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Improving water quality through California's Clean Beach Initiative: an assessment of 17 projects

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Abstract California's Clean Beach Initiative (CBI) funds projects to reduce loads of fecal indicator bacteria (FIB) impacting beaches, thus providing an opportunity to judge the effectiveness of various CBI water pollution control strategies. Seventeen initial projects were selected for assessment to determine their effectiveness on reducing FIB in the receiving waters along beaches nearest to the projects. Control strategies included low-flow diversions, sterilization facilities, sewer improvements, pier best management practices (BMPs), vegetative swales, and enclosed beach BMPs. Assessments were based on statistical changes in pre- and postproject mean densities of FIB at shoreline monitoring stations targeted by the projects. Most low-flow diversions and the wetland swale project were effective in removing all contaminated runoff from beaches. UV sterilization was effective when coupled with pretreatment filtration and where effluent was released within a few hundred meters of the beach to avoid FIB regrowth. Other BMPs were less effective because they treated only a portion of contaminant sources impacting their target beach. These findings should be useful to other coastal states and agencies faced with similar pollution control problems.

Keywords Water quality · Fecal indicator bacteria · Beach pollution · BMPs

Introduction

The US Congress demonstrated that having good water quality at recreational beaches is a national priority when they amended the Clean Water Act in 2000 by passing the Beaches Environmental Assessment and Coastal Health (BEACH) Act. This legislation addressed the problem of pathogens and pathogen indicators in coastal waters by:

1. Requiring new or revised water quality standards for pathogens or their indicators
2. Requiring the US Environmental Protection Agency (EPA) to conduct studies associated with pathogens and human health
3. Directing the US EPA to award grants to develop and implement beach monitoring and assessment programs (US EPA 2006a)

To implement this Act, the US EPA works with state and local government agencies to improve pollution control efforts, thus reducing potential adverse health effects along the nation's beaches

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(US EPA 2006a). Water quality problems stemming from contamination by sewage and runoff containing pathogenic organisms increase the incidence of illnesses among swimmers (e.g., Cabelli et al. 1982; Haile et al. 1999) potentially leading to extensive beach closures. Both illnesses and closures result in economic losses (Given et al. 2006). The public is keenly aware of potential health risks from swimming in contaminated water and use available water quality information in determining when and where to go to the beach, especially if they plan on swimming or surfing (Hanemann et al. 2004). For these reasons, maintaining good water quality at beaches is a primary goal for beach and resource managers.

There can be many sources of the fecal bacteria that cause beaches to exceed water quality criteria. Runoff from urbanized areas typically has elevated levels of enteric organisms, especially as the amount of impervious area increases with urban development (Young and Thackston 1999) and the potential for contamination from accidental spills of sewage increases. Along California coastal areas, runoff from storm drains and river inputs has been shown to be a significant source of fecal indicator bacteria (FIB) and associated pathogens (e.g., see Gold et al. 1990; Jiang et al. 2001; Reeves et al. 2004; Stein and Tiefenthaler 2004; Ackerman et al. 2005). An epidemiological study conducted in Santa Monica Bay and proximity to storm drains correlated swimmer illness to FIB densities (Haile et al. 1999) and was the basis for the California bathing water standards. Wildlife feces, mainly from birds, are another source of FIB impacting beaches (Ricca 1998; Alderisio and DeLuca 1999; Ferguson et al. 2003; Grant et al. 2001; Surbeck et al. 2006). Similarly, resuspended sediments with attached FIB can be washed from wetland or estuarine areas, increasing levels of these microorganisms in adjacent beach waters (e.g., Steets and Holden 2003; Surbeck et al. 2006). Beach sediments, inoculated by FIB from various sources, can be reservoirs for viable populations of fecal microorganisms due to regrowth (Davies et al. 1995; Ferguson et al. 2005; Lee et al. 2006; Yamahara et al. 2007). Finally, swimmers themselves can be a source of FIB and pathogens (e.g., Makintubee et al. 1987), especially at enclosed beaches where very young children play in the water. Given the variety of potential FIB sources, improving and maintaining good beach water quality is a challenge for beach managers.

The Clean Beach Initiative

Shortly after the BEACH Act was adopted, California established the Clean Beach Initiative (CBI) in 2001, which dedicated grant funding to the State's most polluted beaches for source control studies and capital projects to reduce beach fecal pollution (Gold 2005). Projects receiving grant funding typically comprised one to several best management practices (BMPs) designed to treat or divert contaminated water to remove impacts on nearby beaches. Ideally, successful projects would allow beaches to more consistently meet bathing water quality criteria, compared to preproject periods when beaches were frequently closed or posted with warnings about health risks to swimmers. To date, approximately $55.6 million has been allocated to 94 projects.

As part of the CBI program, an assessment was performed of 17 initial projects to determine if they effectively reduced densities of FIB at target beaches. These assessments provide opportunities to learn what projects successfully reduce beach pollution based on a range of strategies and give insights into the necessary ingredients for success. Several of these projects, such as those at piers or within enclosed beaches, had multiple BMPs. Three projects were located in central California with the remainder in southern California (Fig. 1). Projects fell into the following six categories (Table 1):

Diversions In most of California, the sanitary and storm water sewers are separate systems. Runoff entering the storm water system eventually will reach the ocean from coastal watersheds, collecting pollutants along the way. Low-flow diversions are designed to redirect runoff from beach waters into sanitary sewers for treatment at nearby sewage treatment facilities. They generally operate during the summer months when rainfall is limited and beach usage is the highest. Because of the relatively limited capacity of their

