National Center For Environmental Research

Final Report: Identification and Control of Non-Point Sources of Microbial Pollution in a Coastal Watershed

NCER Research Project Search

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Title: Identification and Control of Non-Point Sources of Microbial Pollution in a Coastal Watershed
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EPA Project Officer: Stelz, Bill
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Description:

Objective:

The objectives of this study were to: (1) characterize the magnitude and variability of fecal indicator bacteria (FIB) loads in the watershed along an inland to coastal gradient that includes street gutters, storm channels, tidal channels, and the surf-zone at Huntington Beach; (2) examine linkages between FIB and other indicators of human pathogens; (3) develop strategies to control FIB loads during nonstorm periods; and (4) aid decisionmaking by examining the perspectives of stakeholders, including beachgoers, environmentalists, local businesses, public health officials, and wastewater utility managers on various aspects of beach pollution problems, such as the causes, health risks, and responsibility to pay.

California beaches are a critical component of the culture and economy of California and are threatened by coastal pollution. Beach recreation in California accounts for $5.5 billion of the Gross State Product (King and Symes, 2003). Nowhere has there been greater attention on beach pollution than at Huntington Beach in southern California.

Huntington Beach, consisting of Huntington State Beach and Huntington City Beach, is located along a northwest to southeast striking section of the Pacific coastline between Los Angeles and San Diego, in Orange County, California. Several areas of Huntington State Beach have suffered chronic beach postings and closures over the past several years as a result of elevated concentrations of FIB in the surf zone (Kim and Grant, 2004). This beach is very popular (more than 5 million visitors per year), and the combination of surf zone pollution and significant beach usage implies that a large number of people (perhaps as many as 50,000) may acquire highly credible gastroenteritis from swimming and surfing in this area each year (Turbow, et al., 2003). FIB pollution at Huntington State Beach is thought to be caused by a combination of sources, including dry and wet weather runoff from the surrounding community, bird droppings deposited in the Talbert Marsh, and regrowth of bacteria on vegetation and marsh sediments (Grant, et al., 2001; Reeves, et al., 2004). Additional potential sources of FIB include the offshore discharge of partially treated sewage effluent (Boehm, et al., 2002a), the offshore discharge of power plant cooling water that contains FIB from plant wash-down and other activities (Boehm, et al., 2002b), resuspension of contaminated sediments (Sanders, et al., 2004), bather shedding, the accumulation of bird droppings along the shoreline and offshore, the exfiltration of sewage-contaminated groundwater, and contributions from watershed outlets located north and south of the study area, including the Los Angeles River, the San Gabriel River, and outlets for Huntington Harbor and Newport Bay (Kim, et al., 2004).

This project focuses on the Talbert Watershed in Huntington Beach and Fountain Valley, California, which drains to Huntington Beach and is a significant stressor of Huntington Beach water quality. The Talbert Watershed encompasses 3,400 hectares in the cities of Huntington Beach and Fountain Valley. The watershed is urbanized and consists of residential developments, commercial districts, plant nurseries, and light industry. This area of southern California has separate storm water and sanitary sewer systems, therefore, dry and wet weather runoff flows to the ocean without treatment. Runoff from the Talbert Watershed is conveyed along street gutters to inlets that connect to underground storm water pipelines. These pipelines connect to a network of three flood control channels (Fountain Valley, Talbert, and Huntington Beach) that converge near the ocean at a constructed wetland known as the Talbert Marsh. Ocean water floods both the Talbert Marsh and the lower reaches of the open channels during rising tides (flood tides), and a brackish mixture of ocean water and runoff drains from the system during falling tides (ebb tides). The Talbert Watershed is nearly flat and only a few feet above sea level. This geographical setting hinders drainage by gravity alone, so a system of transfer stations is used in the lower reaches of the Talbert Watershed to pump runoff into the open channels from storm water pipelines. Each transfer station, or pump station, consists of a forebay, where runoff can be stored, and several pumps. Pumping of runoff to the channels occurs intermittently during dry weather periods and continuously during storms. Talbert Marsh is a 10-hectare remnant of what used to be an extensive (1,200 hectare) saltwater wetland and dune system in coastal Orange County. The majority of this wetland system was drained and filled over the past century for agricultural reclamation and urban development. Most of what remained of the historical wetland, including Talbert Marsh, was cut off from tidal flushing by the construction of the Pacific Coast Highway and channelization of the surrounding area for flood control. As part of a habitat restoration effort, tidal flushing in the Talbert Marsh was restored in 1990 when a new tidal inlet was constructed. Since its restoration, Talbert Marsh has become a typical southern California tidal saltwater marsh with open water, wetland, and upland habitats (Grant, et al., 2001). Pickle weed (*Salicornia virginica*) is the dominant macrophytic vegetation, and the marsh is utilized by several special-status bird species, including the California least tern, brown pelican, and Beldings savannah sparrow.

