4-2008

Using Composite Sampling Techniques to Monitor Bathing Beach Water Quality in Kalamazoo County, Michigan

Jeffrey David Reicherts

USING COMPOSITE SAMPLING TECHNIQUES TO MONITOR BATHING BEACH WATER QUALITY IN KALAMAZOO COUNTY, MICHIGAN

by

Jeffrey David Reicherts

A Thesis
Submitted to the
Faculty of the Graduate College
in partial fulfillment of the
requirements for the
Degree of Master of Arts
Department of Geography

Western Michigan University
Kalamazoo, Michigan
April 2008

ACKNOWLEDGEMENTS

I started the Graduate program in January 2006 with a strong desire to hone my skills in geographic information science. The Geography Department at Western Michigan University provided the necessary coursework and interests to further my education. I am grateful to Dr. David Dickason (Department Chair at the time of application) for reviewing and accepting my application. For two years, I had the opportunity to enroll in and take a wide variety of geography courses and was taught by some of the finest instructors. I want to thank Dr. Lisa DeChano, Dr. Kathleen Baker, Dr. Charles Emerson, and Dr. Chansheng He for making all the courses interesting and motivating me to do my best work. I would also like to thank the other faculty members and administrative staff for making my academic experiences quite positive.

I owe deepest appreciation to my thesis committee for their on-going support, encouragement, and interest in my thesis topic. I want to thank Dr. Charles (Jay) Emerson, my thesis advisor, for his guidance and willingness to discuss the "nuts and bolts" of this project. I am also indebted to Dr. Chansheng He and Dr. Frank Wolf, who served as members on my thesis committee. I will never forget their willingness to assist me and guide me through the research process and the writing of this manuscript.

This project would not have been possible if it wasn't for the tremendous amount of support from my employer. I want to recognize Kalamazoo County government for allowing me to take on the added responsibility of pursuing higher education. Specifically, I want to thank Jim Rutherford (Health and Community Services

Department Deputy Director), Deb Cardiff (Environmental Health Bureau Director), and Kim Finkbeiner (Environmental Health Bureau Supervisor) for their support and having confidence in me to undertake this project. I also want to express a sincere thank you to the laboratory staff for taking on additional samples and assisting me in the analytical processes and composite sampling methods. Additionally, I would like to recognize my co-workers who have continued to support my work and passion for water resources and geographic information science.

While enrolled in coursework at Western Michigan University I had the opportunity to develop friendships with many undergraduate and graduate students. These friendships were partly responsible for my success in the Geography Department and this experience means so much more knowing that I gained some new friends during this process.

Lastly, but most importantly, I am truly grateful for the amount of support I received from my family. I want to recognize and thank my parents, Dave Reicherts and Marv and Sharon Stewart, for caring and always interested in the progress of my graduate studies. During the course of my studies, I spent many hours on campus and was unavailable at home. My wife (Annie), daughter (Kerri), and son (Jacob) deserve a huge "THANK YOU" for understanding and being part of a truly positive experience. I can't express how much their support was vital to my academic success. I love you all!

Jeffrey David Reicherts

USING COMPOSITE SAMPLING TECHNIQUES TO MONITOR
BATHING BEACH WATER QUALITY IN
KALAMAZOO COUNTY, MICHIGAN

Jeffrey David Reicherts, M.A.

Western Michigan University, 2008

The Kalamazoo County Health and Community Services Department conducts water quality monitoring at public bathing beaches to determine public health risks and compliance with Michigan water quality standards. These standards require local health departments to collect and analyze a minimum of three water samples during each sampling event. Water samples are analyzed for *Escherichia coli* (*E. coli*) bacteria, an organism that indicates the presence of fecal contamination. During the 2007 sampling season, nine bathing beaches were monitored once each week. Three individual point samples ($n = 486$) and a composite sample ($n = 144$) were analyzed for each sampling event. This study compared the sample results of traditional (multiple individual point samples) and composite sampling methods. No statistically significant differences in bacteria concentrations were found between composite sample analysis and individual point sample analyses ($r = 0.780 – 0.996$, $p < 0.0001$). With a reduction in budget (as a result of composite sampling) and sampling frequency, the results of a retrospective cost analysis indicate numerous violations would have been missed. Composite sampling is a viable alternative (to traditional sampling techniques) that can be more protective of public health, cost effective, promote increased temporal frequencies, and maintain adequate spatial coverage.

TABLE OF CONTENTS

APPENDICES

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Water Quality

Recreational water quality is an asset to many communities in the country and more specifically around the Great Lakes region. The quality of Great Lakes and inland waters for example, may dictate the number of visitors or tourists who vacation within a community during the summer. Organizations who administer local water quality monitoring programs are often responsible for determining the quality of recreational bathing waters. For example, local health departments frequently monitor bathing beach water quality during the summer months to protect public exposure to surface water that do not meet numeric bacteriological criteria. In Michigan, water quality compliance is based on the collection of a minimum of three representative samples in the defined swimming area during each sampling event. A geometric mean of the sample set is then computed to determine compliance for total body contact recreation.

What is analyzed in a water sample to determine compliance to these criteria? In most cases in the United States, water samples are analyzed for *Escherichia coli* (*E. coli*) bacteria, an organism that indicates fecal contamination. Surface water resources and immediate swimming areas are often plagued with pollution. The most common sources of pollution include stormwater runoff, combined sewer overflows (CSO's), wildlife, domestic animals, boating wastes, sewage treatment discharges, and malfunctioning on-site sewage treatment systems (septic systems). All of these pollution sources can have adverse effects on water quality, which places public health at risk. Many violations of water quality occur immediately after rain events because precipitation easily carries pollutants to nearby surface water resources.

Because pathogens in sewage-contaminated waters can cause a wide range of diseases, which include ear, nose, and throat problems, gastroenteritis, dysentery, hepatitis, and respiratory illness, bathing beach water pollution threatens public health (Dorfman and Stoner 2007). The consequences of these swimming-associated illnesses can be worse for children, elderly people, pregnant women, cancer patients, and others with weakened immune systems (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 (NRDC'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 percent from 2005 (Dorfman and Stoner 2007). This increase may be in part due to an increase in monitoring activities across the nation. The premise behind most bathing beach monitoring programs is to reduce the risk of human exposure to contaminated recreational waters by monitoring and assessing water quality and notifying and educating the general public regarding beach health.

Problem Statement

Why is the geometric mean used with regards to beach monitoring and not the arithmetic mean? The geometric mean is often utilized to evaluate data covering several orders of magnitude. It is calculated by taking the n-th root of the product of n numbers. The geometric mean is the average of the logarithmic values of a data set, converted back to a base 10 number. Concentrations of chemical substances and microorganisms are often averaged using the geometric mean for scientific and regulatory purposes (Parkhurst 1998).The geometric mean minimizes the impact from an abnormally low or high number, which can be represented as an outlier. Thus, a high concentration of bacteria calculated with the geometric mean may not be judged as serious as the same concentration calculated with the arithmetic mean. Parkhurst (1998) argues that the geometric mean is less protective of public health and therefore should not be used for regulatory purposes. The geometric means are also of little use for mass balance analyses or for fate and transport studies of either chemical substances or microorganisms in the environment for the same reason (Parkhurst 1998). The arithmetic mean may be more useful in bacteriological monitoring. The arithmetic mean is the average of a list of numbers; the sum of all the members of the list is divided by the number of items in the list. Arithmetic means are easier to calculate and understand, scientifically more meaningful, and more protective of public health (Parkhurst 1998). This calculation benefits public health officials as it is more responsive to outliers, the type of data that officials must monitor closely.

In Kalamazoo County, Michigan, bathing beach water quality monitoring is conducted weekly, typically between Memorial Day and Labor Day at nine public facilities. Laboratory analytical costs associated with the bathing beach monitoring program can exceed $7,000 (based on a charge of $13.00 per individual sample) during a typical 20-week summer. Additional costs to a bathing beach monitoring program include staffing, equipment, and mileage; however, analytical costs make up a majority of the budget necessary to conduct bathing beach monitoring.

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 other Great Lakes states (Table 1). For example, other Great Lakes States (i.e., Indiana, Illinois, Ohio, and Wisconsin) conduct bathing beach monitoring and base compliance on the analysis of a single water sample, as stated in the United States Environmental Protection Agency (USEPA) ambient water quality criteria. This presents a substantial difference in associated sampling costs. The high costs of laboratory analytical procedures frequently strain environmental and public health budgets (USEPA 1995).

Many coastal authorities have elected to sample surface water on a daily basis to address temporal variation (Kinzleman, *et al.* 2006). The data represented in Table 1 is for Great lakes beaches only and illustrates the monitoring frequency variability among the Great Lakes states. According to the Testing the Waters annual report (2007), the

Table 1. Beach monitoring frequency and criteria comparison among Great Lakes states

State	# Beaches / Miles of Shoreline	Monitoring Frequency	Water Quality Standard
Illinois	54 / 20	5 / week - Daily	235 cfu / 100 mL[a]
Indiana	25 / Unknown	1 / week - Daily	235 cfu / 100 mL
Michigan	207 / 71	1 – 3 / week	300 cfu / 100 mL[b]
Minnesota	39 / 30	1 – 2 / week	235 cfu / 100 mL
New York	39 / Unknown	1 – 2 / week	235 cfu / 100 mL
Ohio	21 / 7	1 – 5 / week	235 cfu / 100 mL
Pennsylvania	12 / Unknown	2 / week	235 cfu / 100 mL
Wisconsin	192 / 55	1 – 5 / week	235 cfu / 100 mL

[a]The USEPA BEACH Act required standards for total body contact recreation: an *E. coli* single-sample maximum of 235 colony forming units (cfu) per 100 mL water.

[b]The MDEQ required standards for total body contact recreation: Shall not contain more than a maximum of 300 *E. coli* colonies per 100 mL water based on the geometric mean of three or more samples taken during the same sampling event.

NRDC found that 203 out of 207 Michigan Great Lakes beaches, which represent 71 miles of coastline, were monitored just once a week during the 2006 season; the remaining four were monitored two or three times each week. Michigan ranks the highest in length of Great Lakes coastline, number of Great Lakes beaches identified, and number of Great Lakes beaches monitored, but lags behind when it comes to monitoring frequency. Is this truly protecting public health?

Analytical costs would certainly be a factor if a local health department in Michigan chose to sample daily and followed sampling protocols under the Michigan water quality standards. 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 study examines the potential use of composite sampling as a viable, unbiased alternative to traditional sampling in Kalamazoo County, Michigan. The primary objectives of this study were to: 1) incorporate composite sampling methodologies into the 2007 bathing beach monitoring season, 2) compare individual sample computed arithmetic and geometric mean results to composite results, 3) determine statistical similarities and significance between these results, and 4) determine if composite sampling leads toward cost savings associated with sample analyses. To help address these objectives, the following questions will be answered.

1. How does the geometric mean compare to the arithmetic mean with respect to bathing beach sampling?
2. How do composite sample results compare to the arithmetic mean of three individual sample results?
3. Does the geometric mean provide a valid representation of water quality at bathing beaches in Kalamazoo County?
4. Are there cost savings to using composite sampling techniques rather than traditional beach monitoring analyses?

A main objective of any type of compliance monitoring is to have adequate spatial coverage, which provides more representation of the defined sampling area. One way to improve spatial coverage is to collect and analyze multiple samples at various 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 and Kinzleman, *et al*. 2006). Traditional bathing beach monitoring programs are often limited on the number of samples collected and the frequency at which bathing beach monitoring takes place. Analyzing multiple samples and monitoring at increased frequencies (i.e., more than once a week) can be quite costly for the monitoring agency (Bertke 2007). Composite sampling is a technique that can be incorporated into a bathing beach monitoring program, while keeping costs at a minimum and improving spatial coverage and temporal frequencies.

BACKGROUND

Bacteriological Contamination

What are the risks associated with swimming in contaminated surface waters? The pathogenic organisms that can potentially be present in surface water can cause illness through ingestion. Once in the body, the pathogen typically infects the gastrointestinal tract, the result of which is generally gastroenteritis, which has symptoms of nausea, vomiting, diarrhea, and/or fever (Yates 2007). Some of the pathogens can infect organs or the nervous system, thus causing more severe illness (Yates 2007). So, what pathogenic organisms might be found in contaminated surface water? A list of some of the common waterborne enteric pathogens (bacteria, protozoa, and viruses) is shown in Table 2 (Haack 2008, Yates 2007, Jensen and McLellan 2005, and Rose and Katonak 2005). The direct detection of these pathogenic organisms, if feasible, would seem to be the best option for obtaining data to allow a thorough assessment of the public health impact for a waterborne pathogen (Yates 2007). However, technological availability and associated analytical costs are typical limiting factors when public health officials inquire about monitoring these waterborne pathogens.

Why are public health officials concerned about monitoring water quality at bathing beaches? The presence of certain microbial organisms in surface water and bathing beaches can indicate recent fecal contamination. The most common organisms used to determine water quality include total coliforms, fecal coliforms, and *Escherichia coli* (*E. coli*). Total coliforms represent a group of bacteria. Coliforms are defined as any bacteria capable of fermenting lactose (milk sugar) with the production of acid and gas in 48 hours at 35° C under aerobic conditions (Anderson and Davidson 1997). Total

Table 2. Common waterborne pathogens

Bacteria	Protozoa	Viruses
Campylobacter	*Cryptosporidium*	Enteroviruses
Escherichia coli O157:H7	*Entamoeba*	Polio
Legionella	*Giardia*	Coxsackle
Listeria	*Naegleria*	Echoviruses
Pseudomonas		Hepatitis A
Salmonella		Norovirus
Shigella		Rotaviruses
Vibrio cholerae		

coliforms (Figure 1), which include fecal coliforms and *E. coli*, are not only found in the intestinal tract of warm-blooded animals, they are found in soils, plants, and animals and are used as a bacterial indicator of sanitary quality of foods and water (including drinking water). In most instances, coliforms themselves are not the cause of sickness, but they are easy to culture and their presence is used to indicate that other pathogenic organisms of fecal origin may be present (Anderson and Davidson 1997).

Fecal coliforms are a sub-set of the total coliform group. Fecal coliforms may indicate the presence of pathogenic organisms; however, some microorganisms classified as fecal coliforms are not actually from the gastrointestinal tract of animals or humans (Anderson and Davidson 1997). *E. coli*, the most common species of fecal coliform bacteria, is a normal component of the large intestines in humans and other warm-blooded animals. It is found in human sewage in very high numbers and indicates the presence of other pathogenic (disease-causing) organisms.

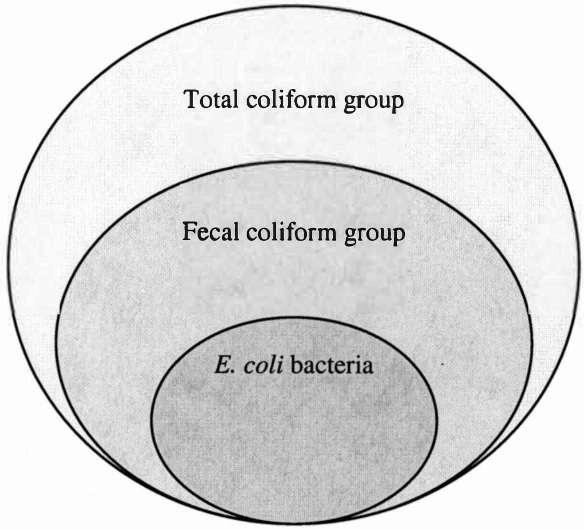


Figure 1. Coliform bacteria illustration

What are *Escherichia coli* (*E. coli*) bacteria? This microorganism is a rod-shaped member of the fecal coliform group that is distinguished from most other coliforms by its ability to ferment lactose at 44° C and by its growth and color reaction on certain types of culture media (Anderson and Davidson 1997). The strain of *E. coli* bacteria typically found in surface water is, for the most part, harmless. The organism provides information when analyzed in surface water samples; it (*E. coli*) tells us that fecal contamination (either by animal or human waste) has taken place and harmful disease-causing organisms may be present. The strain of *E. coli* bacteria that most people may be familiar with is *E. coli* O157:H7, a bacteria that is associated with eating undercooked, contaminated ground beef, drinking unpasteurized milk, swimming in or drinking contaminated water, and eating contaminated vegetables (Anderson and Davidson 1997). This type of *E. coli* bacteria can cause severe illness, but is rarely detected in the surface water environment (Kwak-Hefferan 2007).

E. coli bacteria are considered fecal indicator organisms. The term "indicator" is typically used for a surrogate that is measured instead of analyzing a sample for pathogenic microorganisms (Yates 2007). Fecal indicators tell us that feces is present, however, fecal indicators do not indicate 1) the presence of specific pathogens, 2) the presence of viruses or protozoa, and 3) the presence of non-fecal pathogens (Haack 2008). These organisms are used to assess the potential public health risk in surface water and bathing beach resources (Jensen and McLellan 2005). Surface water resources are often plagued with microbial contamination and some of these agents can cause moderate to severe illness. Many of these organisms are pathogenic, that is they can cause disease or illness if ingested. Because there are hundreds of different pathogens that could be present in the water, it is generally not economically, technologically, or practically possible to test water to determine whether it contains specific pathogens (Yates 2007). So, the idea is to use an organism that is easily detectable and indicates the potential presence of these pathogens.

Just like many other illnesses that affect our human population, recreational waterborne illnesses primarily affect very young, elderly, or debilitated populations (Griffiths 1999). Typically, those who are at risk of potentially becoming ill are those individuals who are completely submerged in the water where the greatest exposure to waterborne pathogens exists. Individuals who wade or swim without submerging the head are at a lesser risk to these waterborne pathogens (Griffiths 1999). Illnesses contracted from recreational waterborne pathogens are difficult to assess, since the symptoms are very similar to other gastrointestinal illnesses. Most people will not become ill if swimming in surface water contaminated with these pathogenic organisms, however, individuals who become sick can become quite ill (Griffiths 1999).

Regulatory Framework

Under the Clean Water Act (33 C.F.R. 1313 (2006)), the USEPA is responsible for publishing water quality criteria that identify thresholds at which pathogens may constitute a risk to human health (United States Government Accountability Office (GAO) 2007). The USEPA, in 1986, conducted several epidemiological studies at both marine and freshwater beaches because of outdated and criticized fecal coliform criteria. Prior to 1986 the numeric standard for primary contact of recreational waters was 200 fecal coliform colonies per 100 milliliters (mL) water. The USEPA identified deficiencies in the study design and in the data used to establish this criterion (USEPA 1986).

Increased monitoring activities across the country are primarily due to recent amendments to the federal Clean Water Act, specifically referred to as 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) (2006) and United States Congress 2000). These amendments 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 BEACH Act of 2000 requires each state and territory with coastal recreation waters to adopt into their water quality standards by April 10, 2004, bacteria criteria that are "as protective of human health as" the 1986 bacteria criteria (USEPA 2004). The 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 5 samples equally spaced over a 30-day period, the geometric mean of the indicated bacterial densities should not exceed 126 colonies *Escherichia coli* (*E. coli*) bacteria per 100 mL water (USEPA 1986). The criteria also include a single sample maximum allowable density of 235 colonies *E. coli* bacteria per 100 mL water. 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. Frequency of bathing beach sampling is, in most cases, at the discretion of the agency conducting the sampling and determined by the annual budget. The USEPA Ambient Water Quality Criteria (1986) states the following:

> It is recommended that sampling frequency be related to the intensity of use of the water body. In areas where weekend use is substantial, weekly samples collected during the peak use periods are reasonable. In less heavily used areas perhaps bi-weekly or monthly samples may be adequate to decide bacterial water quality. In general, samples should be collected during dry weather periods to establish so-called "steady state" conditions. Special studies may be necessary to evaluate the effects of wet weather conditions on waters of interest especially if sanitary surveys indicate the area may be subject to storm water effects. (USEPA 1986)

Like other types of sampling (such as air and soil), the analysis for constituents in water can get quite costly. That is why water quality monitoring programs sample as frequently as the budget allows.

In a memorandum, dated February 13, 1996, to Local Health Departments, the Michigan Department of Public Health (now Michigan Department of Community Health) announced updates to the public bathing beach rules and revised numeric criteria from fecal coliform to *E. coli* as recommended by the USEPA. As a result, the Michigan Department of Community Health (MDCH) and the Michigan Department of Environmental Quality (MDEQ) revised ambient water quality standards for *E. coli* bacteria. These criteria were prepared under guidance of the USEPA and reflect numeric values as protective measures in surface water for body contact recreation.

Specific rules pertaining to these criteria are documented under Michigan Water Quality Standards (Part 4, a promulgated pursuant to Part 31, Water Resources Protection, of the Natural Resources and Environmental Protection Act, 1994 Public Act 451, as amended). The Natural Resources and Environmental Protection Act provides the necessary laws and rules pertaining to environmental and natural resource protection in the State of Michigan.

The purpose of Michigan water quality standards is to establish water quality requirements applicable to the Great Lakes, the connecting waters, and all other surface waters of the state, to protect the public health and welfare, to enhance and maintain the quality of water, to protect the state's natural resources, and to serve the purposes of Public Law 92-500, as amended, 33 C.F.R. 1251 et seq., Part 31, Water Resources Protection, 1994 PA 451, MCL 324.3101 to 324.3119, and the Great Lakes water quality agreement enacted November 22, 1978, and amended in 1987 (Michigan Compiled Laws 1994). 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)

Rule 62(2). All surface waters of the state protected for partial body contact recreation shall not contain more than a maximum of 1,000 *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)

R 323.1100 Designated Uses.

