Microbiological Monitoring of Marine Recreational Waters in Southern California

Kenneth C. Schiff, Stephen B. Weisberg, and John H. Dorsey[1]

ABSTRACT

An inventory was conducted to assess the number, type, spatial distribution, and costs of microbiological monitoring programs in southern California marine waters from Point Conception to the U.S./Mexico International Border. The location of each sampling site was determined using global positioning system (GPS), and estimates of geographic coverage were determined using geographic information system (GIS) techniques. Twenty-one programs conducted 87,007 tests annually at 576 sites in the study area. Sampling efforts varied by more than an order of magnitude among counties. The largest number of sites was sampled in Orange County, whereas the largest number of analyses were performed in Los Angeles County because monitoring programs in this area focus on daily monitoring. Fifteen of the 21 programs were managed by National Pollutant Discharge Elimination System (NPDES) permitted sewage effluent dischargers who sampled both offshore and shoreline waters and typically tested for three indicator bacteria (total coliform, fecal coliform, and enterococcus). Their combined efforts comprised 82% of all of the microbiological indicator analyses conducted on an annual basis. Five of the remaining monitoring organizations were public health agencies (four county, one city), which typically focus their efforts on testing only for total coliforms. Laboratory methodology also varied considerably, with NPDES permittees predominantly utilizing membrane filtration while public health agencies generally used multiple tube fermentation or premanufactured test kits. Nearly three-quarters of all the effort expended in southern California occurred along the shoreline as opposed to offshore locations. Two-thirds of this shoreline effort was focused on high-use sandy beaches and in proximity to perennial freshwater outlets (storm drains and creeks), which are frequent sources of shoreline bacterial contamination. Most sampling occurred at a set of fixed sites that were revisited frequently, but only represented about 7% of the total shoreline. We estimated that roughly $3M is spent annually on monitoring bathing water quality in southern California, exceeding that spent in any other part of the country.

[1]City of Los Angeles, 650 S. Spring, 7th floor, Los Angeles, CA 90014

INTRODUCTION

Southern California coastal waters are an important and unique recreational resource. More than 100 million people visit southern California beaches annually to sunbathe, surf, swim, skin-dive and scuba-dive. On an average summer weekend, more than 600,000 people visit beaches in Santa Monica Bay (SMBRP 1994). These ocean recreation activities contribute approximately $9 billion to the local economy.

Southern California coastal waters are tested extensively for recreational water quality using indicator bacteria, which include total coliforms, fecal coliforms, and enterococcus. Although not necessarily pathogenic, indicator bacteria are found abundantly in wastes with human contributions where pathogenic organisms, such as viruses, are likely to exist. The levels of indicator bacteria in bathing waters have been shown to correlate with the incidence of illness in swimmers from New

Jersey and Santa Monica Bay (Cabelli 1983, Haile *et al.* 1996). Unlike virus tests, which are time-consuming and expensive, measurements of indicator bacteria are relatively fast and inexpensive.

Many organizations conduct microbiological monitoring of beaches in southern California, but these programs are largely independent with no formal mechanism for integrating data. These programs are valuable for assessing the condition of selected individual beaches, but the resulting data are not currently being used to assess the overall condition of southern California beaches. In this article, we present an inventory of these programs to determine the level of effort being expended by monitoring programs in terms of the number, type, spatial distribution, and cost. Our goal is to identify similarities and differences among these programs, and to determine the extent to which they could be integrated to provide the public with a comprehensive microbiological assessment of southern California's coastal waters.

METHODS

A list of organizations that conduct microbiological monitoring in marine waters was compiled by contacting all of the city and county public health agencies and Regional Water Quality Control Boards in southern California. Monitoring organizations were then surveyed to ascertain the following information about each sampling site: station name, location (latitude/longitude, general description, water body type), depth of sampling, analytes measured, analytical methods, and sampling frequency by season. Where latitude and longitude data were unavailable, we conducted field visits with the sampling organization and recorded the position of sampling sites using differential GPS .

