

2012 Orange County Sanitation District (OCSD) Outfall Diversion – Lessons Learned Report



Eric Terrill, Principal Investigator
SCCOOS Technical Director
Scripps Institution of Oceanography
University of California, San Diego
9500 Gilman Drive, Mail Code 0214
La Jolla, CA 92093-0213
(858) 822-3101
eterrill@ucsd.edu

Leslie Rosenfeld, Principal Investigator
CeNCOOS Program Director
Monterey Bay Aquarium Research Institute
7700 Sandholdt Road
Moss Landing, CA 95039
(831) 775-2126
role@mbari.org

Julie Thomas, Co-Investigator
SCCOOS Executive Director
Scripps Institution of Oceanography
University of California, San Diego
9500 Gilman Drive, Mail Code 0214
La Jolla, CA 92093-0214
(858) 534-3034
jthomas@ucsd.edu

John Largier, Co-Investigator
Professor / CeNCOOS Principal Investigator
Bodega Marine Laboratory
University of California, Davis
P.O. Box 247
Bodega Bay, CA 94923
(707) 875-1930
jlargier@ucdavis.edu

Anne Footer, Financial Representative
Marine Physical Laboratory (MPL)
Scripps Institution of Oceanography
University of California, San Diego
291 Rosecrans Street
San Diego, CA 92106
(858) 534-1802
afooter@ucsd.edu

Peter Rogowski, Lead Author
Postdoctoral Researcher
Scripps Institution of Oceanography
University of California, San Diego
9500 Gilman Drive, Mail Code 0214
La Jolla, CA 92093-0214
(858) 822-0681
progowski@ucsd.edu

March 25, 2014

Table of Contents

2012 Orange County Sanitation District (OCSD) Outfall Diversion – Lessons Learned Report	1
I. Introduction	3
II. Sampling Summary	4
III. Recommendations	6
A. Daily Decision Aids	6
B. Pre-Diversion	7
C. Diversion	7
D. Post-Diversion Analysis	8
E. Additional Recommendations	9
IV. Study Assets	9
A. Near Real-Time	10
High Frequency (HF) Radar Derived Surface Currents – Eric Terrill, SIO	10
Moorings	10
B. Delayed Mode	13
Autonomous Profiling Gliders – Burt Jones, Burt Jones Laboratory, USC	13
Drifters – Carter Ohlmann, UCSB	13
REMUS AUV – Eric Terrill, SIO	15
Satellites – Ben Holt, NASA JPL	16
Water Quality Sampling Stations	17
C. Self Contained	19
Current Profilers - George Robertson, OCSD	19
D. Models	21
Southern California Bight (SCB) Models – Yi Chao, RSS	21
E. Web Portal	22
V. References	23

I. Introduction

The Orange County Sanitation District (OCSD) diverted wastewater to a nearshore outfall in late September 2012 as part of an infrastructure rehabilitation project (J-112). OCSD normally discharges highly treated wastewater approximately 7 km offshore at a depth of 60 m (Figure 1); however, from September 11, 2012 through October 2, 2012, the wastewater was diverted to OCSD's 78-inch outfall, located approximately 2.2 km offshore at a depth of 18 m. Diversion from the 120-inch offshore outfall to the 78-inch nearshore outfall, located approximately 2.2 km offshore at a depth of 18 m depth, allowed OCSD to inspect, assess, and rehabilitate the Outfall Land Section and Ocean Outfall Booster Pump Station Piping. The fate and transport of the effluent was expected to change dramatically when discharged offshore at-depth. The plume is expected to remain well below the surface and thus away from areas used for recreation whereas discharge from the nearshore shallow outfall is expected rise to the surface and may be transported into recreational waters. To minimize impacts to public health, the treated wastewater received enhanced disinfection so that state bacterial water contact standards (i.e., AB411) were met prior to discharge and subsequent dilution. The discharged effluent is also a significant source of nutrients to the coastal zone and nearshore discharge may enhance phytoplankton growth.

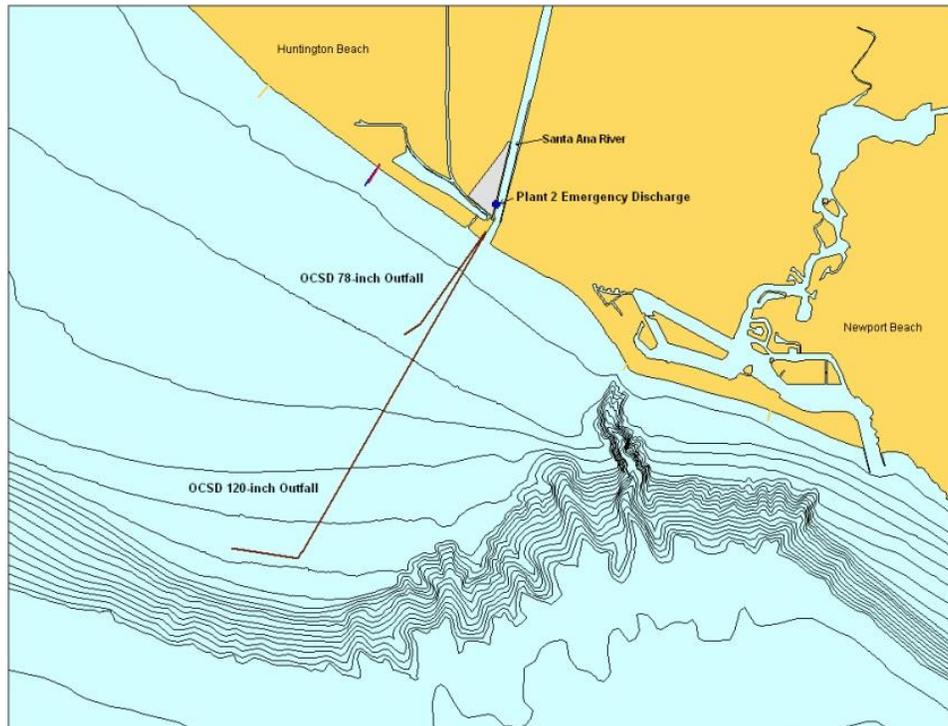


Figure 1. OCSD site map showing the location of the 120-inch outfall, the 78-inch outfall and the surrounding bathymetry.

A monitoring and modeling plan was developed to track the discharged plume, measure the effectiveness of the enhanced disinfection program, and determine environmental effects. The overall goal of the monitoring and modeling plan was to characterize the time-varying spatial extent and dilution of the discharged effluent and any impacts observed in receiving waters during the diversion to the nearshore outfall. The objectives of this Lessons Learned Report are to (1) concisely summarize the sampling methodology during the diversion, and (2)

make recommendations for future diversion projects, based on experience from this OCSD diversion. For a more comprehensive report that covers all aspects of the project (e.g. instrumentation specifics, asset maps, contact information), the interested reader is refer to the 2012 OSCD Outfall Diversion Summary Report.

This Lessons Learned Report fulfills the request from OCSD that the Southern California Coastal Ocean Observing System (SCCOOS) and the Central and Northern California Ocean Observing System (CeNCOOS) provide a summary of results of the diversion’s modeling and monitoring activities and a technical review of the work performed to determine project recommendations for future diversion studies. The work was conducted by multiple institutions (Table 1).

Table 1. OCSD 2012 Diversion participant list.

