	25.088	25.198	25.169	24.984	25.149	25.059	8.341	8.265	8.266	8.431	8.262	8.383
8.5	25.128	25.212	25.186	25.010	25.160	25.087	8.317	8.248	8.261	8.425	8.253	8.362
9.0	25.166	25.224	25.192	25.074	25.187	25.111	8.284	8.237	8.252	8.392	8.241	8.339
9.5	25.192	25.229	25.199	25.120	25.200	25.131	8.260	8.229	8.251	8.349	8.244	8.305
10.0	25.204	25.242	25.209	25.145	25.204	25.155	8.248	8.218	8.247	8.297	8.246	8.282
10.5	25.214	25.273	25.222	25.170	25.208	25.175	8.236	8.194	8.242	8.263	8.243	8.274
11.0	25.236	25.297	25.240	25.202	25.219	25.191	8.222	8.177	8.229	8.238	8.236	8.251
11.5	25.253	25.309	25.264	25.222	25.238	25.201	8.205	8.170	8.213	8.226	8.213	8.243
12.0	25.268	25.327	25.277	25.239	25.268	25.209	8.191	8.169	8.201	8.217	8.191	8.240
12.5	25.295	25.350	25.294	25.253	25.305	25.215	8.184	8.146	8.197	8.210	8.170	8.236
13.0	25.326	25.361	25.313	25.279	25.335	25.239	8.174	8.132	8.186	8.194	8.158	8.218
13.5	25.355	25.375	25.330	25.308	25.353	25.282	8.142	8.120	8.175	8.182	8.133	8.189
14.0	25.375	25.426	25.350	25.332	25.371	25.319	8.105	8.078	8.166	8.164	8.115	8.170
14.5	25.412	25.446	25.369	25.352	25.408	25.352	8.070	8.041	8.145	8.133	8.072	8.123
15.0	25.445	25.454	25.406	25.371	25.424	25.380	8.036	8.032	8.097	8.119	8.051	8.083
15.5	25.454	25.460	25.431	25.404	25.434	25.395	8.026	8.028	8.061	8.073	8.043	8.067
16.0	25.460	25.465	25.451	25.436	25.442	25.420	8.024	8.024	8.044	8.041	8.035	8.047
16.5			25.458	25.460	25.446				8.022	8.023	8.031	

Table 5. Vertical Profile Data Collected on 23 August 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		11.901	10.714		11.033			64.308	64.925		64.304	
1.5	12.189	12.131	12.014	12.120	11.721	12.067	64.447	64.883	64.684	65.107	64.789	64.402
2.0	12.365	12.390	12.198	12.138	12.043	12.124	64.421	64.345	64.966	64.982	64.690	64.385
2.5	12.427	12.622	12.279	12.091	12.510	12.356	64.685	64.180	65.040	65.117	64.622	64.708
3.0	12.446	12.591	12.500	12.063	12.755	12.470	63.491	64.085	64.981	64.782	64.706	64.971
3.5	12.354	12.498	12.591	12.420	12.787	12.690	63.241	63.877	64.288	64.920	64.629	65.122
4.0	12.273	12.430	12.505	12.698	12.435	12.736	63.685	64.506	64.157	64.604	64.955	65.146
4.5	12.235	12.289	12.308	12.717	11.448	12.706	63.826	64.401	64.354	64.635	64.503	65.024
5.0	12.181	12.039	12.141	12.768	11.122	12.656	62.945	64.570	64.237	64.432	64.679	64.797
5.5	12.020	11.214	11.980	12.904	11.019	12.391	63.525	63.919	64.285	64.904	63.921	64.690
6.0	11.954	10.667	11.447	12.818	10.807	12.230	64.116	64.116	64.294	64.909	63.606	65.192
6.5	11.724	10.559	10.595	12.837	10.255	11.980	64.212	62.744	64.037	64.531	63.464	65.148
7.0	11.389	10.027	10.234	12.640	9.939	11.635	63.254	62.469	63.203	64.432	63.841	65.270
7.5	11.180	9.727	9.950	12.244	9.804	11.412	62.675	62.318	62.928	64.331	65.186	63.766
8.0	10.482	9.610	9.876	11.875	9.746	10.790	61.850	61.474	62.341	64.200	66.104	63.650
8.5	10.113	9.515	9.850	10.652	9.732	10.602	62.055	63.184	61.811	64.270	66.931	63.171
9.0	9.800	9.494	9.836	9.850	9.840	10.229	61.738	64.332	60.665	63.567	67.454	62.733
9.5	9.762	9.160	9.636	9.724	9.787	10.050	61.216	63.978	60.291	63.281	64.495	62.843
10.0	9.590	8.726	9.511	9.348	9.710	9.844	61.455	64.510	59.730	61.956	61.187	63.161
10.5	9.312	8.516	9.170	9.440	9.418	9.624	62.348	65.035	59.198	63.143	61.312	62.823
11.0	9.079	8.498	8.897	9.387	9.064	9.657	62.205	66.476	59.837	64.424	60.799	62.484
11.5	8.919	8.342	8.892	9.131	8.725	9.592	64.201	70.590	62.173	62.972	60.399	61.822
12.0	8.615	7.936	8.630	9.059	8.327	9.496	65.280	72.429	64.431	61.256	60.424	61.948
12.5	8.294	7.873	8.439	8.604	8.175	8.978	67.011	76.250	66.730	60.811	62.013	61.873
13.0	7.877	7.513	8.254	8.433	7.826	8.271	71.200	77.790	73.183	62.639	66.394	60.912
13.5	7.555	6.780	7.892	8.052	7.515	8.263	72.964	79.142	75.411	64.084	74.468	61.886
14.0	6.894	6.620	7.648	7.790	6.933	7.359	76.349	80.291	77.920	69.590	76.711	68.618
14.5	6.632	6.644	6.955	7.601	6.825	7.160	79.824	80.536	79.272	73.905	79.448	75.071
15.0	6.592	6.569	6.844	6.517	6.793	7.148	80.029	80.593	79.853	78.568	79.654	76.952
15.5	6.607	6.543	6.500	6.664	6.698	6.786	80.784	80.791	79.783	78.794	79.814	78.717
16.0	6.660	6.548	6.618	6.617	6.690	7.040	81.460	79.509	80.948	79.205	80.049	79.670
16.5			6.704	6.827	6.741				79.736	78.712	80.037	

