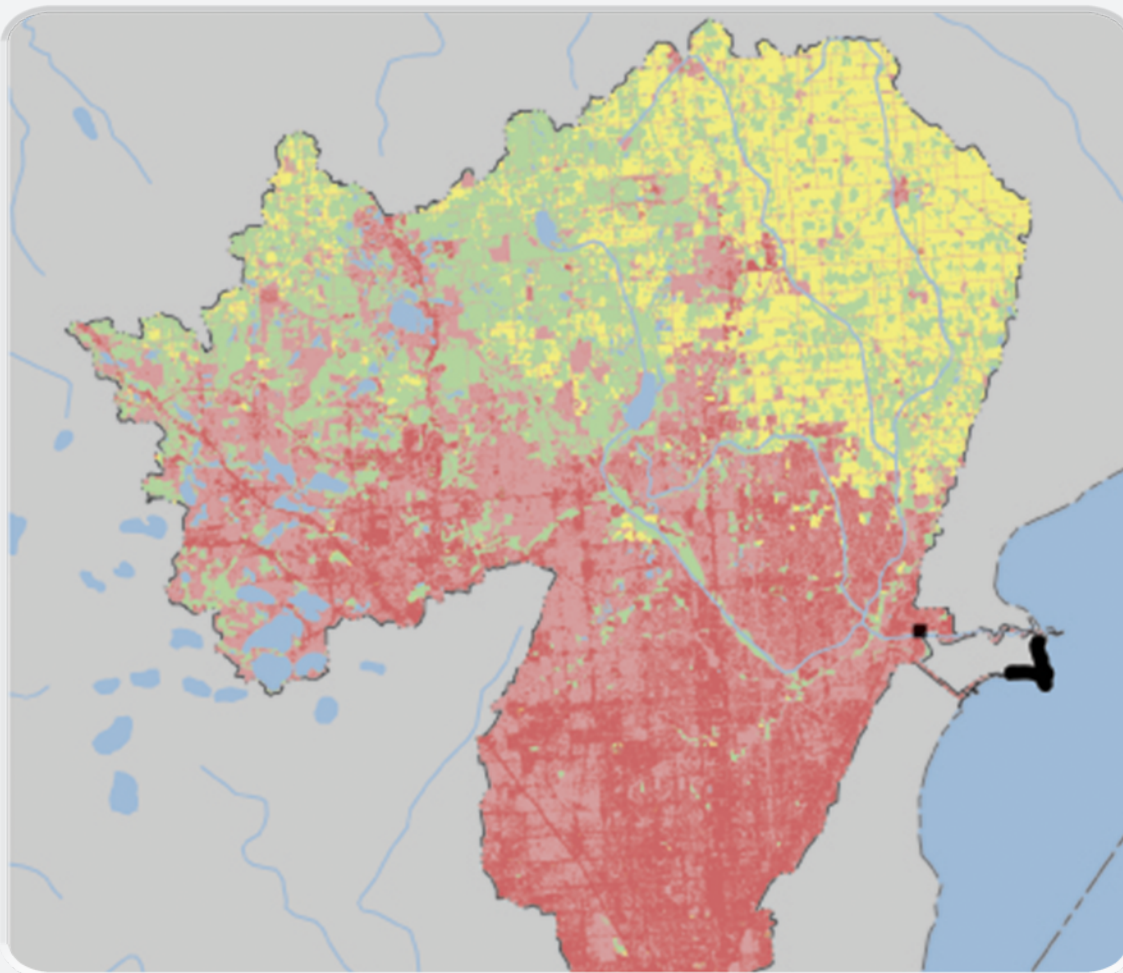


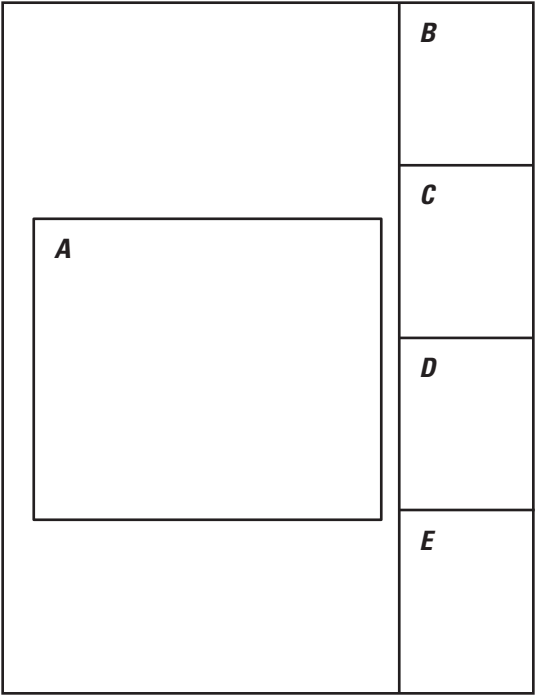
Prepared in cooperation with the U.S. Environmental Protection Agency

# Understanding Sources and Distribution of *Escherichia coli* at Lake St. Clair Metropark Beach, Macomb County, Michigan



Scientific Investigations Report 2021–5089





**Photograph credit.** A, modified figure 1 of this report. B–E, photographs by Lisa Fogarty, U.S. Geological Survey.

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By Lisa R. Fogarty, Jessica A. Maurer, Ian M. Hyslop, Alexander R. Totten,  
Christopher M. Kephart, Angela K. Brennan

Prepared in cooperation with the U.S. Environmental Protection Agency

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**U.S. Department of the Interior  
U.S. Geological Survey**

## U.S. Geological Survey, Reston, Virginia: 2021

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## Contents

Acknowledgments .....	iii
Abstract .....	1
Introduction.....	1
Purpose and Scope .....	3
Previous Studies .....	3
Description of the Study Area .....	4
Sample Collection Methods and Analysis .....	4
Sample Collection .....	4
Sampling Procedures.....	4
Analytical Methods and Analyses .....	11
<i>Escherichia coli</i> ( <i>E. coli</i> ) .....	11
Microbial Source Tracking (MST).....	11
Quality-Assurance and Quality-Control .....	12
Sources and Distribution of <i>Escherichia coli</i> .....	12
Lake St. Clair Surface Water <i>E. coli</i> .....	13
Offshore Surface Water.....	19
Stormwater .....	21
Sediment, Sand, Detritus .....	22
Groundwater.....	23
Environmental Factors .....	26
Microbial Source Tracking .....	28
Synopsis of <i>Escherichia coli</i> Results.....	28
Summary.....	31
References Cited.....	32

## Figures

1. Map showing Clinton River drainage basin and Area of Concern boundary in Michigan .....	2
2. Map showing Lake St. Clair Metropark Beach study area and sampling sites .....	5
3. Graph showing <i>Escherichia coli</i> ( <i>E. coli</i> ) concentrations from replicate samples .....	13
4. Graphs showing boxplots of <i>Escherichia coli</i> concentrations in shallow and deep nearshore surface water.....	16
5. Graph showing <i>Escherichia coli</i> concentrations in shallow and deep samples for the recreational area near beach and designated swimming area sampling sites.....	19
6. Graphs showing <i>Escherichia coli</i> concentrations and daily discharge at USGS station 04165500 by date in 2018 and 2019.....	20
7. Graph showing daily mean discharge at the USGS streamgage 04165500 on the Clinton River at Moravian Drive at Mount Clemens, Michigan, August 1–19, 2019.....	21
8. Photograph showing Lake St. Clair Metropolitan Beach from onshore showing standing water on beach draining into Lake St. Clair after a storm event on May 9, 2019 .....	22

9. Photograph showing Lake St. Clair Metropolitan Beach from offshore showing standing water on beach draining into Lake St. Clair after a storm event on August 1, 2018.....	22
10. Figures showing Lake St. Clair Metropark Beach showing groundwater sampling sites and <i>Escherichia coli</i> concentrations on different dates in 2018–2019.....	25
11. Graph showing <i>Escherichia coli</i> ( <i>E. coli</i> ) concentrations for samples collected during wet and dry conditions in 2018–2019 .....	27
12. Graph showing <i>Escherichia coli</i> concentrations of samples with detection and nondetection of waterfowl marker in surface water and groundwater samples and human marker in groundwater .....	29

## Tables

1. Summary of study sites and sampling dates for surface-water samples.....	6
2. Groundwater sampling sites and collection date .....	7
3. Summary of study sites and sampling dates for beach sand and lake bottoms solid samples.....	8
4. Summary of sites, dates, and times of detritus sample collection.....	10
5. Standard curve characteristics and limits of detection and quantification for microbial source tracking markers.....	12
6. Quality-control sequential field replicate data for microbial source tracking markers.....	13
7. Summary statistics of surface-water samples analyzed for <i>Escherichia coli</i> concentrations in 2018 and 2019 .....	14
8. Summary of exceedances of <i>Escherichia coli</i> concentrations compared the State of Michigan Recreational Water-Quality Criterion for total body contact for a single event .....	18
9. Descriptions of storm drain outlet samples collected along Black Creek and <i>Escherichia coli</i> concentrations for the Lake St. Clair Metropolitan Beach study in 2018 and 2019 .....	23
10. Descriptions of standing water samples collected and <i>Escherichia coli</i> concentrations for the Lake St. Clair Metropolitan Beach Study in 2018 and 2019 .....	23
11. Summary statistics of <i>Escherichia coli</i> concentrations in detritus and beach sand samples collected at the surface and at depth for the Lake St. Clair Metropolitan Beach study in 2018 and 2019.....	24
12. Summary statistics of <i>Escherichia coli</i> concentrations in beach sand samples collected along transects at the beach for Lake St. Clair Metropolitan Beach study in 2018 and 2019.....	24
13. Summary statistics of <i>Escherichia coli</i> concentrations in beach sand samples collected during wet and dry conditions for Lake St. Clair Metropolitan Beach study in 2018 and 2019.....	24
14. Summary of <i>Escherichia coli</i> concentrations in groundwater samples for each sample collection date for the Lake St. Clair Metropolitan Beach Study in 2018 and 2019 .....	26
15. Correlation coefficients for <i>Escherichia coli</i> concentrations in relation to selected environmental variables for Lake St. Clair Metropark Beach in 2018–2019.....	26

16. Description of microbial source tracking results for human (HF183) and waterfowl (GFD) markers and *Escherichia coli* concentrations.....28

## Conversion Factors

### U.S. customary units to International System of Units

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
mile, nautical (nmi)	1.852	kilometer (km)
yard (yd)	0.9144	meter (m)
Area		
acre	4,047	square meter (m <sup>2</sup> )
square mile (mi <sup>2</sup> )	259.0	hectare (ha)
square mile (mi <sup>2</sup> )	2.590	square kilometer (km <sup>2</sup> )
Velocity and flow rate		
cubic foot per second (ft <sup>3</sup> /s)	0.02832	cubic meter per second (m <sup>3</sup> /s)
mile per hour (mi/h)	1.609	kilometer per hour (km/h)
Mass		
ounce, avoirdupois (oz)	28.35	gram (g)

### International System of Units to U.S. customary units

Multiply	By	To obtain
Length		
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
Area		
square meter (m <sup>2</sup> )	0.0002471	acre
Mass		
gram (g)	0.03527	ounce, avoirdupois (oz)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$^{\circ}\text{F} = (1.8 \times ^{\circ}\text{C}) + 32.$$

## Datum

Horizontal coordinate information is referenced to North American Datum of 1983 (NAD 83).

## Supplemental Information

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius ( $\mu\text{S}/\text{cm}$  at 25 °C).

Concentrations of chemical constituents in water are given in either milligrams per liter (mg/L) or micrograms per liter ( $\mu\text{g}/\text{L}$ ).

Concentrations of *Escherichia coli* (*E. coli*) in water are reported as most probable number per 100 milliliters (MPN/100 mL) or as colony-forming units per 100 milliliters (CFU/100 mL).

Microbial source tracking markers are reported as copies per 100 milliliters.

Concentrations of *Escherichia coli* (*E. coli*) in beach sand are reported as most probable number per 100 milliliters of sample water (MPN/100 mL) per gram dry weight (g dw).



## Abbreviations

AOC	Area of Concern
BRL	below reporting level
BUI	Beneficial Use Impairment
CFU	colony-forming units
DSA	designated swimming area
EPA	U.S. Environmental Protection Agency
E. coli	Escherichia coli
HECWFS	Huron to Erie Connecting Waterways Forecasting System
LSCMB	Lake St. Clair Metropark Beach
LoB	limit of blank
LoD	limit of detection
LoQ	limit of quantification
MCHD	Macomb County Health Department
MIBaRL	Michigan Bacteriological Research Laboratory
MPN	most probable number (of bacteria)
MST	microbial source tracking
NFM	National Field Manual
NOAA	National Oceanic and Atmospheric Association
NTU	nephelometric turbidity units
PS	park shoreline
OWML	Ohio Water Microbiological Laboratory
USGS	U.S. Geological Survey
qPCR	quantitative polymerase chain reaction
RNB	recreational area near beach



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## Abstract

Lake St. Clair Metropark Beach (LSCMB) in Michigan is a public beach near the mouth of the Clinton River that has a history of beach closures for public health concerns. The Clinton River is designated as a Great Lakes Area of Concern, and the park has a Beneficial Use Impairment for beach closings because of elevated *Escherichia coli* (*E. coli*) concentrations. The U.S. Geological Survey, in cooperation with the U.S. Environmental Protection Agency and in collaboration with the Michigan Department of the Environment, Great Lakes, and Energy, Macomb County Health Department, and Huron-Clinton Metroparks, completed a 2-year study to determine sources of *E. coli* in LSCMB. Samples were collected during dry and wet weather periods to observe the sampling sites under different conditions. Nearshore surface water samples were collected biweekly July through October in 2018 and May through September in 2019. There were 20 sampling sites along the shoreline of the park and in the channel north of the park. In addition to collecting nearshore surface-water samples, samples were collected from shallow groundwater, lake-bottom material, standing water on the beach and surrounding the recreational beach area, solids (beach sands and detritus), and offshore surface-water sites. In 2019, additional samples for microbial source tracking (MST) were collected on three dates in midsummer and were analyzed for human (HF183) and bird/waterfowl (GFD) MST markers. The concentrations of *E. coli* at LSCMB (in order of highest to lowest *E. coli* concentrations) were as follows: shallow groundwater nearest to the water's edge, surface sands and organic matter (detritus), standing water on the beach, nearshore surface water in and surrounding the recreational beach area, lake-bottom material, and offshore surface water. The combination of low *E. coli* concentrations offshore and higher concentrations nearshore indicate nearshore sources, possibly from beach sands or groundwater, rather than sources coming from offshore Lake St. Clair waters. The subset of samples for MST analysis did not have enough positive results to illustrate MST trends, but this study demonstrated that both human and waterfowl sources can affect the water quality at LSCMB.

