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Monitoring bathing beach water quality using composite sampling

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Abstract Michigan water quality standards for public bathing beaches require local health departments to collect and analyze a minimum of three water samples for *Escherichia coli* during each sampling event. The geometric mean number of *E. coli* colonies is then compared to the 300 colonies per 100 ml standard to determine compliance. This article compares the results of the currently mandated procedure to a composite sampling method, whereby the three samples are mixed in equal volumes and analyzed once. This effectively replaces the geometric mean of the individual sample results with an arithmetic mean. Although arithmetic means are more affected by outliers, this sensitivity to high concentrations is more health conservative than the geometric mean. During the 2007 sampling season, nine bathing beaches were monitored once each week. Three individual point samples and a composite sample were analyzed for each sampling event. No statistically significant differences in bacteria concentrations were found between composite sample analysis and the arithmetic mean of individual point sample analyses. No violations were detected in the 2007 sampling season, so using historical data, a retrospective analysis was performed on samples gathered at nine bathing beaches in Kalamazoo County, Michigan during the years 2001–2007. The arithmetic mean of the three samples taken at each site served as a surrogate composite sample. The benefits of compositing the three samples were investigated assuming a 2/3 reduction in analytical costs. In the traditional sampling method, three individual samples were obtained and analyzed once in every 3-week period during the summer season, whereas compositing was simulated by taking the arithmetic mean of each week's results. The results of this retrospective cost analysis indicates that ten to 14 violations would have been missed using the less frequent traditional sampling and analysis methodology. Composite sampling is a cost-saving alternative to traditional sampling techniques that can be more protective of public health, particularly when the savings are applied to increased numbers of samples in time or space.

Keywords Bathing beach water · *E. coli* concentrations · Water quality standards

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Introduction

Bathing beach water quality

Outdoor, untreated recreational bathing areas are often plagued with pollution from stormwater runoff, wildlife, domestic animals, boating wastes, combined sewer overflows, and malfunctioning septic systems. Pathogens in sewage-contaminated waters can cause a wide range of diseases, including ear, nose, and throat problems, gastroenteritis, dysentery, hepatitis, and respiratory illness (Dorfman and Stoner 2007). Pollution-related closings and health advisories at beaches across the country were more numerous than ever in 2006, according to the Natural Resources Defense Council's annual report on bathing beach water quality. There were more than 25,000 days of closings and advisories in 2006 at ocean, bay, and Great Lakes beaches; an increase of 28% from 2005 (Dorfman and Stoner 2007).

Since bathing beach water quality varies greatly in both space and time, an effective compliance monitoring program must have adequate spatial and temporal coverage to adequately protect public health. One way to improve spatial coverage is to collect and analyze multiple samples at fixed locations within the sampling area (Kinzleman et al. 2006). However, increasing the number of samples to be analyzed increases the costs associated with laboratory analysis (Bertke 2007; Kinzleman et al. 2006).

The cost of testing for chemical and pathogenic contaminants can be quite prohibitive (USEPA 1995). To address the analytical costs associated with bathing beach monitoring, this article examines the potential use of composite sampling, where multiple samples are mixed and analyzed together, to the traditional protocol that analyzes each sample individually. The primary objectives of this study are to: (1) incorporate composite sampling methodologies into the 2007 bathing beach monitoring season in Kalamazoo County, Michigan, (2) compare the arithmetic and geometric mean concentrations derived from individual samples to results obtained from compositing, (3) determine statistical similarities and significance between these results, (4) conduct a retrospective analysis of prior sampling results and simulate the application of a compositing strategy, and (5) determine if composite sampling is cost-effective and adequately protective of public health.

