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
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

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

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U.S. Department of the Interior
U.S. Geological Survey
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## Conversion Factors

### Inch/Pound to SI

<table>
<thead>
<tr>
<th>Multiply</th>
<th>By</th>
<th>To obtain</th>
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<tbody>
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</tr>
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<td>centimeter (cm)</td>
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<td>inch (in.)</td>
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<tr>
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<td>hectare (ha)</td>
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<tr>
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<td>square kilometer (km²)</td>
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<td><strong>Flow rate</strong></td>
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<tr>
<td>cubic foot per second (ft³/s)</td>
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<td>cubic meter per second (m³/s)</td>
</tr>
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</table>

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
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 (mi²) 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).

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.
Concentrations of Fecal-Indicator Bacteria in the Allegheny, Monongahela, and Ohio Rivers and Selected Tributaries, PA, 2001–09

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

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 (km²) (0.37-mi²) 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
Sampling-site name and map number
01 - Allegheny River below Falling Springs Run at Oakmont, PA
02 - Allegheny River at Hulton Bridge at Oakmont, PA
03 - Allegheny River above Quigley Creek at Blawnox, PA
04 - Allegheny River above Shades Run at Aspinwall, PA
05 - Allegheny River below Shades Run at Aspinwall, PA
06 - Allegheny River at Sharpsburg, PA
07 - Allegheny River above Girtys Run at Millvale, PA
08 - Allegheny River above 31st Street Bridge at Pittsburgh, PA
09 - Allegheny River below 31st Street Bridge at Pittsburgh, PA
32 - Allegheny River at 9th Street Bridge at Pittsburgh, PA
33 - Deer Creek at Route 910 near Cheswick, PA
34 - Plum Creek at Milltown, PA
35 - Plum Creek at Verona, PA
36 - Squaw Run at Old Freeport Road near Blawnox, PA
37 - Pine Creek at Etna, PA

EXPLANATION

- Allegheny County study-area boundary
- River or selected tributary
- Sewer outfall
- Monitoring location
- Direction of flow

Number of sewer outfalls upstream

Figure 3. Location of sampling sites and combined sewer overflow locations on the Allegheny River, Allegheny County, Pennsylvania.
Sampling-site name and map number
10 - Monongahela River at Dravosburg, PA
11 - Youghiogheny River at McKeesport, PA
12 - Monongahela River at McKeesport, PA
13 - Monongahela River above Turtle Creek at Duquesne, PA
14 - Monongahela River above Rankin Bridge at Rankin, PA
15 - Monongahela River above Ninemile Run at Homestead, PA
16 - Monongahela River below Streets Run near Baldwin, PA
17 - Monongahela River at South Pittsburgh, PA
18 - Monongahela River at Greenfield at Pittsburgh, PA
19 - Monongahela River at Brady Street Bridge at Pittsburgh, PA
20 - Monongahela River at Pittsburgh, PA
38 - Turtle Creek at Trafford, PA
39 - Thompson Run at Gascola, PA
40 - Thompson Run at Turtle Creek, PA
41 - Turtle Creek at East Pittsburgh, PA
42 - Ninemile Run at Mouth near Swissvale, PA
43 - Streets Run 1000 ft upstream of Mouth at Hays, PA

EXPLANATION
- Allegheny County study-area boundary
- River or selected tributary
- Sewer outfall
- Monitoring location
- Direction of flow
- 94* Number of sewer outfalls upstream

Figure 4. Location of sampling sites and combined sewer overflow locations on the Monongahela River, Allegheny County, Pennsylvania.
Sampling-site name and map number
21 - Allegheny River at 9th Street Bridge at Pittsburgh, PA
22 - Monongahela River at Pittsburgh, PA
23 - Ohio River at Point State Park at Pittsburgh, PA
24 - Ohio River above Brunot Island at Pittsburgh, PA
25 - Ohio River below Jacks Run near Pittsburgh, PA
26 - Ohio River above Neville Island at Avalon, PA
27 - Ohio River below Lowries Run at Emsworth, PA
28 - Ohio River above Toms Run at Emsworth, PA
29 - Ohio River below Emsworth back channel at Emsworth, PA
30 - Ohio River below Neville Island at Coraopolis, PA
31 - Ohio River at Sewickley Bridge at Sewickley, PA
44 - Sawmill Run at Castle Shannon, PA
45 - Chartiers Creek near Bridgeville, PA
46 - Chartiers Creek at Crafton, PA
47 - Lowries Run 1000 ft above Mouth at Ben Avon, PA
48 - Montour Run at Coraopolis, PA