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 3 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 produce oxygen, consume carbon dioxide (CO_2), and decrease water clarity. With depth, the ratio 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). Steadily increasing respiration below the 6-m euphotic zone depleted DO concentrations (dark-blue lines) and the reduced presence of phytoplankton below 10.5 m resulted in an increased water clarity (transmissivity) at depth (light-blue lines).

The influence of the discharge can be seen in the vertical profiles recorded at Stations RW4 and RW5 (Figure 7de). Typically, the presence of dilute wastewater appears as a sharp reduction in salinity and density at depth. During the August 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 the base of the thermocline. 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.

As a result of trapping at depth, there was no evidence of the plume signature within the upper water column. The 3-m Secchi depths were too shallow to capture the signature of the effluent plume, and consequently, no spatial variation was observed, even at Stations RW4 and RW5 (Table 4). The presence of the plume at RW4 and RW5 was also consistent with the southeasterly direction of the drifter transport (Figure 3), and the location of the plume signature delineated by the mid-depth tow (Figure 8).

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 density, anomalies in other seawater properties coincided with the plume's salinity anomaly. However, in contrast to the salinity anomaly, they were all 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 became juxtaposed against the ambient seawater at 8.3 m. For example, wastewater was much warmer than the receiving seawater, yet the thermal signature of the plume (Figure 8a) was negative (cooler) than the surrounding seawater. Similarly, increased transmissivity (water clarity) within ambient seawater near the seafloor (light blue lines in Figure 7) created significant anomalies when contrasted with the murkier waters in the mid and upper water column. This increased transmissivity was associated with the plume signature observed during the mid-depth tow (Figure 8d). Both of these anomalies associated with the trapped plume could only have been generated by the upward displacement of cooler, clearer seawater within the rising effluent plume.

Although the plume reached buoyant equilibrium near 8 m, the momentum of the rising plume initially carried it slightly farther upward in the water column. As a result, a very weak, highly localized plume signature was also apparent at 3.6 m above the southeastern end of the diffuser structure during the shallow tow survey (Figure 9b). In contrast to the signature at depth (Figure 8), however, the signature was restricted to the ZID, and all of the seawater properties exhibited anomalies coincident with the salinity anomaly, including density (Figure 9c).

