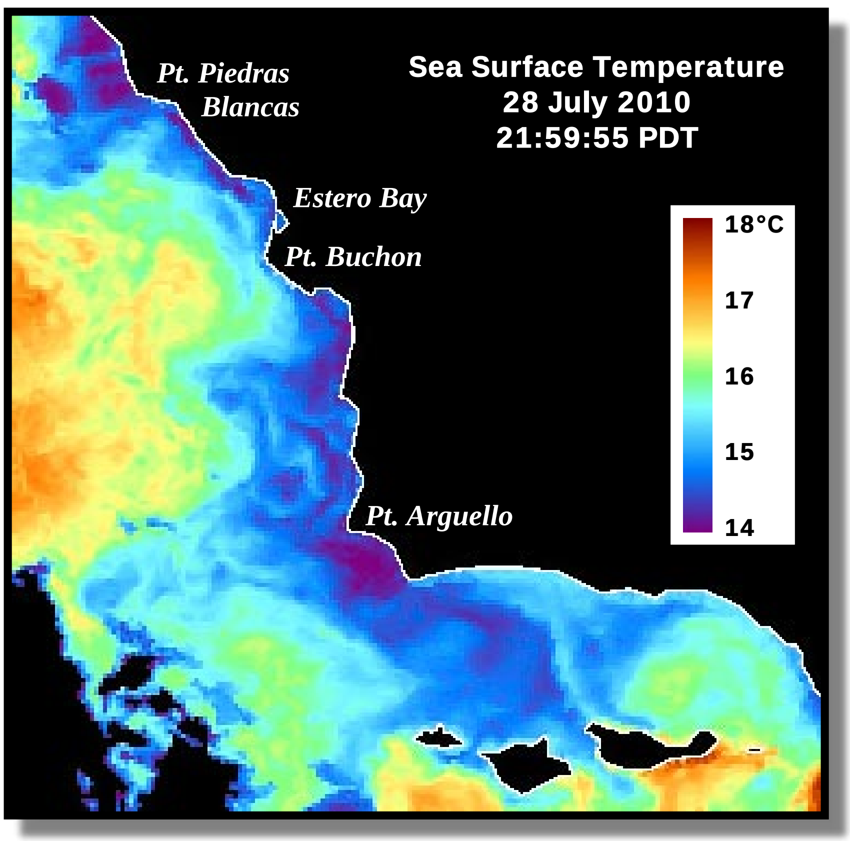
City of Morro Bay and
Cayucos Sanitary District

OFFSHORE MONITORING AND REPORTING PROGRAM

THIRD QUARTER RECEIVING–WATER SURVEY

AUGUST 2010



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 2010

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 2010

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

6 October 2010

Reference: Second Quarter Receiving-Water Survey Report – August 2010

Dear Mr. Keogh:

The attached report presents results from a quarterly receiving-water survey conducted on Thursday, 5 August 2010. 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 during summer oceanographic conditions. Based on report's quantitative analyses of continuous instrumental measurements and qualitative visual observations, 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 high performance levels. 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 2010 field survey described in this report was the sixth receiving-water survey conducted under the current permit.

Under the NPDES discharge permit, seasonal monitoring of offshore receiving-water quality is conducted on a quarterly basis. This report summarizes the results of sampling conducted on 5 August 2010. 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 approximately 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 approximately 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 a horizontal tow survey are conducted in the vicinity of 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 currents generally follow 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.

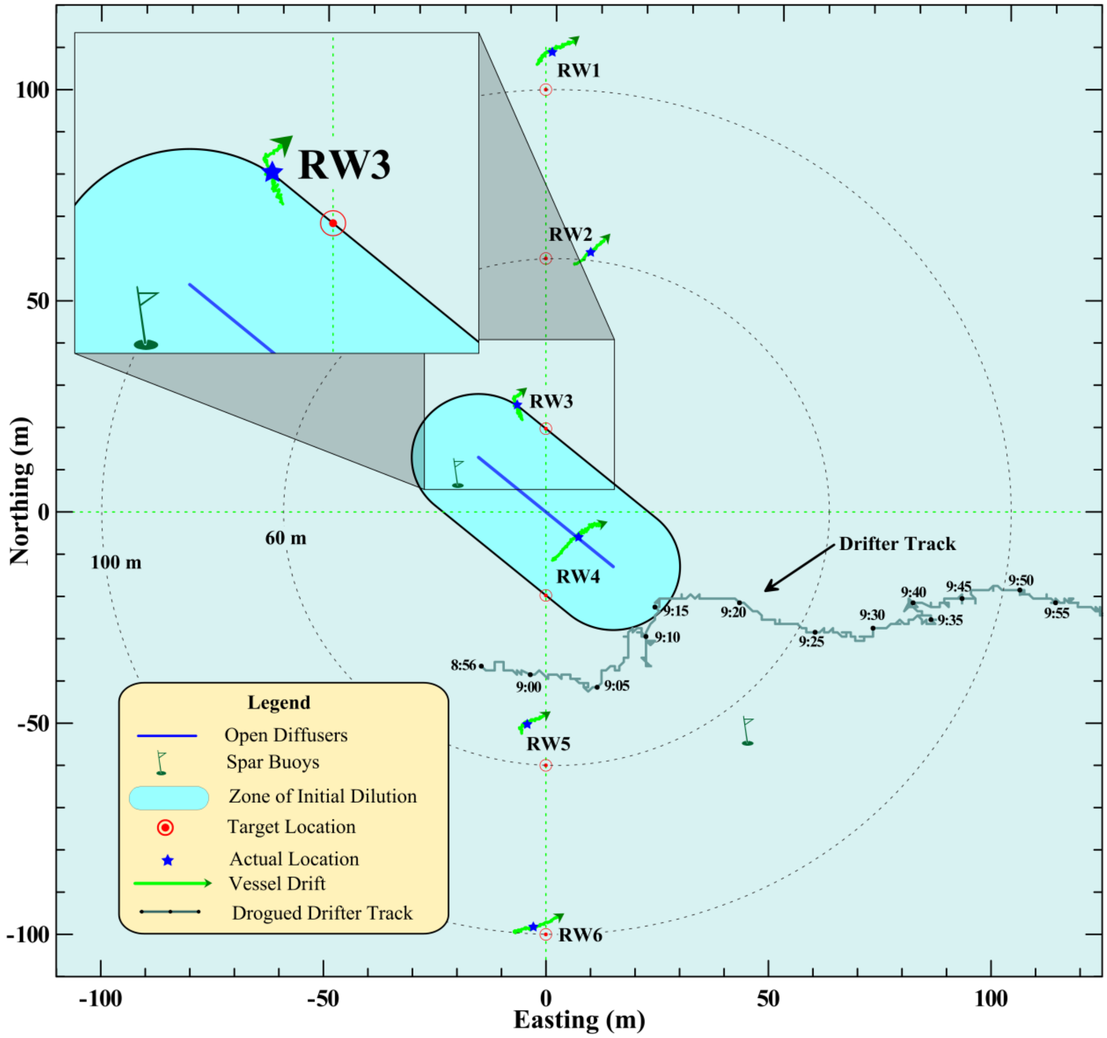


Figure 2. Sampling Station Locations and Drifter Track

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

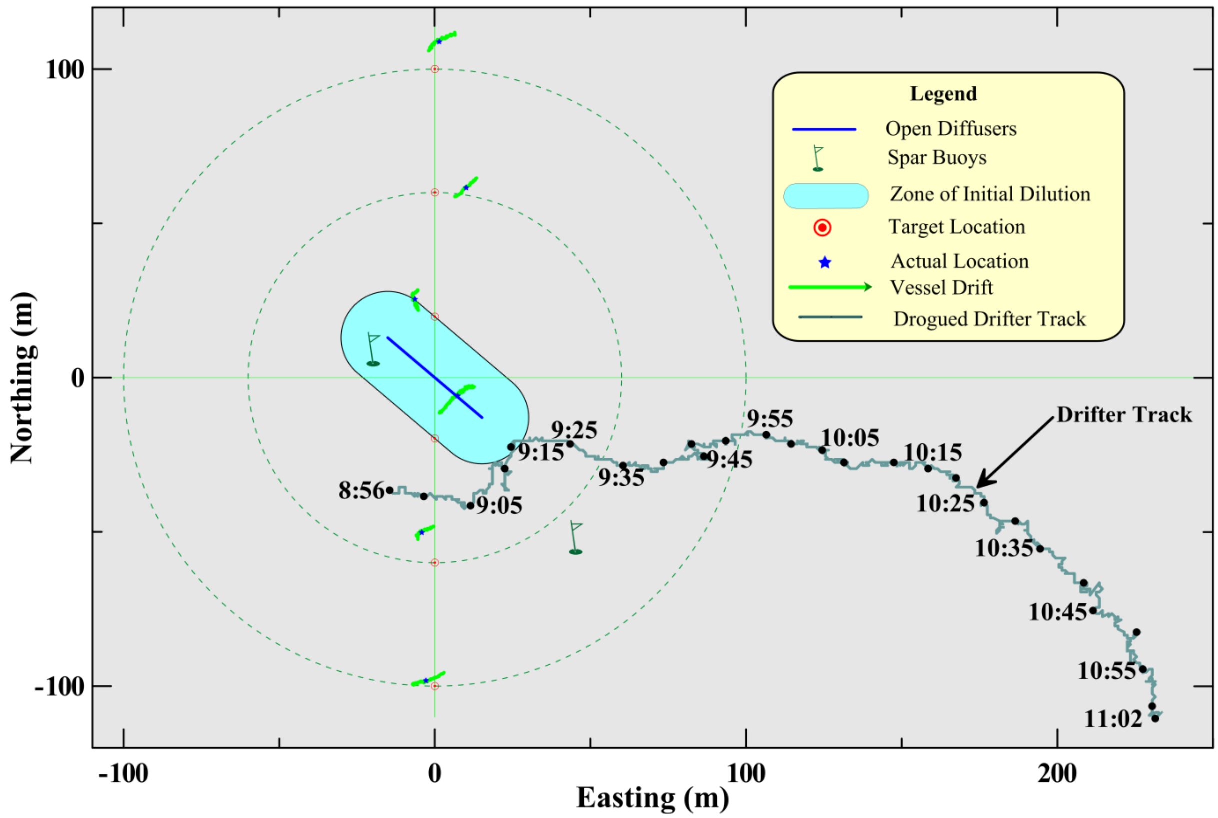


Figure 3. Drogued Drifter Trajectory

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 locate 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 surveys. 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 2010 survey is apparent from the length of the green tracklines in Figure 2. These tracklines trace the horizontal movement of the CTD as it

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

was lowered to the seafloor. Their length and offset from the target locations reflect the overall station-keeping ability during the August 2010 survey. During the time it took the CTD to traverse the water column and reach the seafloor, which averaged 1 min 25 s, the instrument package moved an average of 9.6 m, which was comparable to most prior surveys.