The relative distribution of sampling effort among habitat types was assessed by differentiating sampling sites into offshore and shoreline strata. Shoreline sites were further differentiated into eight categories: (1) high-use sandy beaches, (2) low-use sandy beaches, (3) high-use rocky shoreline, (4) low-use rocky shoreline, (5) perennial freshwater input areas, (6) ephemeral freshwater input areas, (7) embayments, and (8) restricted access areas. Offshore samples were defined as those collected by boat from the open ocean. High-use sandy beaches were defined as beaches where lifeguard services are present (with an estimated > 50,000 beachgoers per year). High-use rocky shoreline was defined as rocky areas popular for diving or surfing activities. Freshwater input areas were defined as those within 100 yards of rivers and creeks which drain into the ocean and were separated into perennial (year-round) and ephemeral (only during storm event) depending on their flow characteristics. Samples from freshwater input areas were only included in the inventory if they were from waters with measurable salt concentration (i.e., monitoring of freshwater creek systems was not included). Embayment samples were defined as those collected by boats or from docks in enclosed water bodies such as Anaheim, Newport, or Mission Bays. Boat-collected samples in embayments were differentiated from offshore samples because of the higher level of recreational activity and likelihood of human water contact in bays. Restricted access areas included military bases, commercial ports, and private shoreline distant from any public access point. These eight shoreline categories were mapped for the entire southern California coast using GIS techniques. Each shoreline type was designated and inserted into the GIS overlay based upon the expertise of local monitoring agencies, cross-referencing designations from the most recent NOAA navigation charts, and using maps from the California State Lands Commission, California Coastal Commission, and City/County governments.

Estimating Spatial Coverage

The spatial coverage of shoreline monitoring (i.e., percentage of shoreline miles) was estimated by plotting each station in the microbiological monitoring inventory onto the digitized map of the southern California shoreline, assigning a representative distance of shoreline to each sample, and then calculating the relative number of monitored and unmonitored shoreline miles for each shoreline category. At freshwater outlets, a sampling site was assumed to be represented by a minimum area of 25 yd. upcoast and downcoast (i.e., 50 yd. total), based upon the findings of Gold *et al.* (1992). All other types of shoreline samples were assumed to represent a shoreline distance of 200 yards (100 yards upcoast and downcoast), based upon Haile *et al.* (1996).

Estimating Monitoring Costs

Annual expenditures on microbiological monitoring in southern California were estimated by assessing both analytical laboratory and sampling costs. Analytical laboratory expenses were calculated based upon the current market rate for microbiological testing, which averages $30 per analysis per sample (i.e., $90 per sample if three indicator bacteria are measured). Sample collection costs were calculated by assuming that a single technician making $30/hr (including benefits and overhead) could sample three sites per hour along the shore and two sites per hour offshore (based upon conversations with agencies presently conducting the efforts). Transportation costs were assumed to be $2 per sample for shoreline monitoring (based upon $0.33 per mile) and $50 per sample for offshore monitoring, where vessel and boat crew are required.

The costs of shoreline monitoring were also expressed per capita, per shoreline mile, and per tourist dollar expended within each county. Population statistics for each county were obtained from the State of California, Department of Finance (1998). Shoreline miles were gathered from the GIS effort described above. Tourism estimates were gathered from the California Trade and Commerce Agency, Division of Tourism (1998).

RESULTS

Twenty-one microbiological monitoring programs were identified, conducting 87,007 indicator bacteria analyses per year at 576 sites throughout southern California (Table 1). Seventy-two percent of these analyses were collected along the shoreline, either along the open coast, in bays and harbors, or near the mouths of creeks and storm drains (Table 1). The remaining 28% were samples taken from offshore areas (up to 100 m depth) to supplement water quality measurements for deep ocean outfalls in compliance with NPDES permit requirements. Fifteen of the 21 monitoring programs were managed by NPDES sewage discharge permittees whose outfalls were sited well offshore. In addition to 100% of the offshore monitoring, NPDES permittees performed 75% of the shoreline bacterial indicator analyses.

The level of shoreline microbiological sampling and analysis effort was not evenly distributed throughout southern California (Table 1). The largest number of monitoring programs (n = 7) were found in San Diego County. The largest number of shoreline sites were sampled in Orange County (n = 145). The largest number of microbiological analyses were conducted in Los Angeles County (n = 26,814 per year). Beach and bay sampling and analyses were roughly 10-fold less in Santa Barbara County (2 programs; 21 sites; 3,276 analyses per year) and Ventura County (2 programs; 29 sites; 2,054 analyses per year).