EXPLANATION
- Allegheny County study-area boundary
- River or selected tributary
- Sewer outfall
- Monitoring location
- Direction of flow

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

[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]

<table>
<thead>
<tr>
<th>USGS station number</th>
<th>USGS station name</th>
<th>Season</th>
<th>7Q10</th>
<th>Median flow</th>
<th>Bankfull flow&lt;sup&gt;1&lt;/sup&gt;</th>
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<td>Allegheny River at Natrona, PA</td>
<td>Recreational</td>
<td>2,660</td>
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<td>75,400</td>
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<td>03075070</td>
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<td>Non-recreational</td>
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<td>128,500</td>
</tr>
</tbody>
</table>

<sup>1</sup>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.
Methods

11

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.

**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](http://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/](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
Concentrations of Fecal-Indicator Bacteria in the Allegheny, Monongahela, and Ohio Rivers and Selected Tributaries, PA, 2001–09

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, ungauged 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 multiparameter 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 location 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

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

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

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)]
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)]

<table>
<thead>
<tr>
<th>Location</th>
<th>All conditions</th>
<th>Dry weather</th>
<th>Wet weather</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>Eschericia coli</em></td>
<td>Fecal coliform</td>
<td>Enterococci</td>
</tr>
<tr>
<td><strong>Streamflow</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>p-value</td>
<td>0.432</td>
<td>0.365</td>
<td>0.269</td>
</tr>
<tr>
<td>n</td>
<td>153</td>
<td>153</td>
<td>153</td>
</tr>
<tr>
<td><strong>Water temperature</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>p-value</td>
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<td>-0.257</td>
<td>-0.029</td>
</tr>
<tr>
<td>n</td>
<td>126</td>
<td>126</td>
<td>126</td>
</tr>
<tr>
<td><strong>pH</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>p-value</td>
<td>0.0007</td>
<td>0.0037</td>
<td>0.7451</td>
</tr>
<tr>
<td>n</td>
<td>152</td>
<td>152</td>
<td>152</td>
</tr>
<tr>
<td><strong>Specific conductance</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>p-value</td>
<td>0.0003</td>
<td>0.0421</td>
<td>0.0872</td>
</tr>
<tr>
<td>n</td>
<td>154</td>
<td>154</td>
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</tr>
<tr>
<td><strong>Dissolved oxygen</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>p-value</td>
<td>-0.116</td>
<td>-0.030</td>
<td>0.092</td>
</tr>
<tr>
<td>n</td>
<td>110</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td><strong>Turbidity</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>p-value</td>
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<td>0.0001</td>
<td>0.0003</td>
</tr>
<tr>
<td>n</td>
<td>144</td>
<td>144</td>
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</tr>
</tbody>
</table>

03049652 Allegheny River at Oakmont, PA

<table>
<thead>
<tr>
<th>Location</th>
<th>All conditions</th>
<th>Dry weather</th>
<th>Wet weather</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>Eschericia coli</em></td>
<td>Fecal coliform</td>
<td>Enterococci</td>
</tr>
<tr>
<td><strong>Streamflow</strong></td>
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03049832 Allegheny River at 9th Street Bridge at Pittsburgh, PA
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)]

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<td><strong>Wet weather</strong></td>
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<tr>
<td><strong>Eschericia coli</strong></td>
<td><strong>Fecal coliform</strong></td>
<td><strong>Enterococci</strong></td>
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<td><strong>Eschericia coli</strong></td>
<td><strong>Fecal coliform</strong></td>
<td><strong>Enterococci</strong></td>
</tr>
<tr>
<td>Streamflow</td>
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<td>&lt;0.001</td>
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<td>&lt;0.001</td>
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<td>&lt;0.001</td>
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<table>
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<td><strong>Wet weather</strong></td>
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<td><strong>Fecal coliform</strong></td>
<td><strong>Enterococci</strong></td>
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<td><strong>Eschericia coli</strong></td>
<td><strong>Fecal coliform</strong></td>
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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.