The CTD trajectories shown by the tracklines in Figure 2 often reflect complex interactions between surface currents and wind forces that act on the survey vessel during sampling. Due to the calm sea conditions at the time of the August 2010 survey; however, the tracklines in the Figure primarily reflect the residual momentum of the survey vessel as it approached each target location. As seen in Figure 2, the vessel approached most stations from the southwest. Although brief thrust reversals were successful at eliminating the majority of residual vessel momentum prior to initiation of the downcast, a limited northeastward drift is apparent at most stations.

Although relatively small, and comparable to the survey vessel's 12-m length, lateral drift of the CTD during the vertical hydrocasts can complicate 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 to be complete. For example, during the August 2010 survey, none of the measurements recorded at Station RW4 were subject to the limitations because the CTD was within the ZID boundary throughout the entire vertical cast at that station (Figure 2). Similarly, only the deepest measurements collected at Station RW3 were subject to the limitations because the CTD traversed the ZID boundary as it was lowered through the water column (see Figure 2 inset).

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 requires 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 2010 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.

Table 2. Average Position of Vertical Profiles during the August 2010 Survey

	Time (PDT)				Closest Approach	
Station	**Downcast**	**Upcast**	**Latitude**	**Longitude**	**Range[5](m)**	**Bearing[6](°T)**
RW1	9:17:51	9:19:13	35° 23.258' N	120° 52.503' W	97.4	10
RW2	9:13:14	9:14:32	35° 23.232' N	120° 52.497' W	54.8	27
RW3	9:10:20	9:11:33	35° 23.213' N	120° 52.508' W	15.3[7]	35
RW4	9:06:16	9:07:34	35° 23.196' N	120° 52.499' W	**0.3[8]**	221
RW5	9:01:03	9:02:34	35° 23.172' N	120° 52.507' W	41.9	207
RW6	8:56:00	8:57:48	35° 23.146' N	120° 52.506' W	87.1	192

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 Portions of the CTD cast at this station were located within the ZID boundary.
8 The entire CTD cast at this station was located within the ZID boundary.

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. 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 but steady east-southeastward flow during the August 2010 survey (Figures 2 and 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. Unfortunately, a failure in the drogue's attachment harness resulted in the irretrievable loss of the drogue during its deployment at the beginning of the August 2010 survey at 8:34 PDT. A substitute drogue was constructed in the field from materials on hand, and was subsequently deployed. Although not as sensitive to mid-depth currents as the original curtain-shade drogue, the track from this substitute drifter still provided a reasonable indication of the mid-level flow during the August 2010 survey.

The substitute drifter was deployed just south of the ZID at 8:56 PDT, and was recovered two hours later, at a location 257 m southeast of its deployment location. The black dots in Figures 2 and 3 show the drifter's progress at five-minute intervals. The uniform spacing between the time stamps reflects the relatively slow, but constant speed of the drifter throughout the survey, which averaged 3.4 cm/s, or 0.07 knots.

For the most part, flow was directed due east during the first half of the survey. At approximately 9:05 PDT however, the survey vessel passed very close to the drifter and the vessel's propeller wash transported the drifter northward, resulting in the artificial offset apparent in Figure 3. At 10:15 PDT, approximately one hour into the tow portion of the survey and just prior to the start of the mid-depth tow, the drifter track acquired a southerly component that was partially consistent with the onset of an outgoing (ebb) tide that strengthened around the same time (Figure 4). In the absence of other influences, an ebb tide normally induces a weak southwestward (offshore) flow in the survey region. However, flow is often also influenced by external processes, such as wind-generated upwelling or passing offshore eddies. Upwelling also normally induces a weak southerly flow.

The satellite image on the cover of this report documents upwelling conditions that prevailed throughout much of the summer of 2010. The cover image was recorded one week prior to the survey, when skies were clear enough for sea-surface temperatures to be measured by infrared sensors on one of NOAA's polar orbiting satellites. Persistent cloud cover throughout much of the month of August prevented the acquisition of a satellite image from closer to the survey date

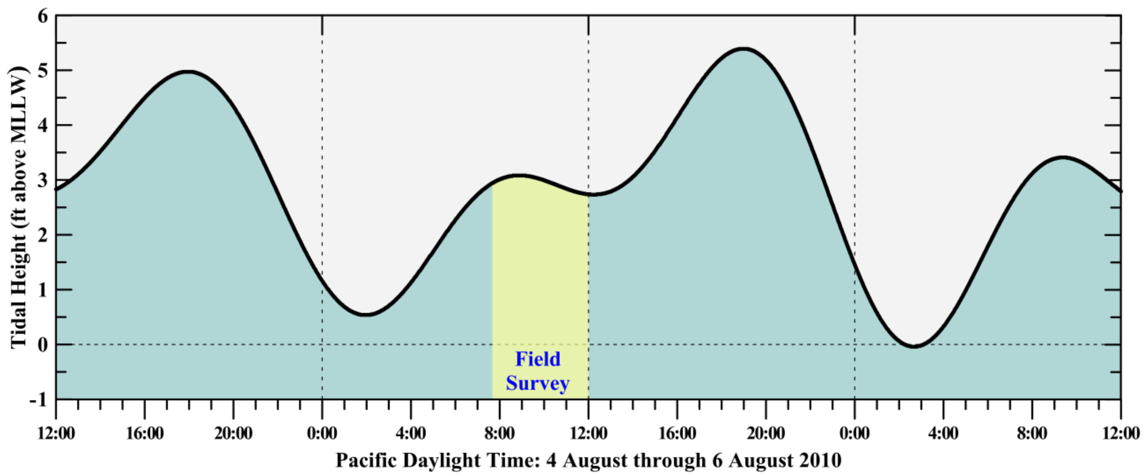


Figure 4. Tidal Level during the August 2010 Survey

Upwelling season normally begins sometime during late March and or early April as shown by the positive (blue) upwelling indices in Figure 5. At this time, there is a 'spring' transition to more persistent southeastward-directed 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, as seen in the image on the cover of this report.

The satellite image on the cover shows that, one week prior to the survey, cool (14˚C) sea-surface temperatures were present within Estero Bay, while temperatures farther offshore exceeded 17˚C (orange and red areas). The lower Estero Bay sea surface temperatures depicted in the satellite image were consistent with the near-surface temperatures measured by the CTD during the August 2010 survey.[9]

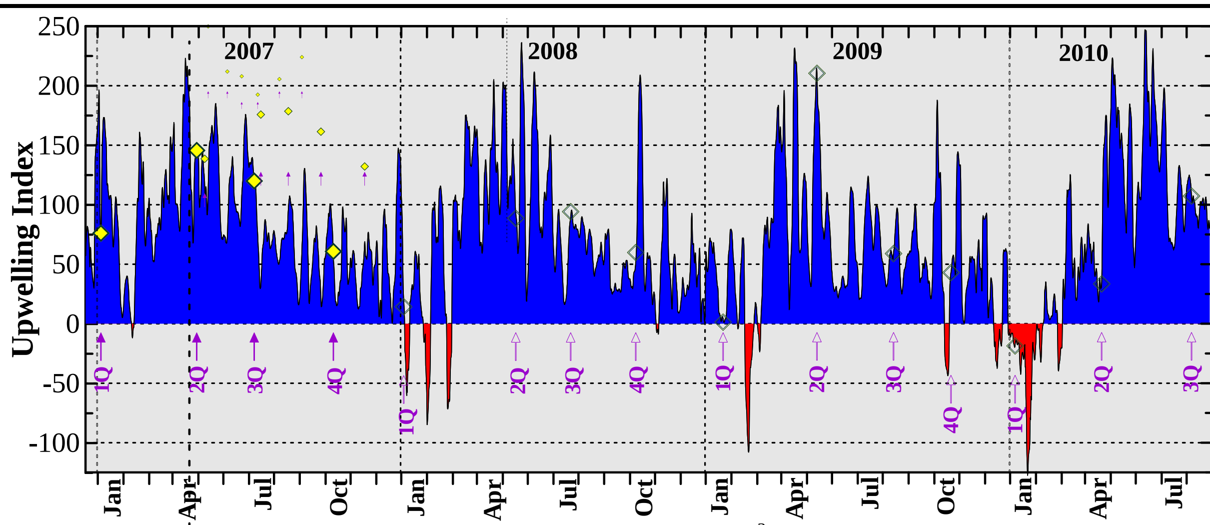


Figure 5. Five-Day Average Upwelling Index ($m^3/s/100m$ of coastline)

9 Refer to Table 5 and Figure 6 for receiving-water properties recorded during the vertical hydrocasts.

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.

Stronger-than-normal winds measurably increased the persistence and strength of upwelling events along the central California coastline during the summer of 2010. Combined with a rapidly strengthening La Niña condition, this acted to depress seawater temperatures in the region. For example, prior to August, seawater temperatures averaged only 12˚C at the nearby Diablo Canyon Nuclear Power Plant intake. This is a full two degrees cooler than normal for this time of year, and represents the lowest average temperature since records started being kept in 1976.[10]

La Niña phenomena are characterized by unusually cold ocean temperatures in the equatorial Pacific. During a La Niña event, high pressure builds in the eastern equatorial Pacific while low pressure develops to the west, producing a stronger equatorial pressure gradient. The easterly trade winds strengthen, causing upwelling off the coastlines of Peru and Ecuador to intensify, and lowering sea surface temperatures throughout the Eastern Pacific Ocean, including along California's central coast.

METHODS

The 38 ft F/V *Bonnie Marietta*, owned and operated by Captain Mark Tognazzini of Morro Bay, served as the survey vessel on Thursday, 5 August 2010. Bonnie Luke of Marine Research Specialists (MRS) was the 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.

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, the Secchi depth measures natural light penetration, which can be limited by increased suspended particulate loads from plankton

[10] http://www.sanluisobispo.com/2010/08/28/1267200/la_nina_helping_chill_our_summer.html

blooms, onshore runoff, seafloor sediment resuspension, and wastewater discharge. It is 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 and June 2006 for testing and calibration. Because of increasing temporal drift associated with aging DO probes, the DO probe was replaced on both occasions. As is the case before all surveys, the CTD system was calibrated at the MRS laboratory prior to the August 2010 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 pre-cruise calibration coefficients determined by MRS closely corresponded with prior factory calibrations.