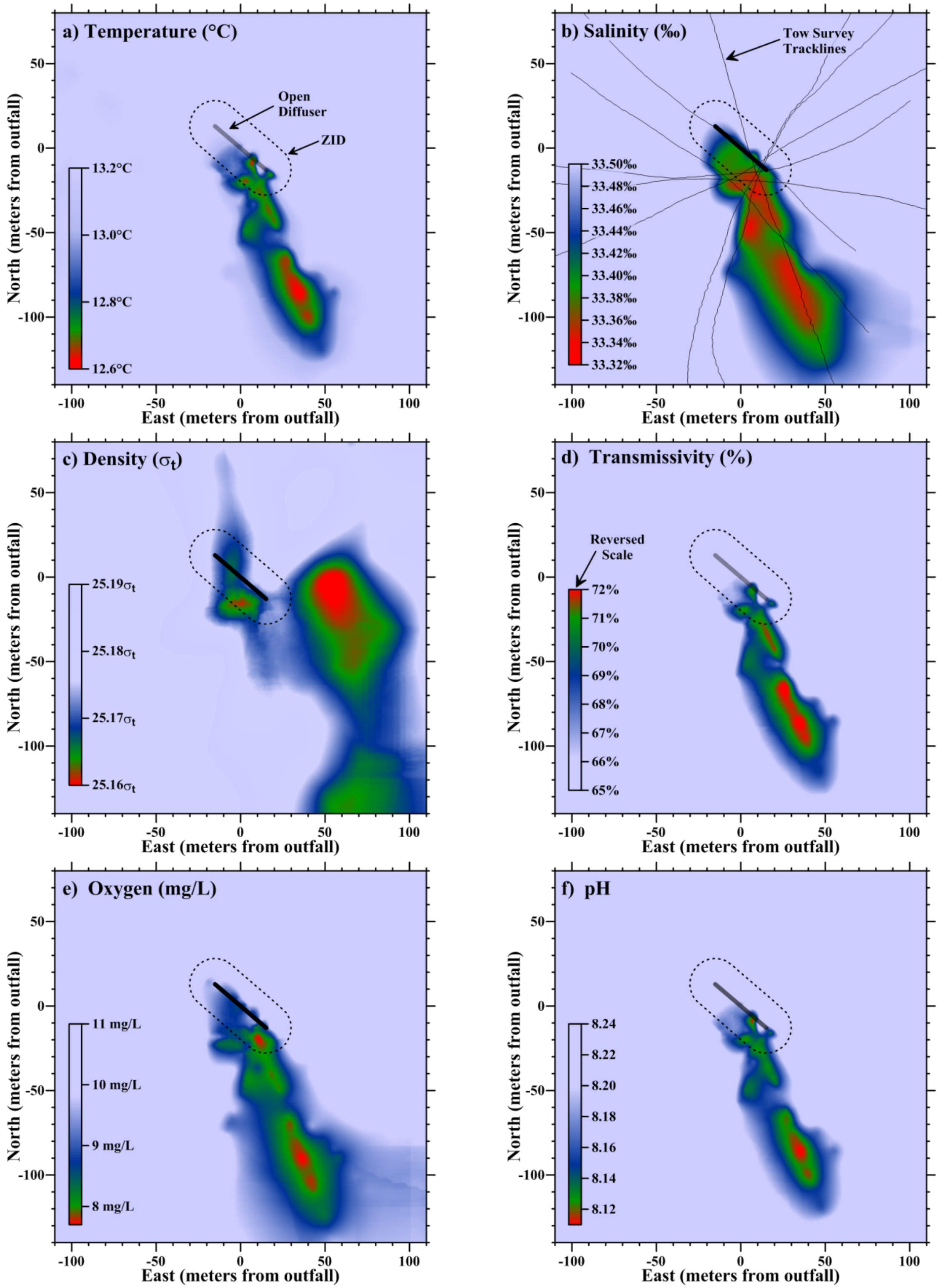


Figure 8. Horizontal Distribution of Mid-Depth Water-Quality Parameters 8.3 m below the Sea Surface

