Prepared in cooperation with Concerned Citizens of Montauk and the New York State Department of Environmental Conservation

Using Microbial Source Tracking To Identify Fecal Contamination Sources in Lake Montauk on Long Island, New York

Scientific Investigations Report 2022–5038

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U.S. Geological Survey

Cover. U.S. Geological Survey scientists collecting a water sample at the Stepping Stones Pond Culvert in Montauk, New York, viewed looking northwest from the east side of the culvert during a sampling trip; photograph by Tristen Tagliaferri, U.S. Geological Survey.

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Concentrations of fecal coliform bacteria are given in most probable number per 100 milliliters (MPN/100 mL).

Abbreviations

BacCan	canine-associated *Bacteroides* marker
FC	fecal coliform bacteria
GFD	waterfowl-associated *Helicobacter* marker
HF183	human-associated *Bacteroides* marker
MPN	most probable number
MST	microbial source tracking
NWIS	National Water Information System
NYSDEC	New York State Department of Environmental Conservation
Rum2Bac	ruminant-associated *Bacteroides* marker
USGS	U.S. Geological Survey

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Executive Summary

The U.S. Geological Survey worked in cooperation with the Concerned Citizens of Montauk and the New York State Department of Environmental Conservation to assess the potential sources of fecal contamination entering the Lake Montauk embayment as part of a study of seven estuarine embayments across Long Island, New York, from June 2018 to July 2019. Water samples are routinely collected by the New York State Department of Environmental Conservation in Long Island embayments and analyzed for fecal coliform bacteria (FC), an indicator of fecal contamination, to determine the closure of shellfish beds for harvest and consumption. Concentrations of fecal coliform signify the potential for pathogenic (disease-causing) bacteria to be present.

Indicator bacteria alone cannot determine either the biological or geographical sources of contamination. Microbial source tracking (MST) is a method used to determine these sources of contamination. Microbial source tracking laboratory techniques can ascertain whether genetic material obtained from *Bacteroides* or *Helicobacter* bacteria in water or sediment is consistent with humans, canines (dogs), ruminants (deer, sheep), or waterfowl (water birds). *Bacteroides* and *Helicobacter* are genera of bacteria found in the gut of most warm-blooded animals. These techniques can also quantify the concentration of genetic markers found.

Information such as sample location, weather and season, surrounding land use, and additional water-quality data for the location where the sample was collected help determine the geographical source and conveyance of land-based water to the embayment. The presence of genetic material and FC in samples collected at the same time is important to show that the fecal coliform is likely from the host source detected. It is possible for waters with waste infiltration to have genetic material present but no fecal indicators, such as disinfected water from a wastewater treatment plant or from groundwater that has passed through a sandy aquifer.

Water samples were collected in the summer and winter seasons. In each of the two seasons, one sample was collected in dry weather, and one, after substantial rainfall. Two groundwater samples and one sediment sample were also collected during this study. Surface-water source sites sampled for Lake Montauk include the Little Reed Pond Culvert, Little Reed Pond Outlet, South Beach, Stepping Stones Pond, and the Stepping Stones Pond Culvert sites.

Human and waterfowl fecal contributions to Lake Montauk were detected across the landscape. Among the potential sources of fecal-contaminated water contributing to Lake Montauk—groundwater, pond drainage, stormwater runoff, and marinas (boats)—stormwater runoff and pond drainage were identified as the most likely transport mechanism of fecal contamination to Lake Montauk. Additionally, 15 of 16 samples collected throughout this study at receptor sites (the lake itself) had FC concentrations that were all at or below the FC reporting limit (less than 18 or 20 MPN/100 mL).

The highest frequency of FC detections in source site samples was found to be under wet summer conditions at the South Beach, Stepping Stones Pond, and Stepping Stones Pond Culvert sites (300, 220, and more than 16,000 MPN/100 mL, respectively). Samples from receptor sites adjacent to marinas (Lake Montauk Inlet and Star Island North sites) had a higher frequency of human marker detections but were associated with FC concentrations at or below the reporting limit, indicating minimal human influence on FC loads from the sampled receptor sites to Lake Montauk during this study. The absence of FC and the human MST marker in all groundwater samples indicated limited transport of bacteria in the subsurface groundwater through the sandy aquifer material, which is consistent with results throughout Long Island. It is unlikely that water from septic systems influenced the lake given the available data. Although data for FC concentrations are unavailable for the sediment sample at the South Beach site, this sample was negative for all MST markers and is unlikely to contribute FC from the tested host organisms during resuspension events caused by tidal shifts or boat wakes.

Targeted sampling of the sediment and groundwater would be needed in and around Lake Montauk to fully determine the potential of fecal contamination from these sources.

A classification scheme was developed that considered conditions such as high FC concentrations (particularly during dry weather samples) and contributions from human and canine waste based on detection of MST markers. The sites were assessed to assist stakeholders and resource managers in prioritizing which source sites are consistently contributing fecal coliforms to Lake Montauk throughout the year. The Little Reed Pond Culvert and South Beach sites were classified as locations most likely to contribute fecal contamination to Lake Montauk.

Introduction

To better understand fecal contamination sources in coastal embayments of Long Island, New York, microbial source tracking (MST) and fecal coliform bacteria (FC) data were collected by the U.S. Geological Survey in cooperation with the Concerned Citizens of Montauk and the New York State Department of Environmental Conservation (NYSDEC) from seven embayments from June 2018 to July 2019 (U.S. Geological Survey, 2020a). The objective of this research was to identify the different pathogen sources, both the host organism (such as human, mammals, or birds) and geographic origin (such as urban and storm runoff and submarine groundwater discharge) to embayments with fecal contamination. The embayments selected represent a mix of sewered and unsewered areas, differing levels of impervious land cover, varying population density, and a variety of land-use types so as to transfer what is learned to other areas beyond the seven studied. In total, 353 samples were collected in the 7 Long Island embayments. These were primarily surface-water samples but also include 17 groundwater, 11 sediment, 2 sewage influent, and 8 fecal samples.

The presence of fecal contamination in Lake Montauk and resulting hazards posed to marine resources and human health is of increasing concern. Recreational uses of the lake, including shellfishing and public bathing, are frequently restricted due to high counts of FC, which are used as indicators for when pathogens may be present. Pathogen loads can be influenced by watershed land-use, proximity to point sources such as municipal separate storm sewer systems, as well as tidal exchange and circulation transporting pathogens from outside the study area (Gao and others, 2015), sediment resuspension (O’Mullan and others, 2019), and human recreation (including boating). Nonpoint sources may include shallow groundwater discharge, given that all East Hampton and surrounding areas rely on onsite wastewater disposal systems, such as cesspools and septic systems. Through routine FC monitoring, the NYSDEC has identified fecal contamination as a concern in Lake Montauk. Microbial source tracking techniques are necessary to determine the dominant source (human, canine, ruminant, waterfowl) and geographic origin of FC using land use, topography, and hydrology to establish a framework. The success of future pathogen-control measures may be measured by the decline in FC concentrations.