<i>Principle Investigator</i>	<i>Affiliation</i>	<i>Work Performed</i>	<i>Funding</i>
Dave Caron/Caron Laboratory	University of Southern California (USC)	Phytoplankton Response	J-112 and NOAA ECOHAB
Yi Chao	Remote Sensing Solutions, Inc. (RSS)	Regional Ocean Modeling System (ROMS)	J-112
Ben Holt	Jet Propulsion Laboratory (JPL)	Satellite Support Imagery	J-112
Meredith Howard	Southern California Coastal Water Research Project (SCCWRP)	Project Management and investigator on the NOAA ECOHAB grant	NOAA ECOHAB and SCCWRP
Burt Jones/Jones Laboratory	University of Southern California (USC)	Slocum Gliders and near real-time water quality moorings	J-112 and NOAA ECOHAB Grant
Raphael Kudela	University of California, Santa Cruz (UCSC)	Robotic submarine gliders, surface glider and other moored instruments	NOA ECOHAB and NSF Grant
Andrew Lucas	Scripps Institution of Oceanography (SIO)	Wire Walkers	NOAA ECOHAB Grant
Carter Ohlman	University of California, Santa Barbara (UCSB)	Drifters	J-112
George Robertson	Orange County Sanitation District (OCSD)	Offshore Sampling	J-112
John Ryan	Monterey Bay Aquarium Research Institute (MBARI)	Environmental Sample Processor (ESP)	NOAA ECOHAB
Eric Terrill	Scripps Institution of Oceanography (SIO)	HF Radar, Telemetered Buoy, and AUV Mission	J-112
Michael Von Winkleman	Orange County Sanitation District (OCSD)	In-Plant Sampling and Nearshore Sampling	J-112

II. Sampling Summary

The sampling program was comprised of four parts: in-plant, nearshore waters, offshore near-outfall waters, and offshore regional scale:

In-Plant: The enhanced disinfection program’s effectiveness was monitored by sampling the pre-discharge effluent (in-plant) up to four times daily. Values for the total and fecal coliform and enterococci bacteria were

predominantly below their respective geometric and single sample means. No trends or changes were seen in ammonia values.

Nearshore: Daily shoreline sampling for three fecal indicator bacteria (FIB; total coliform, fecal coliform and enterococci), temperature and salinity occurred at 17 surf-zone stations located along the shore from Sunset Beach to Crystal Cove.

Surf-zone water temperatures typically fell between 17 and 21 °C and did not appear to be affected by the discharge plume. Two regional drops in water temperature were seen on September 15 and 29, coinciding with spring tides. Salinity also did not illustrate impacts from the discharge plume with similar changes occurring throughout the region during spring tides.

Total coliform counts along the coast were all below the single sample standard of 10,000 MPN/100 mL and, with few exceptions, single-sample counts were also below the 30-day geometric mean standard of 1,000. No changes were seen in either temporal or spatial patterns due to the diversion. Greater variability and higher values were seen primarily from 9N to 3N and were consistent with the occurrence of spring tide events. Similar patterns were seen in fecal coliform bacteria counts.

Enterococci bacteria showed more variability than either total or fecal coliform bacteria. In addition single sample standards were exceeded on several occasions and at multiple stations. However, similar to the two coliform bacteria, the temporal and spatial patterns did not change during the diversion.

Offshore Near-Outfall: An integrated approach was used to characterize the discharge plume and determine its impacts on the receiving waters.

- One telemetered mooring consisting of an integrated Acoustic Doppler Current Profiler (ADCP) and temperature string was deployed prior to the diversion near the short outfall diffusers to monitor time-varying ocean currents and temperature. Two telemetered Water Quality Monitoring (WQM) buoys were also deployed up- and downcoast of the short outfall to measure biologic and optical (bio-optical) water properties in surface waters. Co-located with the WQM buoys were two current profilers housed in trawl-resistant bottom mounts (TRBMs). Additionally, three bottom mounted current profilers were deployed elsewhere in the study area.
- To map the spatial extent of the plume, two vessel-based sampling plans and an Autonomous Underwater Vehicle (AUV) survey were conducted: (i) weekly picket-line sampling of FIB and NH₃-N along the 10 meter (~30 foot) bottom-contour, performed in conjunction with the nearshore (shoreline) sampling; (ii) CTD profiles and discrete FIB and NH₃-N samples at 48 stations located up- and downcurrent of the short outfall – stations were located in two, overlapping 12x4 grids (up- and downcoast); (iii) a one-day AUV monitoring survey was performed to track the fate and transport of the wastewater plume under dynamic ambient ocean conditions.
- To track surface plume dispersion, water-following drifters were deployed and along-track sampling of temperature, salinity and colored dissolved organic matter (CDOM) was done to determine surface plume concentration and to quantify rates of dilution concurrent with advection trajectories.

Offshore Regional Scale: In addition to local-scale characteristics of the plume (within several kilometers of the outfall pipe), several methods were utilized to track the plume in the far-field.

- Three Webb Slocum electric gliders were utilized during the diversion (two actively deployed while one was serviced) to monitor the spatial and temporal variability of salinity, temperature, and optical properties (CDOM, backscatter, chlorophyll, phycoerythrin/rhodamine) of the effluent in the far-field.
- Numerical modeling used the Regional Ocean Modeling System (ROMS) code and included 3 nested domains with increasing spatial resolutions of 750-m, 250-m and 75-m over the region of interest. Boundary conditions were obtained from an ongoing, operational ROMS model that provides real-time, data-assimilating physical oceanographic output.
- Data were used from two satellites: (i) the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), an imaging instrument flown on NASA's Terra satellite, and (ii) the Advanced Land Imager (ALI) and Hyperion sensors on NASA's EO-1 satellite.

III. Recommendations

From a combination of observations and analyses that have been completed to-date, the OCS D monitoring and modeling project yields the following recommendations for monitoring and modeling of future diversions.

A. *Daily Decision Aids*

The following are a list of components used daily during the OCS D diversion and are recommended for future diversions to guide in-situ sampling.

- A web portal provides a centralized, interactive web presence for performers, decision makers, and the general public to access information and observations that plays an integral role in a diversion monitoring program. Daily use of an online webpage that displays near real-time observations can help guide and adapt monitoring activities for making improved measurements in support of the diversion. The web portal should include visualization or links to background physical parameters such as wind, waves, currents, and temperature; daily summaries of monitoring efforts; and data products such as trajectories or models. Having access to these observations allows participants and program managers to make educated decisions regarding asset placement and go/no go field operations. The portal could also have a participant only area to upload and disseminate data between performers that may not be publicly distributable, but would allow for scientific collaborations. Integrated information management systems are a critical tool to efficiently assess and manage observational programs and studies.
- The near-real-time ADCP data and trajectory estimates were key decision aids that reduced in-situ sampling of "non-plume" waters – thus focusing available resources on the plume. It is recommended that a telemetered mooring containing an ADCP and Conductivity and Temperature (CT) string be a standard element in future outfall diversions. However, surface plumes are typically very thin and the first velocity bin of the ADCP used for the OCS D diversion was at ~4 m below the ocean surface. For a surfacing plume, it is recommended to add an instrument (e.g. Acoustic Doppler Velocimeter, ADV) to measure the near-surface (~1 m) current velocity which will represent plume motion when present and thus yield a more accurate surface plume trajectory estimate. As flow offshore may be significantly different, an additional monitoring buoy could be deployed further offshore to guide in-situ sampling when the plume moves offshore.

- The ROMS and ongoing surface current observations from High Frequency (HF) Radar were used daily to determine general circulation patterns within the observational domain. A similar model approach with nesting is recommended, however further analysis is required to assess how well the model flow patterns and dispersion matched observations at the scale of interest. It is likely that further data assimilation is required (e.g. 2 km resolution HF radar derived surface currents if available) to reproduce specific flow features on a daily/tidal time scale. Further, a plume model could be coupled to the ROMS model to provide plume nowcasts.
- The objective for glider observations during the diversion was to receive regional data in near real-time to be used for daily planning of in-situ sampling. However, glider data transmission was too infrequent (2-3 days) to be incorporated into daily planning due to the amount of data collected that when downloaded, would lead to significant operational downtime of the vehicle. It is recommended to use gliders for regional scale data, but daily data transmissions need to be scheduled so that observations can be used in planning next-day in-situ sampling.

B. Pre-Diversion

- Deployment of an ADCP/CT mooring prior to the diversion will provide data on the expected surfacing of the plume and horizontal excursions. It is recommended that such data be used in a plume model to yield a priori estimates of plume behavior.
- Incubation studies in the laboratory using natural plankton assemblages to examine the response of the phytoplankton community over several days when subjected to different levels of effluent enrichment showed the potential for significant phytoplankton blooms. This is low-cost and recommended.
- A centralized database for all diversion related observational data is recommended – this will allow a quicker “spin-up” of high-resolution model grids, advance the assimilation of data into high-resolution numerical models, and provide daily analysis and graphical representation of data as obtained.