<table>
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<tr>
<th>Conditions</th>
<th>All conditions</th>
<th>Dry weather</th>
<th>Wet weather</th>
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<tr>
<td></td>
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<td>&lt;.0001</td>
<td>&lt;.0001</td>
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<td>n</td>
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<td>p-value</td>
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<td>pH</td>
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<td>0.119</td>
<td>0.056</td>
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<td>p-value</td>
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<td>p-value</td>
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<td>Dissolved oxygen</td>
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<td>&lt;.0001</td>
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<tr>
<td>n</td>
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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)]

<table>
<thead>
<tr>
<th></th>
<th>All conditions</th>
<th>Dry weather</th>
<th>Wet weather</th>
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<tbody>
<tr>
<td></td>
<td>Eschericia coli</td>
<td>Fecal coliform</td>
<td>Enterococci</td>
</tr>
<tr>
<td>Streamflow</td>
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03084400 Turtle Creek at Trafford, PA

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<td>Enterococci</td>
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<tr>
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03084750 Thompson Run at Gascola, PA
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)]

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<th>Wet weather</th>
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<td></td>
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<td>Enterococci</td>
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<tr>
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03084800 Thompson Run at Turtle Creek, PA

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<th>Wet weather</th>
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<td>Fecal coliform</td>
<td>Enterococci</td>
</tr>
<tr>
<td>Streamflow</td>
<td>0.439</td>
<td>0.300</td>
<td>0.412</td>
</tr>
<tr>
<td>p-value</td>
<td><strong>0.0409</strong></td>
<td>0.1752</td>
<td>0.0565</td>
</tr>
<tr>
<td>n</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>Water temperature</td>
<td>-0.354</td>
<td>-0.429</td>
<td>-0.555</td>
</tr>
<tr>
<td>p-value</td>
<td>0.0702</td>
<td><strong>0.0257</strong></td>
<td><strong>0.0027</strong></td>
</tr>
<tr>
<td>n</td>
<td>27</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td>pH</td>
<td>-0.060</td>
<td>-0.131</td>
<td>-0.311</td>
</tr>
<tr>
<td>p-value</td>
<td>0.7613</td>
<td>0.5063</td>
<td>0.107</td>
</tr>
<tr>
<td>n</td>
<td>28</td>
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<td>28</td>
</tr>
<tr>
<td>Specific conductance</td>
<td>-0.492</td>
<td>-0.390</td>
<td>-0.434</td>
</tr>
<tr>
<td>p-value</td>
<td><strong>0.0079</strong></td>
<td><strong>0.0401</strong></td>
<td><strong>0.0209</strong></td>
</tr>
<tr>
<td>n</td>
<td>28</td>
<td>28</td>
<td>28</td>
</tr>
<tr>
<td>Dissolved oxygen</td>
<td>-0.125</td>
<td>-0.187</td>
<td>-0.107</td>
</tr>
<tr>
<td>p-value</td>
<td>0.5423</td>
<td>0.3592</td>
<td>0.6025</td>
</tr>
<tr>
<td>n</td>
<td>26</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>Turbidity</td>
<td>0.594</td>
<td>0.713</td>
<td>0.647</td>
</tr>
<tr>
<td>p-value</td>
<td><strong>0.0007</strong></td>
<td>&lt;.0001</td>
<td><strong>0.0002</strong></td>
</tr>
<tr>
<td>n</td>
<td>29</td>
<td>29</td>
<td>29</td>
</tr>
</tbody>
</table>
### 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

<table>
<thead>
<tr>
<th>All conditions</th>
<th>Dry weather</th>
<th>Wet weather</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Eschericia coli</td>
<td>Fecal coliform</td>
</tr>
<tr>
<td>Streamflow</td>
<td>0.562</td>
<td>0.401</td>
</tr>
<tr>
<td>p-value</td>
<td>0.0005</td>
<td>0.0187</td>
</tr>
<tr>
<td>n</td>
<td>34</td>
<td>34</td>
</tr>
<tr>
<td>Water temperature</td>
<td>-0.086</td>
<td>-0.025</td>
</tr>
<tr>
<td>p-value</td>
<td>0.5991</td>
<td>0.8803</td>
</tr>
<tr>
<td>n</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>pH</td>
<td>-0.634</td>
<td>-0.404</td>
</tr>
<tr>
<td>p-value</td>
<td>&lt;.0001</td>
<td>0.0107</td>
</tr>
<tr>
<td>n</td>
<td>39</td>
<td>39</td>
</tr>
<tr>
<td>Specific conductance</td>
<td>-0.140</td>
<td>-0.286</td>
</tr>
<tr>
<td>p-value</td>
<td>0.3964</td>
<td>0.0772</td>
</tr>
<tr>
<td>n</td>
<td>39</td>
<td>39</td>
</tr>
<tr>
<td>Dissolved oxygen</td>
<td>-0.239</td>
<td>-0.240</td>
</tr>
<tr>
<td>p-value</td>
<td>0.1374</td>
<td>0.1353</td>
</tr>
<tr>
<td>n</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Turbidity</td>
<td>0.063</td>
<td>0.591</td>
</tr>
<tr>
<td>p-value</td>
<td>&lt;.0001</td>
<td>0.0001</td>
</tr>
<tr>
<td>n</td>
<td>37</td>
<td>37</td>
</tr>
</tbody>
</table>

