Prepared in cooperation with the Allegheny County Sanitary Authority and Allegheny County Health Department

Occurrence and Trends in the Concentrations of Fecal-Indicator Bacteria and the Relation to Field Water-Quality Parameters in the Allegheny, Monongahela, and Ohio Rivers and Selected Tributaries, Allegheny County, Pennsylvania, 2001–09

Scientific Investigations Report 2015–5136

U.S. Department of the Interior
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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.59	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.0283	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

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

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

Altitude, as used in this report, refers to distance above the vertical datum.

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 in either milligrams per liter (mg/L) or micrograms per liter (µg/L).

Occurrence and Trends in the Concentrations of Fecal-Indicator Bacteria and the Relation to Field Water-Quality Parameters in the Allegheny, Monongahela, and Ohio Rivers and Selected Tributaries, Allegheny County, Pennsylvania, 2001–09

By John W. Fulton, Edward H. Koerkle, Jamie L. McCoy, and Linda F. Zarr

Abstract

The U.S. Geological Survey (USGS), in cooperation with the Allegheny County Health Department and Allegheny County Sanitary Authority, collected surface-water samples from the Allegheny, Monongahela, and Ohio Rivers and selected tributaries during the period 2001–09 to assess the occurrence and trends in the concentrations of fecal-indicator bacteria during both wet- and dry-weather conditions.

A total of 1,742 water samples were collected at 52 main-stem and tributary sites. Quantifiable concentrations of *Escherichia coli* (*E. coli*) were reported in 1,667 samples, or 97.0 percent of 1,719 samples; concentrations in 853 samples (49.6 percent) exceeded the U.S. Environmental Protection Agency (EPA) recreational water-quality criterion of 235 colonies per 100 milliliters (col/100 mL). Quantifiable concentrations of fecal coliform (FC) bacteria were reported in 1,693 samples, or 98.8 percent of 1,713 samples; concentrations in 780 samples (45.5 percent) exceeded the Commonwealth of Pennsylvania water contact criterion of 400 col/100 mL. Quantifiable concentrations of enterococci bacteria were reported in 912 samples, or 87.5 percent of 1,042 samples; concentrations in 483 samples (46.4 percent) exceeded the EPA recreational water-quality criterion of 61 col/100 mL. The median percentage of samples in which bacteria concentrations exceeded recreational water-quality standards across all sites with five or more samples was 48 for *E. coli*, 43 for FC, and 75 for enterococci. *E. coli*, FC, and enterococci concentrations at main-stem sites had significant positive correlations with streamflow under all weather conditions, with *rho* values ranging from 0.203 to 0.598. Seasonal Kendall and logistic regression were evaluated to determine whether statistically significant trends were present during the period 2001–09. In general, Seasonal Kendall tests for trends in *E. coli* and FC bacteria were inconclusive. Results of logistic regression showed no significant trends in dry-weather exceedance of the standards; however, significant decreases in the likelihood that wet-weather *E. coli* and FC bacteria concentrations will exceed EPA recreational standards were found at the USGS streamgaging station Allegheny River at 9th Street Bridge. Nonparametric correlation analysis, including Spearman's *rho* and the paired Prentice-Wilcoxon test, was used to screen for associations among fecal indicator bacteria concentrations and the field characteristics streamflow, water temperature, pH, specific conductance, dissolved-oxygen concentration, and turbidity.

Introduction

The U.S. Geological Survey (USGS) collected surface-water samples from October 2001 through September 2009 to assess the occurrence and trends in the concentrations of fecal-indicator bacteria in the Allegheny, Monongahela, and Ohio Rivers (Three Rivers) near Pittsburgh, Pennsylvania (Pa.). Samples were collected at main-stem sites during both dry and wet weather from April through October during 2001–04 and selected years thereafter and, in 2004, the program was changed to focus on wet-weather sampling and to include selected tributaries to the Three Rivers.

Exposure to pathogenic bacteria and viruses (pathogens) in surface water can have adverse health effects on humans by increasing the risk of gastrointestinal, respiratory, eye, ear, throat, and skin diseases. Because individual pathogens are difficult to detect and measure directly (Chapra, 1997, p. 504), monitoring programs commonly rely on the nonpathogenic indicator organisms, such as fecal coliform (FC) and fecal streptococcus bacteria, as surrogates; if they are present, it is assumed that additional, more harmful pathogens may coexist. Traditionally, FC was the most widely used fecal-indicator bacterium used for monitoring; however, its use is problematic because not all FC bacteria are fecal in origin. Enterococci and *Escherichia coli* (*E. coli*), in contrast, originate in the intestines of warm-blooded animals and their presence is evidence of fecal contamination. Both indicators can occur naturally in the environment (Hardina and Fujioka, 1991). Both can be sampled and quantified by using standard methods, and both are relatively abundant in human and animal waste. Because the die-off rates for enterococci and *E. coli* are lower than that of FC, they provide a better measure of the risk of gastrointestinal illness related to recreational contact with water (U.S. Environmental Protection Agency, 2001).

Purpose and Scope

This report (1) documents the 2001–09 streamflow and water-quality results for field parameters such as water temperature, pH, specific conductance, dissolved-oxygen concentration, and turbidity; (2) presents the results of trend analyses for fecal-indicator bacteria (*E. coli* and FC); (3) describes the influence of wet- and dry-weather events on fecal-indicator bacteria concentrations by comparing their spatial distribution at various receptor sites, such as marinas and water-supply intakes, and at sampling locations in the Three Rivers; and (4) presents results from nonparametric correlation analyses to screen for associations among fecal-indicator bacteria concentrations and the field characteristics streamflow, water temperature, pH, specific conductance, dissolved-oxygen concentration, and turbidity. A total of 1,742 water samples were collected at 52 main-stem and tributary sites on the Allegheny, Monongahela, and Ohio Rivers.

Study Area

The study area of approximately 730 square miles (mi^2) includes the areal extent of Allegheny County, Pennsylvania (fig. 1) that consists of the Three Rivers and selected tributaries, which together constitute the river system entering and exiting the county. The Allegheny River reach begins at the C.W. Bill Young Lock and Dam (river mile 14.5) and extends downstream to Lock and Dam No. 2 (river mile 6.7) and to the Point at Pittsburgh, where the Allegheny and Monongahela Rivers join to form the Ohio River. Similarly, the Monongahela River reach begins at Locks and Dam No. 3 (river mile 23.8) and extends to the Lock and Dam at Braddock (river mile 11.2) and to the Point at Pittsburgh. The Ohio River reach extends from the Point at Pittsburgh (river mile 0.0) to the Emsworth Locks and Dam (river mile 6.2) on the main channel and the non-navigable back channel to the Dashields Locks and Dam (river mile 13.3).

Five tributaries (Deer Creek, Plum Creek, Squaw Run, Pine Creek, and Girtys Run) to the Allegheny River, five tributaries (Youghiogheny River, Thompson Run, Turtle Creek, Ninemile Run, and Streets Run) to the Monongahela River, and four tributaries (Sawmill Run, Chartiers Creek, Lowries Run, and Montour Run) to the Ohio River were incorporated in the sampling design. Tributary locations relative to the receiving water and approximate drainage-basin areas are summarized in table 1 (at end of report).

USGS streamgages were selected for monitoring water quality in the Allegheny County Sanitary Authority (ALCOSAN) service area (fig. 2) and to identify potential upstream contributions to the Three Rivers and its tributaries. Approximately 414 combined sewer overflows (CSOs) exist within Allegheny County (Committee on Water Quality Improvement for the Pittsburgh Region, 2005); however, the number and distribution of these structures vary from basin to basin. The Allegheny River serves as the principal water-supply source for the City of Pittsburgh and areas to the east and northeast. The Monongahela River services large areas south of Allegheny County. The Ohio River is the source of water for populations north of the river. In addition, several municipalities pump water from wells or galleries that are located adjacent to the Three Rivers.

Previous Investigations

Federal, State, local, and private agencies and other groups have monitored receiving waters in the Three Rivers since 1976. In general, concentrations of indicator bacteria are highest during the summer months after storm events. Previous investigations by Fulton and Buckwalter (2004) and Buckwalter and others (2006) are summarized briefly below.

The Ohio River Valley Water Sanitation Commission (ORSANCO) has been monitoring bacteria in the Ohio River since 1992. From May through October each year, three surface-water grab samples are collected near the left water's edge (LWE facing downstream), near the right water's edge (RWE facing downstream), and at mid-stream locations at river mile 1.4 and 4.3 (distance measured in miles downstream from the confluence of the Allegheny and Monongahela Rivers in Pittsburgh) at a frequency of five per month. Electronic data can be accessed from the Ohio River Valley Water Sanitation Web site, http://www.orsanco.org/bacteria (Ohio River Valley Water Sanitation Commission, 2010).

From 1976 through 1989, the USGS partnered with the U.S. Environmental Protection Agency (EPA) to operate a surveillance network at the Allegheny River at New Kensington, Pa., and the Monongahela River at Braddock, Pa. Samples were collected at these sites from 1989 through 1994 as part of another USGS program, the National Stream Quality Accounting Network (NASQAN). These same stations were operated in 1995 as part of the USGS National Water-Quality Assessment (NAWQA) Program. During each program, surface-water samples were collected mid-stream at a frequency of either one per month or quarterly and analyzed for concentrations of FC and fecal streptococci. The USGS participated in two supplemental programs in the Three Rivers area near Pittsburgh, Pa., that included sampling and analysis for indicator bacteria. Fulton and Buckwalter (2004) and Buckwalter and others (2006) discuss their findings associated with *E. coli*, enterococci, FC, and various field parameters in main-stem river and tributary samples collected during July–September 2005. All water-quality data can be accessed from

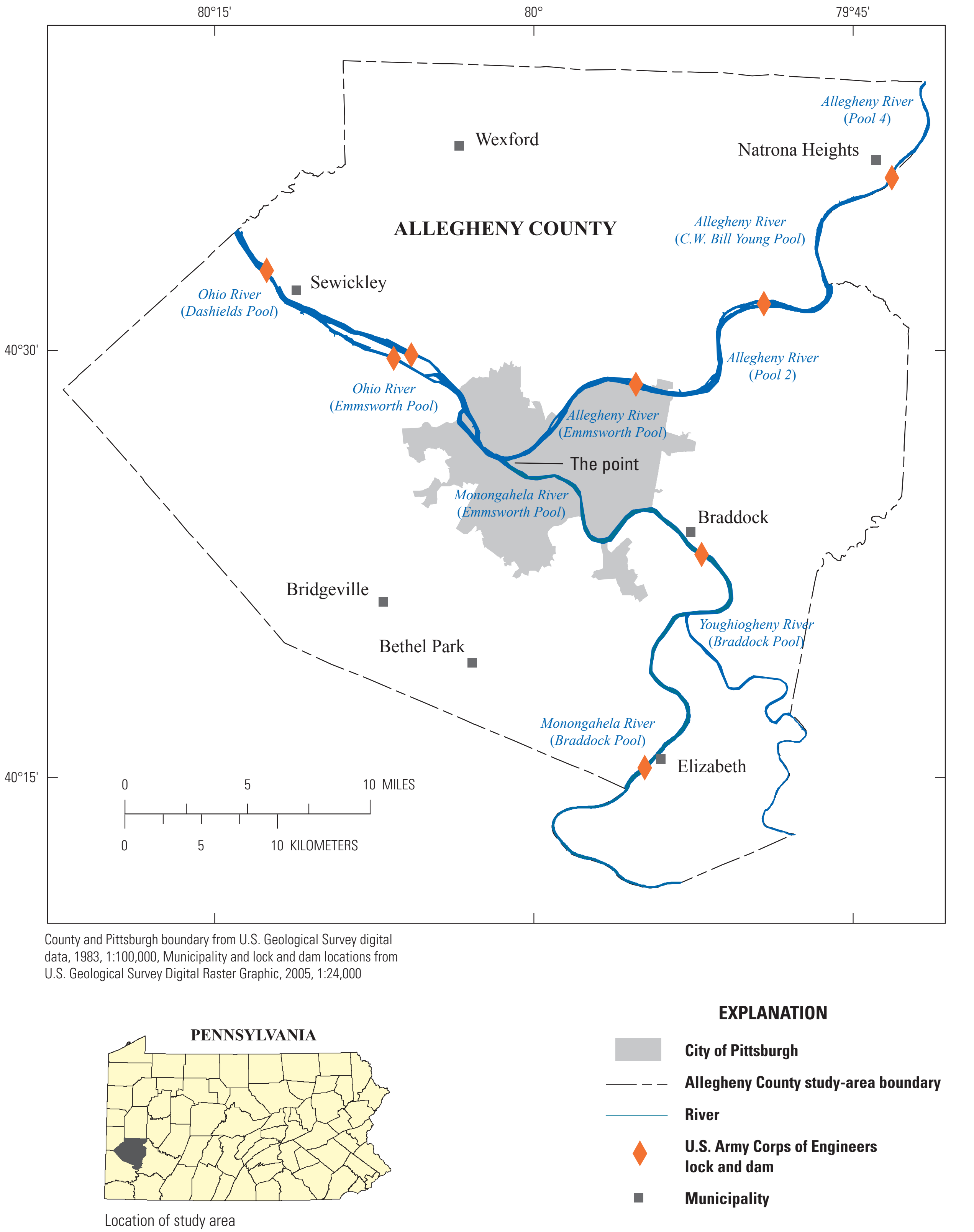

Figure 1. Study area and location of U.S. Army Corps of Engineers flow-control structures on the Allegheny, Monongahela, and Ohio Rivers, Allegheny County, Pennsylvania.

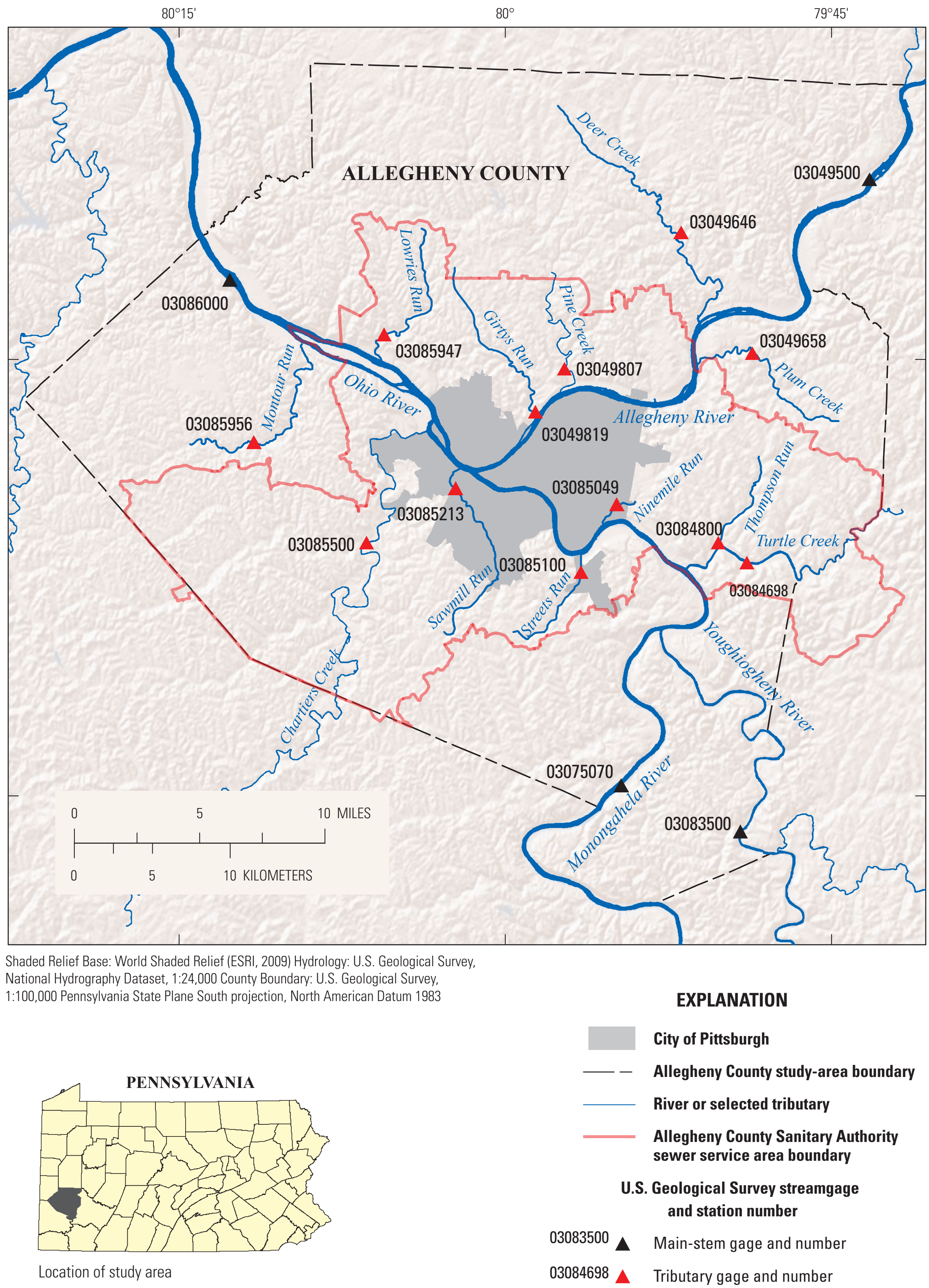

Figure 2. Location of U.S. Geological Survey streamgaging stations on the Allegheny, Monongahela, and Ohio Rivers, Allegheny County, Pennsylvania.

the USGS National Water Information System (NWIS) Web site at http://nwis.waterdata.usgs.gov/pa/nwis/qwdata.

Bacteria monitoring has been implemented by a variety of local groups, including water companies; the Allegheny County Health Department (ACHD); and the 3 Rivers 2nd Nature project at the Frank-Ratchye STUDIO for Creative Inquiry (3R2N), part of the College of Fine Arts at Carnegie Mellon University in Pittsburgh. Pa. The bacteria data collected by the water companies and the ACHD are unpublished. 3R2N-issued annual reports summarizing water-quality data for the Three Rivers and selected tributary sites that focus on various navigation pools within the region, where recreational boating is common in the summer. Sampling sites are selected on the basis of public access and inflow points discharging to the Three Rivers. Water-quality constituents and other parameters measured as part of this program include total coliform, *E. coli*, enterococci, pH, temperature, specific conductance, and dissolved-oxygen concentration. Knauer and Collins (2002) summarized findings that include results of fecal-indicator bacteria sampling during the summer of 2001 for sites on the Monongahela River from river mile 11.5 to 35.0 and on selected tributary streams to the Monongahela River.

A comprehensive report on water resources, water quality, and causes of water-quality impairment in southwestern Pennsylvania that included data from several sources such as water-treatment plants, the ACHD, the USGS, the U.S. Army Corps of Engineers, universities, and independent studies was published in 2005 (Committee on Water Quality Improvement for the Pittsburgh Region, 2005). The report documented concentrations of *E. coli*, enterococci, and FC as well as the waterborne, pathogenic protozoans Giardia and Cryptosporidium in the Three Rivers and selected tributaries. Other studies have documented the presence of fecal-indicator bacteria in rivers, streams, and wastewaters also found to be contaminated with Giardia and Cryptosporidium. Giardia was found in water samples collected from the Allegheny and Youghiogheny Rivers during 1994–97 (States and others, 1997). The relevance of the documented presence of pathogens in surface waters in the Three Rivers area is that recreational contact with these waters carries the risk of contracting illnesses, and the occurrence of nonpathogenic fecal-indicator bacteria (*E. coli*, enterococci, and FC) may indicate when that risk is present.

Networks

To evaluate the occurrence of and trends in concentrations of fecal-indicator bacteria, a network of rain gages and streamgages was established to characterize water quality and quantity during dry- and wet-weather events of varying magnitudes and spatial distribution of rainfall in both the main-stem river and tributary systems.

Main-Stem Rivers

The study-area boundaries were selected to evaluate water quality within the ALCOSAN service area and to identify potential upstream contributions of fecal-indicator bacteria to both the Three Rivers and their tributaries. Sampling was not done synoptically; rather, an individual basin (for example, the Allegheny River Basin) and its associated tributaries were targeted during a particular sampling event. River transects, continuous-record tributary sites, and candidate receptor sites (sensitive areas including surface-water intakes and areas of intensive river recreational use) are illustrated in figures 3 through 5 for the Allegheny, Monongahela, and Ohio Rivers, respectively. Periodic adjustments to river-transect sampling locations were necessary as a result of river traffic and lock and dam renovations.