Sampling frequency also differed among counties (Table 2). Only in Los Angeles and Orange Counties was daily monitoring conducted on any beach or bay; more than 65% of the effort in Los Angeles County was directed toward daily monitoring. The difference in sampling frequency between winter and summer was small, except in Ventura County where the effort in summer nearly quadrupled. Santa Barbara and Los Angeles Counties maintained the same level of effort throughout the year.

Bacterial indicators and testing methods varied among monitoring programs, with the distinction being most pronounced between health agencies and NPDES permittees (Table 3). Public health departments focused on total coliform measurements, measuring at almost twice the frequency of fecal coliforms and three times the frequency of enterococcus. In contrast, most NPDES dischargers measured all three indicators at most sites. Additionally, health departments primarily tested for bacteria using the multiple tube fermentation method or Idexx^{TM} kits (Colilert and Enterolert). In contrast, NPDES permittees relied primarily on the membrane filtration method.

Spatial Allocation of Shoreline Monitoring

Microbiological sampling occurred in all of the shoreline habitats delineated, but the allocation of effort among them was not equal. The majority of effort was directed towards high-use sandy beaches (55%), where human water contact is most likely (Table 4). Perennial and ephemeral stormwater outlets, which are a frequent source of bacterial contamination, received nearly 20% of the sampling effort while accounting for less than 2% of the shoreline. This category represented the greatest proportional allocation of effort among habitats. Restricted access areas received the least proportional allocation of effort.

Although a large amount of effort was conducted throughout southern California, most efforts were allocated towards revisiting a selected set of sites. For example, high-use sandy beaches received the greatest amount of sampling effort, yet only 11% of the high-use sandy beach shoreline was monitored (Table 5). Perennial freshwater inputs, which are potential sources of chronic indicator bacteria contamination, were the most extensively monitored, with 31% of the storm drain areas sampled. Approximately 7% of the southern California shoreline as a whole was monitored.

Monitoring coverage of the coastline varied among counties (Table 5). The most extensive coverage occurred in Orange County (10% of county total), followed by Los Angeles, San Diego, Ventura, and Santa Barbara Counties. Likewise, the coverage among different beach types was not consistent within or between counties. Up to 50% of beaches adjacent to freshwater inputs were monitored in Santa Barbara, Orange, and San Diego Counties; 20% or less of these

TABLE 1. Agencies which conduct routine microbiological monitoring in southern California. *NPDES permittee.

Collecting Agency	Shoreline/Bays No. of Sites	Shoreline/Bays No. of Analyses per year	Offshore No. of Sites	Offshore No. of Analyses per year	Total No. of Sites	Total No. of Analyses per year
- Santa Barbara County -						
Santa Barbara County Department of Health Service	14	2,184	-	-	14	2,184
Goleta Sanitation District*	7	1,092	13	468	20	1,560
- Ventura County -						
City of Ventura*	16	884	-	-	16	884
City of Oxnard*	13	1,170	13	3,408	26	4,578
- Los Angeles County -						
Los Angeles County Department of Health Services	33	5,148	-	-	33	5,148
City of Los Angeles, Hyperion Wastewater Treatment plant	18	14,220	33	9,000	51	23,220
City of Los Angeles, Terminal Isl. Wastewater Treatment plant	*20	3,414	-	-	20	3,414
Los Angeles County Department of Beaches and Harbors	18	648	-	-	18	648
Los Angeles County Sanitation Districts*	8	2,916	8	3,020	16	5,936
City of Long Beach, Dept.of Health and Human Services	39	468	-	-	39	468
- Orange County -						
Orange County Sanitation District*	17	3,840	4	624	21	4,464
Aliso Water Management Authority*	18	6,864	6	648	24	7,512
South East Regional Reclamation Authority*	17	3,978	13	576	30	4,554
Orange County Environmental Health Division	93	6,968	-	-	93	6,968
- San Diego County -						
San Diego County Department of Environmental Health	45	540	-	-	45	540
City of Oceanside*	10	1,170	12	432	22	1,602
Encina Wastewater Authority*	5	780	10	1,080	15	1,860
San Elijo Wastewater Authority*	7	819	14	504	21	1,323
City of San Diego, Point Loma Wastewater Treatment plant	16	1,872	8	4,320	24	6,192
City of San Diego, Mission Bay*	20	3,120	-	-	20	3,120
International Boundary Water Commission*	8	832	-	-	8	832
Total	442	62,927	134	24,080	576	87,007

beaches were monitored in Los Angeles and Ventura Counties. Approximately one-fifth of the high-use sandy beaches in Los Angeles and Orange Counties were sampled, the highest of the five counties. Less than one-tenth of the high-use sandy beach miles in Ventura and San Diego Counties were monitored. Only a single high-use sandy beach was targeted for monitoring in Santa Barbara County.

