Effect of temporal sampling frequency on shoreline microbiology assessments

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ABSTRACT

More than 80,000 shoreline bacteriological samples are collected annually in southern California to protect beachgoer health, but sampling frequency varies from daily to monthly among sampling sites. To assess the effectiveness of various sampling frequencies, we used the last five years of data from 24 Los Angeles area sites that are monitored daily to simulate five alternative sampling strategies: five weekdays, five days per week including a weekend day, three days per week, weekly, and monthly. In each of these sampling strategies, we included in the simulation the local custom of adaptive sampling, in which a site is resampled the following day if bacterial concentrations exceed the State of California's beach water quality standards. We found that sampling five times per week resulted in observing about 80% of the events in which State standards were exceeded. This frequency dropped to 55, 25, and 5% for three times per week, weekly, and monthly sampling, respectively. Adaptive sampling was not completely effective because nearly 70% of the water quality exceedences were single-day events, even at the most frequently contaminated sites.

INTRODUCTION

Water quality is measured at beaches throughout the country to protect beachgoers from the potential influence of human activity, such as surface runoff, wastewater discharge, and industrial inputs. Although there are federal initiatives to standardize these efforts, most of the programs are presently conducted independently by numerous county health departments, resulting in inconsistencies in program implementation. A review of southern California beach monitoring programs found differences in the number of indicators measured, measurement methods used, and frequency of monitoring (Schiff *et al.* in press). A recent U.S. EPA (2000) survey of beach monitoring throughout the country seems to mimic these differences.

One of the greatest differences found among programs is in sampling frequency. Most monitoring is conducted on a weekly to monthly basis, although no studies have been conducted to evaluate the effectiveness of these different temporal strategies. Twenty-four beach sites in Los Angeles County are monitored daily, providing a unique opportunity to assess the effectiveness of less frequent sampling strategies. Here we sample from those data to assess the extent to which public health is protected using five lesser measurement frequencies presently being employed at other beaches in southern California.

METHODS

Five years of data (January 1, 1995, through December 31, 1999) from 24 Los Angeles County beach sites that are sampled seven days per week were used in the analysis. Eleven of these sites are located on coastal beaches 50 yards from freshwater outlets that drain urban runoff, eleven are located on coastal beaches distant from an urban drain, and two are on a protected beach located inside of the Los Angeles Harbor breakwater. Total coliforms are measured using membrane filtration at each of these sites, while fecal coliforms are measured using membrane filtration at 20 of the sites.

We simulated four sampling frequencies: five days per week, three days per week, weekly, and monthly. The five–days-per-week simulation was conducted using two

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different selectors: (1) all weekdays and (2) Monday through Thursday plus Saturday. The three-days-per-week simulation was conducted using Monday, Wednesday, and Friday as sampling days. The once-per-week sample was taken on Thursday and the monthly sample was taken on the first day of every month. The sampling days were chosen to mimic sampling strategies employed in southern California, although examination of the data revealed little difference among the days of the week in the frequency of bacterial standard exceedences. In each of these simulations, we mimicked the local custom of temporal adaptive sampling, in which a site is resampled the following day if bacterial concentrations exceed the State of California's beach water quality standards. Daily sampling continues until no standards are exceeded.

To assess the effectiveness of these different temporal sampling strategies, we compared the number of exceedences of State of California Health Department beach water quality thresholds that were detected with daily sampling (100% of exceedence detection) to that detected using the other temporal sampling schemes. The State thresholds used were the following single-sample values: (1) total coliform >10,000 organisms per 100 mL, or (2) fecal coliform >400 organisms per 100 mL.

RESULTS

Sampling five times per week resulted in missing approximately 20% of the total or fecal coliform exceedences (Tables 1 and 2). The effect of sampling one of the five days on a weekend, as is the practice at some southern California sites, was negligible. Sampling three times per week resulted in missing approximately 45% of the threshold exceedences observed when sampling daily. Sampling once per week resulted in missing approximately 75% of the exceedences. Sampling once per month missed approximately 95% of the exceedences.

These results were relatively consistent across stations and indicators (Tables 1 and 2). The number of actual exceedences at the stations used in our analysis ranged from 5/year to more than 100/year. For only two of these sites did weekly sampling identify even 40% of the actual State threshold exceedences that were identified with daily sampling. Monthly sampling detected less than 10% of the actual exceedences at 23 of the 24 sites.

DISCUSSION

The percent of water quality threshold exceedences correctly identified with less than daily sampling frequencies was larger than would be expected by chance alone (Tables 1 and 2). This efficiency is due to inclusion of the adaptive strategy for follow-up sampling in the event of an observed exceedence. Even with adaptive sampling, though, lesser sampling frequencies were ineffective, yielding only an approximately 25% identification rate when sampling weekly.

