Efficacy of shallow water sampling to determine exposure of surfers to indicator bacteria at marine beaches

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Abstract

Beach water quality monitoring in southern California is extensive, but samples are collected in shallow water (0.3 m) because breaking waves make sampling in deeper water inconvenient and potentially dangerous. To assess how well shallow water sampling characterizes conditions in deeper waters, we collected paired enterococci samples at the shallow depth where sampling typically occurs, and outside the breaking surf offshore, where surfers typically line up to catch surfable waves. Sampling was conducted at 12 beaches in the summer dry season and 9 beaches following winter rainstorms. Beaches selected for study all had a flowing freshwater creek, surfers present at the site and a history of microbial water quality standards exceedences. Seven pairs of samples at different distances from the freshwater outlets were collected at all beaches. The nearshore and offshore samples were correlated during both the wet and dry sampling periods, but the correlation was higher following rainstorms. Concentrations of enterococci were typically higher in shoreline samples than offshore samples, with the difference being nearly three-fold under dry conditions and only 25% higher under wet conditions. For only one sample pair in dry weather and three sample pairs during wet weather, constituting less than 1% of total samples, did shoreline samples meet water quality standards when a corresponding offshore sample failed the standard.

Introduction

Beach water quality in Southern California is the most intensively monitored in the nation. Over 185,000 water samples are collected and analyzed each year during routine shoreline monitoring at a yearly cost of more than $3 million (Schiff *et al*. 2001). This investment reflects the importance of beaches to the local economy and to the more than 175 million beachgoers that visit southern California beaches each year (Schiff *et al*. 2001).

All shoreline water quality monitoring occurs at a depth of about 0.3 m, as breaking waves make sampling in deeper water inconvenient and potentially dangerous. This is also the depth of exposure for small children, who are the most immunologically susceptible swimmers. The 0.3-m depth is also sampled because it is where sampling was conducted during the primary epidemiology study on which California's water quality standards are based (Haile *et al*. 1999).

It is unclear how well sampling at this depth protects surfers, who receive much of their exposure at locations typically 20 m or more offshore. Surfers are often avid users of recreational waters and among the most vulnerable to waterborne illnesses because of repeated, substantial (head to toe), and sudden exposure. Compounding this exposure, prime surfing locations are often found at the mouths of creeks and rivers where sand bars formed by sediment deposition cause waves to break farther offshore, offering surfers a longer ride. These channels serve as drains that carry urban runoff to the ocean, causing the waters at their outlets to be some of the most contaminated along the beach (Noble *et al*. 2000, 2003; Schiff *et al*. 2003; Jiang *et al*. 2001).

Here we examine the relationship between the microbial water quality of samples taken at the 0.3-m depth and water quality of samples obtained offshore, where surfers typically line up to catch surfa-

