In cooperation with the Northeast Ohio Regional Sewer District

Escherichia coli Concentrations in the Mill Creek Watershed, Cleveland, Ohio, 2001–2004

Open-File Report 2007–1171

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

Cover. Mill Creek in Garfield Heights, Ohio. Photograph by Bernie Sroka, U.S. Geological Survey.

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Suggested citation:
Brady, A.M.G., 2007, *Escherichia coli* concentrations in the Mill Creek watershed, Cleveland, Ohio, 2001–2004: U.S. Geological Survey Open-File Report 2007–1171, 26 p.

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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
liter (L)	0.2642	gallon (gal)
million gallons (Mgal)	3,785	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

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

°F=(1.8×°C)+32

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

°C=(°F-32)/1.8

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Concentrations of bacteria in water are given in colony-forming units per 100 milliliters (CFU/100 mL).

Instantaneous discharges are given in colony-forming units of *Escherichia coli* per second (CFU/s).

Escherichia coli Concentrations in the Mill Creek Watershed, Cleveland, Ohio, 2001–2004

By Amie M. G. Brady

Abstract

Mill Creek in Cleveland, Ohio, receives discharges from combined-sewer overflows (CSOs) and other sanitary-sewage inputs. These discharges affect the water quality of the creek and that of its receiving stream, the Cuyahoga River. In an effort to mitigate this problem, the Northeast Ohio Regional Sewer District implemented a project to eliminate or control (by reducing the number of overflows) all of the CSOs in the Mill Creek watershed. This study focused on monitoring the microbiological water quality of the creek before and during sewage-collection system modifications.

Routine samples were collected semimonthly from August 2001 through September 2004 at a site near a U.S. Geological Survey stream gage near the mouth of Mill Creek. In addition, event samples were collected September 19 and 22, 2003, when rainfall accumulations were 0.5 inches (in.) or greater. Concentrations of *Escherichia coli* (*E. coli*) were determined and instantaneous discharges were calculated. Streamflow and water-quality characteristics were measured at the time of sampling, and precipitation data measured at a nearby precipitation gage were obtained from the National Oceanic and Atmospheric Administration.

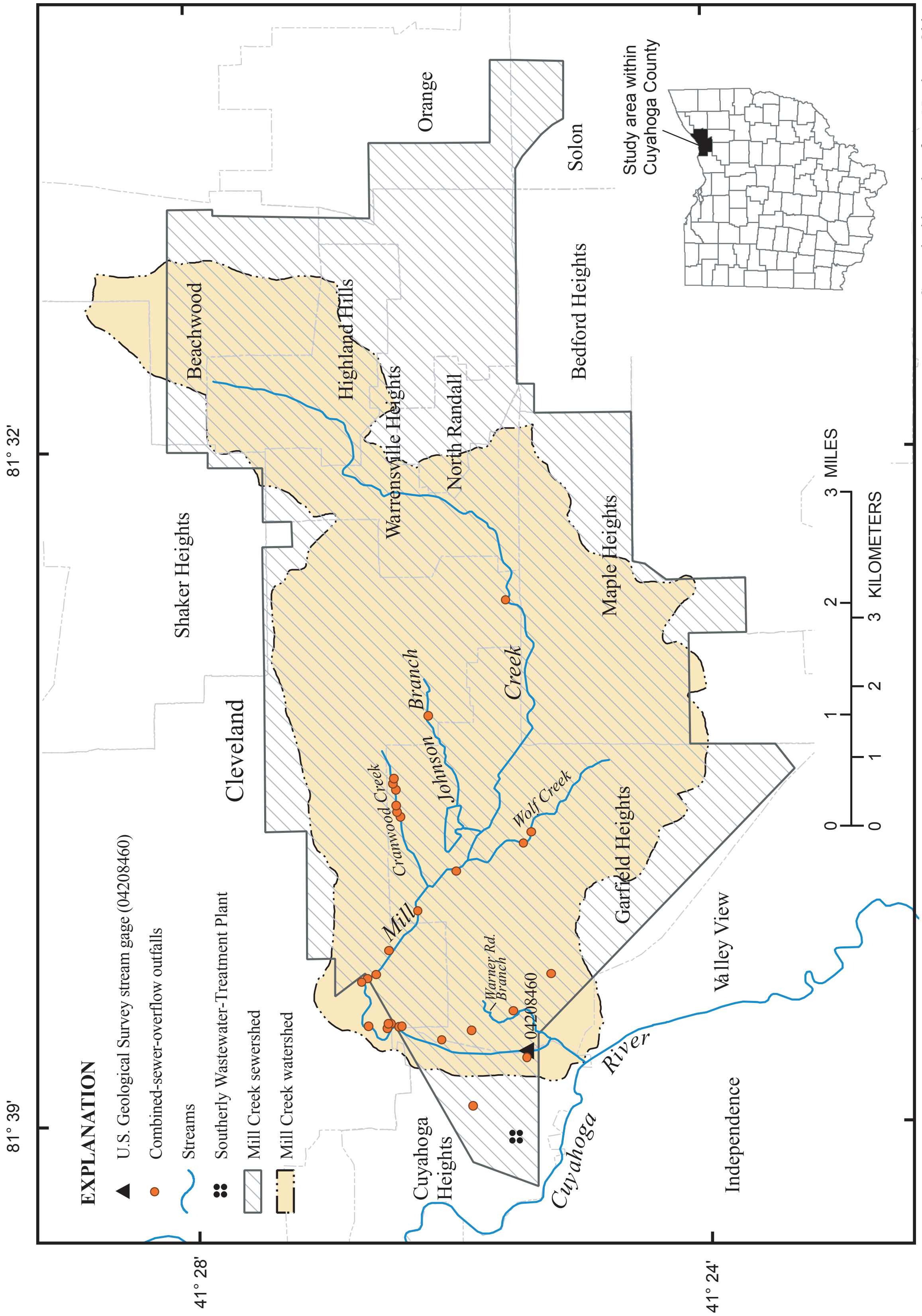
Concentrations of *E. coli* were greater than Ohio's single-sample maximum for primary-contact recreation (298 colony-forming units per 100 milliliters (CFU/100 mL)) in 84 percent of the routine samples collected. In all but one routine sample, *E. coli* concentrations in samples collected when instantaneous streamflows were greater than 20 cubic feet per second (ft^3/s) were greater than Ohio's single-sample maximum. When precipitation occurred in the 24-hour period before routine sample collection, concentrations were greater than the maximum in 89 percent of the samples as compared to 73 percent when rainfall was absent during the 24 hours prior to routine sample collection.

Before modifications to the sewage-collection system in the watershed began, *E. coli* concentrations in Mill Creek ranged from 220 to 29,000 CFU/100 mL. After major modifications, *E. coli* concentrations ranged from 110 to 80,000 CFU/100 mL. The percentage of sample *E. coli* concentrations in the former group greater than Ohio's single-sample maximum was 88 percent, whereas 85 percent of sample concentrations was greater than the maximum after major modifications occurred. Instantaneous discharges of *E. coli* were calculated for each of the modification periods. No statistically significant difference was observed between the median instantaneous discharges of *E. coli* for the premodification and minor-modification periods (5.1×10^6 and 3.6×10^6 CFU per second, respectively).

During rainfall events in September 2003, samples were collected every 15 to 30 minutes. *E. coli* concentrations in all of these samples (*n* = 34) were greater than Ohio's single-sample maximum for primary-contact recreation. On September 19, total accumulated rainfall was 1.7 in., and streamflow reached a peak of 1,040 ft^3/s. Sample collection started after 0.8 in. of precipitation had fallen and continued throughout the remainder of the storm. For these samples, *E. coli* concentrations ranged from 32,000 to 140,000 CFU/100 mL. On September 22, total accumulated rainfall was 0.5 in., and streamflow reached a peak of 497 ft^3/s. Sample collection began before the start of the rain and continued throughout the storm. *E. coli* concentrations ranged from 450 to 260,000 CFU/100 mL.

Introduction

Mill Creek is a tributary of the Cuyahoga River in Cleveland, Ohio (fig. 1). Combined-sewer overflows (CSOs) and sanitary-sewer overflows from aging sewers, along with spills and runoff from landfills, have resulted in water-quality problems in Mill Creek, which in turn have affected the water quality in the Cuyahoga River (Ohio Environmental Protection Agency, 2003a). These overflows can result in health risks to people who use the creek and (or) river for recreation. *Escherichia coli* (*E. coli*) is an indicator of fecal contamination because it inhabits the gastrointestinal tract of warmblooded animals and, as such, its presence also indicates a potential for exposure to pathogenic organisms. Ohio has developed recreational water-quality standards (Ohio Environmental Protection Agency, 2003b) based in part on a U.S. Environmental Protection Agency (USEPA) study in which rates of swimming-related gastrointestinal illness were found to be related to concentrations of *E. coli* in the water (Dufour, 1984).



Sewershed boundary from Northeast Ohio Regional Sewer District, 2005

Figure 1. Location of the study area in northeast Ohio, showing all combined-sewer overflows present before sewage-collection system improvements.

Waters designated “primary contact” are suitable for full-body contact such as swimming and canoeing, whereas “secondary-contact waters” are suitable for partial-body contact such as wading. Mill Creek has been designated by the Ohio Environmental Protection Agency (Ohio EPA) as a primary-contact water. *E. coli* has often been found in both Mill Creek and the Cuyahoga River at concentrations greater than Ohio’s water-quality standards for water-contact recreation (Northeast Ohio Regional Sewer District, 1996; Ohio Environmental Protection Agency, 2003a).

During studies conducted by the Ohio EPA in 1998 and 2002, Mill Creek was designated as a “Category 5” water on Ohio’s Section 303(d) list (1998), meaning it is impaired or threatened. Section 303(d) of the Clean Water Act requires states, territories, and authorized tribes to list and prioritize waters that are impaired and requires that restoration solutions be developed. Total Maximum Daily Loads (TMDL) for bacteria (fecal coliforms and *E. coli*) were developed for the lower Cuyahoga, which includes Mill Creek, by the Ohio EPA and were approved by the USEPA in 2003 (Ohio Environmental Protection Agency, 2006). The Ohio EPA plans to conduct another survey of this segment of the watershed in 2020 (Ohio Environmental Protection Agency, 2006).

To comply with USEPA and Ohio EPA regulatory policies, the Northeast Ohio Regional Sewer District (NEORSD) implemented a modification plan to eliminate or control (by reducing the number of overflows) all of the CSOs in the Mill Creek watershed. This plan incorporates (1) the construction of a tunnel to store wet-weather flow until it can be conveyed to and treated by the Southerly Wastewater Treatment Plant, and (2) construction of new relief sewers to provide additional conveyance to the present interceptor upstream of the tunnel. After all of the modifications to the sewage-collection system are completed, the project is expected to reduce annual overflows to Mill Creek by approximately 430 Mgal (Lester Stumpe, Northeast Ohio Regional Sewer District, written commun. 2007).

In cooperation with the NEORSD, the U.S. Geological Survey (USGS) developed a project to monitor *E. coli* concentrations and compute discharges before and during modifications to the sewage-collection system. Many municipalities across the country are facing issues with aging and failing sewage-collection systems. It was hoped that this study would serve as a demonstration project for other municipalities wanting to monitor their sewage-collection-system modification projects.