Site Description

Lake Montauk is an artificial embayment on the tip of the southern fork on Long Island in the town of East Hampton, Suffolk County, New York (fig. 1). There is a single outlet to Long Island Sound on the northwestern side of the lake. Areas surrounding Lake Montauk are a mix of low-density residential and commercial land use, including Montauk Airport, marinas, and commercial fishing stations. A large part of the waterfront consists of natural shoreline, except for the inlet, which is primarily bulkhead. The entire surrounding area is served by onsite wastewater disposal systems.

Potential contamination sources include stormwater runoff, wildlife, groundwater discharge, and marinas (boats). The sites where surface-water source samples were collected (U.S. Geological Survey, 2020a) for Lake Montauk (fig. 2; table 1.1) are as follows:

- The Stepping Stones Pond site is a small pond located southwest of Lake Montauk. The pond is surrounded by low-density residential housing and undeveloped open space. There is a short walking trail with a pond overlook on the western side.
- The Stepping Stones Pond Culvert site runs under Old West Lake Drive and continuously discharges water from Stepping Stones Pond into Lake Montauk.
- The Little Reed Pond Culvert site is at the culvert constructed from a wide, corrugated pipe that runs under East Lake Drive and continuously discharges water from Little Reed Pond into Lake Montauk. The surrounding area is undeveloped open space with low density residential housing.
- The Little Reed Pond Outlet site is approximately 400 feet west of the Little Reed Pond Culvert sampling site and is the discharge point of water from Little Reed Pond into Lake Montauk. It is on the northeastern shore of Lake Montauk, adjacent to Montauk Airport. This area is sandy and shallow.
- The South Beach site is along the southernmost end of Lake Montauk and is the sampling point furthest from the inlet. This area is used seasonally for recreational swimming, bathing, and watersports. The area sampled drains a ponded wetland area. There are public restrooms adjacent to the site.

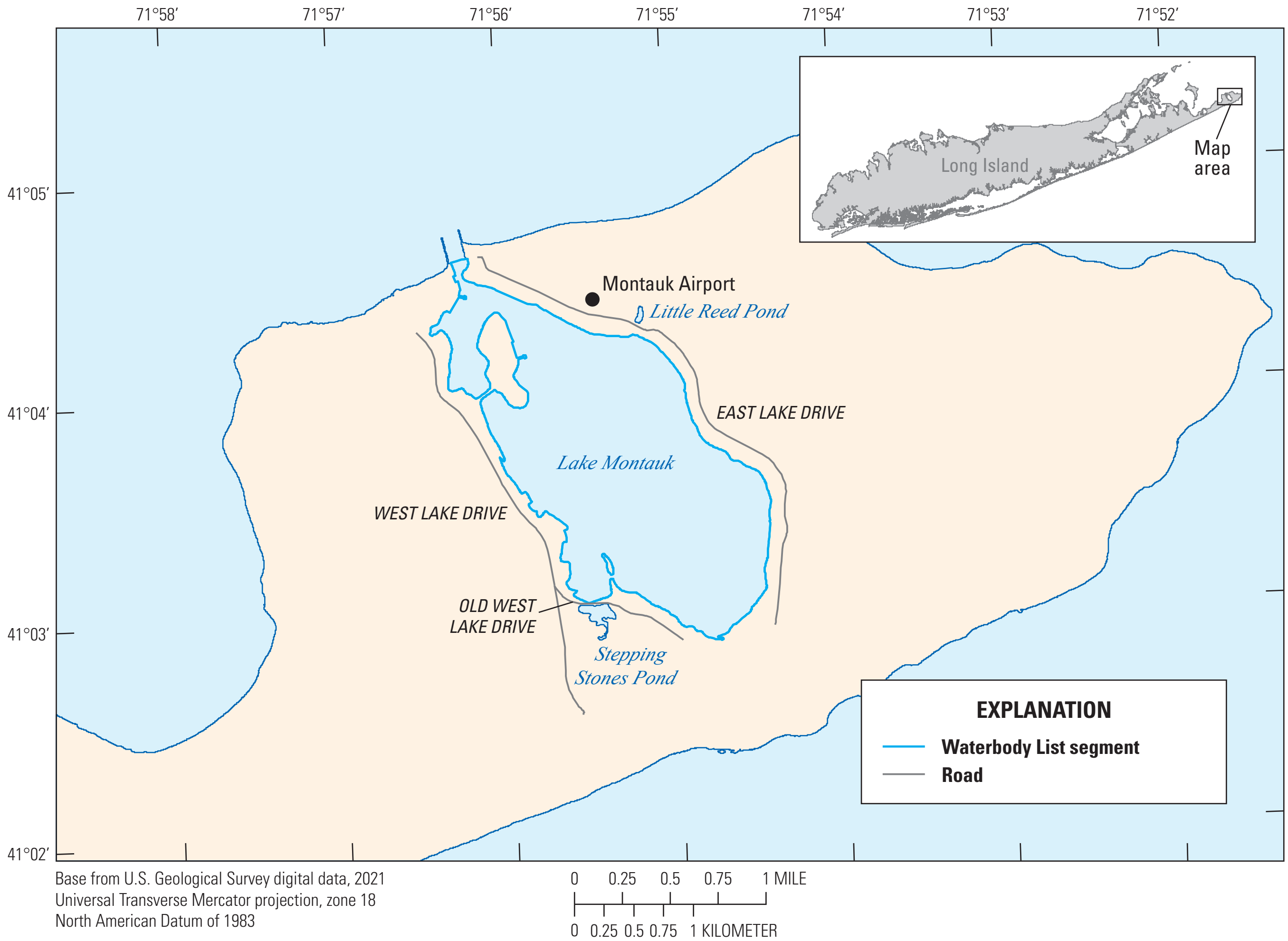

Figure 1. Map showing the extent of the Priority Waterbody List segment surrounding Lake Montauk on Long Island, New York, as designated by the New York State Department of Environmental Conservation (2020). The entire area surrounding Lake Montauk is served by cesspools or septic tanks.