C. Diversion

- Five bottom mounted ADCPs and one ADCP mounted in a telemetered buoy provided current velocities in the OCS D diversion region. Some sites were redundant due to inadequate spacing of the instruments. While at least one telemetered ADCP is highly recommended, deployment of additional ADCPs is suggested. However it is recommended to optimize the spacing of the ADCPs to better capture the variability of currents within the region of interest.
- Capturing the spatial extent and temporal variability of the plume through boat-based profile observations was not successful. It is recommended to redesign this aspect of the plan. Potential alternatives include high-speed surface mapping, with real-time map production (given that the surfaced plume is the focus of attention), combined with either more rapid profiling (e.g., small boat with YSI Castaway) or tow/yo profiles from a boat guided by the real-time surface mapping. This work requires a dedicated (small) vessel. Alternatively, AUV surveys have proven effective at mapping the spatial and temporal extent of wastewater plumes (Wu et al., 1994; Fletcher, 2001; Ramos et al., 2000, 2002, 2007; Rogowski et al., 2012). The path of the vehicle can be optimized for in-plume sampling through utilization of near real-time current data from a telemetered buoy. It is recommended to incorporate glider data download dumps into the AUV path planning so observations can be monitored in a near real-time manner (~ hourly), with the goal of providing daily decision aids during a future diversions.

- Observations of elevated CDOM signature within the plume proved to be a primary natural tracer for the OCSD diversion and it is recommended that both CDOM and salinity are used as primary tracers in future diversions. Temperature observations are also useful.
- Drifters used during the OCSD diversion reflected considerable near-field flow complexities in the surface plume. Use of drifters is recommended to provide surface mapping and real-time support for operational decisions regarding vessel-based sampling locations and to provide post-diversion dilution assessment. It is recommended that drifters are also deployed late afternoon and evening to monitor the effect of the onshore sea breeze (common in California) in advecting the surface plume onshore.
- In-plant, nearshore and offshore FIB sampling showed the effectiveness of disinfection and is recommended as a real-time check on public health risks and post-diversion assessment.
- Offshore sampling of nutrients and phytoplankton is recommended to identify any algal bloom events and, if so, to identify dominant taxa to provide safeguards against impacts of potential harmful algal blooms. Experience in the OCSD monitoring suggests that algal blooms may not always occur.
- Remote sensing from satellites and aircraft has the potential for synoptic imaging of a surfacing discharge plume. However, reliable collection of these data is not always possible (during the OCSD diversion satellite imagery was not available daily due to weather and mechanical failures). Nevertheless, remotely sensed data observed during a diversion may be valuable in post-diversion assessment – specifically it is worth exploring what plume-relevant information that can be obtained from multispectral data. It is recommended that alternative remote sensing approaches be explored prior to future use, e.g., autonomous low-altitude aircraft that can be locally deployed and can remain below cloud cover (yet high enough to yield useful spatial coverage).

D. Post-Diversion Analysis

Further analysis of all data collected during the OCSD diversion is recommended to properly assess the effectiveness of project components and to refine recommendations of high/medium/low priority monitoring and modeling actions during future diversions. The following is a list of recommended analyses:

- A CDOM dilution analysis: compare the effectiveness of dilution calculations using CDOM data with more traditional dilution methods (i.e. dilution estimates using salinity or drifter data).
- An analysis of why no substantial phytoplankton bloom was observed – reasons may be the rapid dilution of nutrients, the inhibition of phytoplankton growth by high NH₄ levels, the occurrence of a bloom beyond the area sampled (time delay in bloom should lead to spatial offset), or the interplay between nutrients and the super-chlorination process (does chlorination inhibit algae growth?).
- ROMs comparison studies. Drifter data and ADCP data were not assimilated into the model. It is recommended to perform a comparison of model results with in-situ observations (ADCP, drifters) to assess the validity and value of ROMS output as an operational tool. Also, analyses could look at potential improvement to model results if adequate data are assimilated (e.g., fine-scale HF Radar, ADCP, drifters).
- Analysis of costs of diverse approaches in terms of personnel, boats and equipment and of the value of benefits accrued from such work – identifying value in daily operations or in post-diversion assessment.

E. Additional Recommendations

- Due to the shallow depth of the diffusers used for the diversion (~18 m), the discharge plume was expected to surface continuously. However, in-situ observations during the diversion suggested a portion of the discharge plume remained at depth. Two potential contributing factors to this are stratification and diffuser design: post-analysis of diversion data is needed to delineate the mechanism. It is recommended to monitor stratification throughout the water column near the diverted discharge using a moored string of CT sensors or wirewalker profiler. The hydrodynamics resulting from the diffuser design and interaction of the high momentum discharge plume with the ambient waters also needs to be reviewed and modeled (if no prior plume model exists) prior to a diversion.
- Budget considerations are needed for the resources and efforts of PIs to provide analyzed data to the authors' of summary documents in a timely fashion to allow for a more thorough review of results before summary documents are drafted. A post-diversion workshop is recommended to review the findings by the PIs with the authors'.
- Better communication before, during, and after the diversion is needed between all groups involved. A more centralized monitoring and modeling plan is recommended, with each component having clear objectives and expected outcomes. Further, it is recommended that a lead investigator (or small group) be identified that can integrate components, activities and analyses. This person/group would subsequently develop reports and conduct post-project assessment. Additionally, a table with list all investigators, assets, and either near real-time or delayed observations and products should be required for everyone to have a clear understanding of deployed assets, data collection, and generated products. An interactive online web portal with not only near real-time observations for planning, but also an interactive link for sharing data would be a helpful tool for collaborations prior, during, and following the diversion. Visualized data formats should be made available in common data formats such as .kml/.kmz or image file (.jpg, .gif, .png) for online visualization, and in ascii or netCDF/THREDDS for distributed data when possible.

Evolving observational instrumentation has the potential to benefit future diversions through collection of higher resolution spatial and temporal datasets. While not used during the OCSD diversion, the following observational methods may potentially improve characterization of a surfacing plume:

- An optimal mode of sampling that would provide highly resolved but spatially sufficient coverage is an airborne optical imager. The hyperspectral capabilities of such a sensor enable it to map multiple properties that can help to characterize the plume.
- Spatial characterization of a discharge plume by an array of AUVs using “artificial intelligence” that uses one or more parameters (e.g. CDOM, Salinity) to track the boundaries of plume tracers could optimize in-situ sampling by providing real-time updates on the spatial and temporal variability of the plumes location.

IV. Study Assets

A brief description of the assets used during the 2012 OCSD Diversion is given in the following sections. For a comprehensive summary of how the assets were utilized the reader is referred to the 2012 OCSD Diversion Summary Report.

A. *Near Real-Time*

High Frequency (HF) Radar Derived Surface Currents – Eric Terrill, SIO

Existing displays of HF radar derived surface current maps and surface “particle plume tracking” provided by the CORDC were made available for data assimilation into the ROMS model and as a navigational decision aid to help guide water quality sampling, respectively.

Moorings

Three telemetered moorings were deployed to measure and transmit ocean currents and water quality conditions. One mooring was deployed at the 78-inch outfall to measure currents and water temperature. The other two moorings, deployed up and downcoast of the short outfall, measured biologic and optical (bio-optical) properties of the surface waters.

a) SIO Outfall Mooring - Eric Terrill, SIO

The mooring consisted of a surface buoy that contained an ADCP, (TRDI Instruments, San Diego, CA), a temperature chain (Precision Measurement Engineering, Encinitas, CA), data logger, satellite telemetry unit, Global Positioning System (GPS) receiver, and a battery pack. The downward looking ADCP profiled ocean currents from 4.3 m deep to the seafloor. All mechanical aspects of the buoy, mooring, and anchoring system were fabricated by Scripps (Figures 2 and 3). The settings for the ADCP are listed in Table 2.

Table 2. Settings for the ADCP used to monitor subsurface currents at OCSD.