Purpose and Scope

This report describes the results of a study to characterize concentrations of *E. coli* in Mill Creek in Cleveland, Ohio, from August 2001 through September 2004, during which time modifications to the sewage-collection system were made. Samples were collected semimonthly near a USGS stream gage on Mill Creek at Garfield Heights and analyzed for *E. coli* concentrations. These data were then examined as a function of streamflow and precipitation, as well as before modifications and during minor modifications to the sewage-collection system to determine whether a reduction of instream concentrations and discharges to the Cuyahoga River could be observed following modifications to the sewage-collection system. In addition, samples collected during two rain events were examined as a function of streamflow and precipitation.

Description of Study Area

Mill Creek drains southeastern Cleveland, Ohio, and its suburbs and has a total drainage area of 19.4 mi^2. The sewer service area, or sewershed, is 27.8 mi^2 and covers most of the watershed (fig. 1). Mill Creek flows into the Cuyahoga River at Independence, Ohio, at about river mile 11.5. The creek originates near Beachwood and flows generally west-southwest. The land use in the watershed is primarily residential and industrial with some wooded areas, and primary-contact recreation is listed by the Ohio EPA among the designated uses of the stream. Although a few segments are culverted, most of the creek is open and natural. The most unique feature of the creek is a waterfall a few miles upstream from the mouth. Typically, streamflows are highest in May and lowest during the late summer or fall (July–October). In October 2001, flows were exceptionally low, and the daily mean was 0.00 ft^3/s on October 3 and 11. Monthly mean flows range from 15.9 to 53.3 ft^3/s (Shindel and others, 2005).

Historically, Mill Creek has been one of the most contaminated streams in the Greater Cleveland Area (Northeast Ohio Regional Sewer District, 1996; Ohio Environmental Protection Agency, 2003a). The source of contamination is mainly from CSOs or failing or malfunctioning home sewage-disposal systems; other sources include spills and runoff from landfills (Lester Stumpe, Northeast Ohio Regional Sewer District, written commun., 2007). Prior to sewage-collection-system modifications, there were a total of 28 CSOs in the watershed. Often, Mill Creek has not met Ohio EPA water-quality standards for primary-contact recreation during either dry- or wet-weather conditions. Primary-contact waters are defined as waters that during the recreation season (May 1 to October 15) are suitable for full-body-contact recreation such as swimming, canoeing, and scuba diving with minimal threat to public health as a result of water quality (Ohio Environmental Protection Agency, 2003b).

Sewage-Collection-System Modifications

The NEORSD began sewage-collection-system modifications in the Mill Creek watershed in May 1997. A tunnel to store and convey wet-weather flow is the backbone of the modification plan. Between August 7 and October 28, 2002, 6 of the 28 Mill Creek CSOs were eliminated or controlled (by reducing the number of overflows) and their overflows redirected into the newly constructed tunnel. These modifications in the sewage-collection system have been estimated to reduce annual overflows into Mill Creek by more than 320 Mgal. Six more CSOs were eliminated or controlled from May 2003 through May 2004. These modifications have been estimated to reduce annual overflows by another 21 Mgal. Further modifications to the sewage-collection system were completed during 2005 and 2006, with estimated reductions in overflows of more than 88 Mgal per year (Lester Stumpe, Northeast Ohio Regional Sewer District, written commun., 2007).

To assist in describing the data, the modification timeline has been divided into three periods based on the volume of overflows eliminated: premodification, major modification, and minor modification. Samples collected prior to August 7, 2002, are characterized as "premodification" samples, meaning they were collected before any CSOs were controlled or eliminated. "Major-modification" samples are those that were collected between August 7 and October 28, 2002, when the most significant modifications to the sewage-collection system were completed (annual overflow reductions of an estimated 320 Mgal). Samples collected after October 28, 2002, are termed "minor-modification" samples (annual overflow reductions of an estimated 22 Mgal).

Methods of Study

The NEORSD collected stream samples before and during sewage-collection system modifications. Samples that were collected semimonthly near the USGS stream gage on Mill Creek at Garfield Heights (station identification number 04208460) are referred to as "routine" samples (fig. 1). A total of 86 routine samples were collected from August 2001 through September 2004. Additional samples that were collected during two rain events in September 2003 are referred to as "event" samples. During these rain events, samples were collected every 15 to 30 minutes for 3.5 to 9 hours (depending on the duration of the rainfall). Stage, used to estimate instantaneous streamflow, was obtained from the USGS stream gage at each sampling. Field measurements of water temperature, pH, dissolved oxygen, and specific conductance were made each time stream samples were collected, but no analyses were conducted on these data.

E. coli concentrations were used to monitor recreational water quality. The Ohio primary-contact single-sample maximum of 298 CFU/100 mL was used as a benchmark to evaluate water quality in this report. For water-quality standards attainment, this standard cannot be exceeded in more than 10 percent of the samples collected during any 30-day period (Ohio Environmental Protection Agency, 2003b).

Sampling Procedures and Microbiological Methods

Sterile techniques were used throughout collection and analysis of samples. Whenever practical, samples were collected using the equal-width-increment method as described by Edwards and Glysson (1999). This method results in a composite sample that represents the streamflow-weighted concentrations of the stream cross section sampled. A handheld depth-integrating sampler was used to collect samples into sterile 1-L polypropylene bottles, which were immediately placed in a cooler with ice and taken to the NEORSD laboratory in Cuyahoga Heights, Ohio, for analysis. If the stream depth and (or) velocity was not sufficient to obtain an isokinetic sample, the sample was collected by the hand-dip method. This method was only required for four routine samples when the creek was frozen and a hand-dip sample was collected after the ice was chipped away (January and February 2004).

Standard membrane-filtration techniques were used with mTEC agar (U.S. Environmental Protection Agency, 1985) to process the samples for *E. coli* enumeration within 6 hours of collection. In this method, samples are filtered through a 0.45-µm-pore-size membrane filter, and the filter is placed onto an mTEC plate. The plates are incubated for 2 hours at 35°C and then transferred to an incubator set to 44.5°C for the remainder of the 22- to 24-hour incubation period. After incubation, the membranes containing colonies are placed onto absorbent pads containing urea broth. Colonies that remain yellow after 15 to 20 minutes are counted as *E. coli*. Concentrations of *E. coli* were calculated using methods described in Myers (2004) and expressed as colony-forming units per 100 milliliters (CFU/100 mL).

Water-Quality and Ancillary Environmental Information

The USGS stream gage on Mill Creek is approximately 0.6 mi upstream from the mouth (fig. 1) and has a contributing drainage area of 17.9 mi^2. Stage, used to estimate instantaneous streamflow, was obtained from the USGS stream gage at each sampling. Water temperature, pH, dissolved oxygen, and specific conductance were measured with a multiparameter water-quality meter each time a sample was collected. The water-quality meter was calibrated before the samples for each day were collected. Daily precipitation amounts were obtained from the precipitation gage at Cleveland Hopkins International Airport (National Oceanic and Atmospheric Administration, 2005b), approximately 13 mi from the sampling site. Trace amounts of rain were transformed to 0.005 in. for data-analysis purposes.

Quality Assurance and Quality Control

Quality-assurance and quality-control (QA/QC) procedures were followed for all phases of data collection and analysis in the field and laboratory and during data validation and assessment. Good field and laboratory practices—cleanliness, safety practices, procedures for media preparation, and specifications for reagent water quality—were adopted by

USGS and NEORSD employees as set forth by American Public Health Association and others (1998) and Britton and Greeson (1989).

Equipment and supplies were routinely checked to ensure proper performance. The incubators were checked to ensure that temperatures were 35°C ± 0.5°C and 44.5 ± 0.2°C. Buffer and media were checked through the use of blanks—sterile buffer water was filtered before and after every sample. Autoclaves also were monitored for proper operation by use of heat-indicating tape (to identify that the equipment was properly sterilized) and by spore strips (vials of bacteria tested for growth after sterilization).

A field blank was collected near the beginning of the project. The collection procedure consisted of taking a 1-L bottle of sterile buffer water, attaching a sterile adaptor and nozzle, and pouring the sterile buffer water into a new, sterile, 1-L bottle. This was treated as a sample and plated in duplicate. Collection of the field blank at the field site is used to demonstrate whether proper sampling procedures are followed and that field personnel are not inadvertently contaminating the samples.

QA/QC samples for *E. coli* analyses were collected by NEORSD and the USGS. NEORSD collected sequential-split replicates every sampling date (approximately 30 annually). A sequential split-replicate consists of two samples collected in succession with aliquots from each sample analyzed twice. The *E. coli* concentrations reported and used in data analysis for routine samples are an average of these split replicates. Twice a year, the USGS collected and analyzed concurrent sequential split-replicate samples. QA/QC samples for *E. coli* analyses were used to qualitatively assess data and were not used for data interpretation.

Routine Sampling

Routine samples were collected from August 2001 through September 2004. A total of 86 samples were collected semimonthly near the USGS stream gage on Mill Creek. The following sections describe environmental and water-quality variables during this study period and their relations to *E. coli* concentrations in the creek. Streamflow, water-quality, and microbiological data are presented in table 1 (at back of report).

Streamflow and Rainfall Characteristics

Streamflow was determined by means of standard USGS techniques (Rantz and others, 1982). Instantaneous streamflow is the streamflow at a particular instant of time (determined from established stage-streamflow relations). Instantaneous streamflows (15-minute recording intervals) for the sampling period in comparison with those at the time of sampling are shown in figure 2. Shading on the figure indicates periods associated with different levels of sewage-collection-system modifications (premodification, major modification, and minor modification).

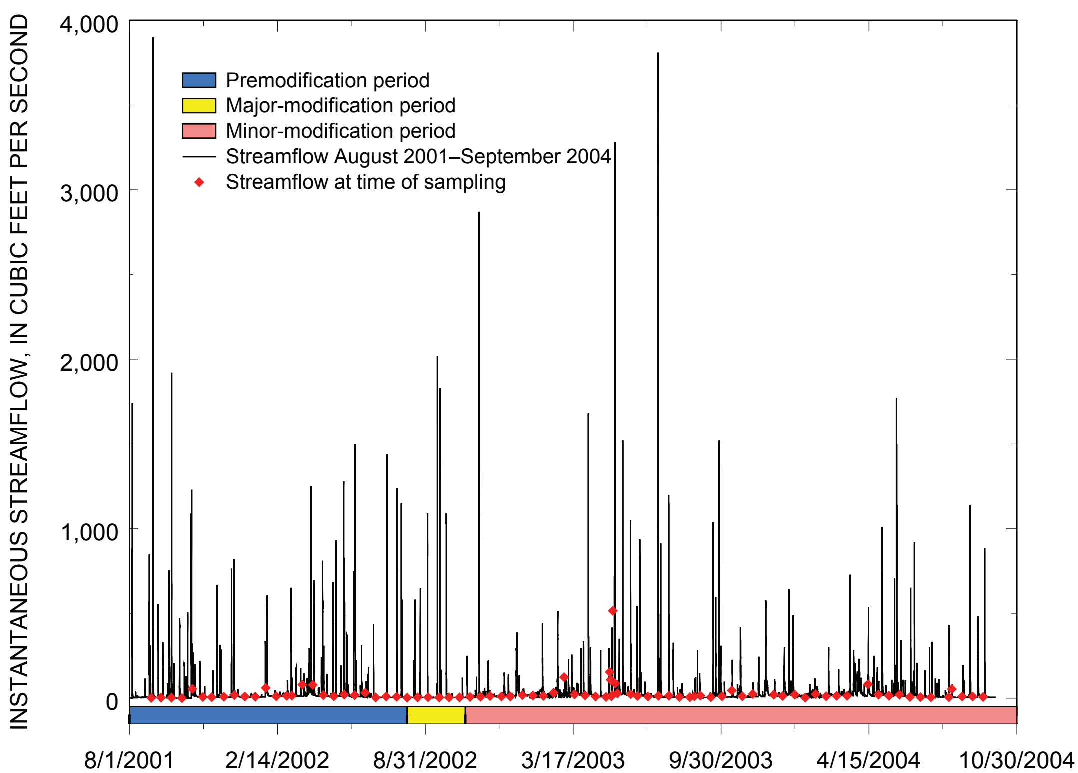


Figure 2. Instantaneous streamflows near the mouth of Mill Creek, Garfield Heights, Ohio, August 2001–September 2004, as related to period of sewage-collection-system modification. Modification periods are defined as “premodification” (prior to August 7, 2002), “major modification” (August 7 to October 24, 2002), and “minor modification” (after October 24, 2002).