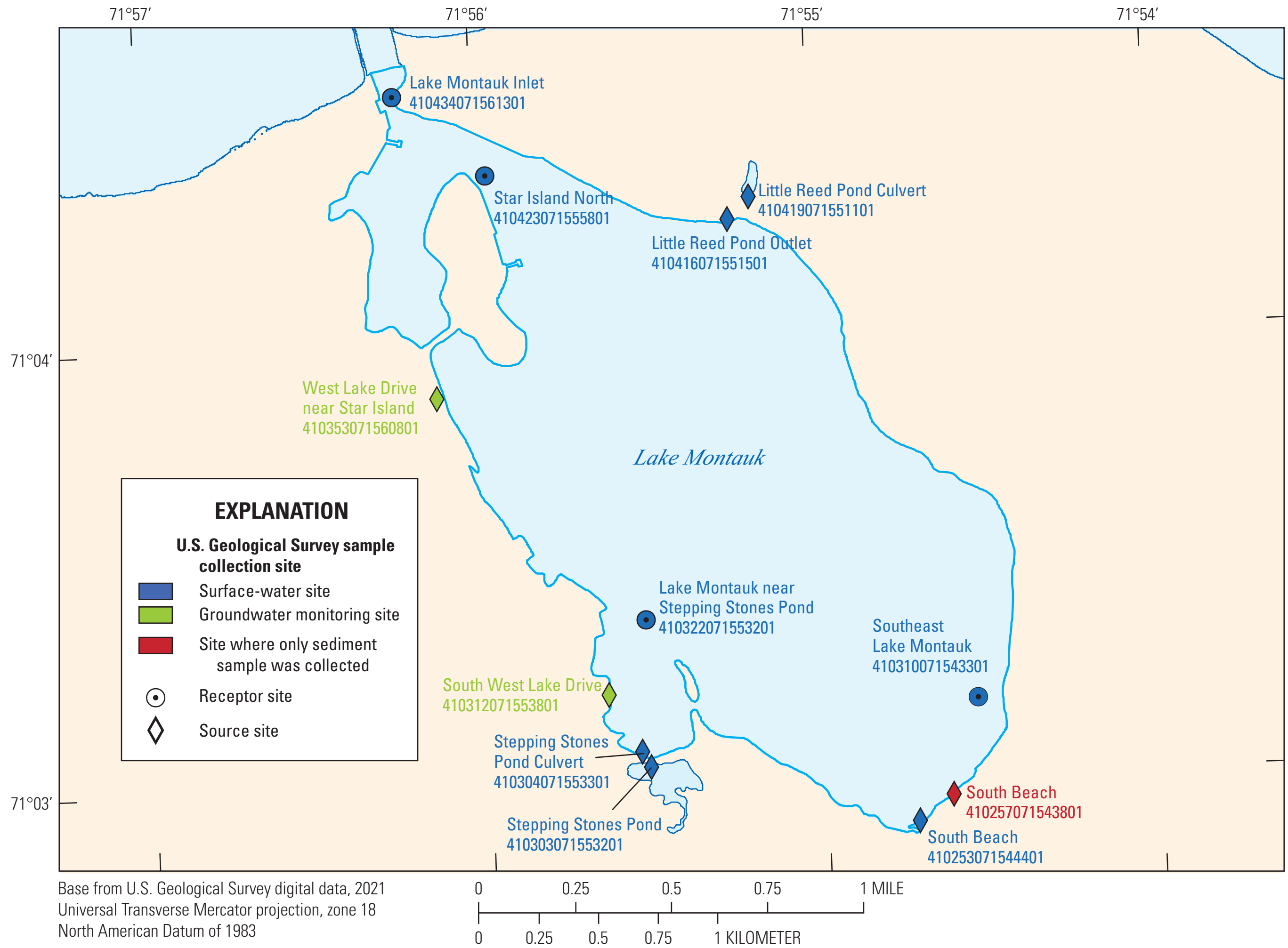

Figure 2. Map showing the locations where surface-water, groundwater, and sediment samples were collected for microbial source tracking analysis in Lake Montauk on Long Island, New York. Data are from U.S. Geological Survey (2020a).

Table 1. Summary of microbial source tracking results in surface-water samples for sites sampled in Lake Montauk on Long Island, New York.

[Ratios are number of samples with detections greater than reporting limit per total number of samples. Reporting limits vary due to analytical processes and matrix interferences. BacCan, canine-associated *Bacteroides* marker; GFD, waterfowl-associated *Helicobacter* marker; HF183, human-associated *Bacteroides* marker; Rum2Bac, ruminant-associated *Bacteroides* marker]

Variable	Ratio of positive detections (detections greater than reporting limit)			
	HF183	Rum2Bac	GFD	BacCan
Summer	2:17	0:17	1:17	0:17
Winter	3:18	0:18	2:18	0:18
Dry	3:18	0:18	2:18	0:18
Wet	2:17	0:17	1:17	0:17
Source	1:19	0:19	3:19	0:19
Receptor	4:16	0:16	0:16	0:16

Approach and Methods

Sampling Methods

From June 2018 to July 2019, twelve sites were sampled in and around Lake Montauk yielding 35 surface-water samples, 3 groundwater samples (including one replicate), and 1 sediment sample. Of the surface-water sites, five were considered to be source sites (waters flowing directly into Lake Montauk from the land), and four were considered to be receptor sites (the lake itself). Seventeen surface-water samples were collected under wet conditions, and eighteen, under dry conditions; seventeen surface-water samples were collected in the summer, and eighteen, in the winter. Quality control samples from the larger MST assessment represent the sample collection and laboratory methods for the Lake Montauk area; quality assurance procedures are presented in Tagliaferri and others (2021). All water-quality and sediment data collected in the field and those analyzed in laboratories as part of this study are available from the U.S. Geological Survey (USGS) National Water Information System (NWIS) database (U.S. Geological Survey, 2020a).

Sampling and laboratory methods used for this study are detailed in Tagliaferri and others (2021). All groundwater and sediment samples in Lake Montauk were collected in June 2019 (with the exception of one groundwater sample collected in July 2019). Wet conditions were defined as more than 0.25 inch of precipitation in 24 hours or 0.50 inch in 48 hours. Dry conditions were defined as less than 0.25 inch of precipitation in 72 hours. Rainfall totaled 0.02 inch on September 9, 2018, and 0.25 inch on September 10, 2018, designating samples collected on September 10, 2018, in Lake Montauk as summer wet samples (more than 0.25 inch within 24 hours). Winter, wet, receptor samples were collected in Lake Montauk on April 17, 2019, with 0.47 inch of precipitation falling on April 15, 2019, 0.12 inch falling on April 16, 2019, and no precipitation on April 17, 2019. Winter, wet, source samples were collected on April 30, 2019, with 0.03 inch of precipitation falling on April 29, and 0.28 inch falling on April 30. Rainfall values were obtained from the Montauk Airport weather station (KMTP; Weather Underground, 2021).

Laboratory Methods

Laboratory methods used for this study are detailed in Fisher and others (2020). Samples for fecal coliforms were analyzed at Suffolk County Department of Health Services Public Environmental Health Laboratory (PEHL). Samples for MST markers were analyzed by the USGS Ohio Water Microbiological Laboratory in Columbus, Ohio. Additional information was either observed or compiled to facilitate interpretation of data. Precipitation measurements from the Montauk Airport weather station (Weather Underground, 2021) were used to determine whether weather conditions were considered dry or wet. Quality assurance for samples collected at Montauk Airport weather station are unavailable. Relative tide stage as noted by USGS field personnel and verified based on tidal predictions available (National Oceanic and Atmospheric Administration, undated) was documented along with the sample information in NWIS (U.S. Geological Survey, 2020a). Land-cover and sewer district geographic information system (GIS) coverages (Nassau County, 2015; Suffolk County, 2020; U.S. Geological Survey, 2020b) were used for data interpretation. These data support the MST results to increase confidence in the geographical source of the water and likely transport mechanisms of fecal contamination to Lake Montauk.

Results

Results of MST and FC were assessed based on concentrations, presence or absence, and relative abundance of host markers with respect to surface-water source and receptor sites. Differences in MST markers and FC concentrations were also compared seasonally and conditionally (that is, wet or dry), with dry weather discharges being of particular concern.