Additionally, a post-calibration of the DO sensor was completed on 18 August 2010. Unusually low DO measurements recorded during the August 5 water-quality survey prompted concerns that the sensor had malfunctioned. However, the post-calibration DO curves were consistent with those of the pre-survey calibration, confirming that no sensor malfunction had occurred. Because oversaturation of the original calibration bath would also have resulted in the reporting of artificially low DO concentrations during the survey, a handheld Orion DO meter (model 830A) was used to independently confirm the saturation point of the calibration bath. The average DO concentrations (8.25-mg/L) in the saturated bath were found to be consistent with contemporaneous readings collected by the DO probe on the CTD, further confirming that the DO sensor on the CTD was performing as designed.

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.

Table 3. CTD Specifications

Component	Depth[11]	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

[11] Maximum depth limit in meters

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. Increased transmittance indicates increased water clarity and decreased turbidity.

During the pre-cruise calibration, 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, 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 June 2006 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, slight temporal trends in pH and DO measurements arose from the sensor’s ongoing equilibration during the survey. These trends were removed by fitting orthogonal polynomials to the pH and DO time series.

Before initial deployment for the vertical hydrocasts, the CTD was held below the sea surface for a four-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.

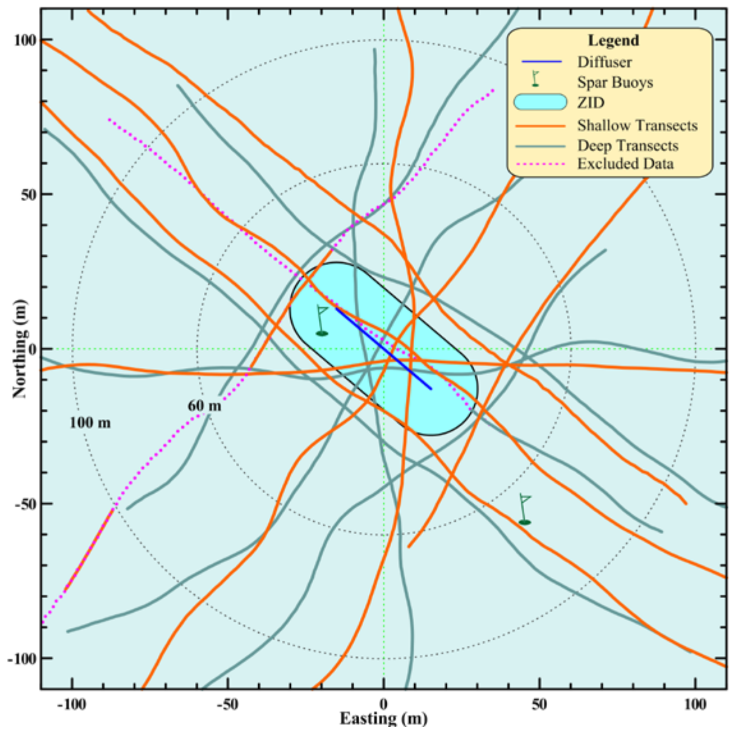


Figure 6. CTD Tracklines during the Tow Surveys

At 9:19 PDT, following the last vertical profile at RW1, 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 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).

Initially, the reconfigured CTD package was towed for 34 min at an average depth of 5.7 m,[12] and an average speed of 1.67 m/s, passing near the diffuser structure eight times. Subsequently, eight additional passes were made with the CTD at an average depth of 8.7 m. During this 32-minute mid-depth-tow, vessel speed averaged 1.73 m/s. At the observed towing speeds and 2 Hz sampling rate, 1.2 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.[13]

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.

First, the salinity data were screened for "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. The strong vertical stratification present during the August 2010 survey caused numerous salinity spikes in

[12] Average depth of the eight shallow tow transects evaluated in the compliance analysis. The three additional transects were removed from consideration due to a vertical offset in tow depth as described in the *Quality Control* section.
[13] Figures 8 and 9 present the horizontal maps of seawater properties measured during the August 2010 survey.

both the vertical profiles and the tow data. However, low-pass filtering of the time series of tow data and vertical smoothing of the profile data effectively mitigated their influence.

Preliminary review of the raw CTD data also determined that data recorded during portions of two of the tow transects were collected at a depth that was offset by one meter or more from the remainder of the tow data. Because the water column was strongly stratified at the time of the August 2010 survey, this slight depth difference resulted in substantial differences in the measured water properties of the respective transects. Additionally, since the significance of potential discharge-related anomalies is evaluated by comparing the amplitudes of measurements acquired at the same depth level, the ability to resolve anomalies within transects with any statistical certainty is compromised when data from different levels are included. Therefore, tow data collected at depths that departed more than one meter from the nominal tow depth (shown by the purple lines in Figure 6) were excluded from the subsequent compliance analysis. Exclusion of this data did not, however, adversely affect the compliance analysis because the remaining transects adequately covered the survey region and met the permit monitoring requirement of at least five passes near the diffuser structure at each tow depth (orange and blue dotted lines in Figure 6).

Similarly, because the overall length of the CTD is close to the 0.5-m standard depth bins used to report the vertical profile data, the ability to compute average values for seawater properties at locations very near the sea surface and seafloor varies depending on how the CTD's depth is influenced by wave and tidal-induced oscillations during its deployment at each station. For example, during the August 2010 survey, data on average seawater properties were not recorded within the shallowest depth bin (0.5 m) at Station RW3 (see Table 5 on Page 16) or within the deepest depth bin (below 15 m) at Stations RW1, RW2, and RW4. Because the spatial coverage of the observations at the remaining stations did not adequately quantify horizontal trends at the very deepest and shallowest depth levels, they were excluded from the subsequent compliance evaluation.

One further anomaly noted in the raw survey data was subsequently investigated for quality control purposes. Near the sea surface, where seawater is normally saturated through atmospheric equilibration, particularly during periods of upwelling, the highest ambient DO concentrations measured only 70% saturation (5.6 mg/L). DO measurements near the seafloor were similarly depressed, with some measurements dropping below 3 mg/L (30% saturation). Historically, lows near the seafloor in the survey area have not dropped below 4.5 mg/L (50% saturation). Although it is normal to find naturally low-oxygen conditions in deep, offshore waters, the occurrence of low-oxygen water close to shore (on the inner continental shelf, or in less than 50 m of water) is highly unusual.

The extremely large offsets from normal conditions observed in the raw field data prompted an investigation into the operation and calibration of the DO sensor to ensure that the measured concentrations were not artifacts of a mechanical malfunction or processing error. However, as described in the Methods Section of this report, the sensor was confirmed to be working properly. The saturation endpoints used in calibrating the CTD were also independently confirmed, indicating that the data were accurately recorded.

Although the uniformly low ambient DO concentrations recorded during the August 2010 survey were not the result the result of the discharge, and therefore not of compliance interest, such phenomena are nevertheless of import in examining and understanding the natural processes that influence the receiving-water environment within Estero Bay. Further analyses indicated that the low ambient DO measurements likely resulted from an unusually prolonged period of strong upwelling. Typically recognized as the primary driver behind the productive fisheries of the central California coast, the August 2010 survey measurements captured a point in time when upwelling had actually become "too much of a good thing."

As discussed previously, nutrient-rich seawater, brought to the sea surface by upwelling facilitates phytoplankton blooms that produced oxygen and consume carbon dioxide (CO_2). Normally, the northwesterly winds that promote upwelling are not constant. When they intermittently relax, mixing of the waters on the continental shelf takes place, replenishing subsurface waters with oxygen. If this periodic relaxation of the winds does not occur, however, oxygen is prevented from reaching and replenishing the subsurface waters. Meanwhile, the dense blooms of phytoplankton spurred by upwelling die and fall to the seafloor, where their decomposition uses up oxygen in nearshore waters. Thus, the intensity and duration of upwelling events that occurred throughout the summer of 2010, led to the abnormally low DO levels observed in the water column during the August 2010 survey (Figure 5).

RESULTS

The third-quarter receiving-water survey began approximately two hours after sunrise at 08:34 PDT on the morning of Thursday, 5 August 2010, with the deployment of the drogued drifter. Over the following two hours, offshore observations and measurements were collected as required by the NPDES monitoring program. The survey ended just after 11:00 PDT with the recovery of the CTD from its mid-depth-tow configuration and the retrieval of the drogued drifter. Observations of beneficial use and the collection of required visual observations of the sea surface were unencumbered throughout the survey.

Auxiliary Observations

Although surface visibility was never impeded, skies were heavily overcast throughout the August 2010 survey. Winds were mild, but constant throughout the survey, with average wind speeds, calculated over one-minute intervals, ranging from 3.6 to 5.6 kt, and peak wind speeds ranging from 5.1 to 10.3 kt (Table 4). The swell was out of the northwest with a significant wave height of 2 to 3 feet. Air temperatures were slightly cooler than average surface-water temperatures, and varied from 12.5°C to 12.9°C.

Table 4. Standard Meteorological and Oceanographic Observations

Station	Location[14] Latitude	Longitude	Diffuser Distance (m)	Time (PDT)	Air (°C)	Cloud Cover (%)	Wind Avg (kt)	Wind Max (kt)	Wind Dir (from) (°T)	Swell Ht/Dir (ft/°T)	Secchi Depth (m)
RW1	35° 23.254' N	120° 52.503' W	89.6	9:18:04	12.6	100	4.3	5.4	SE	2-3/NW	4.0
RW2	35° 23.232' N	120° 52.501' W	52.2	9:13:53	12.9	100	3.8	5.7	SE	2-3/NW	4.0
RW3	35° 23.211' N	120° 52.505' W	16.0	9:10:40	12.5	100	5.6	10.3	SE	2-3/NW	4.0
RW4	35° 23.193' N	120° 52.502' W	5.3	9:06:50	12.5	100	3.6	6.6	SE	2-3/NW	3.5
RW5	35° 23.172' N	120° 52.505' W	40.4	9:01:38	12.8	100	4.6	6.3	SE	2-3/NW	4.0
RW6	35° 23.147' N	120° 52.506' W	84.3	8:56:33	12.8	100	3.8	5.1	SE	2-3/NW	4.0

The 4-m Secchi depths recorded at most stations during the August 2010 survey indicated a low level of ambient water clarity in the upper water column, reflecting the presence of a euphotic zone that extended only 8 m, or just over half the distance to the sea floor. This condition is commonly referred to by fishermen as "coffee water" or "salmon water" for its muddy appearance and its association with good salmon fishing. The limited visibility results from high plankton loads associated with upwelling in the upper water column. Although water clarity near the sea surface was limited, there was no evidence of

[14] Locations are the vessel positions recorded at the time the Secchi depth was measured.

wastewater-related floating particulates, oil sheens, or discoloration of the sea surface observed at any of the stations during vertical profiling, or at any other time during the survey. Additionally, communication with plant personnel during the survey and subsequent review of effluent discharge properties, indicate that the treatment process was performing nominally at the time of the survey.

