
Storm effects on regional beach water quality along the southern California shoreline

Rachel T. Noble¹, Stephen B. Weisberg,
Molly K. Leecaster², Charles D. McGee³,
John H. Dorsey⁴, Patricia Vainik⁵, and
Victoria Orozco-Borbon⁶

ABSTRACT - Two regional studies conducted during dry weather demonstrated that the Southern California Bight (SCB) shoreline has good water quality, except near areas that drain land-based runoff. Here, we repeat those regional studies 36 h after a rainstorm to assess the influence of runoff under high flow conditions. Two hundred and fifty-four shoreline sites between Santa Barbara, California, and Ensenada, Mexico, were sampled using a stratified-random sampling design with four strata: sandy beaches, rocky shoreline, shoreline adjacent to urban runoff outlets that flow intermittently, and shoreline adjacent to outlets that flow year-round. Each site was sampled for total coliforms, fecal coliforms (or *E. coli*), and enterococci. Sixty percent of the shoreline failed water quality standards after the storm compared to only 6% during dry weather. Failure of water quality standards increased to more than 90% for shoreline areas adjacent to urban runoff outlets. During dry weather, most water quality failures occurred for only one of the three bacterial indicators and concentrations were barely above State of California standards; following the storm, most failures were for multiple indicators and exceeded State of California standards by a large margin. The condition of the shoreline in Mexico and the United States was similar following rainfall, which was not the case during dry weather.

INTRODUCTION

Land-based runoff is increasingly being recognized as a source of fecal bacteria and a public health concern at swimming beaches. Noble *et al.* (2000) found that 60% of the Southern California Bight (SCB) shoreline areas receiving urban runoff fail State of California water quality standards. Lipp *et al.* (2001a) demonstrated that the highest indicator bacteria concentrations in Charlotte Harbor, Florida, occur at sites near where urban streams enter the estuary. Mallin *et al.* (2000) found that fecal coliform concentrations in South Carolina were directly correlated with the percent of impervious surface in the watershed. Human viruses are consistently found in southern California's urban runoff (Jiang *et al.* 1999, Noble and Fuhrman 2001), and Haile *et al.* (1999) demonstrated that illness rates in swimmers more than double when swimming at beaches near urban runoff outlets.

The effect of urban runoff on beach water quality is even more severe following rain events. More than half of the beach water quality failures in Santa Monica Bay, California, are associated with rain events, even though it typically rains less than 15 d per year (Schiff *et al.* in press). Several researchers have found significant correlations between beach bacterial concentration and river discharge (Solo-Gabrielle 2000, Dwight *et al.* 2002). Rainfall effects are also apparent on an interannual basis as both Lipp *et al.* (2001b) and Boehm *et al.* (2002) have demonstrated higher beach bacterial concentrations during El Niño years.

While these studies have demonstrated increases in bacterial concentration associated with wet-weather runoff, they are mostly based on integrating existing public health monitoring data, which are focused on high-use beaches and not designed to

¹UNC-Chapel Hill Institute of Marine Sciences, 3431 Arendell St., Morehead City, NC 28557

²Idaho National Environment and Engineering Laboratory, 2525 N. Fremont Ave. Idaho Falls, ID 83415-3779

³Orange County Sanitation District, 10844 Ellis Ave., Fountain Valley, CA 92708

⁴Loyola Marymount University, 1 LMU Drive, North Hall, Los Angeles, CA 90045-2659

⁵City of San Diego Metropolitan Wastewater Dept., 4918 North Harbor Dr., San Diego, CA 92106

⁶Institute de Investigaciones Oceanologicas, Universidad Autonoma de Baja California, Km. 103 Carretera Tijuana-Ensenada, Ensenada, Mexico

assess the spatial extent of stormwater influence. The question of spatial extent is particularly important in southern California, where the rainfall influence on beach water quality is perceived as severe enough that the health departments routinely issue warnings to avoid recreational water contact for at least 3 d following a storm. Here, we present a survey in which 1000 km of the SCB shoreline was synoptically sampled the day after a storm to assess the spatial influence of rainfall on regional water quality.