Streamflow was monitored for prescribed flow conditions at four stations (Allegheny River at Natrona, Pa., Monongahela River at Elizabeth, Pa., Monongahela River at Braddock, Pa., and Ohio River at Sewickley, Pa.) during the recreational season (table 2). Water samples were collected from 10 additional sites on the Allegheny River, 9 additional sites on the Monongahela River, and 10 additional sites on the Ohio River. The Allegheny River at Oakmont was sampled because it is near the boundary of the ALCOSAN service area, the Monongahela River at McKeesport was sampled because its location coincides with the upstream boundary of the ALCOSAN service area, and the Ohio River at Sewickley was sampled as a representative site near the downstream boundary of the ALCOSAN service area.

Tributaries

Water samples also were collected from five tributaries to the Allegheny River, five tributaries to the Monongahela River, and four tributaries to the Ohio River to quantify loads entering the Three Rivers. In general, two sites were selected on each of the tributaries—an upstream site near the boundary of the ALCOSAN service area, and a downstream site at the location of an existing streamgaging station—except Turtle Creek at East Pittsburgh, Pa..

Wet- and Dry-Weather Event Protocols

Variations in streamflow and the spatial distribution of rainfall posed considerable challenges to scheduling the collection of water samples at sites throughout the study area. Precipitation data from the 3 Rivers Wet Weather (3RWW) raingage network (fig. 6) and radar-rainfall on a 1-square-kilometer (km^2) (0.37-mi^2) grid was used to evaluate antecedent dry-weather conditions and the magnitude of wet weather for a given watershed. In addition, streamflow data from the USGS streamgaging network were monitored to

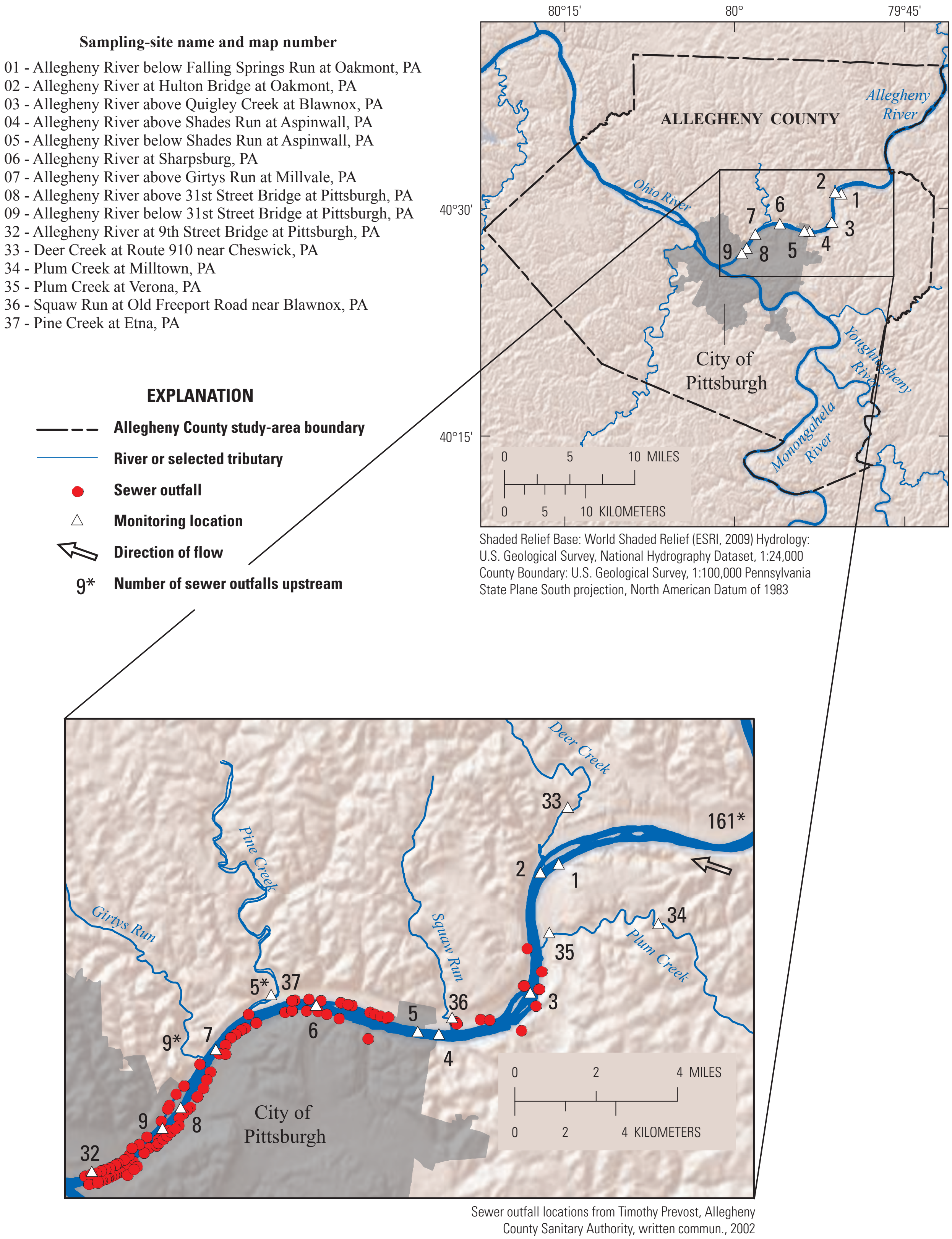

Figure 3. Location of sampling sites and combined sewer overflow locations on the Allegheny River, Allegheny County, Pennsylvania.

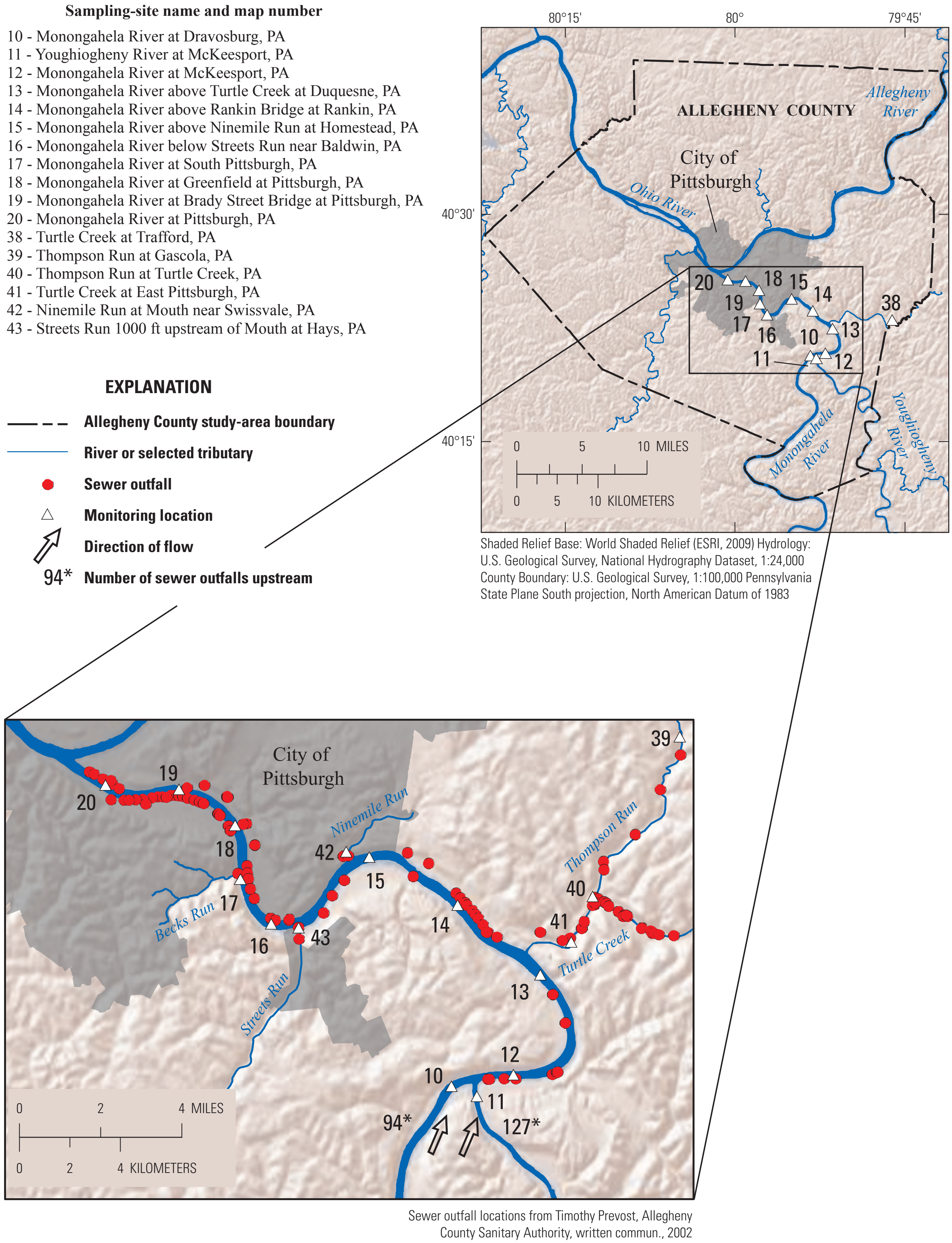

Figure 4. Location of sampling sites and combined sewer overflow locations on the Monongahela River, Allegheny County, Pennsylvania.

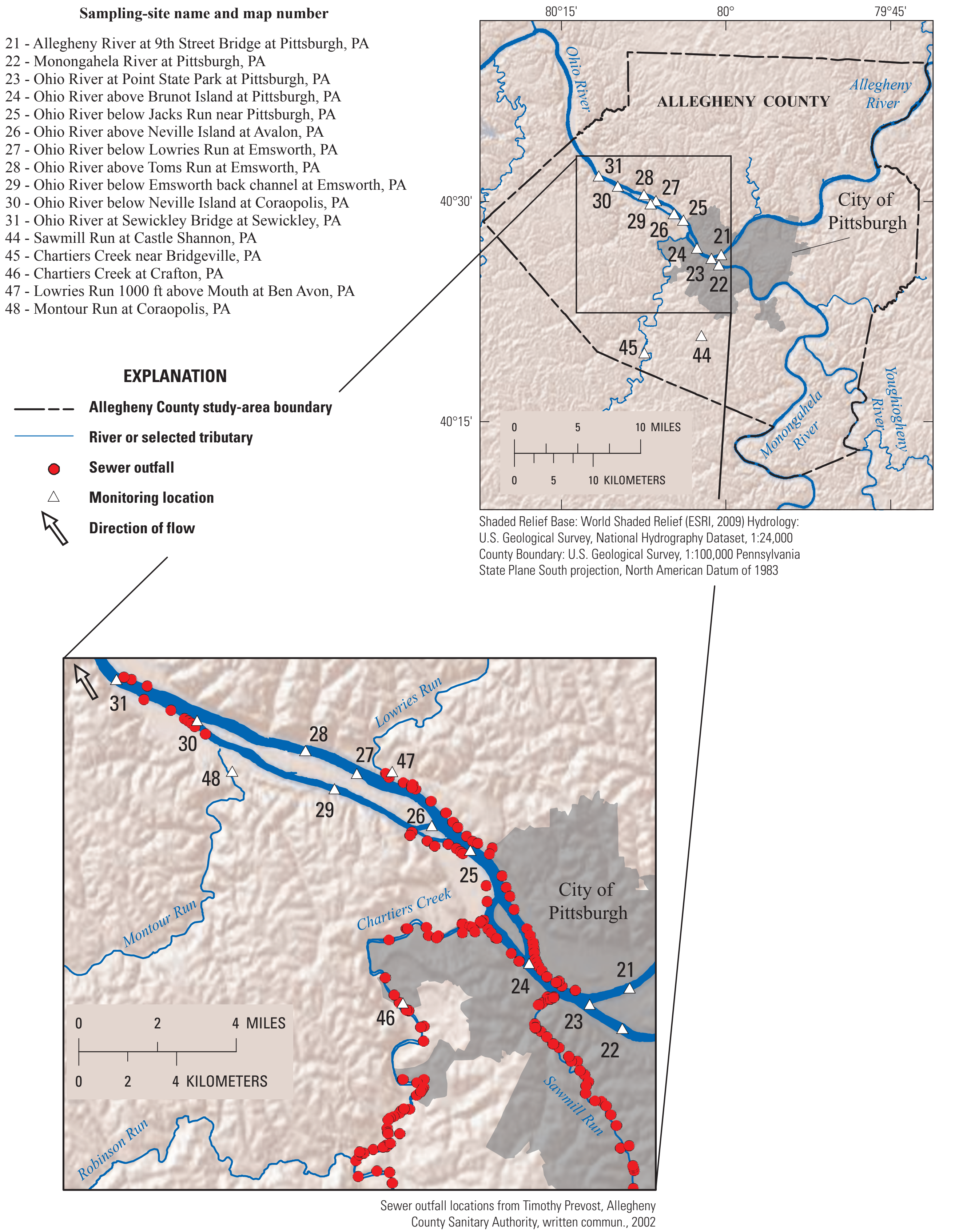

Figure 5. Location of sampling sites and combined sewer overflow locations on the Ohio River, Allegheny County, Pennsylvania.

Table 2. Streamflow statistics in cubic feet per second at streamgaging stations on the Allegheny, Monongahela, and Ohio Rivers, Allegheny County, Pennsylvania, October 1, 1968, to September 30, 2004.

[USGS, U.S. Geological Survey; 7Q10, annual 7-day, 10-year low-flow event; Recreational, May 1 to September 30; Non-recreational, October 1 to April 30]

USGS station number	USGS station name	Season	7Q10	Median flow	Bankfull flow[1]
03049500	Allegheny River at Natrona, PA	Recreational	2,660	7,750	75,400
03049500	Allegheny River at Natrona, PA	Non-recreational	3,140	21,420	75,400
03075070	Monongahela River at Elizabeth, PA	Recreational	688	2,870	61,160
03075070	Monongahela River at Elizabeth, PA	Non-recreational	854	8,640	61,160
03085000	Monongahela River at Braddock, PA	Recreational	1,660	4,550	74,650
03085000	Monongahela River at Braddock, PA	Non-recreational	1,820	11,760	74,650
03086000	Ohio River at Sewickley, PA	Recreational	4,600	12,690	128,500
03086000	Ohio River at Sewickley, PA	Non-recreational	5,380	36,460	128,500

[1]Bankfull flow refers to the 0.80 exceedance probability annual peak flow (1.25-year recurrence interval).

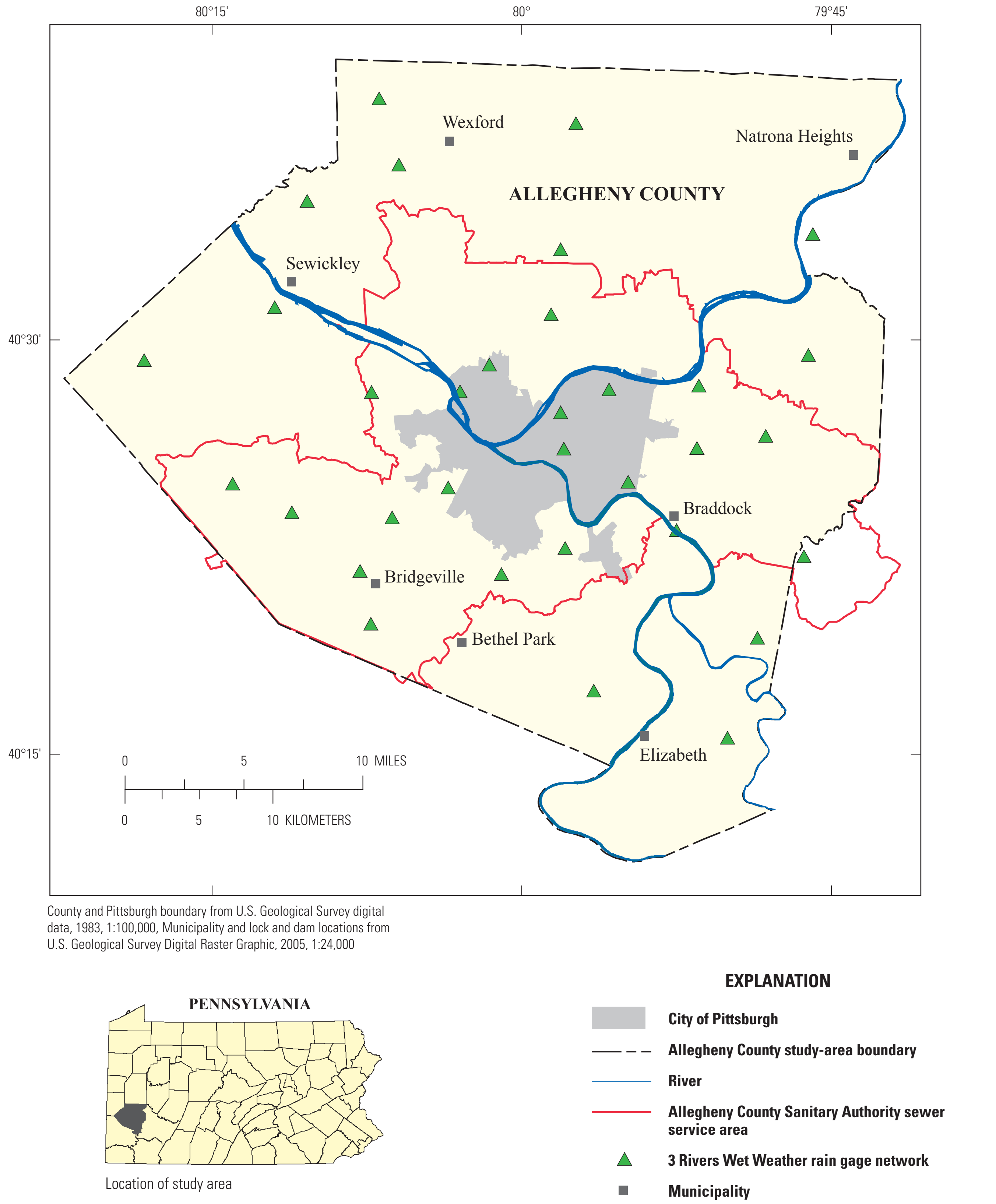

Figure 6. Location of precipitation stations near the Allegheny, Monongahela, and Ohio Rivers, Allegheny County, Pennsylvania.

target flow conditions in the receiving waters for a given storm event. The criteria used to designate wet- and dry-weather events are described below.

Wet-Weather Sampling Event Criteria

The two types of wet-weather event criteria are:

Type A

- No precipitation (rainfall) greater than 0.1 inches (in.) in the local watershed for 48 hours followed by a minimum of approximately 0.3 in. of rainfall (spatially averaged) over a 24-hour period along the Allegheny, Monongahela, or Ohio River. (Attempts were made to capture a range of precipitation greater than 0.3 in. over a 24-hour event period.)
- CSO source streams such as outfalls and tributaries discharging into the Allegheny, Monongahela, or Ohio River are generally active.
- CSO source streams discharging into tributary streams are generally active.

When applicable, additional samples were collected from main-stem rivers on days 1, 3, and 5 following the precipitation event to evaluate bacteria die-off; because of the short duration of the discharge hydrograph and variations in CSO loading, no attempts were made to assess die-off in tributaries following a precipitation event.

Type B

Receiving-water sampling and monitoring data also were collected during extended wet-weather events. The criteria are consistent with guidance for initiating monitoring of wet-weather events as described in the EPA Combined Sewer Overflows Guidance for Monitoring and Modeling (U.S. Environmental Protection Agency, 1999).

The criteria that were used to define an extended wet-weather sampling event (Type B) are similar to those for a wet-weather type A sampling event, with the exception that the 0.3 in. of rainfall may occur over a 72-hour period instead of only a 24-hour period. The specific criteria were—

- No precipitation greater than 0.1 in. in the local watershed for 48 hours followed by a minimum of approximately 0.3 in. of rainfall (spatially averaged) over a 24- to 72-hour period along the corridor of the Allegheny, Monongahela, or Ohio River. (Attempts were made to capture a range of precipitation greater than 0.3 in. over a 24- to 72-hour event period)
- Sources discharging into the Allegheny, Monongahela, or Ohio River are generally active during one or more of the periods of precipitation.
- Sources discharging into tributary streams are generally active during one or more of the periods of precipitation.

When applicable, additional samples were collected from main-stem rivers on days 1, 3, and 5 following the precipitation event to evaluate bacteria die-off.

Dry-Weather Sampling Event Criteria

The criteria used to define suitable dry-weather sampling events on the Three Rivers and tributaries follow those of ORSANCO (Ohio River Valley Water Sanitation Commission, 2006):

- ALCOSAN wet well, a control structure regulating flows at the wastewater-treatment plant, is operating under normal conditions.
- No precipitation greater than 0.1 in. in the local watershed 72 hours before a sampling event (determined from data obtained from the 3RWW rain-gage network at www.3riverswetweather.org).

Dry-weather conditions had to prevail throughout the sampling event. If rain began after some dry-weather samples had been collected, the field program manager determined whether the samples that had already been collected would be discarded or analyzed.