Summary/Accomplishments (Outputs/Outcomes):

To achieve the objectives, extensive monitoring of Talbert Watershed surface waters was conducted to measure the spatio-temporal variability of FIB loads (total coliform, *Escherichia coli*, and *Enterococcus*) and analysis was performed to examine the factors that control fate and transport. Monitoring also was performed to examine the association between FIB and other indicators of fecal pollution. Both one-dimensional and two-dimensional hydrodynamic models were developed to analyze the FIB loads in tidal channels and into the surf-zone and to develop a predictive tool that can be used to examine how bacteria loads would be altered by operational changes to the infrastructure. Surveys were performed to measure stakeholder preferences in the context of multistakeholder, multi-objective beach pollution problems and to support decisionmaking analysis.

Closure and posting of Huntington Beach, California, during the study period was the source of widespread media attention. In response, members of the research team redirected efforts and/or engaged in a number of additional studies to better understand the factors controlling surface water quality in the Huntington Beach surf zone, as well as the response of stakeholders to the unfolding pollution problem. For example, co-principal investigator (PI) Keller focused attention on the decisionmaking of beachgoers (to swim or not to swim) in response to warning signs posted on the beach. Co-PI Keller also focused attention on the decisionmaking of public agencies, who were under great public pressure to remedy the pollution problem but had little understanding of its cause. To better understand the pollution problem, co-PI Grant analyzed short- and long-term FIB monitoring data to identify trends in Huntington Beach bathing water quality. The observed variability was examined in the context of historical management measures, such as passage of the Clean Water Act, construction of a new ocean outfall, and efforts to prevent urban runoff from draining directly to the beach. Co-PI Grant also developed a method to identify and rank the sources of pollution to the surf-zone using high-frequency monitoring data collected along the beach. PI Sanders teamed with University of California (UC) Irvine and UC San Diego researchers to examine the potential for Orange County Sanitation District effluent, discharged roughly 7 km offshore of Huntington Beach, to be transported onshore by internal tides. After the Talbert Marsh was identified as a contributor of FIB to the Huntington Beach surf zone, co-PI Sobsey focused attention on potential health risks associated with water contaminated with bird feces. In particular, marsh bird feces and surface water was examined for *Campylobacter*, *Salmonella,* and male-specific coliphages.

During dry weather, concentrations of FIB were highest in inland urban runoff, intermediate in tidal channels harboring variable mixtures of urban runoff and ocean water, and lowest in ocean water at the base of the watershed. This inland-to-coastal gradient is consistent with the hypothesis that urban runoff from the watershed contributes to coastal pollution. On a year-round basis, the vast majority (> 99%) of FIB loading occurs during storm events when runoff diversions, the management approach of choice, are not operating. During storms, the load of FIB in runoff follows a power law of the form $L \sim Q^n$, where L is the loading rate (in units of FIB per time), Q is the volumetric flow rate (in units of volume per time), and the exponent n ranges from 1 to 1.5. This power law and the observed range of exponent values are consistent with the predictions of a mathematical model that assumes FIB in storm runoff originate from the erosion of contaminated sediments in drainage channels or storm sewers. (Reeves, et al., 2004)