Rule 100(2). All surface waters of the state are designated for, and shall be protected for, total body contact recreation from May 1 to October 31 in accordance with the provisions of R 323.1062. Total body contact recreation immediately downstream of wastewater discharges, areas of significant urban runoff, combined sewer overflows, and areas influenced by certain agricultural practices is contrary to prudent public health and safety practices, even though water quality standards may be met. (Michigan Compiled Laws 1994)

The Michigan Public Health Code (Section 333.12541), Public Act 368 of 1978, authorizes local health departments to monitor and evaluate water quality at public bathing beaches and to determine whether the water is safe for bathing purposes (Macomb County Health Department 2000 and Michigan Compiled Laws 1978). The numeric bacteriological criteria for *E. coli* are also referenced in the Michigan Public Health Code and may be used by the local authority to issue advisories or closures of public beaches. Specifically, the Public Health Code states the following:

Sec. 12541. (1) The local health officer or an authorized representative of the local health department having jurisdiction may test and otherwise evaluate the quality of water at bathing beaches to determine whether the water is safe for bathing purposes. However, the local health officer or authorized representative shall notify the city, village, or township in which the bathing beach is located prior to conducting the test or evaluation. (Michigan Compiled Laws 1978)

(2) If a local health officer or an authorized representative of a local health department conducts a test or evaluation of a bathing beach under subsection (1), within 36 hours of conducting the test or evaluation, he or she shall notify the department, the city, village, or township in which the bathing beach is located, and the owner of the bathing beach of the results of the test or evaluation. (Michigan Compiled Laws 1978)

(3) The owner of the bathing beach shall post at the main entrance to the bathing beach or other visible location a sign that states whether or not the bathing beach has been tested or evaluated under subsection (1) and, if the bathing beach has been tested, the location of where test results may be reviewed. Open stretches of beach or beaches at road ends that are not advertised or posted as public bathing beaches do not need to have signs posted. (Michigan Compiled Laws 1978)

(4) If a local health officer or authorized representative of the local health department conducts a test or evaluation under subsection (1) and, based upon the standards promulgated under section 12544, the health officer or the authorized representative determines that the water is unsafe for bathing, he or she may petition the circuit court of the county in which the bathing beach is located for an injunction ordering the person owning or operating the bathing beach to close the bathing beach for use by bathers or ordering other measures to keep persons from entering on the bathing beach. Upon receipt of a petition under this subsection, the court may grant an injunction if circumstances warrant it. (Michigan Compiled Laws 1978)

These water quality standards are based on health risk studies conducted by the USEPA, MDCH, and MDEQ. The standards are in place to protect human exposure from surface water and bathing beach resources that are in violation of total or partial body contact recreation standards. Local health departments that conduct bathing beach monitoring are required to follow these rules to determine compliance and issue beach related advisories and closures based on the above-mentioned numeric standards.

During the late 1970's and early 1980's the Kalamazoo County Environmental Health & Laboratory Services Bureau (now Environmental Health Bureau) conducted bathing beach monitoring. The program consisted of collecting one surface water sample once a week at twenty-five locations throughout Kalamazoo County during the bathing season (June, July, & August). The surface water samples were diluted and analyzed for total coliform bacteria, a group of organisms that may indicate the presence of other disease-causing microorganisms. The laboratory analysis consisted of using Millipore filters, M-Endo media, multi-tube dilutions, and several days of incubation, a process that was very time consuming, labor intensive, and did not focus on *E. coli* bacteria. After several seasons of collecting water samples and analyzing for total coliform bacteria, the bathing beach monitoring efforts were discontinued by 1985. The lack of personnel and budgetary cuts caused the demise of the monitoring program in Kalamazoo County.

During the summer of 2000, citizens in Pavilion and Brady Townships expressed concerns about surface water quality and bacterial contamination in Portage River and Dorrance Creek, both of which discharge into Indian Lake (Figure 2). The apparent contamination was coming from agricultural runoff from an intensive dairy operation in southeastern Kalamazoo County. These concerns prompted investigations by the MDEQ (Surface Water Quality Division), Michigan Department of Agriculture, USEPA, and the Kalamazoo County Human Services Department (now Kalamazoo County Health and Community Services Department). Investigations and water sample analysis concluded that surface water did have high levels of *E. coli* bacteria. The Kalamazoo County Human Services Department issued public health advisories, notifying the communities to avoid total body contact recreation in Portage River, Dorrance Creek, and Indian Lake. These surface water bodies were posted for most of the summer.

Due to these concerns raised by citizens over surface water quality issues, the Kalamazoo County Board of Commissioners, at their June 20, 2000 meeting directed county staff to initiate and implement a countywide surface water monitoring program. In the fall of 2000 an Ad Hoc Surface Water Advisory Committee was formed to assist county personnel in developing the overall monitoring strategy. Following the direction of the Board of Commissioners, a surface water specialist was hired in January of 2001 to develop, implement, and maintain the surface water monitoring program.

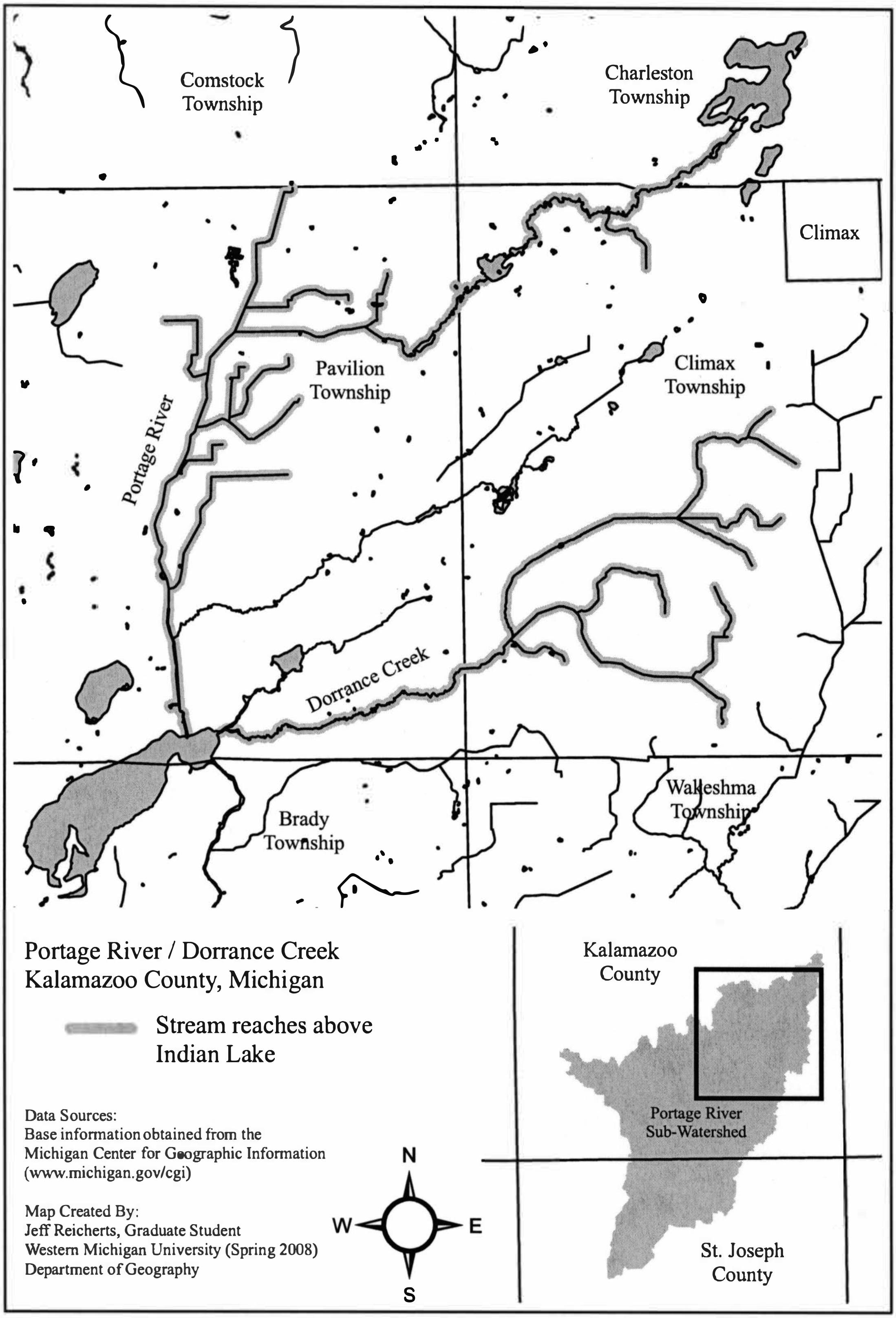


Figure 2. Portage River / Dorrance Creek, Kalamazoo County, Michigan

The surface water monitoring program is divided into two major components: 1) stream and creek monitoring and 2) bathing beach monitoring. Stream and creek monitoring is conducted at various frequencies year round. Water samples are collected for bacteriological analysis and water quality meters are used to measure water temperature, pH, conductivity, dissolved oxygen, and turbidity. The purpose of stream and creek monitoring is to continually assess the quality of Kalamazoo County's surface water resources, identify water quality deficiencies, and track and document trends, while providing water quality information to decision-makers and interested parties.

Bathing beach monitoring consists of weekly sampling starting the first week of May and ending in September, a week beyond Labor Day (typically 18 to 20 weeks). Field staff collect three water samples for bacteriological analysis and use field equipment to record physical water conditions (as stated above). The purpose of the program is to assure a safe and healthy recreational experience for all who visit a bathing beach, determine compliance to Michigan water quality standards for total body contact recreation, and protect public exposure to surface water that does not meet Michigan's Water Quality Standards.

Monitoring and Analysis

Bacteria counts can be highly variable among individual samples collected in the defined swimming area. Both temporal and spatial scales are desired for compliance monitoring. However, costs associated with increased frequencies and increased sample analyses make beach sampling very expensive. Composite sampling has the potential to address temporal and spatial scales in Michigan beaches, keeping costs at a minimum. Composite sampling can substantially reduce analytical costs because the number of required analyses is reduced by compositing several samples into one and analyzing the composited sample (Patil 2002).

What exactly is a composite sample? A composite sample (Figure 3) is made from a number of discrete samples which have been collected from a body of water or other material 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).

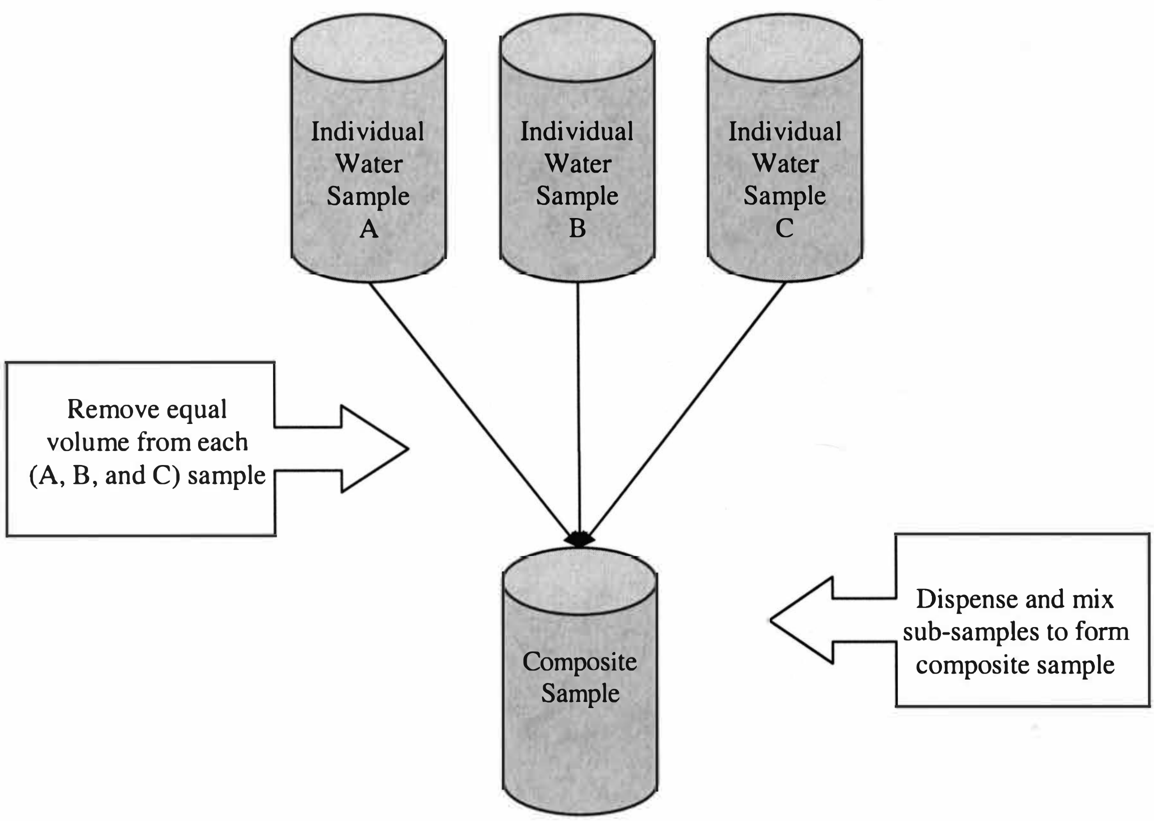


Figure 3. Composite sample illustration

Composite sampling can improve spatial and temporal coverage of an area without increasing the number of analyses (USEPA 2004). According to USEPA (2002), composite sampling has several advantages to that of multiple individual sample analyses. Cost reduction is a primary goal in many sampling programs. If the results of bacteria 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.

Individual water samples can be mixed to form a homogenized sample, which makes this application appropriate. When sampling beach areas, water sample collection should be representative of the defined study area; composite sampling can achieve this representation. Composite sampling has been utilized, not only with water media, 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). Composite sampling has been applied to source-tracking enterococci in coastal bathing beach water (Genthner, *et al.* 2005). Few composite studies have been conducted using *E. coli* bacteria concentrations in bathing beach water.

Composite sampling should not be used if any results indicate the potential masking of areas of concern (Kinzleman, *et al.* 2006). For example, storm sewer outfalls or stream tributaries that discharge into nearby swimming areas may influence bacteria counts in water samples, especially after rain events. A sanitary survey conducted at bathing beach facilities will help address and characterize potential bacteria sources to the immediate swimming area. Bacteria counts can vary across the swimming area; an elevated count in one sample can mask and impact spatial variation among the other two samples during the compositing process. A preliminary review of six years (2001-2006) of bathing beach data (1,151 sampling events) in Kalamazoo County revealed that twenty-six sampling events were in violation of Michigan water quality standards. These sampling events exceeded the daily geometric mean (DGM) of 300 *E. coli* colonies per 100 mL water. If the daily arithmetic mean (DAM) had been used, an additional six sampling events (Table 3) would have caused a violation of Michigan water quality standards. These six cases were represented by one of the three individual samples being extremely higher (different) than the other two in the set.

Table 3. Sampling events (2001-2007) that exceeded 300 *E. coli* colonies per 100 mL water using the arithmetic mean only

Beach	Date	Time	Individual Sample Results[a]			DAM[b]	DGM[c]
			A	B	C		
KB-01	5/19/2004	13:55	1986	9	3	666	37
KB-02	8/01/2006	11:50	105	77	980	387	199
KB-05	7/17/2002	12:00	43	159	2420	874	255
	6/13/2005	11:45	308	866	96	423	295
KB-07	6/13/2001	11:00	131	233	548	304	256
KB-08	8/17/2006	13:40	62	137	770	323	188

[a]Results reported as the number of *E. coli* colonies per 100 mL water.

[b]DAM is the daily arithmetic mean (number of *E. coli* colonies per 100 mL water) for the set of individual sample results.

[c]DGM is the daily geometric mean (number of *E. coli* colonies per 100 mL water) for the set of individual sample results.

Kinzleman, *et al.* (2006) conducted a composite sample study on two Lake Michigan beaches, both located in the City of Racine, Wisconsin, to determine if composite sampling methodologies provided similar results as to individual sample analysis. In their study, Kinzleman, *et al.* (2006) analyzed individual and composited samples using Colilert®-18 and Quanti-Tray®/2000, analytical products from IDEXX Laboratories, Inc. Results of this study indicate a reasonable expectation of a simple 1:1 ratio between the composite samples and the arithmetic mean of the individual samples (Kinzleman, *et al.* 2006).

The United States Geological Survey (USGS) at Ohio conducted similar studies from May through September 2005 on three Lake Erie beaches located in Lorain and Cuyahoga Counties. The USGS compared results from composited samples to those obtained by averaging individual results from multiple-point samples (USGS 2007). In this study, USGS (2007) collected two individual water samples at two Lake Erie beaches (Monday through Friday) and three individual water samples at a third beach (Monday through Thursday). The individual and composite samples were analyzed for *E. coli* bacteria on modified mTEC agar, a membrane filtration using modified membrane-thermotolerant *Escherichia coli* agar (EPA Method 1603). 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).

METHODS

Study Sites

The Kalamazoo County Health and Community Services Department has conducted weekly bathing beach monitoring at nine public bathing beaches (Figure 4); eight since 2001 and a ninth since 2004. The ownership of these facilities includes state (1), county (3), township (2), municipal (2), and village (1) government. The facilities are considered public because they (facilities) may require an annual pass, may charge daily/annual user fees, and are open to the general public. Private facilities such as campgrounds and youth camps are not open to the general public and are not included in this sample.

A sampling event consisted of collecting individual water samples, documenting weather conditions, and recording measurements of water temperature, dissolved oxygen, pH, conductivity, and turbidity (Appendix A). During the summer of 2007, the monitoring plan was modified to include composite sampling techniques for the purpose of this research project. 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. There were two sampling event weeks where composite sampling did not occur; weeks of May 14, 2007 and July 9, 2007. Water sample collection times were recorded on the appropriate laboratory analysis request form (Appendix B and Appendix C). 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.

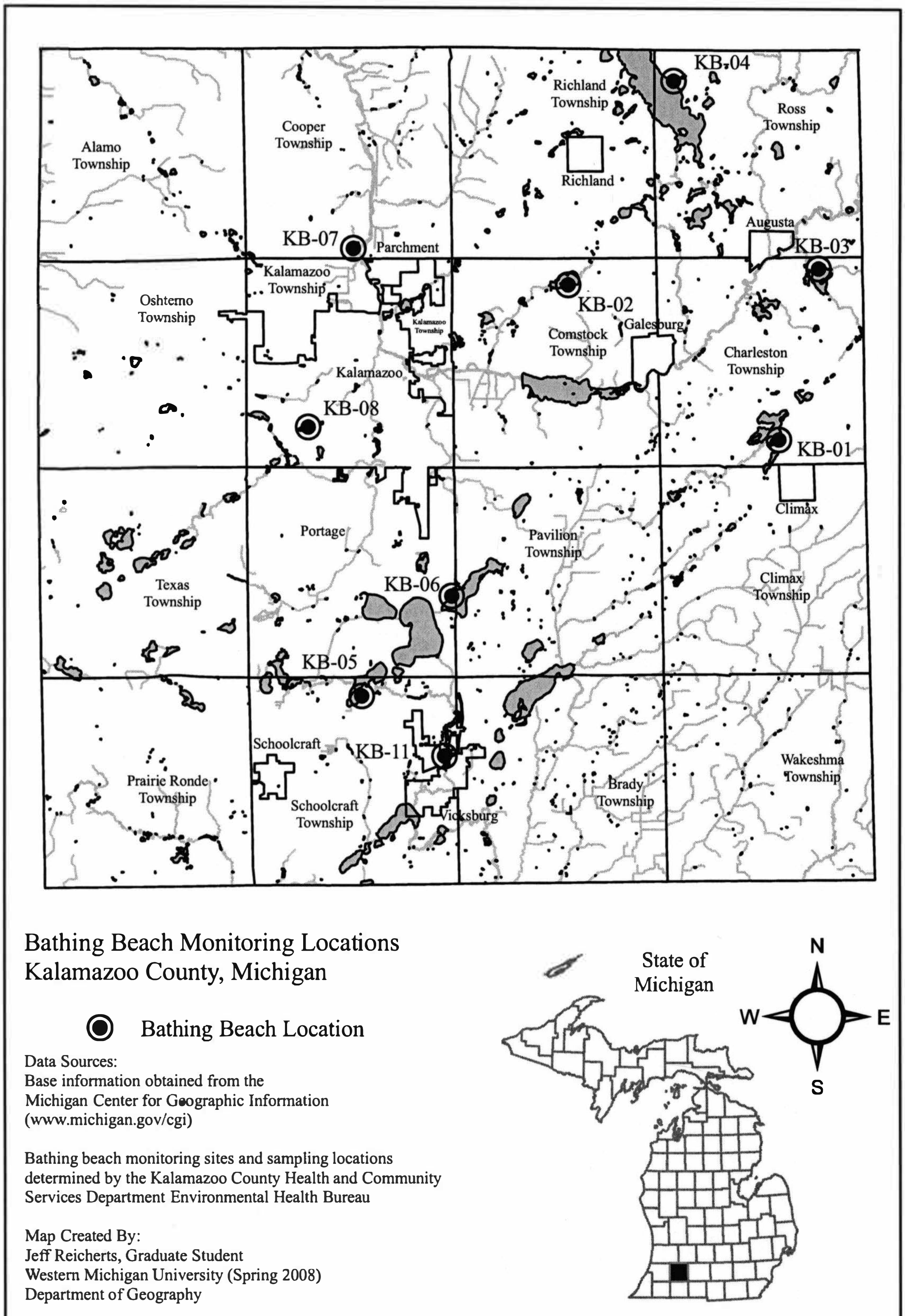


Figure 4. Locations of public bathing beaches in Kalamazoo County, Michigan

Cold Brook County Park (KB-01)

Cold Brook County Park is owned by Kalamazoo County and operated and maintained by the county's Parks Department (www.kalcounty.com/parks/index.htm). The park sits on 276 acres and is located on East "MN" Avenue at South 42nd Street in Charleston Township (Section 34) at 14467 East "MN" Avenue. The bathing beach (Figure 5), which is approximately 265 feet in length, is located on Blue Lake (44 acres), one of three connecting lakes (the others are Long and Portage Lakes) with a total surface area of 325 acres. The Michigan Department of Natural Resources maintains a public boat access site, which is located within the park on the south end of Blue Lake. Other recreational activities include camping, fishing, hiking, picnic shelters, and disc golf.

Land cover around Blue, Long, and Portage Lakes is comprised of primarily forested lands (central hardwoods / oak, aspen-birch, and pine), wetlands (both forested and non-forested), and shrub lands. There are very few homes directly on the three lakes. The wetlands and forested land buffer large tracts of farmland that cover this part of Charleston Township. The bathing beach faces the west, so the prevailing winds can have direct impact on water quality.