The ineffectiveness of all sampling frequencies appears to result because approximately 70% of the water quality excursions lasted only a single day, with fewer than 10% lasting more than three days (Figure 1). The high percentage of single-day events was relatively consistent across seasons and indicators. The adaptive sampling strategy is based upon a paradigm of detecting chronic problems, such as sewage spills. Less than 0.1% of the water quality excursions observed during the study period were attributable to sewage spills (Schiff *et al.* 2000).

To assess whether a lesser sampling frequency with an adaptive component would be effective at capturing chronic events, we repeated our analysis but redefined an excursion to include only those events that lasted for at least two days. Thus, if sampling occurred on the third day of a four-day event, adaptive sampling would correctly identify 50% of the event. Adaptive sampling was more effective in this reanalysis, with three-times-a-week sampling correctly identifying 75% of the water quality exceedence days (Table 3). Adaptive sampling would be increasingly effective if the analysis were limited to events lasting even longer, although events of more than a three-day duration were rare during our five-year study period.

Numerous explanations might account for the short duration of the events. Almost half of the sampling sites were located 50 yards downcoast from urban runoff outlets, which are known sources of bacterial contamination, and shifts in current direction possibly could cause runoff to alternately flow toward and away from the sampling site on successive days. However, shifts in current direction are rare and are more mediated by seasonal shifts in oceanographic conditions than by daily changes in meteorological patterns. Moreover, 13 of the 24 sites were located away from runoff outlets, and no discernible difference in the temporal patterns was observed between these sites and those located near outlets.

Another possible explanation for the short duration of these events is that many of the exceedences were barely above State of California thresholds and could have resulted from normal laboratory measurement error. To assess this possibility, we repeated our analysis using thresholds beyond those which could have resulted from laboratory measurement variability, as established through repeated laboratory

TABLE 1. Percent of California total coliform water quality standard exceedences detected at Santa Monica Bay stations (1995 – 1999) using several sampling frequencies.

Station Name	Type of Site	Number of Exceedences in Five Years	Percent of Water Quality Standard Exceedences Detected 5/Week	5/Week (weekend)	3/Week	1/Week	1/Month
Inner Cabrillo	Harbor	21	81	76	52	38	0
Inner Cabrillo & 34th Street	Harbor	47	83	74	51	30	11
Malibu Creek	Outlet	70	83	77	61	19	4
Topanga Point	Beach	44	77	80	39	25	2
Pulga	Outlet	37	78	84	57	24	3
Santa Monica Canyon	Outlet	47	83	79	53	21	0
Santa Monica Pier	Outlet	51	80	76	57	24	4
Pico-Kenter	Outlet	144	84	79	69	25	6
Ashland	Outlet	189	76	80	52	23	5
Windward	Outlet	34	79	82	62	21	0
Marina del Rey Beach	Beach	88	80	84	60	25	6
Ballona Creek	Outlet	99	77	83	60	27	2
Culver Blvd.	Outlet	89	82	84	62	26	2
Imperial Hwy.	Outlet	77	81	73	55	25	4
Manhattan Beach	Beach	11	91	73	55	27	0
Manhattan Beach Pier	Beach	4	100	75	75	25	0
Hermosa Beach Pier	Beach	17	94	76	59	35	0
Redondo Pier	Beach	34	76	82	47	21	6
Avenue I	Outlet	17	71	71	35	24	0
Palos Verdes Estates	Beach	2	100	100	50	10	0
Long Point	Beach	21	71	62	57	50	0
Abalone Cove	Beach	2	50	100	0	50	0
Portuguese Bend	Beach	6	83	83	67	3	0
Cabrillo Beach	Beach	3	67	67	33	33	0
Overall		1,154	80	79	53	26	2
Expected by Chance			71	71	43	14	3

analyses from the same sample (McGee *et al.* 1999): (1) total coliform > 21,875 organisms per 100 mL and (2) fecal coliform > 875 organisms per 100 mL. The results were very similar when the analysis was repeated using the higher thresholds. For total coliforms, the average percent of exceedences identified with weekly sampling increased from 24 to 25% using the higher threshold, but decreased for fecal coliforms from 27 to 22% (Table 3).