#### 03085213 Sawmill Run at Duquesne Heights near Pittsburgh, PA

<table>
<thead>
<tr>
<th>All conditions</th>
<th>Dry weather</th>
<th>Wet weather</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Eschericia coli</td>
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</tr>
<tr>
<td>Streamflow</td>
<td>0.808</td>
<td>0.821</td>
</tr>
<tr>
<td>p-value</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>n</td>
<td>56</td>
<td>56</td>
</tr>
<tr>
<td>Water temperature</td>
<td>0.270</td>
<td>0.326</td>
</tr>
<tr>
<td>p-value</td>
<td>0.0426</td>
<td>0.0133</td>
</tr>
<tr>
<td>n</td>
<td>57</td>
<td>57</td>
</tr>
<tr>
<td>pH</td>
<td>-0.272</td>
<td>-0.204</td>
</tr>
<tr>
<td>p-value</td>
<td>0.0409</td>
<td>0.1274</td>
</tr>
<tr>
<td>n</td>
<td>57</td>
<td>57</td>
</tr>
<tr>
<td>Specific conductance</td>
<td>-0.463</td>
<td>-0.526</td>
</tr>
<tr>
<td>p-value</td>
<td>0.0003</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>n</td>
<td>56</td>
<td>56</td>
</tr>
<tr>
<td>Dissolved oxygen</td>
<td>-0.365</td>
<td>-0.383</td>
</tr>
<tr>
<td>p-value</td>
<td>0.0053</td>
<td>0.0033</td>
</tr>
<tr>
<td>n</td>
<td>57</td>
<td>57</td>
</tr>
<tr>
<td>Turbidity</td>
<td>0.743</td>
<td>0.716</td>
</tr>
<tr>
<td>p-value</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>n</td>
<td>54</td>
<td>54</td>
</tr>
</tbody>
</table>
**Occurrence and Trends in Concentrations of Fecal-Indicator Bacteria in Streamflow**

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)]

<table>
<thead>
<tr>
<th></th>
<th>All conditions</th>
<th>Dry weather</th>
<th>Wet weather</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>Eschericia coli</em></td>
<td>Fecal coliform</td>
<td>Enterococci</td>
</tr>
<tr>
<td>Streamflow</td>
<td>0.788</td>
<td>0.833</td>
<td>0.739</td>
</tr>
<tr>
<td>p-value</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>n</td>
<td>44</td>
<td>44</td>
<td>44</td>
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<tr>
<td>Water temperature</td>
<td>-0.068</td>
<td>-0.119</td>
<td>0.024</td>
</tr>
<tr>
<td>p-value</td>
<td>0.6646</td>
<td>0.4463</td>
<td>0.8809</td>
</tr>
<tr>
<td>n</td>
<td>43</td>
<td>43</td>
<td>43</td>
</tr>
<tr>
<td>pH</td>
<td>-0.575</td>
<td>-0.542</td>
<td>-0.434</td>
</tr>
<tr>
<td>p-value</td>
<td>&lt;.0001</td>
<td>0.0001</td>
<td>0.0032</td>
</tr>
<tr>
<td>n</td>
<td>44</td>
<td>44</td>
<td>44</td>
</tr>
<tr>
<td>Specific conductance</td>
<td>-0.760</td>
<td>-0.829</td>
<td>-0.732</td>
</tr>
<tr>
<td>p-value</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>n</td>
<td>43</td>
<td>43</td>
<td>43</td>
</tr>
<tr>
<td>Dissolved oxygen</td>
<td>-0.092</td>
<td>-0.038</td>
<td>-0.188</td>
</tr>
<tr>
<td>p-value</td>
<td>0.5506</td>
<td>0.8077</td>
<td>0.2222</td>
</tr>
<tr>
<td>n</td>
<td>44</td>
<td>44</td>
<td>44</td>
</tr>
<tr>
<td>Turbidity</td>
<td>0.845</td>
<td>0.808</td>
<td>0.723</td>
</tr>
<tr>
<td>p-value</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>n</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
</tbody>
</table>