For the entire sampling period, instantaneous streamflow ranged from 0.00 ft^3/s in October 2001 to a maximum of 3,900 ft^3/s in August 2001 with a median value of 11.0 ft^3/s. The streamflow range sampled was 0.03 ft^3/s in October 2001 to 515 ft^3/s in May 2003. The median streamflow for this data set was 12 ft^3/s. Routine sampling did not represent the 0.5 percent of streamflows that were greater than 515 ft^3/s.

During the sampling period, precipitation fell on 60 percent of the days. On the days precipitation fell, daily total rainfall ranged from trace amounts of rain to 2.22 in., with a median of 0.09 in. The maximum daily total (2.22 in.) was on July 8, 2003. The average annual precipitation in the study area is 38.7 in. (National Oceanic and Atmospheric Administration, 2005a). For the sampling period, the annual precipitation totals for 2001 thru 2004 were 37.0, 37.2, 45.0, and 42.3 in., respectively, with an average of 40.4 in.

Statistics for instantaneous streamflow during the entire sampling period and at the time of sampling, and daily precipitation for the three sewage-collection-system modification periods are listed in table 2 (at back of report). Instantaneous streamflows for the premodification period and the minor-modification period show similar minimum and maximum values, but the median value for the minor-modification period was slightly higher (14 ft^3/s) than that of the premodification period (8.6 ft^3/s). During the minor-modification period, precipitation fell on 65 percent of the days, whereas during the premodification period, precipitation fell on 56 percent of the days.

Relation of Concentrations of *Escherichia coli* to Streamflow and Precipitation

E. coli concentrations in the 86 routine samples collected for this study ranged from 110 to 80,000 CFU/100 mL (fig. 3). The median concentration was 1,000 CFU/100 mL. Concentrations were greater than Ohio's single-sample *E. coli* maximum for primary-contact recreation of 298 CFU/100 mL 84 percent of the time. Additionally, *E. coli* concentrations were greater than Ohio's single-sample maximum for secondary-contact recreation of 576 CFU/100 mL 69 percent of the time.

To examine the relation between instantaneous streamflow and *E. coli* concentrations, results were placed into four groups of nearly equal size on the basis of magnitude of streamflow. Box plots of *E. coli* distributions for these four groups are shown in figure 4. For samples collected when streamflow was greater than 20 ft^3/s (the group with the highest streamflows, $n = 20$), *E. coli* concentrations were greater than Ohio's single-sample maximum for primary-contact recreation in all but one sample. This group's median *E. coli* concentration was significantly larger than that of the other groups based on a Tukey-Kramer multiple-comparison test on the $\log_{10}$-transformed data. (The Tukey-Kramer test compares all possible pairs of treatment group medians and is powerful even when treatment group sizes are unequal (Helsel and Hirsch, 2002). The level of significance was set at $\alpha \leq 0.05$.)

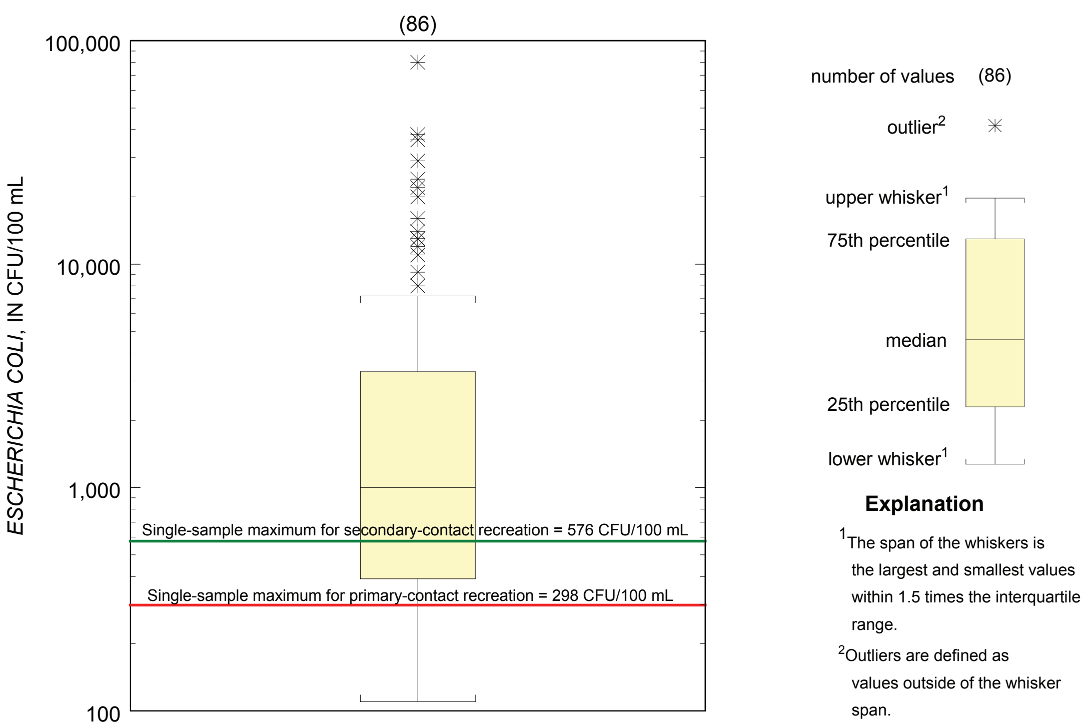


Figure 3. Distribution of *Escherichia coli* concentrations for routine samples collected near U.S. Geological Survey stream gage 04208460, Mill Creek, Garfield Heights, Ohio, August 2001–September 2004. Primary- and secondary-contact recreation maximums are set by the Ohio Environmental Protection Agency (Ohio Environmental Protection Agency, 2002). (CFU/100 mL, colony-forming units per 100 milliliters.)

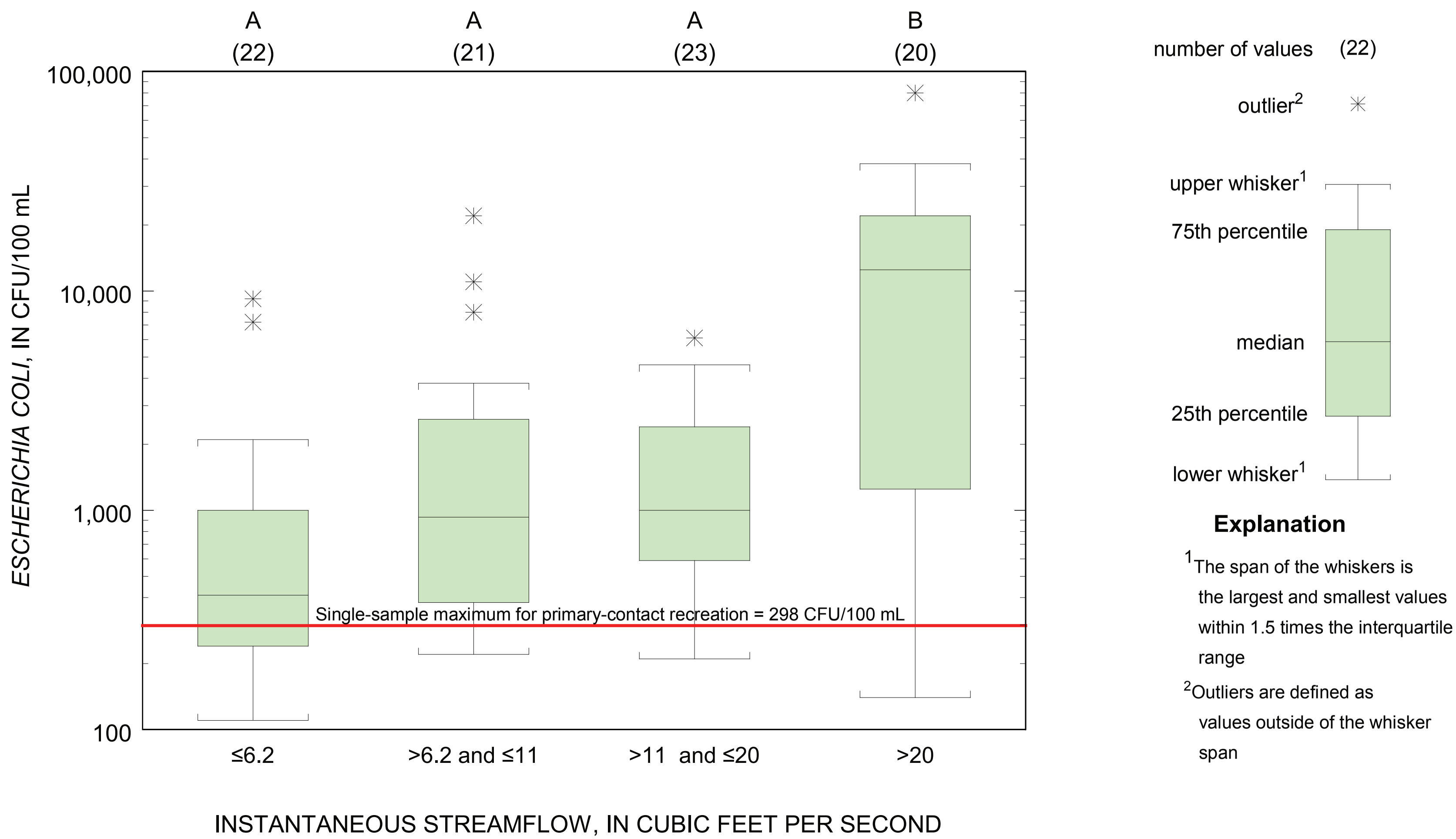


Figure 4. Distribution of *Escherichia coli* concentrations as a function of four ranges of instantaneous streamflow during routine sampling near U.S. Geological Survey stream gage 04208460, Mill Creek, Garfield Heights, Ohio, August 2001–September 2004. (Results of Tukey-Kramer multiple comparison test on the $\log_{10}$-transformed data are presented as letters, and groups with a letter in common do not differ significantly at $\alpha = 0.05$.) Primary-contact recreation maximum is set by the Ohio Environmental Protection Agency (Ohio Environmental Protection Agency, 2002). (CFU/100 mL, colony-forming units per 100 milliliters; ≤, less than or equal to; >, greater than.)