Microbial Source Tracking

The human-associated *Bacteroides* (HF183) marker was the only marker detected at surface-water receptor sites, and both HF183 and waterfowl *Helicobacter* (GFD) markers were detected at surface-water source sites. The human marker was detected five times throughout the Lake Montauk landscape, with four positive detections in receptor site samples and one in a source site sample (Stepping Stones Pond; fig. 3). There were three detections for the waterfowl marker, all in source site samples (fig. 4; table 1). The canine-associated *Bacteroides* (BacCan) markers and ruminant *Bacteroides* (Rum2Bac) markers were not detected, suggesting minimal contribution from domestic dogs and the resident deer population. There were no positive MST marker detections in the groundwater samples collected at the South West Lake Drive and West Lake Drive near Star Island sites or in the sediment sample collected at the South Beach site.

Host Specific Markers

Reporting limits for the two predominant MST markers (HF183 and GFD) detected in Lake Montauk varied slightly because of analytical processes, such as dilutions required because of matrix interferences. Understanding occurrence of the predominant MST markers in Lake Montauk can help prioritize locations for additional investigation and infrastructure improvement and provide a baseline for host contributions when prioritizing sites of concern for assessing FC and after total maximum daily load implementation.

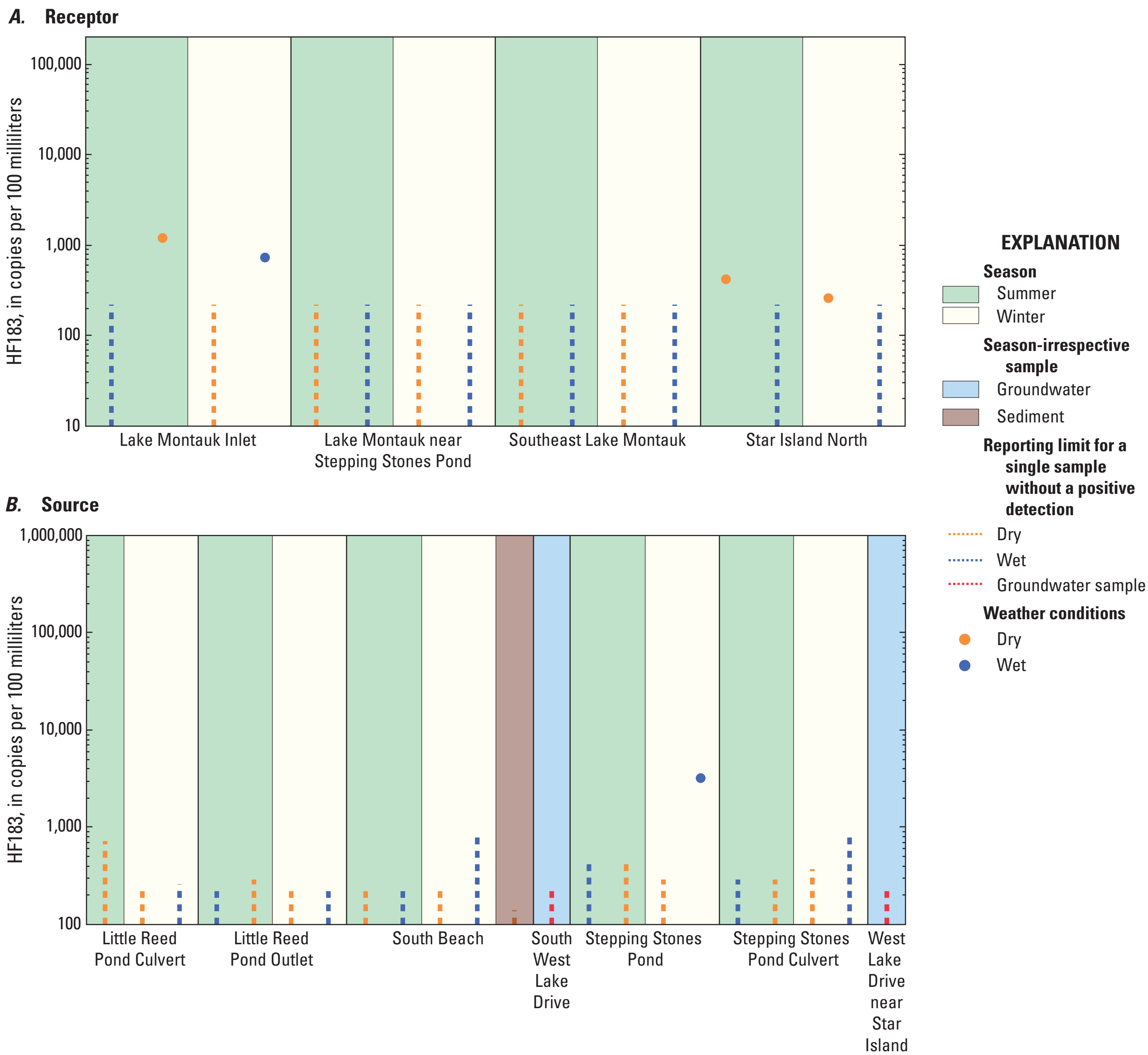

Figure 3. Graphs showing the concentrations of the human *Bacteroides* (HF183) marker, in copies per 100 milliliters for water samples and copies per gram dry weight for sediment samples, from *A*, receptor and *B*, source sites in Lake Montauk on Long Island, New York, under various surface-water sample conditions. Dashed lines indicate reporting limit for a single sample without a positive detection. Scales for marker concentrations are fixed to allow for easy comparison with other embayment study areas on Long Island.