System Parameter	Setting
Acoustic frequency	600 kHz
Pings per ensemble	50
Ensemble interval	5 minutes
Range cell size	1 meter
Measurement standard deviation	1.4 cm/s
Number of depth cells	25

Measurements of water column stratification were made using temperature sensors located at different depths. The buoy contained a temperature chain, which consisted of 7 nodes spaced across the water column, each measuring ocean temperature with accuracy of 0.01°C. Measurements at each depth were synchronized to provide a water column profile of stratification at one-hour intervals. Use of the interconnected temperature measurements provided consistent timing across different water depths and eliminated clock drift problems that often occur when individual, self-recording temperature probes are used. The approximate depths of measurement were 1.8 m, 5.5 m, 8.2 m, 10.9 m, 12.9 m, 15.2 m, 17.6 m. A series of self-contained temperature loggers were co-located with the temperature probes and served as a backup to the T-chain.

The final position of the OCSD mooring was 33.610N, 117.976W, near the 20 m contour. The all-chain mooring was secured with a ~900-lb anchor. The mooring was deployed on August 15, 2012, however due to a memory card failure; the ADCP was swapped and redeployed on August 31, 2012. Deployment and servicing were conducted using the OCSD research vessel Nerissa.

Buoy position, currents, and ocean temperature data were transmitted to shore once each hour using an Iridium Satellite modem which allowed for the computation of near-real-time plume trajectory estimates. Trajectories representing the bulk transport of the water for the entire water column were computed for 24 hours of data and updated on an automated basis with the receipt of the next hour of data. Trajectories were computed from the time series of u and v velocities from the buoy ADCP. This web-accessible spatial information served as a key decision aid for OCSD in-situ sampling.



Figure 2. CORDC and USC Mooring locations. The white cylinder on the mooring to the right is a radar reflector and the cylinder on the left is a GPS tracking device.

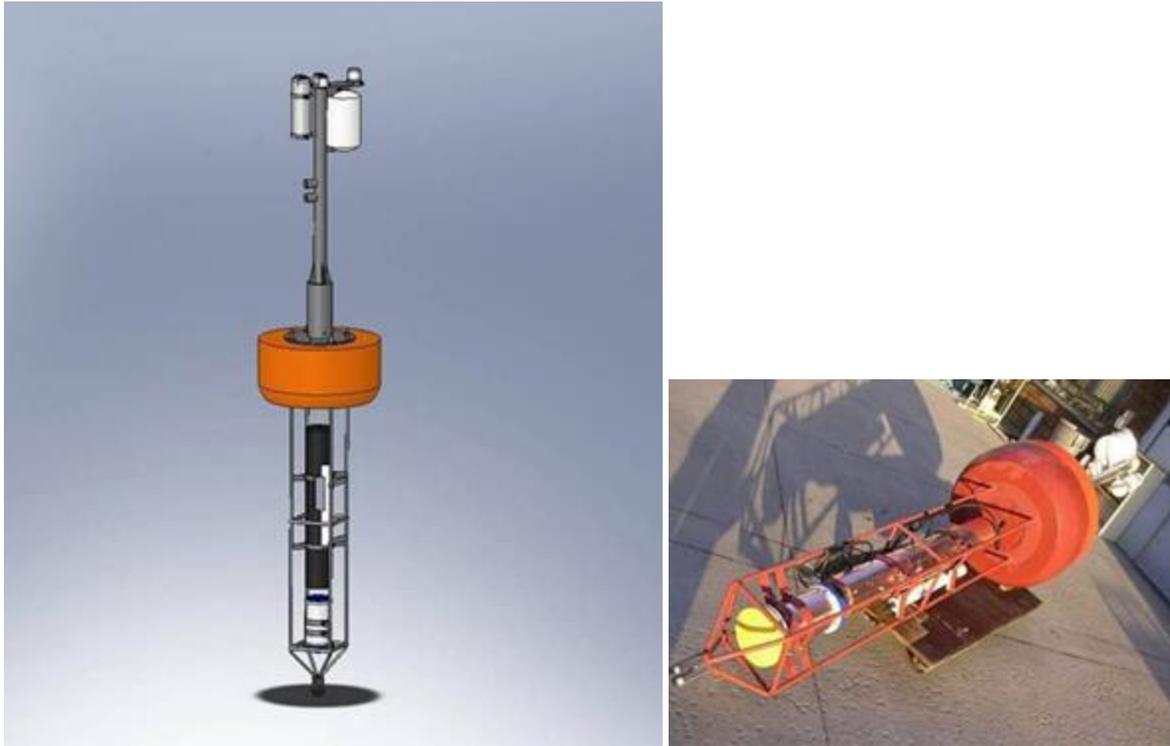


Figure 3. Drawing and a photograph of the Scripps-designed coastal buoy system for measuring stratification and currents at the OCSD diversion site.

b) Water Quality Moorings (WQM) - Burt Jones, Burt Jones Laboratory, USC

The Jones Laboratory worked with OCSD to deploy two moored buoys with scientific instrumentation. These two moorings were each equipped with a WET Labs water quality monitor and a WET Labs cycle-phosphate sensor. The WQMs (Figure 4) were equipped to measure chlorophyll fluorescence, turbidity, dissolved oxygen, temperature, and salinity.



Figure 4. An example of The Burt Jones Laboratory self-contained mooring

B. Delayed Mode

Autonomous Profiling Gliders – Burt Jones, Burt Jones Laboratory, USC

The Jones Laboratory at USC worked closely with OCSD, Southern California Coastal Water Research Project (SCCWRP), University of California, Santa Cruz (UCSC), University of California Los Angeles (UCLA), and JPL to monitor the dispersion and effects of wastewater during the Fall 2012 Orange County wastewater diversion. The Jones Lab deployed and maintained four Webb Slocum electric gliders (Figure 5).

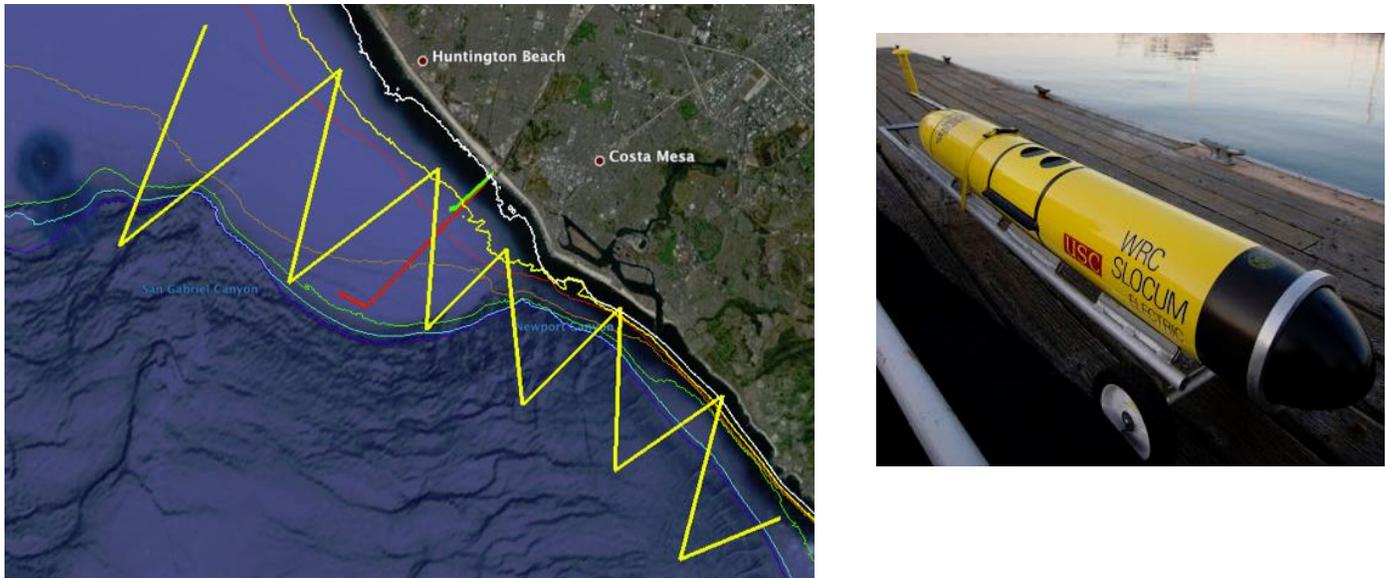


Figure 5. (Left) Fall 2012 Glider Deployment: Two gliders split the transect, one glider to the south and one to the north with overlap near the outfall pipe. The red line extending from shore is the OCSD 120 inch outfall. The light green line is the OCSD 78 inch outfall. (Right) Slocum glider.