Another variable examined was the previous 24-hour precipitation amount (the amount of precipitation that fell in the 24-hour period before 9 a.m. on the day of sampling). Concentrations of *E. coli* in routine samples collected after a dry 24-hour period were compared to concentrations in routine samples collected after precipitation occurred during the previous 24 hours. Box plots of *E. coli* concentrations for these groups are shown in figure 5. The median *E. coli* concentration in samples collected after precipitation fell was 1,400 CFU/100 mL, whereas the median concentration in samples collected when there was no precipitation was 600 CFU/100 mL. A Wilcoxon rank-sum test on these data indicated a significant difference between the medians for these two groups ($Z = -3.25$, $p = 0.0011$). (The Wilcoxon rank-sum test, a nonparametric procedure, is used to compare two independent groups of data. The level of significance was set at $\alpha \leq 0.05$.)

Relation of Concentrations of *Escherichia coli* to Modifications of the Sewage-Collection System

During the premodification period, *E. coli* concentrations in collected samples ($n = 25$) ranged from 220 to 29,000 CFU/100 mL, with a median of 1,300 CFU/100 mL (fig. 6). Concentrations in 88 percent of the samples collected during this period were greater than Ohio's single-sample maximum for primary-contact recreation. *E. coli* concentrations in samples collected during the major-modification period ranged from 120 to 2,100 CFU/100 mL, with a median of 280 CFU/100 mL. Three of the six samples collected during the major-modification period were greater than Ohio's single-sample maximum. Concentrations in samples collected during the minor-modification period ranged from 110 to 80,000 CFU/100 mL with a median of 1,000 CFU/100 mL. Of the samples collected during this period ($n = 55$), 85 percent of the samples were greater than Ohio's single-sample maximum. A Wilcoxon rank-sum test comparing *E. coli* concentrations in samples collected during the premodification and minor-modification periods indicated no significant difference between the median values for these two groups ($Z = -0.70$, $p = 0.4834$).

To represent the magnitude of *E. coli* transport in the creek at the time of sampling, instantaneous discharges of *E. coli* were computed as follows:

$$E.\ coli\ \text{concentration (CFU/100 mL)} \times (10^6\ \text{mL} / 1\ \text{m}^3) \times (1\ \text{m}^3 / 35.31\ \text{ft}^3) \times \text{streamflow (ft}^3\text{/s)}$$

to obtain instantaneous discharges with the units of colony-forming units of *E. coli* per second (CFU/s).

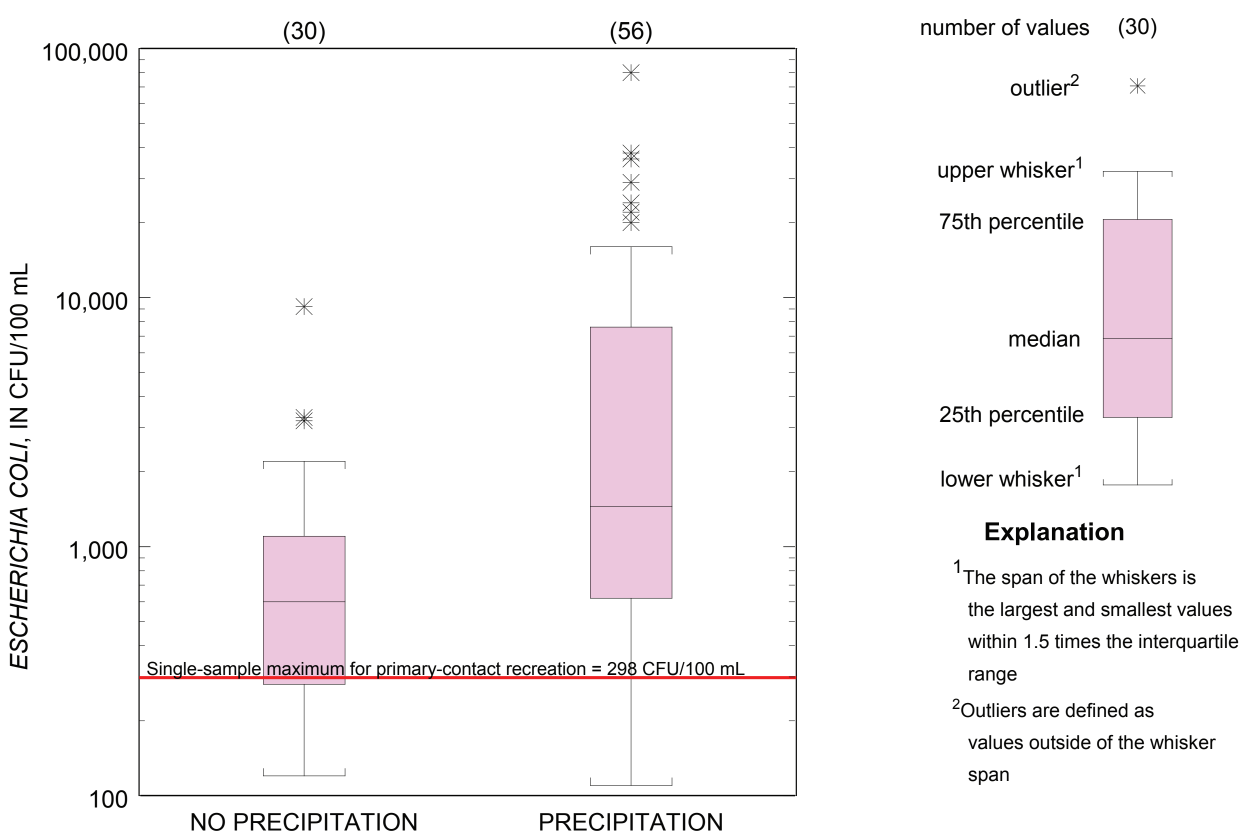


Figure 5. Distribution of *Escherichia coli* concentrations in routine samples collected near U.S. Geological Survey stream gage 04208460, Mill Creek, Garfield Heights, Ohio, when there was no precipitation and when precipitation fell in the 24-hour period prior to 9 a.m. on the day of sampling, August 2001–September 2004. Primary-contact recreation maximum is set by the Ohio Environmental Protection Agency (Ohio Environmental Protection Agency, 2002). (CFU/100 mL, colony-forming units per 100 milliliters.)

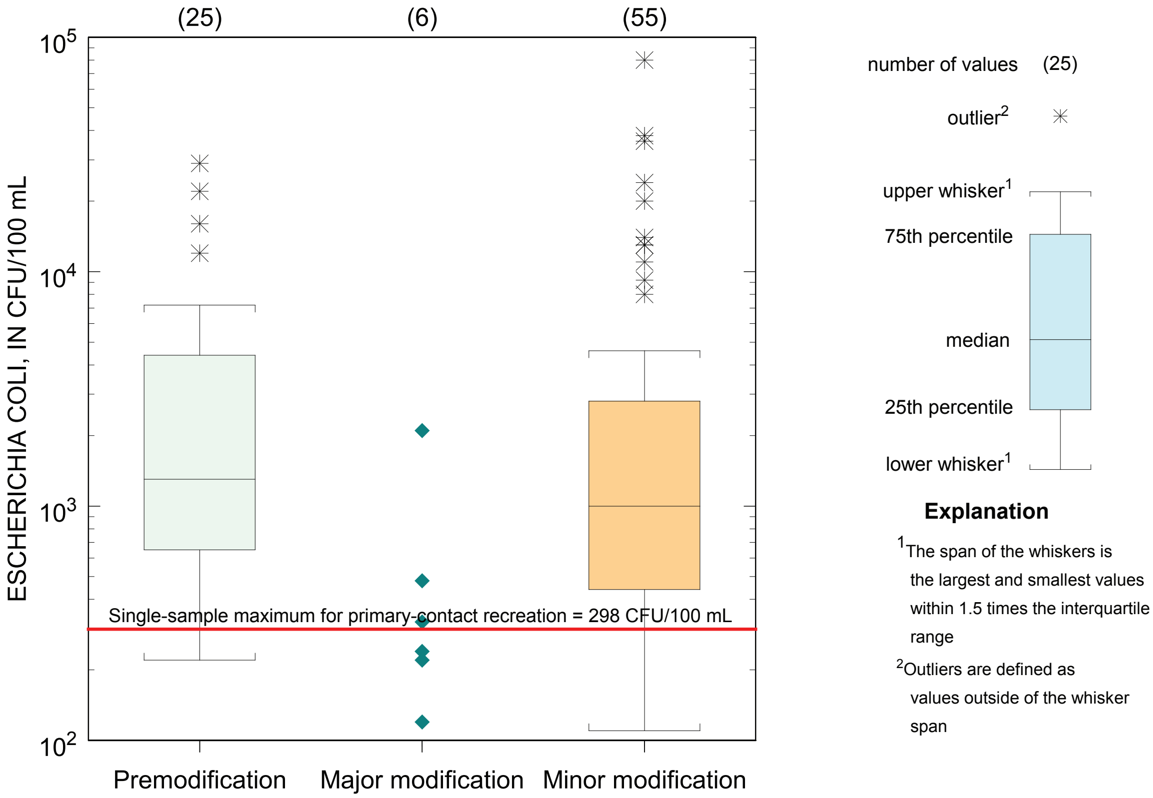


Figure 6. Distribution of *Escherichia coli* concentrations in routine samples collected near U.S. Geological Survey stream gage 04208460, Mill Creek, Garfield Heights, Ohio, during modification periods in the Mill Creek watershed, August 2001–September 2004. Primary-contact recreation maximum is set by the Ohio Environmental Protection Agency (Ohio Environmental Protection Agency, 2002). (CFU/100 mL, colony-forming units per 100 milliliters.)

Among the 86 routine samples, instantaneous discharges of *E. coli* ranged from 5.9×10^3 to 1.2×10^{10} CFU/s with a median of 3.3×10^6 CFU/s. For the pre-, major-, and minor-modification periods, the median instantaneous discharges were 5.1×10^6, 3.0×10^5, and 3.6×10^6 CFU/s, respectively. A Wilcoxon rank-sum test comparing instantaneous discharges of *E. coli* during the premodification and minor-modification periods indicated that there was no significant difference between the median values for these two groups ($Z = 0.42$, $p = 0.6742$). Instantaneous discharges of *E. coli* in relation to instantaneous streamflow are shown in figure 7.

Rainfall-Event Sampling

Samples were collected near the USGS stream gage near the mouth of Mill Creek during two rainfall events in September 2003. Nineteen samples were collected on September 19 immediately after a rainfall accumulation of approximately 0.8 in. and during the remainder of the rainfall event (fig. 8*A*). The total accumulation of rain was 1.7 in. Instantaneous streamflow during sampling ranged from 90 to 1,040 ft^3/s. The median concentration of *E. coli* for these samples was 74,000 CFU/100 mL, and concentrations ranged from 32,000 to 140,000 CFU/100 mL. Concentrations in all of the samples collected during this event were greater than Ohio's single-sample maximum for primary-contact recreation. Instantaneous discharges of *E. coli* ranged from 1.0×10^9 to 2.4×10^{10} CFU/s with a median of 7.3×10^9 CFU/s.