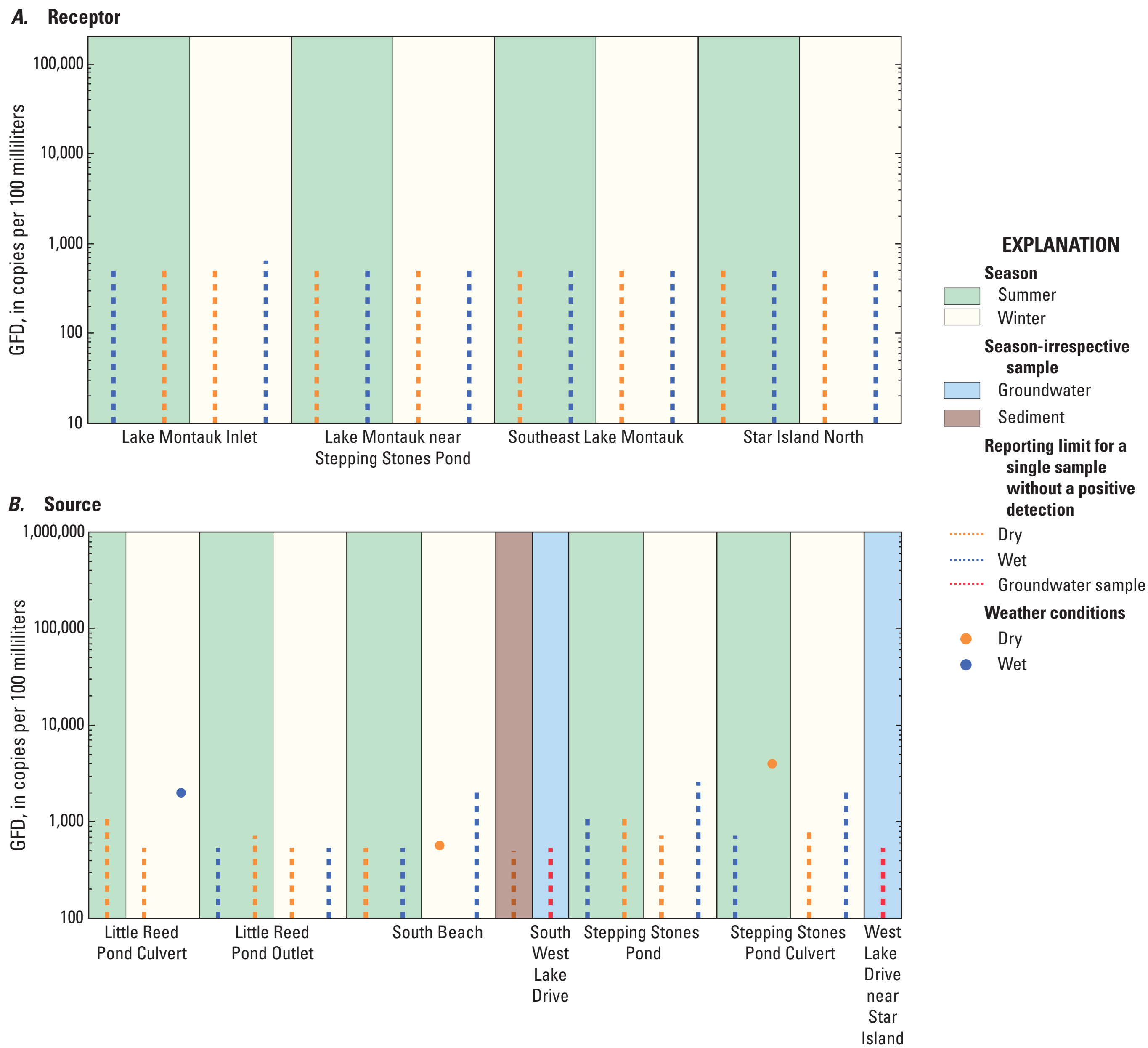

Figure 4. Graphs showing the concentrations of the waterfowl *Helicobacter* (GFD) marker, in copies per 100 milliliters for water samples and copies per gram dry weight for sediment samples, from *A*, receptor and *B*, source sites in Lake Montauk on Long Island, New York, under various surface-water sample conditions. Dashed lines indicate reporting limit for a single sample without a positive detection. Scales for marker concentrations are fixed to allow for easy comparison with other embayment study areas on Long Island.

HF183

There were five positive detections for human-associated *Bacteroides* (HF183) marker in Lake Montauk. Three of the five positive detections were in samples collected during the winter, and the other two, in the summer (table 1). The highest concentration of HF183 (and the only instance of HF183 at a source site) was in the sample collected at the Stepping Stones Pond site (3,200 copies per 100 milliliters [copies/100 mL]; table 1.2; U.S. Geological Survey, 2020a) during wet winter conditions, whereas the lowest concentration that was above the detection limit was in the sample collected at the Star Island North site (260 copies/100 mL) during dry winter conditions. The human marker was detected more frequently in samples from receptor sites and was exclusively detected in samples from receptor sites adjacent to marinas (Lake Montauk Inlet and Star Island North). The low detection frequency of HF183 in samples collected throughout Lake Montauk is indicative of minimal to no human-associated *Bacteroides* inputs from inland sources or sources from within the receptor (including boats and marinas) during this study. Additionally, there were no positive detections of HF183 in the groundwater or sediment samples collected for this study (fig. 3).

GFD

The waterfowl marker was detected in 3 of the 35 surface-water samples collected. All positive detections were in samples collected at source sites and under varying sampling conditions—one sample each in wet winter, dry winter, and dry summer conditions (fig. 4). The lowest concentration of the GFD marker that was above the detection limit was in the sample collected at the South Beach site during dry winter conditions (570 copies/100 mL; table 1.2; U.S. Geological Survey, 2020a). The low detection frequency of GFD in samples collected throughout Lake Montauk is indicative of minimal to no waterfowl-associated *Helicobacter* inputs from inland sources or sources from within the receptor during this study. There were no positive detections of GFD in the groundwater samples collected at the South West Lake Drive and West Lake Drive near Star Island sites or in the sediment sample collected at the South Beach site.

Fecal Coliform Bacteria

Fifteen of 16 (94 percent) receptor site samples and 12 of 19 (63 percent) source site samples had concentrations that were at or below the FC reporting limit (less than [<] 18 or 20 MPN/100 mL). The single receptor sample with a positive FC detection (40 most probable number per 100 milliliters [MPN/100 mL]) was collected at the Lake Montauk Inlet site during wet, summer conditions. The sample with the highest fecal coliform concentration exceeded the upper concentration threshold (greater than [>] 16,000 MPN/100 mL) and was collected in wet, summer conditions at the Stepping Stone Pond Culvert site; this sample was negative for all MST markers (human, waterfowl, ruminant, and canine). All other samples collected at the Stepping Stones Pond Culvert site had concentrations that were at or below detection for FC. Seven of the 35 surface-water samples collected in and around Lake Montauk (20 percent) had concentrations that were above 49 MPN/100 mL (table 1.2; U.S. Geological Survey, 2020a), the 90th percentile concentration determined by the NYSDEC as part of the National Shellfish Sanitation Program (NSSP) closure criteria (U.S. Food and Drug Administration, 2019). Of these seven surface-water source samples, five were collected during the summer, and five under wet sampling conditions (table 1.1; U.S. Geological Survey, 2020a). In general, high FC concentrations were measured during the wet summer conditions.

The relation between FC and marker detection is not straightforward. Fecal coliform and specific host-associated markers may decay at different rates and be present in different abundances. Additionally, host-associated markers have been shown to decay more rapidly than FC (Drozd and others, 2013; Rogers and others, 2011). One of six sample sites with MST marker detections (Little Reed Pond Culvert) had high FC concentrations (110 MPN/100 mL) with the rest at or above the reporting limit for FC.

Nonpoint Sources of Fecal Coliform Bacteria

Potential, major nonpoint contributors of freshwater to Lake Montauk include groundwater seepage and direct stormwater runoff not conveyed by the municipal separate storm sewer system, particularly from ponds and road ends. Fecal coliform concentrations for groundwater samples collected at the South West Lake Drive and West Lake Drive near Star Island sites were below detection (<18 MPN/100 mL), indicating minimal to no contribution of FC to Lake Montauk from groundwater samples collected during these two sampling events. There were no MST markers associated with the groundwater samples.

Another nonpoint source that can contribute to fecal contamination in water samples is sediment during resuspension (O'Mullan and others, 2019). To better understand these contributions, one sediment sample was collected at the South Beach site. There are no fecal coliform data available for the sediment collected at the South Beach site, and there were no MST markers detected in the sediment sample (table 1.2; U.S. Geological Survey, 2020a); therefore, additional, targeted investigations would be needed to determine the degree of contribution to FC loads from sandy shoreline sediments in Lake Montauk.