## Introduction

In the 1980s, the United States and Canada identified 43 Areas of Concern (AOCs) around the Great Lakes (International Joint Commission United States and Canada, 1987). These were geographic areas that were highly degraded by one or more of 14 identified Beneficial Use Impairments (BUIs). The Great Lakes Water Quality Agreement (International Joint Commission United States and Canada, 1987, p. 24) states:

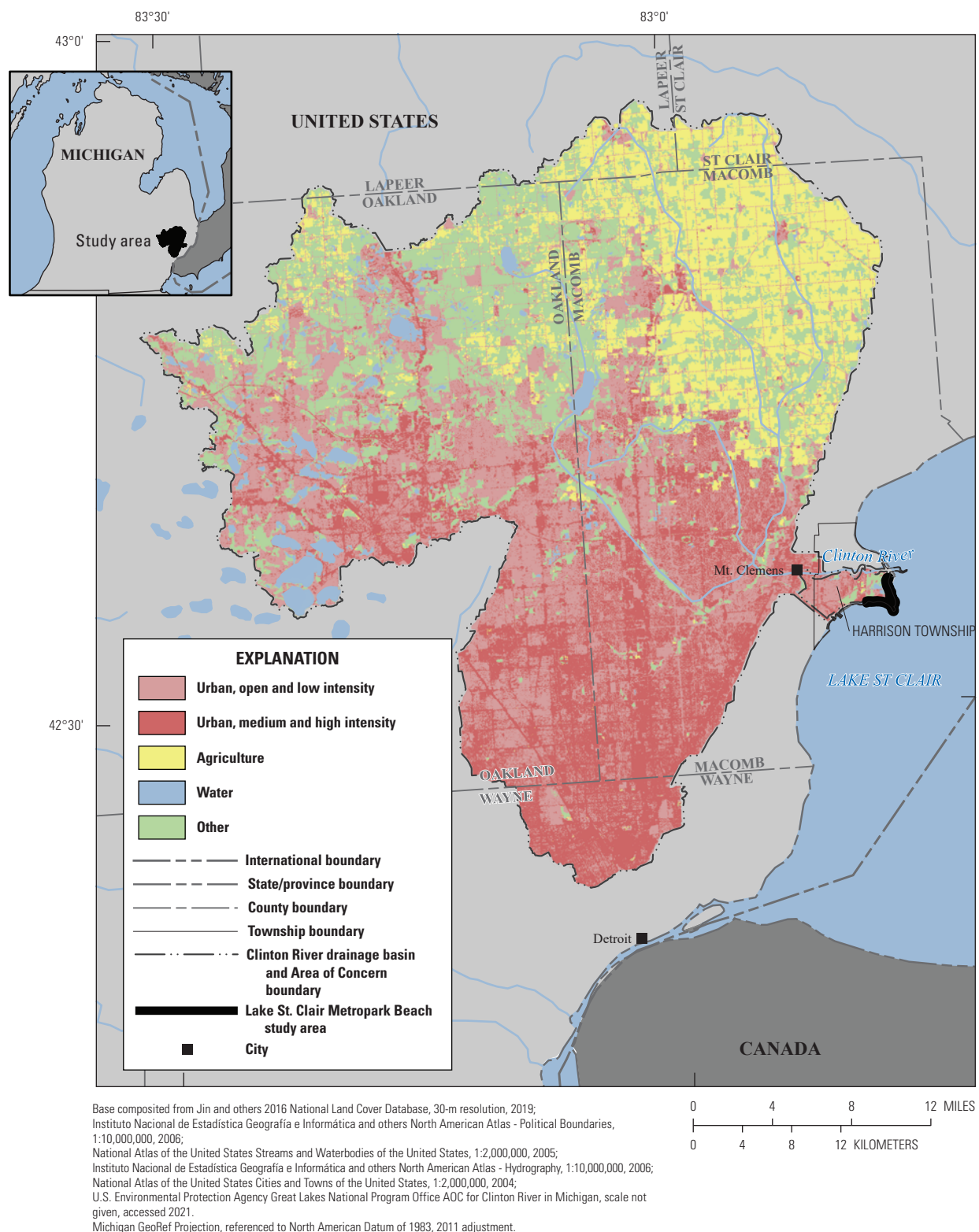
“impairment of beneficial use(s)” means a change in the chemical, physical or biological integrity of the Great Lakes System sufficient to cause any of the following:

- i. restrictions on fish and wildlife consumption;
- ii. tainting of fish and wildlife flavour;
- iii. degradation of fish wildlife populations;
- iv. fish tumors or other deformities;
- v. bird or animal deformities or reproduction problems;
- vi. degradation of benthos;
- vii. restrictions on dredging activities;
- viii. eutrophication or undesirable algae;
- ix. restrictions on drinking water consumption, or taste and odour problems;
- x. beach closings;
- xi. degradation of aesthetics;
- xii. added costs to agriculture or industry;
- xiii. degradation of phytoplankton and zooplankton populations; and
- xiv. loss of fish and wildlife habitat.”

Possible sources of contaminants associated with AOCs may include nonpoint urban and rural runoff, combined sewer overflows, municipal and industrial point source discharges, and contaminated sediments (Michigan Department of Natural Resources, 1988).

The Clinton River AOC includes the entire Clinton River drainage basin and nearshore areas of Lake St. Clair south of the Clinton River mouth in Michigan (fig. 1). Because of high *Escherichia coli* (*E. coli*) concentrations and frequent beach closures, the Lake St. Clair Metropark Beach (LSCMB) in Macomb County, Michigan, was included in the Clinton

## 2 Understanding Sources and Distribution of Escherichia coli at Lake St. Clair Metropark Beach



**Figure 1.** Clinton River drainage basin and Area of Concern boundary in Michigan, with the Lake St. Clair Metropark Beach study area.

River AOC for the Beach Closure BUI (Michigan Department of Environmental Quality, 2009). Beach managers rely on water-quality monitoring programs to indicate the presence of fecal indicator bacteria such as enterococci and *E. coli* to make informed decisions including issuing advisories and closing beaches with the goal of reducing public health risk (U.S. Environmental Protection Agency, 2019).

*E. coli* live in the intestinal tracts of humans, other warm-blooded mammals, and birds. Most strains of *E. coli* do not pose a human health risk; however, *E. coli* can indicate the presence of other disease-causing microorganisms (pathogenic bacteria, viruses, and protozoa) that are found in fecal waste and cause waterborne disease outbreaks nationwide (U.S. Environmental Protection Agency, 2012). The U.S. Environmental Protection Agency (EPA) has established guidelines for Recreational Water-Quality Criteria based on human health risk studies (U.S. Environmental Protection Agency, 2012). The State of Michigan has established state water-quality criteria based on the EPA guidelines (Michigan Department of Environmental Quality, 2006, p. 55) as follows:

“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 milliliters (ml), as a 30-day geometric mean. Compliance shall be based on the geometric mean of all individual samples taken during 5 or more sampling events representatively spread over a 30-day period. Each sampling event shall consist of 3 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 3 or more samples taken during the same sampling event at representative locations within a defined sampling area.”

Since 2000, LSCMB has been closed for 187 days, ranging from 0 to 47 beach closure days in a single year (Michigan Department of Environmental Quality, 2020). The monitoring season typically starts between May 1 and May 31 and continues through September 30 each year, with 122 to 152 beach days a year depending on the start date.

Sources of contamination resulting in beach closures at LSCMB are undetermined. Microbial source tracking (MST) refers to a group of analytical tools used to characterize sources of fecal contamination that can inform management agencies and enable them to implement source-appropriate remediation strategies to improve water quality (Boehm and others, 2003; Francy and others, 2005; U.S. Environmental Protection Agency, 2005; Francy and others, 2006). MST tools are based on the concept that the gastrointestinal systems of warm-blooded animals have different selective pressures that select for specific microbial populations, such as diet or physiological differences. Standard methods have not been developed for MST, but fecal microbial populations are often

characterized through detection and quantification of genetic sequences (MST markers) that are unique to the host animals. Host-associated MST markers have been identified in many warm-blooded mammals such as humans and waterfowl/shorebirds (Francy and others, 2006; Hagedorn and others, 2011). MST markers can thus indicate the originating fecal source, but it is also important to understand the different pathways transporting indicators and contamination. The identified potential contaminant sources and pathways to the LSCMB may include (but are not limited to): (1) the Clinton River; (2) the Clinton River Spillway; (3) storm drain infiltration and groundwater flow to the beach; (4) unnamed channel that drains wetland and residential area at the west end of the park; (5) Lake St. Clair bottom material/sediment (beach sand); and (6) waterfowl, including *Larus* spp. (gulls) and *Branta canadensis* (Canada geese).

## Purpose and Scope

From 2018 to 2019, the U.S. Geological Survey (USGS) cooperated with the EPA to determine likely sources of *E. coli* to LSCMB with the goal of reducing the number of beach closures by informing future beach restoration and mitigation efforts. This report documents *E. coli* concentrations at LSCMB in Macomb County, Mich., from 2018 to 2019. This study was designed to determine if the source(s) of *E. coli* are coming from the offshore waters of Lake St. Clair or localized sources near the recreational areas of LSCMB. Results of this study can be used to help determine status and management options to ultimately remove the beach closure BUI for the Clinton River AOC.

## Previous Studies

Macomb County Health Department (MCHD) has led recreational beach water quality monitoring at LSCMB since 1995 (MCHD, 2020a) and the Clinton River and its tributaries since 1999 (MCHD, 2020b). Fogarty (2007) summarized *E. coli* data collected in the Clinton River drainage basin and at Lake St. Clair beaches as part of the health department monitoring in 2000–2005. During that study period, *E. coli* concentrations exceeded 1,000 colony-forming units (CFU)/100 milliliters (mL; partial body contact standard) in 16 percent of the samples analyzed.

Holtschlag and others (2008) published a two-dimensional hydrodynamic model to simulate horizontal current patterns on Lake St. Clair in response to wind, flow, and water-level conditions. They simulated hypothetical particle tracks and used regression analysis to determine environmental explanatory variables for higher *E. coli* concentrations. Driven primarily by wind direction, hypothetical flow paths from the Clinton River to LSCMB are possible. Results from the logistical regression models that were developed to estimate the probability that *E. coli* concentrations would exceed 300 most probable number (MPN)/100 mL at Memorial and



Metropark (formally called Metropolitan) Lake St. Clair beaches, determined that rainfall preceding the sampling events was positively associated with the probabilities of *E. coli* exceedance. Flow in the Clinton River was negatively associated with bacteria exceedances at Metropark Beach. The Holtschlag and others (2008) study was inconclusive as to if *E. coli* from the Clinton River affected nearby LSCMB, thereby resulting in beach closures.

## Description of the Study Area

This study was completed at the Lake St. Clair Metropark Beach (LSCMB) in Harrison Township, Macomb County, Mich. (fig. 1). The park is a 938-acre recreational area in an urban area along the western shore of Lake St. Clair (fig. 2). The park includes about 600 feet (ft) of sandy beach (LSCMB) on Lake St. Clair. The LSCMB is roughly 3.0 miles west of the mouth of the Clinton River that drains into Lake St. Clair, and it is part of the Clinton River AOC. The Clinton River, with a 760-square-mile drainage basin, meanders a total of 81.5 miles through wetland, forests, farmland, cities, and parks and drains into a suburban and more urbanized area via the mouth of the Clinton River just north of the peninsula along the eastern edge of the park (fig. 1). On the north side of the park, Black Creek (BC) flows from wetland areas in the park out to Lake St. Clair. There are storm drain outlets near the mouth of BC (fig. 2).

This study focused on samples collected from Lake St. Clair around the park and in the swimming areas (table 1). Samples were collected to determine possible source areas such as deeper offshore waters (table 1) that may be affected by the Clinton River. Additional samples collected to help determine sources of *E. coli* included lake-bottom sediment, surface beach sand, beach sand at depth, shallow groundwater at the beach, storm drain outlets, and standing water on land near swimming and recreational areas after rain events.

## Sample Collection Methods and Analysis

The USGS collected samples July through October 2018 and May through August 2019 in shallow and deep nearshore surface water, shallow groundwater, standing water on and surrounding the recreational beach area, storm drain outfalls, and offshore surface water in the Clinton River flow. Sampling results are available in the USGS National Water Information System database (U.S. Geological Survey, 2020) by using the USGS station numbers in table 1–4. Meteorological data were obtained from the National Oceanic and Atmospheric Administration (NOAA), Mt. Clemens Air National Guard Base (NOAA, 2020), and the NOAA Great Lakes Environmental Research Laboratory CoastWatch buoy stations CLSM4 and 45147 in Lake St. Clair (NOAA, 2020b).

## Sample Collection

Twenty nearshore surface water locations were routinely (on average twice per week) sampled in 2018 and 2019 and are grouped by general location: park shoreline (PS), designated swimming area (DSA), recreational area near beach (RNB), and BC (fig. 2). In 2018, the study did not start until later in the beach season, so only 20 sets of samples were collected from July through October. In 2019, 27 sets of samples were collected May through September to represent the full beach season. Additional samples in 2018 and 2019 were collected to capture effects of rainfall. Three additional sampling trips in 2019 were made to collect offshore or groundwater samples when selected routine locations were also sampled. In addition, samples were collected from the lake-bottom sediment, standing water on the beach and surrounding the recreational beach area, beach sand at stratified depths (0 ft, 1 ft, and 2 ft), detritus along the shoreline, and offshore surface water sites. Offshore sampling was completed at 10 sampling locations on August 7, 2019, during Clinton River steady streamflow conditions (daily mean discharge value of 176 cubic feet per second [ $\text{ft}^3/\text{s}$ ] at USGS streamgage 04165500 [USGS, 2020]) and on August 14, 2019, during Clinton River high-flow conditions (daily mean discharge value of 838  $\text{ft}^3/\text{s}$  at USGS streamgage 04165500 [USGS, 2020]; 1.88 inches [in.] of rain [NOAA, 2020] within 24 to 48 hours of offshore sample collection). Additional samples for MST analysis were collected on July 2, July 23, and August 7, 13, and 14, 2019. Samples were collected during various wet (defined as more than 0.10 in. of rain within 24 hours of sampling) and dry (defined as 0.00 in. of rain within 24 hours of sampling) weather conditions.

## Sampling Procedures

Samples were collected by USGS personnel in accordance with the USGS National Field Manual (USGS NFM; USGS, variously dated). Surface-water samples were collected into directional flow from nearshore and offshore sampling locations between 9 a.m. and 2 p.m. local time into 100-mL sterile, transparent, nonfluorescing vessels. Wadeable nearshore surface water samples (sites 3 through 8) were collected as grab samples about 2 ft deep and are referred to as “shallow” samples. Near the beach in waters about 5 ft, samples were collected about 2–3 ft below the surface and referred to as “deep” samples. Water samples collected from standing water on the recreational beach and surrounding grass area were collected using the grab sample technique to collect water in pooled areas. Nonwadeable nearshore surface water samples were also grab samples and were collected into the directional flow from the shore with a 10-ft extendable sample pole. Uncapped turbidity and *E. coli* bottles were attached to the sample pole, lowered between 2 and 3 ft below the surface into directional flow, raised out of the water, and capped. Samples were immediately placed on ice for preservation.