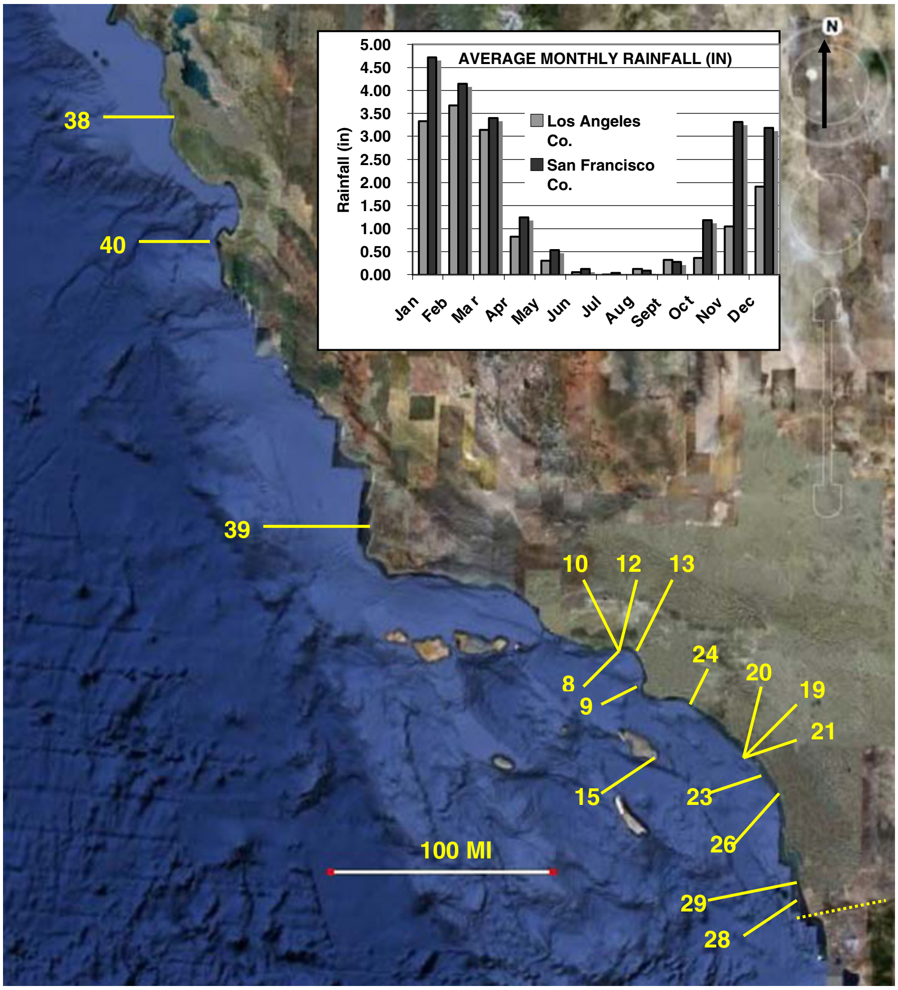

Fig. 1 Location of CBI projects assessed in this report and monthly average rainfall for San Francisco and Los Angeles Counties for the years 1961–2000. *Numbers* correspond to tabular entries in Table 1 (source of rainfall data, http://www.weather.com; image from Google Earth)

collection systems, most diversions operate only during the dry season, defined by California AB411 legislation as the period from April 1 through October 31. If rainfall occurs during this period, excess flows are bypassed around the system to the beach. Nearly half the projects assessed in this project were diversions, with a total of 21 diversions in eight separate projects (Table 1).

Sterilization facilities These projects intercept runoff in a waterway for disinfection using UV radiation, after which the treated effluent is discharged back into the drainage channel where it flows to the beach. In two of the three facilities (Moonlight Beach and Aliso Beach), the influent was filtered prior to UV treatment.

Pier BMPs A series of BMPs were employed at two piers in Santa Monica and Redondo Beach. BMPs focused on reducing organic wastes that attract birds, a significant source of FIB, to waters adjacent to the piers, including garbage disposals for fish carcasses and remains, as well as bird-proof trash cans. Other BMPs improved the containment of trash bins to prevent runoff and repaired or replaced leaking sewage pipes. In addition to these BMPs, an infiltration basin was constructed at the Redondo Pier to treat runoff from surrounding parking areas.

Enclosed beach BMPs Enclosed beaches typically have very poor water circulation, which exacerbates the persistence and growth of FIB in

Table 1 CBI projects included in this assessment; State Water Resources Control Board project numbers correspond with numbered locations on the map in Fig. 1

SWRCB project	Grantee	Project category	Affected beach
8 Santa Monica Pier	City of Santa Monica	Pier BMPs	Santa Monica State Beach
9 Redondo Beach Pier	City of Redondo Beach	Pier BMPs	Redondo Beach State Park
10 Temescal Canyon	City of Los Angeles	Diversion	Will Rodgers State Beach
12 Santa Monica Canyon	City of Los Angeles	Diversion	Will Rodgers State Beach
13 Imperial Highway	City of Los Angeles	Diversion	Dockweiler State Beach
15 Avalon	City of Avalon	Sewer Improvement	Avalon Beach
19 Dana Point	County of Orange	Mixed BMPs	Baby Beach
20 Aliso Beach	County of Orange	Sterilization Facility	Aliso Beach
21 Doheny	City of Dana Point	Diversions (2)	Doheny State Beach
23 Poche Beach	County of Orange	Sterilization Facility	Poche Beach
24 Huntington Beach	County of Orange	Diversion	Huntington State Beach
26 Moonlight Beach	City of Encinitas	Sterilization Facility	Moonlight State Beach
28b Imperial Beach	City of Imperial Beach	Diversion	Imperial Beach
29 Coronado Beach	City of Coronado	Diversions (12)	Coronado City Beach
38 Pacifica	City of Pacifica	Vegetative Swale	Linda Mar State Beach
39 Pismo Beach	City of Pismo Beach	Sewer Improvement	Pismo State Beach
40 Pacific Grove	City of Pacific Grove	Diversion	Lover's Point Beach

beach sands and waters (Ferguson et al. 2005; Lee et al. 2006; Yamahara et al. 2007). One project focused on reducing FIB densities at an enclosed beach, Baby Beach in Dana Point Harbor, using a series of BMPs including a parking lot vegetated swale and storm water infiltration system, bird-proof trash bins, bird exclusion netting beneath a small fishing pier, and a low-flow diversion.

Wetland swales One wetland swale project was implemented in Pacifica to treat runoff from the San Pedro Creek and two urban runoff pump stations. Runoff was redirected to soak into a swale planted with wetland species, preventing it from flowing into the surf zone along southern Linda Mar State Beach.

Sewer improvements This category included two projects. A lift station at Pismo State Beach was renovated to prevent sewage spills into Pismo Creek that had been impacting the beach. The second project, in the city of Avalon on Santa Catalina Island, involved slip-lining 3,068 m (10,065 linear ft) of sewer mains and 48 manholes. The Avalon project resealed the sewers, addressing the concern that sewage-contaminated groundwater was mixing with harbor water and impacting the beach.