Samples collected on September 22 included one sample before any recorded rainfall and 14 samples collected during the rainfall event (fig. 8*B*). The total accumulation of rainfall was 0.5 in. Instantaneous streamflow during sampling ranged from 9.1 to 497 ft^3/s. The concentration of *E. coli* in the sample collected before any rainfall was 590 CFU/100 mL. *E. coli* concentrations in samples collected after the rain began ranged from 450 to 260,000 CFU/100 mL, and the median value in these samples was 82,000 CFU/100 mL. The concentrations of *E. coli* did not increase appreciably until more than 0.3 in. of rain had fallen (fig. 8*B*). The highest *E. coli* concentration (260,000 CFU/100 mL) was observed in a sample collected at peak streamflow (497 ft^3/s). After streamflow reached its maximum, *E. coli* concentrations decreased and ranged from 73,000 to 170,000 CFU/100 mL for the remainder of the event sampling. Concentrations in all of the samples collected during this event were greater than Ohio's single-sample maximum for primary-contact recreation. Instantaneous discharges of *E. coli* ranged from 1.2×10^6 to 3.6×10^{10} CFU/s, with a median of 8.2×10^9 CFU/s.

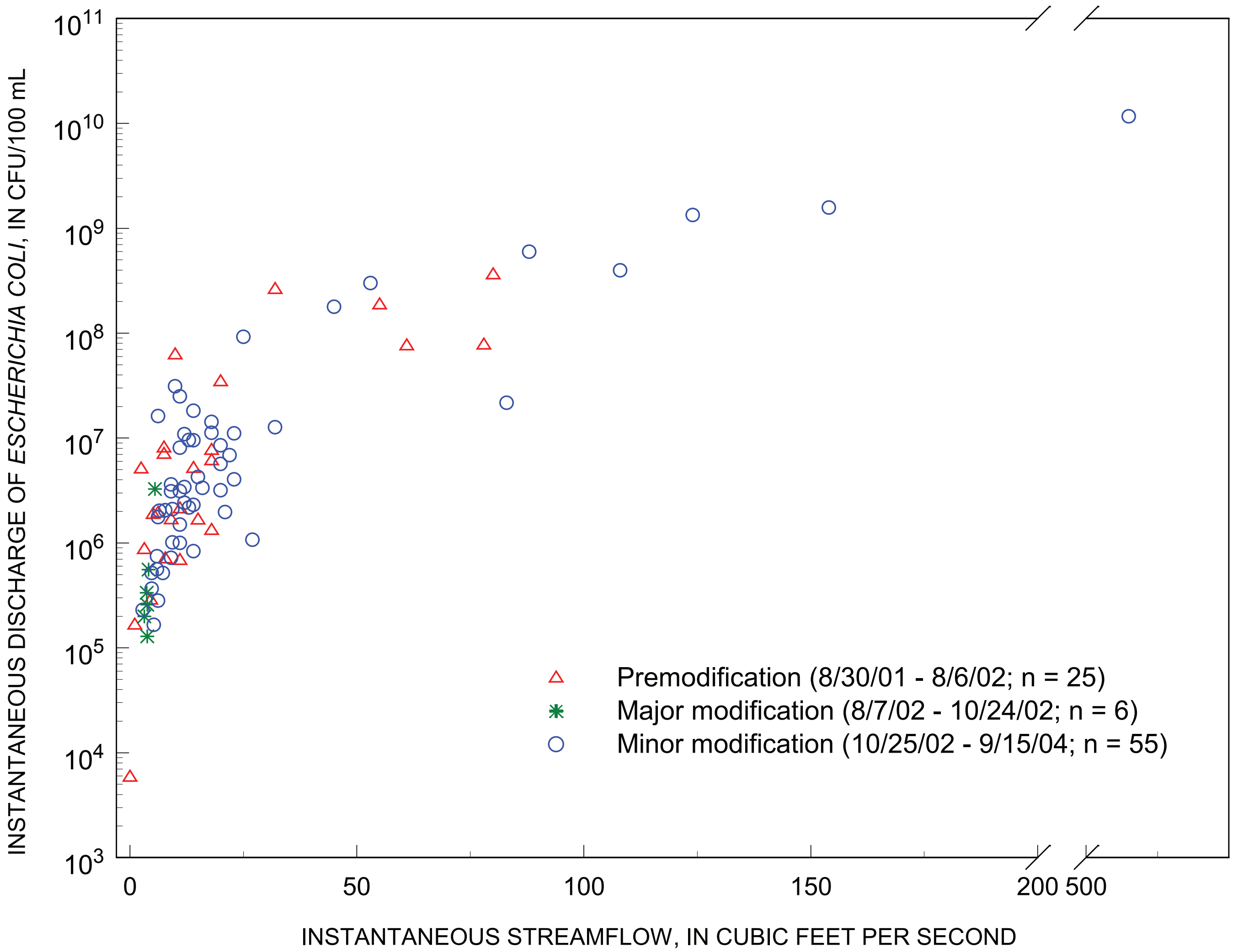


Figure 7. Scatterplot of instantaneous discharges of *Escherichia coli* against instantaneous streamflow before and during modifications to the sewage-collection system in the Mill Creek watershed, Cleveland, Ohio, August 2001–September 2004. (CFU/100 mL, colony-forming units per 100 milliliters.)

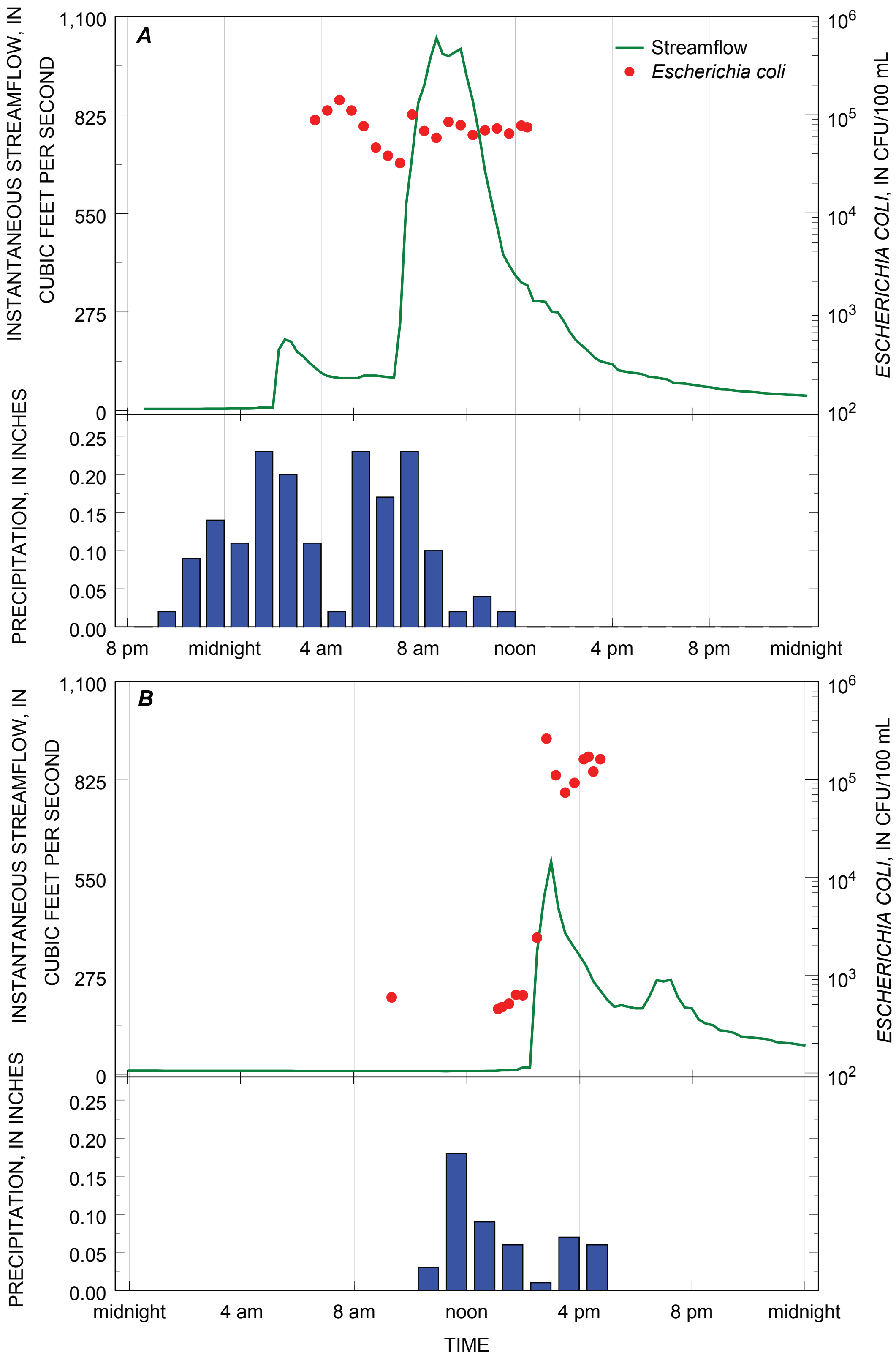


Figure 8. Distribution of *Escherichia coli* concentrations, instantaneous streamflow, and precipitation for rainfall event samples collected near U.S. Geological Survey stream gage 04208460, Mill Creek, Garfield Heights, Ohio. ***A***. September 19, 2003. ***B***. September 22, 2003. (CFU/100 mL, colony-forming units per 100 milliliters.)

Summary

Mill Creek is a small tributary of the Cuyahoga River in Cleveland, Ohio. Historically, it has been considered one of the most heavily contaminated streams in the Greater Cleveland Area (Northeast Ohio Regional Sewer District, 1996; Ohio Environmental Protection Agency, 2003a). Numerous sources of sewage inputs to the stream can pose a health risk to recreationists using the creek and (or) river. *E. coli* concentrations in the creek often have been greater than Ohio's *E. coli* single-sample maximum for primary-contact recreation (298 CFU/100 mL). To help mitigate the contamination issues caused by the combined-sewer overflows (CSOs), the Northeast Ohio Regional Sewer District (NEORSD) has implemented a plan to eliminate or control (by reducing the number of overflows) all of the CSOs in the Mill Creek watershed. This plan incorporates the construction of a tunnel to store and convey wet-weather flow until it can be treated by the Southerly Wastewater Treatment Plant.

The USGS, in cooperation with the NEORSD, investigated *Escherichia coli* (*E. coli*) concentrations in the creek before (August 2001–July 2002) and during (August 2002–September 2004) modifications to the sewage-collection system in the Mill Creek watershed. Specifically, concentrations and instantaneous discharges of *E. coli* in the creek near its mouth were analyzed to determine whether a reduction of instream concentrations and discharges to the Cuyahoga River could be observed following modifications to the sewage-collection system. "Routine" samples were collected by NEORSD semimonthly from August 2001 through September 2004, and "event" samples were collected during two rain events in September 2003. Streamflow and other water-quality characteristics (water temperature, pH, specific conductance, and dissolved oxygen) were also measured at each sampling.