Regulatory framework

The Beaches Environmental Assessment and Coastal Health (BEACH) Act of 2000 (33 C.F.R. 1251 et seq., 1254, 1313, 1314(a), 1341 et seq., 1362, and 1377(e)) amendments to the Clean Water Act provide specific beach monitoring guidelines and establish uniform criteria for testing, monitoring, and notifying public users of possible coastal recreational water quality problems (USEPA 2006). The United States Environmental Protection Agency (USEPA) developed bacteriological criteria based on an accepted illness rate of eight illnesses out of 1,000 swimmers (USEPA 1986). Based on a sampling rate of generally not less than five samples equally spaced in time over a 30-day period, the geometric mean of the indicated bacterial densities should not exceed 126 colonies *Escherichia coli* bacteria per 100 ml of water (USEPA 1986). The criteria also include a single sample maximum allowable density of 235 colonies *E. coli* bacteria per 100 ml. These criteria are stated for full (total) body contact recreation. These densities are all determined based on the collection and laboratory analysis of one individual sample obtained from the bathing beach facility per sampling event.

In 2007, USEPA held a workshop on research needs for developing new ambient water quality criteria (USEPA 2007). The report from this workshop made several recommendations on water quality indicators, analytical methods, risk assessment, and predictive models, but it did not explicitly cover the local scale spatial variability and site-specific field sampling methodology that is the subject of this paper.

Under the guidance of the USEPA, the Michigan Department of Community Health and the Michigan Department of Environmental Quality revised the standards for *E. coli* bacteria in surface water for body contact recreational areas. Specific rules pertaining to these criteria are documented under Michigan Water Quality Standards (Part 4, promulgated pursuant to Part 31, Water Resources Protection, of the Natural

Resources and Environmental Protection Act, 1994 Public Act 451, as amended). All public health agencies in Michigan are required to follow these water quality standards as they relate to bathing beach monitoring activities and microorganisms. The rules state the following:

> R 323.1062 Microorganisms, Rule 62(1)
>
> All waters of the state protected for total body contact recreation shall not contain more than 130 *E. coli* per 100 ml, as a 30-day geometric mean. Compliance shall be based on the geometric mean of all individual samples taken during five or more sampling events representatively spread over a 30-day period. Each sampling event shall consist of three or more samples taken at representative locations within a defined sampling area. At no time shall the waters of the state protected for total body contact recreation contain more than a maximum of 300 *E. coli* per 100 ml. Compliance shall be based on the geometric mean of three or more samples taken during the same sampling event at representative locations within a defined sampling area. (Michigan Compiled Laws 1994)

Due to the analytical costs associated with bathing beach monitoring and the fact that Michigan beach monitors are required to collect a minimum of three individual samples, beach monitoring is less frequent in Michigan as compared to some of the other Great Lakes states (Table 1). Unlike Michigan, the states of Indiana, Illinois, Ohio, and Wisconsin conduct bathing beach monitoring and base compliance on the analysis of a single water sample, as stated in the USEPA ambient water quality criteria.

Table 1 Beach monitoring frequency and water quality standards for the Great Lakes States

State	Monitoring frequency	Single sample water quality standard
Illinois	5 per week—daily	235 cfu/100 ml
Indiana	1 per week—daily	235 cfu/100 ml
Michigan	1–3 per week	300 cfu/100 ml
Minnesota	1–2 per week	235 cfu/100 ml
New York	1–2 per week	235 cfu/100 ml
Ohio	1–5 per week	235 cfu/100 ml
Pennsylvania	2 per week	235 cfu/100 ml
Wisconsin	1–5 per week	235 cfu/100 ml

Composite sampling

A composite sample is made from a number of discrete samples which have been collected from a body of water or other medium and physically mixed into a single sample with the intention that this single sample is representative of all components (Lock 1998). A single analysis is performed on the composite, which is used to represent each of the original individual samples (Patil 2002). Composite sampling is appropriate when individual samples can be adequately homogenized without affecting their integrity or introducing bias (Kinzleman et al. 2006). In effect, the composite sample represents the average conditions in that sampled body of water or other material (Lock 1998).

Composite sampling can improve spatial and temporal coverage of an area without increasing the number of analyses (USEPA 2004). According to the USEPA (2002), composite sampling has several advantages over multiple individual sample analyses. Cost reduction is a primary goal in many sampling programs. If the bacterial concentrations can be measured accurately in individual samples as well as a composite (made of these individual samples), the expectation would be that the composite sample results equal the average of the individual sample results.