Classification of Source Sites

The sites where samples were collected were assessed to better understand geographical sources and transport mechanisms to surface-water receptor sites and the relation between FC and MST marker presence and abundance (table 2). Source sites were assigned a numeric classification as described in Tagliaferri and others (2021) to aid in conceptualizing the degree of contamination potential (table 3). Classifications are based on a sliding scale, with class 1 sites being the most contaminated, and class 5 sites being the least contaminated during this study.

Little Reed Pond Culvert—Class 4

Fecal coliform concentrations were highest in the dry summer and wet winter samples (110 MPN/100 mL in each sample). Waterfowl markers were detected in the wet winter sample; this sample contained the second highest waterfowl marker concentration of the three waterfowl marker detections in Lake Montauk samples (2,000 copies/100 mL). No markers were detected in the other samples collected at this site. Fecal coliform concentrations were not higher in samples from wet conditions than in dry, therefore, stormwater runoff from road ends or Little Reed Pond is not implicated as a source of FC to Lake Montauk during this study.

South Beach—Class 4

Two of four surface water samples collected at this site had FC concentrations above 49 MPN/100 mL but contained no MST markers. The sample collected in dry winter conditions had concentrations that were positive for the waterfowl marker (540 copies/100 mL) but was below detection for FC (<18 MPN/100 mL). Elevated FC concentrations were observed during wet sampling conditions, implicating stormwater influence on FC loads to Lake Montauk at this site during this study.

Little Reed Pond Outlet—Class 5

Little Reed Pond Outlet was the only surface water source site where samples contained no MST markers, most likely due to dilution by the receptor. Three of four samples collected at this site had concentrations that were below the reporting limit for FC (<18 or <20 MPN/100 mL). The dry summer sample had a concentration of FC that was 130 MPN/100 mL and was negative for all MST markers. Given the general absence of FC in wet conditions, stormwater runoff is not suspected to contribute FC to Lake Montauk at this site during this study.

Stepping Stones Pond—Class 5

Three of four samples collected at this site had concentrations that were at or below the reporting limit for FC and ranged from <18 to 220 MPN/100 mL in the wet summer sample. The human marker was detected in the wet winter sample at a concentration of 3,200 copies/100 mL, the highest concentration observed in all of Lake Montauk samples. Available data indicate that stormwater, particularly during the summer, is a source of FC to Lake Montauk.

Stepping Stones Pond Culvert—Class 5

Three of four samples collected at this site had concentrations that were at or below the reporting limit for FC (<18 or <20 MPN/100 mL). The wet summer sample exhibited the highest FC concentration observed in all of Lake Montauk (>16,000 MPN/100 mL). Stepping Stones Pond also had elevated FC detected during wet weather. The lack of human, canine, waterfowl, and ruminant markers coupled with the high FC concentration in the wet summer sample at this site may indicate fecal contamination from an untested source organism during this study. Stormwater flushing water from the pond through the culvert is a source of FC to Lake Montauk during the summer.

Sediment—Class 5

No human, waterfowl, or canine markers were detected in these samples, indicating minimal to no fecal contamination from the tested host organisms to Lake Montauk through the sandy shoreline sediment during this study. Fecal coliform concentrations are not available for sediment samples collected at the South Beach site. However, recent research (O'Mullan and others, 2019; Hassard and others, 2016) indicated that resuspension of sediment along natural shorelines and lakebeds can cause a spike in fecal indicator bacteria in the water column. Therefore, it is possible that, during conditions that result in high wave energy, sediment (particularly organic-rich material) can act as a source of FC when resuspended in the water column as a result of tidal movement, storms, or boat activity. Additional, targeted investigations would be needed to determine the degree of contribution to FC loads from sandy, shoreline sediments in Lake Montauk.

Groundwater—Class 5

The human MST marker was not detected at the West Lake Drive near Star Island or South West Lake Drive sites during this study, suggesting no septic influx to Lake Montauk on the days the two samples were collected. The lack of positive detections for FC in groundwater samples collected throughout Long Island for the island-wide MST study suggests that direct groundwater seepage is an unlikely contributor of FC to Lake Montauk.

Table 2. Geographical sources of water for sample locations in Lake Montauk on Long Island, New York, and the potential for these sites to have contributed to the fecal coliform concentrations observed in the samples.

[MST, microbial source tracking; FC, fecal coliform bacteria; X, potential contributor, —, not a likely contributor based on current data]

Site name	Contamination source	Contributes to fecal contamination in lake?	Remarks
Little Reed Pond Culvert	Wildlife	X	Waterfowl markers were detected in winter months. The surrounding land use and open space indicate wildlife as a likely source of FC.
	Stormwater conveyance or runoff	—	Fecal coliform concentrations were not higher in wet conditions than in dry.
Little Reed Pond Outlet	Pond drainage and wildlife	X	No MST markers were detected and may be diluted at the mouth. Unidentified wildlife may be potential contributors of FC measured.
	Stormwater conveyance or runoff	—	Fecal coliform concentrations were not higher in wet conditions than in dry.
South Beach	Wildlife	X	Waterfowl markers were detected in the dry winter sample.
	Stormwater conveyance or runoff	X	Elevated FC was observed during wet sampling conditions.
	Sediment resuspension	—	Additional, targeted investigation is needed to determine the degree of FC contamination from different sediment types surrounding Lake Montauk. FC is likely low at South Beach due to the sandy nature of the soil.
Stepping Stones Pond	Stormwater conveyance or runoff	X	Fecal coliform data in the summer wet sample show potential for stormwater to flush FC into the pond. Human markers were detected in the winter wet sample.
Stepping Stones Pond Culvert	Pond drainage and Stormwater conveyance or runoff	X	Stormwater is a potential source for substantial FC as shown in the single, wet summer sample that exceeded the reporting threshold for FC. It is likely that accumulated FC from Stepping Stones Pond is flushed into the lake during wet weather and may include septic waste.
West Lake Drive near Star Island	Groundwater	—	Groundwater contribution of FC is unlikely. No microbial source tracking markers were detected.
South West Lake Drive	Groundwater	—	Groundwater contribution of FC is unlikely. No microbial source tracking markers were detected.

Table 3. Sample results for fecal coliform and microbial source tracking markers by source site type at Lake Montauk on Long Island, New York.

[Proposed classification considers concentrations of fecal coliform above 49 most probable number per 100 milliliters (MPN/100 mL), dry weather discharges, and influences of human sewage and canine waste. A fecal coliform concentration of 49 MPN/100 mL is the 90-th percentile concentration determined by the New York State Department of Environmental Conservation as part of the National Shellfish Sanitation Program closure criteria (U.S. Food and Drug Administration, 2019). FC, fecal coliform bacteria; HF183, human-associated *Bacteroides* marker; BacCan, canine-associated *Bacteroides* marker; —, no data]

Site name	Site type	Number of FC samples	Fecal coliform (MPN/100 mL)				Elevated fecal coliform during dry-weather discharge	Sewage affected (HF183)	Canine affected (BacCan)	Class[1]
			Median	25th quartile	75th quartile	Mean				
Little Reed Pond Culvert	Estuary	3	110	55	110	73	Yes	No	No	4
South Beach	Estuary	4	95	95	203	123	No	No	No	4
Little Reed Pond Outlet	Estuary	4	<18	0	33	33	Yes	No	No	5
Stepping Stones Pond	Estuary	4	10	10	70	60	No	Yes	No	5
Stepping Stones Pond Culvert	Estuary	4	10	10	4015	4005	No	No	No	5
West Lake Drive near Star Island	Groundwater	1	—	—	—	—	—	No	No	5
South West Lake Drive	Groundwater	1	—	—	—	—	—	No	No	5
South Beach	Sediment	0	—	—	—	—	—	No	No	5

[1]Class is assigned from 1 to 5, with 1 being the most contaminated and 5 being the least contaminated.