METHODS

Samples were collected along the shoreline of the SCB at 254 sites between Point Conception, California, and Punta Banda, Mexico. All sites were sampled between 0600 and 1000 on February 22, 2000, approximately 36 h after a storm that deposited ca. 3-7 cm of precipitation over the entire study region. These were the same sites sampled by Noble *et al.* (1999, 2000) during two previous dry-weather regional water quality surveys along the shoreline of the SCB. These sites were selected using a stratified random approach, with strata corresponding to four shoreline types: sandy beach, rocky shoreline, perennial urban runoff outlets, and ephemeral urban runoff outlets. Although the basic sample allocation scheme was stratified random, a systematic component was added to minimize clustering of sample sites along the shore. This was accomplished using an extension of the National Stream Survey sampling design of Messer *et al.* (1986) and Overton (1987). The term "urban runoff outlets" is used to describe storm drains, creeks, and rivers that contribute freshwater/stormwater inputs to the coastal Pacific Ocean. A total of 81 urban runoff outlets that convey 99% of the total freshwater input to the SCB were identified and differentiated as perennial or ephemeral based upon whether water flowed year-round or seasonally. Sample sites within the perennial and ephemeral water outlet strata were selected using two methods. First, sites were selected at a random distance within 100 yards of the mouth of the outlet (random sites). Second, a site was placed on the beach at a location as close to the mouth of the outlet as possible (referred to as the point zero site). At the perennial urban runoff outlets, random sites were placed around 39 of the 40 outlets, and point zero sites were placed at 30 of the 40 perennial outlets. At the ephemeral outlets, 36 random sites and 29 point zero sites were sampled from the 41 possible systems.

Samples were collected in sterile sample bottles or Whirl-Pak bags from ankle-deep water on an incoming wave just prior to receding, with the sampler positioned downcurrent from the bottle and the mouth of the bottle facing into the current. After the sample was taken, the bottle was tipped to decant enough sample to ensure 2 to 5 cm of airspace in the sample bottle. The bottle was then tightly capped, stored on ice in the dark, and returned to the laboratory in time to begin analysis within 6 h of sample collection. All samples were tested for total coliforms (TC), fecal coliforms (FC), and enterococci (EC). Collection and processing of samples in a short period was accomplished through cooperative efforts of 21 organizations that conduct routine monitoring of southern California's beaches. Each participating laboratory used their established analytical methods for sampling processing, which include membrane filtration (MF), multiple tube fermentation (MTF), and the defined substrate technology test kits Colilert® and Enterolert® (IDEXX Laboratories, Inc., Portland, ME). All analyses were performed using techniques as outlined in Standard Methods (American Public Health Association 1995) or following the manufacturer's instructions. Comparability among laboratories and among methods was confirmed prior to the study through a series of intercalibration studies (Noble *et al.*, in press). To enhance reliability of comparisons between studies conducted during wet and dry conditions, each laboratory processed samples from the same sites, as they did in the two previous dry-weather regional surveys (Noble *et al.* 1999, Noble *et al.* 2000).

The assessment of shoreline condition focused on estimating the percent of shoreline miles that exceeded a threshold of concern. The State of California daily single-sample water quality standards for TC, FC, EC, and the TC:FC ratio (Table 1) were used as thresholds. The percent of shoreline exceeding the thresholds was estimated for each stratum and for the shoreline as a whole using a ratio estimator (Thompson 1992).

RESULTS

The rainfall event that preceded sampling deposited between 2.5 and 7.0 cm throughout the study area, with the highest quantity measured near the Los Angeles-Ventura county border (Table 2). Duration of the rainfall event averaged 39 h. A smaller storm that produced rainfall quantities between 0.1 and 1.25 cm preceded this storm event by 3 d.

Table 1. Single sample daily bacterial indicator thresholds used in the study.

Indicator	Daily Limits (cfu or MPN per 100 mL)
Total Coliforms	10,000
Fecal Coliforms	400
Enterococci	104
Total Coliform Fecal Coliform Ratio	When total coliforms are >1,000, and TC FC ≤ 10

Table 2. Rainfall quantity (in centimeters) and duration for the storm sampled during the Storm Study (2/20/00–2/21/00). Also included is antecedent rainfall information.