Methods

The primary goal of each CBI project was to reduce densities of FIB in receiving waters, thus better protecting swimmers and other beach goers. Therefore, project effectiveness was assessed in receiving waters nearest the project site rather than at the project site itself. A before/after strategy described by Madge (2004) was used in which pre- and postproject mean densities of FIB (total and fecal coliforms, *Escherichia coli*, enterococci) were compared to determine project effectiveness. Only completed projects with at least 1 year of pre- and postproject shoreline monitoring data were used for this assessment. A similar method was used by Kinzelman et al. (2006) to assess effectiveness of a storm water infiltration and evaporation bed in reducing densities of FIB entering Lake Michigan. The evaluation used here focused on FIB as opposed to pathogens because these bacteria are the basis of most discharge permits and state and federal water quality standards, thus forming the basis for beach postings and closures.

Shoreline data

Assessments included FIB monitoring data collected by various public health agencies at routine shoreline monitoring stations. At these

Table 2 Shoreline monitoring information for each project including range of dates monitored, mean monthly rainfall for pre- and postproject periods, and source for rainfall data

Project	No. monitoring sites	Monitoring period		Mean monthly rainfall (in.)		NCDC COOP station[a]
		Preproject	Postproject	Preproject	Postproject	
Temescal Canyon	1	May 21, 2001 to Oct. 21, 2002	May 27, 2003 to Sep. 27, 2004	0.19	0.54	Santa Monica Pier
Santa Monica Canyon	1	Apr. 1, 2001 to Oct. 31, 2002	Apr. 1, 2003 to Oct. 31, 2004	0.19	0.67	Santa Monica Pier
Imperial Highway	1	Apr. 30, 2001 to Nov. 1, 2002	Apr. 2, 2003 to Oct. 16, 2004	0.35	0.78	Los Angeles Wso Arpt
Doheny	4	Apr. 3, 2001 to Sep. 9, 2003	Sep. 18, 2003 to May 12, 2005	0.82	1.71	Laguna Beach
Huntington Beach	2	May 1, 2001 to May 22, 2003	May 24, 2003 to May 31, 2005	0.62	0.84	Newport Beach Harbor
Imperial Beach	1	Apr. 4, 2002 to Sep. 28, 2004	Oct. 26, 2004 to Aug. 1, 2006	0.44	1.02	Chula Vista
Coronado Beach	2	Apr. 30, 2002 to Apr. 26, 2004	Apr. 29, 2004 to Apr. 27, 2006	0.53	0.94	Chula Vista
Pacific Grove	1	Apr. 1, 2002 to May 17, 2004	May 24, 2004 to Apr. 24, 2006	1.39	1.63	Monterey
Aliso Beach	1	Apr. 3, 2001 to Jul. 30, 2003	Jul. 31, 2003 to Jun. 21, 2005	0.58	0.89	Laguna Beach
Poche Beach	1	Apr. 15, 2003 to Oct. 14, 2003	Apr. 19, 2004 to Oct. 15, 2004	0.23	0.33	Laguna Beach
Moonlight Beach	1	Apr. 3, 2000 to Aug. 6, 2002	Sep. 3, 2002 to Oct. 26, 2004	0.52	0.93	Oceanside Marina
Santa Monica Pier	1	Apr. 1, 2003 to Oct. 31, 2003	Apr. 1, 2004 to Oct. 31, 2004	0.03	0.79	Santa Monica Pier
Redondo Beach Pier	1	Apr. 1, 2003 to Oct. 31, 2004	Apr. 1, 2005 to Aug. 8, 2006	0.87	0.57	Torrance
Dana Point	4	Oct. 2, 2003 to Jul. 13, 2004	Oct. 4, 2005 to Jul. 13, 2006	0.48	0.4	Laguna Beach
Pacifica	1	Apr. 28, 2002 to Apr. 26, 2004	May 3, 2004 to Oct. 31, 2005	2.57	2.35	Pacifica
Avalon	2	Apr. 3, 2000 to Apr. 29, 2002	May 6, 2002 to May 24, 2004	0.86	0.77	Los Angeles Wso Arpt[b]
Pismo Beach	2	Apr. 2, 2001 to Sep. 17, 2003	Sep. 18, 2003 to Jun. 21, 2005	0.75	1.44	Pismo Beach

NCDC Coop Station National Climatic Data Center Cooperative Station

[a] Historic monthly rainfall data available from Western Regional Climate Center (http://www.wrcc.dri.edu/Climsum.html)

[b] Missing data records for Avalon Pleasure Pier during monitoring periods

sites, water samples were collected at ankle depth (≤ 0.3 m) as practiced by all sanitation and health agencies and discussed by Griffith et al. (2007). One to four monitoring sites were selected that were positioned closest to a project where sampling was conducted on a daily to weekly basis (Table 2). Multiple sites were used when possible to gain better resolution of pre-/postproject differences and usually were within a mile of one another. Depending on the monitoring agency, sampling was either performed throughout the year or was restricted to the dry season defined as the period April 1 through October 31. Also given in Table 2 are time periods over which monitoring data were collected for each project and the mean monthly rainfall for pre- and postproject periods.

Testing agencies used collection and testing methods as defined by the following APHA Standard Methods (2005): sample collection (SM 9060A,B), membrane filtration for total coliforms (SM 9222B), fecal coliforms (SM 9222D), and *E. coli.* (SM 9213D m-TEC Modified EPA). Enterococci were tested using membrane filtration according to EPA 1600 (US EPA 2006b).

Some agencies switched from membrane filtration to defined enzyme substrate methods (SM 9223) using Idexx® test kits (http://www.idexx.com) based on intercalibration studies associated with regional shoreline monitoring (Griffith et al. 2006) and with approval from California regulatory agencies and the EPA. Monitoring agencies substituted the Idexx results directly with those from membrane filtration although Griffith et al. (2006) found that the Idexx tests underestimated the other methods by around 10% since it directly measures *E. coli* rather than the broader fecal coliform group.

Data analyses

We tested for differences between FIB group median densities in pre- and postproject periods using a *t* test on $\log_{10}$-transformed data to account variance associated with FIB data (Quinn and Keough 2002). Only data from the dry season, defined as the period April through October in California receiving-water discharge permits, were used in the pre- and postproject implementation comparisons.