Monitoring Costs

Approximately $3 million is spent annually on marine microbiological monitoring in southern California (Table 6). Roughly 70% of that expenditure was for shoreline and bay monitoring. Los Angeles County monitoring cost estimates were highest, approximately 10-fold higher than Santa Barbara County. When expressed as cost per mile of recreational shoreline, similar differences among counties were also apparent. When expressed as per capita expenditure, Ventura County, which had no routine health department monitoring and collected the smallest number of samples, had the second highest expenditure, and Los Angles County the least. When expressed as a fraction of tourism dollars, Orange County had the greatest expenditure on monitoring and San Diego County the least.

DISCUSSION

The amount of marine microbiological monitoring conducted in southern California appears to exceed that in the rest of California or in any other part of the country. Less than $0.5 million is spent annually on monitoring in the rest of California, and the rest of the country combined spends less than $2 million (NRDC 1998). Our estimates of nearly $3 million annually for microbiological monitoring in southern California is a conservative estimate in that it only includes costs of routine monitoring. Most of the agencies we surveyed also sample in response to sewage spills, overflows, and beach closures in addition to what the inventory included. The higher expenditures estimated for southern California reflect the large contributions from NPDES

TABLE 2. Number of shoreline/bay samples analyzed each year in southern California during summer season (April 1 - September 30) and winter season (October 1 - March 31) as a function of monitoring frequency.

County	Summer Season			Winter Season			Total
	M, W, F M thru F or 7 d/wk	1/wk or 5/mo	Biweekly to Monthly	M, W, F M thru F or 7 d/wk	1/wk or 5/mo	Biweekly to Monthly	
Santa Barbara	-	1,638	-	-	1,638	-	3,276
Ventura	-	1,612	-	-	442	-	2,054
Los Angeles	8,763	4,014	630	8,763	4,014	630	26,814
Orange	8,124	3,484	-	5,232	4,810	-	21,650
San Diego	-	4,940	540	-	2,366	1,287	9,133
Total	16,887	15,688	1,170	13,995	13,270	1,917	62,927

permittee monitoring efforts, which is uncommon in shoreline monitoring programs in other parts of the country. Southern California's beach monitoring programs are still among the largest in the country (even without the NPDES effort), but the local coordination between the NPDES and health agencies increases the size and effectivness of local programs.

While monies spent on microbiological monitoring in southern California are substantial, this expenditure reflects the high population density and extensive tourism industry in the area. Southern California has the highest coastal population density of any area in the country (Culliton *et al.* 1988). Coastal tourism in California is estimated to be twice that of any other state in the country; statistics indicate that there are more beach visit-days in southern California than in the rest of the country combined (Table 7).

Considerable difference was found in the allocation of effort by different organizations and across different counties. For example, the Orange County Environmental Health Division collects data from more sites than any other organization, yet conducts less than 25% of the number of analyses performed by Los Angeles City Environmental Monitoring Division. This disparity results because Los Angeles City typically measures three indicators at each site daily, whereas Orange County measures most sites weekly and does not measure enterococcus. No studies have been conducted to assess if the public's interest is best served by allocating effort to more sites, providing more temporal coverage at fewer sites, or increasing the number of indicators measured at each site. What is clear is that the monitoring organizations throughout southern California have not developed a unified strategy to select the most appropriate effort allocation.

One factor that leads to inconsistencies in effort allocation is the different monitoring mandates made by regional, state, and federal agencies governing health departments and NPDES permittees. In southern California, the NPDES permittees and health departments coordinate their efforts to address management needs; however, the Environmental Protection Agency (EPA), State, and Regional Water Quality Control Boards define the NPDES permittee monitoring requirements—not the health departments. The EPA presently endorses the use of enterococcus as a primary bacterial indicator which may be the reason enterococcus is typically measured by NPDES permittees. Since the

TABLE 3. Number of shoreline/bay analyses per year as a function of indicators studied and type of monitoring agency.