The major sources of bacterial contamination to the swimming area at Cold Brook County Park are from wildlife, specifically large numbers of Canada geese. The geese browse mowed lawns and use the grounds for shelter overnight. The swimming area is located at the base of a grassy hillside, an area that is frequented by Canada geese. The Kalamazoo County Parks and Recreation staff has made several attempts to deter geese from this area; fencing placed along the water's edge and spraying grass with bird taste repellents have been utilized with some degree of success.

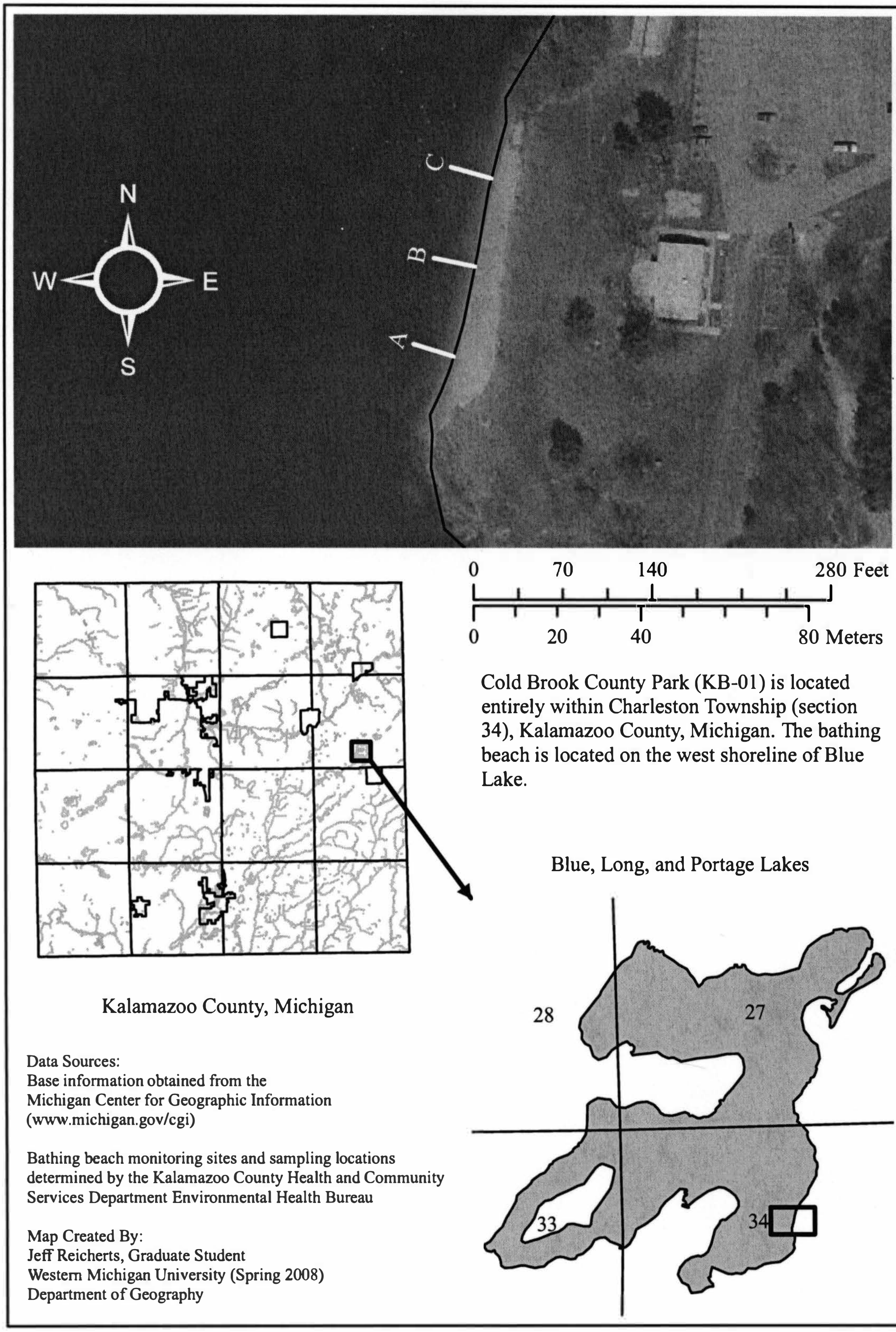


Figure 5. Cold Brook County Park (KB-01) and sampling locations

Robert Morris Park (KB-02)

Robert Morris Park is owned by Comstock Township and operated and maintained by the township's Parks and Recreation Department (www.comstockmi.com/). The park is approximately 40 acres in size and includes a bathing beach (Figure 6) on Campbell Lake, a lake with a surface area of 150 acres. The 150-foot swimming area is bounded by two large docks on the south side of the lake. Robert Morris Park is located at 8415 East "H" Avenue in Comstock Township (Section 3) and offers fishing, playground equipment, sand volleyball court, horseshoe pits, basketball courts, picnic shelters, and disc golf.

Campbell Lake is considered a private lake; a public boat launch does not exist on the lake, nor is there public access of any kind. Single family homes exist on the north, east, and south sides of the lake; these homes are serviced by on-site sewage treatment systems. The west side of the lake is bordered by the Fred McLinden Nature Trails. The predominant land cover around Campbell Lake consists of croplands, grasslands and shrub lands, forested lands (central hardwoods / oak, lowland hardwoods, and pine), and wetlands (both forested and non-forested).

Potential sources of bacterial contamination to the swimming area at Robert Morris Park include wildlife (primarily Canada geese and gull species), parking lot runoff (stormwater), and failing on-site sewage treatment systems.

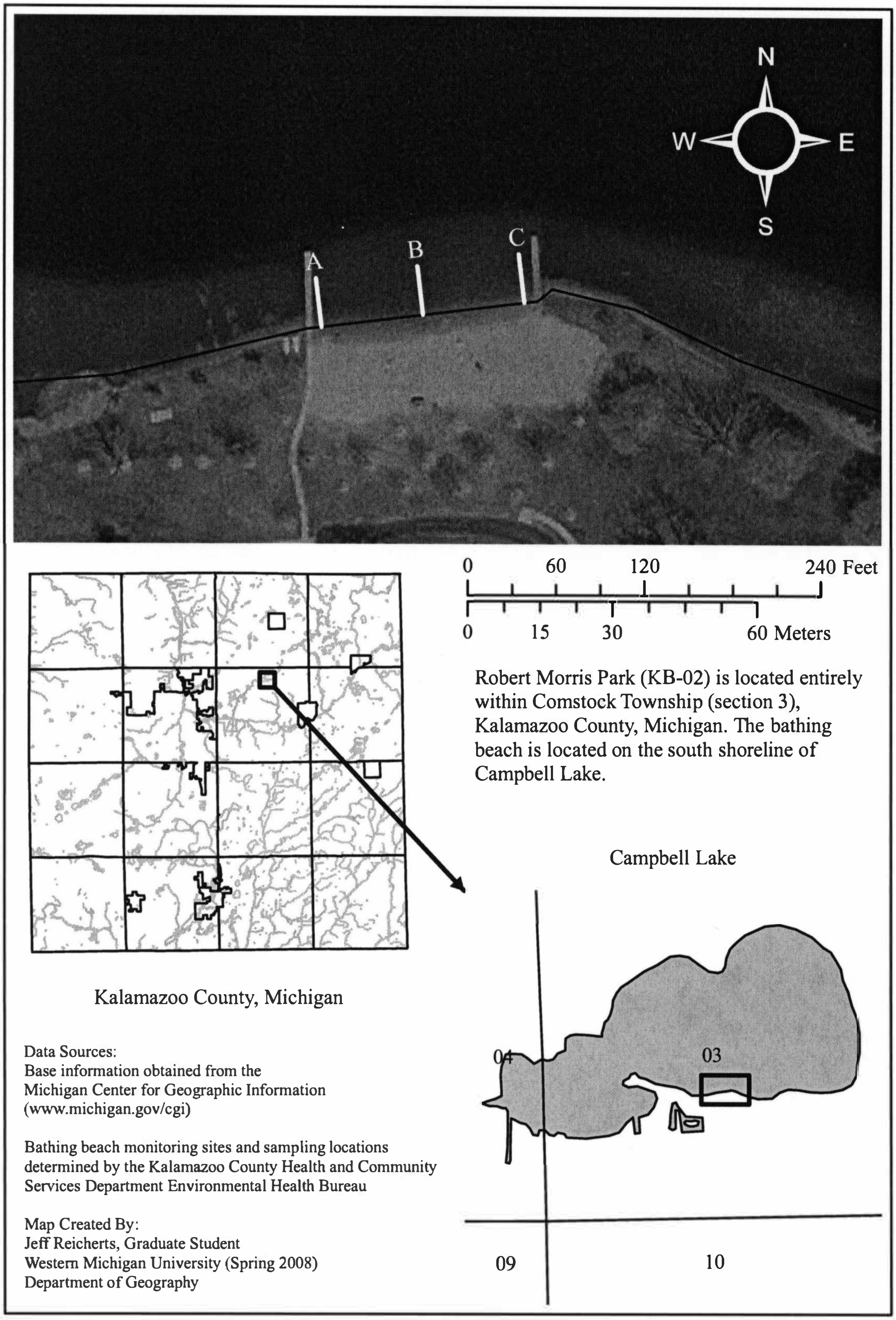


Figure 6. Robert Morris Park (KB-02) and sampling locations

Fort Custer Recreation Area (KB-03)

The Fort Custer Recreation Area is owned by the State of Michigan and operated and maintained by the Department of Natural Resources Parks and Recreation Division (www.michigan.gov/dnr). The recreation area is comprised of over 3,000 acres of open prairies, forestland, and designated camping areas. A bathing beach (Figure 7) of approximately 1,000 feet of shoreline is managed on Eagle Lake (194 acres), one of several lakes found in the recreation area. Fort Custer is located in Charleston Township (Section 2) at 5163 Fort Custer Drive, which is immediately east of the Village of Augusta and west of Battle Creek (Calhoun County). The Fort Custer Recreation Area offers camping, fishing, hunting, and over 25 miles of multi-use trails that are open to mountain biking, horseback riding, dog sledding, hiking, cross country skiing, and snowmobiling.

Land cover that surrounds Eagle Lake in the Fort Custer Recreation Area is predominantly forested lands (central hardwoods / oak, aspen-birch, and pine), wetlands (both forested and non-forested), and open shrub lands. There are three large lakes (including Eagle Lake) that have public boat launch facilities; Jackson Hole and Whitford / Lawler are the other two lakes. Additionally, there is a public boat launch facility on the Kalamazoo River.

Fort Custer Recreation Area is very natural and pristine; there is very minimal human induced development. Potential sources of bacterial contamination to the swimming area on Eagle Lake include wildlife such as gull species, turkey vultures, Canada geese, and white-tailed deer.

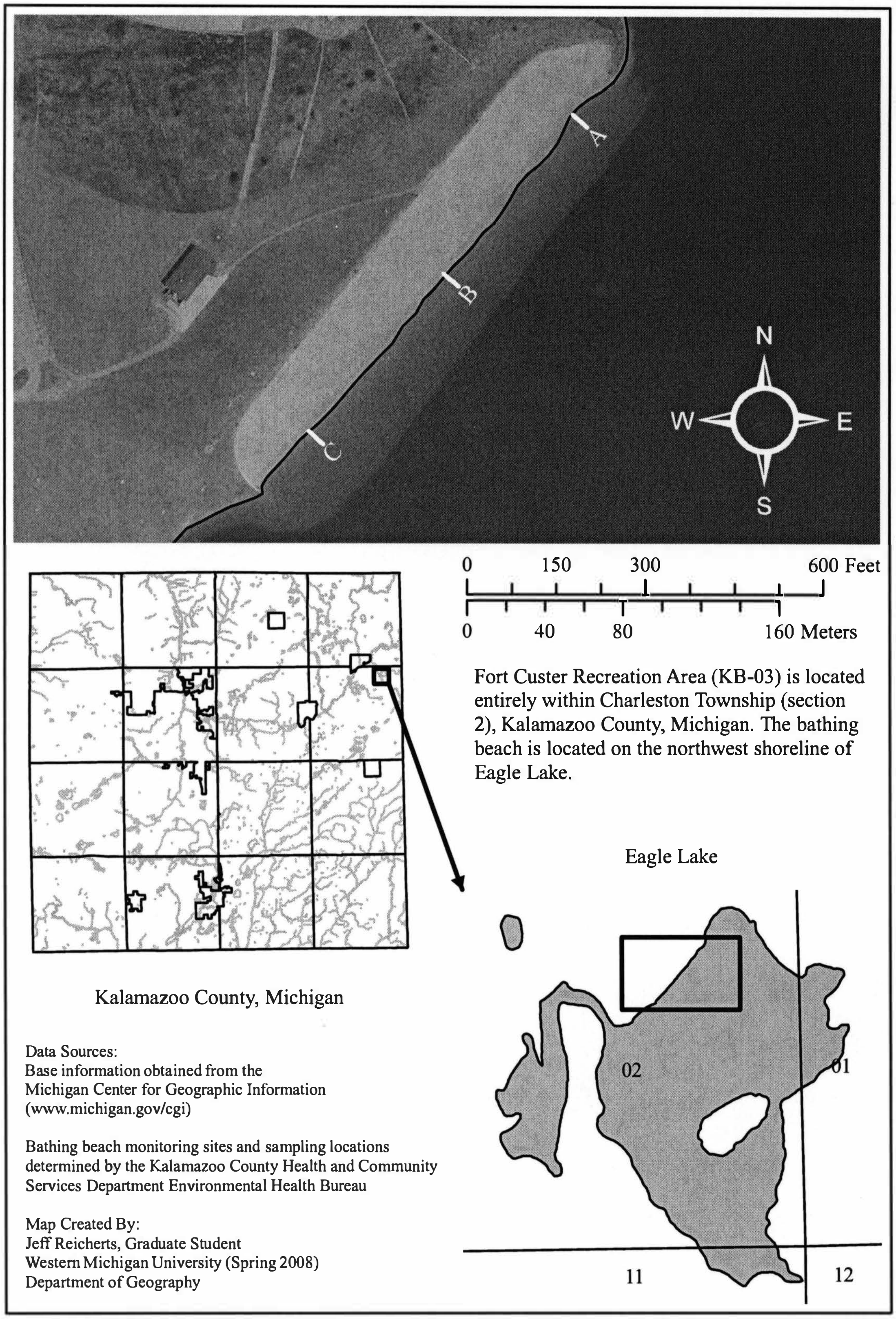


Figure 7. Fort Custer Recreation Area (KB-03) and sampling locations

Ross Township Park (KB-04)

Ross Township Park is owned, operated, and maintained by Ross Township (www.ross-township.us/), a unit of government located in the northeast corner of Kalamazoo County. The park is nestled among a stand of hardwoods on the eastern shoreline of Gull Lake, a 2,000-plus acre lake in Kalamazoo and Barry Counties. The designated swimming area (Figure 8) is approximately 350 feet of shoreline within the park. Ross Township Park is 3.5 acres and located in Section 6 on East Gull Lake Drive (immediately north of East "B" Avenue, near Michigan State University Kellogg Biological Station). The park offers picnic tables and is a local "hotspot" for SCUBA. There are two public boat launch sites on Gull Lake; one is located on the Barry County / Kalamazoo County line at the end of East Baseline Road and the other on the north end of the lake at Prairieville Township Park.

Land cover around Gull Lake is the most diverse as compared to the other lakes in this project. Land cover surrounding Gull Lake comprises urban and built up (multi-family and single family residences and commercial and institutional services), agricultural land (cropland and farmsteads), orchards and tree fruits, grasslands, shrub lands, forested lands (central hardwoods / oak, aspen-birch, lowland hardwoods, and pine), and wetlands (both forested and non-forested). Gull Lake is surrounded entirely by housing and commercial development. All properties are serviced by sanitary sewer through the Gull Lake Sewer Authority.

Potential bacterial contamination to the swimming area at Ross Township Park includes parking lot runoff (stormwater), sanitary sewer leaks, wildlife, and boat waste.

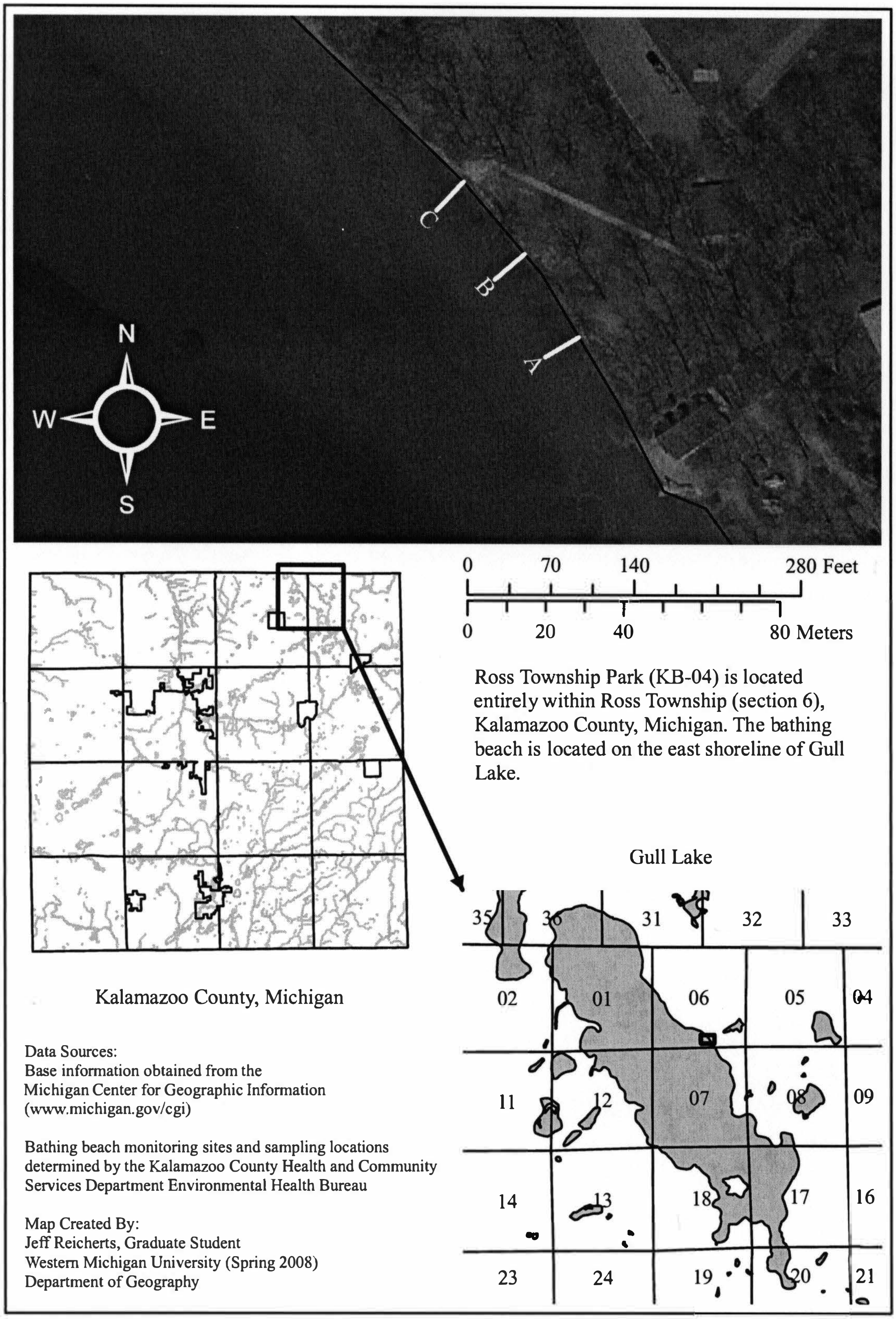


Figure 8. Ross Township Park (KB-04) and sampling locations

Prairie View County Park (KB-05)

Prairie View County Park is owned by Kalamazoo County and operated and maintained by the county's Parks Department (www.kalcounty.com/parks/index.htm). The park sits on 200 wooded acres and is located on East "U" Avenue (immediately west of Portage Road) in Schoolcraft Township (Section 3) at 899 East "U" Avenue. The bathing beach at Prairie View County Park (Figure 9) is located on 300 feet of shoreline along the western shore of Hogsett Lake (78 acres). Hogsett Lake is connected, via a small canal, to the larger Gourdneck Lake (222 acres). Other features in Prairie View County Park include fishing, hiking, and picnic shelters. The Michigan Department of Natural Resources maintains a public boat access site, which is located within the park on the east side of Hogsett Lake.

Land cover around Hogsett Lake is predominantly forested lands (central hardwoods / oak, lowland hardwoods, and pine), forested wetlands (shrub swamps), grasslands, and shrub lands. The entire west side of Hogsett Lake is bordered by the Gourdneck State Game Area. There are very few houses directly on the lake; however, a majority of the shoreline of Gourdneck Lake (the lake to the north) is developed. Sanitary sewer and on-site sewage treatment systems service the residences and businesses found in this region of the county.

Older (failing) on-site sewage treatment systems and wildlife (Canada geese, ducks, swans, gull species, and white-tailed deer) are the primary sources of bacterial contamination to the swimming area at Prairie View County Park.