Methods

Streamflow was measured and water-quality samples were collected in accordance with USGS methods or an equivalent. Discharge measurements were made with a current meter or acoustic Doppler current profiler (ADCP) described by Turnipseed and Sauer (2010); Rantz and others (1982); Craig (1983); and Carter and Davidian (1968) and the USGS Office of Surface Water Hydroacoustics Web page, available at http://il.water.usgs.gov/adcp/ (U.S. Geological Survey, 2014). Water-quality samples were collected in accordance with the USGS National Field Manual for the Collection of Water-Quality Data (U.S. Geological Survey, 1997 to present). Statistical analyses described in detail below were used to compare data and test for trends.

Streamflow Measurement, Water-Quality Sampling, and Laboratory Analyses

Streamflows at the time of water-quality sampling were estimated from continuous-record streamgages or on the basis of ACDP streamflow measurements in accordance with the methods described by Oberg and others (2005). Streamflow and corresponding stage were measured at low, medium, and high stages to facilitate streamflow estimation at any given stage. With the exception of Turtle Creek at East Pittsburgh (for which flow was estimated by adding streamflow at Thompson Run at Turtle Creek and streamflow at Turtle Creek at Wilmerding, then applying a correction factor for the small, ungaged portion of Turtle Creek between Wilmerding and East Pittsburgh), streamflow was measured at streamgaging stations (table 1) or was estimated where water-quality samples were collected. Stage-discharge relations were developed at streamgaging stations on selected tributaries and the Ohio River at Sewickley by using standardized techniques described in Rantz (1982).

Depending on the site (main-stem river, tributary, receptor) and conditions at the time of sampling, either equal-discharge-increment (EDI), equal-width-increment (EWI), single vertical (SV), or grab sampling was used to collect water-quality samples. The degree of mixing was an important consideration in establishing sampling locations. Under conditions of poor mixing, point discharges such as a tributary in which bacteria concentrations are elevated may be strongly deflected by the receiving water and “hug” the side of the receiving-water channel. The velocity distribution from bank to bank was reviewed to establish appropriate EDI sample centroids that were composited to produce the EDI sample characteristic of the transect. During each event, three samples were collected at the main-stem sites: one characteristic of the channel cross-section (EDI or EWI sample), and one grab sample near each bank at each section (approximately 20 feet from shore at a depth of 18 in.). EDI samples provide an advantage over conventional grab samples in that they represent an integrated, discharge-weighted sample. As a result, the concentration can be used in conjunction with the flow rate measured at the section to determine the load at the time of sampling. At tributary sites, one depth-integrated EWI sample was collected; at receptor sites, one depth-integrated SV sample was collected immediately upstream from the selected receptor.

When possible, hydrographs were reviewed for each site, and samples were collected to coincide with a point on the rising limb, at peak flow, and on the falling limb of the hydrograph. Main-stem river flows are regulated and generally respond slowly to wet-weather events, except in instances when they are influenced by power generation. As a result of regulation, main-stem sites were sampled the day following a wet-weather event. Urban streams, in contrast, respond quickly to runoff events. In 2007, the water-quality sampling design was modified in an attempt to capture these variations in stage by sampling the day of the storm.

Water samples were collected using methodologies consistent with those referenced in the USGS National Field Manual for the Collection of Water-Quality Data (U.S. Geological Survey, 1997 to present) or an equivalent. Water temperature, pH, specific conductance, dissolved-oxygen concentration, and turbidity were measured in the field using a YSI 6920 multi-parameter water-quality sonde.

During sampling, aseptic techniques, sterile containers, and equipment were maintained. Water samples to be analyzed for fecal-indicator bacteria were packed in ice and transported within the 6-hour hold time for analysis as required by the USGS (U.S. Geological Survey, 1997 to present) and the EPA (U.S. Environmental Protection Agency, 1999). Concentrations of fecal-indicator bacteria were determined at Microbac Laboratories, Warrendale, Pa., by using membrane-filtration techniques for approved methods to determine bacteriological enumeration. Concentrations of FC bacteria were determined by using procedures described in Standard Methods for the Examination of Water and Wastewater (American Public Health Association and others, 1998, p. 9–63 to 9–65). Concentrations of enterococci bacteria were determined by using standard methods described in American Public Health Association and others (1998, p. 9–76 to 9–78). The method used for *E. coli* bacteria (Method 1103.1 using mTEC Agar) was that of the EPA (U.S. Environmental Protection Agency, 2000, p. 24–35).

Statistical Analyses

Nonparametric correlation analysis was used to screen for significant associations among indicator bacteria concentrations and the field characteristics of streamflow, water temperature, pH, specific conductance, dissolved-oxygen concentration, and turbidity. Significant associations were used to identify those water-quality characteristics that could be useful as potential explanatory variables in additional statistical analyses. Although other parameters may provide valuable information, we chose to review fecal-indicator bacteria and field parameters. The reasons for this approach are many; however, we wanted to conduct a retrospective study based on data from the initial 2001 CSO project, which did not include many of the supplemental parameters available after 2006 (Buckwalter and others, 2006). Spearman’s *rho,* a measure of monotonic association computed on the ranks of data (Helsel, 2005), was used for the analysis. Because *rho* cannot be computed directly for data with multiple censoring limits, the presence of multiple-censored bacteria data required recoding of values less than the highest detection limit to censored values at the highest detection limit (less than [<] 10 col/100 mL). Because the large sample approximation used to compute p-values does not fit the Spearman test statistic for small sample sizes (Helsel and Hirsch, 1992), only sites with 25 or more data values underwent correlation analysis. Significance of correlations was evaluated at the 95-percent confidence level (alpha = 0.05).

The paired Prentice Wilcoxon (PPW) test was applied to determine whether differences were present among data obtained from left-bank, right-bank, and composite samples at a given river location. The presence or absence of significant differences among the three sample types provided information about the representativeness of each type with regard to the mean water quality in the cross section and about possible elevated bacteria concentrations downstream from tributary and outfall locations. The PPW test is a nonparametric paired-sample test suitable for use with data with multiple censoring limits (Helsel, 2005). *E. coli* and FC counts from six Three Rivers and eight tributary sites were grouped by dry- and wet-weather conditions and tested for differences across sampling locations. Enterococci were not included as no additional enterococci concentration data had been collected since Buckwalter and others (2006) reported on sampling-location differences. A minimum dataset size of 12 samples was enforced to minimize p-value errors resulting from large-sample approximation. Censoring levels for *E. coli* and FC were less than < 5 and < 10 col/100 mL. The significance level was set at 95 percent (alpha = 0.05).

The Seasonal Kendall trend test was used to estimate changes in *E. coli* and FC concentrations during the 2001–09 study period. Two versions of the Seasonal Kendall trend test are available in the program ESTREND (Schertz and others, 1991). One version accommodates multiple-censored data but does not accommodate flow adjustment of the data. This version was preferred because of the presence of multiple censoring levels in the data, but it imposes more constraints on the size and distribution of the dataset than the second version. These constraints resulted in all sites being identified as having insufficient data. The second version of the test permits flow adjustment but has conditions that limit censoring to one level and to about 5 percent of the data. Flow adjustment is desirable if bacteria concentrations have an identifiable relation to the magnitude of streamflow and if the streamflows concurrent with sample collection have tended to increase or decrease over the study period. A log-log linear model was selected to flow-adjust *E. coli* and FC concentrations. The model consists of a linear regression applied to the relation between the logarithms of *E. coli* and FC concentrations and the logarithm of streamflow. Residuals from the model are tested for trends over time. The residuals were tested for trend only if the flow-adjustment model was statistically significant. A single season, the May through October recreational period, was defined. Trend significance was evaluated at the 95-percent confidence level.

Logistic regression was used to determine whether the probability of bacteria concentrations in water samples exceeding the recreational standards changed over the sampling period. The standards were 235 col/100 mL for *E. coli* and 400 col/100 mL for FC. For this study, logistic regression was used to model the probability of exceeding recreational standards as a function of the effects of explanatory variables (Helsel, 2005). Multiple-censored data are permissible. Time, streamflow, and turbidity were the modeled explanatory variables. The hypothesis that the probability of exceeding recreational bacteria standards has changed over time is supported if time is determined to be a significant explanatory variable. Streamflow and turbidity were included on the basis of the results of correlation analysis. They were shown to have the strongest and most consistent associations with bacteria concentrations over the study period. Restrictions on the size of the dataset used for logistic regression limited analysis to the five Three Rivers main-stem sites where composite, right-bank, and left-bank samples could be included in the test dataset to ensure a sufficient number of samples. The generally no-significant-difference outcomes of the PPW test for locational differences were considered sufficient justification to include right- and left-bank samples with composite samples in the test dataset without introducing bias in the analysis. Trends in enterococci concentrations were not determined as a result of insufficient data.

Occurrence and Trends in Concentrations of Fecal-Indicator Bacteria in Streamflow

The range in daily streamflow at the main-stem stations during 2001–09 is shown in figure 7. Summary statistics for streamflow at each of the continuous-record stations are given in table 3.

Occurrence of Fecal-Indicator Bacteria

From July 2001 to October 2009, 1,742 water samples were collected at 52 sites in the Three Rivers and selected tributaries for this study. Analytical results for bacteria concentrations and associated field characteristics for those samples are summarized in table 4 (at end of report). Quantifiable concentrations of *E.coli* bacteria were detected in 1,667 (97.0 percent) of 1,719 samples, and the EPA recreational water-quality criterion of 235 col/100 mL was exceeded in 853 samples (49.6 percent). FC bacteria concentrations were quantified in 1,693 (98.8 percent) of 1,713 samples, and the Commonwealth of Pennsylvania water contact criterion of 400 col/100 mL was exceeded in 780 samples (45.5 percent). Enterococci bacteria concentrations were quantifiable in 912 (87.5 percent) of 1,042 samples, and the EPA recreational water-quality criterion of 61 col/100 mL was exceeded in 483 samples (46.4 percent). The median percentage of samples in which recreational water-quality standards were exceeded across all sites from which five or more samples were analyzed was 48 for *E. coli*, 43 for FC, and 75 for enterococci.

Allegheny River Basin

Significant differences in composite, left-bank, and right-bank samples from the Allegheny River reported by Buckwalter and others (2006) continued to be observed with the addition of the 2006–09 data and the increase in the confidence level from 90 to 95 percent (table 5). *E. coli* and FC bacteria concentrations were higher in wet-weather samples collected on the left and right banks than in composite samples at the Oakmont site. Median wet-weather *E. coli* concentrations for left-bank, right-bank, and composite samples were 57, 135, and 22 col/100 mL, respectively; however, FC concentrations in samples collected on the left bank and composite samples were not significantly different. Median wet-weather FC

Table 3. U.S. Geological Survey streamgage statistics for the period of sampling October 1, 2001, to September 30, 2009, in the Allegheny, Monongahela, and Ohio Rivers, Allegheny County, Pennsylvania.

[USGS, U.S. Geological Survey; min, minimum; max, maximum; shaded stations are wire-weight gages; ft³/s, cubic feet per second]

USGS station name	USGS station number	Period of sampling	Instantaneous min discharge (ft³/s)	Instantaneous max discharge (ft³/s)	Mean discharge (ft³/s)	Median discharge (ft³/s)
Allegheny River Basin						
Allegheny River at Natrona, PA	03049500	Oct 2001–Sep 2009	1,490	184,970	20,700	15,760
Deer Creek near Dorseyville, PA	03049646	June 2006–Nov 2009	0	1,347	36	18
Plum Creek at Milltown, PA	03049658	Jun 2006–Oct 2009	0.04	807	23	14
Squaw Run at Old Freeport Road near Blawnox, PA	03049676	Oct 2007–Sep 2009	0.1	725	9	4.2
Girtys Run above Grant Avenue at Millvale, PA	03049819	Jun 2006–Sep 2009	0.59	975	14	5.2
Pine Creek at Grant Avenue at Etna, PA	03049807	Jun 2006–Sep 2009	1.9	2,226	84	48
Monongahela River Basin						
Monongahela River at Elizabeth, PA	03075070	Oct 2001–Sep 2009	180	121,080	9,755	6,025
Youghiogheny River at Sutersville, PA	03083500	Oct 2001–Sep 2009	485	46,370	3,381	2,120
Thompson Run at Turtle Creek, PA	03084800	May 2004–Sep 2009	1	5,283	22	16
Turtle Creek at Wilmerding, PA	03084698	Aug 2004–Sep 2009	13	10,051	191	109
Monongahela River at Braddock, PA	03085000	Oct 2001–Sep 2009	887	142,193	14,288	9,373
Ohio River Basin						
Ninemile near Swissvale, PA	03085049	Jun 2006–Sep 2009	0.11	1,274	3.3	1.7
Sawmill Run at Duquesne Heights nr Pittsburgh, PA	03085213	Apr 2004–Sep 2009	1.2	6,535	19	8
Chartiers Creek at Carnegie, PA	03085500	Oct 2001–Sep 2009	37	27,400	324	200
Lowries Run at Camp Horne near Emsworth, PA	03085947	Jun 2006–Sep 2009	0.5	4,902	16	7.7
Montour Run at Scott Station near Imperial, PA	03085956	Oct 2001–Sep 2009	1.8	8,284	34	16
Ohio River at Sewickley, PA	03086000	Oct 2001–Sep 2009	1,582	313,931	35,870	26,078
Sawmill Run at Castle Shannon, PA	03085160	Mar 2004–Nov 2009	0.11	143	7.5	0.55
Chartiers Creek near Bridgeville, PA	03085290	Mar 2004–Nov 2009	24	11,200	685	114
Thompson Run at Gascola, PA	03084750	Mar 2004–Nov 2009	0.83	162	19	7.3
Streets Run at Hays, PA	03085100	June 2006–Nov 2009	1.04	11	4.2	2.6
Turtle Creek at Trafford, PA	03084400	Mar 2004–Nov 2009	6.3	1,120	123	51

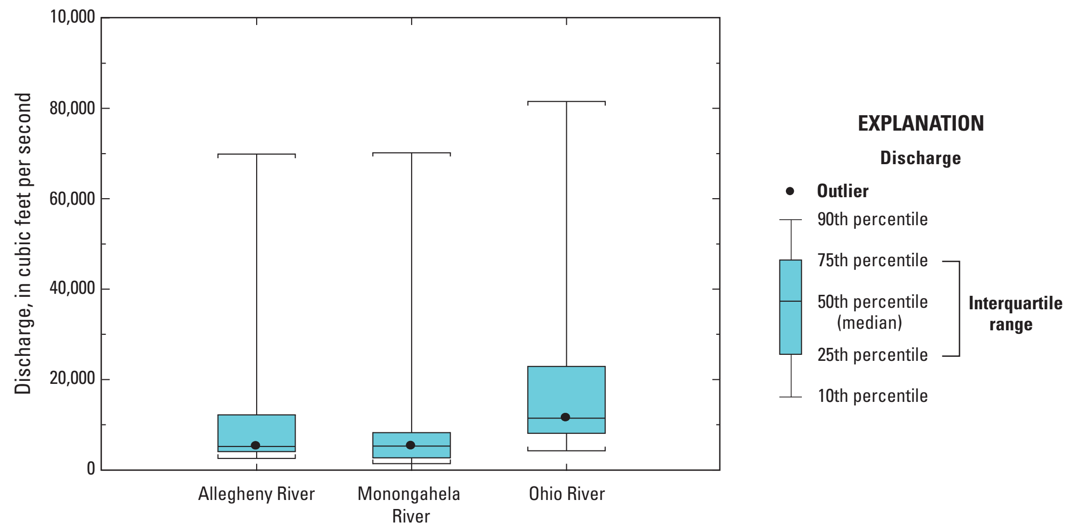

Figure 7. Streamflow statistics for U.S. Geological Survey streamgaging stations on the Allegheny, Monongahela, and Ohio Rivers, Allegheny County, Pennsylvania, during dry- and wet-weather events, October 1, 2001, to September 30, 2009.

Table 5. Results of generalized Wilcoxon paired sample tests of sampling-location difference in concentrations of fecal-indicator bacteria and turbidity in dry- and wet-weather samples from five sampling locations on the Allegheny, Monongahela, and Ohio Rivers, Allegheny County, Pennsylvania, 2001–09.

[n, number of samples; LB, left stream bank looking downstream; RB, right stream bank looking downstream; Comp, composite; >, greater than; ns, not significant at the 95-percent confidence level (p-value < 0.05)]

Number of samples and comparison tested	Allegheny River				Monongahela River				Ohio River	
	Oakmont		9th Street Bridge		McKeesport		Pittsburgh		Sewickley Bridge	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Eschericia coli										
n	21	30	24	36	13	12	25	36	21	31
LB-Comp	ns	0.0075	ns	ns	0.0423	ns	ns	ns	ns	ns
RB-Comp	ns	0.0001	ns	ns	ns	ns	ns	ns	0.0052	ns
LB-RB	ns	0.0101	ns	ns	ns	ns	ns	ns	ns	ns
Fecal coliform										
n	21	30	23	36	13	12	24	35	21	31
LB-Comp	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
RB-Comp	ns	0.0073	ns	ns	ns	ns	ns	ns	0.0052	ns
LB-RB	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Turbidity										
n	18	28	22	33	12	12	23	31	18	29
LB-Comp	ns	ns	ns	0.0012	ns	ns	ns	0.0337	ns	ns
RB-Comp	ns	ns	ns	0.0025	ns	ns	ns	ns	ns	ns
LB-RB	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

concentrations in right-bank and composite samples were 188 and 82 col/100 mL, respectively. Turbidity was significantly higher in composite wet-weather samples from the 9th Street Bridge sampling location than in left- or right-bank samples. Median differences were small (< 2 Nephelometric Turbidity Units [NTUs]) and indicate that median turbidity was 20 percent lower in left- and right-bank samples than in the composite samples from the 9th Street Bridge location, where the median turbidity was lowest (7.2 NTUs) among all main-stem locations. Increasing the number of years of data used in the analysis increased the confidence levels associated with the significant differences, indicating that the conditions responsible for the locational differences, as discussed in Buckwalter and others (2006), persist.

Monongahela River Basin

Differences among bacteria concentrations in composite, left-bank, and right-bank samples from the Monongahela River changed little from those reported by Buckwalter and others (2006). Of the two significant differences found in this study (table 5), the higher turbidity values in wet-weather composite samples from Pittsburgh had been reported previously. A new finding was lower *E. coli* concentrations in dry-weather left-bank samples than in composite samples from the McKeesport station. Median concentrations in left-bank samples were about 60 percent of those in composite samples. Buckwalter and others (2006) discuss possible mechanisms for the differences.

Ohio River Basin

Several changes were observed in composite, left-bank, and right-bank sample differences for Ohio River sites compared to those found by Buckwalter and others (2006). They reported a significant difference between left- and right-bank dry-weather FC concentrations for the Ohio River at Sewickley site. Re-analysis at the 95-percent confidence level with additional data showed an insignificant difference between left- and right-bank FC concentrations (table 5); however, median left-bank FC concentrations remain about twice the right-bank counts. Also, differences between dry-weather right-bank and composite sample concentrations of *E. coli* and FC became significant with the addition of 2006–09 data.

Relations of Concentrations of Fecal-Indicator Bacteria to Other Water-Quality Parameters

The relations between FC concentrations and other water-quality parameters at main-stem and tributary sites are presented below.

Main-Stem Sites

Significant correlations between concentrations of fecal-indicator bacteria and various field water-quality characteristics were found at all Three Rivers main-stem sites (tables 6, 7, and 8) and nine tributary sites (tables 9 and 10). The strongest and most consistent correlations at the five Three Rivers sites were those between streamflow and dry-weather bacteria concentrations.

E. coli, FC, and enterococci concentrations at all Three Rivers sites showed significant positive correlations with streamflow (*rho* = 0.248–0.758). Wet-weather correlations were somewhat weaker (*rho* = 0.141–0.624) and were not significant at two sites. The constantly changing contributions of bacteria from a multitude of sources during wet weather likely result in a more variable relation to streamflow than during dry weather, yielding the lower correlation coefficients.

Turbidity also exhibited a significant positive correlation with bacteria concentration. With two exceptions, turbidity was significantly correlated with fecal-indicator bacteria concentrations during both dry- and wet-weather conditions. At the Monongahela River sites, the correlation between turbidity and bacteria concentration showed weather dependency but, unexpectedly, this dependency was not consistent given the proximity of the sites. Samples from the McKeesport station showed significant dry-weather correlations and poor wet-weather correlations. The reverse was true for samples from Pittsburgh.

All significant correlations of pH and specific conductance with bacteria concentrations were negative. Buckwalter and others (2006) attribute the negative association with specific conductance to an inverse relation between streamflow and specific conductance. This relation results from the dilution of dissolved solids in base flow by increasing amounts of runoff from rainfall with low specific conductance.