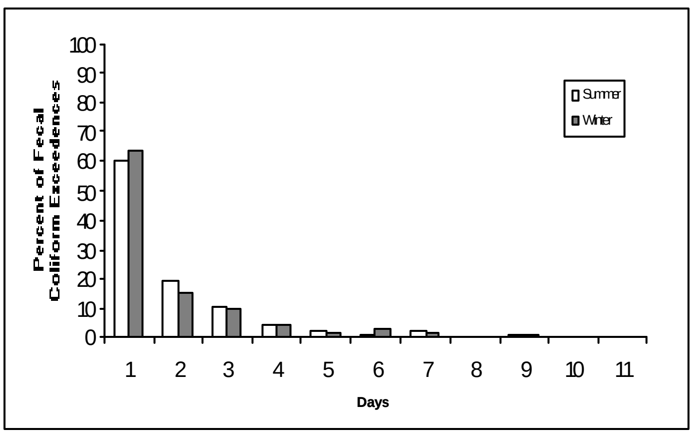
A more likely explanation for the short duration of the water quality exceedences is that the primary sources of contamination come from urban influences, which can be episodic in nature. Southern California is the most urbanized coastal area in the country and also has a very dry climate. Rainfall, particularly during the summer months, is rare; runoff typically results from human activity, such as washing of city streets, over-watering of lawns, etc. Moreover, some of the contamination may result from animal sources, such as birds, whose presence can also be episodic.

Regardless of the source, our findings raise concerns about the effectiveness of the present public warning systems. Most beach monitoring in southern California is limited to weekly sampling (Schiff *et al.* in press), which likely results in a high percentage of missed water quality excursions. Moreover, because of laboratory processing time, the public is typically notified about water quality conditions 24 to 48 h after the sample is collected. Thus, 70% of the warnings are out-of-date when they are issued. This calls into question the desirability of issuing warnings on the basis of a daily threshold exceedence, unless a clear source for continuing contamination has been identified. While the argument can be made that the public has a right to know when water quality exceeds a State threshold, an equal argument can be made that issuing incorrect warnings 70% of the time will serve to undermine confidence in the warning system as a whole. Perhaps a more cogent plan is

TABLE 2. Percent of California fecal coliform water quality standard exceedances detected at Santa Monica Bay stations (1995 – 1999) based on various sampling frequencies.

Station Name	Type of Site	Number of exceedances in five years	Percent of Water Quality Standard Exceedances Detedted				
			5/Week	5/Week (weekend)	3/Week	1/Week	1/Month
Inner Cabrillo	Harbor	73	75	78	51	30	1
Inner Cabrillo & 34th St.	Harbor	536	82	84	69	27	7
Malibu Creek	Outlet	514	84	88	70	34	8
Topanga Point	Beach	161	80	80	53	23	7
Pulga	Outlet	119	76	87	58	26	3
Santa Monica Canyon	Outlet	221	80	83	56	24	2
Santa Monica Pier	Outlet	539	85	85	67	26	8
Pico-Kenter	Outlet	264	81	87	63	21	4
Ashland	Outlet	117	81	79	55	18	6
Windward	Outlet	47	70	81	43	13	2
Marina del Rey Beach	Beach	278	81	82	59	33	9
Ballona Creek	Outlet	127	85	83	65	28	6
Culver Blvd.	Outlet	110	78	81	58	24	4
Imperial Hwy.	Outlet	56	77	75	43	41	5
Manhattan Beach	Beach	14	86	64	50	14	0
Manhattan Beach Pier	Beach	13	85	77	46	31	8
Hermosa Beach Pier	Beach	16	88	75	63	25	0
Redondo Pier	Beach	123	75	76	52	14	3
Avenue I	Outlet	25	92	88	56	16	0
Palos Verdes Estates	Beach	19	89	79	47	32	5
Overall		3372	82	81	59	26	5
Expected by Chance			71	71	43	14	3

FIGURE1. Duration of exceedences at Santa Monica Bay daily monitoring stations (1995 - 1999).



to limit the warning system to exceedences based upon weekly or monthly average values, unless a sewage leak has occurred. The most important need, however, is for development of more rapid detection techniques that allow swimmers to receive warnings based upon samples taken the day of their swimming event.

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TABLE 3. Percent of California water quality standard exceedances from Santa Monica Bay daily monitoring stations from 1995 to 1999 based on various sample frequencies for standard, multi-day and high magnitude triggers for adaptive follow-up sampling.

	Five weekday samples	Five samples per week, one weekend day	Three samples per week	One sample per week	One sample per month
California water quality standard exceedance trigger					
Fecal Coliforms	82	81	59	26	5
Total Coliforms	80	79	53	26	2
Multi-day California water quality standard exceedance trigger					
Fecal Coliforms	85	91	73	36	5
Total Coliforms	87	85	71	36	3
Exceedance of upper limit of laboratory variability trigger					
Fecal Coliforms	81	82	52	26	4
Total Coliforms	78	77	56	19	2

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