The gliders were equipped with a Sea-Bird CTD sensor, a GPS, satellite phone allowing daily data transmission, and optical instruments. The optical sensors included up to three fluorometers with unique excitation/emission channels that measured chlorophyll a (470nm/695nm), CDOM (370nm/460nm) and phycoerythrin/ rhodamine (540nm/570nm), a backscatter sensor at 3 wavelengths (532nm, 660nm, and 880nm) for measuring suspended particles, and one glider had an oxygen sensor.

Additionally, the Jones Laboratory and SCCWRP deployed two gliders in the Spring of 2012, which were the same as the Fall 2012 deployment (Figure 5), to acquire background data that was used by the McWilliams laboratory at UCLA for nearshore modeling of the Newport Beach and Huntington Beach area. Two gliders split the transect, one glider to the south and one to the north with overlap near the outfall pipe.

Drifters – Carter Ohlmann, UCSB

Sampling was performed in the vicinity of OCSD's 78 inch shallow water outflow diffuser. Sampling consisted of deploying water-following drifters (Figure 6) just above the diffuser and performing CTD casts following

drifter motion (Figure 7). The sampling scheme gives characteristics of plume waters as they move from the discharge location and mix with the ambient seawater.

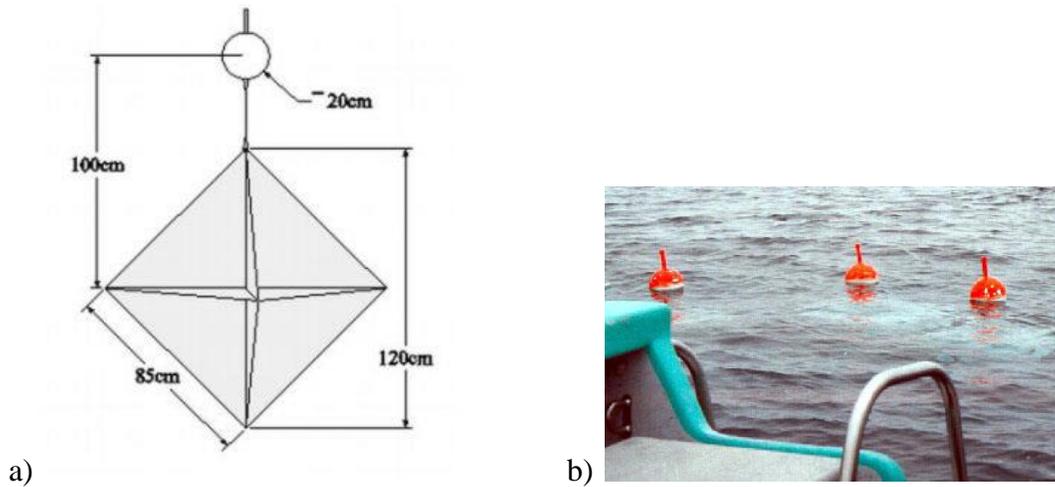


Figure 6. (a) Schematic diagram of the Microstar drifters and (b) a typical drifter deployment. The drifter deployment picture shows the stern of a 21ft skiff in the foreground to provide a sense of scale.



Figure 7. Picture of CTD system used for sampling. White cylindrical instrument in center is CTD, small black cylindrical instrument (upper left) is CDOM fluorometer, and black instrument on right is transmissometer. Lab bench to right of instrument (shown for scale) is roughly 30 inches in height.

REMUS AUV – Eric Terrill, SIO

One REMUS AUV (Figure 8) survey was performed on 9/28/2012 (Figure 9) to monitor the fate and transport of the diverted discharge. The AUV has a 100 m depth rating and 22 hour battery capacity when transiting at 3 knots. It has a diameter of 0.2 m, a length of 1.8 m, a weight of 38 kg, and is ballasted to be slightly buoyant. Survey life is a function of speed, and decreases to 8 hours at maximum speeds of approximately 5 knots. The system uses a compass for heading, Doppler Velocity Log (DVL) for speed and altitude over seafloor, pressure sensor for depth, GPS for surface navigation, and optional acoustic transponders for precise navigation. A computer interface for uploading survey mission profiles and downloading data can be done using a wireless connection. The vehicle is hand launched by a crew of two operating from a small boat. At start, the vehicle obtains a GPS fix to initialize its navigation prior to diving. During the mission, the vehicle relays its position, status, and engineering data using an underwater acoustic modem message to a receiver in the boat on a preconfigured interval, typically every 2 to 3 minutes. In addition, the shipboard system allows ranging to the vehicle as well as having the capability to send low level commands (start, stop, abort). Upon completion of the mission, the vehicle is recovered from the surface. The sensors used for these surveys include a 1200-kilohertz (kHz) ADCP (Teledyne, RD Instruments, Poway, CA), a fast response, high resolution, Conductivity, Temperature, and Depth (CTD, Neil Brown Instruments, Falmouth, MA) sensor and optical fluorometers calibrated to measure backscatter at 650 nm and 880 nm, and CDOM with a range of 0-375 ppb and a sensitivity of 0.09 ppb.



Figure 8. REMUS AUV Mission used in OCSD diversion.

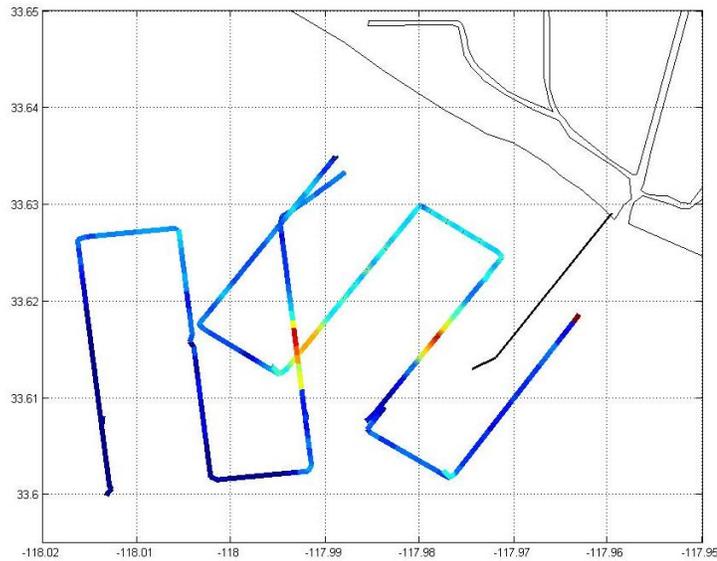


Figure 9. 9/28/2012 REMUS AUV Mission Path.

Satellites – Ben Holt, NASA JPL

Two satellite sensor collections were organized, intended to identify sea surface temperature and ocean optical properties that were related to the diversion. The first instrument is ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer), an imaging instrument flown on NASA’s Terra satellite, which was launched in December 1999 (Figure 10). ASTER is a cooperative effort between NASA and Japan's Ministry of Economy and has been designed to acquire land surface temperature, emissivity, reflectance, and elevation data. ASTER has both visible and near infrared channels as well as thermal infrared (TIR), with the latter of primary interest due to its capability to detect SST at 90 m resolution, which we thought would be advantageous over the coarser resolution MODIS SST data (250 m resolution) because of the fine-scale nature of the anticipated signals. The TIR channels range from 8.125 to 11.65 microns. Each ASTER frame is 60 by 60 km and adjacent frames are collected upon user request.



Figure 10. Artist’s concept of Terra satellite. Image credit: NASA

The second satellite is NASA’s EO-1, launched in 2000, which carries two sensors, Advanced Land Imager

(ALI), and Hyperion. ALI is a multispectral sensor with 30 m resolution and a 37 km swath. The Hyperion sensor is a hyperspectral sensor also with 30 m resolution with a narrow swath of 8 km, which is contained within the ALI swath. These acquisitions are also obtained upon user request. The requests were done in conjunction with John Ryan from the Monterey Bay Aquarium Research Institute (MBARI). There was also an image from HICO, a hyperspectral imager focused on ocean color which is carried onboard the International Space Station.