	Public Health Agencies	NPDES Permittees
Total coliform		
Multiple tube fermentation	7,090	6,141
Membrane filtration	468	16,074
Colilert	728	-
Fecal coliform		
Multiple tube fermentation	4,282	1,417
Membrane filtration	-	13,734
Colilert	728	-
Enterococcus		
Multiple tube fermentation	1,932	1,417
Membrane filtration	-	8,188
Enterolert	728	-
Total	15,956	46,971

TABLE 4. Relative allocation of monitoring effort in southern California by shoreline type.

Shoreline Type	Percent of Shoreline miles	Percent Allocation of Sampling Effort
SANDY		
High Use	25.9	54.5
Low Use	9.3	7.8
ROCKY		
High Use	2.5	3.9
Low Use	2.9	1.8
FRESHWATER INPUTS		
Perennial	1	14.2
Ephemeral	0.7	4.6
EMBAYMENTS	27.5	11
RESTRICTED ACCESS	30.2	2.2
TOTAL	100.0	100.0

recreational water quality objectives for enterococcus in California are only preliminary, it is rarely measured by health departments. Similarly, methodological inconsistencies result from different mandates. The State of California Environmental Laboratory Accreditation Program (ELAP) certifies all NPDES and private laboratories for microbiological analyses of marine recreational waters. The ELAP does not, however, certify laboratories using the Colilert or Enterolert Idexx™ kit methods since they have not been approved by EPA for marine recreational water testing. This accounts for the fact that no NPDES laboratories utilize this method. Public health departments, who do not report to the EPA, have traditionally focused on multiple tube fermentation methods, but are increasingly relying upon the premanufactured Idexx™ kits.

A similar and yet distinct issue that results from the division between NPDES dischargers and health departments is the allocation of nearly $1 million in southern California towards monitoring of offshore areas where few people swim and shellfish standards are not an issue. Moreover, many of these samples are collected at depths up to 100 meters, far below typical diving depths. The NPDES permittees use this monitoring data to track their wastewater plume and ensure that it remains submerged and far from shore. It is not clear whether the public interest is best served by such a large effort distant from the beaches where people swim. It is also interesting that while NPDES permittees accounted for more than 75% of monitoring effort in southern California, all of the NPDES monitoring was conducted by sewage dischargers, even though most publicly owned treatment works (POTWs) have consistently demonstrated that their outfalls are sufficiently offshore to avoid beach exposure. In southern California, stormwater dischargers also hold NPDES permits, yet none of the stormwater permittees presently conduct microbiological monitoring in receiving waters even though 19% of present monitoring efforts are allocated towards stormwater outlets and most of the

TABLE 5. Percent of shoreline miles sampled in southern California by county.

Beach Type	Percent Shoreline Monitoring Coverage by County					
	Santa Barbara	Ventura	Los Angeles	Orange	San Diego	All of Southern California
SANDY						
High Use	2	5.1	21.9	17.7	8.9	11.2
Low Use	2.1	31.9	17.2	< 0.1	12.9	9.9
ROCKY						
High Use	< 0.1	< 0.1	7.7	18.6	9.5	8.7
Low Use	< 0.1	< 0.1	3.8	6.2	3.6	4
FRESHWATER INPUTS						
Perennial	49.7	18.9	15.8	35.4	28	31.4
Ephemeral	< 0.1	< 0.1	4.5	20.1	21	13.2
EMBAYMENTS	< 0.1	4.3	15	9.8	4.1	8.8
RESTRICTED ACCESS	< 0.1	0.6	0.4	1.1	1.1	0.6
TOTAL	1.7	4.3	9.6	10.2	6.4	7.2

public warnings about beach safety in southern California have been associated with stormwater outlets (NRDC 1998).