**Figure 2.** Lake St. Clair Metropark Beach study area and sampling sites.

## 6 Understanding Sources and Distribution of *Escherichia coli* at Lake St. Clair Metropark Beach

**Table 1.** Summary of study sites and sampling dates for surface-water samples.

[USGS, U.S. Geological Survey; ID, identification; LSCMB, Lake St. Clair Metropark Beach]

General location	USGS station ID	Short ID <sup>1</sup>	Sampling time frame	Number of samples
Recreational area near beach (RNB), shallow	423417082480001	LSCMB-3S	July–Oct 2018	20
			May–Sep 2019	30
	423413082473401	LSCMB-7S	July–Oct 2018	20
			May–Sep 2019	28
Recreational area near beach (RNB), deep	423417082480002	LSCMB-3D	July–Oct 2018	20
			May–Sep 2019	30
	423413082473402	LSCMB-7D	July–Oct 2018	20
			May–Sep 2019	28
Designated swimming area (DSA), shallow	423417082475001	LSCMB-4S	July–Oct 2018	20
			May–Sep 2019	30
	423416082474601	LSCMB-5S	July–Oct 2018	20
			May–Sep 2019	28
	423415082474201	LSCMB-6S	July–Oct 2018	20
			May–Sep 2019	30
Designated swimming area (DSA), deep	423417082475002	LSCMB-4D	July–Oct 2018	20
			May–Sep 2019	30
	423416082474602	LSCMB-5D	July–Oct 2018	20
			May–Sep 2019	28
	423415082474202	LSCMB-6D	July–Oct 2018	20
			May–Sep 2019	30
Park shoreline (PS), east	423416082482200	LSCMB-1	July–Oct 2018	20
			May–Sep 2019	27
	423416082481300	LSCMB-2	July–Oct 2018	20
			May–Sep 2019	27
Park shoreline (PS), west	423408082472200	LSCMB-8	July–Oct 2018	20
			May–Sep 2019	29
	423358082471100	LSCMB-9	July–Oct 2018	20
			May–Sep 2019	27
	423349082470000	LSCMB-10	July–Oct 2018	20
			May–Sep 2019	29
	423353082465900	LSCMB-11	July–Oct 2018	20
			May–Sep 2019	29
	423358082470000	LSCMB-12	July–Oct 2018	20
			May–Sep 2019	30
Black Creek (BC)	423402082470500	LSCMB-13	July–Oct 2018	20
			May–Sep 2019	27
	423411082471300	LSCMB-14	July–Oct 2018	20
			May–Sep 2019	27
	423412082471600	LSCMB-15	July–Oct 2018	20
			May–Sep 2019	27

**Table 1.** Summary of study sites and sampling dates for surface-water samples.—Continued

[USGS, U.S. Geological Survey; ID, identification; LSCMB, Lake St. Clair Metropark Beach]

General location	USGS station ID	Short ID <sup>1</sup>	Sampling time frame	Number of samples
Offshore (OS)	423402082480301	LSC-OS-3	Aug 2019	2
	423359082475201	LSC-OS-4	Aug 2019	3
	423356082474201	LSC-OS-6	Aug 2019	2
	423351082473301	LSC-OS-8	Aug 2019	3
	423345082470301	LSC-OS-10	Aug 2019	3
	423351082465601	LSC-OS-11	Aug 2019	2
	423401082465601	LSC-OS-12	Aug 2019	2
	423431082465901	LSC-OS-16	Aug 2019	1
	423503082465401	LSC-OS-17	Aug 2019	2
	423516082461501	LSC-OS-18	Aug 2019	4

<sup>1</sup>Latter part of the short ID is used to identify sites on [figure 2](#).**Table 2.** Groundwater sampling sites and collection date.

[USGS, U.S. Geological Survey; ID, identification; LSCMB, Lake St. Clair Metropark Beach; dates displayed in m/d/yyyy]

USGS station ID	Groundwater site ID	Sample collection date				
		9/11/2018	10/10/2018	6/13/2019	7/23/2019	8/13/2019
423417082475401	LSCMB-3A	x				
423416082474600	LSCMB-7A	x	x			
423414082473701	LSCMB-10A	x				
423415082474301	LSCMB-9A	x	x			
423416082474501	LSCMB-East A	x	x	x	x	x
423416082474503	LSCMB-East B		x	x	x	x
423417082474401	LSCMB-East C		x	x	x	x
423416082474701	LSCMB-Central A	x	x		x	x
423417082474701	LSCMB-Central B		x		x	x
423417082474601	LSCMB-Central C		x		x	x
423416082474901	LSCMB-West A	x	x	x	x	x
423416082474902	LSCMB-West B	x	x	x	x	x
423417082474801	LSCMB-West C	x	x	x	x	x

**Table 3.** Summary of study sites and sampling dates for beach sand and lake bottoms solid samples.

[USGS, U.S. Geological Survey; ID, identification; x, sample collected and analyzed; X, multiple samples at depth collected; dates displayed in m/d/yy]

USGS station ID	8/8/18	8/22/18	9/11/18	9/26/18	10/10/18	6/13/19	7/23/19	8/13/19	8/26/19
Beach sand samples									
423413082473404	x	x	x	X					
423415082474204	x	x	x	X					
423416082474501						X	X	X	X
423416082474503						X	X	X	X
423416082474504		X	x	X	X				
423416082474604	x	x	x	X	X				
423416082474605				X	X				
423416082474701							X	X	X
423416082474804			x						
423416082474901						X	X	X	X
423416082474902					X	X	X	X	X
423417082474204				X					
423417082474401						X	X	X	X
423417082474504		x	X	X	X				
423417082474505				X	X				
423417082474601							X	X	X
423417082474604				X	X				
423417082474701							X	X	X
423417082474704		x	x						
423417082474801						X	X	X	X
423417082474804				X					
423417082474904		X	x	X	X				
423417082474905		x	x	X	X				
423417082474906					X				
423417082475004	x	x	x						
423417082475304	x	x							
423419082475104		x	x						

**Table 3.** Summary of study sites and sampling dates for beach sand and lake bottoms solid samples.—Continued

[USGS, U.S. Geological Survey; ID, identification; x, sample collected and analyzed; X, multiple samples at depth collected; dates displayed in m/d/yy]

USGS station ID	8/8/18	8/22/18	9/11/18	9/26/18	10/10/18	6/13/19	7/23/19	8/13/19	8/26/19
Lake bottom samples									
423353082465804	x								
423359082470004	x								
423403082470404	x								
423409082472504	x								
423412082473404	x								
423414082474204	x	x							
423414082474204			x		x				
423414082474205				x	x				
423414082474604				x	x				
423415082474604	x	x	x		x				
423415082475004				x	x				
423416082475104	x	x							
423416082475104			x		x				
423416082475104									
423416082475404	x								
423416082481304	x								
423417082475804	x								

**Table 4.** Summary of sites, dates, and times of detritus sample collection.

[USGS, U.S. Geological Survey; ID, identification; dates displayed in m/dd/yyyy]

USGS station ID	Date	Time
423416082474501	6/13/2019	1215
423416082474501	7/23/2019	1225
423416082474501	8/13/2019	1015
423416082474501	8/26/2019	1031
423416082474701	7/23/2019	1040
423416082474701	8/13/2019	1150
423416082474701	8/26/2019	0935
423416082474901	6/13/2019	0904
423416082474901	7/23/2019	0845
423416082474901	8/13/2019	0830
423416082474901	8/26/2019	0835

and same-day processing by the Michigan Bacteriological Research Laboratory (Lansing, Michigan; MIBaRL) (Myers and others, 2014).

To evaluate conditions of Lake St. Clair waters and sources to offshore water, samples were collected farther from land and following a transect north to the Clinton River. Offshore sampling locations were selected using the Great Lakes Environmental Research Laboratory Nowcast Huron to Erie Connecting Waterways Forecasting System (HECWFS) via Google Maps (NOAA, 2019). The HECWFS simulated tracer model identified the most probable flow paths of water and particles from the Clinton River to LSCMB. Offshore surface-water samples were collected as grab samples from a boat about 3 ft below the water surface, and deep samples were collected using a Van Dorn sampler (USGS, variously dated). Samples were immediately capped and placed on ice for preservation and same-day processing by the MIBaRL. At each nearshore and offshore sampling site, temperature, specific conductance, and pH were recorded using a calibrated YSI DSS or ProPlus water quality sonde (USGS variously dated). Water chemistry properties were also recorded for standing water samples when there was enough standing water to fully submerge the water quality sonde. Turbidity values at each surface-water sample location were recorded using a calibrated HACH 2100Q handheld turbidimeter with a 10 nephelometric turbidity units (NTU) primary verification standard (USGS, variously dated).

Shallow groundwater samples were collected in 2018 and 2019 (table 2). On the first trip (September 11, 2018), samples, identified as “A,” were collected along the beach near the lake and land interphase at eight locations. Two additional samples were collected upgradient, perpendicular to the lake on the west side of the beach; these samples were identified

as “B” (approximately 50 ft upland) and “C” (approximately 100 ft upland). Based on results from the September sampling event, two additional transects perpendicular to the beach (“Central” and “East”) were added. On October 10, 2018, three samples (A, B, and C) were collected along each transect (West, Central, and East) and at two sites near the lake and land interphase. In 2019, the three transects (East, Central, West) were each sampled again on June 13, July 23, and August 13. Because of public safety and park regulations, piezometers were not installed, and shallow groundwater samples were collected with modifications in accordance with the USGS NFM (USGS, variously dated). A piezometer, an auger, 0.01-in. screened PVC casing, a peristaltic pump, and tubing were used to collect groundwater samples. Equipment was sterilized between sampling locations using 70-percent ethanol and sterile deionized water rinse. Sample depths were measured at each groundwater sample location using a sterilized folding engineer’s ruler. Groundwater used to measure water chemistry properties and obtain samples was collected using a peristaltic pump. Water chemistry properties at each sampling depth were recorded after 2–5 minutes or when properties were stabilized in accordance with modifications to the USGS NFM (USGS, variously dated). Temperature, specific conductance, pH, and dissolved oxygen were measured at each groundwater sampling location using a YSI DSS and (or) ProPlus water quality sonde. Collected groundwater samples were immediately capped and placed on ice for preservation and same-day processing by the MIBaRL.

Solid samples of beach sand, detritus (vegetation, algae, and debris that has accumulated on shore in the swash zone), and lake-bottom material in the recreational swimming area were collected using sterile techniques (tables 3 and 4). In 2018, solid samples were collected on multiple dates across the beach sand area, at the surface (0 ft) 1-, 2-, and 3-foot depths. Lake-bottom samples were also collected offshore in the swimming waters. In 2019, the focus was on the beach sand area. Beach samples were collected at the same locations as the groundwater sampling locations at three discrete sampling depths (surface: 0 ft; mid: 1 ft; and bottom: 2 ft). A 50-mL conical tube was used to collect solid samples. While wearing nitrile gloves, the cap was removed, and care was taken to avoid touching the insides of the cap and the tube. The surface sand (0 ft) and detritus (0 ft) was collected by scraping the tube along the top of the beach sand and in the detritus material until the conical tube was full.

A sterilized auger was used to create a hole for collecting bottom (2-ft) and mid (1-ft) depth beach sand samples. The mid (1-ft) and bottom (2-ft) depths were measured and recorded according to the measured groundwater level and were collected ensuring no groundwater intrusion into the beach sand samples. Sample depths were measured with a folding engineer’s ruler, and beach sand temperatures at each sample depth were collected using a sterilized digital thermometer. The digital thermometer used to collect beach sand temperature was checked with a calibrated National Institute of Standards and Technology digital thermometer. The 50-mL



conical tube was inserted into the wall of the auger hole 1 and 2 ft below the surface. Lake-bottom material was collected using a sterile modified sediment core sampler that collected the top 2 in. of surface lakebed material. Samples were collected in a 2-in. diameter sterilized plastic containers and immediately capped and placed on ice until processing.

Relative directional flow of nearshore surface waters was recorded by attaching flagging tape to the water quality sonde at wadeable surface-water sites and to the extendable sample pole for the nonwadeable surface-water sites. This was compared to NOAA modeled conditions. Photographs were taken, and other weather- and field-related conditions were recorded, including wind direction, barometric pressure, cloud cover, water clarity, and wave height.

Surface-water, groundwater, and standing water samples for MST analysis were collected on July 23, August 7, 13, and 14, 2019, in 500- or 1000-mL sterile polypropylene bottles using previously described sterile sampling techniques. Solid samples for MST were collected on July 2, 23, and August 13, 2019, in 50-mL conical tubes using the same sampling techniques. Solid samples collected on July 23 and August 13 were immediately capped, placed on ice and shipped overnight to the Ohio Water Microbiological Laboratory (Columbus Ohio; OWML) for processing and analysis. Fresh known-source samples from gulls and geese were also collected into 50-mL conical tubes, capped, stored on ice, and shipped overnight to OWML for processing.

## Analytical Methods and Analyses

The EPA recommends measuring enterococci and *E. coli* concentrations as a measure for recreational water quality (U.S. Environmental Protection Agency, 2012). This study followed EPA recommendations for *E. coli* and procedures used by MCHD for beach water quality monitoring (U.S. Environmental Protection Agency, 2012; MCHD, 2019).

### *Escherichia coli* (*E. coli*)

Samples were analyzed for *E. coli* by the MIBaRL using the Colilert-18 Quanti-Tray/2000 method (IDEXX Laboratories, Inc.; Westbrook, Maine). The maximum detection level for this kit is 2419.6 MPN/100 mL. Sample results with no detection are recorded as less than (<) 1 MPN/100 mL. For samples that exceeded this limit, results were reported as greater than (>) 2,400. Solid samples of beach sand, detritus, and lake-bottom samples were processed in accordance with Francy and Darner (1998). Approximately 3 grams of composited sediment were added to 30 mL of deionized water, replacing the standard 1x phosphate buffered saline (often referred to as “PBS”) commonly used. PBS buffering interferes with the enzyme substrate buffer already present in the Colilert-18 reagent. Samples were then diluted to 1:100 and 1:1000 to achieve a representative range of results.

## Microbial Source Tracking (MST)

Water samples were processed immediately after receipt by OWML and solid samples were stored at -20 °C until subsequent analysis within 2 months. Three aliquots of each water sample were filtered through a 0.4-micrometer, 47-millimeter polycarbonate filter (Whatman; Florham Park, N.J.). Filters were then folded aseptically and placed into 2-mL screw cap vials containing 0.3 gram of acid-washed glass beads (Sigma-Aldrich Corp.; St. Louis, Mo.). Negative controls (filter blanks) were filtered each day that samples were processed using sterile buffered water. Filtered samples were then stored at -70 °C until subsequent analysis within a few months.

Solid samples required additional processing prior to filtration and preservation (Francy and Darner, 1998). Solid samples were removed from the -20 °C freezer and allowed to thaw at room temperature. Twenty grams of aseptically mixed solid were placed into a bottle containing 200 mL of sterile phosphate buffer. The solid/buffer mixture was shaken for 45 minutes on a wrist-action shaker, allowed to settle for 30 seconds, and then the liquid phase was poured into another sterile bottle and the remaining solid was discarded. The liquid phase of these samples was then filtered and preserved as described for water samples. Because concentrations of MST markers in solid samples were reported as copies per gram of dry weight (copies/g dw), the percent dry weight and sediment (solid) displacement factor for each sample were established based on methods described in Francy and Darner (1998). Sample DNA was extracted using DNA-EZ extraction kits from GeneRite (North Brunswick, N.J.). The extraction was done according to the manufacturer’s instructions, except that no prefilter was used. Negative extraction controls (extraction blanks), consisting of a 2-mL vial containing only acid-washed glass beads, were processed with each batch of extractions. All DNA extracts were stored at 4 °C until subsequent analysis by quantitative polymerase chain reaction (qPCR) within 5 days of extraction.

Sample extracts were analyzed by qPCR for two MST markers: a human-associated *Bacteroides* marker (HF183; Green and others, 2014) and a waterfowl-associated *Helicobacter* marker (GFD; Green and others, 2012). All qPCR analyses were completed using either an Applied Biosystems StepOne Plus or QuantStudio 3 real-time PCR system (Applied Biosystems; Foster City, Calif.). All samples were analyzed in duplicate. Several no-template controls (qPCR blanks) consisting of molecular-grade sterile water instead of DNA extract were included on each qPCR plate in duplicate. For all samples, matrix inhibition was tested using matrix spikes, and results from diluted samples were used if inhibition was detected (Francy and others, 2017).

Standard curves were generated using plasmids containing the sequences for each of the targeted MST marker genes (Francy and Stelzer, 2012). Each qPCR run included a seven-point standard curve run in duplicate. Standard curve characteristics are listed in table 5. Amplification efficiency is calculated from the slope of the log-linear part of the standard

**Table 5.** Standard curve characteristics and limits of detection and quantification for microbial source tracking markers.