Water Quality Sampling Stations

a) Nearshore Water Quality Sampling Stations - George Robertson, OCSD

Daily shoreline sampling was conducted at the surfzone for three fecal indicator bacteria (FIB; total coliform, fecal coliform and enterococci), temperature and salinity at 17 stations from Sunset Beach to Crystal Cove (Figure 11). Discrete FIB and NH₃-N samples were collected weekly in picketline sampling along the 10 m bottom-contour performed in conjunction with the shoreline sampling.

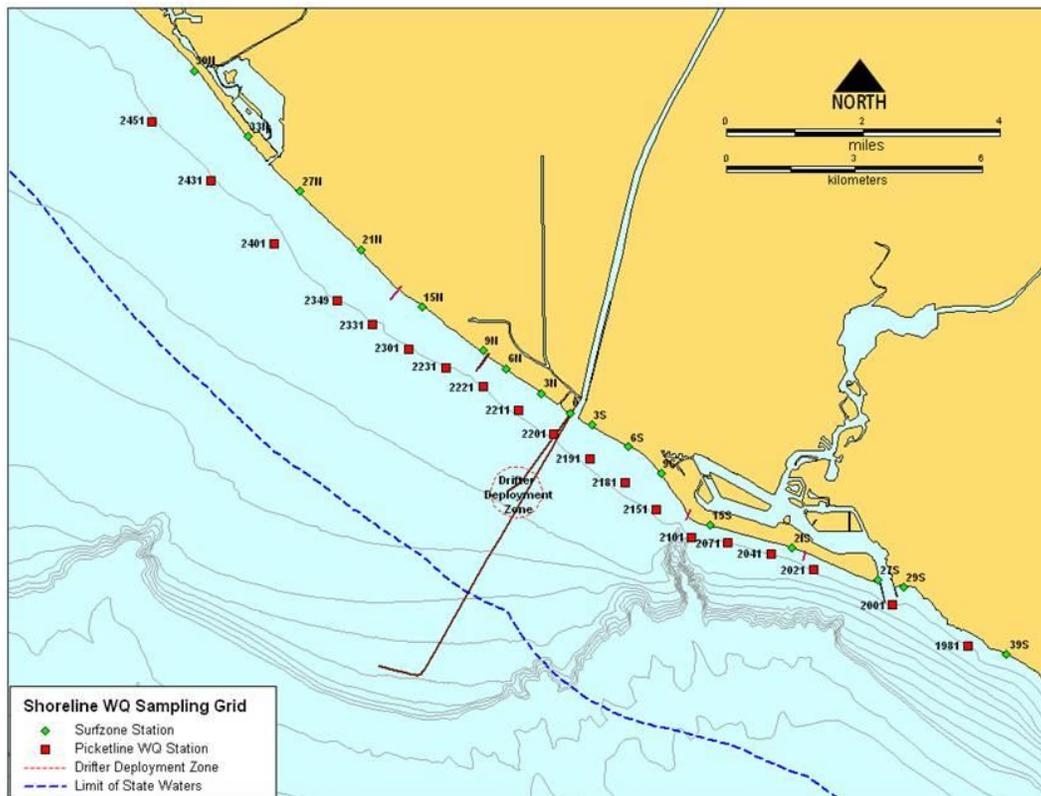


Figure 11. Nearshore¹ Picketline Water Quality Sampling.

¹ Sampling zones correspond with those defined in the California Ocean Plan. Nearshore waters extend out to the 30 ft depth contour or 1,000 ft from shore. Offshore waters extend from the Nearshore zone out to the limit of state waters (3 nautical miles).

b) Offshore Water Quality Sampling Stations - George Robertson, OCSD

This program element included water column profile sampling with a CTD instrument and discrete water sampling for FIBs and NH₃-N (Figure 12).

- Sampling at a subset of 48 stations located at, and downcurrent of, the short outfall. Stations are located in two, overlapping 12x4 grids (up and downcoast of the short outfall). Maximum CTD depths were 60 m.

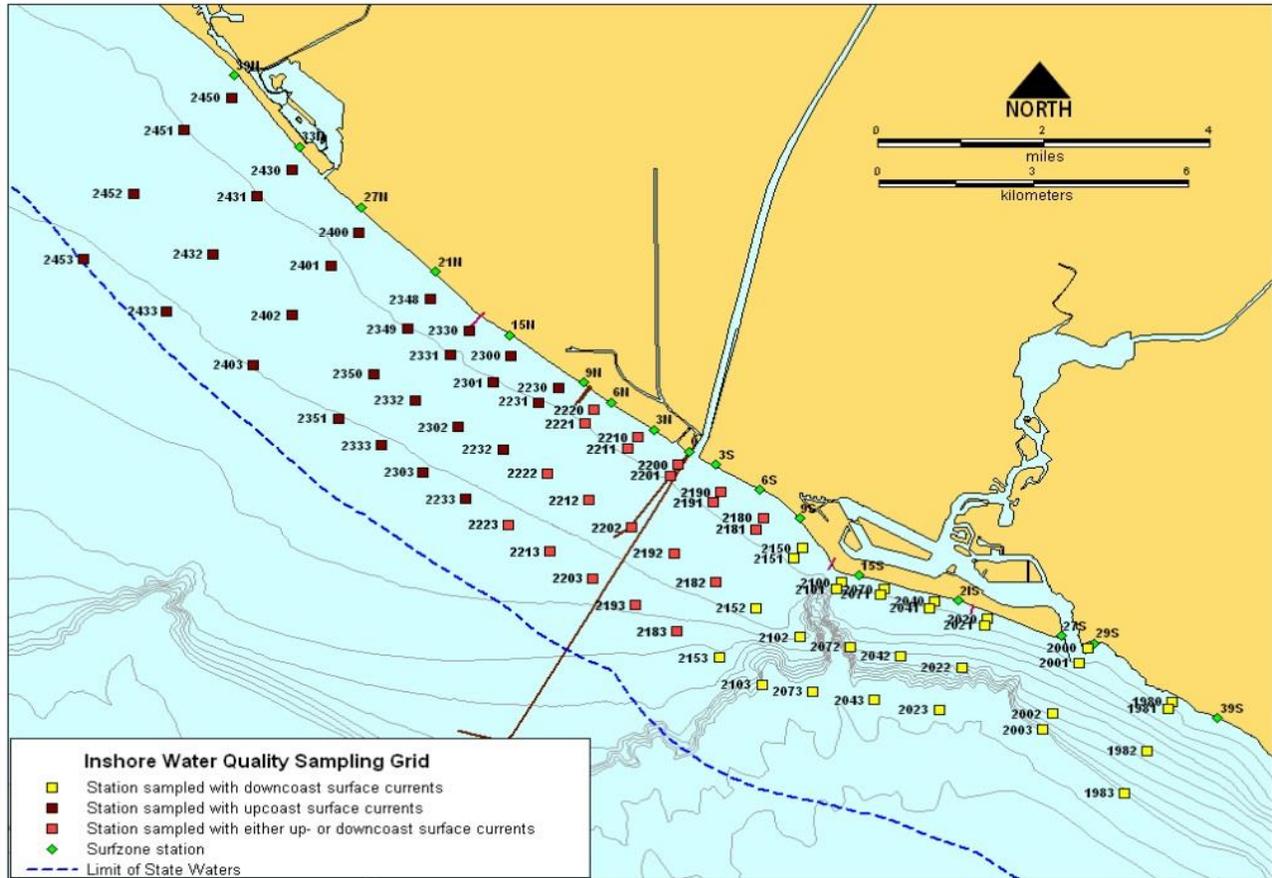


Figure 12. Plume tracking water quality sampling

Two other water quality efforts were made to better understand the temporal and spatial extent of the discharged effluent.

- In-Plant Final effluent sampling: An enhanced disinfection program was conducted during the diversion to the 78-inch outfall with sampling occurring up to four times daily.
- Sediments: With a rising plume and a high-quality effluent, impacts to inshore sediments are not expected. However, sediments were collected before and after the discharge from the short outfall to verify this. Analysis of these data will occur at a later date.

c) *Phytoplankton Response Sampling - Dave Caron, Caron Laboratory, USC*

The diversion discharge constituted a significant, localized input of nutrients to the nearshore environment with potentially major implications for phytoplankton blooms in the nearshore region (See report submitted to OCSD by Jones and Caron, “Anticipated Biological Response to Extended Discharge from a Nearshore, Shallow Outfall”).