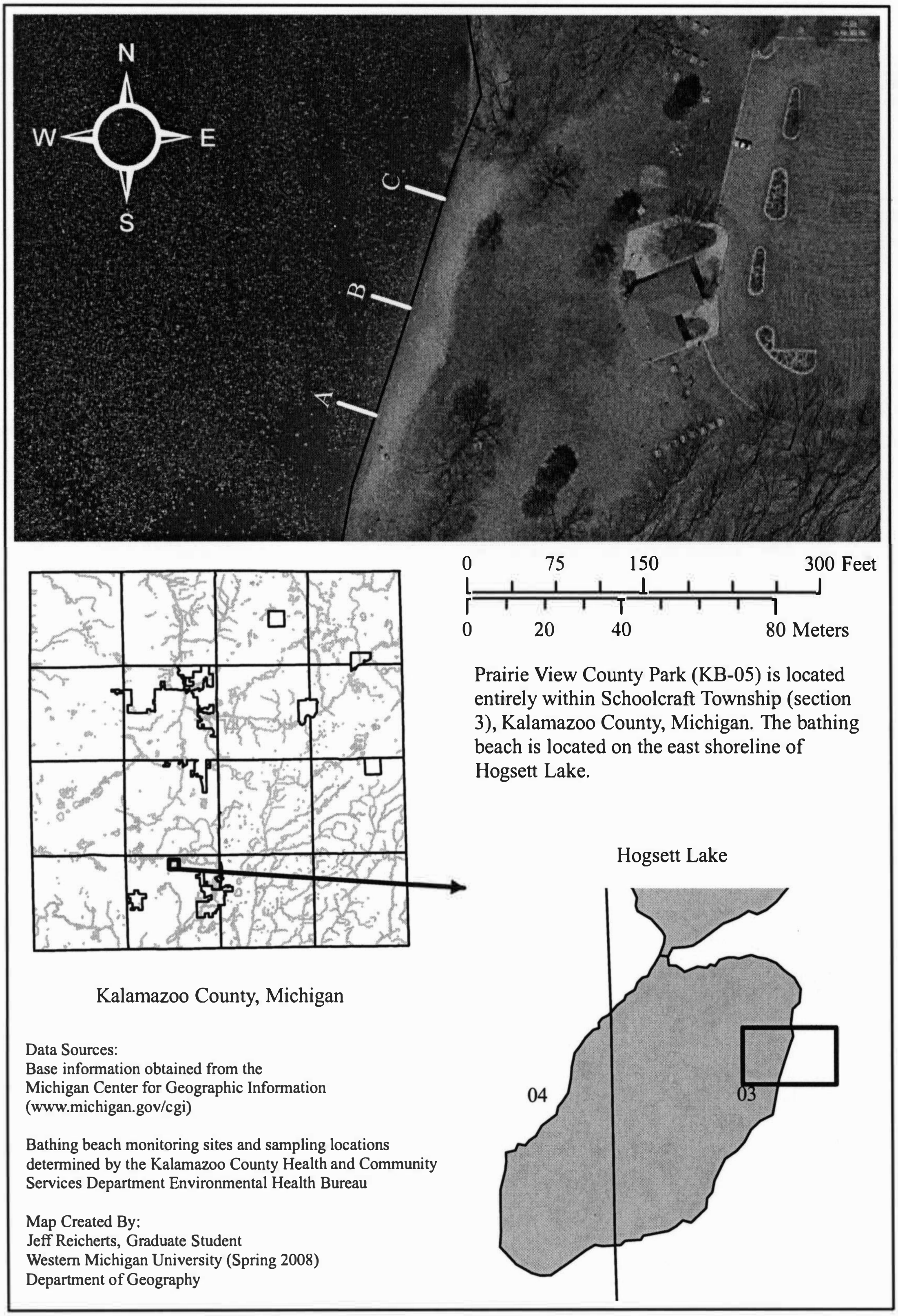


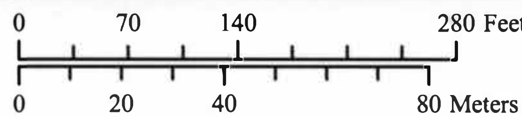
Figure 9. Prairie View County Park (KB-05) and sampling locations

Ramona Park (KB-06)

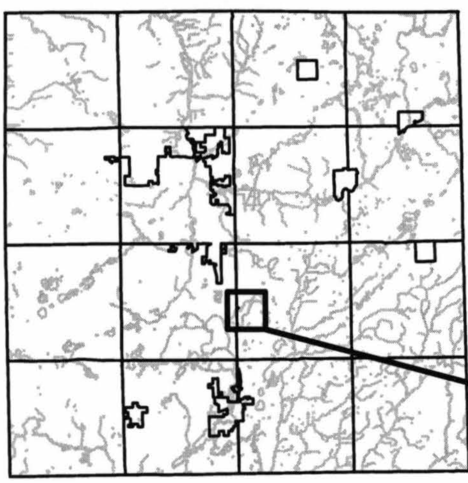
Ramona Park is owned by the City of Portage and operated and maintained by the city's Parks and Recreation Department (http://www.portagemi.com/living/parks.asp). The park is located in Section 24 at 8643 Waruf Avenue, which is in the southeast corner of South Sprinkle Road and Zylman Avenue. Ramona Park is 67 acres and includes a bathing beach (Figure 10) on the western shoreline of Long Lake, a lake with a surface area of 500 acres. The 150 feet of designated shoreline for swimming is just one of the attractions at the park. The park also includes a fishing pier, large play structure, beach house, volleyball courts, picnic shelters, several soccer fields, softball facilities, and tennis and basketball courts. The Michigan Department of Natural Resources maintains a public boat access site, which is located on the south end of Long Lake.

Land cover surrounding Long Lake comprises urban and built up (single family residences and commercial and institutional services), agricultural lands (croplands and farmsteads), orchards and tree fruits, grasslands, shrub lands, forested lands (central hardwoods / oak, aspen-birch, and lowland hardwoods), and wetlands (both forested and non-forested). Long Lake is surrounded entirely by housing and commercial development. Those properties, located in the City of Portage and Pavilion Township, are serviced by sanitary sewer.

Ramona Park attracts large flocks of Canada geese; these geese tend to concentrate in the park on nearby soccer fields and around the bathing beach area. Other potential bacterial sources to the swimming area in Ramona Park include other wildlife (ducks and gulls), stormwater runoff, sanitary sewer leaks, and boat waste.

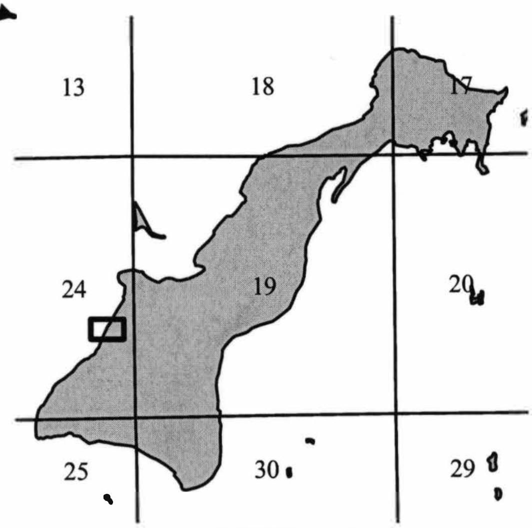


Ramona Park (KB-06) is located entirely within the City of Portage (section 24), Kalamazoo County, Michigan. The bathing beach is located on the west shoreline of Long Lake.



Kalamazoo County, Michigan

Long Lake



Data Sources:
Base information obtained from the Michigan Center for Geographic Information (www.michigan.gov/cgi)

Bathing beach monitoring sites and sampling locations determined by the Kalamazoo County Health and Community Services Department Environmental Health Bureau

Map Created By:
Jeff Reicherts, Graduate Student
Western Michigan University (Spring 2008)
Department of Geography

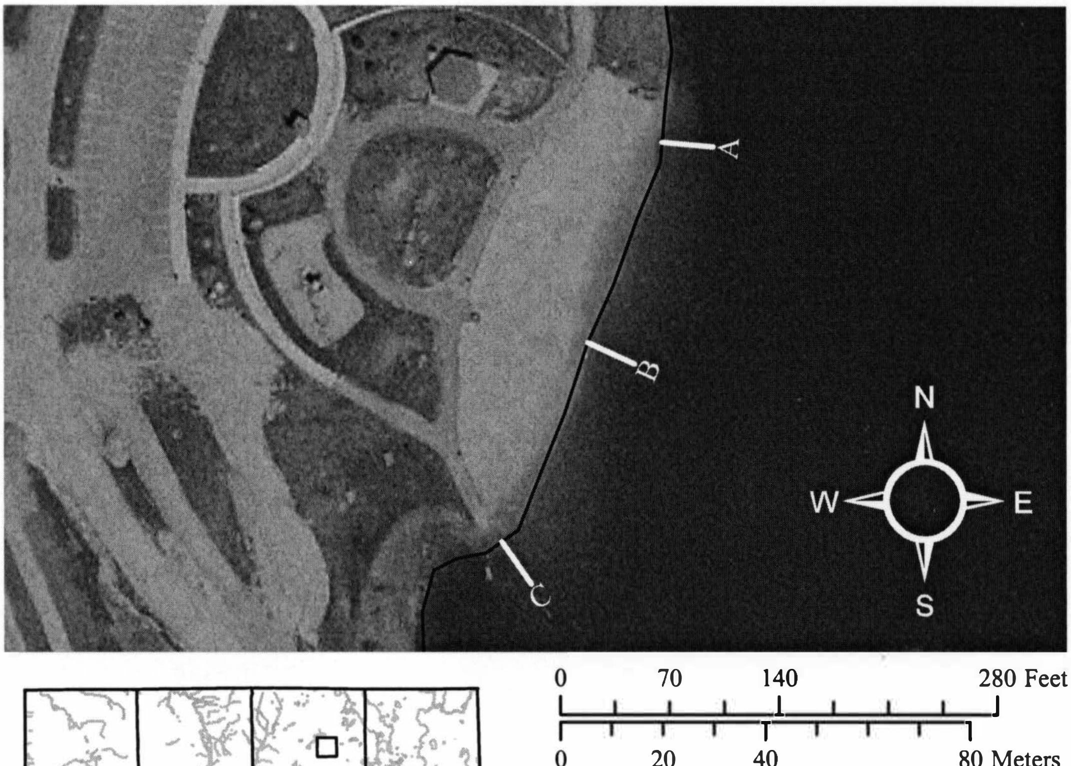
Figure 10. Ramona Park (KB-06) and sampling locations

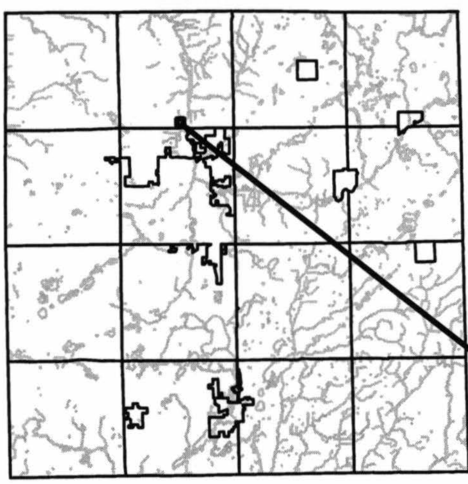
Markin Glen County Park (KB-07)

Markin Glen County Park is owned by Kalamazoo County and operated and maintained by the county's Parks Department (www.kalcounty.com/parks/index.htm). The park consists of approximately 190 acres located on North Westnedge Avenue (immediately north of East "G" Avenue) in Cooper Township (Section 34) at 5300 North Westnedge Avenue. Two distinct land areas make up the park; a portion located on the west side of North Westnedge Avenue features primarily hiking and group picnic shelters and a portion located on the east side of North Westnedge Avenue features a bathing beach (Figure 11), camping, fishing, hiking, and picnic shelters. The east portion includes two man-made lakes; one of which is designated for fishing ($\approx$ 4 acres) and the other for swimming ($\approx$ 8 acres). The lake designated for swimming is referred to as Swimmer's Lake, which offers 300 feet of bathing beach on the western shoreline.

Land cover surrounding Markin Glen County Park is primarily single family residences, light industrial, some commercial, grasslands, shrub lands, and forested lands (central hardwoods / oak and aspen-birch). According to Cooper Township staff, the park is connected to sanitary sewer; however nearby residences can be connected to sanitary sewer or use on-site sewage treatment systems.

Potential sources of bacterial contamination to the bathing beach on Swimmer's Lake at Markin Glen County Park include wildlife (primarily Canada geese), failing on-site sewage treatment systems, and stormwater runoff.

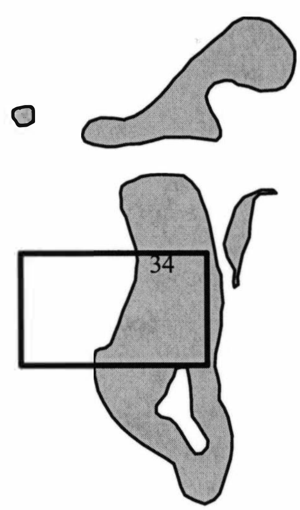




Kalamazoo County, Michigan

Markin Glen County Park (KB-07) is located entirely within Cooper Township (section 34), Kalamazoo County, Michigan. The bathing beach is located on the west shoreline of Swimmer's Lake.

Swimmer's Lake



Data Sources:
Base information obtained from the Michigan Center for Geographic Information (www.michigan.gov/cgi)

Bathing beach monitoring sites and sampling locations determined by the Kalamazoo County Health and Community Services Department Environmental Health Bureau

Map Created By:
Jeff Reicherts, Graduate Student
Western Michigan University (Spring 2008)
Department of Geography

Figure 11. Markin Glen County Park (KB-07) and sampling locations

Woods Lake City Park (KB-08)

Woods Lake City Park is owned by the City of Kalamazoo and operated and maintained by the city's Parks and Recreation Department (www.kalamazoocity.org). Woods Lake is a small 23-acre lake located in a depression at the northwest corner of Oakland Drive and Parkview Avenue. The 6.5-acre park is located at 2900 Oakland Drive (immediately north of Parkview Avenue) in the City of Kalamazoo (Section 29). The northeast shoreline (175 feet) of Woods Lake is managed as a bathing beach (Figure 12). Woods Lake City Park also includes picnic tables and fishing.

Woods Lake is surrounded entirely by development. The predominant land cover includes single family, commercial and institutional, forested lands (central hardwoods / oak), and wetlands (both forested and non-forested). During the late 1990's through the early 2000's, the City of Kalamazoo conducted numerous stormwater improvements around Woods Lake, including a stormwater detention / wetland treatment system on the southwest corner (directly opposite of the bathing beach). This structure captures and treats nearly two-thirds of the lake's drainage area.

The predominant sources of bacterial contamination to the bathing beach on Woods Lake include wildlife (Canada geese, ducks, and swans), stormwater runoff, and pet waste discharges. The homes and businesses around the lake are on sanitary sewer.

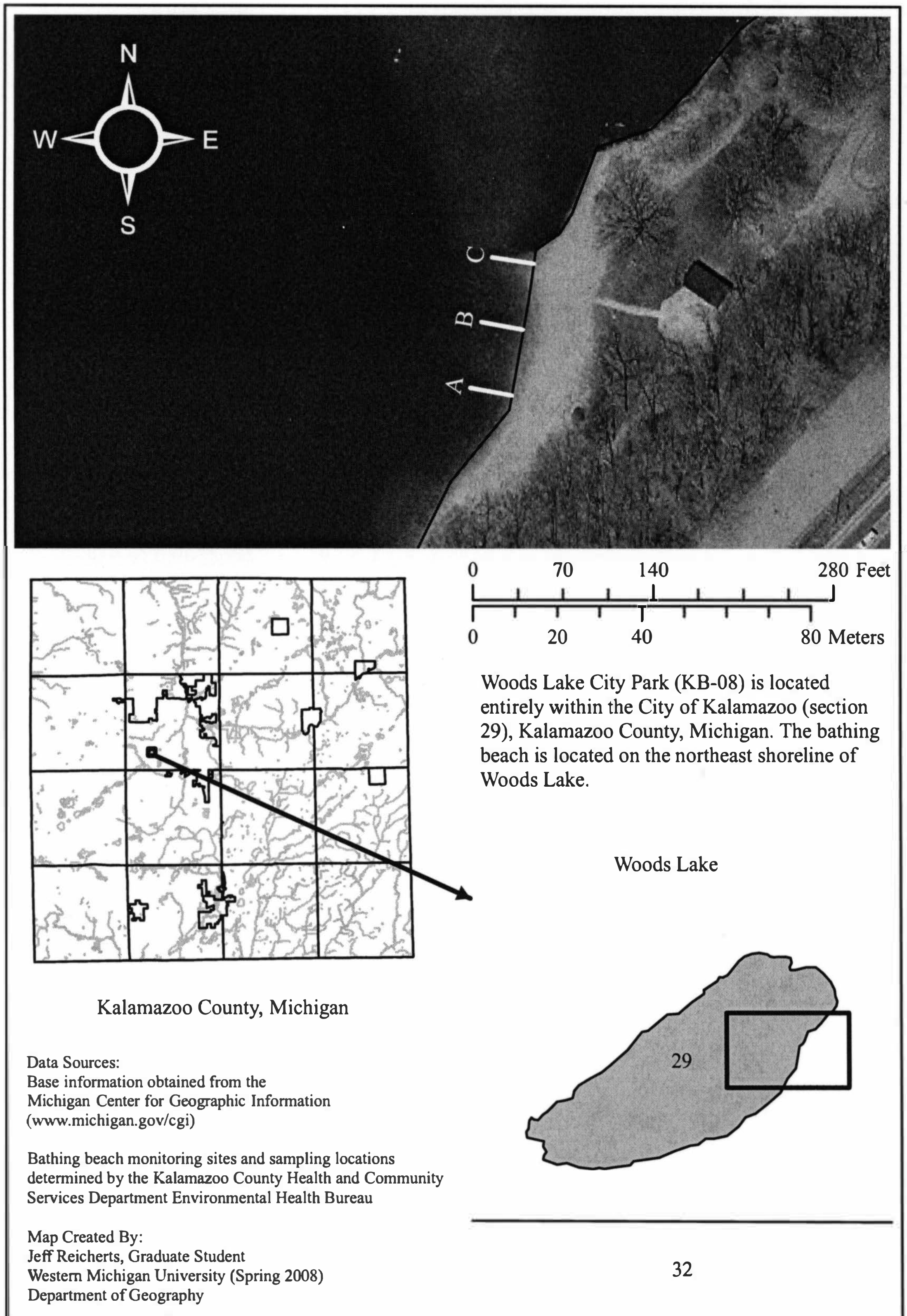


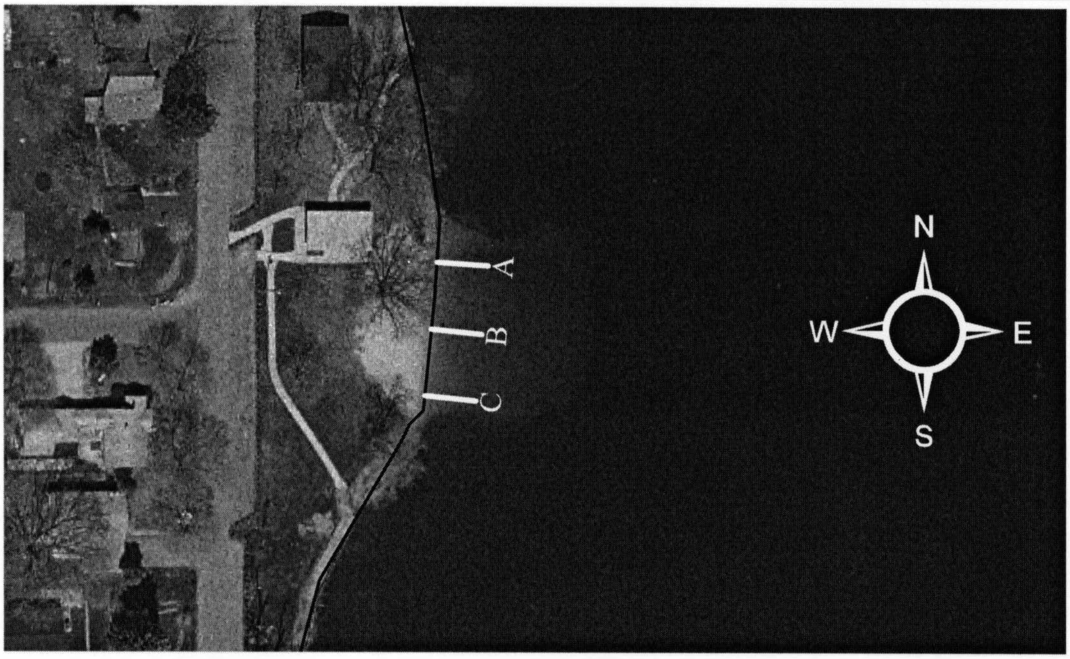
Figure 12. Woods Lake City Park (KB-08) and sampling locations

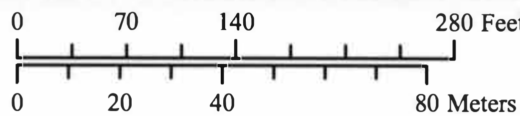
Sunset Lake Park (KB-11)

Sunset Lake Park is owned, operated, and maintained by the Village of Vicksburg (www.vicksburgmi.org/). The 1-acre park is located along Page Street, between Frakes Street and McKain Street. Sunset Lake is 140 acres and offers a bathing beach (Figure 13) with 100 feet of shoreline on the west side. Additionally, the park offers playground equipment, fishing dock, and picnic shelters. A public boat access site is located on the far south end of the park, which provides access to Sunset Lake.

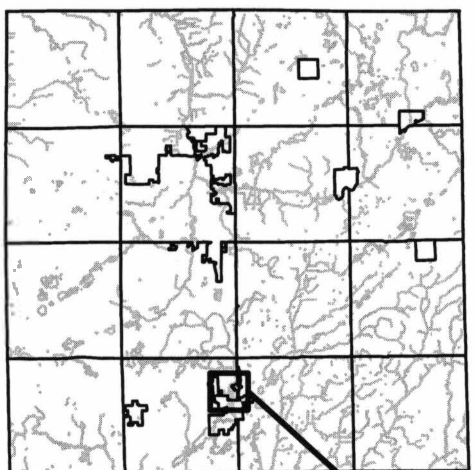
Sunset Lake covers portions of Brady Township, Schoolcraft Township, and the Village of Vicksburg. Land cover around the lake includes urban and built up (multi-family and single family residences), business district, commercial, industrial, croplands, grasslands, shrub lands, forested lands (central hardwoods / oak, aspen-birch, and pine), and wetlands (both forested and non-forested).

Concentrations of Canada geese and other waterfowl can be found on Sunset Lake. This wildlife can contribute to the bacterial contamination at the bathing beach on Sunset Lake. Sanitary sewer and on-site sewage treatment systems service the residences and businesses found in this region of the county.