[MST, microbial source tracking; R<sup>2</sup>, coefficient of determination; qPCR, quantitative polymerase chain reaction; HF183, human-associated *Bacteroides* marker; GFD, waterfowl-associated *Helicobacter* marker; LoB, limit of blanks]

MST marker	Number of standard curves run	Mean amplification efficiency (percent)	Mean R <sup>2</sup> value	Limit of detection (copies/qPCR reaction)	Limit of quantification (copies/qPCR reaction)
HF183	7	101	0.998	14 (6 curves) or 17 (LoB used for 1 curve)	51
GFD	7	95	0.999	27	67

curve, specifically, PCR efficiency is equal to 10-1/slope-1 (Bustin and others, 2009). Conversion of qPCR output to MST marker concentrations was done by interpolating from these standard curves.

Limit of blank (LoB), limit of detection (LoD), and limit of quantification (LoQ) were determined for each assay to describe the lowest concentration of each MST marker that can be differentiated from blank sample results, reliably detected, and quantified, respectively (Francy and others, 2017). The LoB is the lowest concentration that can be reported (with 95-percent confidence) to be greater than the concentration of the blanks. The LoB was determined for each qPCR run from results of negative filtration controls, negative extraction controls, and no-template controls. The LoB was not used to report results unless it was greater than the LoD. If LoB was greater than the LoD, the LoB replaced the LoD. The LoD is the lowest concentration of a marker that can be detected, with 95-percent confidence and distinguishable from the blank sample results. The LoD was determined by analyzing at least 10 replicates each of several dilutions of a positive control. The LoQ is the lowest concentration of each MST marker that can be accurately quantified and is calculated from the standard deviation of the LoD replicates. If a sample result was less than the LoQ but greater than the LoD, the result was qualified as an estimate. If the MST marker was not detected in a sample or if the concentration was less than the LoD, then results were reported as less than the sample reporting limit. The sample reporting limit is specific to each sample and is calculated using the LoD, taking into account the dilution analyzed and the initial sample volume filtered. The LoD and LoQ for each MST assay are listed in [table 5](#).

## Quality-Assurance and Quality-Control

From July to October 2018 and from May to August 2019, blank and replicate samples were collected for quality control to determine bias and variability (Myers, 2014). Thirty-eight field blank samples (approximately 3 percent of the total number of samples analyzed) were collected for this study. Ninety-three sequential replicates (7 percent of the total number of samples analyzed) were collected for all

sample types. Of these 93 sequential replicates, 62 were surface water, 8 were groundwater, 1 was lake-bottom material, and 22 were solid samples.

*E. coli* was not detected in any blanks collected from surface water, groundwater, and sand/sediment. Therefore, little to no bias from outside contamination is expected to affect samples results. Replicate results are shown in [figure 3](#). For most replicate pairs, results were typically in the same order of magnitude; however, on occasion, sample replicates varied as much as 2 orders of magnitude. Out of the 93 replicate pairs, 7 pairs had percent difference (the difference between the two values, divide by their average of the two values, multiplied by 100) greater than 100. This potential variability warrants consideration when evaluating individual *E. coli* sample results.

A total of 12 field sequential replicates were collected from several sites and analyzed for MST markers for this study ([table 6](#)). The HF183 (human) MST marker was not detected above the limit of detection (LoD) for 10 of the 12 replicate pairs. For 1 replicate pair, HF183 was not detected above the LoD in the environmental sample, but the replicate sample was detected at a concentration of 2,800 copies/g dw. For another replicate pair, HF183 was detected at a concentration of 1,800 and 2,500copies/100 mL in the environmental and replicate samples, respectively, resulting in an absolute value log difference of 0.04. The GFD (waterfowl) MST marker was not detected above the LoD for 8 of the 12 replicate pairs. For 2 replicate pairs, GFD was not detected above the LoD in 1 of the 2 samples yet was detected at 2,400 copies per 100 mL and 220 copies/g dw for the paired samples. For the remaining 2 replicate pairs, GFD was detected at similar concentrations with absolute value log differences of 0.08 and 0.07.

## Sources and Distribution of *Escherichia coli*

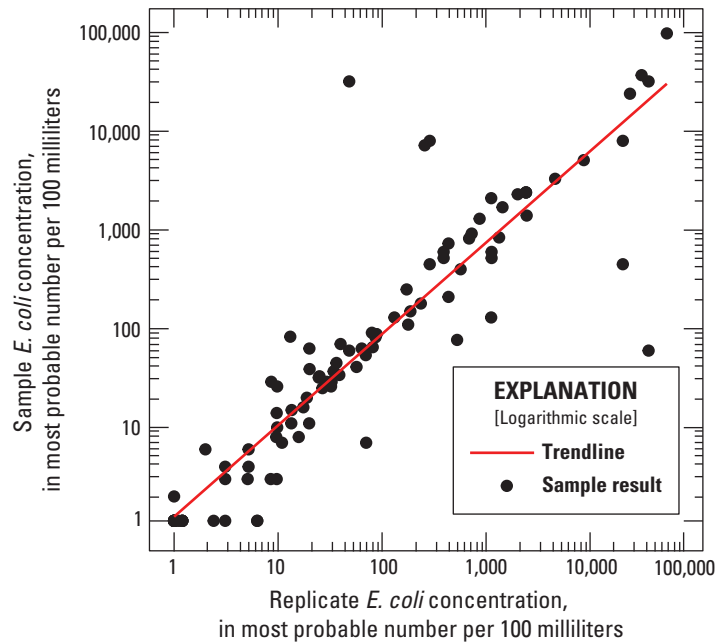
Surface-water samples were collected at locations spanning Lake St. Clair Metropark Park ([fig. 2](#)). The designated swimming area (DSA) includes LSCMB sites 4–6 (shallow and deep swimming waters), with adjacent recreational area near the beach sites (RNB) LSCMB sites 3 and 7 (shallow and deep waters) ([table 1](#)). Samples were also collected around

the PS, LSCMB sites 1–2 and sites 8–12; and BC, LSCMB sites 13–15 (table 1). To understand potential for nearshore sources of *E. coli*, samples were also collected from beach sand, lake bottom, and groundwater. Sampling results are available in the USGS National Water Information System database (USGS, 2020) by using the USGS station numbers in tables 1–4.

### Lake St. Clair Surface Water *E. coli*

*E. coli* concentrations were typically highest in the shallow Lake St. Clair waters in and near the swimming and beach area for the park (table 7; fig. 4). The swimming and recreational deeper water samples were typically lower than their shallow counterparts. Samples collected from Lake St. Clair PS on the east and west ends of the park were generally lower than DSA or RNB, with lowest concentrations in BC samples (table 7; fig. 4).

The State of Michigan Recreational Water-Quality Criterion for total body contact for a single event (sampling date) is 300 CFU/100 mL (or 300 MPN/100 mL), and is based on a geometric mean of three samples (Michigan Department of Environmental Quality, 2006). For this study, only one sample was collected at each location per trip, but 300 MPN/100 mL is used as threshold to evaluate results. Out of 971 surface water samples collected during the study period, nearly 9 percent ( $n=87$ ) of the samples exceeded the water quality criterion (table 8). This threshold was



**Figure 3.** *Escherichia coli* (*E. coli*) concentrations from replicate samples, logarithmic scale.

exceeded most frequently in the shallow samples at the DSA and RNB, followed by the deeper water samples from DSA and RNB, then PS, and the lowest percentage of exceedance was measured at sites along BC.

**Table 6.** Quality-control sequential field replicate data for microbial source tracking markers, Lake St. Clair Metropark Beach, Macomb County, Michigan.

[AVLD is absolute value  $\log_{10}$  difference between replicates A and B; microbial source tracking markers are reported in copies per 100 milliliters for water samples and copies per gram dry weight for solid samples; solid samples are shaded; HF183, human-associated *Bacteroides* marker; GFD, waterfowl-associated *Helicobacter* marker; BDL, result was below the limit of detection; --, no result; dates displayed in m/d/yyyy]

Date	Sample matrix	HF183			GFD		
		A	B	AVLD	A	B	AVLD
7/23/2019	Surface water	BDL	BDL	--	570	960	0.08
7/23/2019	Groundwater	BDL	BDL	--	BDL	BDL	--
8/13/2019	Groundwater	1,800	2,500	0.04	BDL	2,400	--
8/13/2019	Groundwater	BDL	BDL	--	BDL	BDL	--
8/14/2019	Surface water	BDL	BDL	--	BDL	BDL	--
7/2/2019	Beach sand	BDL	BDL	--	BDL	BDL	--
7/2/2019	Beach sand	BDL	BDL	--	380	580	0.07
7/2/2019	Beach sand	BDL	BDL	--	BDL	BDL	--
7/23/2019	Beach sand	BDL	BDL	--	BDL	BDL	--
8/13/2019	Beach sand	BDL	2,800	--	220	BDL	--
8/13/2019	Beach sand	BDL	BDL	--	BDL	BDL	--
8/13/2019	Detritus	BDL	BDL	--	BDL	BDL	--

**Table 7.** Summary statistics of surface-water samples analyzed for *Escherichia coli* concentrations for the Lake St. Clair Metropark Beach study in 2018 and 2019.

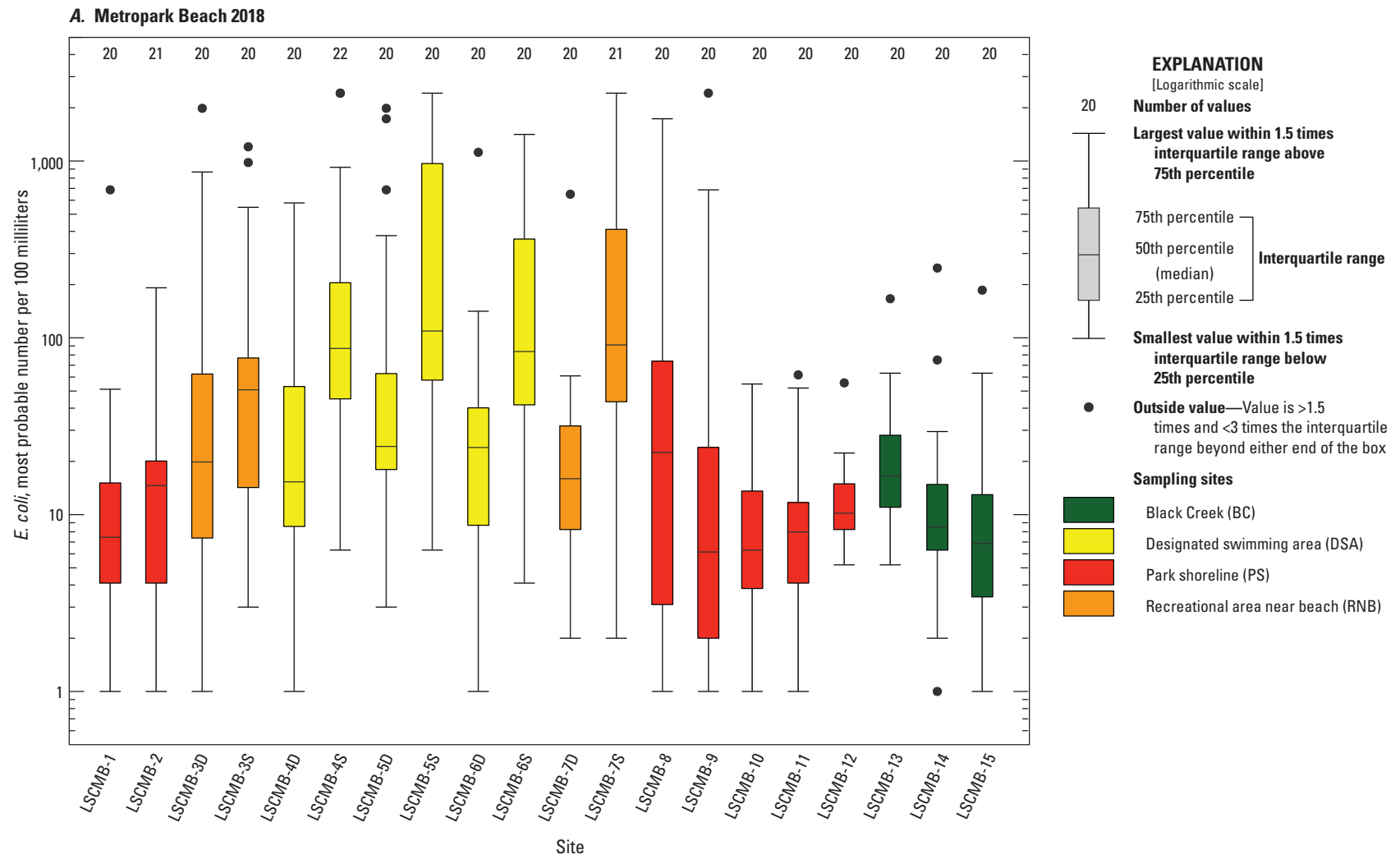
[ID, identification; MPN, most probable number; mL, milliliter; LSCMB, Lake St. Clair Metropark Beach; <, less than; >, greater than]

Sample location	Site ID	Sample time frame	Number of samples	Minimum	Median	Maximum	Number of samples greater than 300 MPN/100 mL
Park shoreline (PS)	LSCMB-1	July–Oct 2018	20	1.0	7.5	580	1
		May–Sep 2019	27	1.0	16	820	3
	LSCMB-2	July–Oct 2018	20	1.0	15	190	0
		May–Sep 2019	27	1.0	9.7	1,400	2
Recreational area near beach (RNB)	LSCMB-3S	July–Oct 2018	20	3.0	51	1,200	3
		May–Sep 2019	30	<1.0	12	>2,400	2
	LSCMB-3D	July–Oct 2018	20	1.0	20	2,000	2
		May–Sep 2019	30	1.0	8.6	>2,400	2
Designated swimming area (DSA)	LSCMB-4S	July–Oct 2018	20	6.3	87	>2,400	4
		May–Sep 2019	30	2.0	40	1,100	2
	LSCMB-4D	July–Oct 2018	20	1.0	15	580	2
		May–Sep 2019	30	1.0	31	980	2
	LSCMB-5S	July–Oct 2018	20	6.3	110	>2,400	7
		May–Sep 2019	28	<1.0	63	820	3
	LSCMB-5D	July–Oct 2018	20	3.0	24	2,000	4
		May–Sep 2019	28	<1.0	24	650	2
	LSCMB-6S	July–Oct 2018	20	4.1	87	1,400	7
		May–Sep 2019	30	2.0	96	>2,400	8
	LSCMB-6D	July–Oct 2018	20	<1.0	24	1,100	1
		May–Sep 2019	30	1.0	39	520	2
Recreational area near beach (RNB)	LSCMB-7S	July–Oct 2018	20	2.0	79	2,400	6
		May–Sep 2019	28	1.0	46	2,000	4
	LSCMB-7D	July–Oct 2018	20	2.0	16	650	1
		May–Sep 2019	28	<1.0	16	1,200	3

**Table 7.** Summary statistics of surface-water samples analyzed for *Escherichia coli* concentrations for the Lake St. Clair Metropark Beach study in 2018 and 2019.—Continued