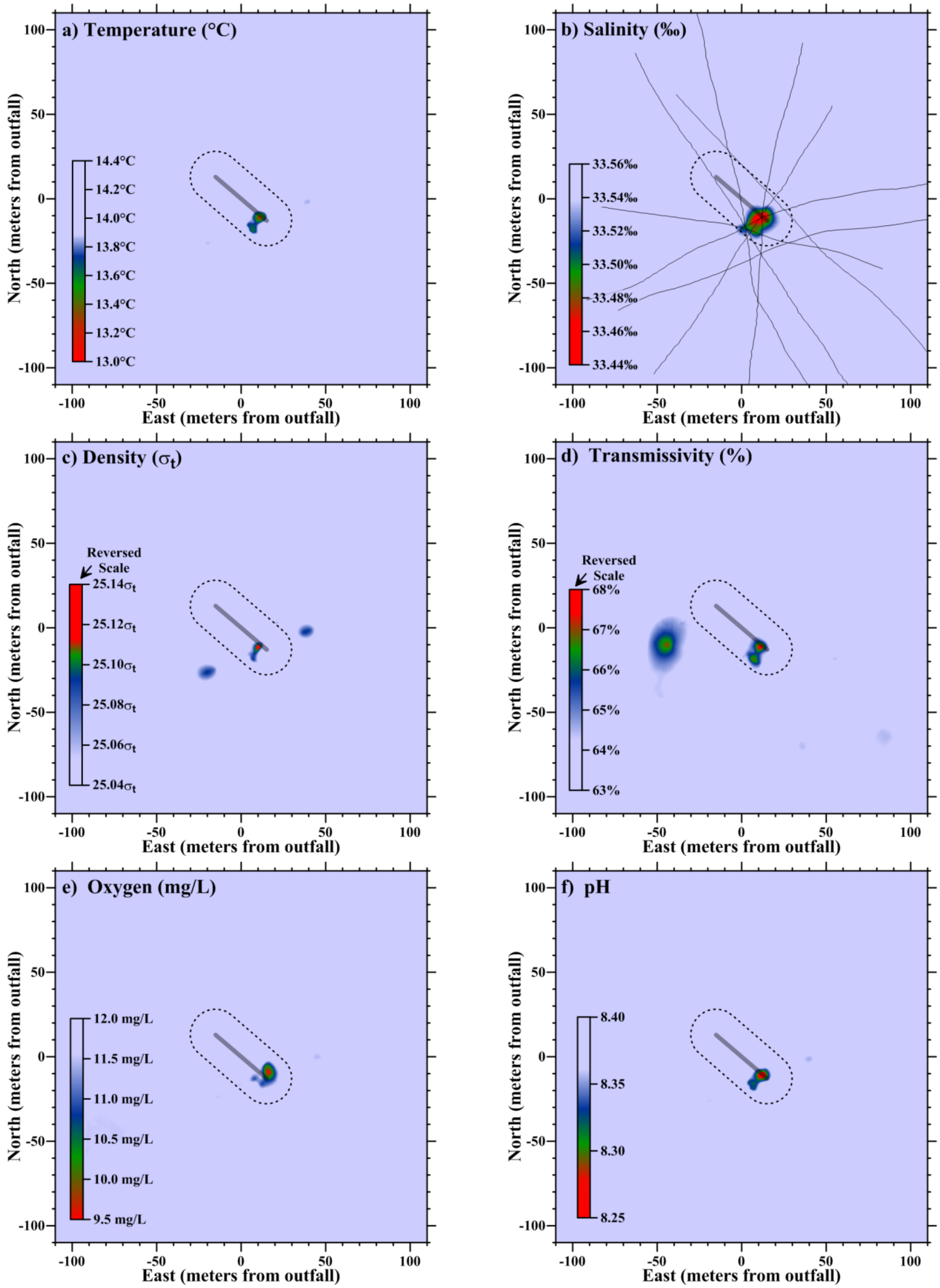


Figure 9. Horizontal Distribution of Shallow Water-Quality Parameters 3.7 m below the Sea Surface

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 increase in transmissivity (Figure 9d), are consistent with the upward transport of ambient seawater within the rising plume.

Outfall Performance

The efficacy of the outfall can be evaluated through a comparison of dilution levels measured at the time of the August 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.

The 133:1 dilution estimate was based on worst-case modeling under highly stratified conditions, where trapping of the plume below a strong thermocline would curtail the additional buoyant mixing normally experienced with 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 higher than the conservative model prediction, 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.

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

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

By rearranging Equation 1, the actual dilution achieved by the outfall can be determined from measured seawater anomalies. This measured dilution can then be compared with the critical dilution factor determined from modeling. Salinity is an especially useful tracer because it directly reflects the magnitude of ongoing dilution. Wastewater-induced patches of lower salinity are apparent near the diffuser structure in the tow-survey maps (Figures 8b and 9b) and in the vertical profile measured at Stations RW4 and RW5 (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:

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

The salinity concentration within MBCSD effluent (C_e)[17] 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 is directly reflected by a larger amplitude salinity anomaly.

The lowest salinity (33.324‰) measured during the August 2011 survey was recorded within the ZID at a depth of 7.6 m during Transect D1 of the mid-depth tow survey (red shading in Figure 8b). This measured salinity corresponds to a 0.213‰ reduction below the mean ambient salinity of 33.537‰ 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 153-fold (Figure 10). This is 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 3.4 m from the diffuser structure, and well below the 6.4-m trapping depth determined from modeling studies.