03085290 Chartiers Creek near Bridgeville, PA

03085500 Chartiers Creek at Carnegie, PA
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.

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### 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)]

<table>
<thead>
<tr>
<th>03085550 Chartiers Creek at Crafton, PA</th>
<th>All conditions</th>
<th>Dry weather</th>
<th>Wet weather</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>Eschericia coli</em></td>
<td>Fecal coliform</td>
<td>Enterococci</td>
</tr>
<tr>
<td>Streamflow</td>
<td>-0.035</td>
<td>-0.523</td>
<td>nd</td>
</tr>
<tr>
<td>p-value</td>
<td>0.9132</td>
<td>0.081</td>
<td>nd</td>
</tr>
<tr>
<td>n</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Water temperature</td>
<td>0.251</td>
<td>0.055</td>
<td>0.559</td>
</tr>
<tr>
<td>p-value</td>
<td>0.1893</td>
<td>0.7785</td>
<td>0.0016</td>
</tr>
<tr>
<td>n</td>
<td>29</td>
<td>29</td>
<td>29</td>
</tr>
<tr>
<td>pH</td>
<td>0.015</td>
<td>0.129</td>
<td>0.001</td>
</tr>
<tr>
<td>p-value</td>
<td>0.9395</td>
<td>0.5059</td>
<td>0.9947</td>
</tr>
<tr>
<td>n</td>
<td>29</td>
<td>29</td>
<td>29</td>
</tr>
<tr>
<td>Specific conductance</td>
<td>-0.590</td>
<td>-0.639</td>
<td>-0.391</td>
</tr>
<tr>
<td>p-value</td>
<td><strong>0.0008</strong></td>
<td><strong>0.0002</strong></td>
<td><strong>0.0359</strong></td>
</tr>
<tr>
<td>n</td>
<td>29</td>
<td>29</td>
<td>29</td>
</tr>
<tr>
<td>Dissolved oxygen</td>
<td>-0.309</td>
<td>-0.116</td>
<td>-0.635</td>
</tr>
<tr>
<td>p-value</td>
<td>0.1025</td>
<td>0.5478</td>
<td><strong>0.0002</strong></td>
</tr>
<tr>
<td>n</td>
<td>29</td>
<td>29</td>
<td>29</td>
</tr>
<tr>
<td>Turbidity</td>
<td>0.607</td>
<td>0.854</td>
<td>0.386</td>
</tr>
<tr>
<td>p-value</td>
<td><strong>0.0006</strong></td>
<td>&lt;<strong>0.001</strong></td>
<td><strong>0.0423</strong></td>
</tr>
<tr>
<td>n</td>
<td>28</td>
<td>28</td>
<td>28</td>
</tr>
</tbody>
</table>
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 12](image)

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 13](image)
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)]