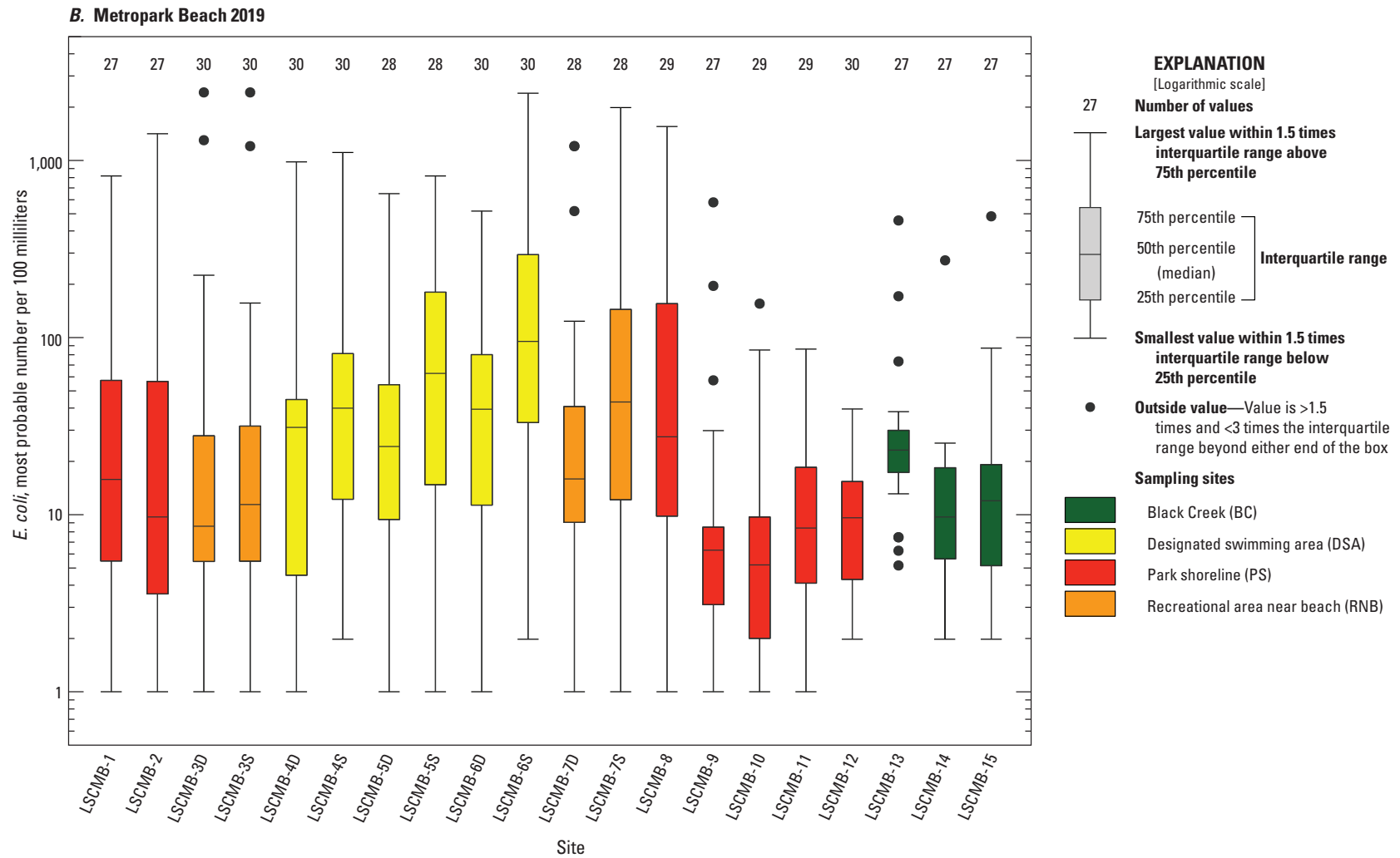
[ID, identification; MPN, most probable number; mL, milliliter; LSCMB, Lake St. Clair Metropark Beach; &lt;, less than; &gt;, greater than]

Sample location	Site ID	Sample time frame	Number of samples	Minimum	Median	Maximum	Number of samples greater than 300 MPN/100 mL
Park shoreline (PS)	LSCMB-8	July–Oct 2018	20	<1.0	22	1,700	3
		May–Sep 2019	29	<1.0	28	1,500	6
	LSCMB-9	July–Oct 2018	20	<1.0	6.2	>2,400	2
		May–Sep 2019	27	1.0	6.3	580	1
	LSCMB-10	July–Oct 2018	20	<1.0	6.3	55	0
		May–Sep 2019	29	1.0	5.2	160	0
	LSCMB-11	July–Oct 2018	20	1.0	8.0	62	0
		May–Sep 2019	29	<1.0	8.4	86	0
	LSCMB-12	July–Oct 2018	20	5.2	10	56	0
		May–Sep 2019	30	2.0	9.7	40	0
Black Creek (BC)	LSCMB-13	July–Oct 2018	20	5.2	17	170	0
		May–Sep 2019	27	5.2	23	460	1
	LSCMB-14	July–Oct 2018	20	1.0	8.5	250	0
		May–Sep 2019	27	2.0	9.8	280	0
	LSCMB-15	July–Oct 2018	20	1.0	6.9	190	0
		May–Sep 2019	27	2.0	12	490	1



**Figure 4.** Boxplots of *Escherichia coli* (*E. coli*) concentrations in log<sub>10</sub> scale in shallow and deep nearshore surface water.





**Table 8.** Summary of exceedances of *Escherichia coli* concentrations compared the State of Michigan Recreational Water-Quality Criterion for total body contact for a single event at Lake St. Clair Metropark Beach based on sampling location, 2018–2019.

[MPN, most probable number; mL, milliliter]

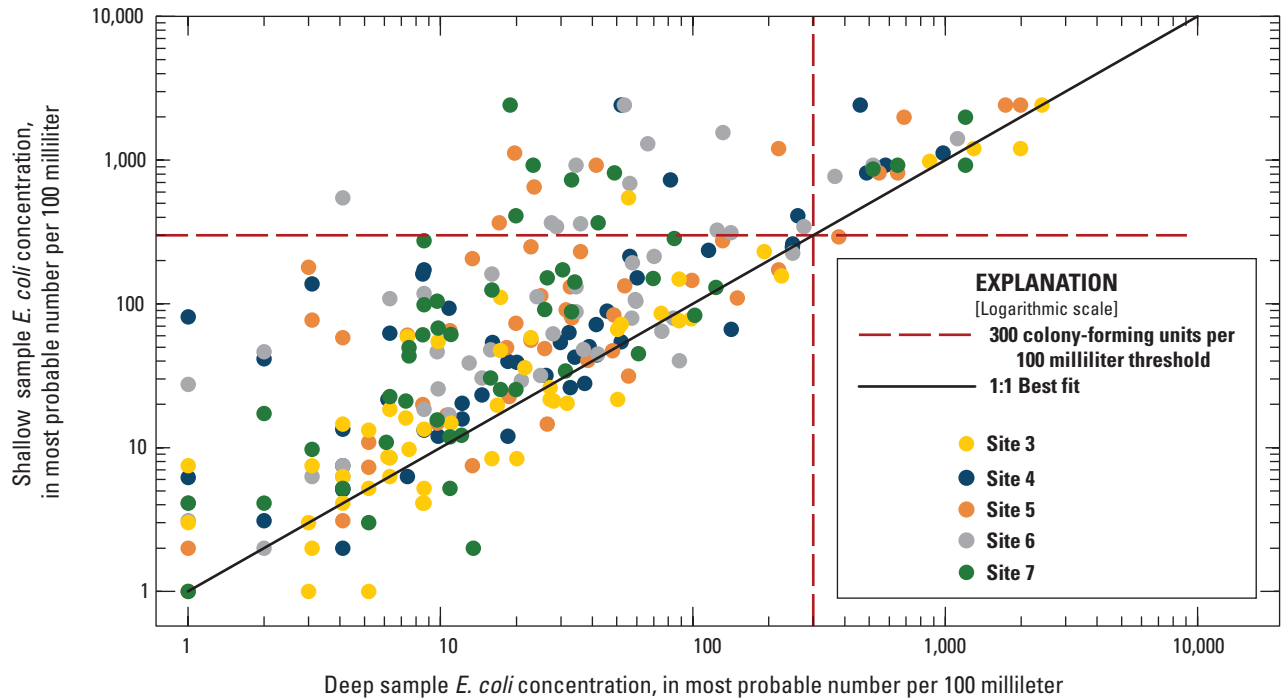
Sample location	Number of samples	Number of samples greater than 300 MPN/100 mL <sup>1</sup>	Percent exceedance
Park shoreline (PS)	338	18	5.3
Recreational area near beach (RNB)-Shallow	98	15	15
Recreational area near beach (RNB)-Deep	98	8	8.2
Designated swimming area (DSA)-Shallow	148	31	21
Designated swimming area (DSA)-Deep	148	13	8.8
Black Creek (BC)	141	2	1.4
<b>Total</b>	<b>971</b>	<b>87</b>	<b>9.0</b>

<sup>1</sup>The State of Michigan Recreational Water-Quality Criterion for total body contact for a single event is 300 colony forming units/100 milliliter (or 300 most probable number/100 milliliter) and is based on a geometric mean of three samples (Michigan Department of Environmental Quality, 2006).

To better understand if water coming in from Lake St. Clair was a source of higher beach *E. coli* concentrations or if high *E. coli* concentrations were a result of sources coming from land or nearshore locations, shallow and deep samples were compared from RNB and DSA sites (fig. 5). For most sample pairs, the shallow water sample had a higher *E. coli* concentration than the corresponding deep water sample, indicating concentrations are likely diluted in offshore Lake St. Clair waters with a source of *E. coli* coming from land or nearshore. There were 42 instances where the shallow concentration exceeded 300 MPN/100 mL and were greater than the deep sample. However, there were instances when deep water concentrations were similar or higher than the shallow water samples (below black line on fig. 5). There were only four instances in which the deep sample was greater than 300 MPN/100 mL and equal to or slightly greater than the shallow sample concentration. Of most significance, were those samples in which one or both samples were at or near the 300 MPN/100 mL threshold.

Evaluating results over time and comparing site locations also indicated the DSA-shallow and RNB-shallow samples were frequently greater than the PS, DSA-deep, RNB-deep, and BC samples (fig. 6) indicating a source from land or near the shoreline rather than offshore waters; however, there were sampling dates in which one or more sites had concentrations greater than or equal to samples from the shallow DSA/RNB sites. In most cases, the source seems to be from land and, in most cases, localized to a specific area. There were a total of five dates when *E. coli* concentrations, other than DSA shallow water samples, were greater than 300 MPN/100 mL from 2018–2019. The dates were as follows:

- On August 8, 22, and 29, 2018, and May 23, June 18, and July 9, 2019, one or two sites exceeded the 300 MPN/100 mL but all other sites had much lower *E. coli* concentrations. Because of the site-specific nature of the high concentrations, the presumed source was likely local to the sampling point and not indicative of a larger source of *E. coli* to the beach or surrounding waters.
- On September 21, 2018, concentrations were high at LSCMB sites 1–9. Shallow samples were greater than deep water samples, with highest concentrations at DSA shallow sites, although LSCMB–9 had equally high concentrations as the shallow sites. The areas received more than 0.5 in. of rain in the preceding 24 hours. The wind was primarily from the south-southwest, southwest, and west-southwest from 14 to 26 miles per hour (mph; NOAA, 2020). Stormwater runoff from the shore and winds keeping water near-shore may be the source of high *E. coli* on this date, given increased relative concentrations in shallower waters (see “Stormwater” section).
- On May 9 and 28, 2019, *E. coli* concentrations exceeded 300 MPN/100 mL at sites LSCMB-1 and LSCMB-2 (east PS). On May 9, all sites from LSCMB 1–9 exceeded 300 MPN/100 mL except the deep samples at LSCMB sites 6 and 7. LSCMB-6D, LSCMB-7D, and LSCMB-9–15 sites were all less than 100 MPN/100 mL. On May 9, no precipitation fell in 24 hours, wind speed was 9–20 mph (from 8 a.m.–2 p.m.) from the southeast, south-southeast,



**Figure 5.** *Escherichia coli* (*E. coli*) concentrations in shallow and deep samples for the recreational area near beach and designated swimming area sampling sites at Lake St. Clair Metropark Beach in 2018–2019, logarithmic scale.

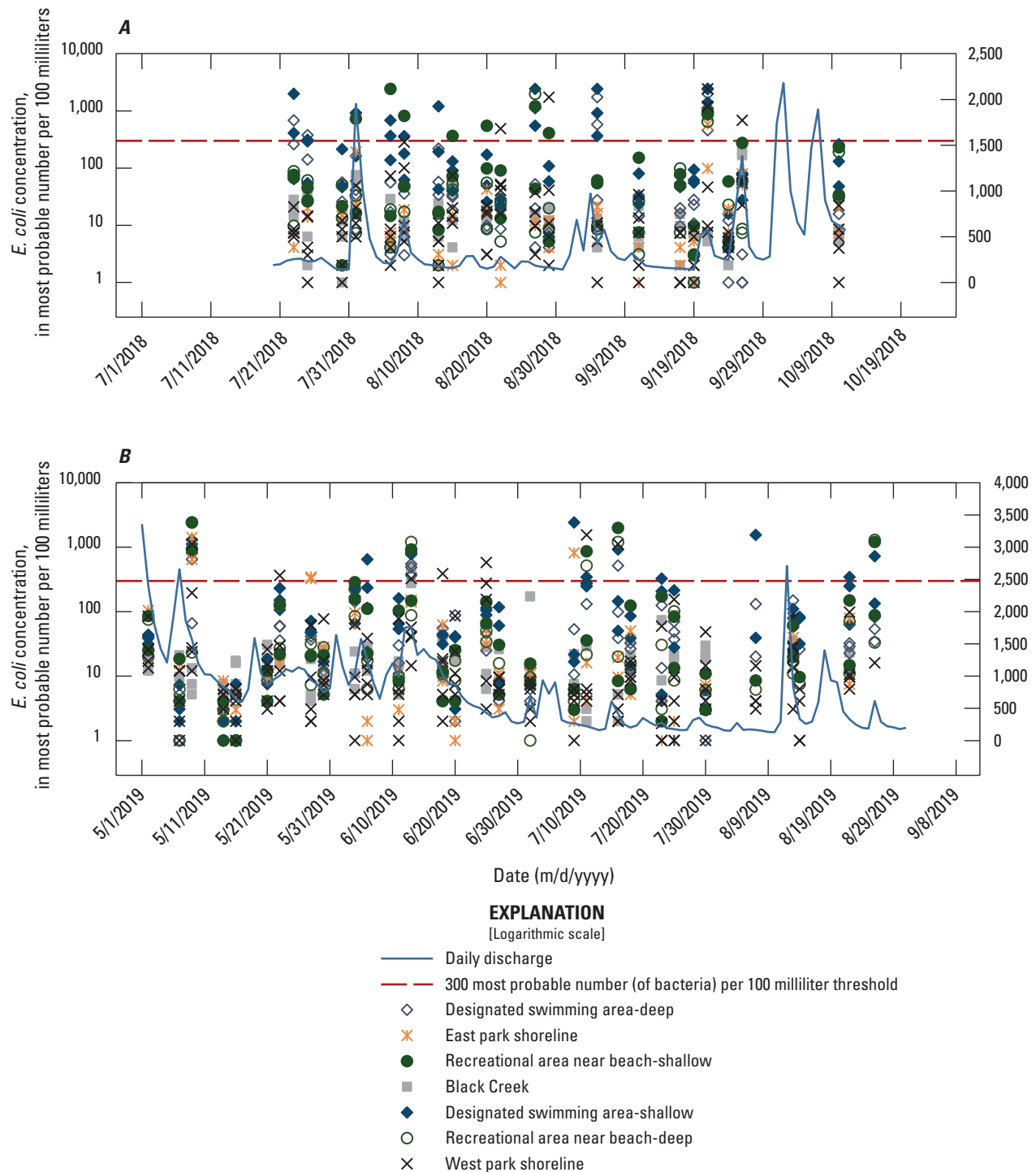
and south (NOAA, 2020). On May 28, only LSCMB-1 and LSCMB-2 sites exceeded the 300 MPN/100 mL *E. coli* threshold. On May 28, precipitation of 0.16 in. in a 24-hour period was recorded with wind speed of 6–16 mph from the southwest, west-southwest, and west (NOAA, 2020). Because the wind was from the south on these dates, it is possible that a source near the east end of the park was contributing to high *E. coli*.