Location	Time Rain Started (2/20)	Time Rain Stopped (2/21)	Duration of Storm (hours)	Rainfall (cm)	Days Since Last Rain	Rainfall from Most Recent Storm (cm)	Duration of Most Recent Storm (hours)
San Ysidro	6:00 am	9:00 pm	40	7.19	3	0.41	9
Plaza Bonita Rd.	6:00 am	4:00 am*	47	3.91	2.5	0.41	23
Fashion Valley	5:00 am	8:00 pm	40	5.11	3	0.71	23
San Onofre	5:00 am	9:00 pm	41	2.79	3	0.30	21
Encinitas	5:00 am	1:00 am*	46	2.69	3	0.41	14
Carlsbad	5:00 am	12:00 am	44	4.09	3	0.51	21
Oceanside	5:00 am	4:00 pm	36	3.63	3	0.30	15
Santa Ana River	6:00 am	4:00 pm	34	4.09	NA	0.00	
Coyote Creek	6:00 am	3:00 pm	33	3.23	NA	0.00	
Point Vicente	6:00 am	8:00 pm	39	3.91	3	1.30	14
Malibu	7:00 am	5:00 pm	35	5.61	3	1.30	18
Oxnard Airport	5:00 am	11:00 am	31	7.06	3	0.43	14
Ventura	4:00 am	12:00 pm	33	7.21	3	0.84	14
Sea Cliff	4:00 am	12:00 am	45	7.47	3	1.09	13
Lechuza Patrol	6:00 am	12:00 pm	31	7.80	3	1.30	17
Point Hueneme	4:00 am	11:00 am	32	4.75	3	0.33	17
Santa Barbara	4:00 am	3:00 am*	48	6.88	3	0.94	13
UCSB	5:00 am	10:00 pm	42	7.34	>19	0.00	
Overall Range			31-48 hours	2.69-7.8 cm	3 days	0-1.3 cm	9-23 hours

More than half (58%) of the SCB shoreline exceeded at least one of the indicator bacteria thresholds (Table 3). Beach areas immediately in front of perennially flowing urban runoff outlets had the highest frequency of threshold failures (87%). The rocky shoreline stratum had the lowest frequency of failures (34%).

EC was the indicator bacteria that exceeded state water quality standards most often, with nearly 100% of the samples that failed standards exceeding for EC (Table 3). EC exceeded water quality standards at

twice the frequency of FC. Approximately three-quarters of the samples failed water quality standards for more than one bacterial indicator during the Storm Study (Table 4), with nearly 90% of the multiple indicator threshold failures occurring for at least three indicators. The highest frequency of multiple indicator threshold failures occurred at the perennial point zero sites (Table 4).

The vast majority of water quality exceedences, regardless of indicator type, were significantly above the water quality thresholds. Using method-specific

Table 3. Percent of shoreline miles that exceeded State of California water quality standards in the Southern California Bight.

	Enterococci	Fecal Coliforms	Total Coliforms	Total:Fecal Ratio<10	Any Indicator
Ephemeral Point Zero	52	26	11	22	52
Ephemeral	38	13	3	11	38
Rocky	34	19	6	7	34
Sandy	59	42	31	18	62
Perennial	67	28	20	17	67
Perennial Point Zero	87	43	33	30	87
All SCB	56	36	24	16	58

Table 4. Percent of shoreline that exceeded single or multiple bacterial indicator standards.

	Any Indicator	Only 1 Indicator	Any 2 Indicators	Any 3 Indicators	All 4 Indicators
Ephemeral Point Zero	52	19	11	19	4
Ephemeral	38	13	14	8	3
Rocky	34	8	19	4	5
Sandy	62	14	10	33	5
Perennial	67	29	13	18	8
Perennial Point Zero	87	40	3	27	17
All SCB	58	15	12	26	5

estimates of laboratory variability developed during the intercalibration exercise (Noble *et al.* in press), we found that 77% of the samples exceeding water quality standards for EC did so by more than one standard deviation of measurement error. Similarly, 42% and 53% of the TC and FC failures exceeded the standard by more than a standard deviation of measurement error.