During dry weather periods, urban runoff controls surface water concentrations of FIB in channels where flushing is weak, and resuspension of FIB from the sediment/water interface controls surface water concentrations near the mouth where flushing by ocean water occurs once per day. The reservoir of FIB at the sediment/water interface is probably linked to settling of bacteria from both dry and wet weather urban runoff, deposition of animal feces, decaying vegetation, and bacterial regrowth. It is not clear whether the FIB are primarily attached to sediments, suspended in pore water, or incorporated into microbial biofilms. Nevertheless, surface water concentrations of FIB are rapidly amplified as turbulence in water column increases. A result is that dry weather urban runoff has little direct impact on surf zone water quality, but significant indirect impact given FIB loads from runoff accumulate at the sediment/water interface and are subsequently resuspended and exported to the surf-zone by tidal currents (Grant, et al., 2001; Arega and Sanders, 2004; Sanders, et al., 2004).

During the project period, dry-weather diversions of urban runoff to the sanitary sewer system were implemented to mitigate impacts to the surf-zone, at a cost of at least $6 million to the County of

Orange and City of Huntington Beach. The efficacy of this approach is unclear, because the vast majority of watershed loads are shed during wet weather, whereas during dry weather, the tidal channels and marsh serve to dissipate loads by promoting die-off and settling. On the other hand, diversions presumably serve to reduce loads of other contaminants, including oil, grease, heavy metals, and so forth and, therefore, may be justified on these grounds. To evaluate whether the diversions are justified on the basis of FIB control, a better understanding of the cycling of FIB in sediments is needed. The alternative is to focus management efforts on wet weather controls. For example, if erosion of sediments is driving the loading of FIB, then regular removal of contaminated sediments accumulating in the storm sewer system might be an appropriate management strategy. The creation of distributed wetland treatment systems, in which contaminants in urban runoff are removed near their source, might also prove useful for reducing downstream impacts (Reeves, et al., 2004).

Research lead by PI Sanders shows that numerical modeling can be performed to predict FIB loads in tidal wetlands, analytes that are notoriously difficult to model because of poorly characterized non-conservative processes. The key parameters needed for accurate predictions of FIB loads, using a validated hydrodynamic model, are: (1) the load as a result of urban runoff; (2) sediment erodibility parameters; and (3) sediment concentrations and surface water die-off rates of enteric bacteria. For channels in the Talbert Watershed, literature values for sediment erodibility and water column die-off rates were used and average concentrations of indicator bacteria were predicted within one-half log unit of measurements. Total coliform were predicted more accurately than *E. coli* or enterococci, both in terms of magnitude and tidal variability. This work is important because it represents the first case where first-principle models were successfully applied to predict FIB in an estuarine setting with significant nonpoint sources. The approach adopted here is highly transferable and could benefit both wetland restoration and water quality compliance efforts on a widespread basis (Sanders, et al., 2004).

Plume tracking studies conducted by UC Irvine and UC San Diego researchers, including PI Sanders, show that Orange County Sanitation Department (OCSD) effluent occasionally moves shoreward toward Huntington Beach into water less than 20 m deep. Analyses of current and temperature observations indicate cold water is regularly advected crossshelf, into and out of the nearshore, at both semi-diurnal and diurnal frequencies. Isotherms typically associated with the wastefield near the outfall are observed just outside the Huntington Beach surf zone, where the total depth is less than 6 m, highlighting the extent of the cross-shelf transport. This advection is attributed to a mode 1 internal motion, or internal tide. Based on this analysis, it is not possible to rule out the possibility that the OCSD plume contributes to poor bathing-water quality at Huntington Beach (Boehm, et al., 2002a). Concerned over potential shoreline impacts, OCSD began a disinfection program in 2002 and initiated a roughly $300 million program to build the necessary infrastructure for full secondary treatment.