Summary

The U.S. Geological Survey, in collaboration with the Concerned Citizens of Montauk and the New York State Department of Environmental Conservation, assessed the potential sources of fecal contamination entering Lake Montauk on Long Island, New York, from June 2018 to July 2019. Water samples are routinely collected in Long Island embayments and analyzed for fecal coliform bacteria (FC), an indicator of fecal contamination, to determine the closure of shellfish beds for harvest and consumption. Fecal indicator bacteria such as fecal coliform signify the potential for pathogenic (disease-causing) bacteria to be present.

Host sources of fecal contamination in Lake Montauk were assessed based on bacterial *Bacteroides* and *Helicobacter* microbial source tracking (MST) markers. Overall, human and waterfowl markers were infrequently and sporadically present in source and receptor samples at low concentrations. By evaluating the MST markers alongside FC data and land-use information, geographical sources of fecal contamination discharging from various source sites, such as culverts and ponds, were better differentiated. Throughout the length of this study, not one receptor sample tested for FC had concentrations above 49 most probable number per 100 milliliters (MPN/100 mL), the National Shellfish Sanitation Program closure criteria.

Among the potential sources of fecal-contaminated water contributing to Lake Montauk—groundwater, pond drainage, stormwater runoff, and marinas (boats)—stormwater runoff and pond drainage were the most likely transport mechanisms for fecal contamination to Lake Montauk. When considering Lake Montauk as a whole, the highest frequency of FC detections in source site samples was found to be under wet summer conditions, as evidenced by the high fecal coliform concentrations at the South Beach, Stepping Stones Pond, and Stepping Stones Pond Culvert sites (300, 220, and more than 16,000 MPN/100 mL, respectively). No point sources to FC contamination to Lake Montauk were identified; however, receptor site samples adjacent to marinas (Lake Montauk Inlet and Star Island North sites) had a higher frequency of human marker detections but were associated with FC concentrations at or below the reporting limit. The absence of FC and human MST markers in groundwater samples indicated that water from septic systems did not influence the lake during this study. Further, the sandy sediment sample collected at the South Beach site was negative for all MST markers and is unlikely to contribute FC from the tested host organisms when resuspended in the water column through tidal shifts or boat activity.

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Appendix 1. Sample Collection in Lake Montauk on Long Island, New York

Table 1.1. Locations where samples were collected in Lake Montauk on Long Island, New York, for bacterial genetic markers and fecal coliform analysis.

[Data are from the National Water Information System (U.S. Geological Survey, 2020). Samples collected include blanks and replicates. Sample conditions of wet and dry indicate whether a sample was influenced by storm or nonstorm conditions, respectively. EST, eastern standard time; —, sample collected irrespective of wet or dry conditions]

Station name	Station identification number	Date	Time (EST)	Sample type	Sample condition	Remarks
Little Reed Pond Culvert	410419071551101	6/27/2018	8:40	Source	Dry	
Little Reed Pond Outlet	410416071551501	6/27/2018	9:00	Source	Dry	
South Beach	410253071544401	6/27/2018	9:35	Source	Dry	
Stepping Stones Pond Culvert	410304071553301	6/27/2018	10:05	Source	Dry	
Stepping Stones Pond	410303071553201	6/27/2018	10:30	Source	Dry	
Star Island North	410423071555801	6/27/2018	10:43	Receptor	Dry	
Lake Montauk near Stepping Stones Pond	410322071553201	6/27/2018	10:54	Receptor	Dry	
Southeast Lake Montauk	410310071543301	6/27/2018	10:58	Receptor	Dry	
Lake Montauk Inlet	410434071561301	6/27/2018	11:19	Receptor	Dry	
Little Reed Pond Outlet	410416071551501	9/10/2018	10:15	Source	Wet	
South Beach	410253071544401	9/10/2018	10:35	Source	Wet	
Lake Montauk Inlet	410434071561301	9/10/2018	10:55	Receptor	Wet	
Lake Montauk near Stepping Stones Pond	410322071553201	9/10/2018	11:09	Receptor	Wet	
Stepping Stones Pond Culvert	410304071553301	9/10/2018	11:10	Source	Wet	
Star Island North	410423071555801	9/10/2018	11:16	Receptor	Wet	
Southeast Lake Montauk	410310071543301	9/10/2018	11:18	Receptor	Wet	
Stepping Stones Pond	410303071553201	9/10/2018	11:20	Source	Wet	
Little Reed Pond Culvert	410419071551101	2/6/2019	9:30	Source	Dry	
Little Reed Pond Outlet	410416071551501	2/6/2019	9:40	Source	Dry	
South Beach	410253071544401	2/6/2019	10:15	Source	Dry	
Stepping Stones Pond Culvert	410304071553301	2/6/2019	10:40	Source	Dry	
Stepping Stones Pond	410303071553201	2/6/2019	11:10	Source	Dry	
Lake Montauk Inlet	410434071561301	2/6/2019	11:49	Receptor	Dry	
Star Island North	410423071555801	2/6/2019	11:51	Receptor	Dry	
Lake Montauk near Stepping Stones Pond	410322071553201	2/6/2019	12:01	Receptor	Dry	
Southeast Lake Montauk	410310071543301	2/6/2019	12:05	Receptor	Dry	
Lake Montauk Inlet	410434071561301	4/17/2019	9:33	Receptor	Wet	
Star Island North	410423071555801	4/17/2019	9:39	Receptor	Wet	
Lake Montauk near Stepping Stones Pond	410322071553201	4/17/2019	10:01	Receptor	Wet	
Southeast Lake Montauk	410310071543301	4/17/2019	10:03	Receptor	Wet	
Little Reed Pond Culvert	410419071551101	4/30/2019	10:40	Source	Wet	
Little Reed Pond Outlet	410416071551501	4/30/2019	10:50	Source	Wet	
South Beach	410253071544401	4/30/2019	11:10	Source	Wet	
Stepping Stones Pond Culvert	410304071553301	4/30/2019	11:30	Source	Wet	
Stepping Stones Pond	410303071553201	4/30/2019	11:40	Source	Wet	
West Lake Drive near Star Island	410353071560801	6/17/2019	9:40	Source	—	Groundwater
West Lake Drive near Star Island	410353071560801	6/17/2019	9:45	Source	—	Groundwater replicate
South Beach	410257071543801	6/17/2019	10:50	Source	—	Sediment
South West Lake Drive	410312071553801	7/8/2019	10:20	Source	—	Groundwater

Table 1.2. Data summary of all samples collected in Lake Montauk on Long Island, New York, for bacterial genetic markers and fecal coliform analysis.