<table>
<thead>
<tr>
<th>USGS station number</th>
<th>USGS station name</th>
<th><em>Eschericia coli</em></th>
<th>Fecal coliform</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td><strong>n</strong></td>
<td><strong>p-value</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Dry weather without flow adjustment</strong></td>
<td></td>
</tr>
<tr>
<td>03049652</td>
<td>Allegheny River at Hulton Bridge at Oakmont, PA</td>
<td>42</td>
<td>0.462</td>
</tr>
<tr>
<td>03049832</td>
<td>Allegheny River at 9th St. Bridge at Pittsburgh, PA</td>
<td>64</td>
<td>1.000</td>
</tr>
<tr>
<td>03083903</td>
<td>Monongahela River at McKeesport, PA</td>
<td>27</td>
<td>na</td>
</tr>
<tr>
<td>03085150</td>
<td>Monongahela River at Pittsburgh, PA</td>
<td>69</td>
<td>0.707</td>
</tr>
<tr>
<td>03085986</td>
<td>Ohio River at Sewickley bridge at Sewickley, PA</td>
<td>50</td>
<td>0.181</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Dry weather with flow adjustment</strong></td>
<td></td>
</tr>
<tr>
<td>03049652</td>
<td>Allegheny River at Hulton Bridge at Oakmont, PA</td>
<td>42</td>
<td>0.806</td>
</tr>
<tr>
<td>03049832</td>
<td>Allegheny River at 9th St. Bridge at Pittsburgh, PA</td>
<td>64</td>
<td>1.000</td>
</tr>
<tr>
<td>03083903</td>
<td>Monongahela River at McKeesport, PA</td>
<td>27</td>
<td>na</td>
</tr>
<tr>
<td>03085150</td>
<td>Monongahela River at Pittsburgh, PA</td>
<td>69</td>
<td>0.707</td>
</tr>
<tr>
<td>03085986</td>
<td>Ohio River at Sewickley bridge at Sewickley, PA</td>
<td>50</td>
<td>0.181</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Wet weather without flow adjustment</strong></td>
<td></td>
</tr>
<tr>
<td>03049652</td>
<td>Allegheny River at Hulton Bridge at Oakmont, PA</td>
<td>37</td>
<td>0.221</td>
</tr>
<tr>
<td>03049832</td>
<td>Allegheny River at 9th St. Bridge at Pittsburgh, PA</td>
<td>54</td>
<td>0.035</td>
</tr>
<tr>
<td>03083903</td>
<td>Monongahela River at McKeesport, PA</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>03085150</td>
<td>Monongahela River at Pittsburgh, PA</td>
<td>52</td>
<td>0.230</td>
</tr>
<tr>
<td>03085986</td>
<td>Ohio River at Sewickley bridge at Sewickley, PA</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Wet weather with flow adjustment</strong></td>
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<tr>
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<td>Allegheny River at Hulton Bridge at Oakmont, PA</td>
<td>37</td>
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</tr>
<tr>
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<td>Allegheny River at 9th St. Bridge at Pittsburgh, PA</td>
<td>54</td>
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</tr>
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<td>0.230</td>
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<tr>
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<td>Ohio River at Sewickley bridge at Sewickley, PA</td>
<td>na</td>
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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)]

<table>
<thead>
<tr>
<th>USGS station number</th>
<th>USGS station name</th>
<th><em>Eschericia coli</em> greater than 235 colonies per 100 mL¹</th>
<th>Fecal coliform greater than 400 colonies per 100 mL²</th>
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<tr>
<td></td>
<td></td>
<td>n</td>
<td>p-value</td>
</tr>
<tr>
<td>Dry weather</td>
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<td></td>
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<tr>
<td>03049652</td>
<td>Allegheny River at Hulton Bridge at Oakmont, PA</td>
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<td>Allegheny River at 9th St. Bridge at Pittsburgh, PA</td>
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<td>Monongahela River at McKeesport, PA</td>
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<td>03085150</td>
<td>Monongahela River at Pittsburgh, PA</td>
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<td>0.225</td>
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<tr>
<td>03085986</td>
<td>Ohio River at Sewickley bridge at Sewickley, PA</td>
<td>50</td>
<td>na</td>
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<tr>
<td>Wet weather</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03049652</td>
<td>Allegheny River at Hulton Bridge at Oakmont, PA</td>
<td>37</td>
<td>0.099</td>
</tr>
<tr>
<td>03049832</td>
<td>Allegheny River at 9th St. Bridge at Pittsburgh, PA</td>
<td>54</td>
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<td>Monongahela River at McKeesport, PA</td>
<td>na</td>
<td>na</td>
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<td>03085150</td>
<td>Monongahela River at Pittsburgh, PA</td>
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<td>03085986</td>
<td>Ohio River at Sewickley bridge at Sewickley, PA</td>
<td>39</td>
<td>0.195</td>
</tr>
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</table>

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 test results 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.