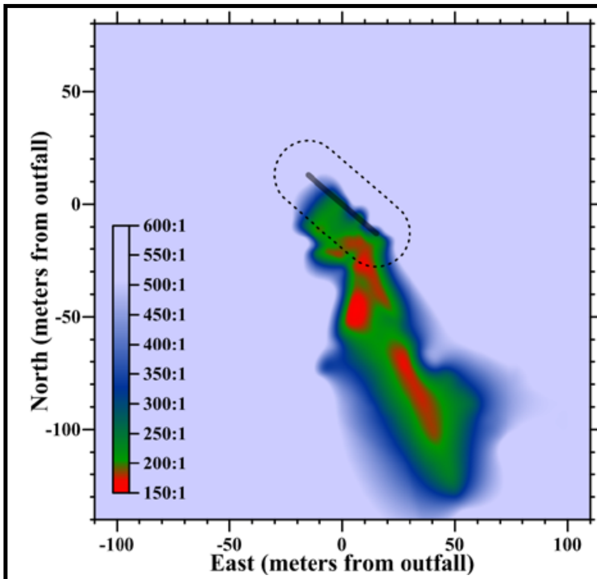


Figure 10. Mid-Depth Plume Dilution Computed from Salinity Anomalies in Figure 8b

Slightly smaller salinity reductions (0.198‰), corresponding to dilution levels exceeding 164-fold, were measured along the southern boundary of the ZID and beyond the ZID to the southeast as the plume spread beneath the thermocline and was carried by the strong prevailing oceanic flow. In fact, patches of the plume with dilutions below 170-fold were observed as much as 80 m from the diffuser structure.

[17] Wastewater samples collected during September 2011 had an average salinity of 0.779‰.

In contrast to the widespread signature of the plume trapped beneath the thermocline, the shallow tow survey captured a highly localized portion of the plume as it briefly extended above the thermocline directly over the diffuser structure (Figure 9). In that case, however, turbulence generated by the plume's 4.6-m upward movement substantially increased dilutions to levels exceeding 257 fold (Figure 11).

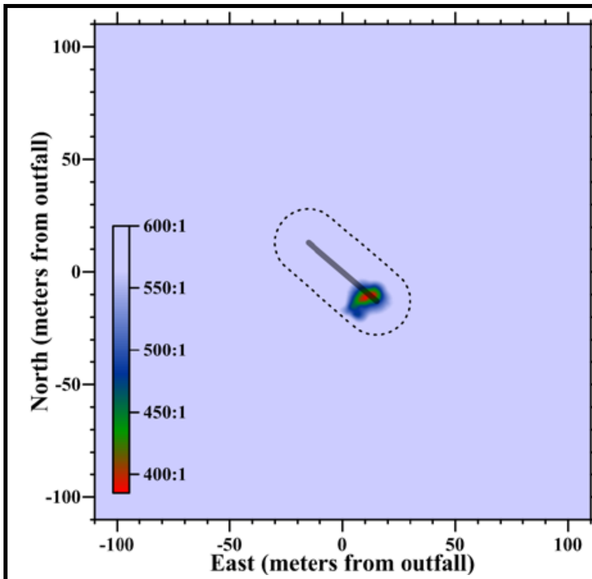


Figure 11. Shallow Plume Dilution Computed from Salinity Anomalies in Figure 9b

Despite this localized excursion into the mixed layer, most of the plume remained trapped below 7 m. Because the observed trapping depth was greater than that predicted by modeling, dilutions below the 133-fold dilution from modeling would potentially be expected. Instead, dilutions exceeded the model predictions. Within the ZID, and well before completion of initial dilution, observed dilutions exceeded 153-fold; significantly exceeding model predictions even though the plume had yet to reach the 6.4-m trapping depth predicted in the model. At 8.3 m, the plume had also already begun to spread laterally beyond the ZID, where observed dilution levels exceeded 164:1, 20% higher than the 133:1 dilution level predicted by modeling that was used to establish end-of-pipe limits on effluent constituents in the MBCSD permit.

The dilution computations demonstrate that, during the August 2011 survey, the outfall was performing better than designed and was rapidly diluting effluent more than 153-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 August 2011 survey, the COP receiving-water objectives were being met by the limits on chemical concentrations within discharged wastewater that are promulgated by the NPDES discharge permit issued to the MBCSD.