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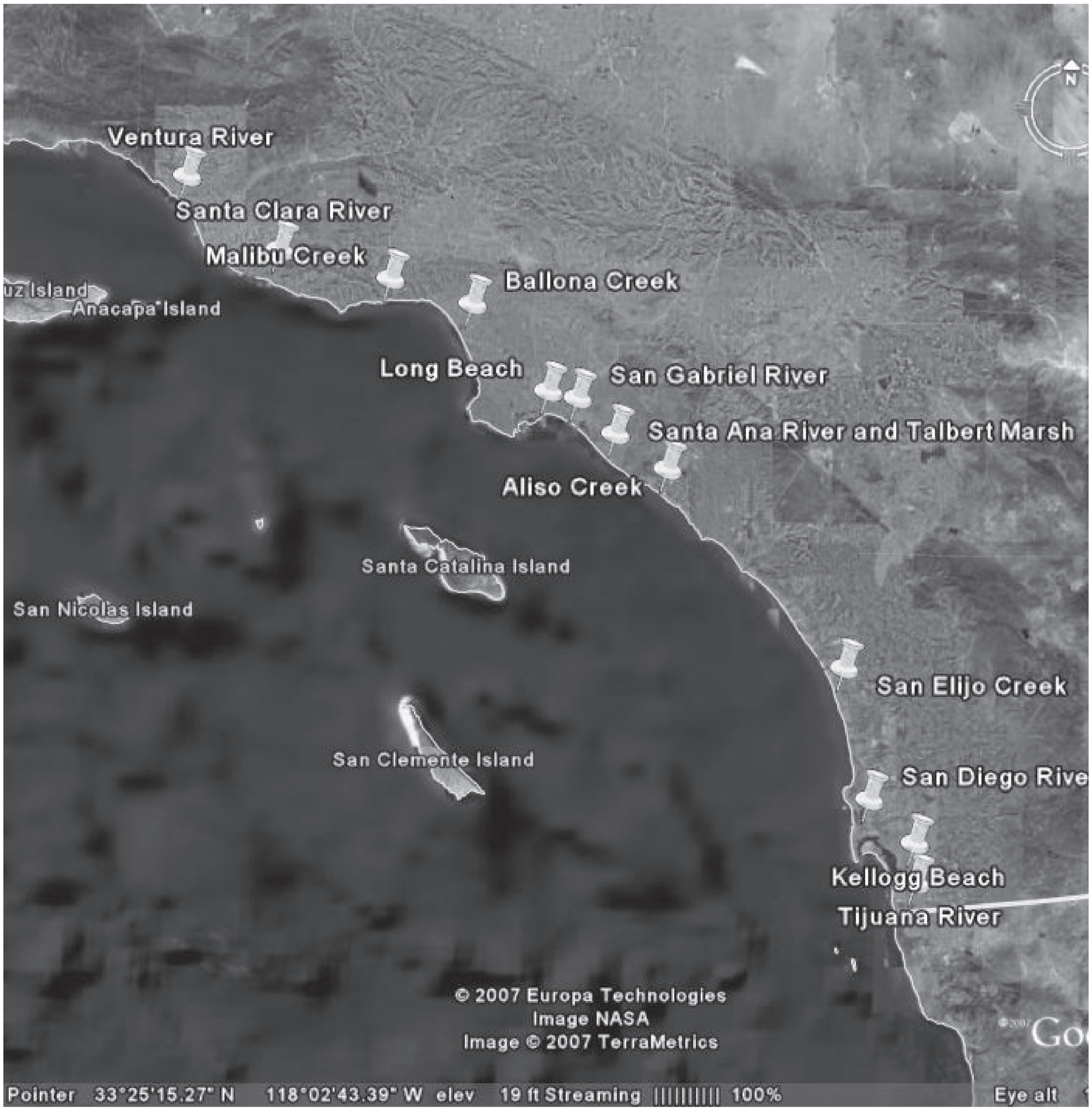

Figure 1. Map of sampling locations.

ble waves. The goal of the study was to determine if samples taken along the shoreline adequately characterize microbiological water quality in deeper waters where surfers receive the majority of their exposure.

METHODS

The study involved paired sampling at shoreline (ankle to knee depth) and offshore (just below the surface in the surfer setup zone) sites near 12 different freshwater outlets (Figure 1). Beaches included in the study were selected based on the following criteria: a) presence of a river or creek flowing across the beach; b) presence of surfers at the site; and c) a significant number (>20% of samples) of microbial water quality standards exceedences in the historical shoreline monitoring.

The first set of sampling events occurred in September 2003, southern California's dry season. One hundred and fourteen pairs of shoreline/offshore samples were collected. Shoreline samples were collected directly in front of each freshwater outlet, from a bridge overlooking the center of the outlet, and from locations at distances of 25, 50, 75, and 225 meters up coast and down coast of the channel. Offshore samples at these same distances were collected either by swimmers, from kayaks, or from personal watercraft directly offshore at the point where surfers were waiting or would typically wait for a surfable wave. Sampling took place at high tide and was repeated at nine of the beaches (Table 1) on the subsequent low tide. Visual cues were used

Table 1. Dry weather sampling sites. Check marks denote when samples where taken in relation to the tidal cycle.

	Ventura River	Santa Clara River	Malibu Creek	Ballona Creek	San Gabriel River	Santa Ana River	Talbert Marsh	Aliso Creek	San Elijo Creek	San Diego River	Kellogg Beach	Tijuana River
High Tide	•	•	•	•	•	•	•	•	•	•	•	•
Low Tide	•	•	•			•	•	•		•	•	•

so that both shoreline and offshore samples were collected simultaneously.