References Cited


References Cited


### 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]

<table>
<thead>
<tr>
<th>USGS station name</th>
<th>Purpose</th>
<th>USGS station number</th>
<th>Map identifier for figures 3–5</th>
<th>Sample obtained from:</th>
<th>River mile (miles)</th>
<th>Drainage area (square miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allegheny River at Natrona, PA</td>
<td>Continuous-record streamgage used to estimate discharge into the Allegheny River Basin</td>
<td>03049500</td>
<td>**</td>
<td>NA</td>
<td>24.3</td>
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<tr>
<td>Allegheny River bl Falling Springs Run at Oakmont, PA</td>
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<td>1</td>
<td>boat</td>
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</tr>
<tr>
<td>Allegheny River at Hulton Bridge at Oakmont, PA</td>
<td>Main-stem upstream QW transect near ALCOSAN service area boundary</td>
<td>03049652</td>
<td>2</td>
<td>bridge, boat</td>
<td>12.7</td>
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<td>Allegheny River ab Quigley Creek at Blawnox, PA</td>
<td>Main-stem intermediate QW transect</td>
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<td>3</td>
<td>boat</td>
<td>10.4</td>
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<td>Allegheny River ab Shades Run at Aspinwall, PA</td>
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<td>Allegheny River at Sharpsburg, PA</td>
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<td>8</td>
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<td>Allegheny River bl 31st St Bridge at Pittsburgh, PA</td>
<td>Main-stem intermediate QW transect</td>
<td>03049828</td>
<td>9</td>
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<td>11,739.0</td>
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<tr>
<td>Allegheny River at 9th St. Bridge at Pittsburgh, PA</td>
<td>Main-stem downstream QW transect</td>
<td>03049832</td>
<td>32</td>
<td>boat</td>
<td>0.7</td>
<td>11,710.0</td>
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<tr>
<td>Deer Creek near Dorseyville, PA</td>
<td>Continuous-record tributary streamgage upstream from the ALCOSAN service area</td>
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<td>--</td>
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<td>Deer Creek at Route 910 near Cheswick, PA</td>
<td>Tributary QW transect upstream from the ALCOSAN service area</td>
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<tr>
<td>Plum Creek at Milltown, PA</td>
<td>Continuous-record tributary streamgage upstream from the ALCOSAN service area</td>
<td>03049658</td>
<td>34</td>
<td>NA</td>
<td>--</td>
<td>17.4</td>
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</table>
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]

<table>
<thead>
<tr>
<th>USGS station name</th>
<th>Purpose</th>
<th>USGS station number</th>
<th>Map identifier for figures 3–5</th>
<th>Sample obtained from:</th>
<th>River mile(^1) (miles)</th>
<th>Drainage area (square miles)</th>
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<td>Squaw Run at Old Freeport Road near Blawnox, PA</td>
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<td>36</td>
<td>wading</td>
<td>--</td>
<td>8.07</td>
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<tr>
<td>Pine Creek at Grant Avenue at Etna, PA</td>
<td>Continuous-record tributary streamgage</td>
<td>03049807</td>
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<td>--</td>
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<td>37</td>
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<td>--</td>
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<td>Girlys Run above Grant Avenue at Millvale, PA</td>
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Monongahela River and tributaries

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<th>River mile(^1) (miles)</th>
<th>Drainage area (square miles)</th>
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<td>Drainage area (square miles)</td>
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<td>Monongahela River at Greenfield at Pittsburgh, PA</td>
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<tr>
<td>Turtle Creek at Trafford, PA</td>
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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.—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]

<table>
<thead>
<tr>
<th>USGS station name</th>
<th>Purpose</th>
<th>USGS station number</th>
<th>Map identifier for figures 3–5</th>
<th>Sample obtained from:</th>
<th>River mile¹ (miles)</th>
<th>Drainage area (square miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ohio River at Point State Park at Pittsburgh, PA</td>
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<td>Sawmill Run at Castle Shannon, PA</td>
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<td>Sawmill Run at Duquesne Heights nr Pittsburgh, PA</td>
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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.—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]

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<th>River mile(^1) (miles)</th>
<th>Drainage area (square miles)</th>
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\(^1\)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.—Continued

<table>
<thead>
<tr>
<th>USGS station number</th>
<th>Streamflow, in cubic feet per second</th>
<th>Water temperature, in degrees Celsius</th>
<th>pH, in standard units</th>
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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]

<table>
<thead>
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<th>pH, in standard units</th>
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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

<table>
<thead>
<tr>
<th>USGS station number</th>
<th>Streamflow, in cubic feet per second</th>
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<th>pH, in standard units</th>
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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]

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[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]

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<th>Specific conductivity, in μS/cm</th>
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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

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<table>
<thead>
<tr>
<th>USGS station number</th>
<th>Eschericia coli, in colonies per 100 milliliters</th>
<th>Fecal coliform, in colonies per 100 milliliters</th>
<th>Enterococci, in colonies per 100 milliliters</th>
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