The failure of California's water quality standards along the Mexican shoreline was similar to that found in the United States (Table 5). For example, 63% and 66% of the shoreline along beaches failed the EC threshold in Mexico and the United States, respectively. Median indicator concentrations of samples that failed standards were also similar between the United States and Mexico, except for FC. FC concentrations were noticeably lower in the United States at both urban runoff outlets and beaches (Table 6).

DISCUSSION

Non-point runoff concerns are exacerbated in southern California because its rivers are highly modified stormwater conveyance systems that are independent of the sewage treatment systems, so urban runoff flows unimpeded to the ocean. When storm events occur, runoff plumes can become large oceanographic features that extend for many kilometers (Bay *et al.* 1999, Hickey and Kachel in press). Moreover, southern California has an arid environment with a short rainy season and long dry periods when the rivers provide minimal runoff. Thus, bacteria and other contaminants accumulate on land between storms, enhancing runoff quality concerns compared to temperate areas where rainfall is more frequent.

The storm effect on water quality is well illustrated by comparison with results from the two dry-weather regional surveys that sampled at the same

Table 5. Comparison of the percentage of total shoreline miles that failed State of California water quality standards in Mexico and the United States following a storm event.

<i>MEXICO</i>			
	Enterococci	Fecal Coliforms	Total Coliforms
Sandy Beach	63	32	11
Point Zero	80	50	20
Entire Shoreline	66	36	15
<i>UNITED STATES</i>			
	Enterococci	Fecal Coliforms	Total Coliforms
Sandy Beach	66	42	31
Point Zero	87	43	33
Entire Shoreline	61	36	24

Table 6. Median indicator concentrations in the United States and Mexico following a storm (reported as MPN or cfu/100 mL).

	Enterococci	Total Coliforms	Fecal Coliforms
<u>Beach</u>			
Mexico	330	490	220
United States	130	900	80
<u>Urban Runoff Outlets</u>			
Mexico	310	1,450	515
United States	228	1,400	80

sites (Noble *et al.* 1999, 2000). The extent of shoreline that exceeded water quality standards during this study was nearly 10 times higher than in the two dry-weather studies (Figure 1). This increase was observed across all shoreline types and among all bacteria indicator types (Figures 1 and 2). Moreover, the magnitude of the exceedences was much greater during this study. During dry weather, two-thirds of the threshold failures were attributable to failure of a single bacterial indicator and most of those failures were barely above the indicator threshold. In contrast, two-thirds of the threshold failures during wet weather were for multiple indicators in which at least one indicator was twice the allowable standard (Figure 3).

Another difference between wet-weather and dry-weather conditions was the comparability in water quality between Mexican and U.S. waters. During dry weather, water quality standards were exceeded five times more often on Mexican beaches

than on U.S. beaches (Noble *et al.* 2000). In contrast, we found that during wet-weather there was no difference in the percentage of impacted shoreline between Mexico and the United States. While the better dry-weather water quality in the U.S. is probably a reflection of their more extensive sewage treatment systems, the comparable wet weather water quality probably reflects the lack of urban runoff treatment in either country. Still, there were some differences between the countries during wet weather. TC to FC ratios were lower in Mexico, regardless of whether samples were taken at an open beach or near an urban runoff outlet (Table 6). Lower TC:FC ratios are usually indicative of fresher fecal contamination and the observed pattern is consistent with the suggestion that Mexican runoff contains greater contributions of fresh human fecal material contamination from untreated sewage, whereas U.S. runoff contains a

higher percentage of decayed animal feces that are washed off with the storm.