COMPLIANCE

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

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

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

The results of these analyses applied to the August 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 August 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 11,355 CTD measurements collected during the August 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 three questions to restrict attention to: 1) the oceanic area where permit provisions apply; 2) changes due to the presence of wastewater particulates; and 3) changes large enough to be reliably detected against the backdrop of natural variation. The measurements that make it through the screening process, if any, can then be compared with Basin-Plan numerical limits and COP allowances. The following subsection provides additional lines-of-evidence that demonstrate compliance with numerical permit limits independent of the screening process. However, the screening process described in this section unequivocally eliminated all of the CTD measurements collected during the August 2011 survey from further consideration. The rationale for evaluating observations for compliance analysis is provided in the following description of the three screening steps.

Table 7. Receiving-Water Measurements Screened for Compliance Evaluation

Topic Addressed	Screening Question	Answer: No	Answer: Yes[18]	*Parameter*
Location	1. Was the measurement collected beyond the 15.2-m ZID boundary where modeling assumes that initial dilution is complete?	*1,575*	*9,779*	All
Wastewater Constituents	2. Did the beyond-ZID measurement coincide with a quantifiable salinity anomaly (≤550:1 dilution level) indicating the presence of detectable wastewater constituents?	*8,748*	*1,031*	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?	*1,031*	*0*	Temperature
		1,031	*0*	Transmissivity
		1,031	*0*	DO
		1,031	*0*	pH

1. Measurement Location: The COP states that compliance with its receiving-water objectives "*shall be determined from samples collected at stations representative of the area within the waste field where initial dilution is completed.*" Initial dilution includes the mixing that occurs from the turbulence associated with both the ejection jet, and the buoyant plume's subsequent rise through the water column. Although currents often transport the plume beyond the ZID before the initial dilution process is complete, as was the case during the August 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, 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 August 2011 dataset eliminated 1,575 of the original 11,355 receiving-water observations from further consideration

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

because they were collected within the ZID (Table 7, Question 1). The remaining 9,779 observations were carried forward in the compliance analysis.

2. Presence of Wastewater Constituents: The MBCSD discharge permit restricts application of the numerical receiving-water limits to excursions caused by the presence of wastewater constituents. This confines the compliance analysis to changes caused "*as the result of the discharge of waste*," as specified in the COP, rather than anomalies that arise from the movement of ambient seawater entrained in the effluent plume. Analyses conducted on quarterly receiving-water surveys over the last decade have demonstrated that the direct influence of dilute wastewater is 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 determine the amount of dilution achieved by initial mixing. Based on statistical analyses of the natural variability in salinity readings measured near the outfall over a five-year period between 2004 and 2008, the smallest reduction in salinity that can be reliability detected within receiving waters is 0.062‰. This represents a dilution level of 542-fold. 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. Of the 9,779 observations that were measured outside the ZID during the August 2011 survey, only 1,031 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). 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 August 2011 ambient seawater data, to establish time-specific natural-variability thresholds in a manner analogous to COP Appendix VI. The percentiles were determined from August 2011 vertical profile data, excluding measurements potentially affected by the discharge.

Table 8. Compliance Thresholds

Water Quality Property	95% Confidence Bound[19]	95th Percentile[20,21]	Natural Variability Threshold[22]	COP Allowance[23]	Basin Plan Limit[24]	Extremum[25]
Temperature (ºC)	0.82	14.57	>15.39	—	—	≤14.70
Transmissivity (%)	-10.2	60.9	<50.7	—	—	≥56.8
DO (mg/L)	-1.38	6.62	<5.24	<4.72	<5.00	≥6.50
pH (minimum)	-0.094	8.036	<7.942	<7.742	<7.000	≥8.022
pH (maximum)	0.094	8.431	>8.525	>8.725	>8.300	≤8.478

Temperature, transmissivity, and DO concentrations associated with the 1,031 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 August 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 appears 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 upward displacement of ambient bottom water rather than the effluent plume.

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 increased transmissivity observed within the plume (Figure 8d and 9d) would not result from the increased presence of wastewater particulates. Although transmissivity did not exceed 70% in ambient seawater above 13 m, transmissivity immediately above the seafloor reached 80% (light-blue lines in Figure 7), and its entrainment in the rising plume could easily account for the transmissivity increases beyond 70% observed within the effluent plume.

Although the reductions in DO and pH that were observed within the plume (Figures 8ef and 9ef) could be ascribed to the presence of acidic, oxygen-demanding wastewater constituents, entrainment of ambient seawater at depth is still more plausible. As with temperature and transmissivity, the DO concentrations below 8 mg/L, and pH concentrations below 8.12, were similar to that of ambient seawater at depth. Even

[19] 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.

[20] 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*."

[21] 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.

[22] 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.

[23] 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.*"

[24] 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.