During the August 2010 survey, visual observations demonstrated continued beneficial use of the coastal waters within Estero Bay by both wildlife and recreational users. Wildlife sightings during the survey were dominated by Brandt's cormorants (*Phalacrocorax penicillatus*), pelagic cormorants (*Phalacrocorax pelagicus*), and western gulls (*Larus occidentalis*). In addition, California brown pelicans (*Pelecanus occidentalis californicus*), and foraging elegant terns (*Sterna elegans*) were also documented. Marine mammal observations included a harbor seal (*Phoca vitulina*), a California sea lion (*Zalophus californianus*), and a southern sea otter (*Enhydra lutris nereis*).

Beach usage by pedestrians, and nearshore water usage by a junior lifeguarding class were evident during the August 2010 survey. In addition, ten recreational fishing vessels were noted utilizing the waters just north of the survey area, and approximately one mile offshore. This area of the bay had apparently produced favorable fishing results for both halibut and sea bass over the preceding two weeks.

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 2010 survey reflect highly stratified conditions indicative of strong upwelling conditions. Upwelling conditions prevail most of the year along the central California coast, generally beginning in March or April, and extending 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 dispersion.

Upwelling-induced gradients are evident in the vertical profiles of seawater properties shown in Figure 7. The profiles reflect the vertical juxtaposition of a near-surface mixed layer and a cold, clear, nutrient-rich but oxygen-poor water mass at depth. Upwelling induces a sharp interface between the two watermasses, which is evident as a rapid decrease in temperature (red lines), DO (dark blue lines), and pH (gold lines) with increasing depth. These decreases are mirrored by a pycnocline where density (black lines) increases between 7 and 13 m. Similarly, transmissivity is substantially lower near the sea surface due to increased primary productivity. Thus, at each of the six stations, upwelling-induced stratification influenced the vertical structure of all the ambient seawater properties except salinity (green lines).

At the time of the August 2010 survey, the overall differences in seawater characteristics near the seafloor and the sea surface were exceptionally pronounced, even compared to other recent 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).

Table 5. Vertical Profile Data Collected on 5 August 2010

Depth (m)	Temperature (°C)						Salinity (‰)					
	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6
0.5	14.309	14.303		14.320	14.296	14.290	33.726	33.721		33.723	33.720	33.719
1.0	14.307	14.302	14.309	14.325	14.299	14.289	33.727	33.721	33.725	33.724	33.720	33.719
1.5	14.308	14.299	14.310	14.322	14.298	14.288	33.726	33.723	33.725	33.727	33.722	33.720
2.0	14.306	14.298	14.310	14.301	14.295	14.287	33.728	33.723	33.725	33.730	33.724	33.719
2.5	14.298	14.295	14.309	14.281	14.293	14.284	33.728	33.725	33.725	33.730	33.724	33.720
3.0	14.295	14.277	14.305	14.250	14.292	14.281	33.728	33.727	33.726	33.731	33.724	33.720
3.5	14.290	14.255	14.295	14.025	14.287	14.277	33.729	33.727	33.728	33.741	33.724	33.719
4.0	14.284	14.226	14.285	13.765	14.281	14.270	33.730	33.729	33.728	33.756	33.724	33.720
4.5	14.281	14.164	14.264	13.523	14.100	14.260	33.730	33.730	33.730	33.816	33.736	33.721
5.0	14.272	14.099	14.243	12.912	13.960	14.252	33.730	33.730	33.726	33.728	33.732	33.720
5.5	14.260	14.041	14.190	12.697	13.758	14.240	33.729	33.735	33.725	33.705	33.748	33.722
6.0	14.247	13.776	14.119	12.602	13.315	14.186	33.731	33.726	33.727	33.698	33.756	33.717
6.5	14.229	13.567	14.050	12.460	13.172	13.998	33.731	33.739	33.724	33.706	33.748	33.720
7.0	14.189	13.493	13.879	11.990	13.086	13.729	33.730	33.730	33.733	33.633	33.750	33.716
7.5	14.081	13.432	13.759	11.679	13.055	13.575	33.723	33.734	33.694	33.619	33.749	33.649
8.0	13.944	13.355	13.570	11.574	12.964	13.280	33.739	33.743	33.714	33.659	33.729	33.722
8.5	13.738	13.258	13.415	11.533	12.721	13.097	33.752	33.709	33.672	33.645	33.752	33.741
9.0	13.658	12.944	13.283	11.660	12.465	13.084	33.716	33.731	33.651	33.591	33.733	33.738
9.5	13.471	12.644	12.649	11.747	12.286	13.069	33.724	33.682	33.722	33.607	33.760	33.735
10.0	13.279	12.308	12.329	11.834	12.214	13.014	33.750	33.732	33.575	33.721	33.750	33.731
10.5	13.016	11.926	12.156	11.916	12.132	12.879	33.735	33.672	33.612	33.718	33.749	33.737
11.0	12.418	11.702	11.982	11.870	12.046	12.629	33.769	33.662	33.554	33.704	33.743	33.701
11.5	11.800	11.695	11.748	11.855	11.923	12.268	33.699	33.705	33.628	33.745	33.751	33.758
12.0	11.733	11.647	11.673	11.756	11.844	12.129	33.754	33.751	33.696	33.750	33.749	33.754
12.5	11.676	11.599	11.626	11.654	11.739	11.938	33.764	33.747	33.741	33.747	33.742	33.743
13.0	11.581	11.540	11.607	11.604	11.659	11.787	33.774	33.767	33.758	33.753	33.754	33.755
13.5	11.535	11.530	11.557	11.486	11.618	11.644	33.773	33.764	33.765	33.764	33.760	33.761
14.0	11.511	11.493	11.515	11.481	11.577	11.558	33.772	33.764	33.767	33.761	33.748	33.760
14.5	11.477	11.482	11.490	11.471	11.496	11.456	33.770	33.763	33.762	33.759	33.754	33.766
15.0		11.478	11.466	11.451	11.439	11.441		33.762	33.764	33.759	33.761	33.760
15.5			11.459		11.435	11.444			33.761		33.758	33.757

Table 5. Vertical Profile Data Collected on 5 August 2010 (continued)

Depth (m)	Density (σ_t)						pH					
	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6
0.5	25.138	25.135		25.133	25.136	25.137	7.420	7.410		7.413	7.405	7.410
1.0	25.139	25.136	25.137	25.133	25.135	25.137	7.420	7.410	7.406	7.413	7.405	7.410
1.5	25.138	25.138	25.137	25.136	25.137	25.138	7.422	7.412	7.412	7.413	7.405	7.410
2.0	25.140	25.138	25.137	25.143	25.139	25.137	7.422	7.413	7.412	7.413	7.405	7.410
2.5	25.142	25.140	25.137	25.147	25.140	25.139	7.421	7.410	7.412	7.413	7.405	7.411
3.0	25.142	25.146	25.138	25.154	25.140	25.139	7.420	7.408	7.412	7.411	7.405	7.410
3.5	25.144	25.150	25.142	25.209	25.141	25.140	7.420	7.409	7.412	7.408	7.405	7.409
4.0	25.146	25.158	25.145	25.275	25.142	25.141	7.418	7.408	7.407	7.404	7.404	7.410
4.5	25.147	25.172	25.151	25.370	25.190	25.144	7.417	7.405	7.406	7.387	7.402	7.410
5.0	25.149	25.185	25.152	25.425	25.216	25.146	7.416	7.402	7.402	7.365	7.396	7.407
5.5	25.151	25.201	25.162	25.449	25.270	25.149	7.416	7.396	7.401	7.318	7.382	7.405
6.0	25.155	25.249	25.179	25.463	25.366	25.157	7.414	7.388	7.396	7.266	7.369	7.405
6.5	25.158	25.302	25.191	25.497	25.389	25.199	7.411	7.376	7.390	7.234	7.341	7.397
7.0	25.167	25.310	25.233	25.529	25.408	25.251	7.415	7.362	7.383	7.217	7.320	7.381
7.5	25.184	25.325	25.228	25.577	25.413	25.231	7.410	7.343	7.367	7.193	7.297	7.360
8.0	25.224	25.348	25.282	25.627	25.416	25.347	7.404	7.331	7.353	7.137	7.274	7.340
8.5	25.277	25.342	25.281	25.624	25.481	25.398	7.392	7.317	7.339	7.098	7.262	7.319
9.0	25.266	25.421	25.292	25.559	25.516	25.398	7.378	7.304	7.319	7.078	7.254	7.295
9.5	25.310	25.442	25.472	25.555	25.572	25.399	7.365	7.280	7.300	7.067	7.226	7.278
10.0	25.368	25.546	25.420	25.627	25.578	25.407	7.347	7.261	7.269	7.064	7.204	7.268
10.5	25.410	25.572	25.482	25.609	25.592	25.439	7.327	7.233	7.234	7.071	7.183	7.262
11.0	25.553	25.606	25.470	25.607	25.604	25.460	7.304	7.191	7.184	7.078	7.169	7.249
11.5	25.616	25.640	25.570	25.641	25.633	25.574	7.275	7.158	7.150	7.077	7.156	7.229
12.0	25.671	25.685	25.638	25.664	25.647	25.597	7.228	7.129	7.125	7.082	7.141	7.201
12.5	25.690	25.691	25.681	25.681	25.661	25.625	7.193	7.102	7.105	7.079	7.130	7.175
13.0	25.715	25.718	25.698	25.695	25.685	25.662	7.178	7.084	7.090	7.068	7.115	7.151
13.5	25.723	25.717	25.713	25.725	25.698	25.693	7.151	7.068	7.079	7.058	7.094	7.126
14.0	25.727	25.723	25.722	25.723	25.696	25.708	7.134	7.056	7.066	7.047	7.081	7.098
14.5	25.731	25.725	25.723	25.724	25.716	25.732	7.113	7.043	7.058	7.037	7.069	7.077
15.0		25.725	25.729	25.728	25.731	25.730		7.023	7.046	7.031	7.059	7.060
15.5			25.727		25.730	25.727			7.021		7.044	7.040

Table 5. Vertical Profile Data Collected on 5 August 2010 (continued)