[Samples collected include blanks and replicates. Bacterial genetic markers are human-associated *Bacteroides* (HF183), ruminant-associated *Bacteroides* (Rum2Bac), waterfowl-associated *Helicobacter* (GFD), and canine-associated *Bacteroides* (BacCan) markers. Station data are available from the National Water Information System (U.S. Geological Survey, 2020). *Bacteroides* samples were analyzed by the U.S. Geological Survey Ohio Microbiology Laboratory. Fecal coliform bacteria samples were analyzed by the Suffolk County Department of Health Services Public and Environmental Health Laboratory. Bacterial genetic marker values in bold typeface indicate that the concentration was greater than the reporting limit; values preceded by a less than (<) symbol indicate the reporting limit for a given assay when a nondetect occurred; values preceded by a greater than (>) symbol indicate that the value exceeded the reporting limit for a given assay. EST, Eastern standard time; copies/100mL, copies of genetic marker per 100 milliliters; MPN/100mL, most probable number per 100 milliliters; *, copies of genetic marker per gram dry weight sediment; E, estimate; b, concentration was greater than the limit of quantification but less than the reporting limit; ~, duplicate qPCR results do not agree; —, assay was not performed]

Station name	Date	Time (EST)	HF183 (copies/ 100 mL)	Rum2Bac (copies/ 100 mL)	GFD (copies/ 100 mL)	BacCan (copies/ 100 mL)	Fecal coliform (MPN/ 100 mL)
Little Reed Pond Culvert	6/27/2018	8:40	<720	<3,760	<1,080	<1,560	110
Little Reed Pond Outlet	6/27/2018	9:00	<290	<2,500	720	<1,000	130
South Beach	6/27/2018	9:35	<220	<1,900	<540	<780	20
Stepping Stones Pond Culvert	6/27/2018	10:05	<290	<2,500	**4,000**	<1,000	20
Stepping Stones Pond	6/27/2018	10:30	<440	<3,800	<1,100	<1,600	<20
Star Island North	6/27/2018	10:43	**[Eb]420**	<1,900	<540	<780	<20
Lake Montauk near Stepping Stones Pond	6/27/2018	10:54	<220	<1,900	<540	<780	<20
Southeast Lake Montauk	6/27/2018	10:58	<220	<1,900	<540	<780	<20
Lake Montauk Inlet	6/27/2018	11:19	**1,210**	<1,880	<540	<780	<20
Little Reed Pond Outlet	9/10/2018	10:15	<220	<1,900	<540	<780	<20
South Beach	9/10/2018	10:35	<220	<1,900	<540	<780	300
Lake Montauk Inlet	9/10/2018	10:55	<220	<1,900	<540	<780	40
Lake Montauk near Stepping Stones Pond	9/10/2018	11:09	<220	<1,900	<540	<780	<20
Stepping Stones Pond Culvert	9/10/2018	11:10	<290	<2,500	<720	<1,000	>16,000
Star Island North	9/10/2018	11:16	<220	<1,900	<540	<780	20
Southeast Lake Montauk	9/10/2018	11:18	<220	<1,900	<540	<780	<20
Stepping Stones Pond	9/10/2018	11:20	<440	<3,800	<1,100	<1,600	220
Little Reed Pond Culvert	2/6/2019	9:30	<220	<1,900	<540	<780	<18
Little Reed Pond Outlet	2/6/2019	9:40	<220	<1,900	<540	<780	<18
South Beach	2/6/2019	10:15	<220	<1,900	**[Eb~]570**	<780	<18
Stepping Stones Pond Culvert	2/6/2019	10:40	<370	<3,100	<900	<1,300	<18
Stepping Stones Pond	2/6/2019	11:10	<290	<2,500	<720	<1,000	<18
Lake Montauk Inlet	2/6/2019	11:49	<220	<1,900	<540	780	<18
Star Island North	2/6/2019	11:51	**[Eb~]260**	<1,900	<540	<780	<18
Lake Montauk near Stepping Stones Pond	2/6/2019	12:01	<220	<1,900	<540	<780	<18
Southeast Lake Montauk	2/6/2019	12:05	<220	<1,900	<540	<780	<18
Lake Montauk Inlet	4/17/2019	9:33	**[E~]730**	<2,300	<650	<940	<18
Star Island North	4/17/2019	9:39	<220	<1,900	<540	<780	<18
Lake Montauk near Stepping Stones Pond	4/17/2019	10:01	<220	<1,900	<540	<780	<18
Southeast Lake Montauk	4/17/2019	1003	<220	<1,900	<540	<780	<18
Little Reed Pond Culvert	4/30/2019	10:40	<260	<2,300	**[E~]2,000**	<940	110
Little Reed Pond Outlet	4/30/2019	10:50	<220	<1,900	<540	<780	<18
South Beach	4/30/2019	11:10	<880	<7,500	<2,200	<3,100	170
Stepping Stones Pond Culvert	4/30/2019	11:30	<880	<7,500	<2,200	<3,100	<18

Table 1.2. Data summary of all samples collected in Lake Montauk on Long Island, New York, for bacterial genetic markers and fecal coliform analysis.—Continued

[Samples collected include blanks and replicates. Bacterial genetic markers are human-associated *Bacteroides* (HF183), ruminant-associated *Bacteroides* (Rum2Bac), waterfowl-associated *Helicobacter* (GFD), and canine-associated *Bacteroides* (BacCan) markers. Station data are available from the National Water Information System (U.S. Geological Survey, 2020). *Bacteroides* samples were analyzed by the U.S. Geological Survey Ohio Microbiology Laboratory. Fecal coliform bacteria samples were analyzed by the Suffolk County Department of Health Services Public and Environmental Health Laboratory. Bacterial genetic marker values in bold typeface indicate that the concentration was greater than the reporting limit; values preceded by a less than (<) symbol indicate the reporting limit for a given assay when a nondetect occurred; values preceded by a greater than (>) symbol indicate that the value exceeded the reporting limit for a given assay. EST, Eastern standard time; copies/100mL, copies of genetic marker per 100 milliliters; MPN/100mL, most probable number per 100 milliliters; *, copies of genetic marker per gram dry weight sediment; E, estimate; b, concentration was greater than the limit of quantification but less than the reporting limit; ~, duplicate qPCR results do not agree; —, assay was not performed]

Station name	Date	Time (EST)	HF183 (copies/ 100 mL)	Rum2Bac (copies/ 100 mL)	GFD (copies/ 100 mL)	BacCan (copies/ 100 mL)	Fecal coliform (MPN/ 100 mL)
Stepping Stones Pond	4/30/2019	11:40	**3,200**	<9,000	<2,600	<3,700	20
West Lake Drive near Star Island	6/17/2019	9:40	<220	<1,900	<540	<780	<18
West Lake Drive near Star Island	6/17/2019	9:45	<290	<2,500	<720	<1,000	<18
South Beach	6/17/2019	10:50	<140*	<1,200*	<500*	<350*	—
South West Lake Drive	7/8/2019	10:20	<220	<1,900	<540	<780	<18

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