Huntington Beach: An In-Depth Study of Sources of Coastal Contamination Pathways and Newer Approaches to Effluent Plume to Dispersion

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Abstract

Following California's enactment of new fecal indicator bacteria (FIB) standards in 1997, Huntington Beach, California, began to experience frequent closures due to high levels of FIBs in 1999 and 2000 causing loss of substantial revenues to local businesses. Efforts underway at the time were unsuccessful in isolating the source of the beach contamination, but several reports implicated the unchlorinated discharge from the Orange County Sanitation District's (OCSD) 1.8 km long ocean outfall diffuser discharging ~250 MGD 7 km offshore from the beach. In repsonse, in 2001 OCSD undertook an intensive 5-month study of the coastal contamination of moored current meters and related sensors, boat-based towed vehicle mapping and hydrographic sampling including microbial counts and ammonium measurements, and beach sampling was used study the distribution of the plume, its associated contamination and the processes that affected plume dispersion. The detailed investigation concluded that the sewage outfall plume was highly unlikely to be the source of such frequent beach contamination. Despite the scientific results, OCSD decided to chlorinate the effluent and to modify the treatment process to become a full secondary treatment operation. Consistent with the results of the scientific investigation, chlorination did not resolve the beach contamination and additional investigations were performed focused more on shore-based sources.

The implementation of an ocean observing system, new oceanographic technologies, and advances in microbial detection have vastly improved our ability monitor, model and forecasts the behavior of ocean outfall plumes and their associated contaminants. It is likely that boat-based techniques of coastal monitoring will be augmented with automated and robotic observational platforms in conjunction with improved coastal ocean model that can provide both nowcasts and forecasts of plume dispersion in near real-time.

Keywords

Outfall; bacteria; contamination; sewage; tracking; modeling; Huntington Beach

INTRODUCTION

Many major coastal cities are served by elaborate sewage treatment systems and coastal wastewater outfalls where treated sewage is released into the coastal ocean using diffuser systems that have been developed through years of effort [*Brooks*, 1960; *Roberts et al.*, 1989; *Roberts*, 1999; *Tian et al.*, 2006]. Because these systems were designed to separate the effluent from areas of major human use, disinfection of the treated sewage was not considered necessary. However, because the sewage was not disinfected, these discharges often represented the single most concentrated source of viable fecal indicator bacteria for a given region.

Southern California is served by four major outfalls with a combined discharge of nearly 1.2 billion gallons $(4.5 \times 10^6 \text{ m}^3 \cdot \text{day}^{-1})$, and numerous smaller outfalls. Because the major outfalls are located offshore at water depths of 55 meters or deeper and the coastal ocean is usually moderately stratified, the discharge plumes from these outfall diffusers seldom surface and then only for limited periods usually associated with weak stratification events in winter.

In 1997, the State of California passed Assembly Bill (AB) 411 requiring routine beach monitoring for fecal indicator bacteria (FIB) during the warm season and if FIB concentrations exceeded certain levels the law postings required beach and closures based on the FIB concentrations. The beaches were to remain closed until FIB levels decreased below the posting levels. Following the implementation of this bill in 1999, the region of Huntington Beach (Figure 1), south of Los Angeles, began to experience frequent closures due to elevated bacterial concentrations along the beach. A



Figure 1. Map (Google Earth) of the Huntington Beach region showing the area where significant bacterial contamination was observed (yellow box), the outfall (red lines), and the larger domain (inset).

conclusion from the evaluation of the timing and frequency of beach contamination was that it appeared to have a period of about 2 weeks corresponding to the spring-neap associated with mixed semi-diurnal tides in the region.

Several efforts attempted to isolate the source of the bacteria. The efforts included a previously planned plume mapping effort in 1999, monitoring of runoff sources, discharge dye studies, and extended beach studies in 2000. The studies included evaluation of sewage infrastructure integrity to ensure that aging or broken transport systems were not the source of the bacterial contamination along Huntington Beach. Although multiple possible sources of FIBs were identified, none of the sources was conclusively resolved to be the source of the persistent problem along Huntington Beach. One report suggested that because the OCSD outfall was the single largest source of FIBs in the area, and because effluent was observed within 2 km of the coast, that the discharge coupled with coastal cross-shelf exchange processes was a likely contributor to the contamination [*Boehm et al.*, 2002]. This prompted a major effort to evaluate whether the outfall was the source of the contamination observed on the beach.