A second set of samplings occurred between February 24 and March 26, 2004, following storm events (>0.1” rain). One hundred and forty two pairs of wet weather samples were collected at nine of the twelve beaches for up to three days following storm events (Table 2). As in dry weather, wet weather samples were collected from the wavewash in front of each creek mouth or from a bridge overlooking the channel, and at specific intervals upcoast and downcoast of the discharge. Unlike dry weather, however, the location of upcoast and downcoast sampling was not fixed. Instead, gradient distances surrounding each freshwater outlet were dictated by the geographic characteristics of each site, the volume of stormwater discharged, and the extent of the discharge plume.

All samples were collected in duplicate in sterile 120-ml polystyrene bottles and transported to local laboratories on ice. Enterococci were enumerated using Enterolert™ (IDEXX Westbrook, ME) defined substrate kits following the manufacturers instructions, or using membrane filtration and EPA Method 1600 (Messer and Dufour 1998). Several agencies also analyzed samples for total coliform, fecal coliform, or *Escherichia coli*; however, enterococci was the only indicator analyzed in all samples at all locations.

Ten local laboratories participated in sample collection and analysis (Table 3), which was necessary to ensure sample holding time requirements were met. Prior to sampling, all laboratories participated in an intercalibration exercise to ensure comparability (Griffith *et al*. 2006). The among laboratory variability was not significantly different from within laboratory variability.

Enterococci data were analyzed in two ways. First, regression was conducted to assess the relationship between paired samples collected along the shore with those collected at the surfer line-up depth offshore. Second, contingency tables were constructed to determine the relative frequency with which pairs of samples produced the same results with respect to the California single-sample water quality standard of 104/100ml for enterococci.

Table 2. Wet weather sampling sites and dates sampled.

	Ballona Creek	Aliso Creek	Santa Ana River	Talbert Marsh	San Gabriel River	Kellogg Beach	San Elijo	San Diego River	Tijuana River
2/24/2004						•	•	•	•
2/27/2004	•	•	•	•	•				
2/28/2004	•	•	•	•	•	•	•	•	•
2/29/2004						•		•	•
3/1/2004	•	•	•	•	•		•		
2/13/2005									•
2/14/2005									•
2/15/2005									•
3/24/2005	•		•	•	•				
3/25/2005			•	•	•				
3/26/2006	•								

Table 3. Laboratories that participated in sample collection and analysis.

Sample Location	Analysis Laboratory
Ventura River	City of Oxnard, Ventura County Environmental Health
Santa Clara River	City of Oxnard, Ventura County Environmental Health
Malibu Creek	City of Los Angeles Environmental Monitoring Division
Ballona Creek	Loyola Marymount University
San Gabriel River	Orange County Sanitation District
Santa Ana River	Orange County Sanitation District
Talbert Marsh	Orange County Sanitation District
Aliso Creek	South Orange County Water Authority, County of Orange Public Health Laboratory
San Elijo Creek	Encina Waste Water Authority, San Elijo Joint Powers Authority*
San Diego River	Marine Environmental Consulting Analytical Systems Inc.
Kellogg Beach	Marine Environmental Consulting Analytical Systems Inc.
Tijuana River	City of San Diego

RESULTS

The relationship between shoreline and offshore enterococcus concentrations during dry weather period was significant, but accounted for only 21% of the variability (Figure 2). Nearly 95% of samples collected at the shoreline during dry weather met water quality standards, with average concentrations along the shoreline more than five times greater than concentrations directly offshore at some sites (Figure 3). This was also reflected in the concordance analysis, where five samples collected at the shoreline exceeded water quality standards, compared to only a single sample exceeding at the offshore sites (Table 4).

The relationship between shoreline and offshore samples was stronger for wet weather than dry weather samples, with shallow samples accounting for 52% of the variability observed in offshore samples (Figure 3). As in dry weather, shoreline samples were higher than offshore, but differences were more extreme in winter (Figure 4). Forty-five percent of wet weather samples exceeded water quality standards and about two-thirds of those simultaneously exceeded standards in shoreline and offshore pairs (Table 5). There were only three samples in which the offshore sample exceeded standards when the shallow sample did not, whereas there were 21 that exceeded onshore but not offshore.