Depth (m)	Dissolved Oxygen (mg/L)						Transmissivity (%)					
	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6	RW-1	RW-2	RW-3	RW-4	RW-5	RW-6
0.5	5.368	5.205		5.388	5.359	5.180	61.178	61.398		60.088	62.228	61.632
1.0	5.419	5.284	5.325	5.436	5.372	5.246	61.206	61.183	60.615	61.005	61.666	61.437
1.5	5.444	5.300	5.351	5.478	5.415	5.307	60.933	61.706	60.946	60.986	61.427	61.607
2.0	5.480	5.359	5.405	5.510	5.480	5.363	60.731	61.495	60.733	60.949	61.312	61.325
2.5	5.489	5.353	5.409	5.506	5.517	5.388	60.697	61.388	61.001	60.740	61.249	61.466
3.0	5.495	5.369	5.449	5.512	5.548	5.437	61.349	61.001	60.804	60.804	61.439	61.574
3.5	5.508	5.387	5.440	5.452	5.549	5.472	60.708	60.983	60.774	60.771	61.505	61.540
4.0	5.501	5.377	5.482	5.319	5.588	5.491	60.726	60.194	60.598	61.493	61.270	60.998
4.5	5.534	5.360	5.462	5.178	5.539	5.489	60.763	60.211	60.491	61.300	61.245	61.139
5.0	5.523	5.342	5.466	4.803	5.447	5.527	60.866	59.990	60.654	66.980	61.053	61.033
5.5	5.492	5.296	5.470	4.427	5.344	5.544	60.635	59.777	60.529	68.176	60.940	60.877
6.0	5.499	5.179	5.449	4.289	5.063	5.546	60.274	60.036	60.565	68.655	60.408	61.118
6.5	5.488	5.064	5.412	4.161	4.830	5.463	60.474	60.268	60.630	69.116	61.692	60.871
7.0	5.468	4.969	5.319	3.865	4.692	5.318	60.354	60.776	60.336	73.565	62.943	60.145
7.5	5.425	4.884	5.247	3.565	4.632	5.105	60.202	61.486	60.461	78.176	63.507	60.238
8.0	5.305	4.825	5.112	3.425	4.551	4.898	60.111	61.944	60.670	77.904	63.787	60.156
8.5	5.207	4.702	4.937	3.356	4.380	4.698	59.169	62.194	62.649	79.048	65.472	62.184
9.0	5.126	4.448	4.750	3.359	4.168	4.615	59.715	64.063	63.062	77.961	68.096	62.752
9.5	4.966	4.178	4.357	3.427	4.034	4.560	60.742	68.300	65.564	76.057	69.815	63.310
10.0	4.753	3.976	4.059	3.529	3.956	4.486	61.636	70.243	69.158	75.303	70.832	63.409
10.5	4.466	3.682	3.850	3.590	3.890	4.370	63.640	74.145	70.513	74.113	71.210	65.314
11.0	4.084	3.467	3.664	3.570	3.824	4.173	70.117	77.765	72.966	75.213	71.931	67.426
11.5	3.636	3.435	3.541	3.543	3.720	3.944	76.614	78.112	75.341	75.162	73.594	70.537
12.0	3.494	3.418	3.477	3.446	3.624	3.812	77.428	78.837	76.727	77.530	75.709	71.329
12.5	3.449	3.366	3.443	3.352	3.491	3.655	78.711	80.235	77.079	78.988	77.870	74.611
13.0	3.368	3.318	3.426	3.276	3.386	3.471	80.405	81.063	78.114	78.620	78.709	76.540
13.5	3.310	3.293	3.383	3.206	3.332	3.299	81.011	81.103	79.758	81.214	79.600	78.668
14.0	3.225	3.217	3.327	3.161	3.268	3.167	81.096	81.276	80.786	81.492	79.877	79.441
14.5	3.097	3.133	3.257	3.133	3.181	3.088	81.401	81.370	81.439	81.568	80.994	82.114
15.0		3.113	3.210	3.089	3.109	2.998		81.296	81.602	82.040	82.305	82.173
15.5			3.218		3.069	2.921			81.593		82.287	82.012

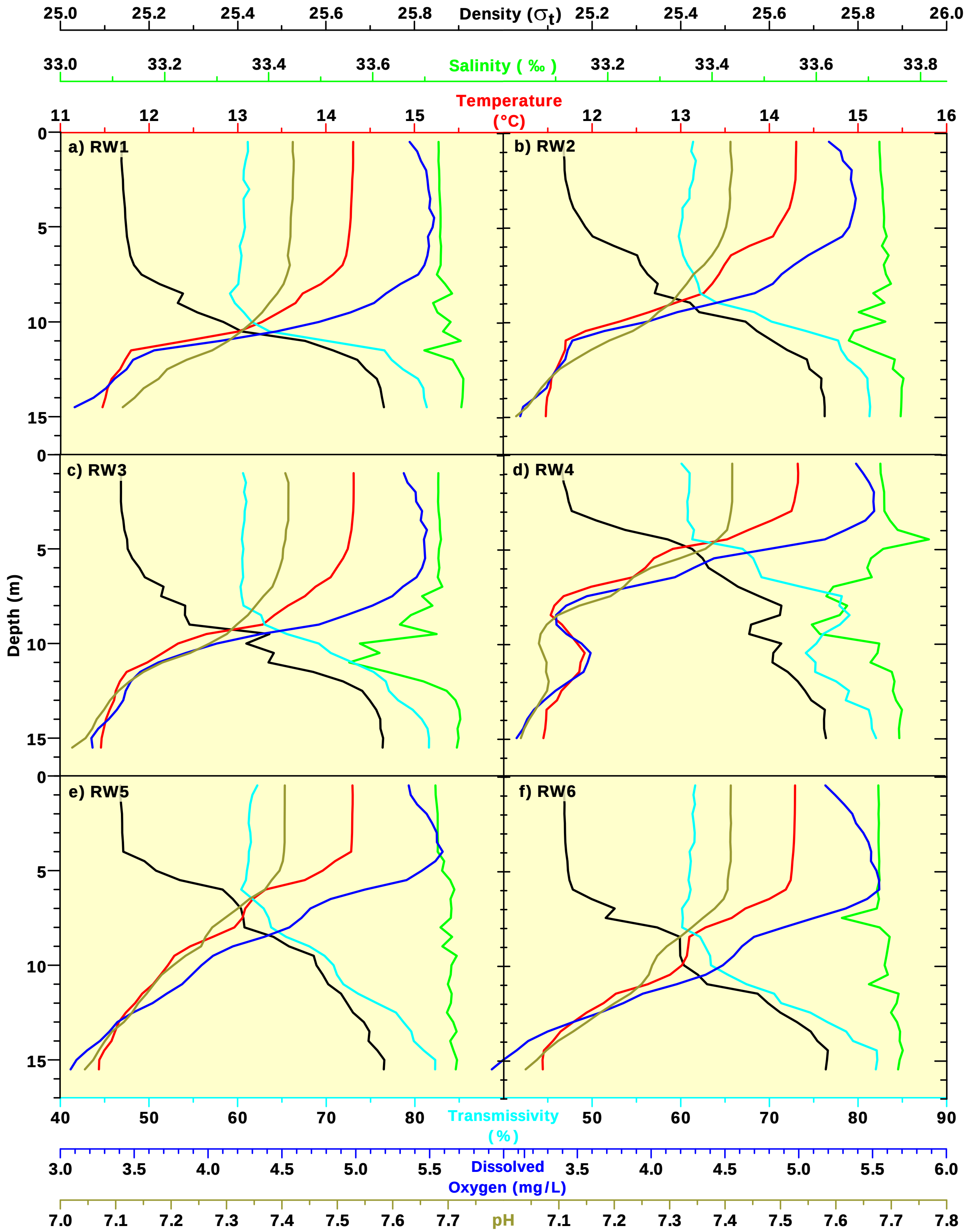


Figure 7. Vertical Profiles of Water-Quality Parameters

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. These processes account for the steady decline in pH (olive-colored lines) with increasing depth that is apparent in each of the vertical profiles. As expected, the associated increases in primary productivity generated by upwelling also resulted in reduced water clarity (light-blue lines) near the sea surface compared to waters at depth. For example, although transmissivities exceeded 80% at depth, within the upper mixed layer, transmissivities were as low as 60%.

The influence of the discharge plume can be seen in the vertical profiles recorded at Stations RW3 and RW4 (Figure 7cd). While both Stations exhibited reduced salinity near 10 m, at Station RW4 entrainment of bottom waters by the rising effluent plume dramatically compressed the thermocline (red line) and reduced the thickness of the overlying surface mixed layer (Figure 7d). As a result, DO, pH, and temperature between 5 m and 10 m at RW4 were perceptibly lower than measurements at other stations, while transmissivity and density were higher. The differing mid-depth seawater characteristics at Station RW4 were consistent with plume's entrainment and upward transport of ambient seawater properties within the seafloor watermass, which was denser, cooler, clearer, more oxygen-depleted, and more acidic than naturally occurring waters within the upper water column.

Outfall Performance

The efficacy of the outfall can be evaluated through a comparison of dilution levels measured at the time of the August 2010 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 similar to those experienced during the August 2010 survey, where trapping of the plume below a strong thermocline curtailed 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. A 9-m rise at the MBCSD outfall translates into a trapping depth that is 6.4 m below the sea surface, just slightly above the mid-depth (8.7 m) tow survey and below the shallow (5.7 m) tow survey conducted on 5 August 2010.

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.

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

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

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

Because the salinity concentration in effluent is negligible, C_e is eliminated in Equation 1 and the dilution ratio (D) can be computed from the salinity anomaly ($A = C_o - C_s$) as:

$$D = \frac{-C_o}{\left(C_o - C_s\right)} \equiv \frac{-C_o}{A} \qquad \text{Equation 2}$$

where: D = the dilution ratio of the volume of seawater mixed with effluent,
C_o = the salinity of the effluent-seawater mixture after dilution by D,
C_s = the background seawater salinity (approximately 33.8‰), and
$A = C_o - C_s$ = the salinity anomaly.