Water temperature and dissolved-oxygen concentrations show a range of positive and negative correlations with respect to bacteria, depending on streamflow condition. For example, water temperature typically showed a weak negative correlation (-0.341 maximum) with bacteria concentration but weak positive correlations were found for the three bacteria types in wet-weather samples from the Allegheny River at 9th Street Bridge station and for enterococci in samples from the Ohio River at Sewickley station. No significant positive correlations were found by Buckwalter and others (2006); however, positive coefficients were reported in this study. Other than significance levels, little change in the pattern of water-temperature correlations was noted. Dissolved-oxygen concentration showed significant correlations only under wet-weather conditions. The correlations were negative, with *rho* less than 0.464, except at the Ohio River at Sewickley station, where

Table 6. Results of Spearman's *rho* correlations between concentrations of fecal-indicator bacteria and field water-quality characteristics, Allegheny River main-stem sites, Allegheny County, Pennsylvania, 2001–09.

[n, number of samples; p-value, probability; <, less than; bold type indicates p-values of 0.05 or less (significance at the 95-percent confidence level)]

	All conditions			Dry weather			Wet weather		
	Eschericia coli	Fecal coliform	Enterococci	*Eschericia coli*	Fecal coliform	Enterococci	*Eschericia coli*	Fecal coliform	Enterococci
03049652 Allegheny River at Oakmont, PA									
Streamflow	0.432	0.365	0.269	0.418	0.387	0.260	0.459	0.415	0.348
p-value	**<.0001**	**<.0001**	**0.0008**	**0.0007**	**0.0017**	**0.0392**	**<.0001**	**<.0001**	**0.0008**
n	153	153	153	63	63	63	90	90	90
Water temperature	-0.298	-0.257	-0.029	-0.325	-0.300	0.074	-0.219	-0.144	-0.009
p-value	**0.0007**	**0.0037**	0.7451	**0.0120**	**0.0210**	0.5764	0.0751	0.2437	0.9414
n	126	126	126	59	59	59	67	67	67
pH	0.001	-0.066	-0.161	0.207	0.222	-0.042	-0.128	-0.272	-0.272
p-value	0.9897	0.4160	**0.0474**	0.0925	0.0708	0.7376	0.2445	**0.0118**	**0.0119**
n	152	152	152	67	67	67	85	85	85
Specific conductance	-0.290	-0.164	-0.138	-0.266	-0.070	-0.111	-0.325	-0.293	-0.249
p-value	**0.0003**	**0.0421**	0.0872	**0.0297**	0.5761	0.3729	**0.0021**	**0.0058**	**0.0203**
n	154	154	154	67	67	67	87	87	87
Dissolved oxygen	-0.116	-0.030	0.092	-0.208	-0.018	0.076	-0.157	-0.226	0.003
p-value	0.2284	0.7578	0.3399	0.1308	0.8976	0.5847	0.2487	0.0944	0.9814
n	110	110	110	54	54	54	56	56	56
Turbidity	0.545	0.328	0.296	0.598	0.521	0.373	0.543	0.279	0.331
p-value	**<.0001**	**<.0001**	**0.0003**	**<.0001**	**<.0001**	**0.0042**	**<.0001**	**0.0088**	**0.0018**
n	144	144	144	57	57	57	87	87	87
03049832 Allegheny River at 9th Street Bridge at Pittsburgh, PA									
	All conditions			**Dry weather**			**Wet weather**		
	Eschericia coli	**Fecal coliform**	**Enterococci**	***Eschericia coli***	**Fecal coliform**	**Enterococci**	***Eschericia coli***	**Fecal coliform**	**Enterococci**
Streamflow	0.262	0.203	0.309	0.482	0.404	0.487	0.133	0.073	0.207
p-value	**0.0003**	**0.0055**	**<.0001**	**<.0001**	**0.0003**	**<.0001**	0.1674	0.4480	**0.0303**
n	185	185	185	75	75	75	110	110	110
Water temperature	-0.099	0.040	0.143	-0.432	-0.133	-0.120	0.189	0.226	0.298
p-value	0.1738	0.5833	**0.0504**	**<.0001**	0.2385	0.2893	**0.0493**	**0.0181**	**0.0016**
n	189	189	189	80	80	80	109	109	109
pH	-0.190	-0.153	-0.239	-0.180	-0.045	-0.211	-0.187	-0.214	-0.259
p-value	**0.0097**	**0.0378**	**0.0011**	0.1142	0.6988	0.0631	0.0547	**0.0276**	**0.0074**
n	184	184	184	78	78	78	106	106	106
Specific conductance	-0.140	0.050	-0.225	-0.273	0.060	-0.254	-0.138	-0.040	-0.263
p-value	0.0540	0.4897	**0.0018**	**0.0138**	0.5955	**0.0223**	0.1514	0.6775	**0.0058**
n	190	190	190	81	81	81	109	109	109
Dissolved oxygen	-0.232	-0.251	-0.359	0.015	0.009	-0.220	-0.456	-0.436	-0.464
p-value	**0.0028**	**0.0012**	**<.0001**	0.8973	0.9382	0.0630	**<.0001**	**<.0001**	**<.0001**
n	163	163	163	72	72	72	91	91	91
Turbidity	0.349	0.242	0.131	0.477	0.209	0.322	0.266	0.248	0.019
p-value	**<.0001**	**0.0011**	0.0833	**<.0001**	0.0744	**0.0051**	**0.0066**	**0.0114**	0.8462
n	177	177	177	74	74	74	103	103	103

Table 7. Results of Spearman's *rho* correlations between concentrations of fecal-indicator bacteria and field water-quality characteristics, Monongahela River main-stem sites, Allegheny County, Pennsylvania, 2001–09.

[n, number of samples; p-value, probability; <, less than; bold type indicates p-values of 0.05 or less (significance at the 95-percent confidence level)]

03083903 Monongahela River at McKeesport, PA

	All conditions			Dry weather			Wet weather		
	Eschericia coli	Fecal coliform	Enterococci	*Eschericia coli*	Fecal coliform	Enterococci	*Eschericia coli*	Fecal coliform	Enterococci
Streamflow	0.557	0.485	0.472	0.757	0.681	0.758	0.141	0.158	0.168
p-value	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	0.4105	0.3583	0.3271
n	66	66	66	30	30	30	36	36	36
Water temperature	-0.513	-0.406	-0.341	-0.547	-0.426	-0.279	0.085	0.122	-0.110
p-value	**<.0001**	**0.0002**	**0.0022**	**0.0002**	**0.0049**	0.0731	0.6215	0.4776	0.5243
n	78	78	78	42	42	42	36	36	36
pH	-0.541	-0.449	-0.400	-0.578	-0.582	-0.559	-0.059	0.060	-0.044
p-value	**<.0001**	**<.0001**	**0.0002**	**<.0001**	**<.0001**	**<.0001**	0.7335	0.7268	0.7972
n	81	81	81	45	45	45	36	36	36
Specific conductance	-0.597	-0.496	-0.543	-0.712	-0.658	-0.570	-0.135	-0.014	-0.322
p-value	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	0.4328	0.9343	0.0552
n	81	81	81	45	45	45	36	36	36
Dissolved oxygen	-0.069	-0.108	-0.200	-0.089	-0.165	-0.273	-0.297	-0.234	-0.359
p-value	0.5382	0.3364	0.0735	0.5618	0.2786	0.0692	0.0786	0.1698	**0.0315**
n	81	81	81	45	45	45	36	36	36
Turbidity	0.587	0.502	0.306	0.696	0.586	0.533	0.091	0.095	-0.132
p-value	**<.0001**	**<.0001**	**0.0062**	**<.0001**	**<.0001**	**0.0002**	0.5984	0.5800	0.4429
n	79	79	79	43	43	43	36	36	36

03085150 Monongahela River at Pittsburgh, PA

	All conditions			Dry weather			Wet weather		
	Eschericia coli	Fecal coliform	Enterococci	*Eschericia coli*	Fecal coliform	Enterococci	*Eschericia coli*	Fecal coliform	Enterococci
Streamflow	0.301	0.283	0.338	0.317	0.248	0.423	0.260	0.214	0.251
p-value	**<.0001**	**<.0001**	**<.0001**	**0.0057**	**0.0319**	**0.0002**	**0.0061**	**0.0245**	**0.0083**
n	185	185	185	75	75	75	110	110	110
Water temperature	-0.291	-0.140	-0.016	-0.401	-0.263	-0.062	-0.200	-0.017	-0.001
p-value	**<.0001**	0.0568	0.8253	**0.0002**	**0.0186**	0.5875	**0.0388**	0.8632	0.9928
n	187	187	187	80	80	80	107	107	107
pH	-0.320	-0.354	-0.232	-0.155	-0.182	-0.028	-0.385	-0.405	-0.301
p-value	**<.0001**	**<.0001**	**0.0014**	0.1660	0.1031	0.8036	**<.0001**	**<.0001**	**0.0018**
n	186	186	186	81	81	81	105	105	105
Specific conductance	-0.271	-0.254	-0.395	-0.082	-0.022	-0.178	-0.376	-0.366	-0.471
p-value	**0.0002**	**0.0004**	**<.0001**	0.4655	0.8438	0.1115	**<.0001**	**<.0001**	**<.0001**
n	189	189	189	81	81	81	108	108	108
Dissolved oxygen	0.072	0.005	-0.218	0.209	0.083	-0.164	-0.157	-0.183	-0.318
p-value	0.3617	0.9502	**0.0054**	0.0736	0.4832	0.1636	0.1462	0.0900	**0.0027**
n	161	161	161	74	74	74	87	87	87
Turbidity	0.353	0.246	0.232	0.180	0.085	0.068	0.521	0.407	0.379
p-value	**<.0001**	**0.0009**	**0.0018**	0.1198	0.4673	0.5573	**<.0001**	**<.0001**	**<.0001**
n	178	178	178	76	76	76	102	102	102

Table 8. Results of Spearman's *rho* correlations between concentrations of fecal-indicator bacteria and field water-quality characteristics, Ohio River main-stem sites (Ohio River at Sewickley, PA), Allegheny County, Pennsylvania, 2001–09.

[n, number of samples; p-value, probability; <, less than; bold type indicates p-values of 0.05 or less (significance at the 95-percent confidence level)]

03085986 Ohio River at Sewickley Bridge at Sewickley, PA									
	All conditions			Dry weather			Wet weather		
	Eschericia coli	Fecal coliform	Enterococci	*Eschericia coli*	Fecal coliform	Enterococci	*Eschericia coli*	Fecal coliform	Enterococci
Streamflow	0.598	0.470	0.431	0.698	0.622	0.439	0.624	0.455	0.458
p-value	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**0.0003**	**<.0001**	**<.0001**	**<.0001**
n	156	156	156	63	63	63	93	93	93
Water temperature	-0.199	-0.001	0.267	-0.184	0.005	0.138	-0.341	-0.077	0.346
p-value	**0.0207**	0.9943	**0.0018**	0.1485	0.9709	0.2795	**0.0034**	0.5230	**0.0029**
n	135	135	135	63	63	63	72	72	72
pH	0.129	0.119	0.056	0.203	0.202	0.161	0.143	0.130	0.043
p-value	0.1038	0.1331	0.4802	0.0998	0.1018	0.1933	0.1703	0.2152	0.6828
n	160	160	160	67	67	67	93	93	93
Specific conductance	-0.373	-0.280	-0.339	-0.553	-0.524	-0.287	-0.360	-0.242	-0.423
p-value	**<.0001**	**0.0003**	**<.0001**	**<.0001**	**<.0001**	**0.0185**	**0.0004**	**0.0193**	**<.0001**
n	160	160	160	67	67	67	93	93	93
Dissolved oxygen	0.344	0.214	0.002	0.192	-0.072	-0.153	0.397	0.339	0.052
p-value	**0.0004**	**0.0297**	0.9855	0.1767	0.6162	0.2826	**0.0036**	**0.0139**	0.7144
n	103	103	103	51	51	51	52	52	52
Turbidity	0.600	0.589	0.537	0.669	0.770	0.592	0.589	0.526	0.530
p-value	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
n	149	149	149	59	59	59	90	90	90

positive correlations for *E. coli* and FC were found. Buckwalter and others (2006) reported only negative correlations for water temperature but positive and negative correlations for dissolved-oxygen concentration, consistent with the current analysis. The significant positive and negative correlations for water temperature and dissolved-oxygen concentration were unexpected, and the reasons for this variability have not been established.

Tributary Sites

Correlations between bacteria concentrations and field water-quality characteristics at the tributary sites varied widely (tables 9 and 10). Tributaries in order of weakest to strongest correlations were Thompson Run, Turtle Creek, Sawmill Run, and Chartiers Creek. Because several of the tributary correlation datasets contain less than 25 values, these correlations should be interpreted with caution. At the two Thompson Run sites, few significant correlations and no favored weather pattern were found, except for turbidity in wet-weather samples from the Thompson Run at Turtle Creek station. The two Turtle Creek sites were similar to the Thompson Run sites in number and distribution of significant correlations.

Significant correlations for the Sawmill Run sites were limited to samples collected under wet-weather conditions, with one exception. Water temperature, specific conductance, dissolved-oxygen concentration, and turbidity correlations for wet-weather samples were significant, with *rho* ranging from 0.347 to 0.687 for Sawmill Run. Significant correlations at upstream and downstream sites were similar in magnitude, with the exception of the correlations of *E. coli* and FC concentrations to streamflow. Correlations of *E. coli* and FC concentrations to streamflow for samples from the Sawmill Run at Duquesne Heights station were the strongest correlations observed in the study. These findings are consistent with those of Buckwalter and others (2006) for the 2001–05 time period. In addition, median FC bacteria concentrations at the Duquesne Heights station were the highest measured during the study. High bacteria concentrations together with the high *rho* values indicate that water with a high bacteria content contributes a greater percentage of the streamflow volume at Duquesne Heights than at other sites. As noted for some of the main-stem site correlations, the correlations of wet-weather enterococci concentrations in wet-weather samples with water temperature, specific conductance, and dissolved-oxygen concentration reversed direction from positive to negative

Table 9. Results of Spearman's *rho* correlations between concentrations of fecal-indicator bacteria and field water-quality characteristics, Monongahela River Basin, Allegheny County, Pennsylvania, 2001–09.

[n, number of samples; nd, no data; p-value, probability; <, less than; bold type indicates p-values of 0.05 or less (significance at the 95-percent confidence level)]

03084400 Turtle Creek at Trafford, PA

	All conditions			Dry weather			Wet weather		
	Eschericia coli	Fecal coliform	Enterococci	*Eschericia coli*	Fecal coliform	Enterococci	*Eschericia coli*	Fecal coliform	Enterococci
Streamflow	0.283	0.213	0.109	0.101	0.021	-0.450	0.117	-0.030	-0.027
p-value	0.1451	0.277	0.5794	0.7963	0.9572	0.2241	0.6342	0.9034	0.9141
n	28	28	28	9	9	9	19	19	19
Water temperature	-0.015	0.090	-0.107	-0.357	-0.151	0.383	0.233	0.385	-0.035
p-value	0.9378	0.6406	0.5821	0.3454	0.6977	0.3089	0.3239	0.094	0.884
n	29	29	29	9	9	9	20	20	20
pH	-0.159	-0.158	-0.193	-0.468	-0.468	0.081	0.054	0.059	-0.046
p-value	0.4026	0.4042	0.3061	0.1725	0.1725	0.8233	0.8196	0.8048	0.8482
n	30	30	30	10	10	10	20	20	20
Specific conductance	-0.402	-0.369	-0.232	0.012	0.243	-0.038	-0.442	-0.381	-0.244
p-value	**0.0278**	**0.0446**	0.2177	0.9734	0.4984	0.918	0.0513	0.0977	0.3
n	30	30	30	10	10	10	20	20	20
Dissolved oxygen	-0.554	-0.599	-0.179	-0.803	-0.720	-0.237	-0.409	-0.495	-0.159
p-value	**0.0018**	**0.0006**	0.3517	**0.0091**	**0.0288**	0.5387	0.073	**0.0266**	0.5026
n	29	29	29	9	9	9	20	20	20
Turbidity	0.409	0.336	0.494	-0.604	-0.588	0.100	0.521	0.407	0.534
p-value	**0.0247**	0.0693	**0.0056**	0.0646	0.0735	0.7827	**0.0185**	0.0749	**0.0154**
n	30	30	30	10	10	10	20	20	20

03084750 Thompson Run at Gascola, PA

	All conditions			Dry weather			Wet weather		
	Eschericia coli	Fecal coliform	Enterococci	*Eschericia coli*	Fecal coliform	Enterococci	*Eschericia coli*	Fecal coliform	Enterococci
Streamflow	0.128	0.100	0.191	-0.383	-0.407	-0.504	0.185	0.140	0.227
p-value	0.5153	0.6142	0.3305	0.349	0.3167	0.2029	0.4344	0.5557	0.3354
n	28	28	28	8	8	8	20	20	20
Water temperature	0.219	0.253	-0.047	0.448	0.460	-0.110	0.235	0.294	0.018
p-value	0.2533	0.1859	0.8097	0.2268	0.2132	0.7781	0.3178	0.2076	0.9395
n	29	29	29	9	9	9	20	20	20
pH	0.201	0.133	-0.123	-0.071	-0.068	-0.799	0.225	0.175	0.102
p-value	0.295	0.4916	0.5253	0.8569	0.8612	**0.0099**	0.3392	0.4604	0.67
n	29	29	29	9	9	9	20	20	20
Specific conductance	-0.790	-0.698	-0.224	-0.661	-0.656	0.247	-0.780	-0.721	-0.354
p-value	**<.0001**	**<.0001**	0.2345	**0.0375**	**0.0392**	0.4911	**<.0001**	**0.0003**	0.1256
n	30	30	30	10	10	10	20	20	20
Dissolved oxygen	-0.354	-0.322	0.097	-0.463	-0.305	-0.100	-0.296	-0.331	0.129
p-value	0.0592	0.089	0.6151	0.209	0.4246	0.7988	0.2046	0.1544	0.589
n	29	29	29	9	9	9	20	20	20
Turbidity	0.175	0.118	0.212	-0.113	-0.215	-0.135	0.193	0.149	0.258
p-value	0.346	0.5264	0.2519	0.7553	0.5513	0.7103	0.4024	0.5183	0.259
n	31	31	31	10	10	10	21	21	21

Table 9. Results of Spearman's *rho* correlations between concentrations of fecal-indicator bacteria and field water-quality characteristics, Monongahela River Basin, Allegheny County, Pennsylvania, 2001–09.—Continued

[n, number of samples; nd, no data; p-value, probability; <, less than; bold type indicates p-values of 0.05 or less (significance at the 95-percent confidence level)]

03084800 Thompson Run at Turtle Creek, PA

	All conditions			Dry weather			Wet weather		
	Eschericia coli	Fecal coliform	Enterococci	*Eschericia coli*	Fecal coliform	Enterococci	*Eschericia coli*	Fecal coliform	Enterococci
Streamflow	0.296	0.105	-0.078	-0.212	-0.298	-0.914	0.335	0.205	0.135
p-value	0.1196	0.5887	0.6888	0.5563	0.4032	**0.0002**	0.1608	0.3992	0.5802
n	29	29	29	10	10	10	19	19	19
Water temperature	-0.083	-0.073	-0.163	0.092	0.159	-0.151	-0.038	-0.064	-0.091
p-value	0.6689	0.7064	0.3969	0.8138	0.6828	0.6977	0.875	0.7889	0.7013
n	29	29	29	9	9	9	20	20	20
pH	-0.007	0.065	-0.066	-0.177	-0.239	-0.438	0.124	0.245	0.165
p-value	0.9701	0.7345	0.7302	0.625	0.5069	0.2052	0.6035	0.2969	0.4867
n	30	30	30	10	10	10	20	20	20
Specific conductance	-0.479	-0.332	-0.248	-0.212	-0.049	-0.448	-0.532	-0.372	-0.232
p-value	**0.0074**	0.0731	0.1872	0.5563	0.8939	0.1943	**0.0157**	0.106	0.3239
n	30	30	30	10	10	10	20	20	20
Dissolved oxygen	0.028	-0.021	-0.001	-0.353	-0.445	-0.684	0.156	0.109	0.144
p-value	0.8869	0.912	0.9954	0.3515	0.2296	**0.0424**	0.5115	0.6488	0.5438
n	29	29	29	9	9	9	20	20	20
Turbidity	0.414	0.345	0.308	0.017	-0.433	-0.374	0.436	0.469	0.445
p-value	**0.0228**	0.0615	0.0975	0.9659	0.2446	0.3215	**0.0484**	**0.032**	**0.0433**
n	30	30	30	9	9	9	21	21	21

03084808 Turtle Creek at East Pittsburgh, PA

	All conditions			Dry weather			Wet weather		
	Eschericia coli	Fecal coliform	Enterococci	*Eschericia coli*	Fecal coliform	Enterococci	*Eschericia coli*	Fecal coliform	Enterococci
Streamflow	0.439	0.300	0.412	-0.632	0.000	-0.600	0.484	0.383	0.400
p-value	**0.0409**	0.1752	0.0565	0.3675	1	0.4	**0.0418**	0.1168	0.1004
n	22	22	22	4	4	4	18	18	18
Water temperature	-0.354	-0.429	-0.555	0.396	-0.718	-0.613	-0.299	-0.255	-0.387
p-value	0.0702	**0.0257**	**0.0027**	0.3786	0.0691	0.1436	0.1999	0.2779	0.0916
n	27	27	27	7	7	7	20	20	20
pH	-0.060	-0.131	-0.311	0.000	-0.355	-0.695	-0.063	-0.109	-0.230
p-value	0.7613	0.5063	0.107	1	0.3876	0.0559	0.7908	0.6486	0.3298
n	28	28	28	8	8	8	20	20	20
Specific conductance	-0.492	-0.390	-0.434	0.323	0.778	0.286	-0.451	-0.349	-0.344
p-value	**0.0079**	**0.0401**	**0.0209**	0.4346	**0.0229**	0.4927	**0.0458**	0.1314	0.1379
n	28	28	28	8	8	8	20	20	20
Dissolved oxygen	-0.125	-0.187	-0.107	-0.036	-0.432	-0.714	0.032	-0.055	-0.010
p-value	0.5423	0.3592	0.6025	0.9394	0.3325	0.0713	0.8979	0.8221	0.9687
n	26	26	26	7	7	7	19	19	19
Turbidity	0.594	0.713	0.647	-0.151	0.693	0.719	0.579	0.530	0.607
p-value	**0.0007**	**<.0001**	**0.0002**	0.7219	0.0568	**0.0446**	**0.0059**	**0.0135**	**0.0035**
n	29	29	29	8	8	8	21	21	21

Table 10. Results of Spearman's *rho* correlations between concentrations of fecal-indicator bacteria and field water-quality characteristics, Ohio River Basin, Allegheny County, Pennsylvania, 2001–09.