The United States Geological Survey compared results from composited samples taken at three Lake Erie beaches located in Lorain and Cuyahoga Counties, Ohio to those obtained by averaging individual results from multiple-point samples (USGS 2007). In this study, two individual water samples were taken at two Lake Erie beaches (Monday through Friday) and three individual water samples at a third beach (Monday through Thursday). Results from this study indicate that *E. coli* concentrations from the arithmetic average of multiple-point (individual) samples and from composited samples are not significantly different ($t = 1.59$, $p = 0.1139$) and yield similar measures of recreational water quality (USGS 2007). A strong, positive linear relationship ($r = 0.981$, $p < 0.0001$) existed between concentrations of the daily average of the multiple-point samples and the composite samples for all beaches combined (Bertke 2007).

Composite sampling has also been applied to source-tracking enterococci in coastal bathing beach water (Genthner et al. 2005). Rajagopal and Williams (1989) investigated the economics of compositing in examining pesticide concentrations in groundwater.

Composite sampling has been utilized, not only with water, but with solid media. For example, soil samples have been collected and composited to define the extent of mercury contamination (Lancaster and Keller-McNulty 1998). The bulking of multiple discrete samples to form a single composite sample has long been recognized as a useful technique to improve the precision of soil sampling (Correll 2001).

Methods

Study sites

The Kalamazoo County Health and Community Services Department has conducted weekly bathing beach monitoring at nine public bathing beaches since 2004 (eight since 2001). The ownership of these facilities includes state (one), county (three), township (two), municipal (two), and village (one) governments. The facilities are open to the general public and may require an annual pass or daily/annual user fees. Private facilities such as campgrounds and youth camps are not included in this sample.

A sampling event consists of collecting individual water samples, documenting weather conditions, and recording measurements of water temperature, dissolved oxygen, pH, conductivity, and turbidity. During the summer of 2007, the monitoring plan was modified to include composite sampling techniques for the purpose of this article. In addition to collecting three individual water samples ($n = 486$) during each visit ($n = 162$), a fourth water sample (the composite ($n = 144$)) was produced in a laboratory setting for each sampling event. All individual water samples were delivered to the Kalamazoo County Health and Community Services Department Laboratory, submitted with the appropriate form, and analyzed for *E. coli* bacteria. There were 2 days (sampling events) when a composite sample was not formed out of the 18 weeks of sampling. A composite sample was not formed the very first week of sampling, week #20 (week of May 14, 2007), and week #28 (week of July 9, 2007). The difference is 18 samples (9 beaches × 2 days × 1 sample = 18).

Sample collection

The Kalamazoo County Health and Community Services Department collects bathing beach water samples at each facility once a week; typically on a Monday or Tuesday. Samples are collected between 08:00 and 12:00 at a depth of 1 ft below the surface in approximately 3–4 ft (waist deep) of water. Three water samples are collected during each sampling event using the grab sampling technique (Bertke 2007; Francy and Darner 2000). Water samples are collected by carefully wading into the water at three designated transects per beach location.

All water samples are collected in sterile, 532 ml (18 oz) Whirl-Pak® Stand-Up bags (www.enasco.com, Nasco, Fort Atkinson, Wisconsin). These bags have a write-on strip for correct sample identification and seal by whirling the bag and then folding the attached tab. A total of 200–300 ml per sample was collected during this study. Three Whirl-Pak® bags were utilized during each sampling event; the bags were labeled with the date, beach code, and an "A", "B", and "C", which indicated the specific water sample collection location. Once collected, the water samples were placed in a cooler, stored on ice packs, and transported to the Kalamazoo County Health and Community Services Department Laboratory.

Once in the laboratory, the three water samples were used to form four individual 100 ml samples (A, B, C, and Composite). The Whirl-Pak® bags were shaken for 1 min to ensure well-mixed, homogeneous samples (Bertke 2007) and then each individual sample (A,B, and C) were poured carefully to the 100 ml fill line of 120 ml sterile bacteriological sample bottles. The composite sample was formed by measuring equal aliquots from the set of Whirl-Pak® bags. An aliquot of 33.3 ml was measured using a sterile 50 ml graduated cylinder. All three aliquots were poured into a 120 ml sterile bacteriological sample bottle to form a 100 ml composite sample. Even though the composite samples were poured last (for each individual sample), there were only seconds between the pouring of the traditional sample and the composite sample from each Whirl-Pak bag, so no bias is assumed. All four samples (per beach) were submitted to laboratory staff for bacteriological analysis.