Because most of the BMPs assessed do not operate during wet weather, rainy days were excluded from the analyses using the following procedure. Rain days to be removed from the data were first identified from preliminary archived climate data available through National Weather Service stations closest to a project site. In the Los Angeles area, for example, rainfall data were obtained from Los Angeles International Airport (LAX) as reported by the Los Angeles-Oxnard NWS office (see preliminary climatology data at http://www.weather.gov/climate/index.php?wfo=lox). If data were earlier than 2004, then archived records available from the Western Regional Climate Center (http://www.wrcc.dri.edu/Climsum.html) were obtained from the nearest remote automated weather station. The day of rain plus the three subsequent days then were removed from the data set to avoid the influence of rain events.

Results

Diversions

The goal of the diversion projects was to divert runoff to the local sewage treatment plant, thus preventing ponding of contaminated water on the beach and contamination of mixing zones ocean water. Flows of contaminated runoff treated ranged from 189.3 m^3/day for the Santa Monica Canyon low-flow diversion to a low of 1.14 m^3/day for the small diversion at Baby Beach in Dana Point Harbor (Table 3). This range of flow volumes places most of the diversion projects at the lower end of the 17 assessed projects, whose collective dry-season flow averaged 770.2 ± 928.2 m^3/day.

Of the 14 monitoring sites associated with diversion projects, FIB densities for all three bacteria groups were reduced during postproject periods by 71% (Tables 4 and 5). Diversions at Santa Monica and Temescal Canyons were the most successful in that densities of all FIB groups were reduced after the projects were implemented, as were most exceedances of FIB standards for single sample criteria (Table 6).

Table 3 Maximum flows as million gallons/day or cubic meters/day diverted or treated by projects when operating during the dry season (April 1–October 31)

SWRCB project	mg/day	m^3/day
8 Santa Monica Pier	N/A	N/A
9 Redondo Beach Pier	0.0500	189.27
10 Temescal Canyon	0.1403	531.25
12 Santa Monica Canyon	0.8590	3,251.67
13 Imperial Highway	0.0060	22.71
15 Avalon	N/A	N/A
19 Dana Pt (Baby Beach)	0.0003	1.14
20 Aliso Beach	0.1000	378.54
21a Doheny Beach (N. Creek)	0.0199	75.37
21b Doheny Beach (Alipaz)	0.0388	146.80
23 Poche Beach	0.4070	1,540.66
24 Huntington Beach	0.4970	1,881.35
26 Moonlight Beach	0.1930	730.58
28b Imperial Beach	0.0018	6.81

The numbers preceding each project are the SWRCB's numerical designation for the project

Successful diversion projects tended to divert nearly all runoff impacting the target beach. During rain events, diversions did not operate, bypassing runoff to the beach with consequential increases in FIB densities. In projects where FIB densities were not significantly reduced, sources of FIB (usually untreated runoff) other than those diverted by the project impacted the beach. For example, despite the two diversion projects, enterococci along Doheny beach actually increased in mean density during the postproject monitoring period, although peak densities decreased as reflected by fewer exceedances of bathing water standards for this group (Table 6). The North Creek storm drain and San Juan Creek discharge onto Doheny State Beach. Increased FIB densities most likely were associated with runoff from these two drainage systems, especially during the postproject period when monthly rainfall averaged 1.71 in., an increase of 0.89 in. from the preproject monitoring period (Table 2).

Sterilization facilities

Of the three sterilization facilities, only the project at Moonlight Beach successfully reduced densities of fecal coliforms ($p < 0.05$) and enterococci ($p < 0.05$; Tables 3 and 4) and exceedances of standards criteria (Table 6) during the postproject period. Comparison of design features at the three facilities suggests that key criteria for success are the level of treatment provided, the distance from the effluent discharge point to the beach, and whether effluent was allowed to pond on the beach. The greatest percent removal efficiencies were obtained by the two facilities incorporating filtration in the treatment prior to UV sterilization (Aliso and Moonlight Beach; Table 7). This treatment train reduced FIB in influent by >95% (Table 7). The distance between the facility's effluent discharge point and the beach-mixing zone was critical. Treated effluent became recontaminated within a few hundred meters after discharge back into the waterway; thus, the further the discharge point was from the beach, the more likely for recontamination to occur. This was especially apparent on Aliso Creek where clean effluent from the disinfection facility was rapidly recontaminated to creek background levels within 7.6 m downstream of the discharge point (Anderson 2005) with no obvious inputs from other sources. Finally, water allowed to pond on the beach becomes further contaminated by FIB from sources such as birds or sediment-dwelling populations of FIB.

The Moonlight Beach facility, operated by the City of Encinitas, was the most successful given its FIB removal efficiencies averaging >99% (City of Encinitas 2006), the relatively short distance from the facility to the mixing zone (250 m), and the absence of ponding on the beach (Table 7). In contrast, the small facility at Poche Beach consisted only of a UV cabinet positioned inside the Poche Creek storm drain (Volz 2005). Although the distance to the surf zone was only 61 m, the relatively lower removal efficiencies (Table 7; 70–82%) and presence of a beach pond probably allowed for rapid recontamination of the treated effluent.

Pier BMPs

The pier BMPs reduced the density of one or two groups of FIB (Tables 4 and 5). This marginal success reflected the fact that BMPs controlled only some of the many sources of FIB associated with these structures. It is especially difficult to control runoff flowing from the piers during

Table 4 Mean densities of pre-and postproject FIB densities at shoreline monitoring sites for each project