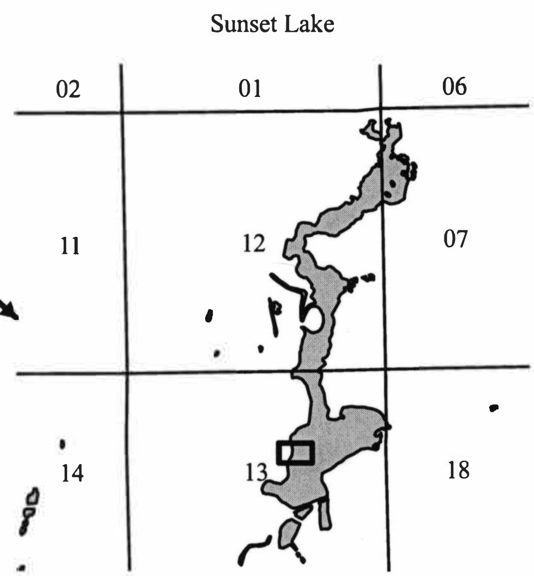




Sunset Lake Park (KB-11) is located entirely within the Village of Vicksburg (section 13), Kalamazoo County, Michigan. The bathing beach is located on the west shoreline of Sunset Lake.



Kalamazoo County, Michigan



Data Sources:
Base information obtained from the
Michigan Center for Geographic Information
(www.michigan.gov/cgi)

Bathing beach monitoring sites and sampling locations
determined by the Kalamazoo County Health and Community
Services Department Environmental Health Bureau

Map Created By:
Jeff Reicherts, Graduate Student
Western Michigan University (Spring 2008)
Department of Geography

Figure 13. Sunset Lake Park (KB-11) and sampling locations

Sample Collection

The Kalamazoo County Health and Community Services Department collected bathing beach water samples at each facility once a week; typically on a Monday or Tuesday. The sampling began Monday, May 14, 2007 and ended Tuesday, September 11, 2007 (n = 18 weeks). All individual samples were collected between 08:00 and 12:00 (with the exception of three sampling events occurring after 12:00) at a depth of 1 foot below the surface in approximately 3-4 feet (waist deep) of water. Three water samples were collected during each sampling event using the grab sampling technique (Bertke 2007 and Francy and Darner 2000). A grab sample is a single sample or measurement collected at a specific time and place that represents the composition of the water only at that time and location. Water sample collection followed historical bathing beach monitoring practices in Kalamazoo County, by carefully wading into the water at three designated transects per beach location (refer to the beach location figures above) and collecting three individual samples. All three water samples (per sampling event) were collected in less than 10 minutes time.

All water samples were collected in sterile, 532 milliliter (18 ounce) 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 milliliters per sample was collected during this study; this was adequate to perform the necessary sample analyses. 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. For example, Whirl-Pak® bags labeled "KB-01A", "KB-01B", and

"KB-01C" would be used for three individual samples collected at Cold Brook County Park (KB-01). 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 milliliter samples (A, B, C, and Composite). For each set of samples, four 120 milliliter sterile bacteriological sample bottles were prepared by writing the sample codes on each bottle. For the A, B, and C samples, the Whirl-Pak® bags were shaken for one minute to ensure a well-mixed, homogeneous sample (Bertke 2007) and then poured carefully to the 100 milliliter fill line of a 120 milliliter sterile bacteriological sample bottle. The composite sample was formed by measuring equal aliquots from the set of Whirl-Pak® bags (Figure 14). An aliquot of 33-34 milliliters was measured using a sterile 50 milliliter graduated cylinder. All three aliquots were poured into a 120 milliliter sterile bacteriological sample bottle to form a 100 milliliter composite sample. All four samples (per beach) were submitted to laboratory staff for bacteriological analysis.

Sample Analysis

The Kalamazoo County Health and Community Services Department Laboratory perform bacteriological analyses for surface water and drinking water samples. It should be noted that the laboratory is part of the Michigan Department of Community Health Regional Laboratory System (CLIA # 23D0876616), is licensed by the Federal Government to perform clinical testing, and is licensed by Michigan Department of Environmental Quality (Kalamazoo County CLIA # 23D0377033 & MDEQ # 0008) for analysis of microbiological and partial chemical testing of drinking water.

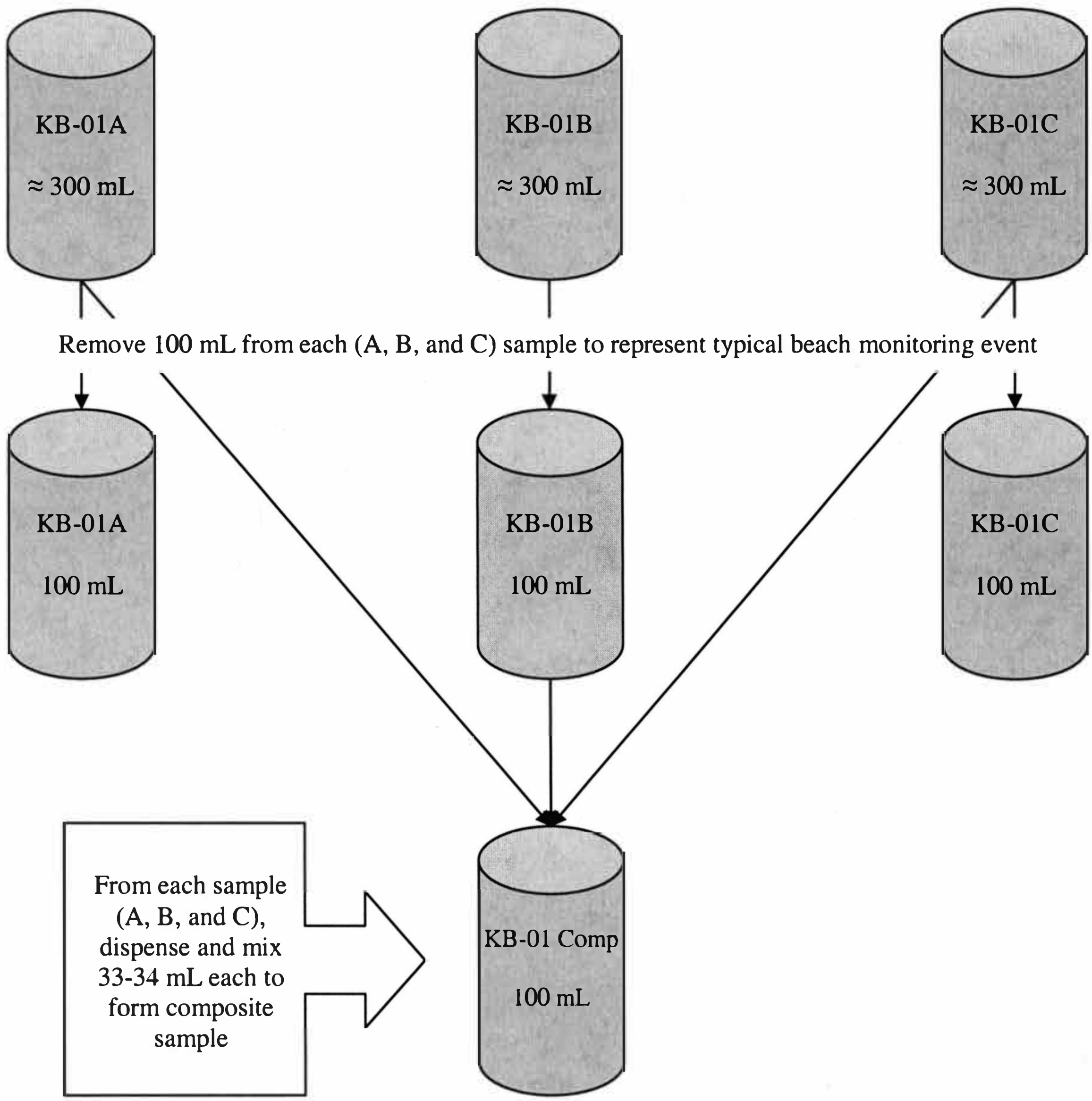


Figure 14. Individual point and composite samples illustration

Across the United States, beach officials continue to use traditional methods that require about 24 hours to detect bacterial indicator levels in bathing beach water samples (Dorfman and Stoner 2007). 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 hours at 35° C, and reporting results as Most Probable Number (MPN). 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 milliliter count. Colilert®-18 can simultaneously detect these bacteria at 1 CFU/100 milliliters within 18 hours even with as many as 2 million heterotrophic bacteria per 100 milliliters present (IDEXX Laboratories, Inc. 2007). This method is USEPA approved, easy to use, reliable, and provides fairly quick results.

Quality assurance and quality control procedures are essential to ensure an acceptable research project. For the purpose of this project field blanks and split replicate samples were implemented during the course of sample collection. A field blank is a "clean" (i.e., deionized or distilled water) sample that is otherwise treated the same as other samples taken from the field and are used to detect any contaminants that may be introduced during sample collection, storage, analysis, and transport (USEPA 1996). 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). Split samples were performed throughout the season, once at each bathing beach. A split sample (or replicate) is used to measure natural variability as well as the precision of the method, monitor, and/or analyst (USEPA 1996). These methods were employed to validate sample collection, storage, transport, and analytical procedures.

Statistical Summary and Analysis

An objective of this research was to compare arithmetic means of the three individual samples to the composite sample result of the respective sampling event (Bertke 2007 and Kinzleman, *et al.* 2006). Each sampling event consisted of four water samples; three individual samples (A, B, and C) that represented a "typical" beach monitoring event and one composite sample. The purpose of this research was to determine if composite sampling is a viable, less costly alternative to traditional bathing beach monitoring in Kalamazoo County. If this method (composite sampling) is not statistically different from individual point sampling (following Michigan water quality standards), then composite sampling should encourage more frequent sampling, while maintaining manageable costs, thereby producing a more reliable estimate of mean indicator (*E. coli*) density (Kinzleman, *et al.* 2006).

Bacteria counts among individual samples can be highly variable. Because of this variability, data were log-transformed ($\log_{10}$) to more normally distribute the data (Bertke 2007 and 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). Correlation coefficients were computed using SPSS (version 15.0 for Windows), a statistical software package.

How can cost savings be achieved using composite sampling techniques, yet maintain adequate spatial coverage? Or better yet, how can monies saved by composite sampling be applied to increased sampling frequency? To illustrate cost savings, a retrospective cost analysis will be demonstrated using the arithmetic means (which in this case will represent a composite sample result) of the entire seven years of data. The assumption will be that the past budgets for laboratory analysis were reduced by two-thirds and the arithmetic means of individual sample analyses will be used to simulate composite sample results.

When a violation of Water Quality Standards occurs, a follow-up sampling event is typically conducted. For the purpose of conducting this cost analysis, these data (follow-up sampling events) and additional data collected in 2006 were eliminated from the seven-year data set. Approximately one-third of all sampling events were selected to simulate the number of sampling events that would be conducted if the budget was cut due to composite sampling techniques. Sampling events were selected by expanding the frequency between sampling events and assigning each sampling event a number from one to twenty. One-third of the sampling events were selected in Microsoft Excel using the "filter" function (1, 4, 7…19, then 2, 5, 8…20, and finally 3, 6, 9…18) for each bathing beach and year individually. 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

Composite Sample Result and Arithmetic Mean Comparison

During the 2007 sampling season, bacteria concentrations were considerably lower as compared to previous monitoring years. There were no sampling events that exceeded Michigan water quality standards for total body contact recreation of 300 *E. coli* colonies per 100 mL water (Table 4). 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. These individual water samples were collected at Robert Morris Park (7/17 and 8/7), Fort Custer Recreation Area (5/30), and Sunset Lake Park (6/4 and 7/9).

Table 4. Summary statistics (2007) of *E. coli* concentrations at public bathing beaches

Beach	Number of Individual Samples		Daily *E. coli* bacteria concentration using the DAM[a] / DGM[b]		
	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

[a]The daily concentrations of *E. coli* bacteria were determined by calculating the daily arithmetic mean (DAM) of three individual water samples. These results were used in comparison with the respective composite sample result.

[b]The daily concentrations of *E. coli* bacteria were determined by calculating the daily geometric mean (DGM) of three individual water samples. These results were used to determine compliance to Michigan water quality standards.

Individual sample results were used to compute the arithmetic and geometric means, which 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 (Figure 15). 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 10 *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 water quality assessment (Bertke 2007).

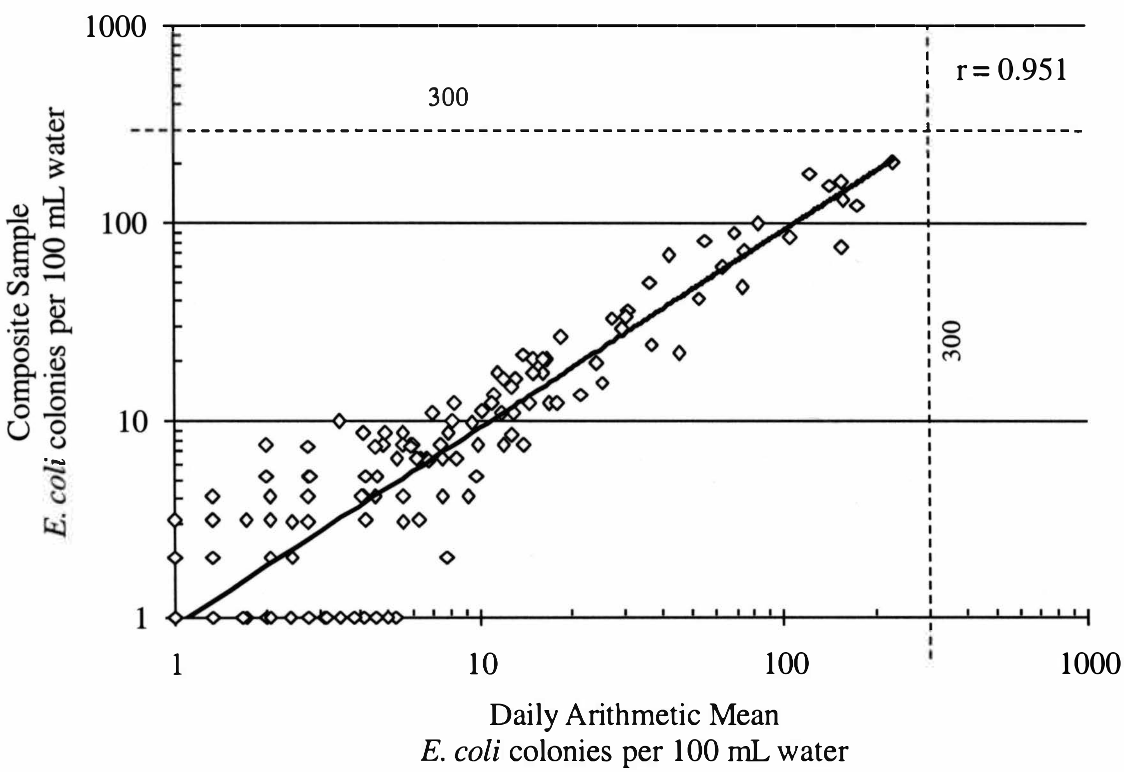


Figure 15. Daily arithmetic mean and composite sample results comparison

The *E. coli* bacteria concentrations of the daily arithmetic mean and the respective composite sample for the nine bathing beaches individually also had strong, positive linear relationships. The Pearson correlation (r) for the individual bathing beaches ranged from 0.780 to 0.996 (Table 5). 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; this indicates that the correlations are statistically significant. Removing the Pearson correlation of 0.780, the range would be 0.926 to 0.996, which indicates very strong, positive correlations between individual sample arithmetic means and corresponding composite sample results.

There is a high degree of variability between individual bathing beaches and with this variability, differences in *E. coli* bacteria concentrations exist between individual

Table 5. Pearson correlation coefficients (r) of daily arithmetic mean (DAM) 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

water samples collected during the same sampling event (Bertke 2007 and 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 beaches and sampling events is presented in Figure 16. These charts (Figure 16) 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.

E. coli densities vary significantly by day, time of day, and water depth (Whitman and Nevers 2004). The expectation was that the composite sample result be in the range of individual sample results and be equivalent to the daily arithmetic mean. Some composite sample results were not in the range of the three individual sample results. However, these composite sample results did not differ much from either the low value or high value of this range. 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 and 15 (48.4%) were slightly below the minimum value of the individual sample results.

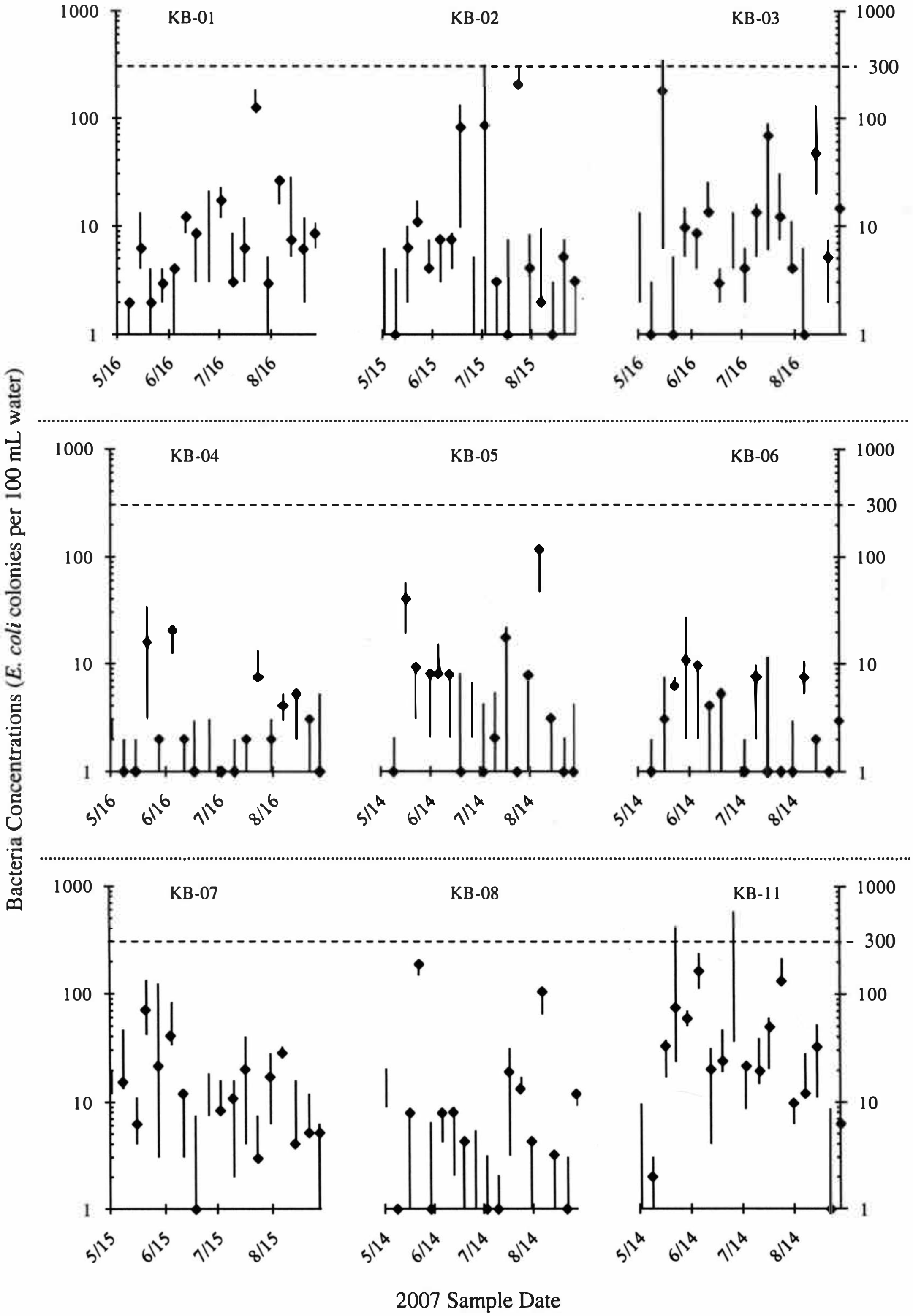


Figure 16. Range of *E. coli* bacteria concentrations (2007) for each bathing beach

Note: The composite sample result is represented as a diamond (♦) and the range of the three individual water sample results is represented as a vertical line (|).

Daily Arithmetic Mean versus Daily Geometric Mean

The daily arithmetic and daily geometric means were computed for all sampling events conducted (n = 1,313) for the past seven monitoring seasons (2001-2007). A total of twenty-six occurrences (2%), represented by the circle (○) in Figure 17, 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 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 Figure 17, exceeded 300 *E. coli* colonies per 100 mL water based on the arithmetic mean only. There is a strong, positive correlation (r = 0.967) between the arithmetic mean and geometric mean; the relationship is strongest when the individual sample results are close to one another.