[25] Maximum or minimum value measured during this survey

if the presence of wastewater particulates decreased DO and pH within the plume, their influence was well within the natural range in ambient seawater properties at the time of the survey. Consequently, their influence on water quality cannot be considered environmentally significant.

Other Lines of Evidence

In addition to the analysis provided above, several additional lines of evidence support the conclusion that all the CTD measurements collected during the August 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 August 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 and density) frequently provides additional valuable insight into the origins of any variations observed during a particular survey. For example, during the August 2011 survey, salinity was the only seawater property that exhibited a perceptible difference from ambient conditions. As discussed previously, however, none of the 11,355 temperature, DO, pH, 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.

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 be deemed to adversely affect beneficial uses if they remained within the natural temperature range at the time of the survey (<15.39°C in Table 8). Such was the case for all 11,355 CTD measurements collected during the August 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. However, because natural light is restricted to the euphotic zone, which extends to approximately twice the Secchi depth, the limit on transmissivity reductions during the August 2011 survey only applied to measurements recorded above 6 m (twice the ambient Secchi depth listed in Table 4). As stated previously, no exceedance occurred during the August 2011 survey. Additionally, the presence of a restricted euphotic zone resulting from upwelling processes means that even if the mid-depth tow(8.3m) had found a substantial reduction in transmissivity due to the presence of wastewater constituents, it would not have been a violation of permit conditions because at that depth it would have had no effect on natural light levels.

Insignificant Wastewater Particulate Loads: The discharge of wastewater particulates on 23 August 2011 did not contribute materially to turbidity within the dilute effluent plume. The suspended-solids concentration measured onshore within effluent prior to discharge was 34 mg/L. After dilution by 153-fold, which was the lowest dilution measured during the survey, the effluent TSS concentration would have the reduced ambient transmissivity by only 1.1%. Similarly, the MBCSD discharge could not have contributed materially to the observed DO fluctuations. The MBCSD treatment process routinely removes 80% or more of the organic material, as demonstrated by the low, 56-mg/L BOD measured within the plant's effluent around the time of the survey. That small amount of BOD would have induced a DO depression of no more than 0.023 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 August 2011 survey.

COP Allowances: The COP does not explicitly require that wastewater-induced changes remain within the ranges in natural variation listed in the third column of Table 8, even though these ranges were conservatively used in the data screening process described in the previous subsections. 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 7.742 during the August 2011 survey. This value is well below the lowest pH measurement of 8.022 recorded during the August 2011 survey. Similarly, the lowest DO concentration measured during the survey (6.5 mg/L) was well above both the lower range in natural variation (5.24 mg/L) and the 10% compliance threshold promulgated by the COP (4.72 mg/L).

Irrelevant Basin-Plan Limits: 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. In contrast to the COP, the central-coast Basin Plan attempts to regulate onshore surface waters in addition to coastal waters with a single fixed numerical limit (fifth column of Table 8). While excursions in pH that exceed 8.3 may be problematic for rivers, streams, and lakes, higher pH levels routinely occur naturally in coastal waters. Nearly half of the pH observations collected during the August 2011 exceeded the Basin-Plan maximum. As described previously, these elevated pH measurements cannot be ascribed to the presence of wastewater constituents because effluent had a much lower pH on the day of the survey. Instead, pH levels exceeding the Basin Plan limit routinely occur naturally within the waters of Estero Bay, as they did during the August 2011 survey.

CONCLUSIONS

The statistical screening analysis quantitatively demonstrated that all measurements recorded during the August 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 were within the natural variability that prevailed at the time of the survey.

Immediately after discharge, the outfall was achieving dilution levels in excess of 153-fold, which exceeded the critical dilution levels predicted by design modeling. Additionally, throughout the water column, computed dilution levels outside the ZID achieved dilutions in excess of 164-fold. Lastly, all of the auxiliary observations collected during the August 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 August 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.

REFERENCES

Davis, R.E., J.E. Dufour, G.J. Parks, and M.R. Perkins. 1982. Two Inexpensive Current-Following Drifters. Scripps Institution of Oceanography, University of California, San Diego, La Jolla, California. SIO Reference No. 82-28. December 1982.

Fischer, H.B., E.J. List, R.C.Y. Koh, J. Imberger, and N.H. Brooks. 1979. Mixing in Inland and Coastal Waters. New York: Academic Press, 483 p.

Kuehl, S.A., C.A. Nittrouer, M.A. Allison, L. Ercilio, C. Faria, D.A. Dukat, J.M. Jaeger, T.D. Pacioni, A.G. Figueiredo, and E.C. Underkoffler 1996. Sediment deposition, accumulation, and seabed dynamics in an energetic fine-grained coastal environment. *Continental Shelf Research*, 16: 787-816.