Clean Beach Initiative project	Nearest shoreline monitoring station(s)	Total coliforms						Fecal coliforms						Enterococci					
		Preproject			Postproject			Preproject			Postproject			Preproject			Postproject		
		Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*
Diversions																			
10 Temescal Canyon	DHS103	391.6	461.7	53	166.7	271.1	50	53.5	128.0	52	24.3	25.5	50	63.9	102.3	51	45.2	67.7	50
12 Santa Monica Canyon	S4	605.5	1,633.0	406	172.9	485.5	389	115.0	248.7	405	55.3	103.6	389	85.3	153.5	64	18.5	35.1	66
13 Imperial Highway	S12	151.9	990.7	407	148.7	1,047.0	391	16.8	51.5	407	39.1	39.4	391	13.5	13.5	66	7.3	14.3	64
21 Doheny	ODB02	694.5	2,590.0	73	605.3	1,419.0	43	159.7	443.5	73	411.2	1,122.0	43	139.2	309.7	74	845.7	2,972.0	43
	OCS2	398.3	2,251.0	88	212.4	627.7	75	168.7	904.3	88	87.1	247.7	75	249.2	1,637.0	88	382.5	2,012.0	75
	OCS0	1,537.0	3,993.0	138	966.8	2,830.0	81	688.4	2,201.0	138	676.6	2,336.0	82	408.7	1,026.0	138	781.2	2,921.0	82
	OCS1	168.9	597.3	138	142.4	345.8	80	78.7	287.0	139	89.7	264.3	80	86.7	168.3	139	112.5	276.6	80
24 Huntington Beach	0	109.3	1,046.0	234	174.3	1,334.0	231	101.9	1,040.0	236	68.0	203.8	231	15.3	45.2	236	27.1	62.5	231
	N6	281.0	1,496.0	241	133.1	455.2	226	269.9	1,503.0	237	125.2	451.0	226	45.6	105.4	237	39.2	76.9	227
	N12	69.0	238.0	236	32.5	37.1	226	64.8	235.7	240	27.6	26.7	226	18.0	31.4	238	10.0	15.0	226
28b Imperial Beach	EH030	291.8	1,966.0	66	1,303.0	4,342.0	34	90.0	377.9	66	37.1	66.9	58	12.9	17.5	66	10.0	10.5	34
29 Coronado Beach	EH050	26.1	20.0	99	24.5	32.2	80	23.3	13.3	99	20.7	22.4	80	12.7	9.1	99	11.5	26.0	80
	IB080	56.6	101.4	137	107.9	720.8	136	20.8	42.9	139	21.9	55.3	137	19.7	86.0	139	12.2	17.7	137
40 Pacific Grove	MON40	94.9	163.0	56	56.4	90.6	45	43.3	63.6	56	34.6	69.0	33	12.5	7.4	56	13.2	14.4	33

Sterilization facilities																			
20 Aliso Beach	OSL09	57.4	114.8	116	78.5	142.7	116	19.6	67.9	117	14.5	27.6	85	21.2	59.4	117	30.4	135.2	85
23 Poche Beach	OCB15	350.4	762.5	58	397.5	581.8	48	71.3	123.2	53	100.5	204.3	48	85.6	220.1	54	125.4	296.7	48
26 Moonlight Beach	EH420	397.2	618.8	91	443.8	1,766.0	87	93.4	157.3	91	67.8	161.8	87	85.2	207.9	91	57.4	225.2	87
Pier BMPs																			
8 Santa Monica Pier	S5	299.9	523.0	194	316.7	1,308.0	196	158.0	243.0	194	134.0	154.0	196	25.0	48.0	33	16.0	14.0	32
9 Redondo Beach Pier	S16	929.1	2,413.0	360	600.4	866.2	213	294.2	960.0	360	330.3	579.0	213	37.6	91.9	56	38.2	55.5	213
Enclosed beach BMPs																			
19 Dana Point	BDP12	336.6	588.6	32	126.9	199.3	26	123.1	244.7	32	61.5	97.6	26	65.6	77.8	32	70.5	193.7	26
	BDP13	424.7	1,455.0	34	80.5	109.4	22	282.4	1,228.0	34	45.9	79.7	22	231.4	874.1	33	19.7	24.6	23
	BDP14	168.1	178.5	31	120.9	221.2	23	81.9	110.6	31	71. 3	158.4	24	101.8	197.8	31	33.5	70.8	24
	BDP15	1,476.0	4,533.0	28	329.2	1,087.0	24	358.3	1,008.0	29	25.4	24.8	24	177.8	506.9	29	31.0	37.8	27
Wetland swales																			
38 Pacifica	SMC50	757.7	3,510	47	157.3	179	38	35.8	37.1	47	24.9	26.4	38	21.7	32.3	47	16.3	25.3	38
Sewer improvements																			
15 Avalon	DHS118	614.4	1,402.0	60	687.8	3,330.0	52	156.1	156.1	60	132.4	163.1	52	182.8	314.7	58	55.8	81.8	52
	DHS120	373	502.9	61	495.6	1,641.0	52	113.3	177.1	61	121.3	118.2	52	65.2	138.1	59	52.5	53.8	52
39 Pismo Beach	PB3	108.4	116.0	89	115.6	127.7	96	63.1	94.7	83	71.5	72.8	88	13.2	9.4	85	26.6	53.0	94
	PB4	232.8	351.4	89	418.3	903.0	112	95.9	145.7	85	249.9	420.4	103	15.4	19.0	90	30.1	50.9	102

Means were based on data collected during dry seasons (April–October) with rain days (plus three subsequent) excluded

Table 5 Ratios of mean FIB densities between pre- and postproject periods at shoreline sampling stations; based on dry periods (April–October) with rain days excluded