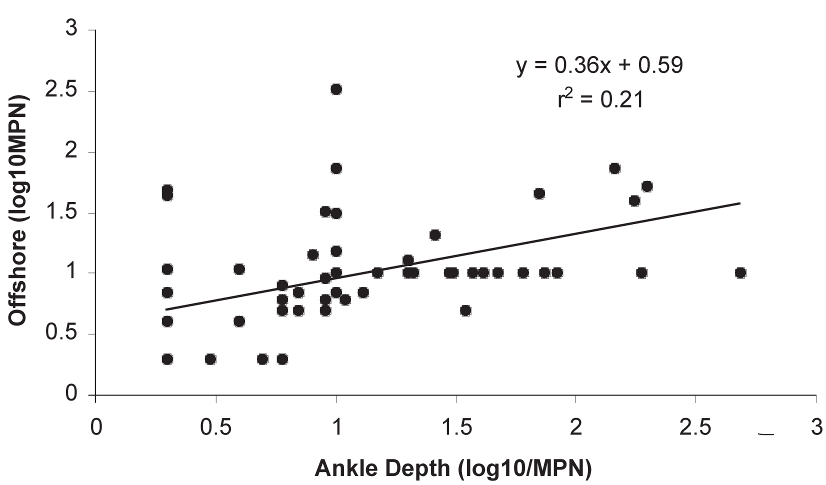

Figure 2. Regression plot for dry weather samples.

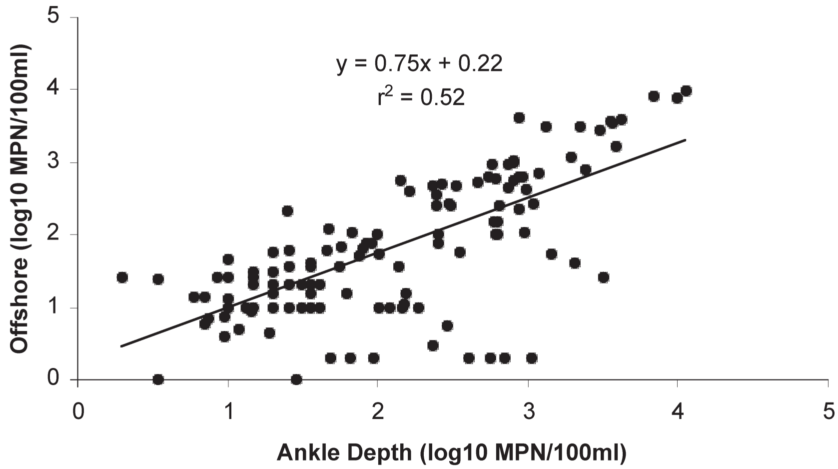

Figure 3. Regression plot for wet weather samples.

Discussion

Water samples taken in shallow shoreline waters were found to be protective of health risk to swimmers and surfers who are exposed to water quality offshore of the sampling site. In only a few cases (<1% in dry weather, <2% in wet weather) did shoreline samples meet water quality standards when a corresponding offshore sample failed standards. In contrast, about 7% of the offshore samples met standards when the corresponding shoreline samples failed standards. This suggests that shallow water sampling may be overprotective. However, surfers are also exposed to water closer to shore when they paddle out from shore or finish their ride by either intentionally dismounting or unintentionally falling from their boards.

Table 4. Percent agreement regarding the California single-sample water quality standard of 104/100 ml for enterococci between samples taken simultaneously during dry weather at shoreline depth and in the surf-zone where surfers line-up.

		Offshore	
		Below Standard	Above Standard
Shoreline	Below Standard	94.7%	0.9%
	Above Standard	4.4%	0.0%

This is not the first study to compare density of fecal indicator bacteria in waters of different depth, though this is the first to specifically examine the depths and locales populated by surfers. Wymer *et al*. (2005) observed that indicator bacteria densities declined with distance from shore up to chest depth. Similarly, in a study of two Lake Erie beaches, Francy *et al*. (2006) found that concentrations of *E. coli* were highest at one and two-foot depths, mid-range at waist depth, and lowest in samples collected 150 feet offshore.