- On June 13, 2019, concentrations at the DSA and BC exceeded 300 MPN/100 mL. Shallow samples were greater than deep samples for LSCMB sites 4–6 but the deep sample was greater than the shallow at LSCMB-7. On this date, BC samples also were greater than 300 MPN/100 mL, but all other offshore samples were less than 300 MPN/100 mL. The area received about 0.8 in. of rain within 24 hours preceding sample collection (NOAA, 2020). There are several storm drains along BC. Stormwater from the park vicinity is a potential source of *E. coli* on this date (see “Stormwater” section).

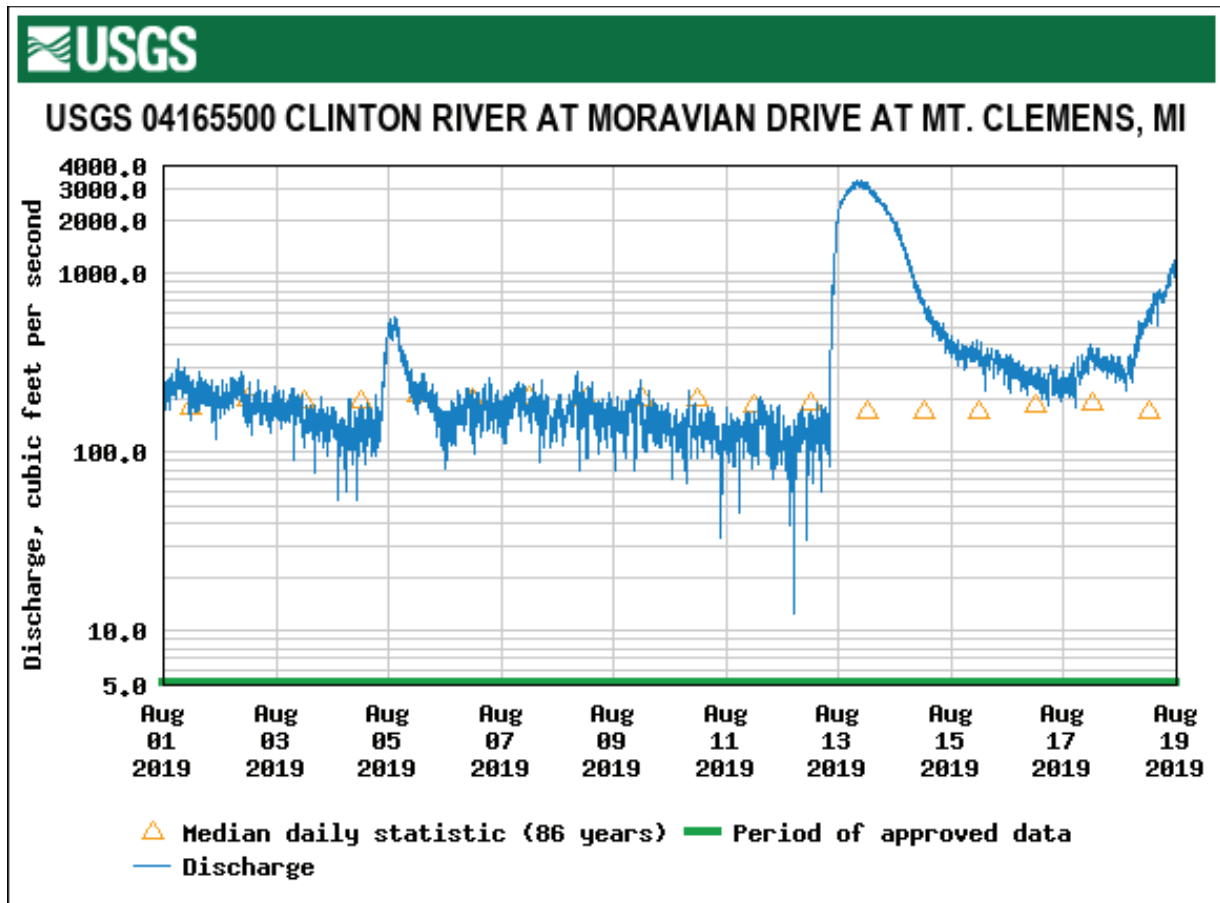
- On July 11, 2019, and July 16, 2019, concentrations were greater than 300 MPN/100 mL at sites LSCMB 6–8. *E. coli* in shallow samples was greater than in deeper samples, and all other PS samples were <100 MPN/100 mL. Similar to other results, this indicates sources closer to land.

## Offshore Surface Water

Samples were collected on August 7, and 14, 2019, about 3 ft below the surface, along a transect north to the Clinton River to more thoroughly investigate Lake St. Clair offshore waters as a source of *E. coli*. The Clinton River was at base-flow condition on August 7, and the daily mean discharge at the USGS streamgage at Moravian Drive at Mt. Clemens, Mich. (USGS streamgage 04165500) on that date was 176 ft<sup>3</sup>/s (fig. 7; U.S. Geological Survey 2020). On August 13, 2019, a rain event in the area produced 1.8 in. of rain (NOAA, 2020). During this rain event, the Clinton River flow peaked on August 13 and was starting to recede on August 14. The daily mean discharge at USGS 04165500 on August 14 was 838 ft<sup>3</sup>/s. Samples were collected on August 14



**Figure 6.** *Escherichia coli* (*E. coli*) concentrations and daily discharge at USGS station 04165500 (U.S. Geological Survey, 2020) by date in, *A*, 2018 and, *B*, 2019 for the Lake St. Clair Metropark study, for sampling sites at Black Creek, east and west park shorelines, and shallow and deep samples for the recreational area near beach and the designated swimming area, logarithmic scale.



**Figure 7.** Daily mean discharge graph at the USGS streamgage 04165500 on the Clinton River at Moravian Drive at Mount Clemens, Michigan, August 1–19, 2019 (U.S. Geological Survey, 2020).

to capture stormwater contributions from the Clinton River to Lake St. Clair. Offshore *E. coli* concentrations ranged from <1 MPN/100 mL to 11 MPN/100 mL. MCHD measured *E. coli* concentrations in the Clinton River drainage basin on August 13 with results as high as >24,000 MPN/100 mL (MCHD, 2020b). At the downstream-most site, the reported concentration was 41 MPN/100 mL at the mouth of the Clinton River to Lake St. Clair (MCHD site 41). At the next Clinton River site upstream (MCHD site 83), *E. coli* concentrations were orders of magnitude higher: 9,800 MPN/100 mL (MCHD, 2020b), coinciding with peak flow of the Clinton River (fig. 7). Once the Clinton River discharges into Lake St. Clair, *E. coli* are diluted and does not affect LSCMB. These data also support the hypothesis of a localized source of *E. coli* near the beach rather than the Clinton River. Given the high concentrations observed in the Clinton River drainage basin after rain, overland flow may be a source of *E. coli* in this landscape.

## Stormwater

To determine the effect stormwater might have on beach concentrations of *E. coli*, samples were collected from several sites: BC storm drain outlets, standing water on the beach, and standing water on grass near the beach area. It was observed in the field that during heavy rain events, the pooling water washed out beach sand into the shallow water (figs. 8 and 9). Water samples were collected from directly in front of these washouts and from standing water on the beach or grass to represent what effect runoff could have on the DSA. Twenty samples (LSCMB-D1, D2, D3) were collected at storm drain outlets along BC (fig. 2). Storm drain outlets were 3–7 feet below the water surface in BC. Concentrations measured at storm drain outlets were generally less than 300 MPN/100 mL (table 9). The 2 samples that exceeded 300 MPN/100 mL were collected on June 13, 2019. Because the storm drain outlet is under water along the shoreline of BC, it is difficult to



determine the actual concentration of *E. coli* from the storm-water versus BC. Similarly, high concentrations were also seen in the BC samples (fig.6), and were also in exceedance of 300 MPN/100 mL. More notable are the *E. coli* concentrations detected in standing water at the beach or on the grass areas near the beach (table 10). In most cases, the concentrations exceeded the maximum quantification concentration of 2,419 MPN/100 mL.

## Sediment, Sand, Detritus

Accumulation of detritus was frequently observed along the shore. Eleven detritus samples were collected over three sampling dates (table 4). Out of the 11 samples, 10 had *E. coli* concentrations greater than 300 MPN/g dw. The median concentration observed was 6,300 MPN/g dw with a maximum concentration of greater than 42,000 MPN/g dw (table 11). To compare sediment across sampling years, a reporting level of 14 MPN/g dw was used for all samples. If *E. coli* was not detected or if concentration were detected below 14 MPN/g dw, values were reported as below reporting level (BRL).

In 2018, beach sand and lake-bottom sediment samples were collected to assess *E. coli* concentration on sediments at LSCMB. A total of 26 lake-bottom sediment samples were collected offshore in DSA and RNB areas (table 3 and 11), 13 samples were BRL (table 11). The median *E. coli* concentration for lake-bottom *E. coli* was 17 MPN/g dw with a maximum of 910 MPN/g dw. Two out of the 26 samples (8 percent) were great than 300 MPN/g dw and were collected nearshore in shallow water less than 3-ft deep in the DSA (USGS sites 423414082474204 and 423415082474604). Higher concentrations were detected in the surface beach sand associated with DSA (table 11). Although the median

concentration for all 2018 beach sand samples was BRL, the percentage of samples greater than 300 MPN/g dw was 12 percent, with 11,000 MPN/g dw the highest concentration observed. Separating the samples by depth, *E. coli* was greater than 300 MPN/g dw in 34 percent of the 29 surface samples, and 0 percent of the 53 samples collected at 1–3-ft depths (table 11).

In 2019, a total of 88 beach sand samples were collected on the beach in the DSA along transects from the lake and upland on the beach. Concentrations greater than 29,000 MPN/g dw were detected and 22 percent (n=19) exceeded 300 MPN/g dw (table 11). Concentrations were highest in the surface sand and decreased with depth (table 11). Samples were also highest (>42,000) in samples collected near the lake interface and decrease upland (table 12). Field observations note that despite best efforts to only collect beach sand, samples on some occasion may contain some detritus as well as the detritus tend to build up in the areas where water washes to the shore.

To determine if precipitation events increased *E. coli* concentrations at the beach, samples were collected during dry periods and after rain. For the purpose of this report in comparing “dry” and “wet” conditions, we used the rainfall variables determined in a previous study (Francy and others, 2006). In the paper, “dry” conditions are when rainfall equals 0 in. and “wet” conditions are when rainfall is greater than 0.10 in. within the 24-hour period preceding the day of sampling (9 a.m. to 9 a.m.). In 2018 all samples were collected under dry conditions. In 2019, beach sand was collected four times: June 13, 2019, and August 13, 2019, under wet conditions, and July 23, 2019, and August 26, 2019, under dry conditions. Results are reported in table 13. *E. coli* concentrations were similar and varied by date more so than wet or dry.



**Figure 8.** Photograph of Lake St. Clair Metropolitan Beach from offshore showing standing water on beach draining into Lake St. Clair after a storm event on May 9, 2019. Photograph by Jessica Maurer, U.S. Geological Survey.



**Figure 9.** Photograph of Lake St. Clair Metropolitan Beach from onshore showing standing water on beach draining into Lake St. Clair after a storm event on August 1, 2018. Photograph by Jessica Maurer, U.S. Geological Survey.

**Table 9.** Descriptions of storm drain outlet samples collected along Black Creek and *Escherichia coli* concentrations for the Lake St. Clair Metropolitan Beach study in 2018 and 2019.

[ID, identification; USGS, U.S. Geological Survey; MPN, most probable number; mL, milliliter; LSCMB, Lake St. Clair Metropark Beach; N/A, not available]

Site ID	USGS station ID	Sample time frame	Number of samples	Minimum MPN/100 mL	Median MPN/100 mL	Maximum MPN/100 mL	Number of samples greater than 300 MPN/100 mL
LSCMB-D1	423412082471603	July-Oct 2018	N/A	N/A	N/A	N/A	N/A
		May-Sep 2019	2	12	14	16	0
LSCMB-D2	423415082471903	July-Oct 2018	6	4.0	12	88	0
		May-Sep 2019	4	6.0	22	370	1
LSCMB-D3	423425082473203	July-Oct 2018	4	9.0	17	160	0
		May-Sep 2019	4	10	16	330	1

**Table 10.** Descriptions of standing water samples collected and *Escherichia coli* concentrations for the Lake St. Clair Metropolitan Beach Study in 2018 and 2019.

[USGS, U.S. Geological Survey; ID, identification; MPN, most probable number; mL, milliliter; >, greater than]

Storm sample type	USGS station ID	Number of samples	Minimum MPN/100 mL	Median MPN/100 mL	Maximum MPN/100 mL	Number of samples greater than 300 MPN/100 mL
Standing water on grass	423418082474101	4	440	>2,400	>2,400	4
	423418082474202	3	260	>2,400	>2,400	2
	423415082473601	1	200	200	200	0
	423415082473802	1	>2,400	>2,400	>2,400	1
	<b>Total of all samples</b>	<b>9</b>	<b>204</b>	<b>&gt;2,400</b>	<b>&gt;2,400</b>	<b>7</b>
Standing water on beach	423417082475003	5	>2,400	>2,400	>2,400	5
	423416082474301	3	>2,400	>2,400	>2,400	3
	423416082474201	8	>2,400	>2,400	>2,400	8
	423416082474201	1	>2,400	>2,400	>2,400	1
	<b>Total of all samples</b>	<b>17</b>	<b>&gt;2,400</b>	<b>&gt;2,400</b>	<b>&gt;2,400</b>	<b>17</b>

Early and late in the season, there were lower *E. coli* concentrations, and during mid-summer, there were higher *E. coli* concentrations. This is consistent with other beach studies (Whitman and Nevers, 2008; Chen and Chang, 2014; Ishii and others, 2007). It is difficult to compare between the wet and dry samplings or between sampling years—the first year of the study started later in the recreational season, so the number of sampling trips was limited by sparse rain events, field personnel availability, and cost of analysis.

## Groundwater

Surface-water monitoring indicated the source of high *E. coli* concentrations at LSCMB was most likely coming from land or near the shore rather than from the offshore

waters of Lake St. Clair. To help beach managers identify possible localized sources, further investigations were done onshore. Water samples were collected from the shallow groundwater at the swimming beach area (fig. 10) on two occasions in 2018 and three in 2019 (table 2). Shallow groundwater was less than 1-ft deep at the land-water interphase and 2- to 3-ft deep upland. On most dates, samples were collected along two to three transects along the beach (east, central, west). Samples were collected from water's edge (A) and upland B and C (fig. 10). In 2018, groundwater samples were not diluted and most exceeded the Colilert-18 detection limits of 2,419 MPN/100 mL for undiluted samples. In 2019, samples were diluted for quantification. Out of 44 groundwater samples analyzed, 34 had *E. coli* concentrations greater than 300 MPN/100 mL (table 14). In general, samples collected from groundwater near the lake had the highest *E. coli*

## 24 Understanding Sources and Distribution of *Escherichia coli* at Lake St. Clair Metropark Beach

**Table 11.** Summary statistics of *Escherichia coli* concentrations in detritus and beach sand samples collected at the surface and at depth for the Lake St. Clair Metropolitan Beach study in 2018 and 2019.