Marine Research Specialists (MRS). 1998. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, Semiannual Benthic Sampling Report, April 1998 Survey. Prepared for the City of Morro Bay, CA. July 1998.

Marine Research Specialists (MRS). 2003. City of Morro Bay and Cayucos Sanitary District, Supplement to the 2003 Renewal Application For Ocean Discharge Under NPDES Permit No. Prepared for the City of Morro Bay and Cayucos Sanitary District, Morro Bay, CA. July 2003.

Marine Research Specialists (MRS). 2011. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 2010 Annual Report. Prepared for the City of Morro Bay, California. March 2011.

[City of] Morro Bay and Cayucos Sanitary District (MBCSD). 2010. The City of Morro Bay-Cayucos Wastewater Treatment Plant Monthly Operations Summary, March 2011.

Regional Water Quality Control Board (RWQCB) - Central Coast Region. 1994. Water Quality Control Plan (Basin Plan) Central Coast Region. Available from the RWQCB at 81 Higuera Street, Suite 200, San Luis Obispo, California. 148p. + Appendices.

Regional Water Quality Control Board (RWQCB) - Central Coast Region and the Environmental Protection Agency (USEPA) – Region IX. 1993a. Waste Discharge Requirements (Order No. 92-67) and Authorization to Discharge under the National Pollutant Discharge Elimination System (Permit No. CA0047881) for City of Morro Bay and Cayucos Sanitary District, San Luis Obispo County.

Regional Water Quality Control Board (RWQCB) - Central Coast Region and the Environmental Protection Agency (USEPA) – Region IX. 1993b. Monitoring and Reporting Program No. 92-67 for City of Morro Bay and Cayucos Sanitary District, San Luis Obispo County (Permit No. CA0047881).

Regional Water Quality Control Board (RWQCB) - Central Coast Region and the Environmental Protection Agency (USEPA) – Region IX. 1998a. Waste Discharge Requirements (Order No. 98-15) and National Pollutant Discharge Elimination System (Permit No. CA0047881) for City of Morro Bay and Cayucos Sanitary District, San Luis Obispo County. 11 December 1998.

Regional Water Quality Control Board (RWQCB) - Central Coast Region and the Environmental Protection Agency (USEPA) – Region IX. 1998b. Monitoring and Reporting Program No. 98-15 for City of Morro Bay and Cayucos Sanitary District, San Luis Obispo County. 11 December 1998.

Regional Water Quality Control Board (RWQCB) - Central Coast Region and the Environmental Protection Agency (EPA) – Region IX. 2009. Waste Discharge Requirements (Order No. R3-2008-0065) and National Pollutant Discharge Elimination System (Permit No. CA0047881) for the Morro Bay and Cayucos Wastewater Treatment Plant Discharges to the Pacific Ocean, Morro Bay, San Luis Obispo County. Effective 1 March 2009.

Sea-Bird Electronics, Inc. (SBE) 1989. Calculation of M and B Coefficients for the Sea-Tech Transmissometer. Application Note No. 7, Revised September 1989.

Sea-Bird Electronics, Inc. (SBE) 1993. SBE 13/22/23/30 Dissolved Oxygen Sensor Calibration and Deployment. Application Note No. 13-1, rev B, Revised April 1993.

Southern California Bight Field Methods Committee (SCBFMC). 2002. Field Operation Manual for Marine Water-Column, Benthic, and Trawl monitoring in Southern California. Technical Report 359. Southern California Coastal Water Research Project. Westminster, CA. March 2002.

State Water Resources Control Board (SWRCB). 2005. Water Quality Control Plan, Ocean Waters of California, California Ocean Plan. California Environmental Protection Agency. Effective February 14, 2006.

State Water Resources Control Board (SWRCB). 2009. Water Quality Control Plan for Enclosed Bays and Estuaries – Part 1 Sediment Quality. California Environmental Protection Agency. Effective August 23, 2009. sed_qlty_part1.pdf [Accessed 03/26/10].

Suter II, Glenn, W. 2007. Ecological risk assessment, 2nd edition. U. S. Environmental Protection Agency, Cincinnati, Ohio. CRC.

Tetra Tech. 1992. Technical Review City of Morro Bay, CA Section 301(h) Application for Modification of Secondary Treatment Requirements for a Discharge into Marine Waters. Prepared for the U.S. Environmental Protection Agency, Region IX, San Francisco, CA by Tetra Tech, Inc., Lafayette, CA. February 1992.