Project	Station	Total coliforms			Fecal coliforms			Enterococci		
		Pre-/ post ratio[a]	*df*	p[b]	Pre-/ post ratio[a]	*df*	p[b]	Pre-/ post ratio[a]	*df*	p[b]
Diversions										
10 Temescal Canyon	DHS103	2.40	101	0.0018*	2.20	100	0.0313*	1.40	99	0.0883
12 Santa Monica Canyon	S4	3.20	793	< 0.0001*	2.00	792	0.0482*	4.70	128	< 0.0001*
13 Imperial Highway	S12	1.00	796	< 0.0001*	0.40	796	< 0.0001*	1.90	128	0.3248
21 Doheny	ODB02	1.15	114	0.6613	0.39	115	0.8474	0.16	115	0.5008
	S-2	1.88	161	0.2124	1.94	161	0.1423	0.65	161	0.7521
	S-0	1.59	217	0.3764	1.02	218	0.8852	0.52	218	0.8695
	S-1	1.19	216	0.8903	0.88	217	0.9191	0.77	217	0.9287
24 Huntington Beach	0	0.63	463	0.0134*	1.50	465	0.0316*	0.56	465	0.0145*
	N6	2.11	465	0.0726	2.16	461	0.0141*	1.16	462	0.9591
	N12	2.12	460	0.0012*	2.35	464	0.0001*	1.80	462	< 0.0001*
28b Imperial Beach	EH030	0.22	98	< 0.0001*	2.43	122	0.1358	1.29	98	0.0004*
29 Coronado Beach	EH050	1.07	177	0.0056*	1.12	177	< 0.0001*	1.10	177	< 0.0001*
	IB080	0.52	285	0.3341	0.94	289	0.5161	1.61	289	0.4393
40 Pacific Grove	MON40	1.68	99	0.1270	1.25	87	0.2274	0.95	87	0.0851
Sterilization facilities										
20 Aliso Beach	OSL09	0.73	230	0.1003	1.35	200	0.6773	0.70	200	0.7884
23 Poche Beach	OCB15	0.88	100	0.3026	0.71	99	0.4551	0.68	100	0.0985
26 Moonlight Beach	EH420	0.89	176	0.1832	1.34	176	0.0246*	1.48	176	0.0042*
Pier BMPs										
8 Santa Monica Pier	S5	1.18	388	0.1404	0.80	388	0.0515	1.18	63	0.5647
9 Redondo Beach Pier	S16	1.54	571	0.0954	0.89	571	< 0.0001*	0.98	267	0.1512
Enclosed beach BMPs										
19 Dana Point	BDP12	2.65	56	0.1160	2.00	56	0.1907	0.93	56	0.3453
	BDP13	5.28	54	0.0083*	6.15	54	0.1744	11.70	54	0.0129*
	BDP14	1.39	52	0.0433*	1.15	53	0.2842	3.04	53	0.0269*
	BDP15	4.48	50	0.1586	14.10	51	0.0205*	5.74	54	0.0992
Wetland swales										
38 Pacifica	SMC50	4.82	83	0.1890	1.44	83	0.1457	1.33	83	0.1179
Sewer improvements										
15 Avalon	DHS118	0.89	110	0.1152	1.17	110	0.2153	3.28	108	0.0026*
	DHS120	0.75	111	0.7881	0.93	111	0.1407	1.24	109	0.8625
39 Pismo Beach	PB3	0.94	183	0.7079	0.88	169	0.6669	0.50	177	0.0389*
	PB4	0.56	199	0.1215	0.38	186	0.0143*	0.51	190	0.0032*

* = significant at $p < 0.05$

[a] Ratio of pre- to postmean density for each FIB group where 1.0 = no change, <1 = increased postproject densities, >1.0 = decreased postproject densities

[b] Probability value from *t* test of log-10 transformed data between pre- and postproject means

Table 6 Total exceedances of California bathing water standards for single sample criteria during pre- and postproject periods

CBI project	Total coliforms (10,000 MPN/100 ml)		Fecal coliforms (400 MPN/100 ml)		Enterococci (103 MPN/100 ml)	
	Preproject	Postproject	Preproject	Postproject	Preproject	Postproject
Temescal Canyon diversion	0	0	1	0	7	5
Santa Monica Canyon diversion	3	0	27	2	14	2
Imperial Hwy diversion	2	1	3	1	2	0
Doheny diversions	10	4	38	32	127	66
Huntington diversion	3	1	22	23	34	40
Imperial Beach diversion	1	1	3	1	1	0
Coronado diversions	0	0	0	1	5	2
Pacific Grove diversion	0	0	0	0	0	0
Aliso Creek disinfection facility	0	0	1	5	5	3
Poche Beach disinfection facility	0	0	2	3	2	2
Moonlight Beach disinfection facility	0	1	5	3	16	6
Santa Monica Pier projects	0	2	17	17	1	0
Redondo Beach Pier projects	1	0	48	52	3	17
Dana Point projects	1	0	9	3	28	7
Pacifica vegetated swale	1	0	0	0	2	1
Avalon sewer project	0	1	10	6	30	15
Pismo Beach sewer project	0	0	4	8	0	8

Criteria are given in the column caption for each FIB group

wash-down cleaning activities and the impact of birds attracted to these structures. With regard to exceedances of single sample criteria, there was relatively little change at Santa Monica Pier, but at Redondo Pier, postproject exceedances increased from three to 17 for enterococci.

Enclosed beach BMPs

After implementing the Baby Beach BMPs in Dana Point Harbor, postproject FIB densities fell at nearly all four of the shoreline monitoring stations (Tables 4 and 5), with all FIB groups displaying a significant decrease (Table 5; $p < 0.05$) at one or two of the four monitoring sites. Exceedances of FIB standards for single samples followed a similar trend, especially for enterococci (Table 6).

Wetland swales

The project at Pacifica, incorporating wetland swales to infiltrate and treat runoff, reduced density of all FIB groups (Tables 4 and 5), although none of the reductions were significant (Table 5;

Table 7 Summary of removal efficiencies and characteristics for UV sterilization facilities

Mean FIB (MPN)	Aliso Creek (filtration, UV)		Poche Creek (UV)		Moonlight Beach (filtration, UV)	
	Influent ($n = 15 - 16$)	Effluent ($n = 15 - 16$)	Influent ($n = 8$)	Effluent ($n = 8$)	Influent ($n = 163$)	Effluent ($n = 163$)
Total coliforms	149,500	4,504	105,167	24,750	16,155	5
Fecal coliforms	105,600	943	44,737	16,999	1,432	3
Enterococci	31,630	810	72,550	17,566	773	3
%Reduction						
Total coliforms	0.97		0.76		>0.99	
Fecal coliforms	0.99		0.62		>0.99	
Enterococci	0.97		0.76		>0.99	
Distance from beach (m)	10,200		61		250	
Outlet type	Pond		Pond		Channel	
FIB reduced?	No		No		Yes	
Source of data	Anderson (2005)		Volz (2005)		City of Encinitas (2006)	

$p > 0.05$). FIB exceedances of the single sample criteria were slightly reduced (Table 6) although preproject exceedances initially were very low for the beach.

Sewer improvements

The two sewer improvement projects had mixed results. Despite reconstruction of the lift station at Pismo Beach, postproject densities at two shoreline stations at Pismo State Beach increased (Table 4), some significantly (Table 5; fecal coliforms and enterococci at station PB4), as did exceedances of standards for fecal coliforms and enterococci (Table 6). The Avalon slip-lining project was more successful in that fecal coliforms and enterococci were reduced at two shoreline sites (Table 5), with significant ($p < 0.05$) reductions for enterococci at one site (Table 5). Along Avalon's beach, both fecal coliforms and enterococci displayed corresponding drops in postproject exceedances of standards (Table 6).