Sample analysis

The concentration of *E. coli* bacteria in both the individual point samples (A, B, and C) and the composite sample was determined using Colilert®-18 and Quanti-Tray®/2000, analytical products from IDEXX Laboratories, Inc. (www.idexx.com, Westbrook, Maine). Colilert®-18 simultaneously detects total coliforms and *E. coli* in drinking water and surface water samples (IDEXX Laboratories, Inc. 2007). Laboratory procedures included adding Colilert®-18 media to each sample, sealing the sample in the Quanti-Tray®/2000, incubating for 18–22 h at 35° and reporting results as most probable number (MPN), a statistical representation of the *E. coli* concentration. For purposes of determining compliance with regulations, MPN was assumed to be equivalent to colony forming units (CFU). Results were achieved by viewing the Quanti-Tray®/2000 under ultraviolet light and counting the number of wells that were *E. coli* positive as indicated by fluorescence. The laboratory staff used a table (provided by IDEXX Laboratories, Inc.) to convert the number of wells that fluoresce to a MPN per 100 ml count. Colilert®-18 can simultaneously detect *E. coli* at 1 CFU/100 ml within 18 h even with as many as 2 million heterotrophic bacteria per 100 ml present (IDEXX Laboratories, Inc. 2007).

Statistical summary and analysis

Bacteria counts among individual samples can vary over a large range of concentrations. Because of this variability, data were log-transformed ($\log_{10}$) to more normally distribute the data (Bertke 2007; Kinzleman et al. 2006). Statistical analysis consisted of evaluating the relationships between individual sample averages (arithmetic and geometric) and the composite sample result using the Pearson product-moment correlation coefficient (Bertke 2007).

No violations were detected in the 2007 sampling season, so using historical data, a retrospective analysis was performed on samples gathered at nine bathing beaches in Kalamazoo County, Michigan during the years 2001–2007. The arithmetic mean of the three samples taken at each site served as a surrogate composite sample. The assumption is that the past budgets for laboratory analysis were reduced by two-thirds and the arithmetic means of individual sample analyses were used to simulate composite sample results. Sampling events were selected by expanding the frequency between sampling events and assigning each sampling event a number from one to 20. Each series of data were used to compare the number of water quality violations (using the geometric mean of the individual sample results) that would have been captured or missed with a reduced (one-third) budget.

Results and discussion

Comparison of composite sample results to arithmetic means

During the 2007 sampling season, bacterial concentrations were considerably lower as compared to previous monitoring years. There were no single sampling events (the geometric mean of three samples at a particular beach) that exceeded Michigan water quality standards for total body contact recreation of 300 *E. coli* colonies per 100 ml water (Table 2). There were five individual sample results out of a total of 486 (1%) that were greater than 300 *E. coli* colonies per 100 ml water, but each of these samples were averaged with low concentrations at the other two sample locations.

Individual sample results were used to compute the arithmetic and geometric means, which

Table 2 *E. coli* concentrations at Kalamazoo County Public Beaches, 2007

Beach	Number of individual samples		*E. coli* bacteria concentration (colonies∣100 ml) (arithmetic mean∣geometric mean)		
	Count	>= 300	Median	Minimum	Maximum
KB-01	54	0	7∣7	1∣1	175∣175
KB-02	54	2	5∣4	2∣1	231∣225
KB-03	54	1	9∣8	2∣1	122∣56
KB-04	54	0	2∣2	1∣1	15∣15
KB-05	54	0	3∣3	1∣1	82∣76
KB-06	54	0	2∣2	1∣1	12∣7
KB-07	54	0	13∣11	3∣2	74∣65
KB-08	54	0	3∣2	1∣1	142∣141
KB-11	54	2	26∣22	2∣2	232∣151

were then used to compare to respective composite sample results. The arithmetic means and respective composite sample results ($n = 144$) were plotted on a scatterplot against a 1:1 line (Fig. 1). These points represent data from all nine bathing beaches. A strong, positive linear relationship between individual sample arithmetic means and composite sample results appear among all nine beaches combined ($r = 0.951$, $p < 0.0001$). Greater variation among data points occurs when bacteria concentrations are less than ten *E. coli* colonies per 100 ml water. Bertke (2007) discovered similar results in her study; the largest variance was observed at concentrations below 50 *E. coli* colonies per 100 ml water. Since these levels of *E. coli* bacteria concentrations are considerably lower than recreational water quality standards, there is no impact on the overall water quality assessment (Bertke 2007).