For routine samples, *E. coli* concentrations ranged from 110 to 80,000 CFU/100 mL. Concentrations were greater than Ohio's *E. coli* single-sample maximum for primary-contact recreation in 84 percent of the samples collected. An examination of the relation between log *E. coli* concentration and streamflow revealed that at streamflows greater than 20 ft^3/s, concentrations in all but one of the samples were greater than Ohio's *E. coli* single-sample maximum for primary-contact recreation. In addition, when precipitation fell within 24 hours before routine sampling, the median *E. coli* concentration was significantly greater than when there was no precipitation.

E. coli water-quality results were examined in groups referred to as "premodification," "major-modification," and "minor-modification" periods. Significant modifications to the sewage-collection system—completed between August 7 and October 28, 2002—were expected to reduce annual combined-sewer overflows by over 320 Mgal. This time interval is referred to as the major-modification period. The premodification and minor-modification periods bracket this interval. *E. coli* concentrations in samples collected ranged from 220 to 29,000 CFU/100 mL for the premodification period, 120 to 2,100 CFU/100 mL for the major-modification period, and 110 to 80,000 CFU/100 mL for the major-modification period. Median *E. coli* concentrations and median *E. coli* instantaneous discharge values were slightly higher in the premodification period compared to the minor-modification period, but the differences were not statistically significant.

During two rainfall events in September 2003, *E. coli* concentrations ranged from 450 to 260,000 CFU/100 mL. On September 19, sampling did not begin until rainfall accumulated 0.8 in., and concentrations of *E. coli* were elevated in comparison to routine samples and remained above 32,000 CFU/100 mL for all samples (n = 19) collected during this rainfall event. On September 22, sampling began before rainfall and continued throughout the event. The highest concentration of *E. coli* (260,000 CFU/100 mL) in a sample collected during this rainfall event was collected during peak streamflow (497 ft^3/s).

Acknowledgments

Eva Hatvani, Ildiko Kubliak, John Rhoades, Thomas Zablotny, and Catherine Zamborsky of the Northeast Ohio Regional Sewer District are thanked for their assistance with project planning and sample collection and analysis. Lester Stumpe of the Northeast Ohio Regional Sewer District is thanked for his assistance in the planning and implementation of this project.

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Table 1. Streamflow, water-quality, and microbiological data for samples collected in Mill Creek, Garfield Heights, Ohio, August 2001–September 2004.

[ft^3/s, cubic feet per second; °C, degrees Celsius; --, no data; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; *E. coli, Escherichia coli*; CFU/100 mL, colony-forming units per 100 milliliters; K, results based on colony count outside the ideal range of 20–80 CFU/100 mL; CFU/s, colony-forming units of *E. coli* per second]

Date	Time	Instantaneous streamflow (ft^3/s)	Water temperature (°C)	pH	Specific conductance (µS/cm)	Oxygen, dissolved (mg/L)	*E. coli* (CFU/100 mL)	Instantaneous discharges (CFU/s)	USGS quality-control trip
Routine samples									
08/30/01	1145	1.1	21.0	7.6	1,000	8.4	530	1.6×10^5	
09/12/01	1045	3.2	17.0	7.8	1,200	9.8	960	8.7×10^5	
09/26/01	1120	2.5	12.0	8.1	800	10.6	7,200	5.1×10^6	
10/10/01	1005	.03	12.5	8.0	1,300	9.6	690	5.9×10^3	
10/24/01	0945	55	17.0	--	400	8.8	K 12,000	1.9×10^8	
11/07/01	1055	6.2	11.0	7.7	1,200	13.0	1,100	1.9×10^6	
11/19/01	1053	5.1	12.0	7.4	1,200	12.0	1,300	1.9×10^6	
12/05/01	1153	7.5	14.0	--	1,200	12.2	K 3,800	8.1×10^6	
12/19/01	1100	18	8.0	7.6	900	11.4	1,200	6.1×10^6	X
01/02/02	1115	9.1	4.0	7.4	1,900	13.2	K 650	1.7×10^6	
01/16/02	1105	7.8	2.1	7.0	100	17.1	320	7.1×10^5	X
01/30/02	1030	61	6.4	8.2	800	11.1	K 4,400	7.6×10^7	
02/13/02	1055	11	1.0	7.1	3,800	16.5	680	2.1×10^6	
02/27/02	1045	14	1.3	7.4	2,000	16.0	1,300	5.2×10^6	
03/06/02	0920	15	2.2	7.2	2,500	15.9	390	1.6×10^6	
03/20/02	0945	80	7.5	7.2	1,200	12.1	16,000	3.6×10^8	
04/03/02	1020	78	6.8	7.1	900	12.6	K 3,500	7.7×10^7	
04/17/02	1020	18	17.7	7.5	1,000	10.6	260	1.3×10^6	X
05/01/02	1015	11	10.2	7.5	1,200	13.8	220	6.8×10^5	
05/15/02	0945	20	12.1	7.0	1,000	10.4	K 6,100	3.4×10^7	
05/29/02	0923	18	16.6	7.2	800	8.9	1,500	7.6×10^6	
06/12/02	0958	32	22.2	7.5	700	7.3	K 29,000	2.6×10^8	
06/26/02	0945	4.6	23.2	7.3	1,200	7.2	220	2.9×10^5	
07/10/02	0945	10	21.5	6.7	600	8.1	K 22,000	6.2×10^7	
07/24/02	0813	7.5	19.5	7.6	700	6.9	3,300	7.0×10^6	
08/07/02	1035	3.2	18.6	6.5	--	10.0	220	2.0×10^5	X

Table 1. Streamflow, water-quality, and microbiological data for samples collected in Mill Creek, Garfield Heights, Ohio, August 2001–September 2004.—Continued

[ft^3/s, cubic feet per second; °C, degrees Celsius; --, no data; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; *E. coli, Escherichia coli*; CFU/100 mL, colony-forming units per 100 milliliters; K, results based on colony count outside the ideal range of 20–80 CFU/100 mL; CFU/s, colony-forming units of *E. coli* per second]

Date	Time	Instantaneous streamflow (ft^3/s)	Water temperature (°C)	pH	Specific conductance (µS/cm)	Oxygen, dissolved (mg/L)	*E. coli* (CFU/100 mL)	Instantaneous discharges (CFU/s)	USGS quality-control trip
Routine samples—*continued*									
08/21/02	0913	3.8	17.3	7.2	1,000	7.8	240	2.6×10^5	
09/04/02	0945	5.5	19.5	7.1	800	8.5	K 2,100	3.3×10^6	
09/18/02	0940	3.7	16.7	7.4	1,100	8.4	320	3.4×10^5	
10/02/02	1000	3.8	19.3	--	1,000	8.3	120	1.3×10^5	
10/16/02	1040	4.1	11.5	7.7	900	9.2	480	5.6×10^5	
10/30/02	1010	6.2	6.6	7.7	700	11.6	1,000	1.8×10^6	
11/13/02	1050	7.8	7.6	7.5	700	11.6	930	2.0×10^6	
11/26/02	0940	12	5.1	7.7	1,000	12.8	710	2.4×10^6	
12/11/02	0940	9.1	.3	7.6	2,500	14.5	1,400	3.6×10^6	
12/23/02	1045	10	1.8	8.0	1,500	15.2	11,000	3.1×10^7	
01/08/03	1010	18	2.1	8.2	1,400	13.5	2,200	1.1×10^7	
01/22/03	1015	15	.3	7.2	2,500	14.5	1,000	4.2×10^6	
02/05/03	0940	14	.1	7.9	2,500	14.9	2,400	9.5×10^6	
02/19/03	0945	32	.0	7.2	600	15.5	1,400	1.3×10^7	
03/05/03	1000	124	3.2	8.0	20	13.4	K 38,000	1.3×10^9	
03/19/03	0930	22	8.6	8.0	1,600	14.6	1,100	6.8×10^6	
04/02/03	0930	16	9.5	7.8	1,600	12.5	740	3.4×10^6	
04/16/03	1030	9.1	13.8	8.1	1,849	14.3	280	7.2×10^5	X
04/30/03	1010	7.3	12.9	7.9	1,723	13.7	250	5.2×10^5	
05/05/03	1045	154	12.6	8.0	1,000	9.7	K 36,000	1.6×10^9	
05/06/03	0955	108	16.3	7.8	600	9.3	13,000	4.0×10^8	
05/07/03	1130	11	14.6	8.0	1,110	11.3	1,000	3.1×10^6	
05/08/03	1135	18	15.5	8.2	1,600	11.8	2,800	1.4×10^7	
05/09/03	0941	515	12.9	8.0	1,200	10.4	K 80,000	1.2×10^{10}	
05/12/03	1100	88	12.1	7.9	1,400	10.5	24,000	6.0×10^8	
05/15/03	1048	27	15.5	7.7	--	10.7	140	1.2×10^6	

Table 1. Streamflow, water-quality, and microbiological data for samples collected in Mill Creek, Garfield Heights, Ohio, August 2001–September 2004.—Continued

[ft^3/s, cubic feet per second; °C, degrees Celsius; --, no data; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; *E. coli, Escherichia coli*; CFU/100 mL, colony-forming units per 100 milliliters; K, results based on colony count outside the ideal range of 20–80 CFU/100 mL; CFU/s, colony-forming units of *E. coli* per second]

Date	Time	Instantaneous streamflow (ft^3/s)	Water temperature (°C)	pH	Specific conductance (µS/cm)	Oxygen, dissolved (mg/L)	*E. coli* (CFU/100 mL)	Instantaneous discharges (CFU/s)	USGS quality-control trip
Routine samples—*continued*									
06/02/03	0930	23	12.3	7.9	1,000	10.3	620	4.0×10^6	
06/11/03	0945	12	18.5	7.7	1,100	7.8	1,000	3.4×10^6	
06/25/03	0938	9.4	19.6	7.7	1,300	7.9	380	1.0×10^6	
07/09/03	0942	13	21.0	7.7	1,067	8.1	2,600	9.6×10^6	
07/23/03	1025	14	19.7	7.9	949	9.0	4,600	1.8×10^7	X
08/06/03	0952	6.2	19.6	7.8	956	8.6	K 9,200	1.6×10^7	
08/20/03	1015	4.8	19.5	8.1	1,100	9.3	270	3.7×10^5	
08/26/03	1205	11	22.0	7.8	1,300	8.0	K 8,000	2.5×10^7	
09/03/03	0948	15	19.5	7.9	681	8.4	1,000	4.2×10^6	
09/17/03	0928	4.8	15.3	7.7	1,211	8.6	380	5.2×10^5	
10/02/03	0937	11	9.4	7.8	1,211	10.4	2,600	8.1×10^6	
10/15/03	1002	45	11.8	7.5	541	7.8	K 14,000	1.8×10^8	
10/29/03	1012	11	9.6	7.8	1,243	10.0	320	1.0×10^6	
11/12/03	1015	25	12.0	7.0	400	12.0	13,000	9.2×10^7	
12/10/03	1045	20	6.2	8.1	2,048	6.7	K 1,500	8.5×10^6	
12/22/03	1140	12	3.9	8.3	3,500	14.8	3,200	1.1×10^7	
01/07/04	1030	20	.0	7.8	2,310	17.0	K 1,000	5.7×10^6	
01/21/04	0957	2.8	.0	7.6	4,518	12.8	290	2.3×10^5	
02/04/04	1025	23	.0	7.0	1,029	12.2	K 1,700	1.1×10^7	
02/18/04	0956	11	.0	7.0	812	11.2	480	1.5×10^6	
03/03/04	1016	14	6.4	8.3	2,512	9.4	580	2.3×10^6	
03/17/04	1019	14	2.5	8.1	16,840	6.8	210	8.3×10^5	
04/14/04	1210	83	7.7	8.4	101	8.3	K 920	2.2×10^7	
04/28/04	1118	21	9.2	8.1	1,305	13.1	330	2.0×10^6	X
05/12/04	1010	13	19.0	7.8	1,430	10.5	590	2.2×10^6	
05/26/04	1038	20	19.3	7.7	1,249	8.8	K 560	3.2×10^6	