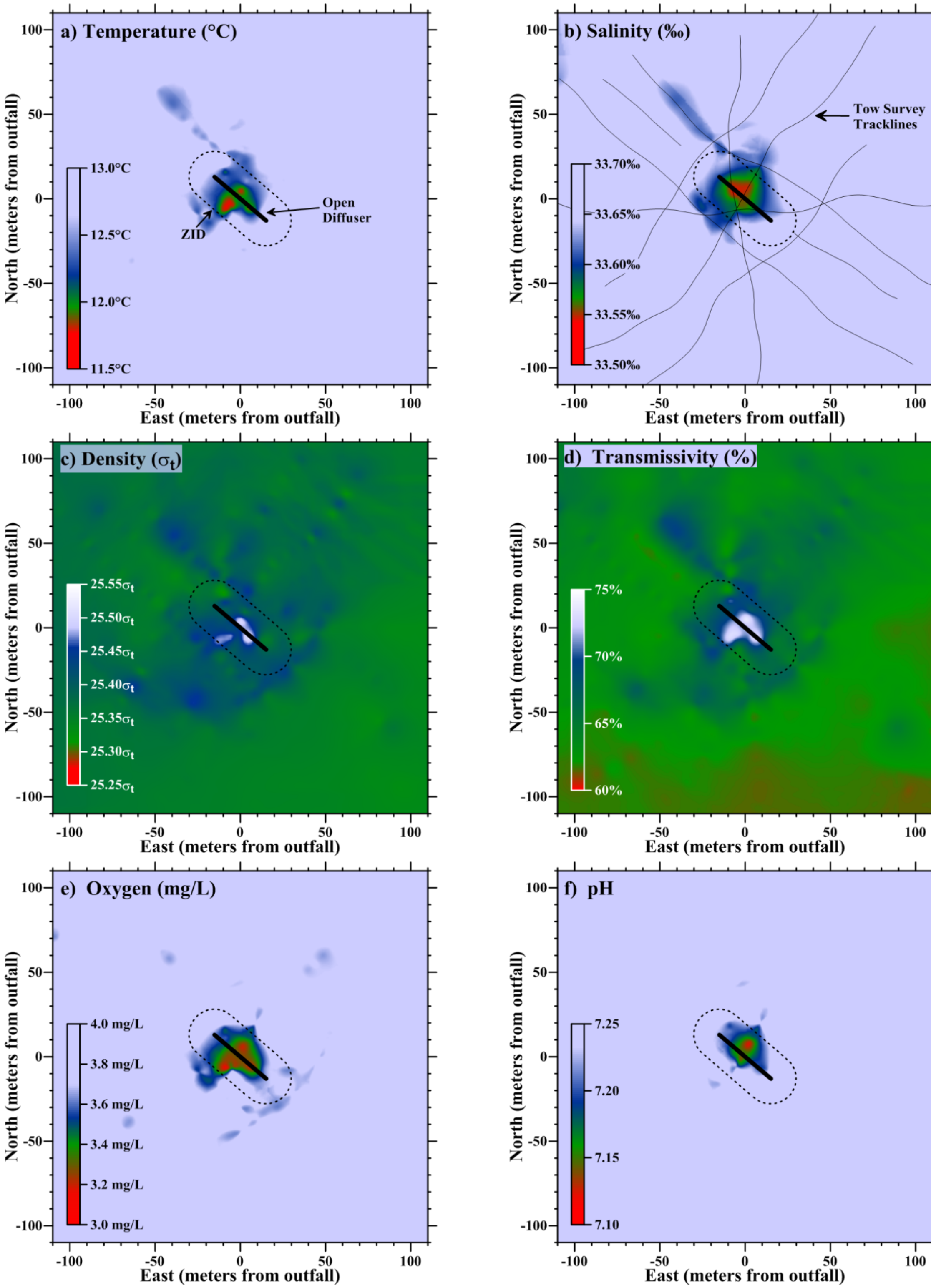


Figure 8. Horizontal Distribution of Mid-Depth Water-Quality Parameters 8.7 m below the Sea Surface

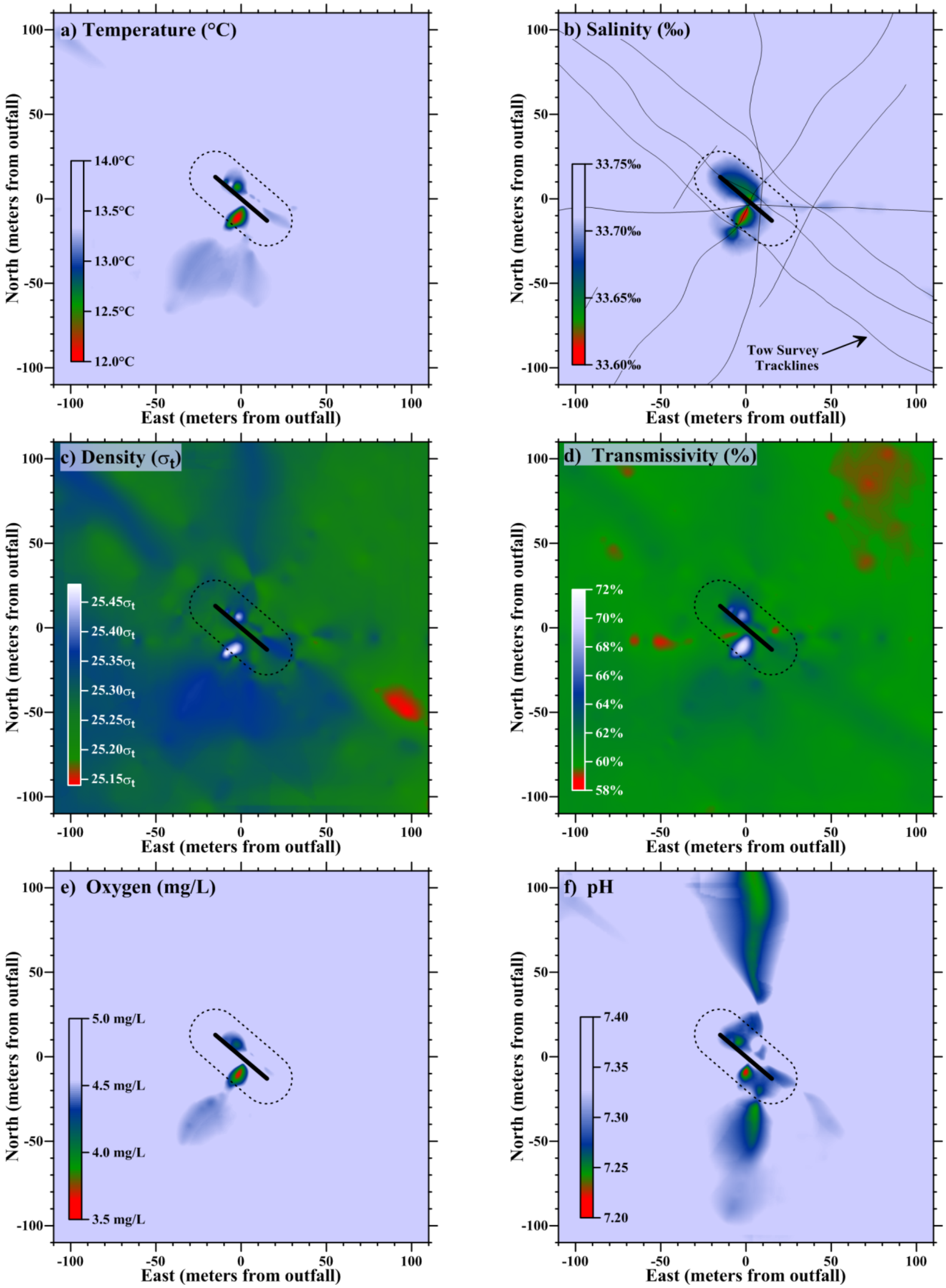


Figure 9. Horizontal Distribution of Shallow Water-Quality Parameters 5.7 m below the Sea Surface

The mid-depth tow shown in Figure 8 captured the plume as it was continuing to undergo intense initial mixing. Using Equation 2 to recast the salinity distribution shown in Figure 8b, resulted in the delineation of a strong plume signature with dilutions below 250-fold that was largely restricted to the ZID and covered a 226-m^2 area (green and red areas in Figure 10). A more diffuse signature with dilutions up to 500-fold was delineated over a larger, 3,500-m^2 area. The lowest salinity (33.544‰) measured during the mid-depth tow was recorded within the ZID at a location only 1.4 m from the nearest diffuser port. This corresponds to a wastewater-induced salinity reduction of -0.161‰ below the mean ambient salinity of 33.705‰ that was measured at the same depth level well beyond the influence of the discharge. It documents the presence of wastewater that has been diluted by more than 209-fold.

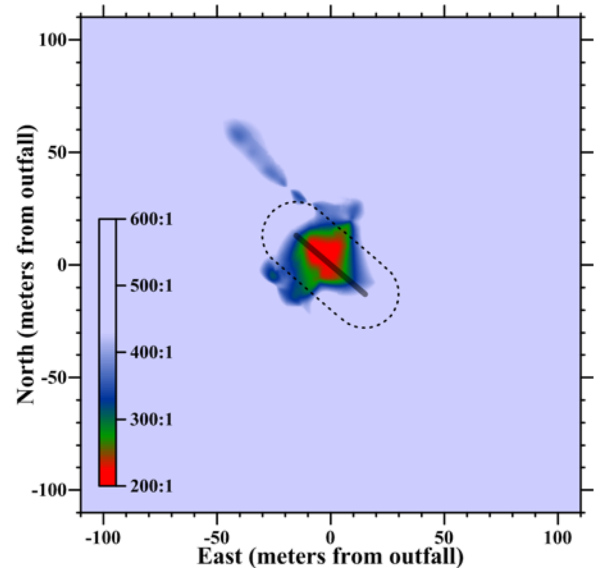


Figure 10. Mid-Depth Plume Dilutions Computed from Salinity Anomalies in Figure 8b

A positive density anomaly coincided with the plume's mid-depth salinity signature (white areas within the ZID in Figure 8c), which indicates the plume was actually denser than the surrounding seawater at 8.7 m. Its presence demonstrates that the negatively buoyant plume had overshot its level of buoyant equilibrium due to the residual momentum of the plume's upward transport. This 'heavy' plume would be expected to sink within the water column before overshooting the equilibrium level yet again, resulting in a vertical oscillatory motion that would continue to rapidly dilute the spreading plume until frictional damping reduced its buoyancy to negligible levels. This slowly-damped vertical oscillatory motion is a well-recognized phenomenon in atmospheric and oceanic dynamics when a parcel of air or water is vertically displaced within a statically stable environment. It demonstrates that the plume was still undergoing initial mixing at this depth level.

The upward momentum of the rising plume was large enough to carry a small portion of the dense plume into the upper water column where its signature was delineated by the shallow tow survey (Figure 11). Turbulence associated with its upward transport to the 5.7-m depth level further diluted the plume to levels exceeding 295-fold.

The high-resolution salinity measurements collected during these horizontal tows demonstrate that that the modeled dilution factor (133:1) was significantly more conservative than that actually achieved by the discharge (>209:1). This was the case even though the plume reached buoyant equilibrium below the 6.4-m trapping depth identified by the conservative dilution modeling.