More than half of the shoreline monitoring effort was focused on freshwater outlets and selected high-use beaches. Although freshwater outlets represent those areas that are most likely to have a problem, and selected beaches are where the public may likely be exposed, they represent only a small portion of the total shoreline. This narrow focus presents a challenge in ensuring that the public receives a complete perspective on the quality of their shoreline. Many groups summarize beach monitoring data on the basis of the number and frequency of beach closures, rather than on the amount of shoreline that is safe (or unsafe) for swimming. Organizations that monitor more extensively, and focus their monitoring towards high-risk areas, are more likely to produce beach warnings or closures. Thus, southern California beaches have developed a reputation as being more unsafe than others in the country, in part due to their greater monitoring activity (NY Times; January 5, 1997). One of the reasons that closures and warnings are frequently used as the primary measure of beach quality is that the information is accessible. The raw bacterial concentration data, which are collected by many organizations that have historically maintained their data independently, are less accessible. Some local organizations, such as the Santa Monica Bay Restoration Project and Heal the Bay in Los Angeles County, and San Diego County Environmental Health Department in San Diego County have already taken steps to provide the public with more complete information through the use of report cards and web sites that characterize conditions across several monitoring organizations within a county.

TABLE 6. Costs per county for microbiological monitoring in southern California. Costs per capita, per mile, and per tourist dollar are for shoreline and bay monitoring only.

County	Estimated Cost (in $1,000)					
	Shoreline/Bay Monitoring	Offshore Monitoring	Total Monitoring	Per capita	Per Mile	Per Million Tourism Dollars
Santa Barbara	111.4	17.2	128.5	$0.27	$1,593	$125
Ventura	76.3	125.5	201.8	$0.28	$1,047	$99
Los Angeles	946.7	535.4	1,482.1	$0.15	$6,721	$78
Orange	794.5	72.0	866.5	$0.32	$6,336	$203
San Diego	313.3	223.2	536.5	$0.19	$1,824	$59
Total	2,242.1	973.3	3,215.4	$0.20	$3,861	$97

The inconsistencies and unresolved policy issues that we observed in southern California appear to be a microcosm of issues faced nationally. The Natural Resources Defense Council (1998) found the same kind of differences in temporal, spatial, and indicator allocation among states that the present study found among counties. California also appears to be a microcosm for a solution. California recently passed legislation (AB 411) requiring the State Health Department to develop a consistent beach monitoring program to be implemented throughout the state. The federal EPA also recently initiated its Beach Environmental Assessment, Closure, and Health (BEACH) program with the goal of increasing consistency in monitoring and reporting. Legislation similar to AB 411 is also pending at the national level.

Resolving inconsistencies among programs requires identifying a common question(s) as a focal point for partnership among monitoring organizations. While cooperation between NPDES discharge monitoring agencies and health departments is probably greater in southern California than in most parts of the country, the allocation of effort indicates there are still differences in focus between them. Public health agencies focus on elevated shoreline bacterial counts relative to water quality standards, whereas NPDES permittees monitor movement of offshore effluent plumes and possible encroachment into inshore recreational waters. The common element of both program types, the public health related to water contact, should provide a common ground for even greater coordination.

Table 7. Beach usage statistics throughout the United States (Data courtesy of R. Gould, U.S. Lifesaving Association)

Region	1997 Beach Usage: No. Beach Visits (in thousands)	1997 Beach Usage: Percent of total
New England	2,643	0.9
Mid-Atlantic	11,020	3.9
South Atlantic	14,949	5.3
Southeast	45,848	16.3
Great Lakes	22,860	8.1
Gulf Coast	2,500	0.9
Northwest	5,831	2.1
Hawaii	20,659	7.4
Northern California	9,073	3.2
Southern California	146,264	51.9
Total	281,648	100.0

One aspect that serves as a focal point for increasing cooperation is the effect of storm drain runoff on ocean quality (Schiff 1997). Health departments have focused their efforts on storm drain discharge locations because they are the area in which closures most frequently occur. Many municipal sewage dischargers focus on these areas because their offshore outfalls occur adjacent to areas of stormwater plumes and they have a need to demonstrate that shoreline closures result from the storm drain plume, not from their outfall. In addition, sewage lines can overflow during heavy rains and the storm drain systems become the transport system for these spills to enter the ocean. Stormwater agencies, while not presently conducting monitoring, are NPDES permittees who may have such responsibilities in the future. Some sewage and stormwater agencies are beginning to merge administratively in southern California for these reasons, with the City of Los Angeles recently reorganizing their Stormwater Management Division into the Bureau of Sanitation and the San Diego County Environmental Health Department, seeking leadership status on the San Diego County stormwater NPDES permit. Regardless of whether stormwater is the unifying issue, partnership between public health and NPDES permitted agencies in data collection and assessments would be an important component of cost-effectively ensuring that coastal water contact safety information is effectively communicated to the public.

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