The *E. coli* bacteria concentrations of the arithmetic mean and the respective composite sample for the nine beaches individually also had strong, positive linear relationships. The Pearson correlation (r) for the individual beaches ranged from 0.780 to 0.996 (Table 3). These values indicate a strong relationship among the average of the individual water samples and the composite sample. The p values are all less than 0.0001, indicating that the correlations are statistically significant.

There is a high degree of variability both between individual bathing beaches and within a set of samples collected during the same sampling event (Bertke 2007; Kinzleman et al. 2006). These concentration differences may be due to the surrounding land cover and land use, localized weather conditions, physical characteristics of the bathing beach, and the specific individual point sampling locations. Variability among the bathing

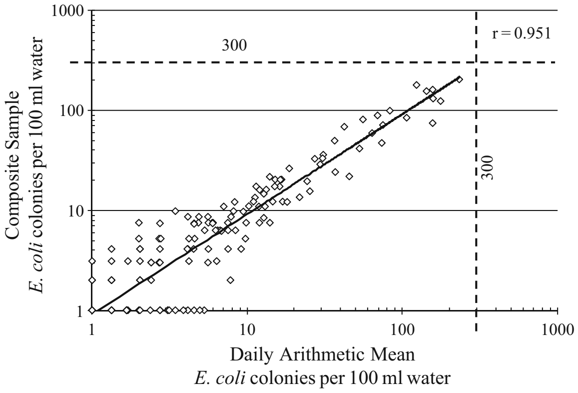

Fig. 1 Arithmetic mean versus composite sample, 2007

Table 3 Pearson correlation coefficients (r) of arithmetic mean and composite sample results, 2007

Beach	Number of sampling events	r	p value
KB-01	16	0.993	<0.0001
KB-02	16	0.987	<0.0001
KB-03	16	0.949	<0.0001
KB-04	16	0.957	<0.0001
KB-05	16	0.993	<0.0001
KB-06	16	0.780	<0.0001
KB-07	16	0.942	<0.0001
KB-08	16	0.996	<0.0001
KB-11	16	0.926	<0.0001
All beaches	144	0.951	<0.0001

beaches and sampling events is presented in Fig. 2. These charts illustrate the composite sample result (represented as a diamond (♦)) and the range of *E. coli* bacteria concentrations for the three individual water sample results (represented as a vertical line (|)) for each weekly sampling event. All of the bathing beaches, except Sunset Lake Park (KB-11), had at least two sampling events where the composite sample result was either higher or lower than the range of the individual sample results. A total of 31 out of 144 (21.5%) composite sample results were outside the high-low range. Of the 31 composite sample results, 16 (51.6%) were slightly above the maximum value