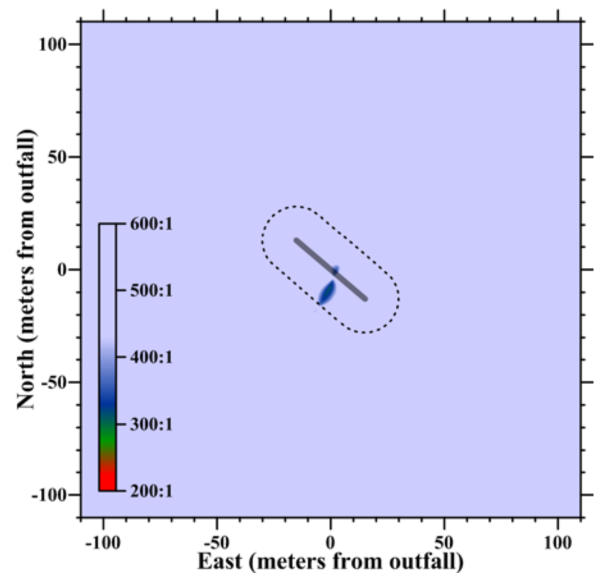


Figure 11. Shallow Plume Dilutions Computed from Salinity Anomalies in Figure 9b

These dilution computations demonstrate that, during the August 2010 survey, the outfall was performing better than designed and was rapidly diluting effluent more than 209-fold well within the ZID and before completion of the initial-dilution process. This dilution level still far 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 2010 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 the compliance of the MBCSD discharge with the water-quality permit limits listed in the NPDES permit. 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, their proximity to the ZID, and their amplitude compared to the natural variation in range found in ambient waters. 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 August 2010 data demonstrate that the MBCSD discharge fully complied with the NPDES discharge permit. Moreover, although observations within the ZID are not subject to compliance evaluations, they often still meet the permitted limits because dilution levels regularly exceed the conservative design specifications assumed in the discharge permit. The quantitative evaluation described in this section documents an outfall and treatment process that was exceeding design expectations during August 2010.

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 2010 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, the numeric limits P5 and P6 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.

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

However, both P5 and P6 also contain narrative limits, which arise from 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 the oceanographic processes described previously. Those 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 between discharge-related changes that arise from the presence of wastewater constituents, which are subject to a compliance evaluation, and changes that arise from the upward movement of ambient seawater, which are specifically excluded from the compliance evaluation.

Lines of Evidence

Evaluating whether any of the 5,199 CTD measurements collected during the August 2010 survey exceeded a permit limit is 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, or other anthropogenic influences (e.g. dredging or oil spills).

Because of this complexity, both a tiered approach and abductive inference were applied to "*multiple-lines-of evidence*" (LOE) to evaluate compliance. Specifically, each receiving-water observation was screened for compliance by evaluating the measurement using the series of questions (lines of evidence) outlined in Table 7. Sequential (tiered) application of the initial three lines of evidence (final column in Table 7) served to both eliminate excursions unrelated to the discharge, and highlight potential non-compliance events.

The remaining measurements were then evaluated collectively (LOE#04 through LOE#06) to arrive at a "best explanation" 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 the concurrences. A best explanation approach serves to limit the uncertainty associated with each individual CTD measurement and provide a more robust compliance assessment. The detailed analysis described below demonstrates that all of the 5,199 CTD measurements collected during the August 2010 survey complied with receiving-water limitations, and that all documented excursions either occurred within the ZID where mixing was still ongoing, or were the result of natural processes unrelated to the discharge.

Anomaly 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 in the water column. The COP also 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, modeling used to establish the MBCSD critical initial dilution of 133:1 assumes completion of dilution within a standard regulatory mixing distance, which is equal to the 15.2-m water depth of the discharge. For the purposes of screening receiving-water data for compliance, this conservative 15.2-m ZID-distance threshold is used in LOE#01 to restrict attention to post-dilution observations. Application of LOE#01 to the original 5,199 receiving-water observations eliminated 477 receiving-water observations from further consideration because they were collected within the ZID (Table 7). This left 4,722 observations that were measured outside the ZID and were carried forward in the compliance analysis.

Presence of Wastewater Constituents

In recognition of the fact that anomalies can result from the upward movement of ambient seawater entrained within the buoyant effluent plume, the MBCSD discharge permit restricts application of the numerical receiving-water limits to excursions caused by the presence of wastewater constituents (LOE#02). As specified in the COP, this confines the compliance analysis to changes caused "*as the result of the discharge of waste*."

Salinity provides a powerful tracer of dilute wastewater that is unrivaled by the other seawater properties. Wastewater's lack of salinity allows the presence of effluent constituents to be identified within the receiving seawater even well beyond the 133-fold critical initial dilution assumed in the discharge permit. In fact, analyses conducted on quarterly receiving-water surveys over the last decade have demonstrated that negative salinity anomalies are the only consistent indicator of the presence of wastewater constituents within receiving waters; the presence of a distinct salinity minimum provides *de facto* evidence of the presence of wastewater constituents. In contrast, the direct influence of dilute wastewater is rarely observed in any other seawater property, except very close (<1 m) to a diffuser port and within its ejection jet.

Table 7. Receiving-Water Measurements screened for Permit Compliance based on Lines of Evidence

LOE	Topic Addressed	Screening Questions	Answer No[15]	Answer Yes[16]
		Tiered Evaluation		
01	Anomaly Location	Was the measurement collected beyond the 15.2-m ZID boundary where modeling assumes that initial dilution is complete?	*477*	*4,722*
02	Salinity Association	Did the measurement coincide with a quantifiable salinity anomaly (≤550:1 dilution level) indicating the presence of detectable wastewater constituents?	*4,428*	*294*
03	Transport Direction	Was the measurement collected downstream of the prevailing flow path?[17]	*na*	*na*[18]

LOE	Topic Addressed	***Abductive Inference Evaluation***[19]	No	Yes	*Parameter*
04	Outside Natural Range of Variation	Did the seawater properties associated with the measurement depart significantly from the natural range in ambient seawater variability present at the time of the survey?	*294*[20]	*0*	all
05	Numerical Limits	Did the measurement's DO or pH exceed Basin-Plan numerical limits?	*0*	*294*	DO <5 mg/L
			294	*0*	7.0> pH >8.3
06	Directional Offset [21]	Was the observed offset in the seawater property consistent with the expected difference between wastewater and receiving-water properties?	*293*	*1*	pH
			293	*1*	Temperature
			289	*5*	Transmissivity
			1	*293*	DO

15 Number of CTD observations eliminated from further consideration by the specific LOE.
16 Number of CTD observations of potential compliance interest remaining after application of this and previous LOEs.
17 Semicircle (±90° of plume-transport direction) relative to the upstream boundary of the ZID
18 Because of strongly sheared flow was not adequately captured by the drogued drifter, LOE#03 was not applied to the dataset and all 294 observations were carried forward.
19 Conducted on the remaining 294 observations that were of potential compliance interest after application of the tiered evaluation
20 Seawater properties in all of the original 5,199 observations remained within the range of natural variability specified in Table 8.
21 During the August 2010 survey, the presence of effluent constituents would induce a decrease in receiving-water transmissivity, and an increase in pH and temperature. Oxygen-demanding material within effluent is assumed to depress DO relative to receiving waters (see discussion in text).

As described previously, wastewater-induced reductions in salinity can be used to directly 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 at least 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.

Application of LOE#02 restricts attention to excursions in temperature, light transmittance, DO, and pH that are related to the presence of wastewater constituents. Specifically, application of LOE#02 eliminates extremely small salinity reductions (<0.062‰) that would not result in discernable changes in other seawater properties. Of the 4,722 observations that were measured outside the ZID (LOE#01), application of LOE#02 effectively eliminated all but 294 of these measurements from further compliance interest (Table 7).

Transport Direction

The plume signature is usually located downstream of the diffuser structure. Therefore, pursuant to LOE#03, excursions in receiving-water properties found in locations inconsistent with the path of drogued drifter are generally excluded from further evaluation. Specifically, LOE#03 excludes measurements that lie within a conservatively designed 180° arc centered at the furthest location along the ZID boundary, opposite (upstream of) the prevailing flow direction measured at the time of the survey. However, exceptions to LOE#03 may occur when flow speeds are low, when there is a complete reversal in flow during the survey, or when sheared current is present.

Although the drogued drifter documented weak, mid-level flow to the east and southeast during the August 2010 survey, preliminary analyses of the survey data indicated the presence of a series of salinity anomalies extending to the north and west of the ZID. These anomalies were almost all located at or below 8.7 m, suggesting that the pronounced water column stratification present during the August survey supported a sheared flow with a countercurrent below the sharp thermocline. Although the drogue drifter was deployed at a depth of approximately 7 m, this appears to have been too shallow to adequately characterize the flow at depth. Therefore, because of the likelihood of strongly sheared flow, LOE#03 was not applied to the August 2010 survey data in order to ensure that all the measurements that could possibly be related to the discharge were evaluated for compliance.

Nevertheless, because most of the 294 remaining measurements of interest were located downstream of the path of plume transport, application of LOE#03 would have only eliminated an additional 67 measurements from further consideration.

Natural Variability

As stated previously, 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 discharge. Thus, quantifying the natural variability around the outfall is necessary for the compliance evaluation under LOE#04.

Table 8. Thresholds of Natural Variation

Water Quality Property	Basin Plan Limit[22]	COP Allowance[23]	Natural Variability Threshold[24]	95^{th} Percentile[25,26]	95% Confidence Bound[27]
Temperature (ºC)	—	—	>15.13	14.31	0.82
Transmissivity (%)	—	—	<49.9	60.2	-10.2
DO (mg/L)	<5.0	-10%	<1.75	3.13	-1.38
pH (minimum)	<7.0	-0.2	<6.952	7.046	-0.094
pH (maximum)	>8.3	0.2	>7.512	7.417	0.094

With that in mind, 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 (Table 8). These ranges in natural variability were used to identify significant departures from ambient conditions that could be indicative of adverse effects on water quality from the discharge. 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 95^{th} percentiles determined from the August 2010 ambient seawater data, to establish natural-variability thresholds in a manner analogous to COP Appendix VI. The percentiles were determined from August 2010 vertical profile data, excluding measurements potentially affected by the discharge, specifically all of the measurements that were recorded within the ZID at Stations RW3 and RW4.

None of the 294 CTD observations identified for further investigation during the tiered evaluation exceeded the thresholds of natural variability for temperature, DO, pH, or transmissivity established by LOE#04. In fact, none of the original 5,199 observations ranged beyond the limits of natural variability.

Exceedance of Numerical Limits

The NPDES permit specifies finite numerical limits for pH and DO measurements (P5 and P6 in Table 6) that are based on Basin Plan objectives for ocean waters. These numeric limits require that the discharge not cause DO measurements to be reduced below 5 mg/L, or cause pH measurements to be either below 7.0 units or above 8.3 units.

22 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.

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 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.

25 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*."

26 The 95^{th}-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.

27 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.