APPROACH

To evaluate the probability that the OCSD outfall was a significant source of bacterial contamination along Huntington Beach a major research program was mounted for the period of May through September 2001. Observational elements included physical oceanographic moorings and bottom tripods equipped with ADCPs to measure current profiles, CTDs to measure variability of temperature and salinity, and thermistor strings to measure the vertical temperature structure. Water column distributions of physical, chemical and biological variables were mapped with a combination of hydrographic CTD and bottle sampling combined with towed vehicle mapping of the distributions of key variables that include nitrate and ammonium and fecal indicator bacteria. The moorings were distributed in two cross-shelf arrays intended to capture cross-shore processes that could transport the effluent plume toward the shore (Figure 2). The hydrographic and tow vehicle lines were distributed around the outfall discharge (Figure 2) so as to capture the distribution and variability of the plume during spring tide periods when it was thought that the plume would be most likely to be transported toward the coasts, coinciding with the periods of highest beach bacterial contamination. Beach sampling included daily measurements at the sampling included daily me

ling locations throughout the summer and hourly sampling during the intensive hydrographic surveys during spring tide conditions.

OBSERVATIONS

Using the observational resources described above, multiple pathways of transport from the outfall diffuser 7 km offshore to the inshore beach region were investigated. From the hydrographic sampling and tow vehicle mapping 3-dimensional curtain

plots of plume were constructed to evaluate the distribution of effluentderived components in the

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Figure 2. Map of continental shelf, outfall location and sampling locations for the HB 2001 study. Red dots indicate hydrographic sites, blue stars are mooring sites and green lines are tow vehicle lines. White dots along the beach indicate bacterial sampling sites.

water column (example shown in Figure 3). During each spring tide study this pattern was repeatedly sampled for a 48-hour period at approximately 8-hour intervals providing 6 repeated surveys over that period. In the example figure the distribution of ammonium, an umambiguous plume tracer for this region, shows the location of the plume along the coast. In this example, the

plume is located mostly below 30 meters depth, except directly over the outfall where the vertical momentum causes an overshoot before the plume turbulence collapses downcurrent (upcoast) from the outfall.

A second example of the cross-shelf plume transport and variability is shown for E. Coli concentration in Figure 4. In this example, the data are plotted as the variation along the cross-shelf line immediately parallel with the diffuser (see Figure 2). The top two panel shows the velocity vectors and the bottom panel shows the E. Coli concentrations at the plume depth. The two sites are 2 and 3.3 km offshore from the beach. The bacteria were clearly transported crossshelf by the tidal oscillations based on the phase relationship of increasing bacterial concentration with tidal shoreward transport (Figure 4). In this example, bacterial concentrations



Figure 3. Curtain plot of ammonium concentration from May 22, 2001. The sections are perpendiciular to the coastline and include data from the hydrographic profiles and the tow vehicle transect. The OCSD outfall is indicated in green. The height of the ammonium concentration over the outfall indicates the initial plume overshoot that occurs before it collapses at the end of the initial mixing field. The plume is clearly advecting toward the left (upcoast) from the diffuser.

decreased significantly (about a factor of 5) from the offshore location (3.3 km) to the location closer to shore (2 km). The observations from 5 cruises from June through September are summarized in Table 1. It is clear that the concentrations that **FIBs** observed of were on Huntington Beach were not observed at 0.8 km off the beach where the lowest concentrations of total coliform bacteria were observed during each observational period. Based on these observations, we conclude that cross-shelf transport from the effluent plume was not a likely source of the high bacterial counts observed in the surf zone.



Alternative pathways were evaluated to determine whether the plume might enter into the nearshore region of Huntington

Figure 4. Time series of currents at moorings HB03 (Line 3, left) and HB05 (Line 4, right panels) top, and E. Coli concentrations (bottom panels).

Beach the nearshore region via a pathway other than direct cross-shelf transport. One proposed pathway was advection of the effluent plume along the shelf edge/upper slope until it entered Newport Canyon where it could be upwelled into the upper layer then advected northward into the vicinity of Huntington Beach where it could then be entrained into the surf zone (Figure 5). To evaluate this hypothesis transport was evaluated using the results from the current meter moorings (HB07, 11, 13 and 03) indicated in the figure. To be validated the current time history would need to support this pathway with an outcome of increased bacterial concentrations at the beach when the current trajectories satisfied the requirements of the pathway (Figure 6). The evaluate the pathway shown in Figure 6, mooring HB07 near the outfall is used to calculate transport to HB11, which is

then used to calculate the transport to HB13. Upcoast flow at HB13 is then transports the plume up to HB03.