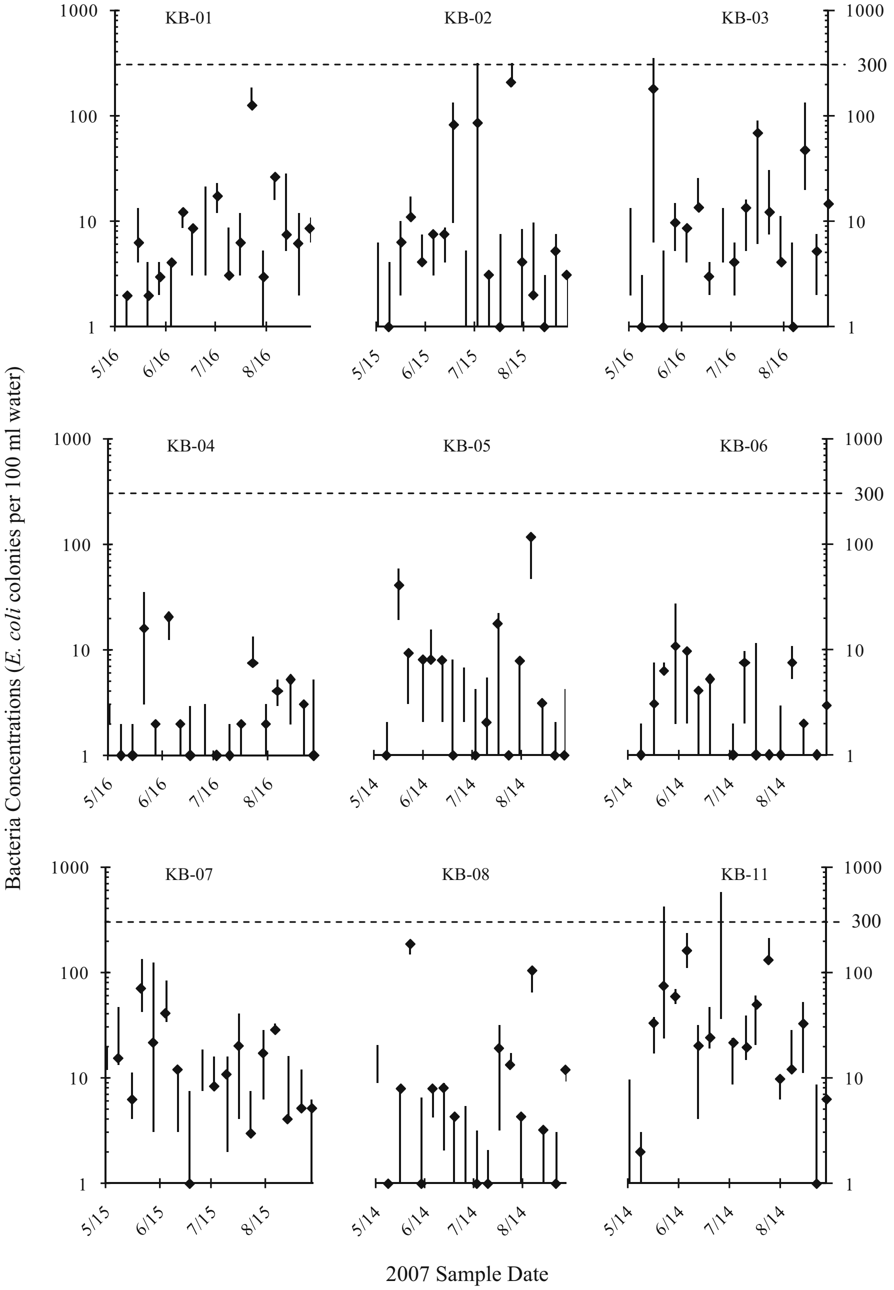

Fig. 2 Range of *E. coli* concentrations (2007) for each bathing beach

Table 4 Split sample results

Beach	Date	Actual sample results				Replicate sample results			
		A	B	C	Comp	A	B	C	Comp
KB-01	2007/07/17	23	12	13	17	33	19	23	19
KB-02	2007/07/24	1	1	3	3	2	1	3	1
KB-03	2007/07/31	91	29	6	68	86	30	6	48
KB-04	2007/08/07	13	9	7	8	9	7	6	5
KB-05	2007/06/13	2	2	2	8	2	1	3	1
KB-06	2007/07/16	1	1	2	1	1	2	1	1
KB-07	2007/07/23	2	3	16	11	11	6	17	6
KB-08	2007/07/30	28	3	3	17	25	10	7	5
KB-11	2007/08/06	214	120	135	131	186	135	124	152

and 15 (48.4%) were slightly below the minimum value of the individual sample results.

Quality assurance and quality control

Quality assurance and quality control procedures were implemented to ensure an acceptable research project and confirm water sampling collection and analytical procedures. For the purpose of this project, field blanks and split replicate samples were analyzed during the course of the sample season. Two field blanks were performed during this study: one set early in the monitoring season (May 29, 2007) and the other toward the end of the season (September 11, 2007). Field blanks were obtained at Markin Glen County Park (KB-08) and Robert Morris Park (KB-02) to assess contamination of samples from filling the Whirl-Pak® bags and transporting the samples to the laboratory. All field blank sample results were reported out as less than 1 cfu.