Two types of studies were conducted to evaluate the response of the local phytoplankton community to this event:

- Experimental studies were conducted twice using natural plankton assemblages contained in bottles to examine the response of the community over the course of several days when subjected to different levels of effluent enrichment;
- Monitoring (via shipboard and shore sampling and sensing) of the response of the natural phytoplankton community in the vicinity of the discharge pipe for response to the discharged effluent.

Experimental Field Studies

Two experimental field studies were conducted prior to the diversion event (‘pre-diversion’) and during the diversion event (‘mid-diversion’) to examine the quantitative and qualitative effects of the OCSD effluent on natural assemblages of phytoplankton. Seawater for these experiments was collected offshore of the short outfall (Figure 3.49) at 2 depths for the ‘pre-diversion’ experiment, the surface (5m) and at the subsurface or deep chlorophyll maximum (DCM; depth varied) and at 1 depth for the ‘mid-diversion’ experiment, at the DCM.

Monitoring Studies: Pier Phytoplankton

Water samples were collected weekly from the Newport and Huntington Beach municipal piers situated north and south of the location of the OCSD effluent pipe sampling to monitor nutrients and phytoplankton composition.

Monitoring Studies: Vessel Sampling

Offshore samples were collected approximately weekly at a routine grid of stations during OCSD’s offshore water quality sampling surveys (from OCSD research vessel Nerissa) and at several stations during additional research cruises aboard the R/V Yellowfin. Samples were collected near-surface and from the subsurface chlorophyll maximum if one was apparent.

A total of 24 pier samples, 110 samples from the Nerissa, and 72 samples from the Yellowfin were collected as part of the monitoring studies.

C. *Self Contained*

Current Profilers - George Robertson, OCSD

Five self-contained current profilers were deployed in TRBMs or tripods (Figure 13). There were two types of current meters; Acoustic Doppler Current Profilers (ADCP) developed by Teledyne RD Instruments and the Nortek AWAC current profile, wave height, and direction instrument. The instruments were named after the moorings that they were deployed next to and the type of instrument installed in the TRBM. Three of the

moorings that they were named after were part of another funded project that ran concurrently to the J-112 OCSD funded project and those moorings are not expanded on in this summary report.

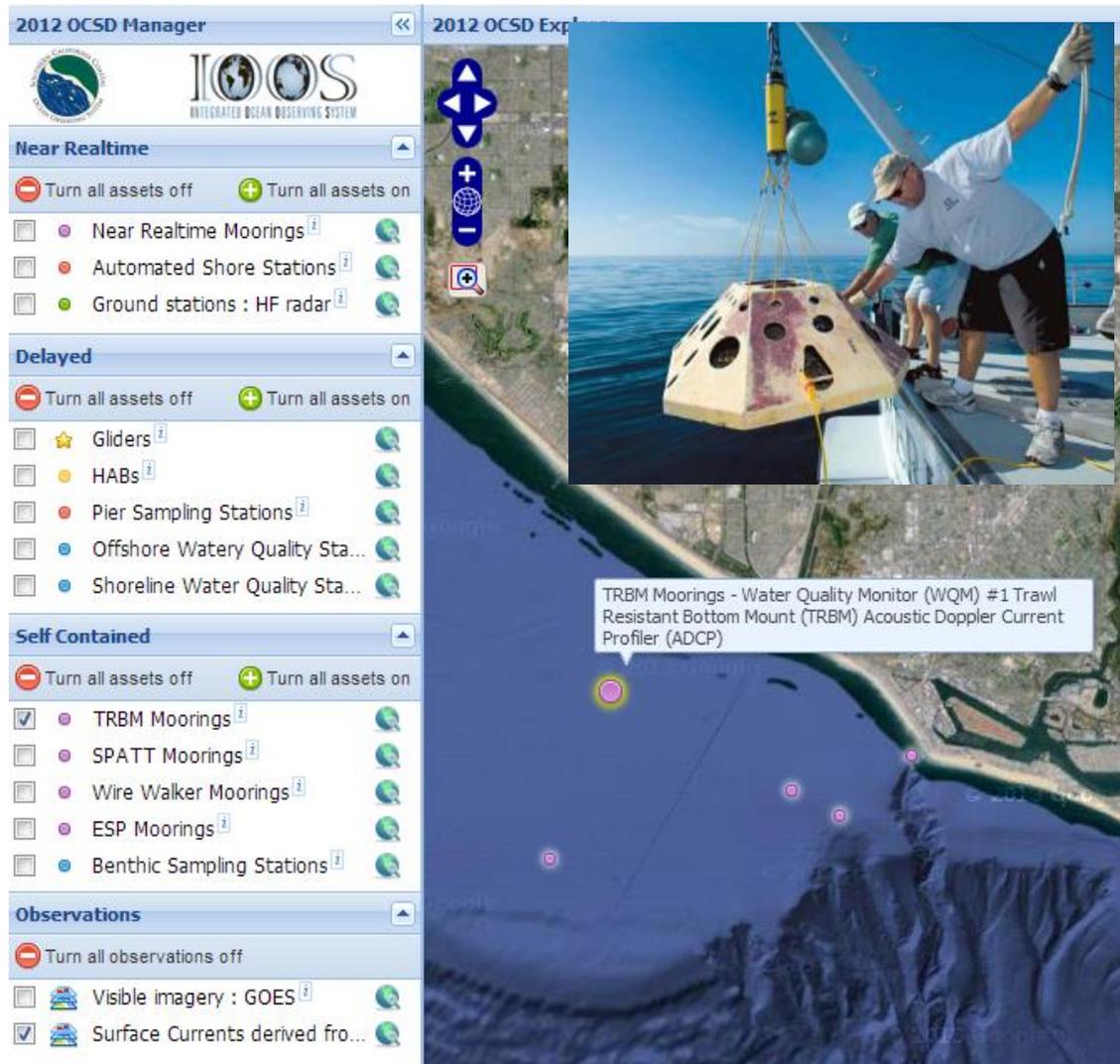


Figure 13. Trawl Resistant Bottom Mounted (TRBM) self contained current profiler mooring locations. Upper right - George Robertson, left, and Michael Mengel, with the OCSD deploy one of five trawl resistant bottom mounts loaded with current meters about 4 ½ miles off the coast near Newport Beach. Photo credit Joshua Sudock, the Orange County Register.

Current Meter	MBARI/ADCP	UCI/AWAC	M19/ADCP	WQM#1/ADCP	WQM#2/ADCP
Latitude	33° 35.7710 N	33° 36.3730 N	33° 35.4250 N	33° 37.0760 N	33° 36.0860 N
Longitude	-117° 56.814 W	-117° 56.111 W	-117° 59.091 W	-117° 59.7690W	-117° 57.444 W
Orientation	Upward	Upward	Upward	Upward	Upward
Depth	20	10	40	20	20
Upper (m)	1-6	2-4	2-13	1-6	1-6
Middle (m)	7-12	5-7	14-25	7-12	7-12
Lower (m)	13-18	8-10	26-37	13-18	13-18

Table 3 Deployment depth, orientation, and strata changes of OCSD current meters enclosed in a Trawl Resistant Bottom Mount (TRBM).

D. Models

Southern California Bight (SCB) Models – Yi Chao, RSS

Early in the project, it was realized that it was not feasible to implement data assimilation in the proposed higher resolution Regional Ocean Modeling System (ROMS), mostly because of the limited time and resources. Instead, it was decided that the real-time data assimilative ROMS currently being run in the SCB with 1 km resolution would be used to provide the lateral boundary conditions for a 3 domain nested ROMS configuration with increasing spatial resolutions of 750 m, 250 m and 75 m over the region of interest (Figure 14). This serves to transmit the broader effects of the winds and the California Current System and its spontaneous mesoscale eddies down to the local shelf circulation with its submesoscale vortices, surface fronts and filaments, separating topographic currents, and drag-induced lateral shear in shallow-water approaching the shoreline.