The public health risk of the high indicator bacteria concentrations observed in this study are unclear, particularly if the source material has a large animal contribution. Most studies relating bacterial indicator levels to illnesses rates have been conducted at locations where the primary source of bacteria is human sewage rather than urban runoff. The only epidemiological study that focused on the human health concerns associated with urban runoff was conducted in Santa Monica Bay, California and was limited to assessing health effects of dry-weather runoff (Haile *et al.* 1999). Currently, most public health agencies in southern California issue countywide warnings to avoid recreational water contact following all storms of 25 mm or greater. Our findings of high, spatially extensive indicator bacteria counts suggest that warnings on large spatial scales are appropriate, but additional epidemiological studies to evaluate the health effects of wet-weather urban

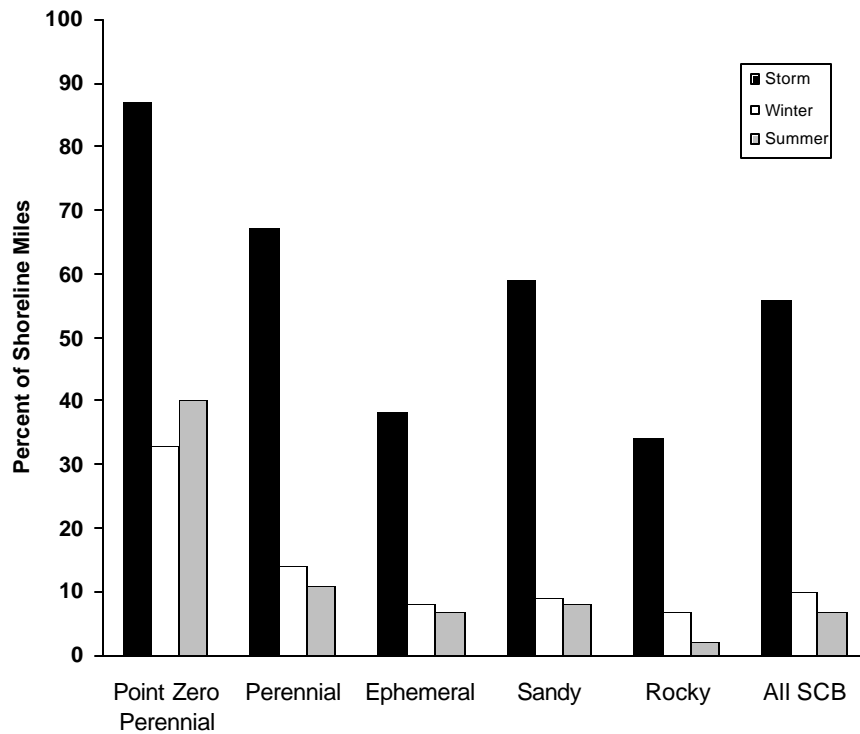


Figure 1. The extent of water quality threshold exceedences in the Southern California Bight during the Summer and Winter studies (dry) compared to the present Storm Study (wet), by shoreline type.

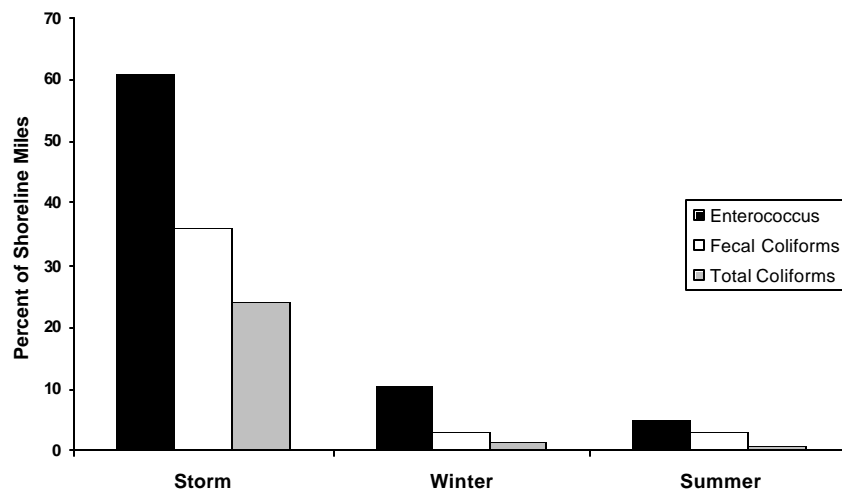


Figure 2. The extent of water quality threshold exceedences among indicator bacteria in the Southern California Bight during the Summer and Winter studies (dry) compared to the Storm Study (wet).