[n, number of samples; nd, no data; p-value, probability; <, less than; bold type indicates p-values of 0.05 or less (significance at the 95-percent confidence level)]

03085160 Sawmill Run at Castle Shannon, PA

	All conditions			Dry weather			Wet weather		
	Eschericia coli	Fecal coliform	Enterococci	*Eschericia coli*	Fecal coliform	Enterococci	*Eschericia coli*	Fecal coliform	Enterococci
Streamflow	0.562	0.401	0.413	0.367	0.293	0.096	0.286	0.137	0.271
p-value	**0.0005**	**0.0187**	**0.0153**	0.3317	0.4444	0.8064	0.1651	0.5137	0.1893
n	34	34	34	9	9	9	25	25	25
Water temperature	-0.086	-0.025	0.170	-0.123	-0.053	0.218	0.328	0.452	0.466
p-value	0.5991	0.8803	0.2954	0.7043	0.871	0.4971	0.0879	**0.0158**	**0.0124**
n	40	40	40	12	12	12	28	28	28
pH	-0.634	-0.404	-0.336	-0.368	-0.288	-0.146	-0.456	-0.101	-0.176
p-value	**<.0001**	**0.0107**	**0.0363**	0.2657	0.3904	0.6686	**0.0147**	0.6084	0.3699
n	39	39	39	11	11	11	28	28	28
Specific conductance	-0.140	-0.286	-0.227	0.049	0.144	0.121	-0.490	-0.762	-0.546
p-value	0.3964	0.0772	0.1644	0.8799	0.6561	0.7079	**0.0094**	**<.0001**	**0.0032**
n	39	39	39	12	12	12	27	27	27
Dissolved oxygen	-0.239	-0.240	-0.277	-0.518	-0.442	-0.043	-0.455	-0.479	-0.475
p-value	0.1374	0.1353	0.0833	0.0842	0.1501	0.895	**0.015**	**0.0099**	**0.0107**
n	40	40	40	12	12	12	28	28	28
Turbidity	0.603	0.591	0.398	0.342	0.306	0.124	0.587	0.587	0.356
p-value	**<.0001**	**0.0001**	**0.0148**	0.3037	0.3602	0.7161	**0.0016**	**0.0016**	0.0742
n	37	37	37	11	11	11	26	26	26

03085213 Sawmill Run at Duquesne Heights near Pittsburgh, PA

	All conditions			Dry weather			Wet weather		
	Eschericia coli	Fecal coliform	Enterococci	*Eschericia coli*	Fecal coliform	Enterococci	*Eschericia coli*	Fecal coliform	Enterococci
Streamflow	0.808	0.821	0.069	0.240	0.331	0.037	0.814	0.818	0.066
p-value	**<.0001**	**<.0001**	0.6141	0.4777	0.32	0.9145	**<.0001**	**<.0001**	0.6663
n	56	56	56	11	11	11	45	45	45
Water temperature	0.270	0.326	-0.451	0.400	0.423	0.074	0.347	0.429	-0.489
p-value	**0.0426**	**0.0133**	**0.0004**	0.1976	0.1703	0.819	**0.0197**	**0.0033**	**0.0007**
n	57	57	57	12	12	12	45	45	45
pH	-0.272	-0.204	-0.049	0.116	0.270	0.604	-0.138	-0.107	-0.143
p-value	**0.0409**	0.1274	0.7193	0.7189	0.3964	**0.0374**	0.3674	0.486	0.3471
n	57	57	57	12	12	12	45	45	45
Specific conductance	-0.463	-0.526	0.391	-0.322	-0.500	-0.077	-0.382	-0.465	0.491
p-value	**0.0003**	**<.0001**	**0.0029**	0.307	0.0978	0.8109	**0.0106**	**0.0015**	**0.0007**
n	56	56	56	12	12	12	44	44	44
Dissolved oxygen	-0.365	-0.383	0.493	-0.203	-0.373	0.190	-0.351	-0.392	0.553
p-value	**0.0053**	**0.0033**	**<.0001**	0.5266	0.2321	0.5539	**0.0181**	**0.0078**	**<.0001**
n	57	57	57	12	12	12	45	45	45
Turbidity	0.743	0.716	-0.154	-0.078	-0.189	-0.037	0.684	0.687	-0.230
p-value	**<.0001**	**<.0001**	0.2664	0.8205	0.5788	0.9151	**<.0001**	**<.0001**	0.1378
n	54	54	54	11	11	11	43	43	43

Table 10. Results of Spearman's *rho* correlations between concentrations of fecal-indicator bacteria and field water-quality characteristics, Ohio River Basin, Allegheny County, Pennsylvania, 2001–09.—Continued

[n, number of samples; nd, no data; p-value, probability; <, less than; bold type indicates p-values of 0.05 or less (significance at the 95-percent confidence level)]

03085290 Chartiers Creek near Bridgeville, PA									
	All conditions			**Dry weather**			**Wet weather**		
	Eschericia coli	**Fecal coliform**	**Enterococci**	***Eschericia coli***	**Fecal coliform**	**Enterococci**	***Eschericia coli***	**Fecal coliform**	**Enterococci**
Streamflow	0.788	0.833	0.739	-0.116	0.211	0.267	0.771	0.803	0.711
p-value	**<.0001**	**<.0001**	**<.0001**	0.7206	0.5106	0.4016	**<.0001**	**<.0001**	**<.0001**
n	44	44	44	12	12	12	32	32	32
Water temperature	-0.068	-0.119	0.024	0.804	0.613	0.314	0.216	0.148	0.303
p-value	0.6646	0.4463	0.8809	**0.0016**	**0.0342**	0.3206	0.2424	0.4254	0.0979
n	43	43	43	12	12	12	31	31	31
pH	-0.575	-0.542	-0.434	0.470	0.246	0.201	-0.679	-0.601	-0.469
p-value	**<.0001**	**0.0001**	**0.0032**	0.1234	0.4417	0.5301	**<.0001**	**0.0003**	**0.0067**
n	44	44	44	12	12	12	32	32	32
Specific conductance	-0.760	-0.829	-0.732	0.550	0.239	0.050	-0.731	-0.802	-0.697
p-value	**<.0001**	**<.0001**	**<.0001**	0.064	0.4544	0.8778	**<.0001**	**<.0001**	**<.0001**
n	43	43	43	12	12	12	31	31	31
Dissolved oxygen	-0.092	-0.038	-0.188	-0.413	-0.265	-0.446	-0.192	-0.135	-0.275
p-value	0.5506	0.8077	0.2222	0.1821	0.406	0.1457	0.2921	0.4607	0.1277
n	44	44	44	12	12	12	32	32	32
Turbidity	0.845	0.808	0.723	0.556	0.224	0.046	0.787	0.792	0.758
p-value	**<.0001**	**<.0001**	**<.0001**	0.0758	0.5084	0.8935	**<.0001**	**<.0001**	**<.0001**
n	40	40	40	11	11	11	29	29	29

03085500 Chartiers Creek at Carnegie, PA									
	All conditions			**Dry weather**			**Wet weather**		
	Eschericia coli	**Fecal coliform**	**Enterococci**	***Eschericia coli***	**Fecal coliform**	**Enterococci**	***Eschericia coli***	**Fecal coliform**	**Enterococci**
Streamflow	0.650	0.605	0.694	-0.385	-0.405	0.185	0.612	0.596	0.562
p-value	**<.0001**	**<.0001**	**<.0001**	**0.0358**	**0.0264**	0.3274	**<.0001**	**<.0001**	**<.0001**
n	109	109	109	30	30	30	79	79	79
Water temperature	-0.093	-0.066	0.104	0.379	0.125	0.339	0.010	0.051	0.267
p-value	0.3391	0.4989	0.2862	**0.0391**	0.5106	0.0671	0.9293	0.6579	**0.0181**
n	108	108	108	30	30	30	78	78	78
pH	-0.075	-0.046	-0.194	0.389	0.484	0.218	-0.158	-0.157	-0.204
p-value	0.4376	0.6353	**0.0443**	**0.0334**	**0.0068**	0.2477	0.1661	0.1686	0.0728
n	108	108	108	30	30	30	78	78	78
Specific conductance	-0.666	-0.679	-0.666	-0.001	-0.203	0.242	-0.673	-0.656	-0.659
p-value	**<.0001**	**<.0001**	**<.0001**	0.9972	0.2823	0.1967	**<.0001**	**<.0001**	**<.0001**
n	108	108	108	30	30	30	78	78	78
Dissolved oxygen	-0.062	-0.102	-0.219	-0.230	-0.171	-0.611	-0.294	-0.326	-0.410
p-value	0.5378	0.3066	**0.0269**	0.2206	0.3669	**0.0003**	**0.0123**	**0.0052**	**0.0003**
n	102	102	102	30	30	30	72	72	72
Turbidity	0.561	0.592	0.727	-0.596	-0.522	0.087	0.583	0.627	0.691
p-value	**<.0001**	**<.0001**	**<.0001**	**0.0071**	**0.022**	0.7246	**<.0001**	**<.0001**	**<.0001**
n	90	90	90	19	19	19	**71**	**71**	**71**

Table 10. Results of Spearman's *rho* correlations between concentrations of fecal-indicator bacteria and field water-quality characteristics, Ohio River Basin, Allegheny County, Pennsylvania, 2001–09.—Continued

[n, number of samples; nd, no data; p-value, probability; <, less than; bold type indicates p-values of 0.05 or less (significance at the 95-percent confidence level)]

03085550 Chartiers Creek at Crafton, PA									
	All conditions			Dry weather			Wet weather		
	Eschericia coli	Fecal coliform	Enterococci	*Eschericia coli*	Fecal coliform	Enterococci	*Eschericia coli*	Fecal coliform	Enterococci
Streamflow	-0.035	-0.523	nd	-0.500	0.500	nd	-0.009	-0.519	nd
p-value	0.9132	0.081	nd	0.6667	0.6667	nd	0.9827	0.152	nd
n	12	12	12	3	3	3	9	9	9
Water temperature	0.251	0.055	0.559	-0.311	-0.587	0.238	0.230	-0.032	0.606
p-value	0.1893	0.7785	**0.0016**	0.416	0.0969	0.5376	0.3303	0.8932	**0.0046**
n	29	29	29	9	9	9	20	20	20
pH	0.015	0.129	0.001	-0.741	0.094	-0.430	-0.201	-0.299	-0.096
p-value	0.9395	0.5059	0.9947	**0.0225**	0.8106	0.2475	0.3958	0.2006	0.6876
n	29	29	29	9	9	9	20	20	20
Specific conductance	-0.590	-0.639	-0.391	-0.311	-0.587	0.238	-0.616	-0.377	-0.655
p-value	**0.0008**	**0.0002**	**0.0359**	0.416	0.0969	0.5376	**0.0038**	0.1011	**0.0017**
n	29	29	29	9	9	9	20	20	20
Dissolved oxygen	-0.309	-0.116	-0.635	0.356	0.390	-0.061	-0.675	-0.423	-0.801
p-value	0.1025	0.5478	**0.0002**	0.3471	0.2996	0.8769	**0.0011**	0.063	**<.0001**
n	29	29	29	9	9	9	20	20	20
Turbidity	0.607	0.854	0.386	0.857	0.536	0.090	0.517	0.851	0.261
p-value	**0.0006**	**<.0001**	**0.0423**	**0.0137**	0.2152	0.8477	**0.0165**	**<.0001**	0.2523
n	28	28	28	7	7	7	21	21	21

between the upstream Castle Shannon site and the downstream Duquesne Heights site on Sawmill Run. Although significant, these correlations cannot be explained with existing data because of the sign reversal.

Bacteria concentrations at the Chartiers Creek sites also showed significant correlations with most of the field characteristics under wet-weather conditions. Significant correlations in dry-weather samples were limited to two each for the Bridgeville and Crafton sites and eight for the Chartiers Creek at Carnegie station. Change in the sign of the correlation was evident for several of the dry-weather sample correlations. The small dataset sizes likely contributed to this inconsistency. Unlike those for samples from Sawmill Run, values of *rho* for samples from Chartiers Creek generally decreased from the upstream to the downstream sites, although the small dataset size for Chartiers Creek at Crafton, Pa. (USGS station 03085550) should be noted.

The results of correlation analysis show few reasonably strong and consistent associations between bacteria concentrations and field characteristics. Most of the correlations have low coefficients, have an inconsistent positive or negative sign, or lack sufficient data to support a reliable statistical evaluation of the relations. The strongest and most consistent correlations were those for the relations of bacteria concentrations to streamflow and turbidity for samples from the main-stem Three Rivers sites, and those for the relations of bacteria concentrations to turbidity and specific conductance for samples from the tributary sites. The field characteristics with the strongest correlations were used as covariates in trend analysis.

Trend Analysis

No consistent trends in bacteria concentrations at main-stem sites are apparent over the 2001–09 period (figs. 8–17), with the possible exception of decreases in *E. coli* and FC concentrations in samples from the Monongahela River at Pittsburgh station after 2007. Because the number of samples collected during this period was small, however, the statistical significance of the decreases is questionable. Seasonal Kendall and logistic regression trend tests were applied to determine whether trends exist.

Seasonal Kendall tests for trends in *E. coli* and FC bacteria over the study period were generally inconclusive.

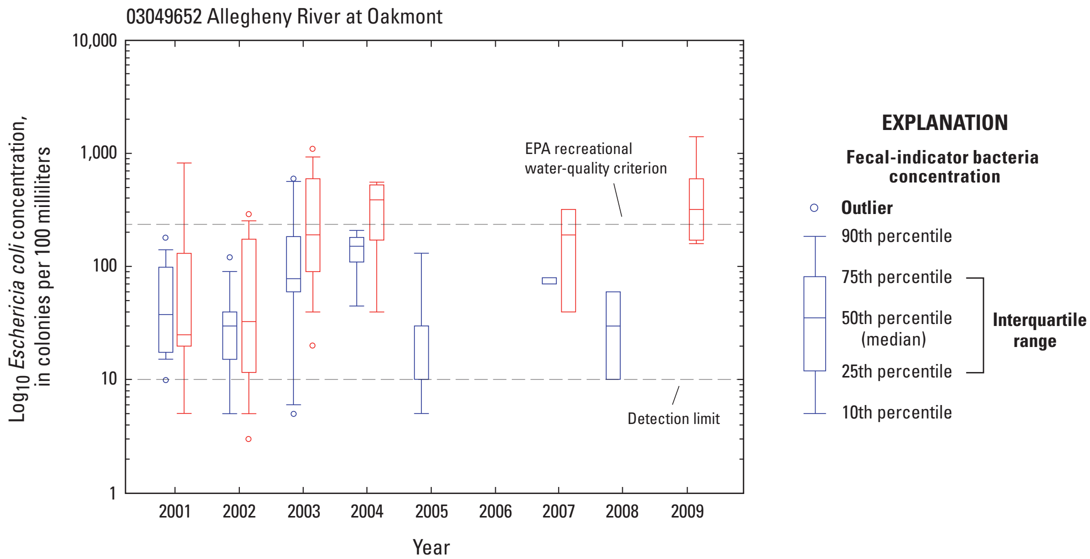

Figure 8. Comparison of *Escherichia coli* concentrations in composite samples collected during wet- and dry-weather events at U.S. Geological Survey streamgaging station 03049652 on the Allegheny River near Pittsburgh, Allegheny County, Pennsylvania, 2001–09. (Wet-weather events shown in red; dry-weather events shown in blue; EPA, U.S. Environmental Protection Agency)

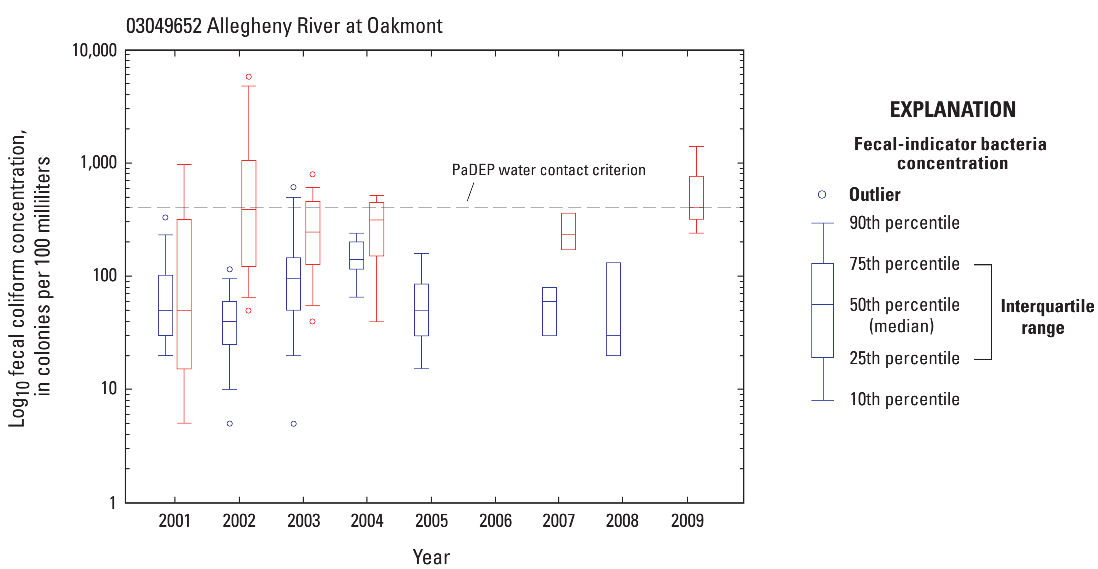

Figure 9. Comparison of fecal coliform concentrations in composite samples collected during wet- and dry-weather events at U.S. Geological Survey streamgaging station 03049652 on the Allegheny River near Pittsburgh, Allegheny County, Pennsylvania, 2001–09. (Wet-weather events shown in red; dry-weather events shown in blue; PaDEP, Pennsylvania Department of Environmental Protection)