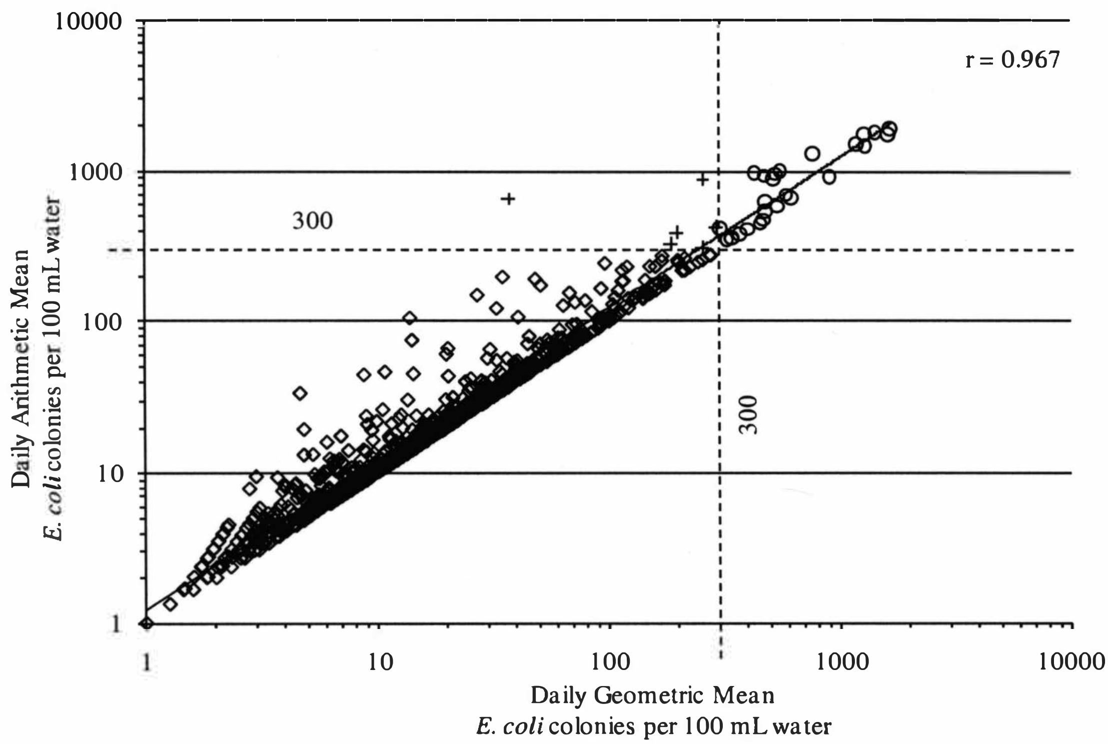


Figure 17. Daily arithmetic and geometric mean results comparison

Note: The data points represented by a circle (○) are those sampling events that exceeded 300 *E. coli* colonies per 100 mL water based on the arithmetic and geometric mean. The data points represented by a plus sign (+) are those sampling events that exceeded 300 *E. coli* colonies per 100 mL water based on the arithmetic mean only.

Cost Analysis

A simple cost model divides the beach monitoring program into four major components (Table 6); labor, transportation, in-direct (overhead), and analytical (Figure 18). Labor costs include training of technician, staff time to prepare equipment, drive to beach locations, conduct sampling, and return to the laboratory. Transportation includes the cost of driving between the office, beach monitoring locations, and the laboratory. Overhead includes administrative and financial analyst time, utilities, and other in-direct 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 (DAM) versus the traditional sampling approach (DGM) 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. This cost model assumes current rules / methods will result in an advisory or closure only when there is danger. What the model does not consider are the costs associated with

Table 6. Associated costs with the Kalamazoo County beach monitoring program

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

issuing an advisory or closure on a bathing beach. This could, for example, include local economic costs, cost of illness, or park fees obtained when the beach is open.

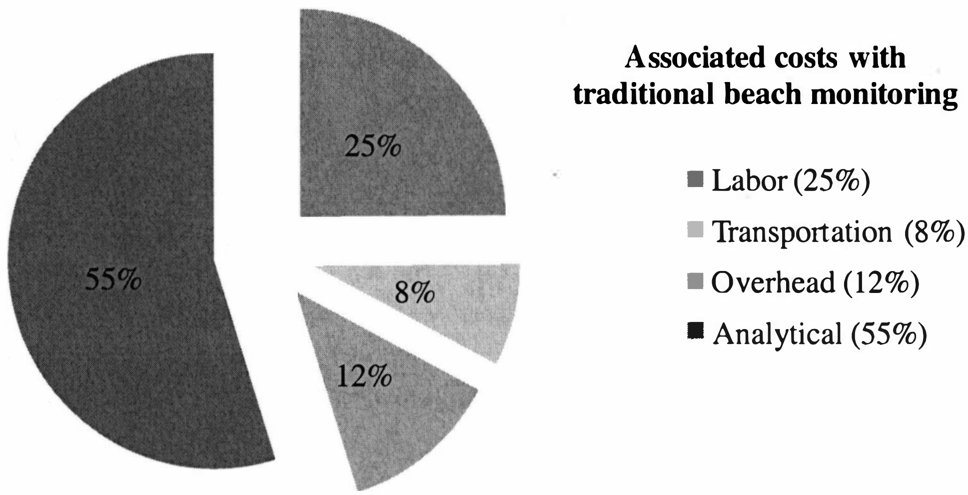


Figure 18. Associated costs with traditional beach monitoring methods

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, whereas traditional sampling costs would be three times as much (approximately \$7,020). Because the other costs (labor, transportation, and in-direct) would virtually be unchanged during a typical monitoring season, a savings of approximately \$4,680 (or 37%) could be achieved using composite sampling methods over traditional methods.

Composite Method Simulation

A series of three separate data sets were selected from the seven years of data (n = 1,117) to determine if beach advisories / 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. However, the money saved using the composite methodologies could be applied to increased monitoring frequencies.

Using the daily arithmetic mean (simulated composite sample result) 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 seven-year time frame. The number of sampling events with an assigned number (Table 7) of "1, 4,

Table 7. Retrospective cost analysis sampling events summary

Beach	Number of Events	Number of Violations[a]		Series 1, 4, 7…19			Series 2, 5, 8…20			Series 3, 6, 9…18		
		DAM	DGM	n[b]	c[c]	m[d]	n	c	m	n	c	m
KB-01	130	4	3	46	1	3	43	0	4	41	2	2
KB-02	126	2	1	45	1	1	42	1	1	39	0	2
KB-03	132	0	0	47	0	0	44	0	0	41	0	0
KB-04	132	0	0	47	0	0	44	0	0	41	0	0
KB-05	130	2	0	46	1	1	43	0	2	41	1	1
KB-06	131	3	3	47	1	2	43	0	3	41	2	1
KB-07	129	6	6	45	5	1	43	1	5	41	0	6
KB-08	130	2	2	46	0	2	43	2	0	41	0	2
KB-11	77	0	0	27	0	0	26	0	0	24	0	0
Totals	1,117	19	15	396	9	10	371	4	15	350	5	14

[a]The number of water quality violations determined by either the daily arithmetic mean (DAM) or daily geometric mean (DGM).

[b]The number of monitoring events (n) represented by the different series (every three weeks) of data for each beach.

[c]The number of water quality violations that were captured (c) following the retrospective cost analysis.

[d]The number of water quality violations that were missed (m) following the retrospective cost analysis.

7…19” (n = 396), “2, 5, 8…20” (n = 371), and “3, 6, 9…18” (n = 350) would have missed ten, fifteen, and fourteen violations respectively, out of a total of nineteen. All nineteen violations exceeded the daily 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 daily geometric mean of the three individual samples. Thus, compositing is more conservative of public health, since it is easier to declare a violation.

Assume the current procedures yield a “correct” decision. Thus in 1,098 and 15 monitoring cases, or 1,113 of 1,117 simulated cases, the two methods yielded the same results, that is the methods either were correct identifying compliant beaches or beaches in violation (Figure 19). In 4 of 1,117 simulated cases, the daily arithmetic mean (composite result) method yielded a “wrong” action. In each of these four cases, the beach was closed when it should have been left open. There were no cases where the daily arithemetic mean passed when the daily geometric mean failed. These errors did not result in less protection of public health; however, it did, result in unnecessary closings

Daily Arithmetic Mean	Daily Geometric Mean: Pass	Daily Geometric Mean: Fail
Pass	1,098 (98.3%)	0 (0.0%)
Fail	4 (0.4%)	15 (1.3%)

Figure 19. Summary of simulated beach monitoring results

0.4% of the time. Both the cost of not closing when there is a danger and the cost of closing when there is no danger are very difficult to estimate.

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 (Table 8) 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). A field blank (also referred to as a trip blank) typically represents a sample of distilled or deionized (contaminant-free) water and is carried into the field and then back to the laboratory to identify errors or contamination in sample collection and analysis. Field blanks were conducted 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, which means that there were no positive large and small wells on the IDEXX Quanti-Tray®/2000.

Table 8. Field blank sample results

Beach	Date	Sample Results[a]			
		A	B	C	Comp
KB-08	5/29/2007	< 1	< 1	< 1	< 1
KB-02	9/11/2007	< 1	< 1	< 1	< 1

[a]Sample results reported by the Kalamazoo County Health and Community Services Department Laboratory as the number of *E. coli* bacteria colony forming units (cfu) per 100 mL water.

Split samples (Table 9) 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 9, the concentrations of *E. coli* bacteria are very similar between what is referred to as 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 result measurements. These quality assurance and quality control methods were employed to validate sample collection, storage, transport, and laboratory analytical procedures.

Table 9. Split sample results

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

[a]Sample results reported by the Kalamazoo County Health and Community Services Department Laboratory as the number of *E. coli* bacteria colony forming units (cfu) per 100 mL water.

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 (as compared to traditional methods) to monitoring bathing beaches in Kalamazoo County and potentially around 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 to Michigan water quality standards. A limitation during this study occurred with no sampling events exceeding Michigan water quality standards of 300 *E. coli* colonies per 100 mL water. The results of this research identified if any statistically significant differences in *E. coli* bacteria concentrations occurred between composite sample analysis and the arithmetic mean of individual point sample analyses.

Use of Composite Sampling Methods

The results indicate that the composite sample results were not significantly different from the arithmetic mean of the individual sample results. The cost of sample analysis is 37% cheaper than traditional methods; as one sample is analyzed compared to three individual samples. There appears to be comparable protection of public health as compared to traditional methods. Compositing is conservative and errors on the side of public health; when it differs from the traditional method (DGM) it fails when it should pass, but never passes when it should fail (as illustrated in Figure 19). A beach is closed a small percent of the time (0.4%) when it should have remained open, thus placing a negative perception toward the beach.

The use of composite sampling would free up a significant amount of money. Should these dollars be utilized to enhance the beach monitoring program? The nine public bathing beaches in Kalamazoo County have very good water quality, as documented over the past seven years (2001-2007) of monitoring. Some considerations for this “extra” money include more frequent sampling, sampling during critical weather periods, and sampling facilities that may chronic water quality issues.

In general and beyond Kalamazoo County, composite sampling could be a viable alternative approach to bathing beach monitoring programs in the Great Lakes Basin. For beaches that do not have chronic bacteria concentration problems, composite sampling can provide money-savings as compared to multiple point sample analyses. The savings achieved could be used to conduct more frequent monitoring (either daily or weekly) in attempts of better characterizing bacteria concentrations and water quality at beaches that do have chronic contamination issues. Additional monitoring could take place immediately after storm events; this is typically when bacteria concentrations are highest. The process of compositing samples is a step toward obtaining the best characterization of mean indicator density, which in turn will provide a better illustration of the likelihood and magnitude of any significant elevation of *E. coli* above normal background levels (Kinzleman, *et al.* 2006).

The source of bacteria can be very difficult to detect. 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. Public education usually is in the form of visual signage, fliers, and the local media. For example, signs can be posted telling beach visitors not to feed the ducks and geese because ducks and geese can contribute to the bacteria concentrations in the beach. Monies saved from compositing can be used to conduct annual lake surveys. These surveys are used to identify changes in land use and land cover surrounding the lake and immediate beach area; they (surveys) aid in tracking down the elimination or potential development of contamination sources. Lastly, microbial source tracking could be used to identify specific sources, which is crucial for targeting the elimination of contamination sources. See below for more information on microbial source tracking.

The quickest analytical method to achieve bacteria concentration in a water sample is currently 18 hours. This is one area that receives much debate, since a public health department is issuing an advisory or closure on a day when they do not know the bacteria concentrations, that is, the public health department is acting on data that is at least 18 hours old. Rapid testing certainly has some value with respect to beach monitoring. Monies saved from composite sampling could be utilized to conduct rapid testing research in beaches where bacteria concentrations are known to be high throughout the day. See below for more information on rapid testing approaches.

Further Research

Composite sampling strategies should be implemented in other Michigan bathing beach monitoring programs to confirm their application and reliability. A target group of beaches to be included in a future study should include those beaches that have several

Michigan Water Quality Standard violations during the course of a season. It is important to verify that beaches that violate Michigan water quality standards using traditional methods also violate using composite sampling strategies. Currently, bathing beach monitoring research around the Great Lakes region and the entire country for that matter focuses on predictive modeling, rapid test methods, and microbial (bacteriological) source tracking.

Predictive Modeling

The best available USEPA method for *E. coli* analysis in surface water returns data for evaluation after a minimum of 18 hours (using IDEXX Laboratory, Inc. Colilert®-18 and Quanti-Tray®/2000). The lag time between the collection of field samples and the decision to close a particular swimming beach is an issue of concern for public officials and communities faced with announcing beach advisories or closures, conducting follow-up sampling, and re-opening beaches when contamination is no longer a concern. Limited resources restrict sampling to one day per week regardless of climatic or local conditions prior to or during sampling. Technology promising near instantaneous field readings of *E. coli* is highly desired and expected as the next logical step in recreational water quality monitoring.

In the absence of an available instrument that can read or estimate *E. coli* counts, water quality specialists must settle for currently available laboratory methods that produce next day results. A growing body of evidence indicates that *E. coli* counts vary dramatically over time and often, previous day *E. coli* counts do not predict present day counts adequately (Olyphant 2004). Multiple linear regression models are currently being used to predict or forecast *E. coli* counts (or log-transformed counts) on Great Lakes beaches (Francy, Darner and Bertke 2006, Nevers and Whitman 2005, National Oceanic Atmospheric Administration (NOAA) 2005, and Olyphant 2004), where bacteria counts are the dependent variable and environmental condition parameters are the independent variables. It is also apparent and was emphasized by the model developers that these regression models are site-specific. Some of the environmental conditions considered in model development (for Great Lakes beaches) that had strong, positive correlations with bacteria counts included precipitation, wind direction and speed, wave height, water clarity (turbidity), air and water temperature, wildlife concentrations, solar radiation, and nearby inputs (i.e., combined sewer overflows and outfalls) (Francy, Darner and Bertke 2006, Nevers and Whitman 2005, and Pfister and Olyphant 2005).

The Kalamazoo County Health and Community Services Department (in partnership with Kieser and Associates, a local environmental consultant) conducted a predictive modeling project (refer to http://www.kalcounty.com/eh/sw-reports.htm for the final report) during the 2006 sampling season following some of the methods and techniques presented by Francy, Darner and Bertke (2006), Nevers and Whitman (2005), and Pfister and Olyphant (2005). The purpose of the project was to develop reliable predictive tools (empirical relationships and/or modeling) for potential use in the bathing beach monitoring program and to improve forecasts of beach closures on inland lakes. When advisories are issued on these bathing beaches the first question often asked is "what caused the elevated levels of bacteria?" This can be very difficult to determine and depends exclusively on localized events (i.e., rain storms, concentrated animal feeding operations, wildlife concentrations, or wind direction). Predictive models can be used as a tool and are not meant to replace existing water monitoring programs.

Several regression model equations were developed for the study sites. The models incorporated environmental conditions (independent variables) specific to each bathing beach location. Parameters used in this study included weighted rainfall, water temperature, wind direction and speed, conductivity, turbidity, and surface conditions. Additionally, the number of bathers and waterfowl were considered. The multiple linear regression equations did not yield hoped-for results ($r^2 = 0.24$ to 0.49) in predicting *E. coli* concentrations (dependent variable) in the bathing beaches studied. The problems with the regression model approach results in part from the limited number of violations measured. These events were very rare in the period of record (4% of all the samples). A total of twenty-six violations were recorded in six years; only two were correctly predicted using the equations.

The historic frequency of beach closures in Kalamazoo County is low and the exceedance counts of *E. coli* are lower compared to public swimming beaches in other regions of the country that face more serious contamination issues, such as raw sewage overflow. For example, the City of Grand Rapids has often been accused of contributing to the bacteria concentrations on Lake Michigan beaches when raw sewage is discharged to the Grand River. There is utility in a focused effort to develop predictive relationships as many organizations like Kalamazoo County face the same requirements for the protection of public health with the same limitations of budget and staffing resources.

Microbial Source Tracking

Specific sources of bacteriological contamination are very difficult to determine; such sources include urban stormwater runoff, wildlife concentrations, nearby agricultural sources, failing on-site septic systems, and accidental discharges in the swimming area. Indicator bacteria do not necessarily pose a direct health risk to humans, but do suggest the likely presence of harmful pathogenic organisms, such as the microorganisms listed in Table 2. These disease-causing organisms are often found in low numbers (as compared to *E. coli* bacteria,), difficult to collect, expensive to find and analyze, and found in both human and non-human sources of fecal pollution.

A method of growing interest to the beach monitoring and research communities is using a technique called microbial source tracking. This is one of several names given to the process of identifying the particular source (e.g., human, cattle, or bird) of fecal contamination in water (Field and Scott 2007). Stormwater managers want to be able to send in a water sample and once analyzed, be told what it (microorganism) is and where it came from (source) (Baxter 2007). The process of comparing the microorganism's DNA to a "library" of samples in the region allows for accurate source identification. Once the source is identified, appropriate actions can take place to prevent further contamination into the nearby bathing beach or surface water. These methods can be extremely costly, however, in cases where bacteria counts are very high in bathing waters, microbial source tracking methods and techniques can effectively identify fecal contamination sources.

Rapid Test Methods

Provisions to the BEACH Act strongly encourage the USEPA to develop accurate, rapid test methods to determine bathing beach water quality. This is crucial since the best available USEPA approved method for *E. coli* analysis in surface water returns data for evaluation after a minimum of 18 hours. Finding out that beach water has elevated bacteria concentrations a day after sampling does not effectively protect public health from potentially dangerous microorganisms. New test methods, when approved by the USEPA, should improve public notification of poor water quality conditions.

There are several rapid test methods available, but none of them have been USEPA approved or used beyond experimentation. For example, the Quantitative Polymerase Chain Reaction (QPCR) method uses a gene probe to detect *Enterococci* and *Bacteroides* in water samples. Biosensors are also being used to detect microorganisms. Fiber optics is being used in these sensors to detect microbiological and chemical constituents in water samples. In all of these cases, analysis occurs in less than two to three hours, a considerable improvement to traditional bathing beach water sample analyses. Notifying the general public of a potential health threat in recreational waters is of upmost important, so being timely in posting water quality conditions is imperative.

In summary, the research items presented above (predictive modeling, microbial source tracking, and rapid test methods) illustrate great potential with beach monitoring around the country. They (methods) offer possibilities in predicting bacteria concentrations without collecting water samples, identifying specific sources of bacteria, and using technologies that enumerate bacteria concentrations much quicker than traditional water sample analyses. However, the costs associated with these technologies are quite excessive; composite sampling is a viable alternative that can be more protective of public health, cost effective, promote increased temporal frequencies, maintain adequate spatial coverage, and serve the purpose in the short-term.

REFERENCES

Anderson, Kim A., and P. Michael Davidson. "Drinking water and recreational water quality: Microbiological criteria." University of Idaho, July 1997.

Baxter, Roberta. "Bacteria and beaches: Avoiding the mix." *Stormwater*, September 2007: 86-90.

Bertke, Erin E. "Composite analysis for *Escherichia coli* at coastal beaches." *Journal of Great Lakes Research* (International Association for Great Lakes Research) 33 (2007): 335-341.

Correll, Raymond L. "The use of composite sampling in contaminated sites - a case study." *Environmental and Ecological Statistics* (Kluwer Academic Publishers) 8 (2001): 185-200.

Dorfman, Mark, and Nancy Stoner. *Testing the waters: A guide to water quality at vacation beaches.* Washington, DC: Natural Resources Defense Council, 2007, 1-377.

Field, Katherine G., and Troy M. Scott. "Microbial source tracking." *Michigan State University Center for Water Sciences Pathogen Workshop Series.* East Lansing, Michigan, 2007. 1-22.

Francy, Donna S., and Robert A. Darner. "Comparison of methods for determining *Escherichia coli* concentrations in recreational waters." *Water Research* (Elsevier Sciences Ltd.) 34, no. 10 (2000): 2770-2778.

Francy, Donna S., Robert A. Darner, and Erin E. Bertke. *Models for predicting recreational water quality at Lake Erie beaches.* Science Investigations Report 2006-5192, Reston, Virginia: United States Department of the Interior United States Geological Survey, 2006, 1-13.

Genthner, Fred J., Joseph P. James, Diane F. Yates, and Stephanie D. Friedman. "Use of composite data sets for source-tracking enterococci in the water column and shoreline interstitial waters on Pensacola Beach, Florida." *Marine Pollution Bulletin* (Elsevier Ltd.) 50 (2005): 724-732.

Griffiths, Tom. *Better beaches: Management and operation of safe and enjoyable swimming beaches.* Ashburn, Virginia: National Recreation and Parks Association, 1999.

Haack, Sheridan K. "Waterborne disease: What is the potential?" *West Michigan Epi Exchange.* Hastings, Michigan: United States Geoplogical Survey, January 25, 2008. 1-41.

IDEXX Laboratories, Inc. "Colilert®-18 Test Kit Instructions." Westbrook, Maine: IDEXX Laboratories, Inc., 2007.

Jensen, Erika T., and Sandra L. McLellan. "Beach closings: Science versus public perception." *American Institute of Biological Sciences.* April 2005. http://www.actionbioscience.org/environment/Jensen_McLellan.html (accessed March 16, 2007).

Kinzleman, Julie L., Alfred P. Dufour, Larry J. Wymer, Gareth Rees, Kathy R. Pond, and Robert C. Bagley. "Comparison of multiple point and composite sampling for monitoring bathing water quality." *Lake and Reservoir Management* (North American Lake Management Society) 22, no. 2 (2006): 95-102.

Kwak-Hefferan, Elizabeth. "Beach bummer: Criteria for closing beaches flawed, experts say." *Medill Reports*, August 23, 2007.

Lancaster, Vicki A., and Sallie Keller-McNulty. "A review of composite sampling methods." *Journal of the American Statistical Association* 93, no. 443 (September 1998): 1216-1230.

Lock, William H. "Composite sampling." *National Environmental Health Forum Monographs, Soil Series No. 3*, 1998: 1-19.

Macomb County Health Department. *Developing a bathing beach monitoring program.* Environmental Health Services Division, Macomb County, Michigan: Michigan Department of Environmental Quality, 2001, 1-18.

Michigan Compiled Laws. "Natural Resources and Environmental Protection Act, Act 451." *Part 4 Water Quality Standards, Rule 323.1062 Microorganisms.* Legislative Council, State of Michigan, 1994.