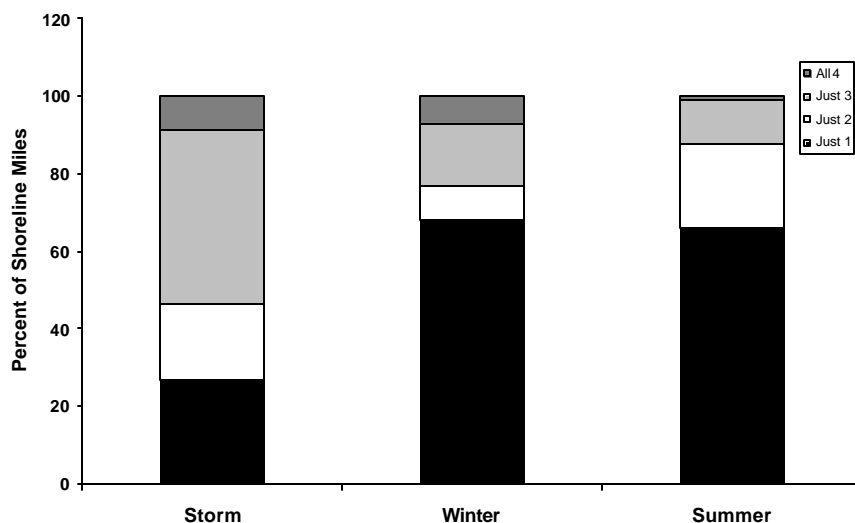


Figure 3. Relative frequency of multiple water quality threshold exceedences in the Southern California Bight during the Summer and Winter studies (dry) compared to the Storm study (wet).

runoff are advisable to further support these management actions.

LITERATURE CITED

American Public Health Association (APHA). 1995. Standard methods for the examination of water and wastewater, 18th edition. Edited by A.D. Eaton, L.S. Clesceri and A.E. Greenberg. Washington, DC.

Bay, S., B.H. Jones, and K.C. Schiff. 1999. Study of the impact of stormwater discharge on Santa Monica Bay. (USCSG-TR-02-99). Executive Summary Report prepared for the Los Angeles County Department of Public Works. Alhambra, CA. USC Sea Grant Program. Los Angeles, CA.

Boehm, A.B., S.B. Grant, J.H. Kim, S.L. Mowbray, C.D. McGee, C.D. Clark, D.M. Foley and D.E. Wellman. 2002. Decadal and shorter period variability and surf zone water quality at Huntington Beach, California. *Environmental Science and Technology* 36: 3885-3892.

Dwight, R.H., J.C. Semenza, D.B. Baker and B.H. Olson. 2002. Association of urban runoff with coastal water quality in Orange County, California. *Water Environment Research* 74: 82-90.

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.

Hickey, B. and N. Kachel. 2003. The influence of river plumes in the Southern California Bight. *Continental Shelf Research*, in press.

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

Lipp, E.K., R. Kurz, R. Vincent, C. Rodriguez-Palacios, S. R. Farrah and J.B. Rose. 2001a. The effects of seasonal variability and weather on microbial fecal pollution and enteric pathogens in a subtropical estuary. *Estuaries* 24: 266-276.

Lipp, E.K., N. Schmidt, M.E. Luther and J.B. Rose. 2001b. Determining the effects of El Nino-Southern

Oscillation events on coastal water quality. *Estuaries* 24: 491-497.

Mallin, M., K. Williams, E. Esham, and R. Lowe. 2000. Effect of human development on bacteriological water quality in coastal watersheds. *Ecological Applications* 10: 1047-1056.