The higher bacterial concentrations observed inshore probably reflect the greater proximity to the urban runoff drainage systems that are the principal source of fecal indicator bacteria for southern California beaches (Schiff *et al*. 2003). Flows from these creeks during dry weather are generally small relative to longshore transport. Grant *et al*. (2005) found that along-shore flux is about 100 times greater than cross-shelf flux. Several dye studies have shown that the creek water typically remains entrained in a narrow band parallel to shore, with only occasional offshore excursions associated with riptides (Kim *et al*. 2004, Grant *et al*. 2005, Rosenfeld *et al*. 2006, Clarke *et al*. 2007). Moreover, Taggart (2002) found that bacterial concentrations generally diluted an order of magnitude within 100 m from a freshwater outlet during low flow. This contrasts, however, with wet weather conditions, when freshwater flows increase substantially and the predominant transport of stormwater plumes is cross-shelf (Warrick *et al*. In press). This

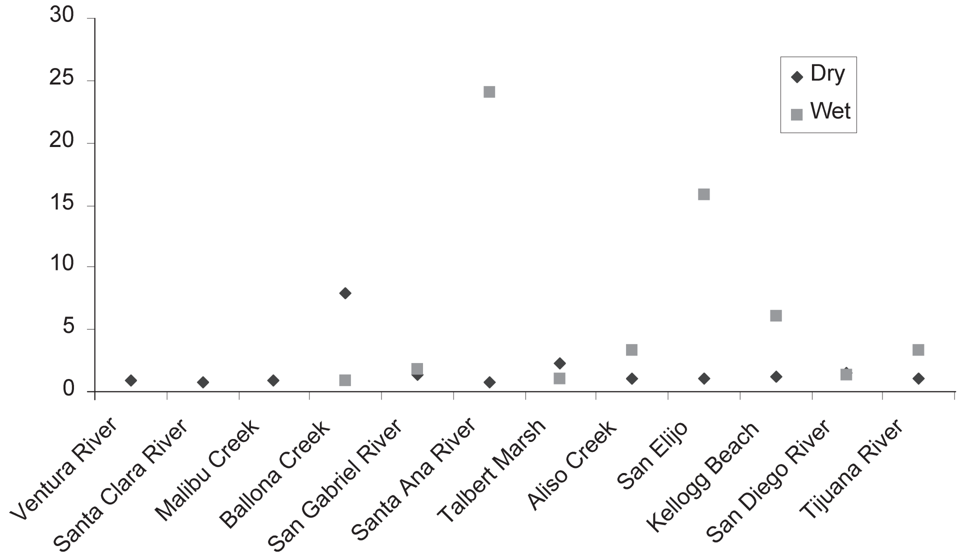

Figure 4. Ratio of average enterococci concentrations in shoreline samples relative to those offshore in wet and dry weather.

would account for the much smaller onshore-offshore differences in bacterial concentrations that we observed in wet weather.

Despite our finding that indicator bacteria levels are typically higher in shallow water than offshore, it is unclear whether surfers receive a higher level of protection than do shallow-water bathers. The water quality standards and associated warning system are based on epidemiology studies which focused on individuals who swam only once during a potential incubation period (approximately two weeks). Surfers often surf multiple times a week and their exposure is more substantial than the typical bather due to pushing under waves to paddle out and occasional wipeouts (falling off a surfboard). This higher exposure than has been quantified in epidemiology studies may require a lower bacterial concentration threshold for issuing warnings in order to achieve the same level of protection for surfers. However, additional epidemiology studies that focus on multiple exposure swimmers would be necessary to establish an appropriate bacterial level that is protective of health risks to surfers.

Table 5. Percent agreement regarding the California single-sample water quality standard of 104/100 ml for enterococci between samples taken simultaneously during wet weather at shoreline depth and in the surfzone where surfers line-up.

		Offshore	
		Below Standard	Above Standard
Shoreline	Below Standard	54.9%	2.1%
	Above Standard	14.8%	28.2%

Literature Cited

Clarke, L.B., D. Ackerman and J. Largier. 2007. Dye dispersion in the surf zone: measurements and simple models. *Continental Shelf Research* 27:650-669.

Francy, D.S., E.E. Bertke, D.P. Finnegan, C.M. Kephart, R.A. Sheets, J. Rhoades and L. Stumpe. 2006. Use of spatial sampling and microbial source-tracking tools for understanding fecal contamination at two Lake Erie beaches. US Geological Survey Scientific Investigations Report 2006–5298. USGS. Columbus, OH.

Grant S.B., J.H. Kim, B.H. Jones, S.A. Jenkins, J. Wasyl and C. Cudaback. 2005. Surf zone entrainment, along-shore transport, and human health implications of pollution from tidal outlets. *Journal of Geophysical Research* 110:C10025. doi:10.1029/2004JC002401.