It should be emphasized that this proposed effort was closely coordinated with the USC and University of California, Los Angeles (UCLA) activities on the glider deployment and ROMS development, respectively. Additional support from OCSD and SCCOOS are also acknowledged.

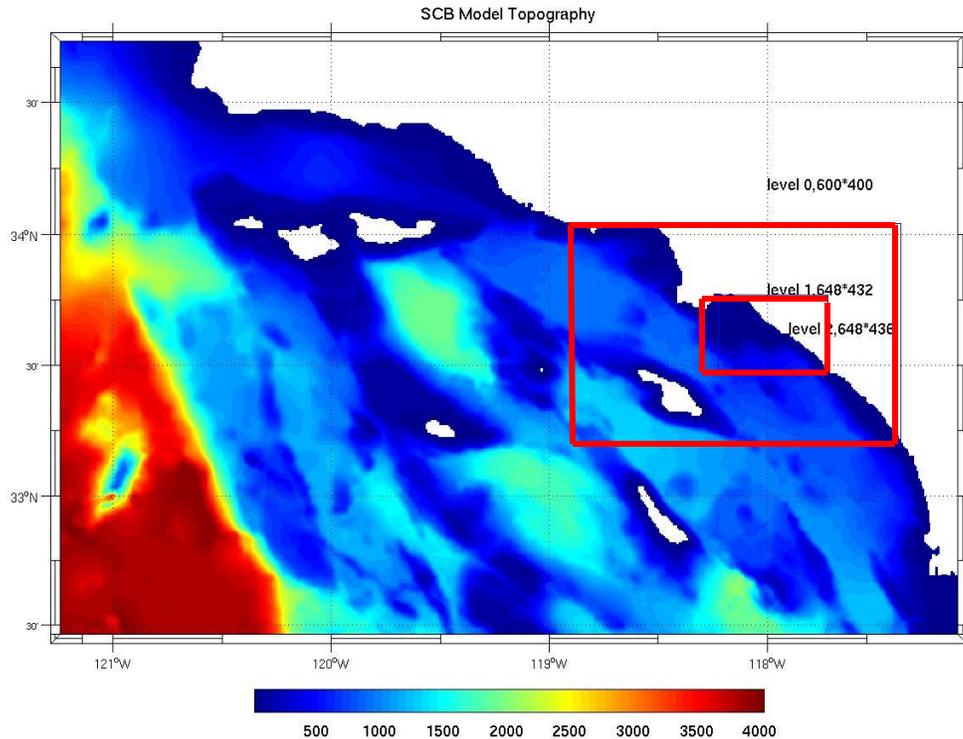


Figure 14. Hierarchy of three nested grids on which the OCSD outfall simulations are based. The outermost grid is for the Southern California Bight, and it has a horizontal grid spacing of $dx = 750$ m. The middle grid have $dx = 250$ m. The innermost San Pedro Bay grid with $dx = 75$ m. Color indicates the bathymetry with units in meters.

E. Web Portal

The OCSD diversion page provided an overall summary of OCSD’s diversion sampling program, graphical maps of field sampling locations based upon Google mapping services, as well as near real-time and in-situ environmental observations or links to those observations. An administrative interface was designed to allow for upload and posting of additional nearshore sampling and ocean modeling, including a daily summary of environmental conditions for regulators and environmental managers provided by OCSD.

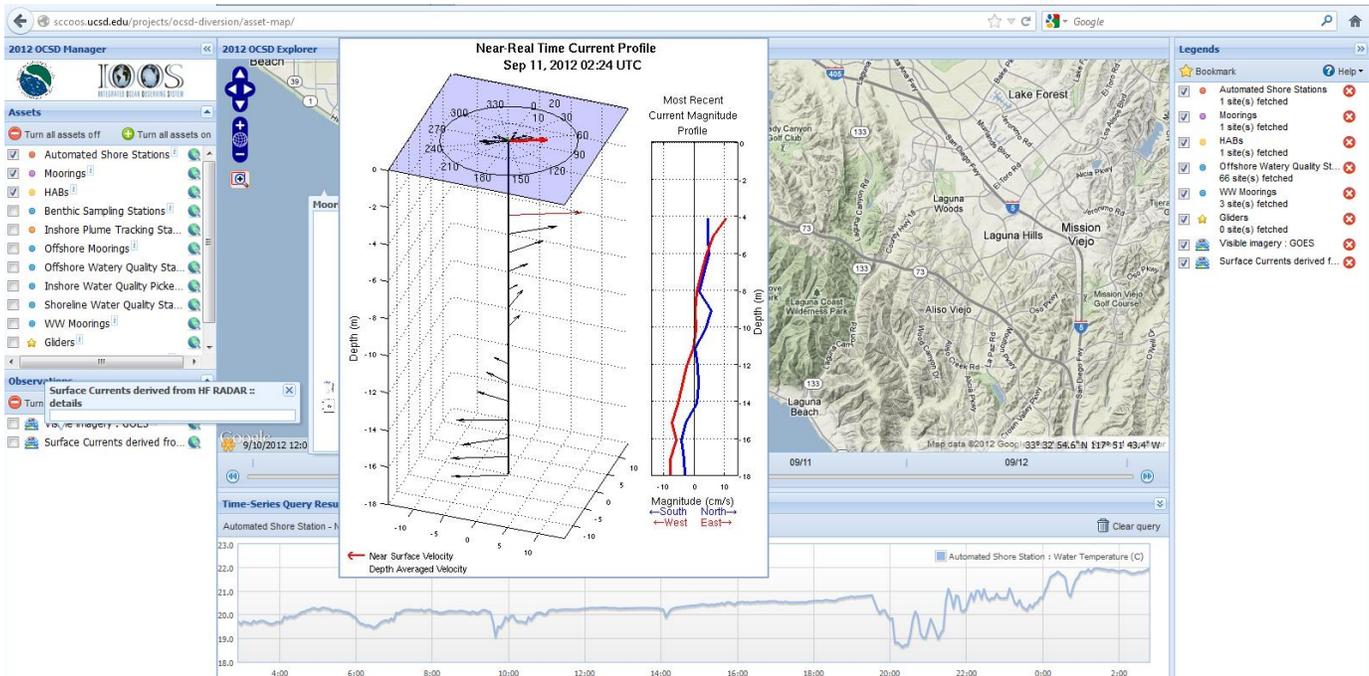


Figure 15. OCSD diversion page example, displaying near-real time current profile Sept 11, 2012 02:24 UTC.

V. References

- Jones, B. H., L., Washburn, Y. Wu (1991), The dispersion of ocean outfall plumes: physical and biological dynamics, presented at Coastal Zone '91, Proc. of 7th Symposium on Coastal & Ocean Management. ASCE, Long Beach, CA.
- Ramos, P., M. V. Neves, F. L. Pereira (2007), Mapping and initial dilution estimation of a sewage outfall plume using an autonomous underwater vehicle, *Continental Shelf Res.*, 27, 583–593.
- Ramos, P., M. V. Neves, N. Cruz, F. L. Pereira (2000), Outfall monitoring using Autonomous Underwater Vehicles, presented at Marine Waste Water Discharges MWWD 2000, Genova, Italy.
- Ramos, P., M. V. Neves, F. L. Pereira, I. Quintaneiro (2002), Mapping the Aveiro sea outfall plume: sampling strategy for an Autonomous Underwater Vehicle, presented at 2nd International Conference on Marine Waste Water Discharges, MWWD 2002, Istanbul, Turkey.
- Ramos, P., S. R. Cunha, M. V. Neves, F. L. Pereira, I. Quintaneiro (2005), Sewage Outfall Plume Dispersion Observations with an Autonomous Underwater Vehicle, *Water Science and Technology*, 52, 12.
- Rogowski, P., E. Terrill, M. Otero, L. Hazard, and W. Middleton (2012), Mapping ocean outfall plumes and their mixing using autonomous underwater vehicles, *J. Geophys. Res.*, 117, C07016, doi:[10.1029/2011JC007804](https://doi.org/10.1029/2011JC007804).
- Wu, Y. C., L. Washburn, B. H. Jones (1994), Buoyant plume dispersion in a coastal environment-evolving plume structure and dynamics, *Continental Shelf Res.*, 14, 1001–1023.