Messer, J.J., C. W. Ariss, J.R. Baker, S.K. Drouse, K.N. Eshleman, P.N. Kaufman, R. A. Linthurst, J. M. Omernik, W.S. Overton, M.J. Sale, R. D. Shonbrod, S.M. Stanbaugh, and J.R. Tutshall, Jr. 1986. National Surface Water Survey: National Stream Survey, Phase I-Pilot Survey. EPA-600/4-86-026. U. S. Environmental Protection Agency. Washington, D C.

Noble, R.T., J.H. Dorsey, M.K. Leecaster, C.D. McGee, D. Moore, V. Orozco-Borbon, P.M. Vainik, and S.B. Weisberg. 1999. Southern California Bight 1998 Regional Monitoring Program: Volume II. Winter Shoreline Microbiology. Southern California Coastal Water Research Project. Westminster, CA.

Noble, R.T., J. Dorsey, M. Leecaster, D. Reid, K.C. Schiff and S.B. Weisberg. 2000. A regional survey of the microbiological water quality along Southern California Bight shoreline. *Environmental Monitoring and Assessment* 64: 435-447.

Noble, R.T. and J.A. Fuhrman. 2001. Enteroviruses detected in the coastal waters of Santa Monica Bay, California: Low relation to bacteriological indicators. *Hydrobiologia* 460: 175-184.

Noble, R.T., S. B. Weisberg, M. K. Leecaster, C. McGee, K. Ritter, P. Vainik and K. Walker. 2003. Comparison of methods for measuring bacterial indicators of beach water quality. *Environmental Monitoring and Assessment*, in press.

Overton, S.W. 1987. A sampling and analysis plan for streams, in the national surface water survey conducted by EPA. Technical Report No. 117. Department of Statistics, Oregon State University. Corvallis, OR.

Schiff, K.C., S.B. Weisberg and J.H. Dorsey. 2001. Microbiological monitoring of marine recreational waters in southern California. *Environmental Management* 27: 149-157.

Schiff, K.C., J. Morton and S.B. Weisberg. 2003. Retrospective evaluation of shoreline water quality along Santa Monica Bay beaches. *Marine Environmental Research*, *in press*.

Schiff, K. and P. Kinney. 2001. Tracking sources of bacterial contamination in stormwater discharges from Mission Bay. *Water Environment Research* 73: 534-542.

Solo-Gabrielle, H.M., M.A. Wolfert, T.R. Desmarais and C.J. Palmer. 2000. Sources of *Escherichia coli* in a coastal subtropical environment. *Applied and Environmental Microbiology* 66: 230-237.

Stevens, D.L., Jr. and T.M. Kincaid. 1997. Variance estimation for subpopulation parameters from samples of spatial environmental populations. Proceedings of the American Statistical Association Section on Statistics and the Environment. American Statistical Association. Alexandria, VA.

Thompson, S.K. 1992. Sampling. Wiley and Sons. New York, NY.

ACKNOWLEDGEMENTS

The authors wish to thank all of the participants in the study who spent laboratory time and also attended the many meetings in preparation for the regional microbiology study conducted in February 2000; these include Algalita Marine Research Foundation, Aliso Water Management Authority and Southeast Regional Reclamation Authority, Aquatic Bioassay and Consulting Laboratories, City of Long Beach Department of Health & Human Services, City of Los Angeles Environmental Monitoring Division, City of Los Angeles Stormwater Division, City of Oceanside, City of Oxnard, City of San Diego, City of Santa Barbara, City of Ventura Wastewater Treatment Plant, Encina Wastewater Authority, Goleta Sanitation District, Instituto de Investigaciones Oceanológicas (UABC), Los Angeles County Department of Health Services, Los Angeles County Sanitation Districts, Los Angeles Regional Water Quality Control Board, Orange County Environmental Health Division, Orange County Public Health Laboratory, Orange County Sanitation District, San Diego County Department of Environmental Health, San Diego Recreational Water Quality Control Board, San Elijo Joint Powers Authority, Santa Barbara County Health Care Services, Southern California Marine Institute, State Water Resources Control Board of California, Surfrider Foundation, University of Southern California Wrigley Institute for Environmental Studies, Ventura County Environmental Health Division. We also thank Mr. Larry Cooper for development of a microbiology database for the regional studies.