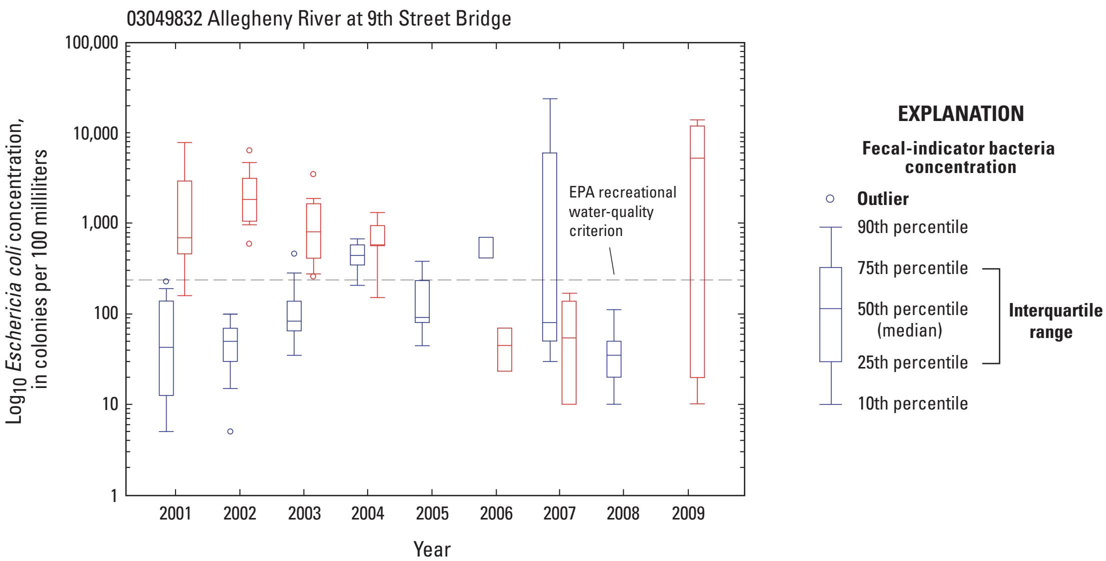

Figure 10. Comparison of *Escherichia coli* concentrations in composite samples collected during wet- and dry-weather events at U.S. Geological Survey streamgaging station 03049832 on the Allegheny River near Pittsburgh, Allegheny County, Pennsylvania, 2001–09. (Wet-weather events shown in red; dry-weather events shown in blue; EPA, U.S. Environmental Protection Agency)

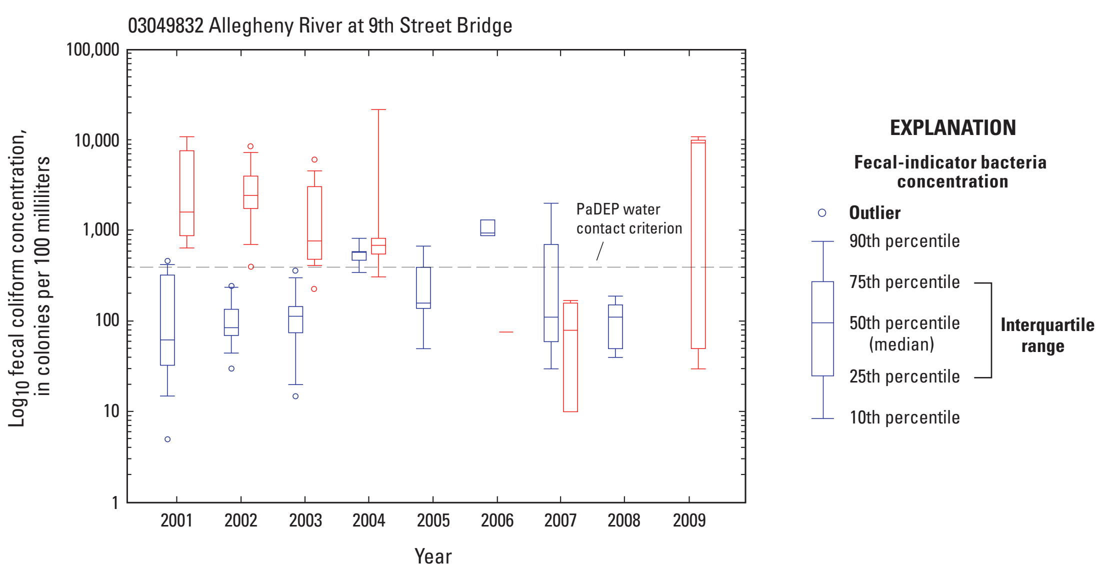

Figure 11. Comparison of fecal coliform concentrations in composite samples collected during wet- and dry-weather events at U.S. Geological Survey streamgaging station 03049832 on the Allegheny River near Pittsburgh, Allegheny County, Pennsylvania, 2001–09. (Wet-weather events shown in red; dry-weather events shown in blue; PaDEP, Pennsylvania Department of Environmental Protection)

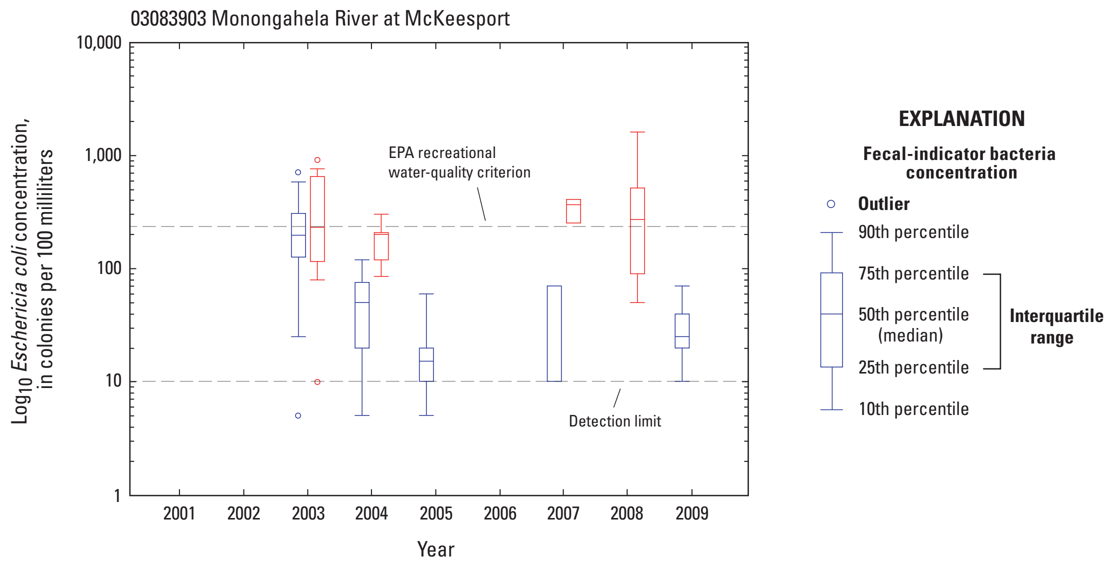

Figure 12. Comparison of *Escherichia coli* concentrations in composite samples collected during wet- and dry-weather events at U.S. Geological Survey streamgaging station 03083903 on the Monongahela River near Pittsburgh, Allegheny County, Pennsylvania, 2001–09. (Wet-weather events shown in red; dry-weather events shown in blue; EPA, U.S. Environmental Protection Agency)

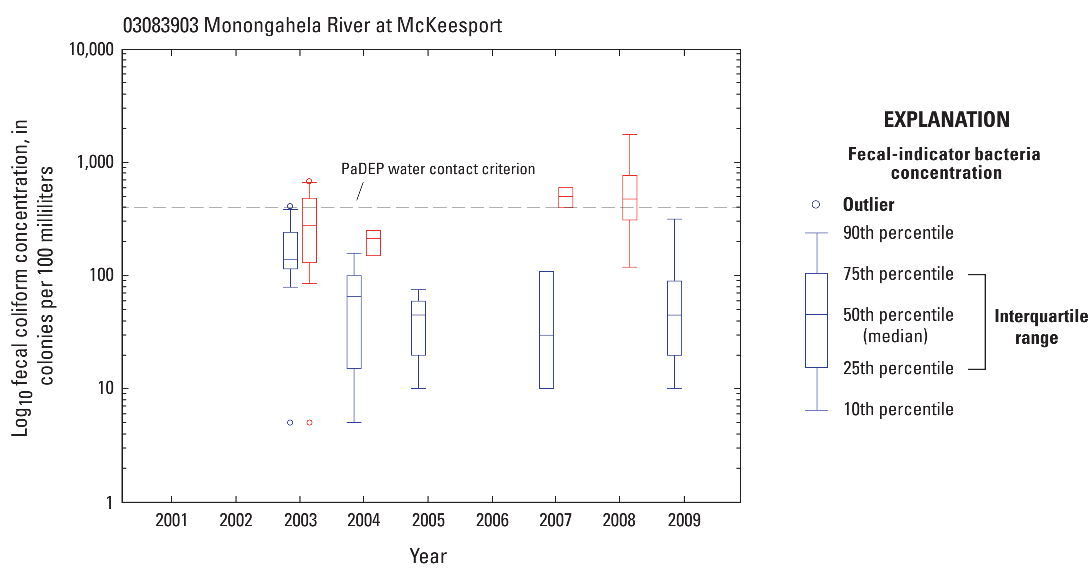

Figure 13. Comparison of fecal coliform concentrations in composite samples collected during wet- and dry-weather events at U.S. Geological Survey streamgaging station 03083903 on the Monongahela River near Pittsburgh, Allegheny County, Pennsylvania, 2001–09. (Wet-weather events shown in red; dry-weather events shown in blue; PaDEP, Pennsylvania Department of Environmental Protection)

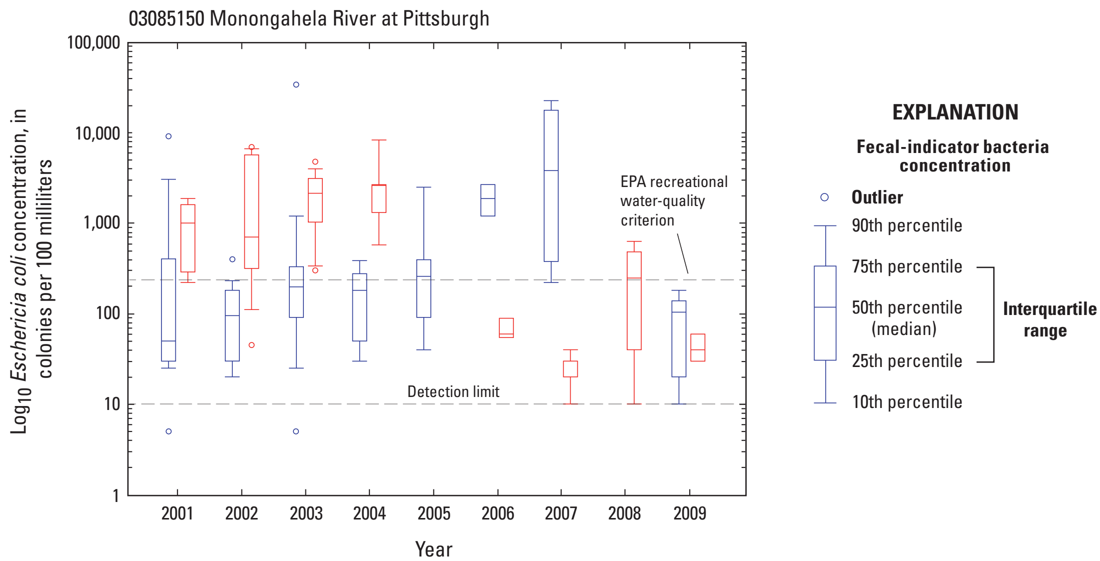

Figure 14. Comparison of *Escherichia coli* concentrations in composite samples collected during wet- and dry-weather events at U.S. Geological Survey streamgaging station 03085150 on the Monongahela River near Pittsburgh, Allegheny County, Pennsylvania, 2001–09. (Wet-weather events shown in red; dry-weather events shown in blue; EPA, U.S. Environmental Protection Agency)

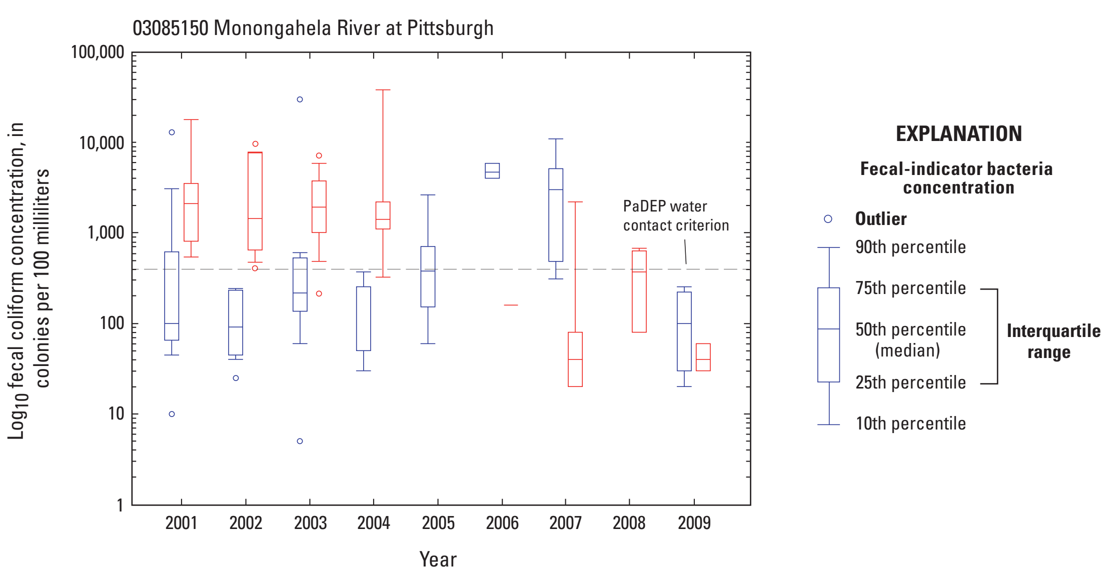

Figure 15. Comparison of fecal coliform concentrations in composite samples collected during wet- and dry-weather events at U.S. Geological Survey streamgaging station 03085150 on the Monongahela River near Pittsburgh, Allegheny County, Pennsylvania, 2001–09. (Wet-weather events shown in red; dry-weather events shown in blue; PaDEP, Pennsylvania Department of Environmental Protection)

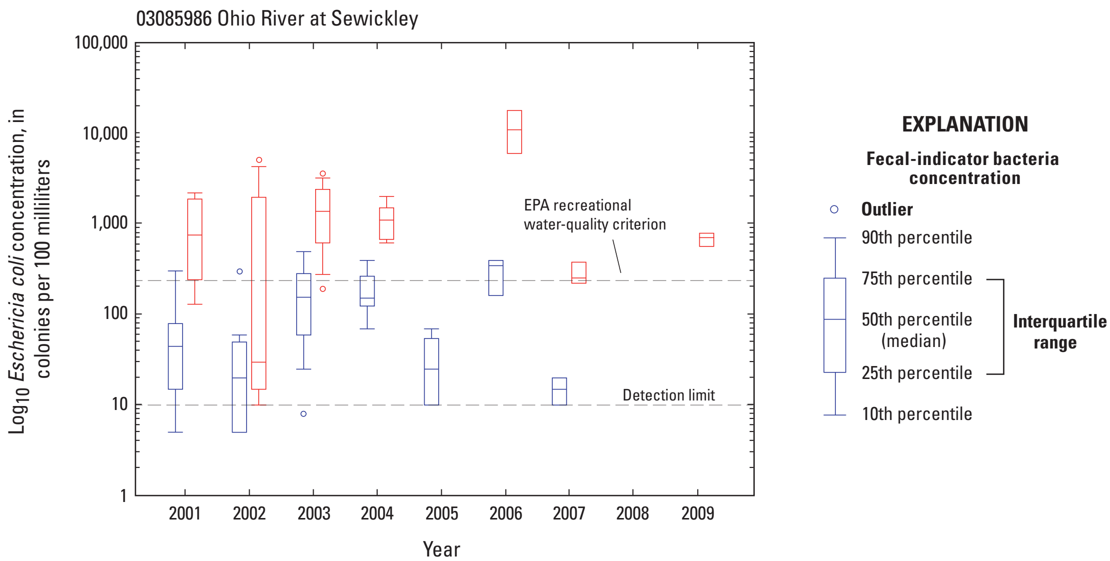

Figure 16. Comparison of *Escherichia coli* concentrations in composite samples collected during wet- and dry-weather events at U.S. Geological Survey streamgaging station 03085986 on the Ohio River near Pittsburgh, Allegheny County, Pennsylvania, 2001–09. (Wet-weather events shown in red; dry-weather events shown in blue; EPA, U.S. Environmental Protection Agency)

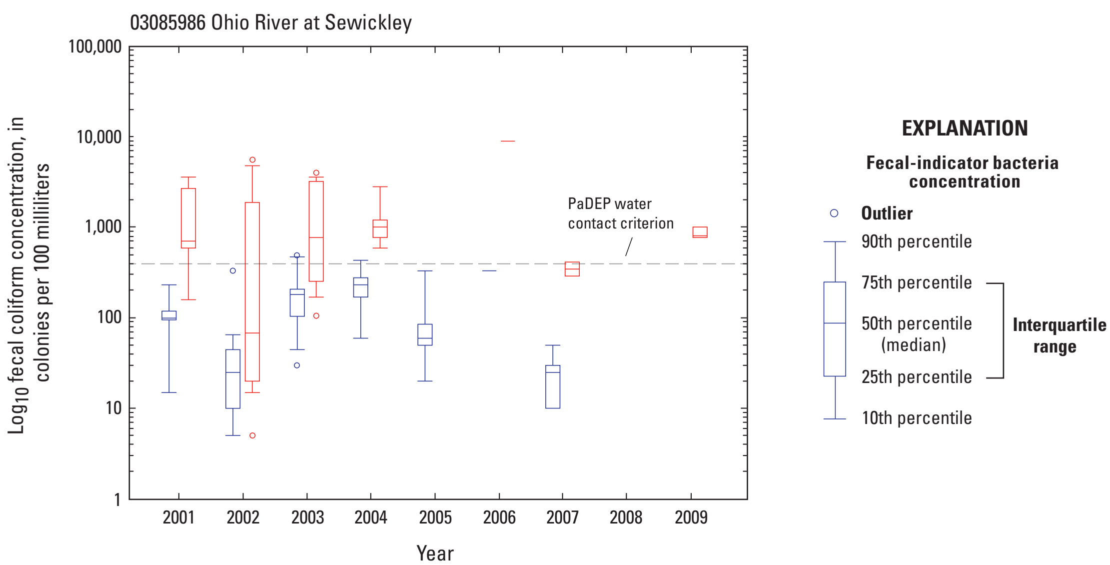

Figure 17. Comparison of fecal coliform concentrations in composite samples collected during wet- and dry-weather events at U.S. Geological Survey streamgaging station 03085986 on the Ohio River near Pittsburgh, Allegheny County, Pennsylvania, 2001–09. (Wet-weather events shown in red; dry-weather events shown in blue; PaDEP, Pennsylvania Department of Environmental Protection)

Considering the large number of potential sources contributing bacteria to the Three Rivers under varying conditions, significant trends in the data for samples from the main-stem sites were not expected.

No significant trends were detected in *E. coli* or FC concentrations in samples collected under dry-weather conditions from the Allegheny River at Oakmont and at 9th Street Bridge, and from the Monongahela River at Pittsburgh (table 11). Trends in samples collected from the Monongahela River at McKeesport and the Ohio River at Sewickley Bridge stations could not be tested as a result of poor temporal distribution of the dry-weather data.

A significant trend in bacteria concentrations in samples collected under wet-weather conditions was observed at one site—significant decreasing trends in wet-weather *E. coli* and FC concentrations in samples from the Allegheny River at 9th Street Bridge station (table 11). The trend rates reported for the 9th Street Bridge location were fairly strong at -43 and -66 percent per year for *E. coli* and FC, respectively.

The trends in bacteria reported for the 9th Street Bridge location may reflect short-term variability rather than a sustained decrease in bacteria concentration. Median bacteria concentrations in wet-weather samples show a pronounced and consistent decline from 2002 through 2006; it is on the

Table 11. Results of Seasonal Kendall test for trends in bacteria at five sites on the Allegheny, Monongahela, and Ohio Rivers, Allegheny County, Pennsylvania, 2001–09.