Plume mapping using the tow vehicle demonstrated the transport of the plume along the shelf edge to Newport Canyon, where elevation of the plume within the canyon provided evidence that the first portion of the transport from the outfall to Newport Canyon could occur. When this pathway is examined through the entire time series for the summer of 2001, the pathway is completed only a limited number of times based on the time series of observations from current meter observations. When the likelihood of this mechanism occuring is compared with the number of FIB exceedances along the Huntington Beach, this pathway is an unlikely source of the repeated



Figure 5. Hypothetical alternative pathway of transport (indicated by the green band) of discharged effluent from the OCSD outfall diffuser into the nearshore region in front of Huntington Beach. Mooring locations used in the analysis are indicated by the dots designated HB07, HB11 HB13 and HB03.



Figure 6. Schematic showing the evaluation scheme for the Newport Canyon pathway (Figure 5) of plume transport from the outfall to the region along Huntington Beach including the AES power plant cooling water intake and discharge. The time windows for each step in the pathway are indicated in the labels above the schematic.

contamination events that were observed along Huntington Beach (Table 2).

Although this is not an exhaustive presentation of the results from the Huntington Beach studies, the examples are representative of the observations that were obtained during the intensive study in the summer of 2001, as well as additional studies in prior years. The overall conclusion of this study was that the outfall design was achieving its intended design goal of minimizing the surfacing the OCSD sewage effluent discharged through the diffuser 7 km offshore, and minimizing its impact with the beach region where public contact was likely. Although the outfall, at the time, was a large source of viable fecal indicator bacteria, these bacteria were unlikely to connect with the beach region, and therefore probably not the source of the frequent exceedances of FIBs on Huntington Beach.

New Technologies

Since the time of the Huntington Beach Study, new technologies have been implemented that enable more comprehensive and detailed studies of plume processes *in situ*. These new technologies coupled with the implementation of ocean observing networks provide the potential of not only tracking and monitoring outfall plumes, but other sources of contamination near urbanized and industrialized coastlines.

One area of improvement is in the rapid detection of FIBs from environmental samples using qPCR techniques. Recent evaluations have demonstrated that qPCR techniques can provide reliable indications of FIB levels sufficient for public health agencies to be able to identify exceedances and post a contaminated site within a matter of hours rather than the traditional 24-hours that was required by standard incubation methods [*Griffith and Weisberg*, 2011]. Efforts are ongoing to merge these techniques into automated systems such as the Monterey Bay Aquarium Research Institute's (MBARI) environmental sample processor (ESP) [*Scholin et al.*, 2009]. The MBARI ESP can be deployed from piers, fixed moorings or drifing floats, telemetering its data in real-time, providing remotely sensed detection and notification of FIB concentrations.

Within the last five years, autonomous vehicles have rapidly been integrated into reasearch and observation efforts. Two types of autonomous underwater vehicles (AUVs) are being used for coastal outfall dispersion studies. Autonomous gliders propel themselves by adjusting their buoyancy to be either negatively or positiviely buoyant. The vehicle pitch is adjusted with the buoyancy change such that the flow over the wings propels the glider forward during both descent and ascent. Because of the small amount of power required for propulsion gliders are able to sustain deployments of weeks to months.

Colored dissolved organic matter (CDOM) is often an excellent tracer of plume for extended distances and time outline the areas where effluent plume was detected.

Glider Rusalka - CDOM Fluor. (μg-QSE· I⁻¹) - Apr 04 2009 1839 - Apr 07 2009 0442 UT



Figure 7. A glider map of CDOM, indicative of the effluent plume from the OCSD outfall diffuser, for the period of April 4-7, 2009. The red line extending from the coast indicates the outfall pipe, the effluent and can be used to track the with the diffuser located at the end of the pipe. The circled areas

periods [Petrenko et al., 1997]. The example shown in Figure 7 shows the dispersion of the effluent plume from the OCSD outfall during a period of relatively weak alongshore flow. As can be seen the plume spreads out into multiple patches some of which can become guite wide and thin as the plume advects away from the diffuser. From deployments such as this, effluent plumes can be characterized by the observations from the vehicle for extended periods. Plume statistics for a smaller outfall show the distribution of the plume depth and the statistics of plume direction relative to the diffuser over a two-week period (Figure 8). The statistics indicate that the plume remained submerged over this two-week period and the plume was primarily advected in the alongshore direction.