Discussion

The 17 CBI projects assessed in this report are grouped into categories based on their overall success at increasing compliance with standards and lowering postproject densities of FIB along their respective target beaches (Fig. 2). The most successful projects were those that captured and reduced or eliminated all major sources of FIB impacting beach waters. Half of the low-flow diversions were successful because all runoff was diverted from beaches to local sewage treatment facilities. The remaining diversions were less successful at reducing FIB pollution in receiving waters if the target beach was impacted by other uncontrolled sources such as runoff, bird, and other animal feces, or FIB regrowth in sediments and water. Good examples of less effective diversions were at Huntington State Beach that is impacted by runoff from the Santa Ana River and Talbert Marsh and Doheny State Beach at the mouth of San Juan Creek.

Diversion facilities typically are operated only during the dry season from April through October. Outside this period, there are many dry-weather days when people are swimming and surfing and are potentially exposed to contaminated runoff. Some coastal municipalities, such as the City of Los Angeles, are addressing this risk by upgrading their low-flow diversions to operate year round. This upgrade will be accomplished by installing automated systems that shut off during initial stages of a storm when capacity in the sewer reaches a set level. After the storm passes and volumes of sewage and

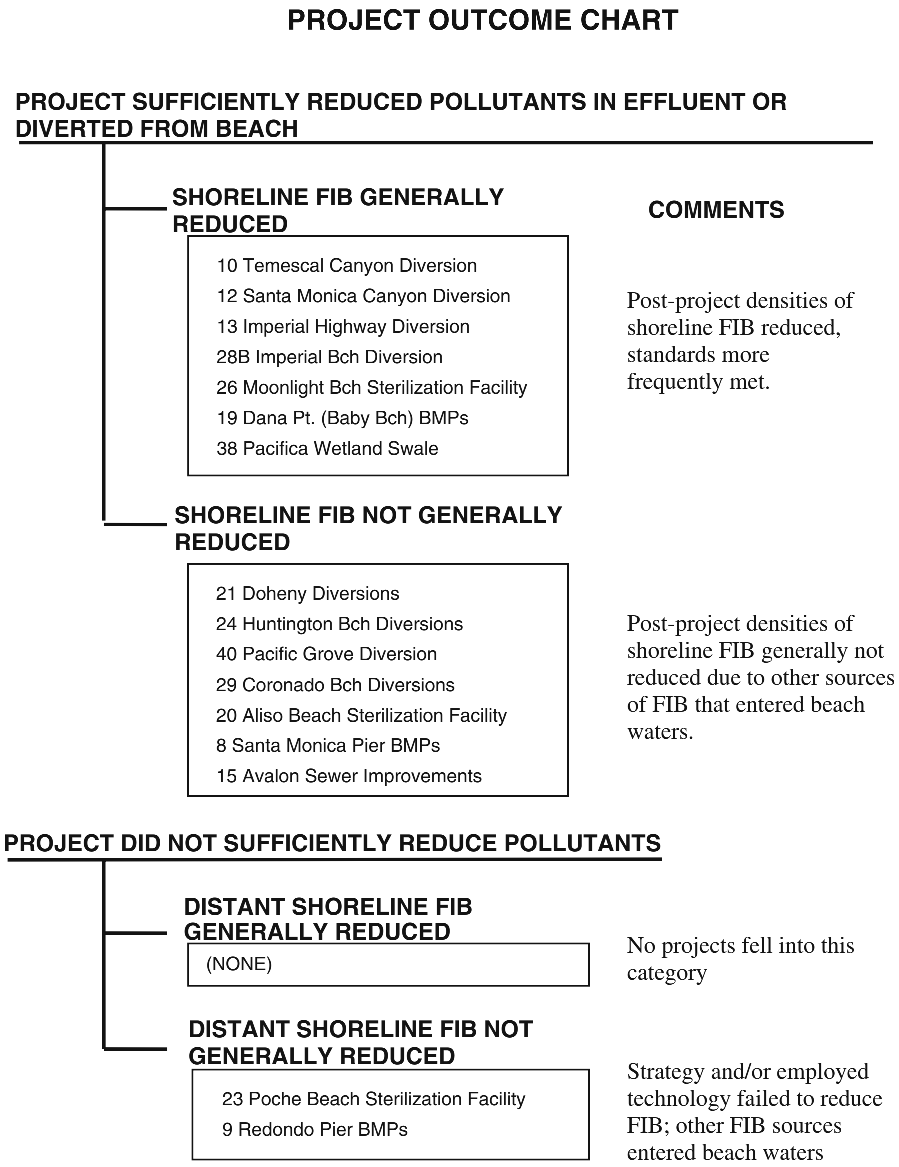

Fig. 2 Relative success of the 17 CBI projects based on lowering of FIB densities at shoreline stations (Table 5) and meeting single-sample water quality criteria (Table 6). *Numbers* preceding the project name refer to the SWQCB designation (Table 1)

infiltrated runoff in the collection system drop to acceptable levels, then the diversions will be reactivated. Other municipalities using low-flow diversions should work with their sewage agencies to adopt similar strategies, thus significantly reducing health risks during dry winter days. For example, based on National Weather Service rainfall records from Los Angeles Airport during the winter of 2007–2008 (http://www.weather.gov/climate/index.php?wfo=lox), diversions could have been operating for 82 out of a possible 152 days, or 54% of the winter period. The nonoperational days included the day of rain plus three subsequent to allow flows in the sanitary sewers to return to normal levels.

Rainfall in central and northern California is greater than that of southern California. Based on rainfall records for the period 1971–2000, the mean monthly rainfall (inches) for San Francisco County was 1.86 in. compared to 1.26 in. in Los Angeles County (Table 1). Considering the winter of 2007–2008, diversions in the San Francisco coastal area could have been operating for a total of 72 out of 152 days, or 47% of the time. Operational days in this example were only ten fewer for San Francisco than Los Angeles. This example, however, is based on a "dry year" typical of a La Niña climatic condition when winters in California are cooler and drier than normal. In contrast, climatic conditions can shift into much warmer and wetter winters, particularly in southern California, when El Niño events periodically occur. When beach managers are deciding whether or not to install low-flow diversion systems, they need to balance the potential operational days given climatic swings between dry and wet winters with reduced risk to swimmers by diverting contaminated runoff.