Griffith, J.F., L.A. Aumand, I.M. Lee, C.D. McGee, L.L. Othman, K.J. Ritter, K.O. Walker and S.B. Weisberg. 2006. Comparison and verification of bacterial water quality indicator measurement methods using ambient coastal water samples. *Environmental Monitoring and Assessment* 116:335-344.

Haile, R.W., J.S. Witte, M. Gold, R. Cressey, C.D. McGee, R.C. Millikan, A. Glasser, N. Harawa, C. Ervin, P. Harmon, J. Harper, J. Dermand, J. Alamillo, K. Barrett, M. Nides and G. Wang. 1999. The health effects of swimming in ocean water contaminated by storm drain runoff. *Journal of Epidemiology* 104:355-363.

Jiang, S.C., R. Noble, W. Chu. 2001. Human adenoviruses and coliphage in urban runoff-impacted coastal waters of southern California. *Applied and Environmental Microbiology* 67:179-184.

Kim, J.A., S.B. Grant, C.D. McGee, B.F. Sanders and J.L. Largier. 2004. Locating sources of surf zone pollution: A mass budget analysis of fecal indicator bacteria at Huntington Beach, California. *Environmental Science and Technology* 38:2626-2636.

Messer, J.W. and A.P. Dufour. 1998. A rapid specific membrane filtration procedure for enumeration of enterococci in recreational water. *Applied Environmental Microbiology* 64:678-680.

Noble, R., J. Dorsey, M. Leecaster, V. Orozco-Borbon, D. Reid, K. Schiff and S. Weisberg. 2000. A regional survey of the microbiological water quality along the shoreline of the southern California bight. *Environmental Monitoring and Assessment* 64:435-447.

Noble, Rachel T., S.B. Weisberg, M.K. Leecaster, C.D. McGee, J.H. Dorsey, P. Vainik and V. Orozco-Borbon. 2003. Storm effects on regional beach water quality along the southern California shoreline. *Journal of Water and Health* 1:23-31.

Rosenfeld, L.K., C.D. McGee, G.L. Robertson, M.A. Noble and B.H. Jones. 2006. Temporal and spatial variability of fecal indicator bacteria in the surf zone off Huntington Beach, CA. *Marine Environmental Research* 61:494-510.

Schiff, K.C., J. Morton and S.B. Weisberg. 2003. Retrospective evaluation of shoreline water quality along Santa Monica Bay beaches. *Marine Environmental Research* 56:245-253.

Schiff K., J. Dorsey, and S. Weisberg. 2001. Marine microbiological monitoring in the southern California Bight. *Environmental Management* 27:149-157.

Taggart, M. 2002. Oceanographic and Discharge Factors affecting Shoreline Fecal Bacteria Densities around Storm Drains and Freshwater Outlets at Marine Beaches. School of Public Health, University of California. Los Angeles, CA.

Warrick, J.A., P. DiGiacomo, S.B. Weisberg, N. Nezlin, M. Mengel, B. Jones, C. Ohlmann, L. Washburn and E. Terrill. In press. River plume patterns and dynamics within the Southern California Bight. *Continental Shelf Research*.

Wymer, L.J., A.P. Dufour, K.P. Brenner, J.W. Martinson, W.R. Stutts and S.A.Schaub. 2005. The EMPACT Beaches Project; Results from a study on microbiological monitoring in recreational Waters. EPA 600/R-04/023. United States Environmental Protection Agency. Washington, DC.

California Bight 1998 Regional Monitoring Program. Technical Report 386. Southern California Coastal Water Resource Project. Westminster, CA. www.sccwrp.org.

Suren, A.M. and S. McMurtrie. 2005. Assessing the effectiveness of enhancement activities in urban streams: II. Responses of invertebrate communities. *River Research and Applications* 21:439-453.

US Environmental Protection Agency (USEPA). 2002. Research Strategy: Environmental Monitoring and Assessment Program. USEPA Office of Research and Development. http://www.epa.gov/emap/html/pubs/docs/resdocs/restrat02.html.

USEPA. 2006a. Aquatic Resources Monitoring Web Site. http://www.epa.gov/nheerl/arm/.

USEPA. 2006b. Aquatic Resources Monitoring – Design. http://www.epa.gov/nheerl/arm/designpages/monitdesign/sample_size.htm.

USEPA. 2007. Environmental Monitoring and Assessment Program. http://www.epa.gov/emap/.

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