Table 1. Streamflow, water-quality, and microbiological data for samples collected in Mill Creek, Garfield Heights, Ohio, August 2001–September 2004.—Continued

[ft^3/s, cubic feet per second; °C, degrees Celsius; --, no data; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; *E. coli, Escherichia coli*; CFU/100 mL, colony-forming units per 100 milliliters; K, results based on colony count outside the ideal range of 20–80 CFU/100 mL; CFU/s, colony-forming units of *E. coli* per second]

Date	Time	Instantaneous streamflow (ft^3/s)	Water temperature (°C)	pH	Specific conductance (µS/cm)	Oxygen, dissolved (mg/L)	*E. coli* (CFU/100 mL)	Instantaneous discharges (CFU/s)	USGS quality-control trip
				Routine samples—*continued*					
06/09/04	0952	6.5	21.2	7.7	1,522	7.4	K 1,100	2.0×10^{6}	
06/23/04	1014	6.0	18.0	8.2	1,280	7.2	440	7.5×10^{5}	
07/07/04	0940	6.0	22.4	7.1	1,604	7.2	330	5.6×10^{5}	
07/21/04	1010	5.3	21.0	7.8	1,200	9.4	110	1.6×10^{5}	
08/04/04	1008	53	21.0	7.4	1,117	8.3	20,000	3.0×10^{8}	X
08/18/04	1022	9.1	18.6	7.2	1,473	8.3	K 1,200	3.1×10^{6}	
09/01/04	0948	9.4	17.3	7.8	99	9.5	790	2.1×10^{6}	
09/15/04	1016	6.2	17.9	7.7	1,437	7.8	160	2.8×10^{5}	
				Event samples					
09/19/03	0345	119	18.7	7.9	497	9.4	88,000	3.0×10^{9}	
09/19/03	0415	96	18.8	7.9	381	8.8	110,000	3.0×10^{9}	
09/19/03	0445	90	18.8	7.6	344	8.8	140,000	3.6×10^{9}	
09/19/03	0515	90	18.8	7.7	399	8.0	110,000	2.8×10^{9}	
09/19/03	0545	97	18.8	7.9	335	8.0	76,000	2.1×10^{9}	
09/19/03	0615	97	18.8	7.9	338	8.4	46,000	1.3×10^{9}	
09/19/03	0645	93	18.7	7.9	350	8.3	38,000	1.0×10^{9}	
09/19/03	0715	244	18.9	7.9	375	8.9	32,000	2.2×10^{9}	
09/19/03	0745	714	18.9	8.0	309	8.1	100,000	2.0×10^{10}	
09/19/03	0815	909	18.9	8.0	261	8.4	68,000	1.8×10^{10}	
09/19/03	0845	1,040	18.8	8.0	253	8.9	58,000	1.7×10^{10}	
09/19/03	0915	990	18.8	8.0	270	8.4	84,000	2.4×10^{10}	
09/19/03	0945	1,010	18.9	8.0	282	8.6	78,000	2.2×10^{10}	
09/19/03	1015	864	18.8	8.0	288	9.2	62,000	1.5×10^{10}	
09/19/03	1045	668	18.9	8.0	285	9.0	69,000	1.3×10^{10}	
09/19/03	1115	515	18.9	8.0	290	8.1	72,000	1.0×10^{10}	
09/19/03	1145	405	18.9	8.0	296	8.8	64,000	7.3×10^{9}	

Table 1. Streamflow, water-quality, and microbiological data for samples collected in Mill Creek, Garfield Heights, Ohio, August 2001–September 2004.—Continued

[ft^3/s, cubic feet per second; °C, degrees Celsius; --, no data; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; *E. coli, Escherichia coli*; CFU/100 mL, colony-forming units per 100 milliliters; K, results based on colony count outside the ideal range of 20–80 CFU/100 mL; CFU/s, colony-forming units of *E. coli* per second]

Date	Time	Instantaneous streamflow (ft^3/s)	Water temperature (°C)	pH	Specific conductance (µS/cm)	Oxygen, dissolved (mg/L)	*E. coli* (CFU/100 mL)	Instantaneous discharges (CFU/s)	USGS quality-control trip
Event samples—*continued*									
09/19/03	1215	357	18.8	8.0	311	8.9	77,000	7.8×10^{9}	
09/19/03	1245	306	18.8	8.0	318	9.0	74,000	6.4×10^{9}	
09/22/03	0920	9.1	16.2	7.6	1,197	10.4	590	1.5×10^{6}	
09/22/03	1307	9.8	17.6	8.0	1,192	10.9	450	1.2×10^{6}	
09/22/03	1315	11	17.6	8.0	1,182	10.1	470	1.5×10^{6}	
09/22/03	1330	11	17.7	8.0	1,178	10.8	510	1.6×10^{6}	
09/22/03	1345	12	17.7	8.0	1,168	10.3	630	2.1×10^{6}	
09/22/03	1400	19	17.8	8.0	1,167	10.0	620	3.3×10^{6}	
09/22/03	1430	343	17.9	8.0	1,084	9.2	2,400	2.3×10^{8}	
09/22/03	1450	497	18.4	8.0	644	9.5	260,000	3.7×10^{10}	
09/22/03	1510	467	19.0	8.0	441	10.1	110,000	1.4×10^{10}	
09/22/03	1530	395	19.0	8.0	404	10.8	73,000	8.2×10^{9}	
09/22/03	1550	363	19.2	8.0	341	11.0	92,000	9.4×10^{9}	
09/22/03	1610	334	19.3	8.0	277	11.0	160,000	1.5×10^{10}	
09/22/03	1620	303	19.3	8.0	273	11.0	170,000	1.4×10^{10}	
09/22/03	1630	260	19.3	8.0	278	11.0	120,000	8.8×10^{9}	
09/22/03	1645	234	19.3	8.0	285	11.1	160,000	1.1×10^{10}	

Table 2. Streamflow and precipitation statistics for sewage-collection-system modification periods, Mill Creek watershed, Cleveland, Ohio, August 2001–September 2004.

[ft^3/s, cubic feet per second; n, number of samples; min., minimum; max., maximum; Improvement periods are defined as premodification, before August 7, 2002; major modification, August 7–October 24, 2002; and minor modification, after October 24, 2002. Precipitation data were obtained from National Oceanic and Atmospheric Administration, 2005b; trace amounts of rainfall were transformed to 0.005 inch for data-analysis purposes. Instantaneous streamflow was obtained from the U.S. Geological Survey stream gage 04208460, Mill Creek, Garfield Heights, Ohio]

Modification period	Instantaneous streamflow (ft^3/s)								Precipitation (inches)			
	Sampling period				At time of sampling							
	n	min	max	median	n	min	max	median	n	min	max	median
Premodification	35,597	0.0	3,900	8.6	25	0.03	80	11	342	0.005	1.42	0.10
Major modification	7,583	2.8	2,020	4.1	6	3.2	5.5	3.8	79	.005	1.18	.10
Minor modification	67,160	2.6	3,810	14	55	2.8	515	13	692	.005	2.22	.085

Appendix 1

Appendix 1. Variability of *Escherichia coli* concentrations in Mill Creek, Garfield Heights, Ohio, August 2001–September 2004

Quality-assurance and quality-control (QA/QC) procedures were followed for all phases of data collection and analysis in the field and laboratory. QA/QC samples were collected and analyzed to assess any bias and (or) variability associated with the data as a result of collection methods or laboratory methods. This bias and (or) variability must be known so that the data can be adequately interpreted. The following analysis is used for illustration purposes only.

Sequential split-replicate samples were collected to examine the variability of *Escherichia coli* (*E. coli*) concentrations. Between-bottle differences will show variability in *E. coli* concentrations as a result of collection methods as well as analytical methods. Within-bottle differences will show any inconsistencies in analytical methods. Results of NEORSD QC samples are listed in table 1.1. USGS QA/QC trips to the site were conducted to observe any differences in collection methods and (or) laboratory analysis procedures between USGS and NEORSD personnel. Results of USGS QC samples are listed in bold font in table 1.1.

Samples were designated in the following manner. For the first bottle collected, A was the first split and B was the second split. For the replicate sample, the first split was called C, and the second split was called D. Within-bottle differences were calculated for the following replicate pairs: A-B and C-D. Between-bottle differences were calculated for these replicate pairs: A-C, A-D, B-C, and B-D. Additionally, the data were analyzed in three groups: regular, USGS, and NEORSD QC. Regular samples were those collected on days the USGS did not make a QA/QC trip to the site (within-bottle $n = 136$; between-bottle $n = 275$). USGS samples are the samples collected during a USGS QA/QC trip and analyzed by the USGS, and NEORSD QC samples are the same samples but were analyzed by the NEORSD (for both agencies, within-bottle $n = 14$; between bottle $n = 24$).

Within-bottle and between-bottle differences in *E. coli* concentrations were calculated by determining the absolute value of the percent difference between the $\log_{10}$-transformed sample pairs (PDs). Absolute values were used because the designations of A, B, C, and D were randomly assigned. Data were $\log_{10}$ transformed because the untransformed data were not normally distributed. The within-bottle and between-bottle PDs for regular samples are shown in figure 1.1. Generally, the PDs are uniformly distributed across the range of observed *E. coli* concentrations between 0 and 10 percent, indicating that about 10 percent of the variability in sample concentrations is due to field and (or) analytical methods. However, there are several outliers of the between-bottle PDs near 1,000 CFU/100 mL. These outliers were collected on two sampling dates (May 26 and June 9, 2004), and indicate that there were some differences in sample collection of the replicate bottles.

Summary statistics for PDs are listed in table 1.2. Based on the results of a Kruskal-Wallis multiple-comparison test, the within-bottle median PDs were not statistically different between regular, USGS, and NEORSD QC samples ($K = 0.099$, $p = 0.9518$). This indicates that analytical variability for *E. coli* concentrations was similar for both agencies. Further, a Wilcoxon rank-sum test comparing the between-bottle median PDs showed no significant difference between USGS and NEORSD QC ($Z = -1.21$, $p = 0.2274$) or between NEORSD QC and regular median PDs ($Z = -0.84$, $p = 0.4037$).

For all three groups (regular, USGS, and NEORSD QC), the median between-bottle PDs, representing analytical and sampling variability, were greater than the median within-bottle PDs, representing analytical variability. The Wilcoxon rank-sum tests show statistically significant differences in the median between-bottle and median within-bottle PDs for all three groups.

Table 1–1. Quality-control data for *Escherichia coli* concentrations in water samples collected in Mill Creek, Garfield Heights, Ohio, August 2001–September 2004, and analyzed by the Northeast Ohio Regional Sewer District and the U.S. Geological Survey.