Split samples (Table 4) were analyzed once at each bathing beach. A split sample represents two or more replicate samples that have originated from a common sample container. The purpose of split samples is to verify laboratory analytical methods, techniques, and protocols. From the results in Table 4, the concentrations of *E. coli* bacteria are very similar between the actual result and the replicate result for each of the given samples (A, B, C, and composite). The differences between the actual result and the replicate result were not significantly different for all nine split sampling events performed (one for each beach) based on the computation of a paired t test ($t = 0.256$, $p = 0.800$). Results of replicate samples were used to evaluate the repeatability of the bacteria measurements. These quality assurance and quality control methods were employed to validate sample collection, storage, transport, and laboratory analytical procedures.

Arithmetic mean versus geometric mean

In a retrospective analysis of the entire database of beach monitoring results (Kalamazoo County 2007), the arithmetic and geometric means were compared for all sampling events conducted at nine beaches for the past seven monitoring seasons (2001–2007; $n = 1{,}313$) (Kalamazoo County 2007). A total of 26 occurrences (2%), represented by the circle (○) in Fig. 3, exceeded 300 *E. coli* colonies per 100 ml water, based on the geometric mean of the sample set. These occurrences also were greater than 300 *E. coli* colonies

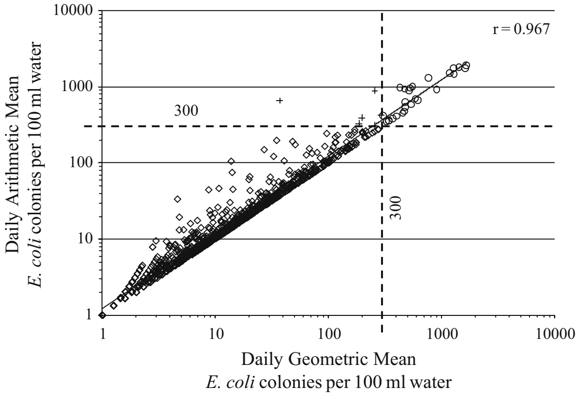

Fig. 3 Arithmetic and geometric mean *E. coli* concentrations, 2001–2007

Table 5 Retrospective 2001–2007 sampling results with 1/3 analytical budget reduction

Beach	Events	Violations detected by compositing (arithmetic mean)	Weeks 1, 4, …19		Weeks 2, 5, …20		Weeks 3, 6, …18	
			Detected	Missed	Detected	Missed	Detected	Missed
KB-01	130	4	1	3	0	4	2	2
KB-02	126	2	1	1	1	1	0	2
KB-03	132	0	0	0	0	0	0	0
KB-04	132	0	0	0	0	0	0	0
KB-05	130	2	1	1	0	2	1	1
KB-06	131	3	1	2	0	3	2	1
KB-07	129	6	5	1	1	5	0	6
KB-08	130	2	0	2	2	0	0	2
KB-11	77	0	0	0	0	0	0	0
Total	1,117	19	9	10	4	15	5	14

per 100 ml water based on the arithmetic mean of the sample set. An additional six sampling events (0.5%), represented by the plus sign (+) in Fig. 3, exceeded 300 *E. coli* colonies per 100 ml based on the arithmetic mean, but were in compliance based on the geometric mean.

Composite method simulation

A series of three separate data sets were selected from 2001 to 2007 sampling seasons (n = 1,117) to determine if beach advisories or closures would be detected using composite sampling techniques. These retrospective sampling events simulate the number of sampling events performed with the budget cut to one-third, which represents the potential cost savings with the implementation of composite sampling methodologies.