Propelled vehicles such as the Hydroid REMUS AUV use similar sensor suites as the gliders, but can navigate at speeds up to 4 knots (7 km/hr) for deployment periods on the order of 24 hours. Thus they can cover distances much more quickly than gliders and provide relatively detailed quasisynoptic mapping of outfall plumes within the limitations of the battery life of the vehicle. These vehicles have proven effective in detailed mapping of outfall plumes [Ramos et al., 2007;



Figure 8. Statistics for the plume from the San Juan Creek outfall off Dana Point, California. The outfall diffuser is located 3.15 km offshore at 30 m depth. The left panel shows the histogram of plume depth over the course of the deployment. The right panel shows vectors that represent the probability of the direction of the plume during the course of the deployment.

Rostowski et al., this symposium]. Plume mapping with propelled vehicles provides short-term quasi-synoptic maps provide high-resolution detail near the outfall, complementing the longer term, often larger scale mapping accomplished with gliders.

Surface current mapping using high frequency radar provides real-time surface maps the ocean currents that provide the ability to track and predict the transport of contaminant inputs in the surface layer of the ocean. Surface current mapping provides at least two direct applications to outfall plume tracking. Should the effluent plume surface then the surface current mapping provides a real-time mechanism for creating the plume trajectory as well as providing a short-term forecast of where the plume is headed. Secondly, the data provides a real-time input into data-assimilating operational ocean models, thereby increasing the accuracy of these three-dimensional models and their forecasts capabilities.

Recent improvements in three-dimensional modeling of coastal ocean dynamics are providing new insights into the dispersion and statistics of the distribution of contaminant plumes. For example, the UCLA modeling group led by James McWilliams has recently implemented a high-resolution coastal model that has 75 meter horizontal resolution that is appropriate to the scale of coastal effluent and runoff plumes. The models are already being used for dispersion of passive tracers [*Watson et al.*, 2010] at scales that are approach those important to outfall plumes. The models have improved ability to handle nearshore processes where wave-current interactions become much more important [*Uchiyama et al.*, 2009]. Linking biogeochemical models with the physical models enables the evaluation of not only public health risks, but also the effects of large discharges on ecosystem dynamics and local biogeochemical cycles [*Gruber et al.*, 2006]. This is especially important for large outfalls that discharge large amounts of nitrogen and phosphorus into the coastal ecosystem in forms and ratios distinct from natural sources.

All of these elements, as well as more traditional observations from boats and moorings, contribute to coastal ocean observing systems that have the potential to provide continuous real-time observations and operational models with nowcasts and near-term forecasts of coastal dynamics. At the least these resources provide the capability for intensive studies that can clarify, provide comprehensive statistical analysis and resolve questions of whether a coastal outfall is a major source of contamination, such as occurred along Huntington Beach in 1999-2001. Ideally, these types of observations will become a routine part of our coastal monitoring in major urban regions providing observations and modeling statistics that contribute not only to the design and management of ocean outfalls, but also to the evaluation of the direct influences of urbanized coastlines to regional climate change, ecosystem changes, and issues that we may have not yet considered.

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Table 1. Maximum concentrations of Total Coliforms along each hydrographic line parallel to the shore during each the intensive observation periods. The shaded areas indicate the values that exceed California Ocean Plan geometric mean value (1000 MPN/100ml) for posting of the beach area.

Location	Distance Offshore (km)	June 20-22	July 5-7	July 20-22	August 19-21	Sept. 15-17	Mean
Beach	0.0	3750	2512	4054	2321	2760	2566
Line 1	0.4	119	96	15416	154	123	3182
Line 2	0.8	52	41	20	41	20	39
Line 3	2.0	122	1465	324	31	3076	1003
Line 4	3.3	60	1789	5166	96	18144	5051

Table 2. Evaluation of number of possible of contamination events via the Newport Canyon pathway. These statistics are for the period from

Number of	Outfall to	Newport Canyon	Shoreline	Shoreline	Comment
Possible Events	Newport Canyon	to Santa Ana	Exceedances	Exceedances	
		River		$\pm 1 \text{ day}$	
8	5	4	0	2	Exceedance preceded plume arrival