[--, no data; K, results based on colony counts outside the ideal range of 20–80 colonies per plate; *, indicates field blank sample; <, less than; E, estimated]

Date	Concentration of *Escherichia coli* (colony-forming units per 100 milliliters)			
	Bottle 1 [A]	Bottle 1 split [B]	Bottle 2 [C]	Bottle 2 split [D]
8/30/2001	530	--	--	--
9/12/2001	960	--	--	--
9/26/2001	7,200	--	--	--
10/10/2001	690	--	--	--
10/24/2001	K 13,000	K 12,000	--	--
11/7/2001	1,200	1,100	1,000	940
11/19/2001	1,200	1,200	1,400	1,400
12/5/2001	K 3,700	K 3,900	K 3,800	K 3,900
12/19/2001	1,300	1,100	1,100	1,300
12/19/2001	**3,500**	**2,700**	**2,400**	**2,400**
1/2/2002	730	670	K 630	K 570
1/16/2002	320	320	*<1	*<1
1/16/2002	**200**	**200**	***<1**	***<1**
1/30/2002	K 3,500	K 3,800	K 5,100	K 5,300
2/13/2002	690	680	680	650
2/27/2002	1,300	1,200	1,400	1,300
3/6/2002	370	390	420	390
3/20/2002	20,000	18,000	13,000	14,000
4/3/2002	K 3,900	K 3,700	K 3,400	K 3,000
4/17/2002	260	240	290	260
4/17/2002	**250**	**270**	**E 170**	**E 350**
5/1/2002	210	200	230	220
5/15/2002	7,300	6,700	K 5,000	K 5,300
5/29/2002	1,600	1,500	1,600	1,500
6/12/2002	25,000	26,000	K 29,000	K 35,000
6/26/2002	230	200	260	180
7/10/2002	27,000	K 18,000	K 18,000	26,000
7/24/2002	3,300	2,900	3,700	3,400
8/7/2002	260	220	180	200
8/7/2002	**300**	**250**	**280**	**320**
8/21/2002	250	280	210	240
9/4/2002	K 2,000	K 2,100	K 2,100	K 2,100
9/19/2002	360	330	310	300
10/2/2002	140	120	110	120

Table 1–1. Quality-control data for *Escherichia coli* concentrations in water samples collected in Mill Creek, Garfield Heights, Ohio, August 2001–September 2004, and analyzed by the Northeast Ohio Regional Sewer District and the U.S. Geological Survey.—Continued

[--, no data; K, results based on colony counts outside the ideal range of 20–80 colonies per plate; *, indicates field blank sample; <, less than; E, estimated]

Date	Concentration of *Escherichia coli* (colony-forming units per 100 milliliters)			
	Bottle 1 [A]	Bottle 1 split [B]	Bottle 2 [C]	Bottle 2 split [D]
10/16/2002	500	510	480	450
10/30/2002	1,100	1,000	1,200	850
11/13/2002	850	950	810	1,100
11/26/2002	680	730	710	720
12/11/2002	1,400	1,200	1,400	1,400
12/23/2002	12,000	14,000	8,400	10,000
1/8/2003	2,500	2,000	1,800	2,400
1/22/2003	1,200	1,000	1,000	1,000
2/5/2003	2,400	2,700	2,000	2,400
2/19/2003	1,300	1,200	1,600	1,400
3/5/2003	K 35,000	K 34,000	K 42,000	K 40,000
3/19/2003	1,400	1,400	810	810
4/2/2003	680	720	800	740
4/16/2003	360	330	200	220
4/16/2003	**300**	**300**	**410**	**380**
4/30/2003	270	240	250	230
5/5/2003	K 39,000	K 45,000	K 28,000	K 31,000
5/6/2003	14,000	14,000	13,000	11,000
5/7/2003	1,100	1,200	840	880
5/8/2003	2,800	2,800	2,900	2,500
5/9/2003	K 80,000	K 110,000	K 50,000	K 80,000
5/12/2003	27,000	21,000	21,000	26,000
5/15/2003	140	130	140	140
6/2/2003	640	590	690	560
6/11/2003	1,300	1,200	790	810
6/25/2003	390	360	420	330
7/9/2003	2,400	2,400	2,800	2,900
7/23/2003	4,700	5,200	3,900	4,500
7/23/2003	**920**	**720**	**K 1,700**	**K 1,600**
8/6/2003	K 10,000	K 9,300	K 9,100	K 8,600
8/20/2003	240	330	260	240
8/26/2003	K 8,300	K 8,100	K 7,200	K 8,600
9/3/2003	1,200	--	890	--
9/17/2003	410	350	370	410

Table 1–1. Quality-control data for *Escherichia coli* concentrations in water samples collected in Mill Creek, Garfield Heights, Ohio, August 2001–September 2004, and analyzed by the Northeast Ohio Regional Sewer District and the U.S. Geological Survey.—Continued

[--, no data; K, results based on colony counts outside the ideal range of 20–80 colonies per plate; *, indicates field blank sample; <, less than; E, estimated]

Date	Concentration of *Escherichia coli* (colony-forming units per 100 milliliters)			
	Bottle 1 [A]	Bottle 1 split [B]	Bottle 2 [C]	Bottle 2 split [D]
10/2/2003	2,600	2,100	3,000	2,500
10/15/2003	K 16,000	14,000	15,000	12,000
10/29/2003	340	--	300	--
11/12/2003	15,000	16,000	13,000	9,400
12/10/2003	1,400	1,400	K 1,600	K 1,500
12/22/2003	3,600	4,300	2,300	2,800
1/7/2004	K 930	K 1,100	K 1,100	K 1,100
1/21/2004	320	290	270	270
2/4/2004	K 1,600	K 1,600	K 2,000	K 1,700
2/18/2004	410	510	450	540
3/3/2004	590	560	590	590
3/17/2004	170	170	260	230
4/14/2004	K 1,200	K 1,100	K 700	K 700
4/28/2004	310	340	340	350
4/28/2004	**1,100**	**1,600**	**1,300**	**1,400**
5/12/2004	600	--	620	550
5/26/2004	270	--	K 850	--
6/9/2004	660	540	K 1,700	1,600
6/23/2004	490	--	400	--
7/7/2004	340	350	310	330
7/21/2004	97	110	120	110
8/4/2004	22,000	22,000	18,000	18,000
8/4/2004	**K 30,000**	**25,000**	**23,000**	**22,000**
8/18/2004	K 1,100	K 1,500	K 1,200	K 1,100
9/1/2004	800	--	780	--
9/15/2004	150	130	160	180

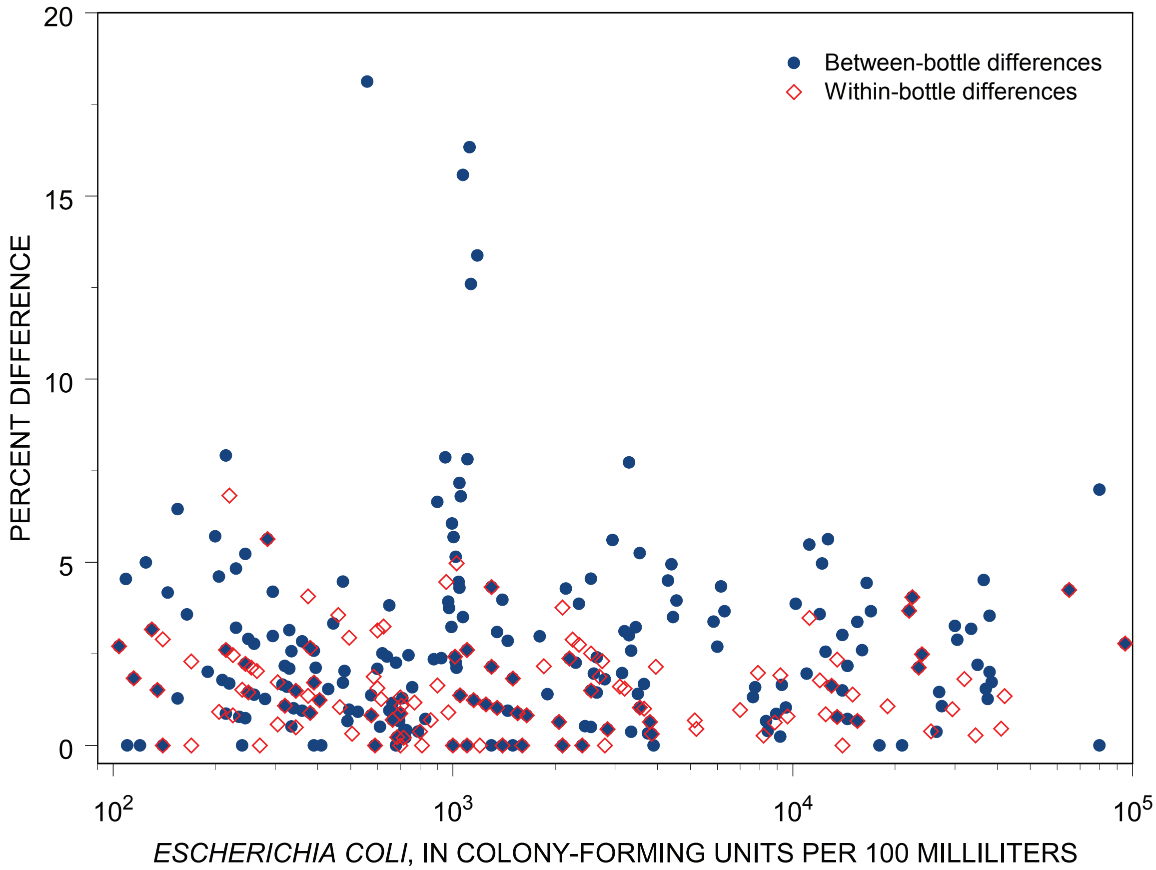

Figure 1–1. Absolute value of the percent difference ($\log_{10}$-transformed data) between quality-control replicate samples for concentrations of *Escherichia coli* in Mill Creek, Garfield Heights, Ohio, August 2001–September 2004.

Table 1–2. Summary statistics for the percent differences (absolute value of the percent difference of the $\log_{10}$-transformed data) for within-bottle and between-bottle comparisons of replicate quality-control samples for concentrations of *Escherichia coli* in Mill Creek, Garfield Heights, Ohio, August 2001–September 2004.

[NEORSD, Northeast Ohio Regional Sewer District; USGS, United States Geological Survey]

	Number of samples	Mean percent	Standard deviation percent	Median percent	Minimum percent	Maximum percent
			Regular samples – NEORSD			
Within bottle	136	1.5	1.3	1.2	0.0	6.8
Between bottle	275	2.6	2.6	2.0	.0	18.1
			Quality-control samples			
USGS within bottle	14	1.7	1.6	1.3	.0	5.2
USGS between bottle	24	4.1	3.1	3.2	.8	12.1
NEORSD within bottle	14	1.4	1.0	1.5	.0	3.0
NEORSD between bottle	24	3.2	3.0	2.0	.0	10.4

USGS

Amie M. G. Brady—***Escherichia coli* Concentrations in the Mill Creek Watershed, Cleveland, Ohio, 2001–2004**—Open-File Report 2007–1171