—. "Public Health Code, Act 368." *Article 12 Environmental Health, Part 125 Campgrounds, Swimming Areas, and Swimmer's Itch, Section 333.12541 Testing and evaluating quality of water at bathing beaches.* Lansing, Michigan: Legislative Council, State of Michigan, 1978.

National Oceanic Atmospheric Administration (NOAA). "High-tech monitoring improves timeliness of Illinois beach closures." *Coastal Services: Linking People, Information, and Technology*, January/February 2005: 6.

Nevers, Meredith B., and Richard L. Whitman. "Nowcast modeling of *Escherichia coli* concentrations at multiple urban beaches of southern Lake Michigan." *Water Research* (Elsevier Ltd.) 39 (2005): 5250-5260.

Olyphant, Greg A. "Developing a prototypical predictive model for beach closings in Indiana." *Indiana Geological Survey: A research institue of Indiana University.* 2004. http://igs.indiana.edu/survey/projects/BeachClosings/index.cfm (accessed October 15, 2007).

Olyphant, Greg A., and Richard L. Whitman. "Elements of a predictive model for determining beach closures on a real time basis: The case of 63rd Street Beach Chicago." *Environmental Monitoring and Assessment* (Kluwer Academic Publishers) 98 (2004): 175-190.

Parkhurst, David F. "Arithmetic versus geometric means for environmental concentration data." *Enviornmental Science and Technology* (American Chemical Society) 32, no. 3 (February 1998): 92A-98A.

Patil, Ganapati P. *Composite sampling.* Vol. 1, in *Encyclopedia of Environmetrics*, by Abdel H. El-Shaarawi and Walter W. Piegorsch, 387-391. Chichester: John Wiley and Sons, 2002.

Pfister, Mark A., and Greg A. Olyphant. "Swimcast: Predicting E. coli concentrations at two beaches in Lake County, Illinois." *NOAA Coastal Services Center, Coastal Zone 2005.* July 17-21, 2005. http://www.csc.noaa.gov/cz/2005/pdfs/pfistercafe.pdf (accessed October 17, 2007).

Rabinovici, Sharyl J. M., Richard L. Bernknopf, Anne M. Wein, Don L. Coursey, and Richard L. Whitman. "Economic and health risk trade-offs of swim closures at a Lake Michigan beach." *Enviornmental Science and Technology* (American Chemical Society) 38, no. 10 (2004): 2737-2745.

Rose, Joan B., and Rachel Katonak. "Risks to human health associated with water and food contaminated with animal wastes." Department of Fisheries and Wildlife, Michigan State University, East Lansing, Michigan, 2005, 1-8.

United States Congress. "Beaches Environmental Assessment and Coastal Health (BEACH) Act of 2000." 106th Congress, Public Law, 106-284, 114 Statute, 2000. 870-877.

United States Environmental Protection Agency (USEPA). "Ambient Water Quality Criteria for Bacteria." EPA 440/5-84-002. Washington, DC: Office of Water Regulations and Standards Criteria and Standards Division, January 1986.

—. "EPA Observational Economy Series." *Volume 1: Composite Sampling.* EPA-230-R-95-005. Washington, DC: Policy, Planning, and Evaluation, August 1995.

—. "The Volunteer Monitor's Guide to Quality Assurance Project Plans." EPA-841-B-96-003. Washington, DC: Office of Wetlands, Oceans, and Watersheds, September 1996.

—. "Guidance on Choosing a Sampling Design for Environmental Data." EPA-240-R-02-005. Washington, DC: Office of Water, December 2002.

—. "Nationwide bacteria standards protect swimmers at beaches." *United States Environmental Protection Agency Beach Monitoring and Notification.* November 2004. http://www.epa.gov/waterscience/beaches/rules/bacteria-rule-final-fs.htm (accessed March 16, 2007).

—. "Implementing the BEACH Act of 2000: A Report to Congress." EPA-823R-06-001. Washington, DC: Office of Water, October 2006.

—. "Ecological Risk Assessment." *United States Environmental Protection Agency Mid-Atlantic Risk Assessment.* March 7, 2007. http://www.epa.gov/reg3hwmd/risk/eco/faqs/composite.htm (accessed March 16, 2007).

United States Geological Survey (USGS). *USGS Ohio Water Science Center Improved Monitoring Methods.* 2007. http://oh.water.usgs.gov/beach_monitoring_methods.htm (accessed March 22, 2007).

United States Government Accountability Office (GAO). "EPA and States have made progress in implementing the BEACH Act, but additional actions could improve public health protection." GAO-07-591. Washington, DC: Great Lakes Report to Congressional Requesters, May 2007.

Whitman, Richard L., and Meredith B. Nevers. "Escherichia coli sampling reliability at a frequently closed Chicago beach: Monitoring and management implications." *Environmental Science and Technology* (American Chemcial Society) 38 (2004): 4241-4246.

Yates, Marylynn V. "Introduction to waterborne pathogens." *Michigan State University Center for Water Sciences Pathogen Workshop Series.* East Lansing, Michigan, 2007. 1-7.

APPENDIX A

Bathing Beach Monitoring Field Datasheet

Kalamazoo County
Health & Community Services
Environmental Health Bureau ~ Surface Water Monitoring Program

Bathing Beach Monitoring Field Data Sheet

KB-01

Surface Water: Blue Lake
Park Name: Cold Brook County Park
Monitoring Location: East 'MN' Avenue, east of North 42nd Street
Jurisdiction: Charleston Township **Section Number:** 34 **Type:** beach
Sub-Basin: Portage River at Indian Lake **Watershed:** St. Joseph River

Collector: Jeff--31 **Sample Date:** Wednesday, July 04, 2007 **Sample Time:** **AM / PM**

General Weather Conditions

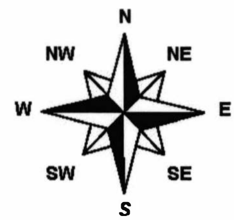
Weather (check most appropriate weather conditions)

☐ clear ☐ partly cloudy ☐ overcast ☐ fog / haze
☐ drizzle ☐ sleet / hail ☐ rainy ☐ snow

Wind (check most appropriate wind direction)

☐ calm ☐ slight breeze ☐ moderate breeze ☐ windy

If wind is not "calm", circle the appropriate wind direction in the figure at right.



Surface Water Physical Appearance **(check appropriate for each category)**

Water Surface	Water Clarity	Water Color		Odors / Smells	
☐ calm	☐ clear	☐ clear	☐ milky / white	☐ none / natural odor	
☐ ripples	☐ slightly turbid	☐ green	☐ light brown	☐ sewage	☐ fishy
☐ waves	☐ moderately turbid	☐ gray	☐ medium brown	☐ anaerobic	☐ musty
☐ white-caps	☐ highly turbid	☐ black	☐ dark brown	☐ rotton eggs	☐ oily

Other Physical Site Observations **(check all that apply)**

☐ none	☐ weed growth	☐ oil film	☐ sewage debris	☐ erosion
☐ foam	☐ algal blooms	☐ fish kills	☐ birds	☐ natural debris
☐ bubbles	☐ floating scum	☐ trash debris	☐ animals	☐ other

Total number of beach visitors present: ________ in the water ________ on the beach

Total number of birds (waterfowl) present: ________ gulls ________ geese ________ ducks / swans

Water Quality Measurements

	KB-01-A Left		**KB-01-B** Middle		**KB-01-C** Right	
Meter Storage #:	________		________		________	
Water Temperature:	________ F		________ F		________ F	
Dissolved Oxygen:	________ mg / L	________ % Sat.	________ mg / L	________ % Sat.	________ mg / L	________ % Sat.
pH:	________ units		________ units		________ units	
Conductivity:	________ mS / cm		________ mS / cm		________ mS / cm	
TDS:	________ g / L		________ g / L		________ g / L	
Turbidity:	________ NTU		________ NTU		________ NTU	
E. coli Bacteria:	________ MPN		________ MPN		________ MPN	

Calculated Geometric Mean: Daily: ________ MPN 30-Day: ________ MPN

KB-01 Cold Brook County Park Charleston Township

Friday, January 25, 2008

APPENDIX B

Laboratory Analysis Request Form – Individual Samples

Kalamazoo County
Health & Community Services

Bathing Beach Monitoring
Laboratory Analysis Request Form

Environmental Health Bureau ~Surface Water Monitoring Program

Laboratory analysis request of Esherichia coli (E. coli) bacteria levels in surface water.

Sample Date: Wednesday, July 04, 2007 **Record Mileage:** Start: ________

Collector: Jeff--31 End: ________

Lab #	Site Code	Monitoring Location	Time
________	KB-01--A	Blue Lake at Cold Brook County Park	
________	KB-01--B	East 'MN' Avenue, east of North 42nd Street	________
________	KB-01--C	Charleston Township in Section Number 34	KB-01
________	KB-02--A	Campbell Lake at Robert Morris Park	
________	KB-02--B	East 'H' Avenue, east of North 30th Street	________
________	KB-02--C	Comstock Charter Township in Section Number 3	KB-02
________	KB-03--A	Eagle Lake at Fort Custer Recreation Area	
________	KB-03--B	M-96, east of the Village of Augusta	________
________	KB-03--C	Charleston Township in Section Number 2	KB-03
________	KB-04--A	Gull Lake at Ross Township Park	
________	KB-04--B	East Gull Lake Drive, north of East 'B' Avenue	________
________	KB-04--C	Ross Township in Section Number 6	KB-04

Starting Specimen Number KCHCSD Laboratory Use Only	Relinquished By KCHCSD Environmental Health	Date	Time	Accepted By KCHCSD Laboratory	Time

12 beach water samples collected and delivered to the Kalamazoo County HCS Department Laboratory

Note: For bathing beaches, three (3) surface water samples are collected at each sampling event.

Sample A from the left side of the beach. Sample B from the center of the beach. Sample C from the right side of the beach.

Page 1 of 1 Friday, January 25, 2008

APPENDIX C

Laboratory Analysis Request Form – Composite Samples

Kalamazoo County
Health & Community Services

Bathing Beach Monitoring
Laboratory Analysis Request Form

Environmental Health Bureau ~Surface Water Monitoring Program

Laboratory analysis request of Esherichia coli (E. coli) bacteria levels in surface water.

Sample Date: ______________________

Collector: Jeff--31

Lab #		Site Code	Monitoring Location	Time
☐	________	**KB-01 COMP**	Cold Brook County Park, Charleston Township	________ KB-01 COMP
☐	________	**KB-02 COMP**	Robert Morris Park, Comstock Township	________ KB-02 COMP
☐	________	**KB-03 COMP**	Fort Custer Recreation Area, Charleston Township	________ KB-03 COMP
☐	________	**KB-04 COMP**	Ross Township Park, Ross Township	________ KB-04 COMP
☐	________	**KB-05 COMP**	Prairie View County Park, Schoolcraft Township	________ KB-05 COMP
☐	________	**KB-06 COMP**	Ramona Park, City of Portage	________ KB-06 COMP
☐	________	**KB-07 COMP**	Markin Glen County Park, Cooper Township	________ KB-07 COMP
☐	________	**KB-08 COMP**	Woods Lake City Park, City of Kalamazoo	________ KB-08 COMP
☐	________	**KB-11 COMP**	Sunset Lake Park, Village of Vicksburg	________ KB-11 COMP

These samples were formed by mixing equal sub-samples from Samples A, B, and C from the bathing beach sampling event; this forms a 100 ml composite sample to be analyzed for bacteria. The samples with a check indicates those samples collected on the given day.

Starting Specimen Number KCHCSD Laboratory Use Only	Relinquished By KCHCSD Environmental Health	Date	Time	Accepted By KCHCSD Laboratory	Time

____ Number of samples analyzed by the Kalamazoo County Health and Community Services Department Laboratory.

Note: For bathing beaches, three (3) surface water samples are collected at each sampling event.
This sample is a composite of mixing the three samples together.

Sample A from the left side of the beach. Sample B from the center of the beach. Sample C from the right side of the beach.

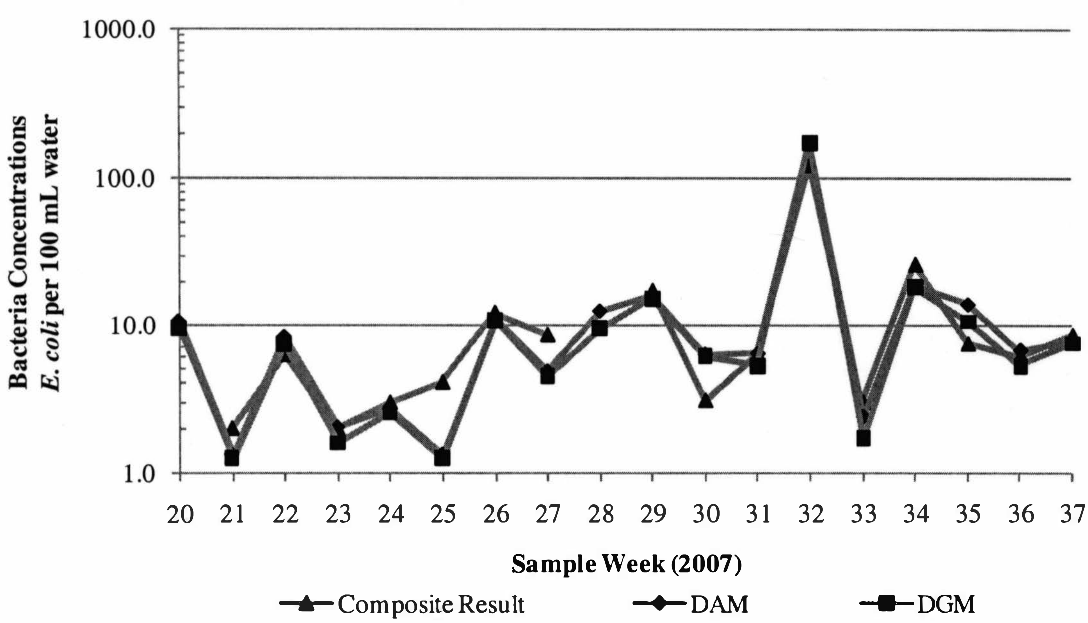
Page 1 of 1

APPENDIX D

Bathing Beach Water Quality Raw Data (2007)

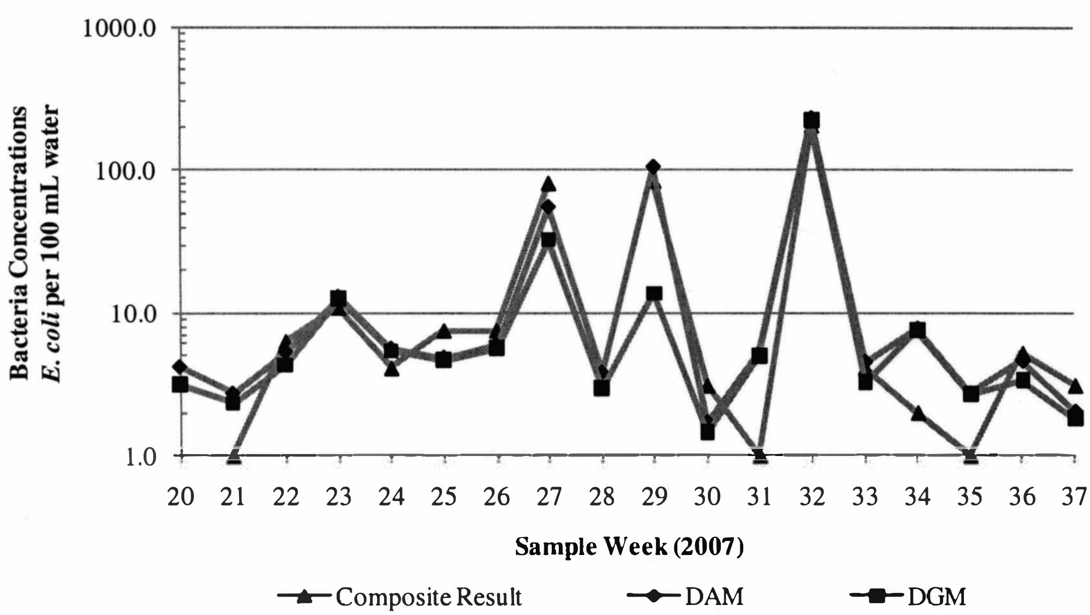
Cold Brook County Park (KB-01)

Sample Week	Date	Time	Sample A	Sample B	Sample C	Composite Result	DAM	DGM
20	05/16/07	13:30	10.7	5.2	16.1	NA	10.7	9.6
21	05/23/07	10:45	1.0	1.0	2.0	2.0	1.3	1.3
22	05/30/07	11:15	4.1	7.5	13.5	6.3	8.4	7.5
23	06/05/07	11:00	1.0	1.0	4.1	2.0	2.0	1.6
24	06/12/07	9:20	4.1	2.0	2.0	3.0	2.7	2.5
25	06/19/07	9:55	1.0	2.0	1.0	4.1	1.3	1.3
26	06/26/07	9:45	13.2	11.0	8.6	12.2	10.9	10.8
27	07/02/07	8:15	7.4	3.1	4.1	8.6	4.9	4.5
28	07/10/07	8:30	13.2	3.1	21.3	NA	12.5	9.6
29	07/17/07	10:00	22.8	12.1	13.4	17.3	16.1	15.5
30	07/24/07	10:15	5.2	8.6	5.2	3.1	6.3	6.1
31	07/31/07	11:15	4.1	12.1	3.1	6.3	6.4	5.4
32	08/07/07	9:45	185.0	167.0	172.5	123.6	174.8	174.7
33	08/14/07	9:35	1.0	1.0	5.2	3.0	2.4	1.7
34	08/21/07	9:55	17.1	16.0	22.6	26.2	18.6	18.4
35	08/28/07	9:55	28.1	8.5	5.2	7.5	13.9	10.7
36	09/04/07	9:10	12.1	6.3	2.0	6.2	6.8	5.3
37	09/11/07	10:00	6.3	6.3	10.9	8.6	7.8	7.6



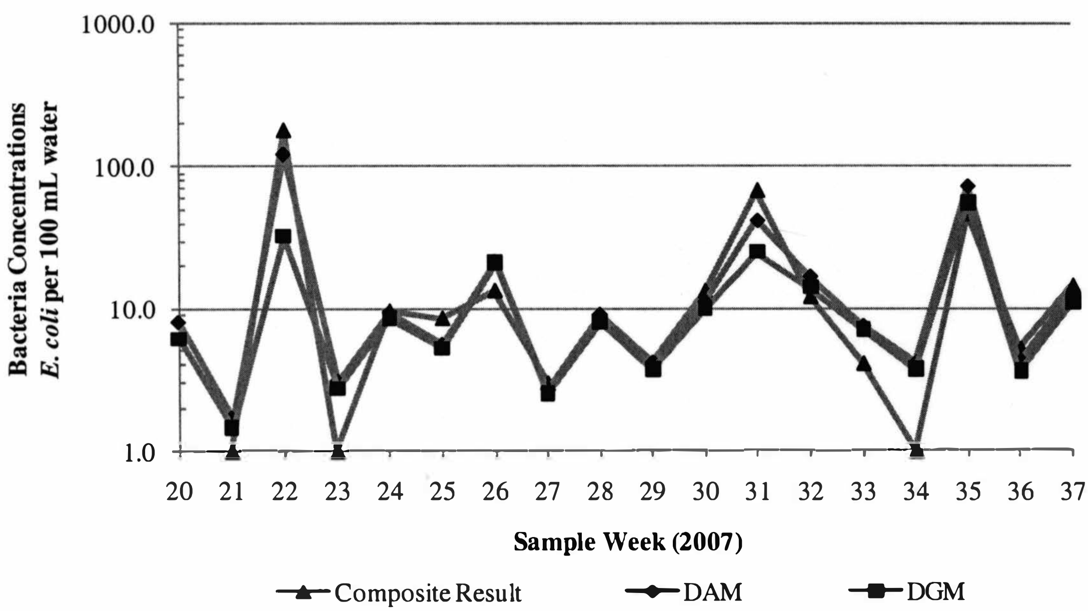
Robert Morris Park (KB-02)

Sample Week	Date	Time	Sample A	Sample B	Sample C	Composite Result	DAM	DGM
20	05/15/07	11:45	1.0	5.2	6.3	NA	4.2	3.2
21	05/22/07	9:30	1.0	4.1	3.1	1.0	2.7	2.3
22	05/30/07	9:00	4.1	2.0	9.8	6.3	5.3	4.3
23	06/05/07	8:40	17.1	9.8	12.0	10.9	13.0	12.6
24	06/12/07	8:40	4.1	7.5	5.2	4.1	5.6	5.4
25	06/19/07	9:00	3.1	5.2	6.2	7.5	4.8	4.6
26	06/26/07	9:00	8.5	4.1	5.2	7.5	5.9	5.7
27	07/02/07	11:30	9.7	28.2	128.1	80.9	55.3	32.7
28	07/10/07	11:30	1.0	5.2	5.2	NA	3.8	3.0
29	07/17/07	9:15	1.0	8.5	307.6	84.2	105.7	13.8
30	07/24/07	9:30	1.0	1.0	3.1	3.1	1.7	1.5
31	07/31/07	8:45	3.1	7.5	5.2	1.0	5.3	4.9
32	08/07/07	9:00	185.0	198.9	307.6	203.5	230.5	224.5
33	08/14/07	8:45	8.4	1.0	4.1	4.1	4.5	3.3
34	08/21/07	9:15	8.5	5.2	9.6	2.0	7.8	7.5
35	08/28/07	9:05	3.1	3.1	2.0	1.0	2.7	2.7
36	09/04/07	12:25	5.2	1.0	7.5	5.2	4.6	3.4
37	09/11/07	9:20	1.0	3.1	2.0	3.1	2.0	1.8