Analysis of Huntington Beach monitoring data lead by co-PI Grant shows that the concentration of FIB varies over time scales that span at least seven orders of magnitude, from minutes to decades. Sources of this variability include historical changes in the treatment and disposal of wastewater and dry weather runoff, El Niño events, seasonal variations in rainfall, spring-neap tidal cycles, sunlight-induced mortality of bacteria, and nearshore mixing. On average, total coliform concentrations have decreased over the past 43 years, although point sources of shoreline contamination (storm drains, river outlets, and submarine outfalls) continue to cause transiently poor water quality. These transient point sources typically persist for 5 to 8 years and are modulated by the phase of the moon, reflecting the influence of tides on the sourcing and transport of pollutants in the coastal ocean. Indicator bacteria are very sensitive to sunlight; therefore, the time of day when samples are collected can influence the outcome of water quality testing. These results demonstrate that coastal water quality is forced by a complex combination of local and external processes and raise questions about the efficacy of existing marine bathing water monitoring and reporting programs (Boehm, et al., 2002b). Further analysis led by co-PI Grant reveals that protocols used to decide whether to post a sign are prone to error. Errors in public notification (referred to here as posting errors) originate from the variable character of pollutant concentrations in the ocean, the relatively infrequent sampling schedule adopted by most monitoring programs (daily to weekly), and the intrinsic error associated with binary advisories in which the public is either warned or not. We derived a probabilistic framework for estimating posting error rates, which at Huntington Beach range from 0 to 41 percent, and show that relatively high sample-to-sample correlations (> 0.4) are required to significantly reduce binary advisory posting errors. Public misnotification of coastal water quality can be reduced by utilizing probabilistic approaches for predicting current coastal water quality, and adopting analog, instead of binary, warning systems (Kim and Grant, 2004).

Research lead by co-PI Sobsey on the potential health risks of bathing water contaminated by bird feces has lead to only preliminary findings. Specifically, *Campylobacter* and male specific coliphages were identified in Talbert Marsh bird feces and in marsh surface waters near the marsh. *Salmonella* was found only in bird feces samples and not water samples. Analysis continues to understand the relationship between microbes in bird feces and surrounding surface waters, and potential health impacts.

Research lead by co-PI Keller indicates that stakeholders share diverse opinions about the causes of beach pollution, the risks to beachgoers, and the responsibility to pay. In the context of a multi-objective decision model, stakeholders disagree on the appropriate weights of objectives. For example, local businesses heavily weigh economics whereas beachgoers heavily weigh health risks. Stakeholders also disagree on the severity of pollution problems. For example, environmentalists believe the probability of an environmental health problem is high when beaches are posted, but beachgoers do not. Relative to beachgoers' perceptions of potential health risks, surveys showed a peer effect: decisions to enter the water at posted beaches were strongly affected by whether or not others were in the water (Biswas and Keller, 2004; Biswas, et al., 2004).

Conclusions:

The vast majority of FIB loads in runoff from the Talbert Watershed are shed during storms and are associated with particles that appear to be scoured from the water collection system, including street gutters, storm pipes, and storm channels. Loads in runoff during dry weather periods account for roughly 1 percent of the annual runoff load and dissipate within the tidal channels by a combination of die-off and settling.

Loads exported from the watershed to the surf zone during dry weather period are deflected along the shoreline by wave driven currents and can cause exceedances of water contact recreation standards. Model predictions show the origin of such loads is the scouring by tidal currents of FIB at the sediment/water interface of tidal channels and Talbert Marsh. FIB at the sediment/water interface are linked to urban runoff FIB loads during both dry and wet weather periods, bird droppings, decaying vegetation, and bacterial regrowth. Because intertidal wetlands are to some extent natural generators of FIB, these results call into question the exclusive use of FIB as the basis of water contact recreation standards at beaches near the outlet of these water bodies.