[MPN, most probable number; g dw, grams dry weight; BRL, below reporting level of 14 MPN/g dw; >, greater than; ft, foot]

Depth	Number of samples	Minimum MPN/g dw	Median MPN/g dw	Maximum MPN/g dw	Number of samples greater than 300 MPN/g dw	Percent exceeding 300 MPN/g dw
<b>Detritus</b>	11	72	6300	>42,000	10	91
<b>Lake-bottom sediment</b>	26	BRL	17	910	2	8
<b>2018 beach sand</b>						
Surface (0 ft depth)	29	BRL	76	11,000	10	34
Mid (1 ft depth)	24	BRL	BRL	36	0	0.0
Bottom (2–3 ft depth)	29	BRL	BRL	BRL	0	0.0
<b>2018 Total</b>	<b>82</b>	<b>BRL</b>	<b>BRL</b>	<b>11,000</b>	<b>10</b>	<b>12</b>
<b>2019 beach sand</b>						
Surface (0 ft depth)	33	BRL	450	>29,000	18	55
Mid (1–1.5 ft depth)	33	BRL	BRL	691	1	3
Bottom (2–3 ft depth)	22	BRL	BRL	28	0	0
<b>2019 Total</b>	<b>88</b>	<b>BRL</b>	<b>17</b>	<b>&gt;29,000</b>	<b>19</b>	<b>22</b>

**Table 12.** Summary statistics of *Escherichia coli* concentrations in beach sand samples collected along transects at the beach for Lake St. Clair Metropolitan Beach study in 2018 and 2019.

[MPN, most probable number; g dw, grams dry weight; BRL, below reporting level of 14 MPN/g dw; >, greater than]

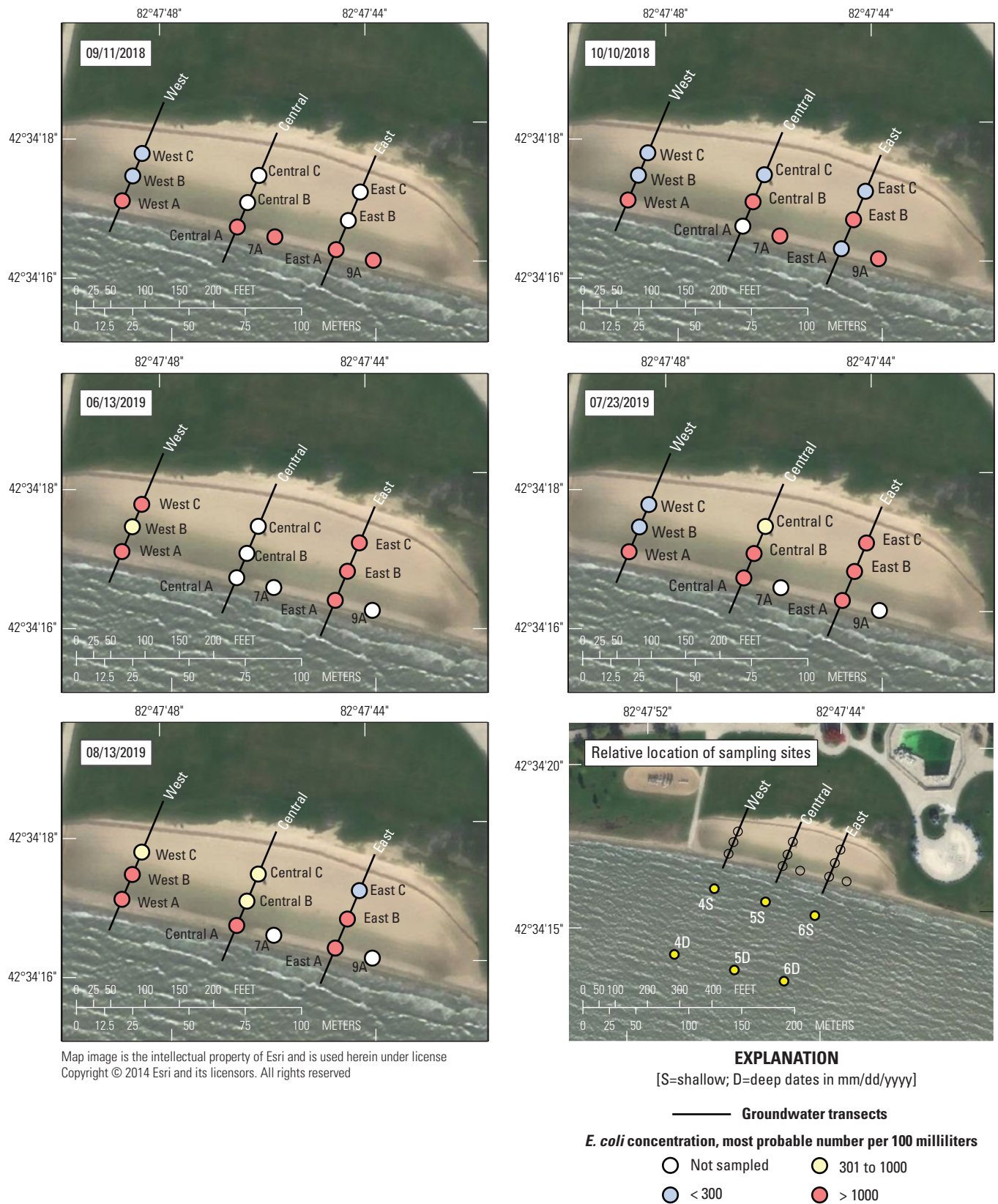
Sample by location from shore	Number of samples	Minimum MPN/g dw	Median MPN/g dw	Maximum MPN/g dw	Number of samples greater than 300 MPN/g dw	Percent exceeding 300 MPN/g dw
“A” samples nearest lake	33	BRL	560	>42,000	15	45
“B” samples midway up beach	33	BRL	BRL	>29,000	8	24
“C” samples farthest upland on beach	33	BRL	BRL	3,500	5	15

**Table 13.** Summary statistics of *Escherichia coli* concentrations in beach sand samples collected during wet and dry conditions for Lake St. Clair Metropolitan Beach study in 2018 and 2019.

[MPN, most probable number; g dw, grams dry weight; BRL, below reporting level of 14 MPN/g dw; >, greater than]

Sampling date	Number of samples	Minimum MPN/g dw	Median MPN/g dw	Maximum MPN/g dw	Number of samples greater than 300 MPN/g dw	Percent exceeding 300 MPN/g dw
All 2018 (dry)	82	BRL	BRL	11,000	10	12
6/13/2019 (wet)	16	BRL	18	298	0	0.0
7/23/2019 (dry)	24	BRL	19	8,500	8	33
8/13/2019 (wet)	24	BRL	22	>29,000	6	25
8/26/2019 (dry)	24	BRL	BRL	5,000	5	21





**Figure 10.** Lake St. Clair Metropark Beach showing groundwater sampling sites and *Escherichia coli* (*E. coli*) concentrations on different dates in 2018–2019.

**Table 14.** Summary of *Escherichia coli* concentrations in groundwater samples for each sample collection date for the Lake St. Clair Metropolitan Beach Study in 2018 and 2019.

[MPN, most probable number; mL, milliliter; dates displayed in m/d/yyyy]

Condition	Date	Number of samples	Minimum MPN/100 mL	Median MPN/100 mL	Maximum MPN/100 mL	Number of samples greater than 300 MPN/100 mL	Percent exceedance
Dry	10/10/2018	11	52	8200	>2,400	6	63
Dry	7/23/2019	9	98	4,600	16,000	7	78
Wet	9/11/2018	9	150	>2,400	>2,400	7	78
Wet	6/13/2019	6	400	19,000	24,000	6	100
Wet	8/13/2019	9	63	3,300	98,000	8	89

concentrations detected in this study; (fig. 10). Concentrations often decreased as sampling points moved upland but, in most cases, remained higher than 300 MPN/100 mL (fig. 10). The more upland the sample, the deeper the groundwater table. The decrease may be a result of increased sand barrier between the surface and groundwater. Alternatively, the groundwater sample locations closer to the lake may also be affected by lake water.

To determine if rain contributed to groundwater *E. coli* samples, results were grouped into “wet” and “dry” conditions based on rainfall similar to sediment samples. “Wet” conditions, determined by receiving rain in the preceding 24 hours, were sampled on September 11, 2018, June 13, 2019, and August 13, 2019. “Dry” conditions, determined by receiving no rain in the preceding 24 hours, were sampled on October 10, 2018, and July 23, 2019. *E. coli* in groundwater results varied on the different sampling dates with 33–100 percent exceedance of 300 MPN/100 mL overall. The two “dry” events had the lowest percent exceedance: 63 percent on October 10, 2018, and 78 percent on July 23, 2019 (table 14). But with only a few sample collection dates, it is difficult to determine the factors responsible for the difference in concentrations observed. Regardless, given the high concentrations detected in the groundwater, this could be a source of *E. coli* in swimming waters under specific conditions but was not assessed in this study.

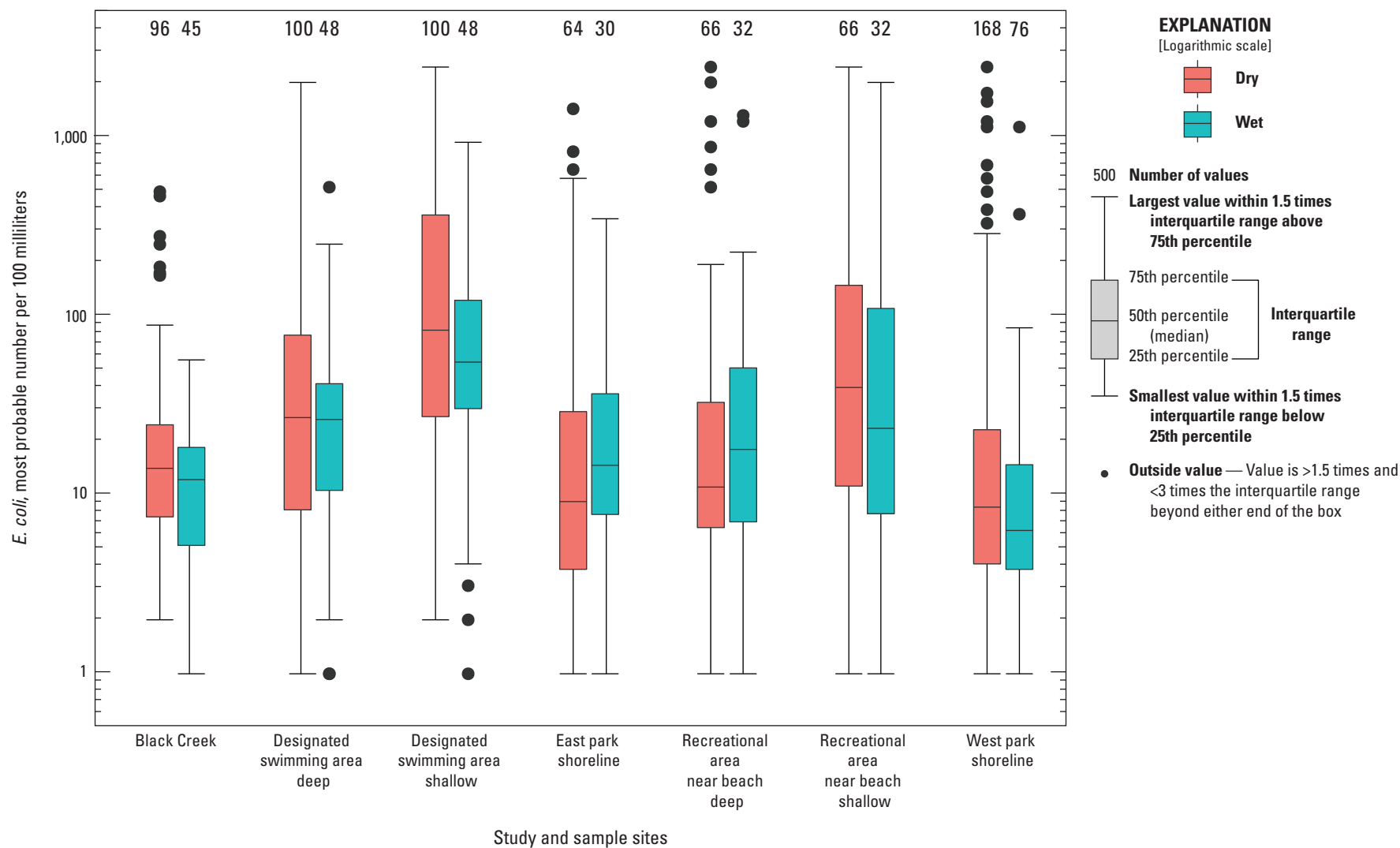
## Environmental Factors

The Pearson correlation coefficient was computed between many environmental variables and *E. coli* concentrations measured at LSCMB (table 15) to explore their potential relations. The coefficient produced from the Pearson analysis provides a measure of how closely related two variables are with positive one being a perfect and direct correlation and a negative one being a perfect and inverse correlation. Correlations close to zero are considered weak or not correlated. In this study, *E. coli* concentrations were not statistically correlated (values less than 0.35) with common environmental

variables such as wind, precipitation, or waves. While standing water after a rain event contained high concentrations of *E. coli*, there was not a correlation between rainfall (wet/dry) conditions and *E. coli* concentration in the surface water or groundwater (fig. 11) nor for precipitation (table 15).

**Table 15.** Correlation coefficients for *Escherichia coli* concentrations in relation to selected environmental variables for Lake St. Clair Metropark Beach in 2018–2019.

Environmental variable	Correlation coefficient
Water temperature	0.3555
Clinton River temperature	0.2944
5-day cumulative precipitation	0.2856
Wave direction	0.2418
4-day cumulative precipitation	0.2341
3-day cumulative precipitation	0.1935
Clinton River turbidity	0.1796
Clinton River discharge	0.1450
pH	0.1369
Wave height	0.1311
Air temperature	0.1267
Clinton River velocity	0.1093
Wave periods	0.1007
Eastward air velocity	0.1005
2-day cumulative precipitation	0.0797
Lake St. Clair specific conductance	0.0327
Dewpoint	-0.0845
Clinton River specific conductance	-0.1542
Cloud cover	-0.1580
Northward air velocity	-0.1799
Clinton River dissolved oxygen	-0.2794



**Figure 11.** *Escherichia coli* (*E. coli*) concentrations for samples collected during wet and dry conditions at Lake St. Clair Metropark in 2018–2019.

Microbial Source Tracking

For the first year of the study, results indicated the source of *E. coli* was probably not coming from offshore Lake St. Clair waters but rather from localized sources at or near the beach. Waterfowl (in particular gulls) were suspected as a potential source of *E. coli*. Because of the number of beach visitors, a marker for human fecal contamination was also evaluated and might come from leaking wastewater or storm systems. A total of 146 samples were analyzed for human (HF183) markers and waterfowl (GFD) markers; 11 (8 percent) had a human marker detection and 22 (15 percent) had a waterfowl marker detection (table 16). The GFD marker was not detected in offshore surface-water samples nor BC water samples. A greater percentage of DSA and RNB shallow samples had detection of GFD (40 percent) than DSA and RNB deep samples (10 percent). On shore, GFD was detected in detritus and surface beach sand 50 percent and 19 percent of samples, respectively. GFD was detected in a lower percentage (7 percent) of beach sand at 1-ft depth and not detected in beach sand at 2-ft depth. Additionally, GFD was detected in 22 percent of the groundwater samples. Only one standing water sample was analyzed for MST markers which was positive for GFD. HF183 was not detected in surface water offshore, BC, PS, or shallow DSA or shallow RNB samples. It was not detected in the single standing water sample. HF183 was detected in 7–13 percent of groundwater and solid samples.

Despite a small percentage of detections, there was a relation between detection of the GFD marker and *E. coli* concentrations (fig. 12) in surface and groundwater. A Wilcoxon rank sum exact test was run to determine if there was a significant difference in *E. coli* concentrations when

MST markers were detected or not detected. At a 95-percent confidence (p-values less than 0.05) there was significant difference in *E. coli* concentrations for samples positive for GFD for surface-water and groundwater samples. There were only three HF183 detections, so no statistical analysis was done. Similarly, both MST markers were detected in low percentage in sand and detritus samples, and there was no statistically significant difference in *E. coli* concentrations in samples with detection compared to those without detections.