Pursuant to LOE#05, the pH within all 294 of the observations of interest remained well within the acceptable range. In contrast, DO concentrations within all of the remaining 294 observations were below the 5-mg/L minimum threshold prescribed by the Basin Plan. However, these DO exceedances did not constitute a violation of the permit provision because, as outlined by the natural variability thresholds generated for LOE#04 (Table 8), the recorded DO concentrations were consistent with the oxygen levels of ambient receiving waters in Estero Bay at the time of the survey. In fact, more than 80% of the total 5,199 DO observations recorded during the survey, fell below the 5 mg/L threshold. As discussed previously, these unusually low ambient DO levels prompted MRS to conduct a post-calibration of the DO sensor as well as independently verify the DO sensor's accuracy to ensure that the data had not been corrupted. Instead, the low levels resulted from a prolonged period of upwelling, which led to depletion of oxygen levels within the nearshore environment.

Directional Offset

The final line of evidence used to assess compliance with the permit limits and objectives was an evaluation of the directional offset of the water properties of the 294 remaining CTD measurements (Table 7). Analysis of the directional offset of CTD measurements is useful because wastewater and receiving-seawater properties vary from one another in several predictable ways. For example, upon discharge, wastewater is fresher, warmer, and lighter than the ambient receiving waters of Estero Bay. Under most conditions, wastewater is also more turbid than the receiving waters. As such, the presence of wastewater constituents will reduce the salinity, density, and transmissivity of the receiving seawater (negative offset), while temperature will be increased (positive offset). Additionally, at the time of the August 2010 survey, effluent pH (7.7) measured at the treatment plant was uniformly higher than the pH of the ambient receiving-waters (<7.5), therefore, wastewater constituents would be expected to increase pH (positive offset).

The presence of oxygen-demanding materials in wastewater can also result in a reduction in DO in receiving waters. Reductions in DO levels below 5 mg/L, or below 10% from that which occurs naturally are of compliance concern (P5 in Table 6). However, the MBCSD treatment process routinely removes 80% or more of the organic material, as demonstrated by the low, 51.6-mg/L biochemical oxygen demand (BOD) measured within an effluent sample collected from the treatment plant on the day following the August 2010 survey. This small BOD concentration would have induced a DO depression of no more than 0.023 mg/L after dilution (MRS 2003). In the absence of tangible influence from effluent BOD, the wastewater constituents would be expected to cause a DO increase in subsurface receiving waters (positive offset) within Estero Bay. This is because the effluent has been oxygenated by recent contact with the atmosphere, whereas receiving waters at depth are typically depleted in DO, particularly during periods of pronounced upwelling such as during the August 2010 survey.

Application of LOE#06 to the 294 remaining measurements identified which water-property offsets were consistent with known differences between receiving and wastewater properties. For example, only five of the 294 measurements of interest exhibited a reduction in transmissivity (Figure 12). Although reductions in transmissivity can be caused by the presence of wastewater particulates, this was not the case for at least four of the five transmissivity anomalies. The four transmissivity reductions (<0.52%) recorded northwest of the diffuser structure along mid-depth tow Transects #2 and #7 were too large to have been caused by the presence of wastewater that had been diluted 478 fold.[28] In addition, the four

[28] After 478-fold dilution, the 23-mg/L concentration of suspended solids measured in effluent on 5 August 2010 could have induced a reduction in transmissivity of no more than 0.22%.

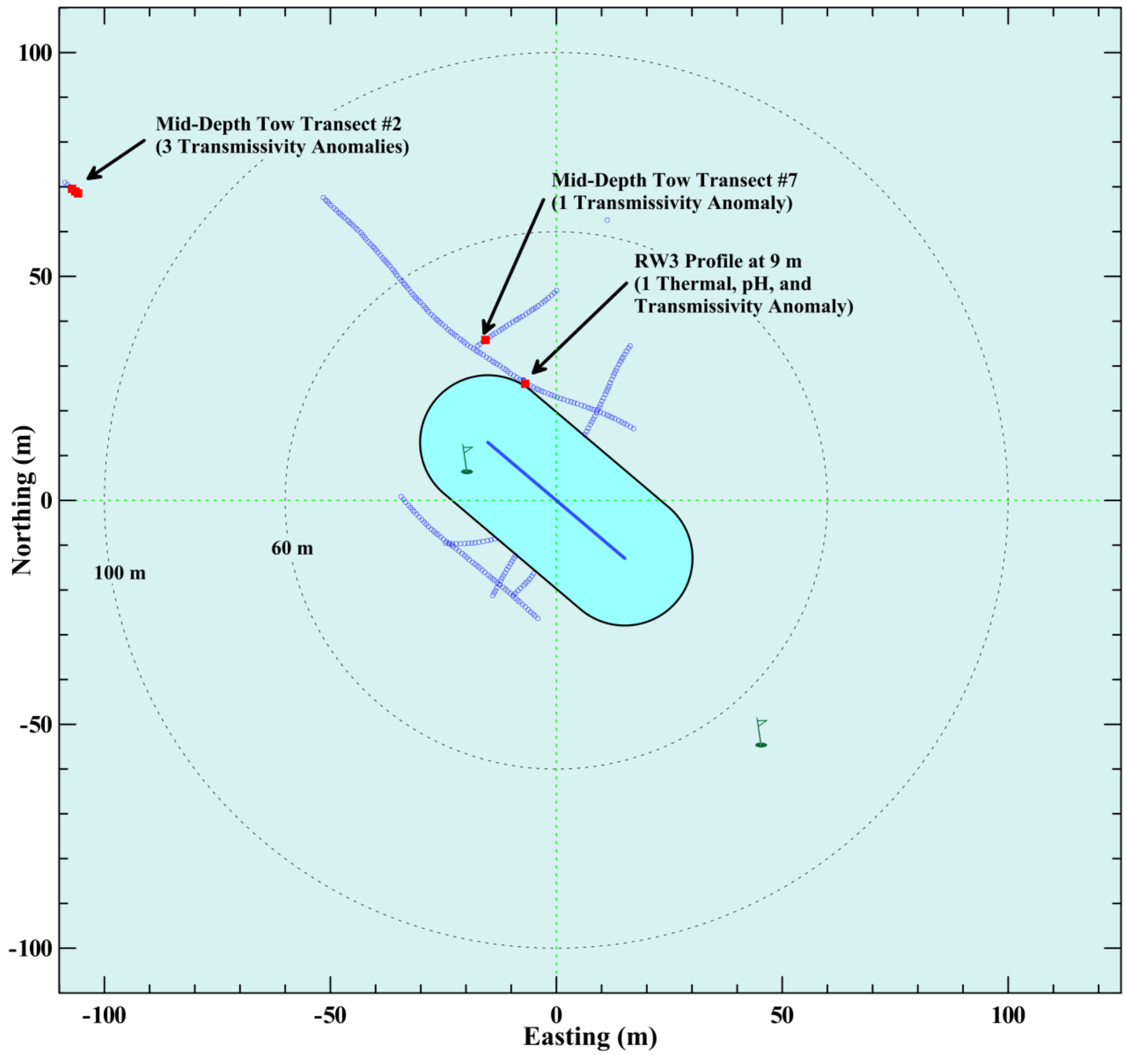


Figure 12. Locations of the 294 Measurements of Potential Compliance Interest

transmissivity anomalies were located well away from the ZID and were not coincident with anomalies in pH and temperature. Instead, these isolated transmissivity anomalies were probably caused by slight depth variations within the strong vertical gradient of ambient turbidity present at the time of the survey. Nevertheless, the measured transmissivities within these anomalies were well within the range of transmissivity measured nearby within ambient receiving waters at similar depth levels.

In contrast, dilute wastewater constituents could conceivably have contributed to the remaining transmissivity anomaly recorded at 9 m along the ZID boundary during the vertical cast at Station RW3. Contrary to the other four transmissivity anomalies, directional offsets in temperature, DO, pH, and salinity anomalies were all consistent with the presence of dilute wastewater at that location. Regardless, the depths of all five of the transmissivity reductions exceeded 8.9 m and thus did not constitute an exception to Permit Limit #P4 (Table 6) because they were all measured below the 8-m euphotic zone. Consequently, the slight increases in turbidity could not have adversely affected the transmission of natural light during the August 2010 survey, because it had already been naturally attenuated within the upper water column.

The spatial coincidence of the directional offsets measured at 9 m during the RW3 vertical cast suggests that the CTD captured a fragment of the effluent plume as it exited the ZID during its descent. Thus, the presence of dilute wastewater constituents provides the abductive "best explanation" for the measurements. The exceedingly small magnitudes of the offsets were consistent with the 440-fold dilution level determined from the associated salinity anomaly at that location. At this depth, the plume was still buoyant, and undergoing mixing as it rose through the water column. The positive DO anomaly associated with this measurement was consistent with the presence of oxygenated effluent with negligible BOD. It was the only observation of compliance interest that exhibited a higher DO concentration than the ambient receiving waters at the same depth level (Table 7).

Regardless of its origin, the amplitudes of the offsets associated with this measurement were too small[29] to be of compliance concern. Specifically, the measured transmissivity (63%), pH (7.319), temperature (13.3°C), and DO (4.8 mg/L) were well within the ranges in ambient seawater properties at unaffected locations within the survey area (LOE#04 in Table 7). This consistency is apparent from a visual comparison of the vertical profiles at Station RW3 (Figure 7c) with those of Stations RW1, RW2, RW5, and RW6 (Figure 7abef). The overall shapes and ranges of the profiles in all four seawater properties are virtually indistinguishable. The only clear signature of wastewater influence was the localized salinity decrease between 10 and 12 m (green line in Figure 7c). In fact, the visually imperceptible influence of highly diluted wastewater in the other water properties only became apparent through application of the rigorous quantitative LOE analyses. As described previously, the transmissivity anomaly was too deep to affect the penetration of ambient light (P4 in Table 6) and only reductions in DO are of compliance concern (P5). Similarly, the pH of 7.32 associated with the measurement was well within the allowable range (7.0 to 8.3), and the amplitude of the pH offset (0.012) was much smaller than the allowable 0.2 offset (P6). Lastly, the 0.22°C temperature increase was far too small to affect beneficial uses (P3), especially considering the presence of much warmer ambient seawater elsewhere in the water column.

CONCLUSIONS

All measurements recorded during the August 2010 survey complied with the receiving-water limitations specified in the NPDES discharge permit, and were within natural variability that prevailed at the time of the survey. The presence of dilute wastewater constituents was delineated from salinity anomalies within a discharge plume that was localized near, and within the ZID.

Within the upper water column, computed dilution levels of more than 209-fold were substantially greater than the critical dilution levels predicted by design modeling. Additionally, all of the auxiliary observations collected during the August 2010 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 2010 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.

[29] Transmissivity=-0.46%; pH=+0.012; Temperature=+0.22°C; and DO=+0.15 mg/L

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). 2010. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 2009 Annual Report. Prepared for the City of Morro Bay, California. March 2010.

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

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.