On the basis of FIB control, the efficacy of dry weather diversions in Talbert Watershed is unclear, although diversions presumably serve to mitigate other types of pollution as well. A better understanding of the cycling of FIB between the water column and sediments is needed to evaluate the linkages between wet weather and dry weather loads in relation to sediment interactions.

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Type	Citation	Project	Document Sources
Journal Article	Arega F, Sanders BF. Dispersion model for tidal wetlands. *Journal of Hydraulic Engineering* 2004;130(8):739-754.	R828011 (Final)	
Journal Article	Boehm AB, Sanders BF, Winant CD. Cross-shelf transport at Huntington Beach. Implications for the fate of sewage discharged through an offshore ocean outfall. *Environmental Science & Technology* 2002;36(9):1899-1906	R828011 (2001) R828011 (Final)	• Full-text: ACS Publications Full Text EXIT Disclaimer • Other: ACS Publications PDF EXIT Disclaimer
Journal Article	Grant SB, Sanders BF, Boehm AB, Redman JA, et al. Generation of enterococci bacteria in a coastal saltwater marsh and its impact on surf zone water quality. *Environmental Science and Technology* 2001;35(12):2407-2416.	R828011 (2000) R828011 (2001) R828011 (Final)	not available
Journal Article	Reeves RL, Grant SB, Mrse RD, Copil-Oancea CM. Scaling and management of fecal indicator bacteria in runoff from a coastal urban watershed in southern California. *Environmental Science & Technology* 2004;38(9):2637-2648.	R828011 (Final)	• Full-text: ACS Full Text EXIT Disclaimer • Other: ACS PDF EXIT Disclaimer
Journal Article	Sanders BF, Arega F, Sutula M. Modeling the dry-weather tidal cycling of fecal indicator bacteria in surface waters of an intertidal wetland. *Water Research*. 2005;39(14):3394-3408.	R828011 (Final)	

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Progress and Final Reports:
2000 Progress Report
2001 Progress Report
Original Abstract

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Bird Droppings Are Blamed for Bacteria

By Stanley Allison June 02, 2001 in print edition B-9

A team of UC Irvine researchers has concluded that waterfowl and other animal droppings from a saltwater marsh and the Santa Ana River are a significant source of bacteria contaminating the ocean waters off Huntington Beach.

In a report that will be published in the June 15 issue of Environmental Science and Technology, the researchers point to inherent flaws in the design of the man-made saltwater Talbert Marsh.

Stanley Grant, the UCI professor who led the 18-month study of the ocean contamination problem at Huntington Beach, said water containing fecal bacteria, pesticides, nutrients and other materials filters through the marsh and then flows into the ocean in about 40 minutes– which is too fast.

For the marsh to act as a natural cleanser and remove contaminants, the water must spend at least a week filtering through the wildlife preserve, Grant said.

Even though other sources such as urban runoff from the Santa Ana River may have contributed to the contamination that resulted in four miles of beach closures for most of the summer of 1999, the levels of bacteria from the marsh were hundreds of times more than the state limits, the researchers said.

The team's conclusions contradict the accepted environmental theory that wetlands purify contaminated water flowing into the ocean.

The findings suggest that approximately 4.6 million saltwater marshes in the U.S. could be similarly affected, Grant said.

Mark Gold, a spokesman for the conservation group Heal the Bay, said that finding animal droppings in a nature preserve is nothing new, and insists that marshes still serve as a cleanser for other, more hazardous, contaminates.

"It's not surprising that wetlands are sources of fecal bacteria," Gold said. "What wetlands are great at doing is removing nutrients and metals."

The 25-acre wetlands preserve is on the inland side of Pacific Coast Highway at Brookhurst Street. Part of the Talbert watershed that encompasses 12 square miles in Huntington Beach and Fountain Valley, it attracts thousands of migratory birds and other wildlife each year.

The UCI researchers also say that the nearby AES power plant contributes to the shore's contamination. The study suggests that partly treated sewage released four miles offshore from the Orange County Sanitation District treatment plant is being pulled back to the shore by tides and the plant as it draws water to cool its towers.