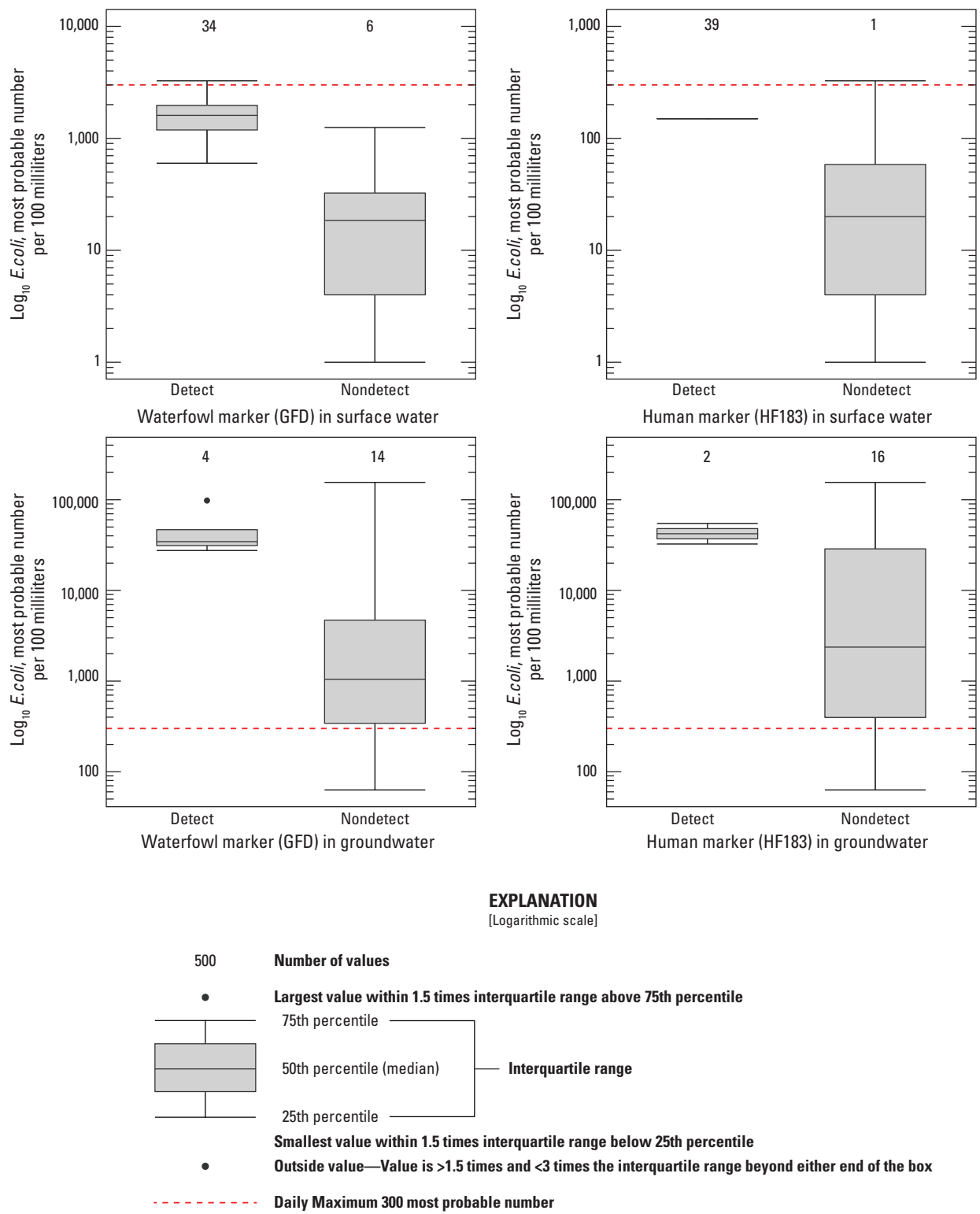
Synopsis of Escherichia coli Results

Continued progress is being made in reducing sources of fecal pollution in the Clinton River AOC, yet beach closures at LSCMB remain a concern. Monitoring by MCHD has determined high concentrations of *E. coli* in the Clinton River and contributing drainage basin. Discharging to the north of the LSCMB, the Clinton River has been identified as a possible source of contamination to the beach. Other environmental variables (such as wind speed and direction, precipitation, and water levels) have also been noted as environmental factors that correlate to high *E. coli* concentrations at the beach, and this indicates *E. coli* may come from offshore (Holtschlag and others, 2008); however, nearshore sources such as stormwater, waterfowl, and park visitors may also contribute to the *E. coli* concentrations. This study evaluated the *E. coli* concentrations nearshore and offshore of LSCMB to determine likely sources of *E. coli* in swimming waters that result in beach closures. Throughout the study, quality control samples were collected to determine the level of bias and variability. All field blanks were negative providing confidence that there was not a systemic contamination affecting sample results. Variability in

Table 16. Description of microbial source tracking results for human (HF183) and waterfowl (GFD) markers and Escherichia coli concentrations.

[BC, Black Creek; PS, park shoreline; DSA, designated swimming area; RNB, recreational area near beach; ft, feet]

Sample type	Total number of samples analyzed	Percent HF183 detections (number)	Percent GFD detections (number)
Offshore	7	0 (0)	0 (0)
BC surface water	6	0 (0)	0 (0)
PS surface water	14	0 (0)	7 (1)
DSA and RNB deep surface water	10	10 (1)	10 (1)
DSA and RNB shallow surface water	10	0 (0)	40 (4)
Standing water on beach	1	0 (0)	100 (1)
Groundwater	18	11 (2)	22 (4)
Detritus	8	13 (1)	50 (4)
Beach sand surface	27	7 (2)	19 (5)
Beach sand 1-ft depth	27	11 (3)	7 (2)
Beach sand 2-ft depth	18	11 (2)	0 (0)
Total	146	8 (11)	15 (22)



**Figure 12.** *Escherichia coli* (*E. coli*) concentrations of samples with detection and nondetection of waterfowl marker (GFD) in surface water and groundwater samples and human marker (HF183) in groundwater, logarithmic scale.



the replicate samples warrant consideration when evaluating individual *E. coli* sample results. Conclusions drawn from this study are based on multiple lines of evidence and evaluation of results in comparable groups to reduce the inherent variability in sample collection and analysis techniques.

During the study period (2018–2019), results do not indicate that the Clinton River or other offshore areas are sources of *E. coli* to LSCMB. This assessment is supported by low to nondetectable concentrations of *E. coli* offshore and along a transect from the beach to the Clinton River. In addition, lake-bottom sediments also had low concentrations of *E. coli* and thus are an unlikely source. Results indicated it is more likely *E. coli* is coming from onshore near the swimming beach rather than from Lake St. Clair waters coming to shore. Highest *E. coli* concentrations were recorded in shallower swimming waters at the beach, shallow groundwater, and detritus sand at the beach.

Sediment and beach sand may serve as a reservoir for *E. coli* strains that can establish populations and intensify in quantity during peak recreation times in the summer months. *E. coli* concentrations exceeded 300 MPN/100 mL in 91 percent of the detritus and 45 percent of the surface beach sand samples. A study by Francy and Darner (1998) determined that bacteria survive longer in sediment and beach sand than water. This may be a result of available organic matter required for growth or particulates that protected from ultraviolet radiation.

Decades of beach studies have indicated that *E. coli* from multiple sources can survive and promulgate in sand then be washed into the recreational waters, elevating fecal-indicator bacteria counts (Whitman and Nevers, 2003; Byappanahalli and others, 2003; Alm and others, 2006; Ishii and others, 2007; Vogel and others, 2016; Palmer and others, 2020). The groundwater at the beach is about 2–3 ft below land surface. *E. coli* may transport from the surface to groundwater during recharge after rain event or during beach grooming when surface sand is raked. *E. coli* could be release to nearshore surface waters by physical and hydrological processes (Francy and others, 2006; Ishii and others, 2007; Vogel and others, 2016).

This nearshore land-to-groundwater-to-lake connection can be dynamic, and it is possible there may be continuous movement of *E. coli* population from land to water. Ishii and others (2007) determined that waves can be important in the early colonization and distribution of *E. coli* in sediment and beach sand and in the release from sediment and beach sand to lake water. Their study indicated that sediment and sand were acting as sources and sinks of *E. coli* and contributing to beach closures. It is likely that there is water movement back and forth in this interphase, but the current study was not designed to address groundwater flow or lake interaction.

*E. coli* concentrations in the groundwater samples in this study were orders of magnitude higher than the lake water. Concentrations were highest near the lake/land interphase, which indicates groundwater could be a source of *E. coli* to the lake; however, groundwater also might be a sink for *E. coli* from the lake and stored in the shallow groundwater. As lake water moves inland, *E. coli* in the lake may accumulate on or in between sand particles. However, it is important to note that while concentrations were often lower upland, concentrations in the farthest upland area (farther from lake) were still commonly orders of magnitude higher than the lake water. Byappanahalli and others (2006) determined similar *E. coli* concentrations can persist for extended periods in backshore sand and groundwater. Interestingly, sand samples collected near the groundwater table contained very low *E. coli* concentrations compared to the surface and groundwater. It is possible that during rain events, *E. coli* is quickly transported through the shallow sediment into the groundwater where it can remain or be stored in sediment at the water table and released by wave actions, foreshore sand erosion, and precipitation (Beversdorf and others, 2006; Ishii and others, 2007; Malott and others, 2016; Vogel and others, 2016).

Waterfowl (in particular gulls) congregate at or near the beach and may be an originating source of *E. coli* at LSCMB. Fecal material from waterfowl may contribute to *E. coli* on the beach sand, which can then be transported into the nearshore water through wave action, runoff after rain events, wind movement, or human transfer. Fecal matter may also be transported through the sand to the shallow groundwater. However, it is still uncertain how and if this contributes to the periodic beach closures and risk to public health. The waterfowl MST marker (GFD) was detected in 15 percent of the samples at low concentrations (table 16). Most of those detections were on the beach sand, groundwater, and shallow swimming waters. There were indications that the presence of the GFD marker was related to higher *E. coli* concentrations, but the sample size was small. It is also important to note that the human (HF183) MST marker was also detected in these samples; therefore, a human fecal source cannot be ruled out.

Survival of *E. coli* and MST markers are often different, with MST markers being typically more representative of recent fecal contamination (Dick and others, 2010). *E. coli* may be introduced in the beach sand and over time become naturalized and then moved to nearshore waters via runoff, wave action, or groundwater transport (Ishii and others, 2007; Ge and others, 2012; Rumball and others, 2020). Because MST markers are different analytes from *E. coli* (genetic sequences from *Bacteroides* [HF183] and *Helicobacter* [GFD] spp.), different transport and survival characteristics can be expected, and thus, MST markers may not be good markers for “older,” naturalized *E. coli*. The low concentrations of MST markers from this study might indicate that *E. coli* is

naturalized or older, or MST markers might indicate alternative sources such as dogs or wildlife. The MST analysis in this study was limited to five sampling dates; thus, further studies with more temporal coverage would be needed to determine if *E. coli* residing on the sand or in the groundwater are from recent fecal contamination or naturalized populations. Better understanding of the fecal source and transport mechanisms would be helpful in determining how to reduce *E. coli* to prevent beach closures and in informing risk to human health.

Temporal and spatial variability of environmental factors such as temperature, wind, and precipitation affect fate and transport of fecal-indicator bacteria, and previous studies have determined positive correlations between *E. coli* concentrations and weather variables (Whitman and others, 2004; Holschlag and others, 2008; Francy and others, 2013; Vogel and others 2016). Holschlag and others (2008) determined that rainfall before sampling, water temperature, turbidity, water levels, and wind (directions and speed) were positively correlated with *E. coli* concentrations within a 2-day timespan of *E. coli* sample collection at LSCMB. Results from this study were less conclusive. There was no statistical correlation of *E. coli* concentrations to environmental variables such as temperature, wind, waves, and precipitation. This could be a result of *E. coli* concentration being variable across the sites on any sampling date. Previous studies were based on a single *E. coli* concentration representing the swimming waters. This study however, included samples from 15 locations around the park. On most dates, the *E. coli* concentrations were highly variable between sites; therefore, it is not surprising larger scale environmental properties were not correlated.

Despite a lack of correlation between *E. coli* concentrations and precipitation, standing water left behind after rainfall contained higher *E. coli* than most of the surface-water samples. Shallow surface-water samples had *E. coli* concentrations that were no higher after precipitation than those samples collected during dry periods. Precipitation may contribute to the movement of *E. coli* to the groundwater where the groundwater samples collected after precipitation had a higher frequency of exceeding 300 CFU/100 mL. The sampling of groundwater was limited in this study, but groundwater, beach sand, and standing water after rain events had the highest concentrations of *E. coli* measured in this study. With a lower *E. coli* concentration offshore than in shallow swimming water and the high concentrations at the beach, it is likely the source of *E. coli* resulting in beach closures originates at the park near the beach. Nevers and others (2020) determined *E. coli* and MST in water represented short-term condition while the sand and sediment reflected more of a long-term (months to years) condition. MST results indicate potential for both a waterfowl and human fecal source in beach sand, groundwater, and shallow swimming waters which has been reported in similar urban beach studies (Byappanahalli and others, 2015). A better

understanding of the physical and biological processes at the beach could aid in determining sources of *E. coli* that result in periodic LSCMB closures. Groundwater connection to the lake could be better understood by a series of seepage studies to measure flow direction to and from lake and groundwater. Additionally, a better temporal and spatial representation of the groundwater and sand *E. coli* at LSCMB could be used to inform modeling efforts to address the localized movement of *E. coli* in this system. Understanding the roles of these sources would provide a better framework for beach management practices aimed at reducing *E. coli* at Metropark Beach.

## Summary

The objective of this study was to determine likely sources of *Escherichia coli* (*E. coli*) at Lake St. Clair Metropark Beach in Macomb County, Michigan. The study area is within the Clinton River Area of Concern with a Beneficial Use Impairment because of frequent beach closures. The U.S. Geological Survey, in cooperation with the U.S. Environmental Protection Agency, and in collaboration with the Michigan Department of the Environment, Great Lakes, and Energy, Macomb County Health Department, and Huron-Clinton Metroparks, completed a two-year study (2018–2019) that evaluated *E. coli* concentrations in recreational swimming water, lake water surrounding the park, offshore Lake St. Clair waters, storm water, lake-bottom sediment, beach sand, stormwater, and groundwater at the beach. Results from this study indicate the source of *E. coli* to Lake St. Clair Metropark Beach is likely to be localized at the swimming area rather than being transported in from offshore waters. *E. coli* concentrations were highest in shallow groundwater and surface sand, with lowest concentrations occurring in offshore waters and lake bottom sediment. Potential sources include human and waterfowl at or near the beach area. Microbial source tracking analysis showed that indeed indicators of these sources could be detected but this did not consistently relate to *E. coli* concentrations. The potential of stormwater to transport *E. coli* from the beach to swimming waters could be observed from sediment wash-out areas at the beach following significant rain. Pools of water on and near the beach following rain had concentrations similar to the beach sand and groundwater, higher than the swimming waters. Though there are indications of *E. coli* sources on the land near swimming waters, it is not understood where the *E. coli* on land originates or how it is transported to the water resulting in beach closures. A better understanding of the transport and fate of *E. coli* in the beach sand and groundwater could aid in determining sources of *E. coli* that result in periodic closure at Lake St. Clair Metropark Beach.



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