The wetland swale project was very successful, but more projects of this type must be implemented to better judge their success at filtering runoff and reducing FIB densities along beaches. Evidence from other studies, summarized by Rifai (2006), shows that constructed wetlands successfully reduce FIB densities. He reported that average wetland efficiency at reducing pathogenic organisms and FIB was 88.3% ($n = 15$ studies). The dominant mechanisms removing these organisms were adsorption/settling/sedimentation processes, death from visible and UV light, and competition and predation from other microorganisms. Muthukrishnan et al. (2004) describe how vegetated swales, small treatment wetlands, and other biofiltration systems are being used more frequently to infiltrate and remove contaminants in runoff, especially in urban settings. In contrast, Grant et al. (2001) found that enterococci emerging from the Talbert Marsh, a saltwater marsh in southern California, impacted the surf zone of the adjacent Huntington Beach. The source of these bacteria most likely was from urban runoff and bird activity. However, as more of the contaminated runoff impacting the Talbert Marsh was diverted into the sewers for treatment during dry weather, the levels of enterococci and other bacterial indicators fell, demonstrating the cleansing action of the marsh system Jeong et al. (2008).

Overall, utilizing vegetated areas and wetland systems would appear to effectively protect beaches from FIB contamination in coastal watersheds having suitable land for locating projects. The added value to this type of BMP is increased habitat for wetland biota, especially birds, and the corresponding aesthetic appeal.

Sterilization facilities appear promising provided that the influent is pretreated with filtration to reduce suspended solids prior to UV disinfection, the discharge point is as close to the surf zone as possible, and the effluent is not allowed to pond on the beach. The Moonlight Beach UV facility combined these design features to significantly lower FIB counts at the beach.

Pretreatment filtration in sterilization facilities is needed to reduce suspended solids that can shield microorganisms from UV radiation. Both the Aliso Creek and Moonlight Beach facilities employed the use of multimedia filters that remove particles as small as 20–50 μm. However, bacteria and viruses not attached to larger particles would still pass through the filters, thus requiring the effluent to pass through a UV or other disinfection stage. Both facilities achieved removal efficiencies exceeding 97% for all indicator groups (Table 7) compared to the facility at Poche Beach (62–76% removal efficiency) that lacked a pretreatment filtration. While both facilities at Aliso Creek and Moonlight Beach achieved removal efficiencies ≥97%, effluent from the Aliso facility still did not meet water quality criteria for two of the FIB groups. This result may reflect the greater concentration of FIB in the influent treated by Aliso relative to that at Moonlight Beach and also engineering and operational details of the filtering and UV systems.

Even though a disinfection facility can produce good quality effluent, the cleaned water can be recontaminated by FIB after discharge back into the waterway from a variety of sources. In studying a small subwatershed in southern California, Jiang et al. (2007) found that the major contributors to fecal coliforms in downstream reaches were droppings from birds and other wildlife, soil amendments, and regrowth of these bacteria within the storm drains. This situation was demonstrated by Anderson (2005) for the UV facility on Aliso Creek where cleaned runoff became rapidly recontaminated within meters of the discharge point, thus limiting its ability to reduce FIB densities at the receiving beach. The potential for regrowth is high not only in waterways but also in beach ponds where the water can stagnate, becoming further contaminated by FIB populations residing in sediments (e.g., see Desmarais et al. 2002; Ferguson et al. 2003, 2005; Yamahara et al. 2009) and within the water column (Jiang et al. 2007). Therefore, when designing a disinfection facility, factors such as levels of natural turbidity, distance to the beach, and regrowth potential must be considered.

Other categories of projects were less successful mainly because they focused on only one or a few sources of contamination when many were present. Piers are challenging given the variety of FIB sources such as feces from birds, rodents, growth on organic matter from fish cleaning and discarded bait, domestic pets, leaks from aging sewer systems, and runoff from trash containment areas. Bird feces could be a prime source of fecal material, driving up FIB densities on the piers and in surrounding water (e.g., see Alderisio and DeLuca 1999; Ricca 1998), and are difficult to control. The sewer improvement projects may have repaired local problems in the collection systems, but other sources of FIB still remained uncontrolled.

The ultimate goal of these projects is to increase the safety of swimmers, surfers, and other beach users by reducing or eliminating pathogens from the water. Overall water quality in California has improved since passage of the Clean Water Act in 1972 owing to improvements in sewage treatment and disposal and implementation of State and Federal regulations to control nonpoint runoff pollution. Sources of fecal contamination to California's inshore coastal waters therefore have shifted from the disposal of sewage effluent via offshore outfalls to nonpoint runoff, particularly from developed watersheds (Dojiri et al. 2003). For example, in the waters offshore Huntington Beach, California, Boehm et al. (2002) noted that levels of fecal coliforms fell over the past 43 years, but transient poor water quality did exist around storm drains, river outlets, and adjacent submarine outfalls. Water quality improvements continue to be made as programs like the CBI are implemented to control runoff pollution, but these improvements are realized mainly during the dry season.

The new challenge for storm water programs will be to reduce risk to beach users, particularly surfers, during wet weather. During winter conditions, Noble et al. (2003) found that the percentage of southern California coastline meeting water quality criteria fell from 95% to 60% as contaminated runoff impacted greater stretches of coastline. Surfers were shown to experienced higher rates of illness during wetter winters and at beaches in urbanized watersheds (Dwight et al. 2004). Reducing FIB in storm runoff to meet water quality criteria may prove to be impossible given the uniqueness of FIB on surfaces throughout watersheds and the volumes encountered (Surbeck et al. 2006), at least for end-of-pipe projects like diversions and filtration/sterilization facilities described in this paper. Perhaps the best approach in reducing FIB and potential pathogens in runoff will be by increasing the use of vegetated areas and treatment wetlands throughout urban watersheds. Using methods similar to those of Jeong et al. (2008), engineered wetlands could be properly sized to determine their carrying capacity for contaminated runoff. A side benefit would be the great esthetic appeal of such areas and their use by migrating and resident biota.

Conclusion

Of the 17 projects assessed for their effectiveness in reducing densities of fecal indicator bacteria in beach receiving waters, the most effective were low-flow diversions and a wetland swale that removed all contaminated runoff from beach waters. Ultraviolet sterilization was effective provided runoff was first filtered to reduce suspended solids, and effluent was released close to the surf zone to avoid FIB regrowth. Other projects, such as pier BMPs and sewer improvements, had limited success because receiving beach waters were impacted by other sources of FIB from contaminated runoff, regrowth in sediments or water, or feces from birds and other animals. Lessons learned from this assessment can be used to better design the BMPs to enhance their operations and to reduce beach pollution.

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