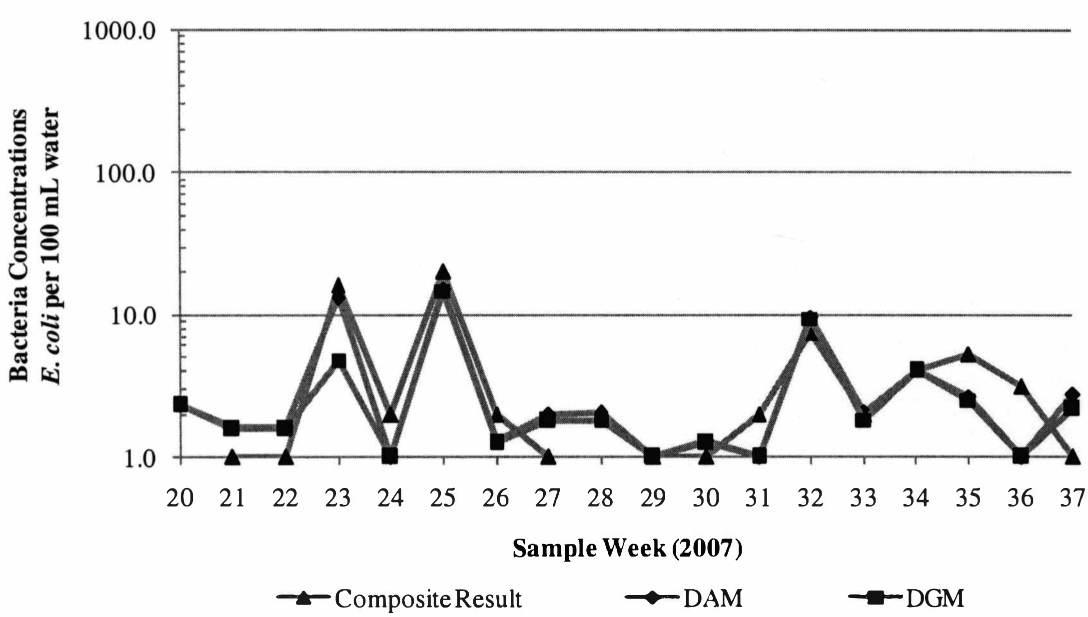
Fort Custer Recreation Area (KB-03)

Sample Week	Date	Time	Sample A	Sample B	Sample C	Composite Result	DAM	DGM
20	05/16/07	12:45	8.6	13.5	2.0	NA	8.0	6.1
21	05/23/07	10:00	1.0	1.0	3.1	1.0	1.7	1.5
22	05/30/07	10:30	344.8	6.3	16.1	178.9	122.4	32.7
23	06/05/07	10:15	2.0	2.0	5.2	1.0	3.1	2.8
24	06/12/07	10:15	8.4	14.6	5.2	9.7	9.4	8.6
25	06/19/07	10:50	8.5	4.1	4.1	8.6	5.6	5.2
26	06/26/07	10:45	24.7	14.6	25.6	13.5	21.6	21.0
27	07/02/07	9:15	2.0	4.1	2.0	3.0	2.7	2.5
28	07/10/07	9:30	13.5	9.7	4.1	NA	9.1	8.1
29	07/17/07	11:15	6.3	4.1	2.0	4.1	4.1	3.7
30	07/24/07	11:15	12.2	16.1	5.2	13.4	11.2	10.1
31	07/31/07	10:15	90.6	29.2	6.1	68.4	42.0	25.3
32	08/07/07	10:30	30.9	12.1	7.5	12.2	16.8	14.1
33	08/14/07	10:25	6.3	11.0	5.2	4.1	7.5	7.1
34	08/21/07	10:45	4.1	2.0	6.3	1.0	4.1	3.7
35	08/28/07	10:50	133.4	66.3	19.7	47.1	73.1	55.9
36	09/04/07	10:10	7.5	2.0	3.1	5.2	4.2	3.6
37	09/11/07	11:00	19.5	13.5	5.2	14.6	12.7	11.1



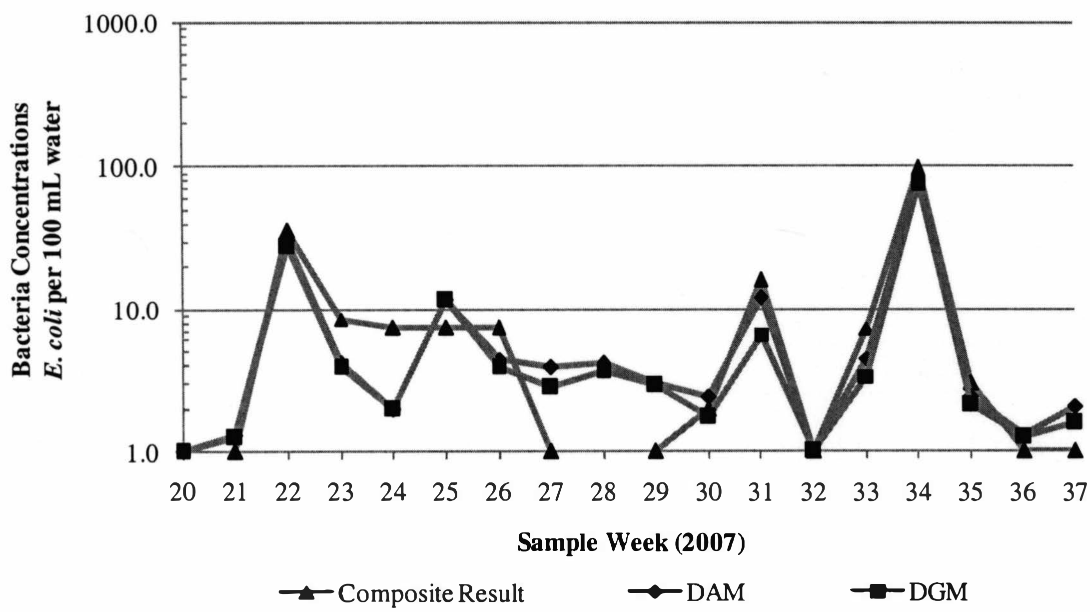
Ross Township Park (KB-04)

Sample Week	Date	Time	Sample A	Sample B	Sample C	Composite Result	DAM	DGM
20	05/16/07	11:25	2.0	2.0	3.1	NA	2.4	2.3
21	05/23/07	8:55	2.0	1.0	2.0	1.0	1.7	1.6
22	05/30/07	9:45	2.0	1.0	2.0	1.0	1.7	1.6
23	06/05/07	9:25	1.0	3.1	35.5	16.1	13.2	4.8
24	06/12/07	11:00	1.0	1.0	1.0	2.0	1.0	1.0
25	06/19/07	11:30	14.5	18.5	12.2	20.3	15.1	14.8
26	06/26/07	11:30	1.0	1.0	2.0	2.0	1.3	1.3
27	07/02/07	10:30	2.0	1.0	3.0	1.0	2.0	1.8
28	07/10/07	10:30	3.1	1.0	2.0	NA	2.0	1.8
29	07/17/07	12:00	1.0	1.0	1.0	1.0	1.0	1.0
30	07/24/07	11:50	2.0	1.0	1.0	1.0	1.3	1.3
31	07/31/07	9:30	1.0	1.0	1.0	2.0	1.0	1.0
32	08/07/07	11:30	13.4	8.6	7.4	7.5	9.8	9.5
33	08/14/07	11:40	2.0	3.1	1.0	2.0	2.0	1.8
34	08/21/07	11:30	3.0	4.1	5.2	4.1	4.1	4.0
35	08/28/07	11:30	4.1	2.0	2.0	5.2	2.7	2.5
36	09/05/07	11:20	1.0	1.0	1.0	3.1	1.0	1.0
37	09/11/07	11:45	2.0	1.0	5.2	1.0	2.7	2.2



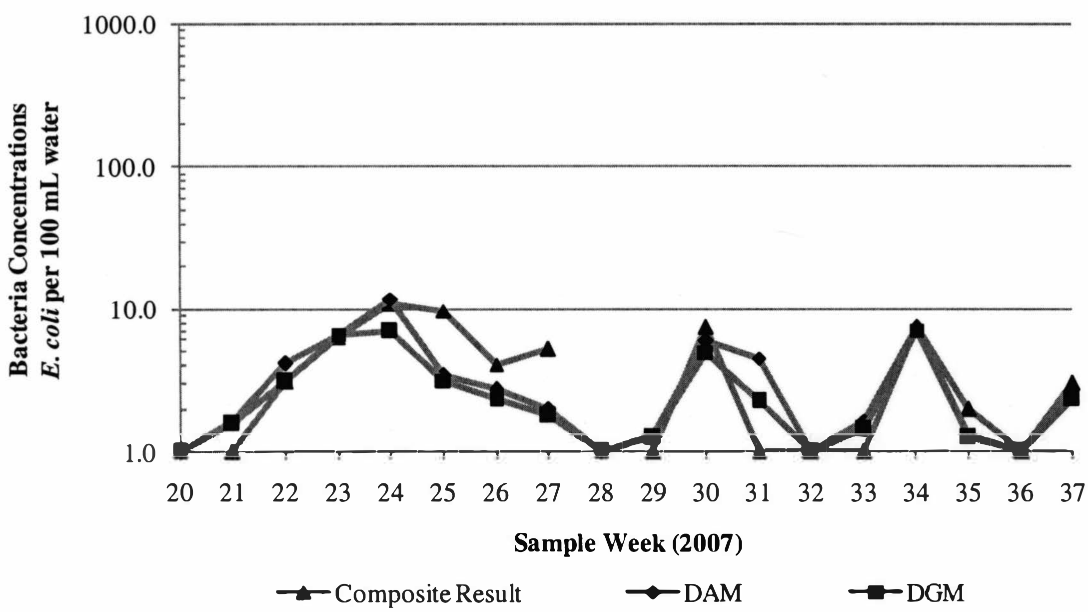
Prairie View County Park (KB-05)

Sample Week	Date	Time	Sample A	Sample B	Sample C	Composite Result	DAM	DGM
20	05/14/07	10:40	1.0	1.0	1.0	NA	1.0	1.0
21	05/21/07	10:30	1.0	1.0	2.0	1.0	1.3	1.3
22	05/29/07	10:10	50.4	24.1	17.7	35.9	30.7	27.8
23	06/04/07	10:45	6.3	3.1	3.0	8.6	4.1	3.9
24	06/13/07	9:00	2.0	2.0	2.0	7.5	2.0	2.0
25	06/18/07	10:45	13.2	14.1	8.5	7.5	11.9	11.7
26	06/25/07	10:30	2.0	4.1	7.5	7.4	4.5	3.9
27	07/02/07	10:30	1.0	7.5	3.1	1.0	3.9	2.9
28	07/09/07	9:35	2.0	4.1	6.3	NA	4.1	3.7
29	07/16/07	10:15	4.1	2.0	3.1	1.0	3.1	2.9
30	07/23/07	10:40	1.0	1.0	5.2	2.0	2.4	1.7
31	07/30/07	10:00	1.0	14.8	20.1	16.0	12.0	6.7
32	08/06/07	10:20	1.0	1.0	1.0	1.0	1.0	1.0
33	08/13/07	10:50	1.0	7.5	5.1	7.3	4.5	3.4
34	08/20/07	11:00	103.9	101.7	41.7	99.0	82.4	76.1
35	08/27/07	10:50	1.0	3.1	3.1	3.0	2.4	2.1
36	09/04/07	11:00	1.0	1.0	2.0	1.0	1.3	1.3
37	09/10/07	11:00	4.1	1.0	1.0	1.0	2.0	1.6



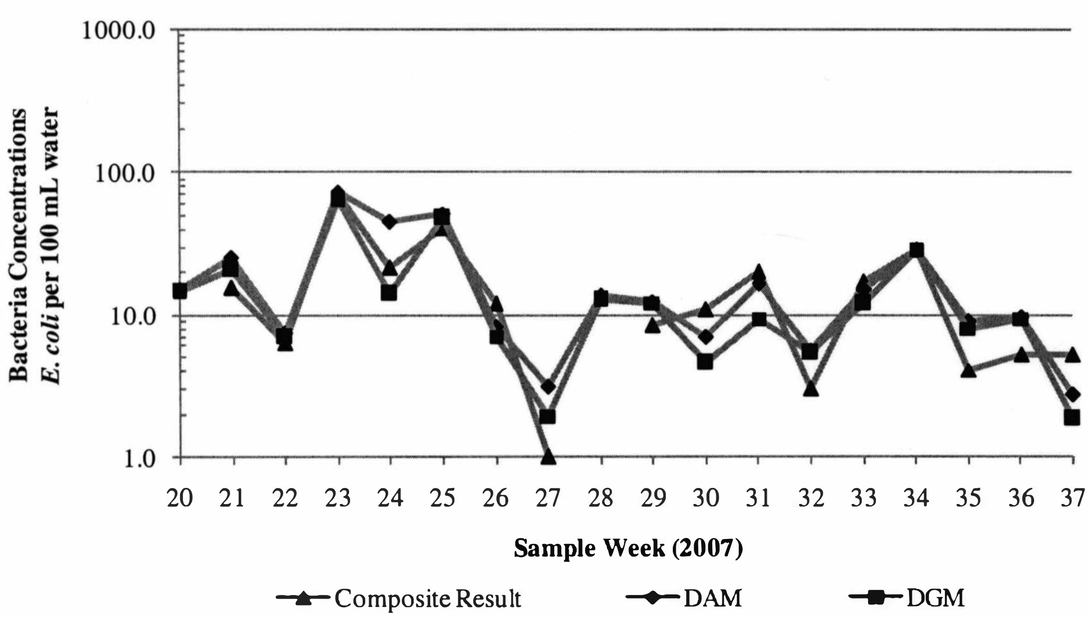
Ramona Park (KB-06)

Sample Week	Date	Time	Sample A	Sample B	Sample C	Composite Result	DAM	DGM
20	05/14/07	9:15	1.0	1.0	1.0	NA	1.0	1.0
21	05/21/07	9:00	2.0	2.0	1.0	1.0	1.7	1.6
22	05/29/07	9:00	7.5	4.1	1.0	3.1	4.2	3.1
23	06/04/07	9:25	6.3	7.4	6.3	6.3	6.7	6.6
24	06/11/07	10:05	6.3	27.2	2.0	10.9	11.8	7.0
25	06/18/07	9:35	5.2	3.1	2.0	9.8	3.4	3.2
26	06/25/07	9:50	3.1	4.1	1.0	4.1	2.7	2.3
27	07/02/07	10:00	3.0	1.0	2.0	5.2	2.0	1.8
28	07/09/07	8:10	1.0	1.0	1.0	NA	1.0	1.0
29	07/16/07	9:40	1.0	1.0	2.0	1.0	1.3	1.3
30	07/23/07	10:05	2.0	6.3	9.7	7.5	6.0	5.0
31	07/30/07	9:20	1.0	1.0	11.6	1.0	4.5	2.3
32	08/06/07	10:15	1.0	1.0	1.0	1.0	1.0	1.0
33	08/13/07	10:15	3.0	1.0	1.0	1.0	1.7	1.4
34	08/20/07	10:20	10.9	5.2	6.3	7.5	7.5	7.1
35	08/27/07	10:00	1.0	2.0	1.0	2.0	1.3	1.3
36	09/04/07	10:30	1.0	1.0	1.0	1.0	1.0	1.0
37	09/10/07	10:00	1.0	3.1	4.1	3.0	2.7	2.3



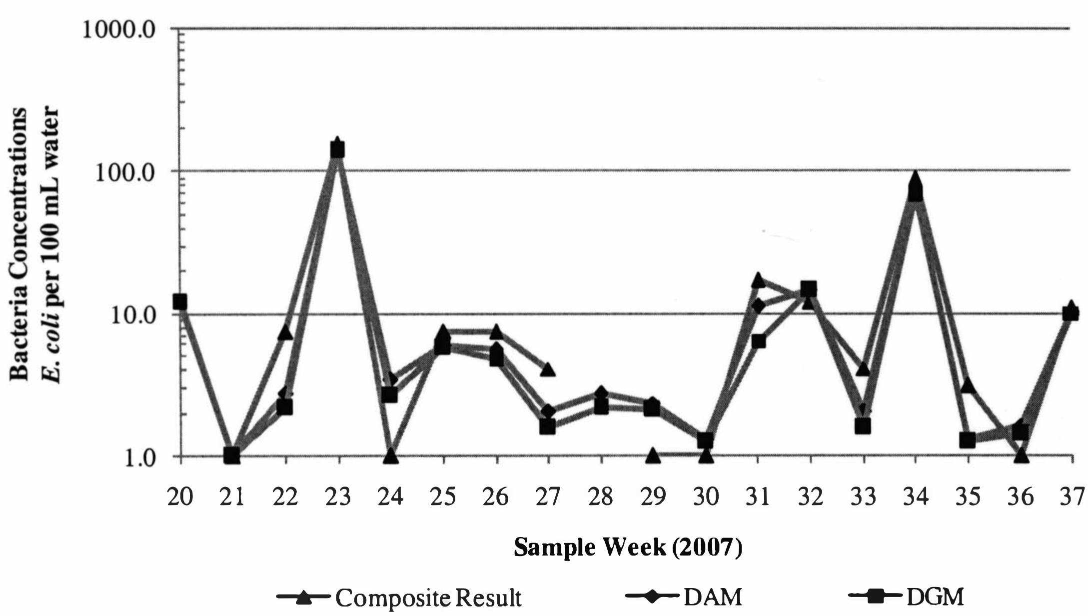
Markin Glen County Park (KB-07)

Sample Week	Date	Time	Sample A	Sample B	Sample C	Composite Result	DAM	DGM
20	05/15/07	10:45	13.2	19.7	12.1	NA	15.0	14.7
21	05/22/07	10:10	47.4	14.8	13.4	15.5	25.2	21.1
22	05/30/07	8:10	7.4	4.1	11.0	6.3	7.5	6.9
23	06/04/07	8:05	41.4	50.4	131.4	71.2	74.4	65.0
24	06/11/07	8:50	7.5	3.1	125.0	21.8	45.2	14.3
25	06/18/07	8:15	39.3	83.9	34.5	41.4	52.6	48.5
26	06/25/07	8:25	9.7	3.1	12.0	12.1	8.3	7.1
27	07/02/07	8:40	1.0	1.0	7.4	1.0	3.1	1.9
28	07/09/07	11:30	18.1	7.5	16.0	NA	13.9	13.0
29	07/16/07	8:20	8.6	16.1	13.5	8.4	12.7	12.3
30	07/23/07	8:30	2.0	3.1	16.0	10.9	7.0	4.6
31	07/30/07	8:20	4.1	5.2	40.4	20.3	16.6	9.5
32	08/06/07	8:30	5.2	4.1	7.4	3.0	5.6	5.4
33	08/13/07	8:50	6.3	9.8	28.8	17.3	15.0	12.1
34	08/20/07	9:00	27.9	32.3	27.9	28.8	29.4	29.3
35	08/27/07	8:20	6.3	5.2	15.8	4.1	9.1	8.0
36	09/04/07	9:15	9.8	7.4	11.9	5.2	9.7	9.5
37	09/10/07	8:30	1.0	1.0	6.3	5.2	2.8	1.8



Woods Lake City Park (KB-08)

Sample Week	Date	Time	Sample A	Sample B	Sample C	Composite Result	DAM	DGM
20	05/14/07	11:30	11.0	8.5	18.7	NA	12.7	12.0
21	05/21/07	11:40	1.0	1.0	1.0	1.0	1.0	1.0
22	05/29/07	11:10	2.0	5.2	1.0	7.4	2.7	2.2
23	06/04/07	8:45	125.9	133.4	166.4	155.3	141.9	140.9
24	06/11/07	9:20	6.2	3.1	1.0	1.0	3.4	2.7
25	06/18/07	8:55	7.5	4.1	6.3	7.4	6.0	5.8
26	06/25/07	9:05	2.0	6.3	8.5	7.5	5.6	4.7
27	07/02/07	9:20	1.0	4.1	1.0	4.1	2.0	1.6
28	07/09/07	10:30	5.2	1.0	2.0	NA	2.7	2.2
29	07/16/07	9:00	3.0	3.1	1.0	1.0	2.4	2.1
30	07/23/07	9:00	1.0	2.0	1.0	1.0	1.3	1.3
31	07/30/07	11:30	27.9	3.1	3.1	17.3	11.4	6.4
32	08/06/07	9:10	13.4	14.6	15.6	12.2	14.5	14.5
33	08/13/07	9:30	4.1	1.0	1.0	4.1	2.0	1.6
34	08/20/07	9:40	57.3	77.6	71.2	88.8	68.7	68.2
35	08/27/07	9:15	1.0	2.0	1.0	3.1	1.3	1.3
36	09/04/07	9:50	1.0	1.0	3.0	1.0	1.7	1.4
37	09/10/07	9:25	11.0	8.6	11.0	11.0	10.2	10.1



Sunset Lake Park (KB-11)

Sample Week	Date	Time	Sample A	Sample B	Sample C	Composite Result	DAM	DGM
20	05/14/07	10:05	9.8	1.0	3.1	NA	4.6	3.1
21	05/21/07	9:45	2.0	1.0	3.1	2.0	2.0	1.8
22	05/29/07	9:35	17.1	37.3	36.9	33.1	30.4	28.7
23	06/04/07	10:00	23.8	31.8	410.6	74.4	155.4	67.7
24	06/11/07	10:40	69.1	51.2	69.7	59.1	63.3	62.7
25	06/18/07	10:10	110.6	120.1	235.9	160.7	155.5	146.3
26	06/25/07	11:00	31.3	13.4	4.1	20.2	16.3	12.0
27	07/02/07	11:00	43.9	18.9	47.3	24.1	36.7	34.0
28	07/09/07	9:15	579.4	80.9	36.9	NA	232.4	120.0
29	07/16/07	11:00	23.3	8.6	9.8	21.6	13.9	12.5
30	07/24/07	8:30	18.7	14.6	39.3	19.5	24.2	22.1
31	07/30/07	10:30	60.9	20.3	27.9	49.6	36.4	32.6
32	08/06/07	11:00	214.3	119.8	135.4	130.9	156.5	151.5
33	08/13/07	11:30	9.5	6.3	8.6	9.8	8.1	8.0
34	08/20/07	11:30	11.1	14.4	28.5	12.1	18.0	16.6
35	08/27/07	11:30	52.8	17.5	11.0	32.7	27.1	21.7
36	09/04/07	11:40	5.2	8.6	1.0	1.0	4.9	3.5
37	09/10/07	11:30	8.6	6.0	4.1	6.3	6.2	6.0