[USGS, U.S. Geological Survey; n, number of samples; na, not applicable; ns, not significant at the 95-percent confidence level (p-value < 0.05)]

USGS station number	USGS station name	*Eschericia coli*			Fecal coliform		
		n	p-value	Trend	n	p-value	Trend
		Dry weather without flow adjustment					
03049652	Allegheny River at Hulton Bridge at Oakmont, PA	42	0.462	ns	41	0.312	ns
03049832	Allegheny River at 9th St. Bridge at Pittsburgh, PA	64	1.000	ns	64	1.000	ns
03083903	Monongahela River at McKeesport, PA	27	na	na	27	na	na
03085150	Monongahela River at Pittsburgh, PA	69	0.707	ns	67	0.707	ns
03085986	Ohio River at Sewickley bridge at Sewickley, PA	50	0.181	ns	51	0.133	ns
		Dry weather with flow adjustment					
03049652	Allegheny River at Hulton Bridge at Oakmont, PA	42	0.806	ns	41	0.221	ns
03049832	Allegheny River at 9th St. Bridge at Pittsburgh, PA	64	1.000	ns	64	0.764	ns
03083903	Monongahela River at McKeesport, PA	27	na	na	27	na	na
03085150	Monongahela River at Pittsburgh, PA	69	0.707	ns	67	0.452	ns
03085986	Ohio River at Sewickley bridge at Sewickley, PA	50	na	na	51	0.133	ns
		Wet weather without flow adjustment					
03049652	Allegheny River at Hulton Bridge at Oakmont, PA	37	0.221	ns	37	0.086	ns
03049832	Allegheny River at 9th St. Bridge at Pittsburgh, PA	54	0.035	down	54	0.024	down
03083903	Monongahela River at McKeesport, PA	na	na	na	na	na	na
03085150	Monongahela River at Pittsburgh, PA	52	0.230	ns	52	0.072	ns
03085986	Ohio River at Sewickley bridge at Sewickley, PA	na	na	na	na	na	na
		Wet weather with flow adjustment					
03049652	Allegheny River at Hulton Bridge at Oakmont, PA	37	0.221	ns	37	0.806	ns
03049832	Allegheny River at 9th St. Bridge at Pittsburgh, PA	54	0.035	down	54	0.024	ns
03083903	Monongahela River at McKeesport, PA	na	na	na	na	na	na
03085150	Monongahela River at Pittsburgh, PA	52	0.230	ns	52	0.072	ns
03085986	Ohio River at Sewickley bridge at Sewickley, PA	na	na	na	na	na	na

strength of this decline that a significant trend was reported. The addition of data for 2007 and 2008 did not alter this result because the difference in concentration from 2006 to 2007 was minimal and data for 2008 were lacking. In 2009, however, median concentrations of *E. coli* and FC were two orders of magnitude greater than those in 2007 and were the highest reported for the location during the entire study period (figs. 10 and 11). Although these increases did not alter the outcome of the Seasonal Kendall trend test, additional data on the natural variability in bacteria concentrations and factors that influence bacteria—specifically, a comparison of rainfall variables and their influence on bacteria concentrations (Walker, 1993)—would be needed to determine whether the 2009 concentrations are outliers or are indicative of a return to *E.coli* and FC concentrations in the ranges reported prior to the 2002–06 decline.

Significant trends in the probability of fecal-indicator bacteria concentrations exceeding recreational standards were limited to one site and one weather condition. Logistic regression trend tests were performed on *E. coli* and FC data collected from the five main-stem Three Rivers sites. No trends in dry-weather exceedance of the standards were found for the Allegheny River at 9th Street Bridge or the Monongahela River at Pittsburgh station (table 12). Dry-weather trends could not be evaluated at the three remaining sites because of an insufficient number of data points with concentrations that exceeded the recreational standards. Significant decreases in the likelihood that *E. coli* and FC bacteria concentrations will exceed recreational standards under wet-weather conditions were found at the Allegheny River at 9th Street Bridge station. The probability of detecting *E. coli* at concentrations greater than 235 col/100 mL and FC at concentrations greater

Table 12. Results of logistic regression test for trends in probability of exceeding recreational bacteria standards at five sites on the Allegheny, Monongahela, and Ohio Rivers, Allegheny County, Pennsylvania, 2001–09.

[USGS, U.S. Geological Survey; mL, milliliters; n, number of samples; na, not applicable; ns, not significant at the 95-percent confidence level (p-value < 0.05)]

USGS station number	USGS station name	*Eschericia coli* greater than 235 colonies per 100 mL[1]			Fecal coliform greater than 400 colonies per 100 mL[2]		
		n	p-value	Trend	n	p-value	Trend
		Dry weather					
03049652	Allegheny River at Hulton Bridge at Oakmont, PA	42	na	na	41	na	na
03049832	Allegheny River at 9th St. Bridge at Pittsburgh, PA	64	0.073	ns	64	0.081	ns
03083903	Monongahela River at McKeesport, PA	27	na	na	27	na	na
03085150	Monongahela River at Pittsburgh, PA	69	0.225	ns	67	0.078	ns
03085986	Ohio River at Sewickley bridge at Sewickley, PA	50	na	na	51	na	na
		Wet weather					
03049652	Allegheny River at Hulton Bridge at Oakmont, PA	37	0.099	ns	37	0.257	ns
03049832	Allegheny River at 9th St. Bridge at Pittsburgh, PA	54	0.026	-0.085	54	0.001	-0.193
03083903	Monongahela River at McKeesport, PA	na	na	na	na	na	na
03085150	Monongahela River at Pittsburgh, PA	na	na	na	na	na	na
03085986	Ohio River at Sewickley bridge at Sewickley, PA	39	0.195	ns	37	0.846	ns

[1] *Eschericia coli*: U.S. Environmental Protection Agency recreational water-quality criterion (U.S. Environmental Protection Agency, 1986).

[2] Fecal coliform: Pennsylvania Department of Environmental Protection water contact criterion (Commonwealth of Pennsylvania, 2015).

than 400 col/100 mL decreased 8 and 19 percent, respectively (table 12). These results support the Seasonal Kendall trend test results; however, the caveats regarding the validity of the Seasonal Kendall results apply to the logistic regression results as well. Although streamflow and turbidity were used as covariates, neither was a significant explanatory variable.

Summary and Conclusions

The U.S. Geological Survey and its partners collected surface-water samples from the Three Rivers and its tributaries in Allegheny County, Pennsylvania, during the period 2001–09 to assess the occurrence and trends in concentrations of fecal-indicator bacteria during dry- and wet-weather conditions. To quantify the effects of these organisms on receiving waters, a network of rain and streamgages was established to target sampling efforts to weather events of varying magnitudes and distributions.

Nonparametric correlation analyses, including Spearman's *rho* and the paired Prentice Wilcoxon test, were used to screen for associations among indicator-bacteria concentrations and field characteristics streamflow, water temperature, pH, specific conductance, dissolved-oxygen concentration, and turbidity. The Seasonal Kendall trend test and logistic regression were used to quantify discernable trends in the data.

The data evaluated were the results of analyses of 1,742 water samples collected at 52 main-stem and tributary sites. Quantifiable concentrations of *Escherichia coli* (*E.coli)* bacteria were detected in 97.0 percent of 1,719 samples; concentrations in 49.6 percent exceeded the U.S. Environmental Protection Agency (EPA) recreational water-quality criterion of 235 colonies per 100 milliliters (col/100 mL). Fecal-coliform (FC) bacteria were detected in 98.8 percent of 1,713 samples; concentrations in 45.5 percent exceeded the Commonwealth of Pennsylvania water contact criterion of 400 col/100 mL. Enterococci bacteria were detected in 87.5 percent of 1,042 samples; concentrations in 46.4 percent exceeded the EPA recreational water-quality criterion of 61 col/100 mL. The median percentage of samples in which bacteria concentrations exceeded recreational water-quality standards across all sites with five or more samples was 48 for *E. coli*, 43 for FC, and 75 for enterococci. *E. coli*, FC, and enterococci concentrations at all Three Rivers sites had significant positive correlations with streamflow under all weather conditions, with correlation coefficients ranging from 0.203 to 0.598. Two trend tests (Seasonal Kendall and logistic regression) were evaluated to determine whether statistically significant trends were present. In general, results of the Seasonal Kendall test for trends in *E. coli* and FC bacteria were inconclusive. Given the number and distribution of source streams that contribute bacteria to the receiving water, this conclusion was expected. No significant dry-weather trends in concentrations of *E. coli* and FC were detected at either the Allegheny River at Oakmont, Allegheny River at 9th Street Bridge, or Monongahela River at Pittsburgh station.

On the basis of logistic regression, no significant trends in dry-weather exceedance of the standards were reported; however, significant decreases in the likelihood that wet-weather *E. coli* and FC bacteria concentrations will exceed recreational standards were found at the Allegheny River at 9th Street Bridge site. The probability of detecting *E. coli* concentrations greater than 235 col/100 mL and FC concentrations greater than 400 col/100 mL decreased 8 percent and 19 percent, respectively, during the period examined. As a result of the variability of weather, sampling patterns, and sampling frequency, the cause of this downward trend could not be determined. These trends may be associated with short-term weather effects or sampling patterns rather than with a corrective engineering measures designed to reduce loads of bacteria to the Allegheny River upstream from the 9th Street Bridge in Allegheny County, Pennsylvania.

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Table 1. Description of sampling and streamgage sites on the Allegheny, Monongahela, and Ohio Rivers and selected tributaries, Allegheny County, Pennsylvania, 2001–09.

[USGS, U.S. Geological Survey; ALCOSAN, Allegheny County Sanitary Authority; **, shown in figure 2; --, not determined; NA, not applicable as site is for computing stream discharge only; QW, water quality; RM, river mile]

USGS station name	Purpose	USGS station number	Map identifier for figures 3–5	Sample obtained from:	River mile[1] (miles)	Drainage area (square miles)
Allegheny River and tributaries						
Allegheny River at Natrona, PA	Continuous-record streamgage used to estimate discharge into the Allegheny River Basin	03049500	**	NA	24.3	11,410.0
Allegheny River bl Falling Springs Run at Oakmont, PA	QW receptor	03049643	1	boat	13.3	11,548.0
Allegheny River at Hulton Bridge at Oakmont, PA	Main-stem upstream QW transect near ALCOSAN service area boundary	03049652	2	bridge, boat	12.7	11,577.0
Allegheny River ab Quigley Creek at Blawnox, PA	Main-stem intermediate QW transect	03049668	3	boat	10.4	11,625.0
Allegheny River ab Shades Run at Aspinwall, PA	Main-stem intermediate QW transect	03049677	4	boat	8.1	11,640.0
Allegheny River bl Shades Run at Aspinwall, PA	QW receptor	03049678	5	boat	8.0	11,641.0
Allegheny River at Sharpsburg, PA	Main-stem intermediate QW transect	03049690	6	boat	6.0	11,652.0
Allegheny River above Girtys Run at Millvale, PA	Main-stem intermediate QW transect	03049812	7	boat	3.8	11,733.0
Allegheny River ab 31st St Bridge at Pittsburgh, PA	QW receptor	03049825	8	boat	2.5	11,736.0
Allegheny River bl 31st St Bridge at Pittsburgh, PA	Main-stem intermediate QW transect	03049828	9	boat	2.0	11,739.0
Allegheny River at 9th St. Bridge at Pittsburgh, PA	Main-stem downstream QW transect	03049832	32	boat	0.7	11,710.0
Allegheny River and tributaries						
Deer Creek near Dorseyville, PA	Continuous-record tributary streamgage upstream from the ALCOSAN service area	03049646	**	NA	--	27.0
Deer Creek at Route 910 near Cheswick, PA	Tributary QW transect upstream from the ALCOSAN service area	03049649	33	wading	--	49.1
Plum Creek at Milltown, PA	Continuous-record tributary streamgage upstream from the ALCOSAN service area	03049658	34	NA	--	17.4

Table 1. Description of sampling and streamgage sites on the Allegheny, Monongahela, and Ohio Rivers and selected tributaries, Allegheny County, Pennsylvania, 2001–09.—Continued

[USGS, U.S. Geological Survey; ALCOSAN, Allegheny County Sanitary Authority; **, shown in figure 2; --, not determined; NA, not applicable as site is for computing stream discharge only; QW, water quality; RM, river mile]

USGS station name	Purpose	USGS station number	Map identifier for figures 3–5	Sample obtained from:	River mile[1] (miles)	Drainage area (square miles)
Plum Creek at Verona, PA	Tributary QW transect upstream from the ALCOSAN service area	03049660	35	wading	--	20.3
Squaw Run at Old Freeport Road near Blawnox, PA	Continuous-record tributary streamgage and QW transect	03049676	36	wading	--	8.07
Pine Creek at Grant Avenue at Etna, PA	Continuous-record tributary streamgage	03049807	**	NA	--	57.3
Pine Creek at Etna, PA	Tributary QW transect upstream from the ALCOSAN service area	03049810	37	wading	--	66.8
Girtys Run above Grant Avenue at Millvale, PA	Continuous-record tributary streamgage and QW transect	03049819	**	wading	--	13.4
Monongahela River and tributaries						
Monongahela River at Elizabeth, PA	Continuous-record streamgage used to estimate discharge into the Monongahela River Basin	03075070	**	NA	24.0	5,340.0
Monongahela River at Dravosburg, PA	Main-stem upstream QW transect near ALCOSAN service area boundary	03076900	10	boat	16.0	5,433.0
Youghiogheny River at Sutersville, PA	Continuous-record tributary streamgage	03083500	**	NA	--	1,715.0
Youghiogheny River at McKeesport, PA	QW tributary transect	03083900	11	boat	0.5	1,732.0
Monongahela River at McKeesport, PA	Main-stem intermediate QW transect	03083903	12	boat	14.7	7,200.0
Monongahela River ab Turtle Cr at Duquesne, PA	Main-stem intermediate QW transect	03083910	13	boat	12.0	7,208.0
Monongahela River ab Rankin Bridge at Rankin, PA	Main-stem intermediate QW transect	03085008	14	boat	10.0	7,364.0
Monongahela River ab Ninemile Run at Homestead, PA	Main-stem intermediate QW transect	03085030	15	boat	8.0	7,369.0
Monongahela River bl Streets Run near Baldwin, PA	Main-stem intermediate QW transect	03085116	16	boat	5.5	7,389.0
Monongahela River at South Pittsburgh, PA	QW receptor	03085120	17	boat	4.5	7,360.0

Table 1. Description of sampling and streamgage sites on the Allegheny, Monongahela, and Ohio Rivers and selected tributaries, Allegheny County, Pennsylvania, 2001–09.—Continued

[USGS, U.S. Geological Survey; ALCOSAN, Allegheny County Sanitary Authority; **, shown in figure 2; --, not determined; NA, not applicable as site is for computing stream discharge only; QW, water quality; RM, river mile]

USGS station name	Purpose	USGS station number	Map identifier for figures 3–5	Sample obtained from:	River mile[1] (miles)	Drainage area (square miles)
Monongahela River at Greenfield at Pittsburgh, PA	Main-stem intermediate QW transect	03085134	18	boat	3.5	7,394
Monongahela River and tributaries						
Monongahela River at Brady Bridge at Pittsburgh, PA	QW receptor	03085140	19	boat	2.2	7,400.0
Monongahela River at Pittsburgh, PA	Main-stem downstream QW transect	03085150	20	boat	0.8	7,367.0
Turtle Creek at Trafford, PA	Tributary streamgage and QW transect	03084400	38	wading, bridge	--	55.5
Thompson Run at Gascola, PA	Tributary streamgage and QW transect	03084750	39	wading, bridge	--	5.77
Thompson Run at Turtle Creek, PA	Continuous-record tributary streamgage and QW transect	03084800	40	wading, bridge	--	18.0
Turtle Creek at Wilmerding, PA	Continuous-record tributary streamgage	03084698	**	wading, bridge	--	123.0
Turtle Creek at East Pittsburgh, PA	QW tributary transect	03084808	41	bridge	--	147.0
Ninemile Run near Swissvale, PA	Continuous-record tributary streamgage	03085049	**	NA	--	5.31
Ninemile Run at Mouth near Swissvale, PA	QW tributary transect	03085050	42	wading	0.1	6.09
Streets Run at Hays, PA	Continuous-record tributary streamgage	03085100	**	NA	--	8.21
Streets Run 1000 ft upstream of Mouth at Hays, PA	QW tributary transect	03085113	43	wading	0.2	10.0
Ohio River and tributaries						
Allegheny River at 9th Street Bridge at Pittsburgh, PA	Main-stem upstream QW transect	03049832	21	boat	0.7	11,710.0
Monongahela River at Pittsburgh, PA	Main-stem upstream QW transect	03085150	22	boat	0.8	7,367.0

Table 1. Description of sampling and streamgage sites on the Allegheny, Monongahela, and Ohio Rivers and selected tributaries, Allegheny County, Pennsylvania, 2001–09.—Continued

[USGS, U.S. Geological Survey; ALCOSAN, Allegheny County Sanitary Authority; **, shown in figure 2; --, not determined; NA, not applicable as site is for computing stream discharge only; QW, water quality; RM, river mile]

USGS station name	Purpose	USGS station number	Map identifier for figures 3–5	Sample obtained from:	River mile[1] (miles)	Drainage area (square miles)
Ohio River at Point State Park at Pittsburgh, PA	QW receptor	03085154	23	boat	0.0	19,145.0
Sawmill Run at Castle Shannon, PA	Tributary streamgage and QW transect	03085160	44	wading, bridge	8.2	1.04
Sawmill Run at Duquesne Heights nr Pittsburgh, PA	Continuous-record tributary streamgage and QW transect	03085213	**	wading, bridge	0.9	18.1
Chartiers Creek near Bridgeville, PA	Tributary streamgage and QW transect	03085290	45	wading, bridge	16.1	160.0
Chartiers Creek at Crafton, PA	Tributary streamgage and QW transect	03085550	46	wading, bridge	4.2	270.0
Chartiers Creek at Carnegie, PA	Continuous-record tributary streamgage and QW transect	03085500	**	wading, bridge	8.9	257.0
Ohio River above Brunot Island at Pittsburgh, Pa	Main-stem intermediate QW transect	03085215	24	boat	1.5	19,166.0
Ohio River below Jacks Run near Pittsburgh, PA	Main-stem intermediate QW transect	03085670	25	boat	4.0	19,452.0
Ohio River above Neville Island at Avalon, PA	QW receptor	03085700	26	boat	4.8	19,400.0
Ohio River below Lowries Run at Emsworth, PA	Main-stem intermediate QW transect	030859502	27	boat	6.7	19,478.0
Ohio River above Toms Run at Emsworth, PA	Main-stem intermediate QW transect	030859504	28	boat	6.9	19,480.0
Ohio River and tributaries						
Ohio River below Emsworth Back Channel Dam at Emsworth, PA	QW receptor	030859512	29	boat	7.9	19,479.0
Lowries Run at Camp Horne near Emsworth, PA	Continuous-record tributary streamgage	03085947	**	NA	1.5	15.4
Lowries Run 1000 ft above Mouth at Ben Avon, PA	QW tributary transect	030859501	47	wading, bridge	0.7	16.9
Montour Run at Scott Station near Imperial, PA	Continuous-record tributary streamgage downstream from ALCOSAN service area	03085956	**	NA	--	25.4

Table 1. Description of sampling and streamgage sites on the Allegheny, Monongahela, and Ohio Rivers and selected tributaries, Allegheny County, Pennsylvania, 2001–09.—Continued

[USGS, U.S. Geological Survey; ALCOSAN, Allegheny County Sanitary Authority; **, shown in figure 2; --, not determined; NA, not applicable as site is for computing stream discharge only; QW, water quality; RM, river mile]

USGS station name	Purpose	USGS station number	Map identifier for figures 3–5	Sample obtained from:	River mile[1] (miles)	Drainage area (square miles)
Montour Run at Coraopolis, PA	QW tributary transect downstream of ALCOSAN service area	03085960	48	wading, bridge	6.7	36.2
Ohio River below Neville Island at Coraopolis, PA	Main-stem intermediate QW transect	03085966	30	boat	10.0	19,532.0
Ohio River at Sewickley bridge at Sewickley, PA	Main-stem downstream QW transect	03085986	31	boat, bridge	11.8	19,538.0
Ohio River at Sewickley, PA	Continuous-record streamgage used to estimate discharge out of the basin	03086000	**	NA	13.3	19,500.0

[1]River miles are measured from the site to the mouth of the Allegheny River, the mouth of the Monongahela River, or, for the Ohio River and tributaries, the confluence of the Allegheny and Monongahela Rivers. River miles are not given for some main-stem and tributary sampling sites that do not coincide with long-term streamgaging stations or sites not within the study-area boundaries.

Table 4. Summary statistics for streamflow, water temperature, pH, dissolved-oxygen concentration, specific conductivity, turbidity, and concentrations of fecal-indicator bacteria for 52 sampling sites in Allegheny County, Pennsylvania, 2001–09.