Using the currently mandated geometric mean of three samples to determine a violation of water quality standards, a reduction in budget, and therefore a reduction in sampling frequency, would cause some violations to be missed over the 7-year time frame. The number of sampling events with an assigned number (Table 5) of "1, 4, 7…19" ($n = 396$), "2, 5, 8…20" ($n = 371$), and "3, 6, 9…18" ($n = 350$) would have missed ten, 15, and 14 violations, respectively, out of a total of 19. All 19 violations exceeded the arithmetic mean of 300 *E. coli* colonies per 100 ml water; four of these events were violations based on the arithmetic mean (simulating a three-sample composite), but were not violations based on the geometric mean of the three individual samples. Thus, compositing is more conservative of public health, since it is easier to declare a violation (Parkhurst 1998).

Assuming the current regulatory procedures yield a "correct" decision, in 1,113 of 1,117 retrospective simulated sampling events, the two methods yielded the same results, that is, the methods either correctly identified compliant beaches or beaches in violation. In four of the 1,117 simulated cases, the arithmetic mean (composite result) method would have closed a beach that would have been in compliance using the geometric mean of three individual samples.

Cost analysis

A simple cost model divides the beach monitoring program into four major components (Table 6); labor, transportation, indirect (overhead), and analytical. Labor costs include technician training

Table 6 Associated costs with the Kalamazoo County beach monitoring program

Component and associated costs	Cost
Labor: 12 h/week × 20 weeks × $12/h	$2,880
Training: 12 h/technician × 1 technician × $25/h	$300
Transportation: 100 miles/week × 20 weeks × $0.505/mile	$1,010
Overhead: 12 h/week × 20 weeks × $6.65/h	$1,596
Analytical: 3 samples/beach × 9 beaches × 20 weeks × $13/sample	$7,020
Total costs following a traditional beach monitoring method	$12,806

and staff time to: prepare equipment, travel to the sampling site, perform sampling, and return to the laboratory. Transportation costs include the costs of driving between the office, beach monitoring locations, and the laboratory. Overhead includes administrative and financial analyst time, utilities, and other indirect costs. The analytical costs include the laboratory scientist time, analytical preparation time, and the analysis to quantify *E. coli* bacteria.

The cost of a composite sampling approach versus the traditional sampling approach is virtually the same with the exception of the laboratory analytical fees; the composite approach would require the analysis of a single sample, whereas the traditional approach requires the analysis of three individual samples. What the model does not consider are the costs associated with issuing an advisory or closure on a bathing beach. This could, for example, include loss of park fees obtained when the beach is open.

Since the alternative sampling approach (compositing) requires fewer samples to be analyzed, as compared to traditional sampling analyses, cost savings could be achieved. Laboratory analytical costs associated with composite sampling would be approximately $2,340 annually, whereas traditional sampling costs would be three times as much (approximately $7,020). Because the other costs (labor, transportation, and indirect) would virtually be unchanged during a typical monitoring season, annual savings of approximately $4,680 (or 37% of the total costs of traditional monitoring (Table 5)) could be achieved using composite sampling methods.

Summary and conclusions

Summary

The Kalamazoo County Health and Community Services Department bathing beach monitoring plan incorporated composite sampling techniques during the 2007 sampling season. The purpose of this research was to determine if composite sampling methodologies provide a more cost-effective approach to monitoring bathing beaches in Kalamazoo County and potentially throughout the State of Michigan. This research employed innovative sampling methods to determine if composite sampling provides reliable and unbiased results in order to determine compliance with Michigan water quality standards.

The results indicate that the composite sample results were not significantly different from the arithmetic mean of the individual sample results. The cost of composite sample analysis is 37% cheaper than traditional methods, since in this case, one sample is analyzed compared to the three individual samples currently mandated by regulation. As compared to taking the geometric mean of three individual sample results, compositing is more health conservative and; when it differs from the traditional method it flags a beach for closing when the traditional method indicates it should remain open.

The use of composite sampling would free up a significant amount of money annually. These savings could be applied to more frequent sampling, sampling during critical weather periods, and increased sampling frequency at beaches with chronic water quality issues. Additional monitoring could take place immediately after storm events when bacterial concentrations are typically higher. In some cases the monies saved by compositing could be applied to correcting problems and eliminating contamination sources altogether. This would be the next step toward improving water quality, not just monitoring it. Some considerations include public education, annual lake surveys, and microbial source tracking.

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