[USGS, U.S. Geological Survey; n, number of samples; nd, no data; µS/cm, microsiemens per centimeter at 25 degrees Celsius; WQS, water-quality standard; NTU, Nephelometric Turbidity Units; <, less than; --, not sampled]

USGS station number	Streamflow, in cubic feet per second				Water temperature, in degrees Celsius				pH, in standard units			
	n	Maxi-mum	Median	Minimum	n	Maxi-mum	Median	Mini-mum	n	Maxi-mum	Median	Mini-mum
03049652	154	26,300	4,930	3,080	126	33.0	24.1	14.5	152	8.7	7.3	6.3
03049832	185	69,890	5,220	2,530	189	30.0	23.6	11.2	184	8.6	7.6	4.6
03083903	66	74,000	6,381	1,707	78	29.6	24.1	15.3	81	8.0	7.4	7.1
03085150	185	70,160	5,270	1,390	187	30.0	24.3	14.6	186	8.7	7.6	4.6
03085986	156	81,500	11,550	4,070	135	32.0	22.5	11.3	160	8.3	7.2	6.5
03084400	28	960	34.25	9.33	29	23.5	18.5	3.5	30	8.8	7.8	7.1
03084750	28	120	4.19	1.97	29	20.0	16.5	5.0	29	8.1	7.7	5.1
03084800	29	665	16.2	7.87	29	22.0	17.0	4.5	30	8.7	7.8	6.9
03084808	22	8,710	164.5	57.8	27	27.5	18.5	4.0	28	8.4	7.8	6.6
03085160	34	43.7	0.73	0.1	40	25.5	16.1	5.6	39	8.3	7.8	7.1
03085213	56	1530	14.55	4.03	57	27.0	19.3	4.5	57	8.2	7.8	6.8
03085290	44	13,500	133	36.6	43	22.8	17.0	3.9	44	8.2	7.7	6.6
03085500	109	11,600	289	54	108	23.1	15.1	4.0	108	8.6	7.5	5.8
03085550	12	326	111	54	29	27.5	19.5	5.1	29	8.5	7.8	7.0
03049643	2	7,630	7,034	6,437	5	23.7	23.5	22.0	5	8.0	7.5	7.3
03049649	8	385	5.3	0.47	8	19.4	16.9	6.3	8	8.3	8.0	7.3
03049660	8	85	8.8	2.8	8	21.0	18.9	6.9	8	8.2	8.1	7.2
03049668	18	13,500	5,448	4,410	18	24.3	23.8	22.2	18	8.2	7.7	7.1

Table 4. Summary statistics for streamflow, water temperature, pH, dissolved-oxygen concentration, specific conductivity, turbidity, and concentrations of fecal-indicator bacteria for 52 sampling sites in Allegheny County, Pennsylvania, 2001–09.—Continued

[USGS, U.S. Geological Survey; n, number of samples; nd, no data; µS/cm, microsiemens per centimeter at 25 degrees Celsius; WQS, water-quality standard; NTU, Nephelometric Turbidity Units; <, less than; --, not sampled]

USGS station number	Streamflow, in cubic feet per second				Water temperature, in degrees Celsius				pH, in standard units			
	n	Maximum	Median	Minimum	n	Maximum	Median	Minimum	n	Maximum	Median	Minimum
03049674	nd	nd	nd	nd	3	24.1	22.4	10.3	3	7.6	7.1	6.7
03049676	4	49	12.7	4.7	5	18.8	17.7	6.3	5	8.2	8.0	7.3
03049677	18	13,900	5,758	4,410	18	24.3	24.0	21.7	18	8.3	7.7	7.2
03049678	2	7,660	7,320	6,980	6	24.3	23.8	21.8	6	8.3	7.8	7.3
03049690	21	14,100	4,710	3,800	21	24.5	23.4	21.6	21	8.2	7.8	7.2
03049810	7	504	62	7.2	8	20.3	18.6	6.8	8	8.1	7.8	7.0
03049812	21	13,800	4,830	2,878	21	24.3	23.3	21.4	21	8.1	7.7	7.2
03049819	8	62	4	2	8	19.6	17.6	7.5	8	8.0	7.9	6.6
03049825	3	8,580	5,825	4,883	7	24.2	23.3	21.6	7	8.0	7.9	7.1
03049828	21	13,800	4,936	2,878	21	24.2	23.4	21.4	21	8.0	7.7	7.1
03076900	21	73,900	3,408	777	21	27.4	25.0	18.4	21	7.7	7.6	6.8
03083900	21	8,610	1,054	791	21	25.1	23.3	17.1	21	8.9	7.7	7.1
03083910	21	74,000	4,576	2,532	21	26.9	24.5	18.3	21	8.1	7.7	7.1
03084698	1	84	nd	84	1	24.6	24.6	24.6	1	9.1	9.1	9.1
03085008	21	76,464	7,000	1,925	21	26.9	24.3	18.7	21	8.1	7.7	7.0
03085030	21	75,000	7,087	2,107	21	27.1	24.1	18.8	21	7.9	7.7	7.0
03085050	5	12	6	2	5	22.5	21.1	17.8	5	8.8	8.5	7.8
03085113	7	9	5	3	7	21.7	19.2	16.3	7	8.1	7.6	6.5

Table 4. Summary statistics for streamflow, water temperature, pH, dissolved-oxygen concentration, specific conductivity, turbidity, and concentrations of fecal-indicator bacteria for 52 sampling sites in Allegheny County, Pennsylvania, 2001–09.—Continued

[USGS, U.S. Geological Survey; n, number of samples; nd, no data; µS/cm, microsiemens per centimeter at 25 degrees Celsius; WQS, water-quality standard; NTU, Nephelometric Turbidity Units; <, less than; --, not sampled]

USGS station number	Streamflow, in cubic feet per second				Water temperature, in degrees Celsius				pH, in standard units			
	n	Maximum	Median	Minimum	n	Maximum	Median	Minimum	n	Maximum	Median	Minimum
03085116	21	77,481	7,087	1,472	21	26.8	24.1	18.7	21	7.9	7.6	6.9
03085120	3	9,311	2,057	1,712	6	26.7	24.0	18.8	6	7.8	7.6	6.8
03085134	21	69,398	7,087	1,550	21	26.8	24.1	18.6	21	7.7	7.6	6.7
03085140	4	11,571	5,224	1,504	7	26.7	24.1	18.8	7	7.7	7.5	7.1
03085154	1	10,496	10,496	10,496	7	24.7	21.1	14.8	6	8.2	7.6	7.6
03085215	21	84,000	8,529	5,050	21	33.0	20.6	11.2	21	8.3	7.6	7.4
03085670	18	81,640	8,315	5,050	18	25.6	21.0	11.3	18	8.2	7.6	7.5
03085700	1	11,201	11,201	11,201	7	23.8	20.7	12.0	7	8.2	7.6	7.5
030859501	7	10	6	2	8	24.9	18.0	5.6	8	8.7	8.4	7.1
030859502	18	20,216	5,906	3,840	18	23.5	20.6	17.9	18	8.1	7.5	7.3
030859504	2	20,216	15,709	11,201	7	23.5	20.4	12.2	7	8.1	7.5	6.6
030859512	15	6,980	1,686	1,300	18	23.5	20.3	18.1	18	8.0	7.6	7.4
030859515	1	11,201	11,201	11,201	3	22.6	19.6	11.5	3	7.6	7.3	6.8
03085960	8	24,290	40	3	8	24.3	17.2	5.9	8	8.2	8.0	7.2
03085966	18	77,860	8,390	5,280	21	23.5	20.1	12.3	21	8.0	7.5	7.3
03085000	85	9,090	4,210	532	84	29.0	26.5	19.5	85	8.6	7.6	6.9

Table 4. Summary statistics for streamflow, water temperature, pH, dissolved-oxygen concentration, specific conductivity, turbidity, and concentrations of fecal-indicator bacteria for 52 sampling sites in Allegheny County, Pennsylvania, 2001–09.—Continued

[USGS, U.S. Geological Survey; n, number of samples; nd, no data; µS/cm, microsiemens per centimeter at 25 degrees Celsius; WQS, water-quality standard; NTU, Nephelometric Turbidity Units; <, less than; --, not sampled]

USGS station number	Dissolved-oxygen concentration, in milligrams per liter				Specific conductivity, in µS/cm				Turbidity, in NTU			
	n	Maximum	Median	Minimum	n	Maximum	Median	Minimum	n	Maximum	Median	Minimum
03049652	110	12.5	9.0	6.0	154	483	350	171	144	95	7	1
03049832	163	14.0	8.5	1.2	190	505	348	132	177	120	6	0
03083903	81	12.0	7.8	0.6	81	569	314	168	79	220	10	1
03085150	161	11.9	8.0	0.4	189	618	386	178	178	180	10	2
03085986	103	11.2	8.3	6.5	160	510	375	229	149	60	11	2
03084400	29	14.7	10.7	8.0	30	918	784	250	30	340	12	0
03084750	29	13.8	9.7	8.2	30	1,857	1,390	550	31	1,130	6	0
03084800	29	14.0	9.7	8.6	30	2,044	1,535	580	30	900	8	2
03084808	26	14.2	10.0	6.0	28	1,479	1,043	294	29	2,000	47	8
03085160	40	13.8	9.1	5.6	39	4,300	1,270	154	37	75	2	0
03085213	57	14.0	8.9	6.2	56	2,509	1,186	195	54	600	20	0
03085290	44	13.3	8.6	6.1	43	1,470	902	115	40	340	25	1
03085500	102	16.9	9.7	6.0	108	1,677	1,130	251	90	1,850	65	11
03085550	29	15.9	8.2	6.0	29	1,877	1,340	614	28	200	42	0
03049643	5	9.2	8.8	7.9	5	442	380	302	4	14	4	4
03049649	8	10.7	10.0	8.4	8	1,566	1,249	435	8	810	13	0
03049660	8	11.0	9.5	8.2	8	3,332	1,677	472	7	490	10	1
03049668	18	9.3	8.7	7.9	18	483	412	314	15	41	6	2

Table 4. Summary statistics for streamflow, water temperature, pH, dissolved-oxygen concentration, specific conductivity, turbidity, and concentrations of fecal-indicator bacteria for 52 sampling sites in Allegheny County, Pennsylvania, 2001–09.—Continued

[USGS, U.S. Geological Survey; n, number of samples; nd, no data; µS/cm, microsiemens per centimeter at 25 degrees Celsius; WQS, water-quality standard; NTU, Nephelometric Turbidity Units; <, less than; --, not sampled]

USGS station number	Dissolved-oxygen concentration, in milligrams per liter				Specific conductivity, in µS/cm				Turbidity, in NTU			
	n	Maximum	Median	Minimum	n	Maximum	Median	Minimum	n	Maximum	Median	Minimum
03049674	3	11.7	8.8	8.3	3	340	318	314	2	24	12	0
03049676	5	11.3	9.6	8.8	5	935	797	687	4	46	24	3
03049677	18	9.7	8.6	8.1	18	464	406	314	15	24	5	4
03049678	6	11.4	8.9	8.1	6	466	405	313	5	21	5	3
03049690	21	9.6	9.2	8.3	21	480	385	304	18	56	5	1
03049810	8	11.2	9.0	8.4	8	1,130	883	603	7	260	18	2
03049812	21	9.6	9.1	8.0	21	483	400	305	15	77	7	0
03049819	8	11.0	9.1	8.7	8	1,455	1,207	559	7	120	8	1
03049825	7	9.6	9.0	8.0	7	476	405	304	6	44	6	0
03049828	21	9.4	9.0	7.8	21	468	409	309	18	31	7	1
03076900	21	9.0	8.1	7.6	21	554	421	232	21	210	13	1
03083900	21	10.4	8.5	7.5	21	538	354	213	21	32	15	2
03083910	21	9.2	8.2	7.6	21	775	399	204	21	280	12	1
03084698	1	15.9	15.9	15.9	1	1,012	1,012	1,012	1	41	41	41
03085008	21	9.6	8.1	7.8	21	547	424	292	21	510	21	4
03085030	21	9.6	8.2	7.8	21	554	416	46	21	970	16	2
03085050	5	9.2	8.2	7.9	5	1,542	1,173	580	4	77	10	0
03085113	7	9.0	8.2	8.0	7	1,338	1,178	825	6	570	1	0

Table 4. Summary statistics for streamflow, water temperature, pH, dissolved-oxygen concentration, specific conductivity, turbidity, and concentrations of fecal-indicator bacteria for 52 sampling sites in Allegheny County, Pennsylvania, 2001–09.—Continued

[USGS, U.S. Geological Survey; n, number of samples; nd, no data; µS/cm, microsiemens per centimeter at 25 degrees Celsius; WQS, water-quality standard; NTU, Nephelometric Turbidity Units; <, less than; --, not sampled]

USGS station number	Dissolved-oxygen concentration, in milligrams per liter				Specific conductivity, in µS/cm				Turbidity, in NTU			
	n	Maximum	Median	Minimum	n	Maximum	Median	Minimum	n	Maximum	Median	Minimum
03085116	21	9.5	8.3	7.9	21	554	405	18	21	220	15	3
03085120	6	9.4	8.3	7.1	6	558	420	208	6	500	11	4
03085134	21	9.2	8.4	8.0	21	570	404	276	21	1,000	15	4
03085140	7	9.2	8.1	7.5	7	579	405	284	7	170	19	6
03085154	5	10.2	9.6	7.6	7	542	423	309	5	26	5	1
03085215	19	11.1	8.7	6.6	21	450	428	164	15	76	6	2
03085670	18	11.7	9.8	7.7	18	483	456	170	15	77	6	0
03085700	7	10.8	8.5	7.2	7	478	450	206	4	51	5	1
030859501	8	15.4	12.0	2.1	8	1,208	981	559	5	270	24	5
030859502	18	10.1	9.3	7.1	18	495	460	238	9	9	5	3
030859504	7	10.9	9.4	6.7	7	498	458	263	4	31	4	3
030859512	18	11.3	9.4	7.8	18	495	457	263	9	7	5	1
030859515	3	12.4	9.4	9.2	3	448	445	434	1	15	15	15
03085960	8	13.2	9.9	9.0	8	1,900	1,018	675	7	34	0	0
03085966	21	11.4	9.3	8.3	21	524	456	274	15	120	12	2
03085000	66	9.9	7.6	6.2	85	789	404	235	85	60	10	2

Table 4. Summary statistics for streamflow, water temperature, pH, dissolved-oxygen concentration, specific conductivity, turbidity, and concentrations of fecal-indicator bacteria for 52 sampling sites in Allegheny County, Pennsylvania, 2001–09.—Continued

[USGS, U.S. Geological Survey; n, number of samples; nd, no data; µS/cm, microsiemens per centimeter at 25 degrees Celsius; WQS, water-quality standard; NTU, Nephelometric Turbidity Units; <, less than; --, not sampled]

USGS station number	*Eschericia coli*, in colonies per 100 milliliters					Fecal coliform, in colonies per 100 milliliters					Enterococci, in colonies per 100 milliliters				
	n	Maxi-mum	Median	Minimum	Percent exceed-ing WQS	n	Maxi-mum	Median	Mini-mum	Percent exceed-ing WQS	n	Maxi-mum	Median	Mini-mum	Percent exceed-ing WQS
03049652	159	1,400	60	3	14	158	5,750	95	<5	11	141	690	15	<5	21
03049832	189	24,000	150	<5	42	187	22,000	255	5	43	149	995	30	<5	30
03083903	81	1,600	110	<5	23	81	1,800	125	<5	12	60	320	15	<5	17
03085150	191	39,000	250	<5	52	187	50,000	370	<5	48	149	3,400	30	<5	35
03085986	161	18,000	130	<5	39	158	31,000	170	<5	30	141	2,000	25	<5	26
03084400	29	13,000	580	10	72	31	15,000	510	40	61	24	11,000	305	<10	75
03084750	30	30,000	115	<10	33	31	34,000	120	<10	23	24	9,600	50	<10	42
03084800	30	49,000	1,200	60	83	32	43,000	1,250	50	75	25	9,100	340	<10	88
03084808	28	42,000	4,700	790	100	30	77,000	5,350	720	100	25	17,000	730	60	96
03085160	39	28,000	1,500	10	95	40	110,000	1,600	200	90	33	21,000	640	<10	94
03085213	59	510,000	8,000	70	97	60	410,000	11,500	220	93	37	180,000	2,200	70	100
03085290	43	28,000	1,200	40	65	44	32,000	1,500	20	66	34	23,000	1,200	10	91
03085500	108	150,000	2,000	<10	84	109	110,000	2,300	<10	83	97	40,000	1,200	40	94
03085550	29	39,000	580	110	72	30	47,000	1,400	200	83	18	3,900	1,470	200	100
03049643	5	330	110	30	20	5	510	110	10	20	--	--	--	--	--
03049649	8	20,000	310	80	50	8	20,000	398	70	50	--	--	--	--	--
03049660	8	16,000	390	30	63	8	16,000	350	50	50	--	--	--	--	--
03049668	18	1,200	110	<10	28	18	1,100	90	30	17	--	--	--	--	--

Table 4. Summary statistics for streamflow, water temperature, pH, dissolved-oxygen concentration, specific conductivity, turbidity, and concentrations of fecal-indicator bacteria for 52 sampling sites in Allegheny County, Pennsylvania, 2001–09.—Continued

[USGS, U.S. Geological Survey; n, number of samples; nd, no data; µS/cm, microsiemens per centimeter at 25 degrees Celsius; WQS, water-quality standard; NTU, Nephelometric Turbidity Units; <, less than; --, not sampled]

USGS station number	*Eschericia coli*, in colonies per 100 milliliters					Fecal coliform, in colonies per 100 milliliters					Enterococci, in colonies per 100 milliliters				
	n	Maximum	Median	Minimum	Percent exceeding WQS	n	Maximum	Median	Minimum	Percent exceeding WQS	n	Maximum	Median	Minimum	Percent exceeding WQS
03049674	3	34,000	890	20	67	3	49,000	870	10	67	--	--	--	--	--
03049676	5	4,700	340	80	60	5	4,700	250	60	20	--	--	--	--	--
03049677	18	1,100	115	10	33	18	1,000	190	<10	39	--	--	--	--	--
03049678	6	680	95	10	33	6	610	160	40	33	--	--	--	--	--
03049690	21	19,000	140	30	43	21	27,000	310	50	43	--	--	--	--	--
03049810	8	14,000	870	<10	88	8	18,000	1,055	20	75	--	--	--	--	--
03049812	21	13,000	140	20	43	21	10,000	280	50	43	--	--	--	--	--
03049819	8	29,000	9,350	20	88	8	36,000	9,950	30	88	--	--	--	--	--
03049825	7	6,900	130	10	43	7	11,000	260	110	43	--	--	--	--	--
03049828	21	12,000	120	<10	43	21	14,000	240	60	43	--	--	--	--	--
03076900	21	630	130	<10	24	21	810	210	<10	19	--	--	--	--	--
03083900	21	3,200	90	<10	43	21	5,000	150	20	38	--	--	--	--	--
03083910	21	970	220	<10	48	21	1,300	410	80	52	--	--	--	--	--
03084698	1	110	110	110	0	1	150	150	150	0	--	--	--	--	--
03085008	21	1,200	230	30	48	21	4,200	300	60	38	--	--	--	--	--
03085030	21	820	220	<10	48	21	810	260	30	38	--	--	--	--	--
03085050	5	33,000	280	80	60	5	31,000	370	120	40	--	--	--	--	--
03085113	7	200,000	520	90	71	7	200,000	430	100	57	--	--	--	--	--

Table 4. Summary statistics for streamflow, water temperature, pH, dissolved-oxygen concentration, specific conductivity, turbidity, and concentrations of fecal-indicator bacteria for 52 sampling sites in Allegheny County, Pennsylvania, 2001–09.—Continued

[USGS, U.S. Geological Survey; n, number of samples; nd, no data; µS/cm, microsiemens per centimeter at 25 degrees Celsius; WQS, water-quality standard; NTU, Nephelometric Turbidity Units; <, less than; --, not sampled]

USGS station number	*Eschericia coli*, in colonies per 100 milliliters					Fecal coliform, in colonies per 100 milliliters					Enterococci, in colonies per 100 milliliters				
	n	Maximum	Median	Minimum	Percent exceeding WQS	n	Maximum	Median	Minimum	Percent exceeding WQS	n	Maximum	Median	Minimum	Percent exceeding WQS
03085116	21	6,700	300	20	52	21	6,500	280	10	48	--	--	--	--	--
03085120	6	980	230	30	50	6	640	120	40	33	--	--	--	--	--
03085134	21	1,400	300	<10	52	21	2,100	390	10	43	--	--	--	--	--
03085140	7	520	200	100	43	7	930	260	80	29	--	--	--	--	--
03085154	6	2,900	72	20	33	7	3,600	155	50	29	--	--	--	--	--
03085215	21	27,000	100	<10	43	17	4,400	240	10	41	--	--	--	--	--
03085670	18	3,500	220	<10	50	16	5,000	200	<10	38	--	--	--	--	--
03085700	6	1,300	22	<10	17	7	9,000	130	20	29	--	--	--	--	--
030859501	7	200,000	4,300	570	100	8	200,000	5,750	390	88	--	--	--	--	--
030859502	18	1,100	66	<10	28	16	7,600	148	20	31	--	--	--	--	--
030859504	6	1,300	156	<10	33	6	1,400	188	20	33	--	--	--	--	--
030859512	15	980	160	20	27	15	1,100	220	20	20	--	--	--	--	--
030859515	3	930	80	10	33	3	1,100	80	30	33	--	--	--	--	--
03085960	7	1,800	80	<10	29	8	5,500	395	19	50	--	--	--	--	--
03085966	21	26,000	190	10	38	17	5,000	110	<10	24	--	--	--	--	--
03085000	85	12,000	320	<5	58	85	23,000	360	25	47	85	1,300	25	<5	33

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