Prepared in cooperation with the National Park Service

Escherichia coli Concentrations in Recreational Streams and Backcountry Drinking-Water Supplies in Shenandoah National Park, Virginia, 2005–2006

Scientific Investigations Report 2007–5160

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

Cover. **White Oak Run in Shenandoah National Park, Virginia** *(photograph taken by Kenneth E. Hyer, U.S. Geological Survey)*.

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Conversion Factors

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

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

$$°F = (1.8 \times °C) + 32$$

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

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

E. coli concentrations are reported in units of colonies per 100 milliliters of water (col/100 mL).

Escherichia coli Concentrations in Recreational Streams and Backcountry Drinking-Water Supplies in Shenandoah National Park, Virginia, 2005–2006

By Kenneth E. Hyer

Abstract

Although fecal contamination of streams is a problem of national scope, few investigations have been directed at relatively pristine streams in forested basins in national parks. With approximately 1.8 million visitors annually, Shenandoah National Park in Virginia is subject to extensive recreational use. The effects of these visitors and their recreational activities on fecal indicator bacteria levels in the streams are poorly understood and of concern for Shenandoah National Park managers.

During 2005 and 2006, streams and springs in Shenandoah National Park were sampled for *Escherichia coli* (*E. coli*) concentrations. The first study objective was to evaluate the effects of recreational activities on *E. coli* concentrations in selected streams. Of the 20 streams that were selected, 14 were in basins with extensive recreational activity, and 6 were in control basins where minimal recreational activities occurred. Water-quality sampling was conducted during low-flow conditions during the relatively warm months, as this is when outdoor recreation and bacterial survivorship are greatest. Although most sampling was conducted during low-flow conditions, approximately three stormflow samples were collected from each stream. The second study objective was to evaluate *E. coli* levels in backcountry drinking-water supplies throughout Shenandoah National Park. Nineteen drinking-water supplies (springs and streams) were sampled two to six times each by Shenandoah National Park staff and analyzed by the U.S. Geological Survey for this purpose.

The water-quality sampling results indicated relatively low *E. coli* concentrations during low-flow conditions, and no statistically significant increase in *E. coli* concentrations was observed in the recreational streams relative to the control streams. These results indicate that during low-flow conditions, recreational activities had no significant effect on *E. coli* concentrations. During stormflow conditions, *E. coli* concentrations increased by nearly a factor of 10 in both basin types, and the Virginia instantaneous water-quality standard for *E. coli* (235 colonies per 100 milliliters) frequently was exceeded.

The sampling results from drinking-water supplies throughout Shenandoah National Park indicated relatively low *E. coli* concentrations in all springs that were sampled. Several of the streams that were sampled had slightly higher *E. coli* concentrations relative to the springs, but no *E. coli* concentrations exceeded the instantaneous water-quality standard. Although *E. coli* concentrations in all the drinking-water supplies were relatively low, Shenandoah National Park management continues to stress that all hikers must treat drinking water from all streams and springs prior to consumption.

After determining that recreational activities in Shenandoah National Park did not have a statistically significant effect on low-flow *E. coli* concentrations, an additional concern was addressed regarding the quality of the water releases from the wastewater-treatment plants in the park. Sampling of three wastewater-treatment plant outfalls was conducted in 2006 to evaluate their effects on water quality. Samples were analyzed for *E. coli* and a collection of wastewater organic compounds that may be endocrine disruptors. Relatively elevated *E. coli* concentrations were observed in 2 of the 3 samples, and between 9 and 13 wastewater organic compounds were detected in the samples, including 3 known and 5 suspected endocrine-disrupting compounds.

Introduction

Fecal contamination of streams has resulted in elevated concentrations of fecal indicator bacteria and has become a problem of national scope. Elevated levels of fecal bacteria in surface waters indicate the increased likelihood of pathogens, and pose a potential health risk to people who come into physical contact with these waters. State regulatory agencies have classified many surface waters as impaired with respect to bacterial water-quality standards. Of the approximately 9,900 miles of rivers that were included in the Commonwealth of Virginia's 2004 305(b) water-quality assessment, approximately 5,000 river miles (or about half the river miles assessed) were classified as impaired because of elevated levels of fecal indicator bacteria (Virginia Department of Environmental Quality, 2004). For freshwater systems in Virginia, the bacterial water-quality standard is based on *Escherichia coli* (*E. coli*), and the instantaneous water-quality standard is 235 colonies per 100 milliliters (col/100 mL) of water.

Elevated concentrations of fecal bacteria have been linked to human activities, such as agriculture and urbanization (Wiggins, 1996; Hagedorn and others, 1999), and to the presence of wildlife (Simmons and others, 1995). Despite widespread evaluation and characterization of fecal-bacteria concentrations in many impaired stream environments, minimal research has been conducted on more pristine forested systems, such as those in many national parks.

Shenandoah National Park (SNP) in Virginia (fig. 1) has approximately 1.8 million visitors each year (Shane Spitzer, Shenandoah National Park, written commun., 2003), and is subject to extensive recreational use and activity. Recreational activities in SNP include camping, hiking, swimming, fishing, and horseback riding. Pets are permitted in SNP provided they are leashed. SNP has numerous lodges and facilities that support visitors' activities, and these facilities are serviced by wastewater-treatment plants (WWTPs), septic systems, or pit toilets, depending on the size of the facility. The effects of SNP visitors and their associated recreational activities on fecal-bacteria concentrations in the streams in SNP have been largely unknown and are of concern to SNP managers.

In one of the few published studies of the effects of human activities on water quality in national parks, Farag and others (2001) documented the occurrence of human fecal contamination in streams—presumably from hikers and campers. Derlet and Carlson (2006) documented increased bacterial detection rates in wilderness streams and lakes with heavy pack-animal traffic, although backpacking activity did not appear to increase bacterial detection rates. These studies indicate that recreational use could adversely affect streamwater quality. Additional studies would be needed to further understand these possible effects on water quality.

Because of the large number of recreational visitors each year, there is concern that some streams in SNP may have elevated fecal-bacteria concentrations, which could pose a potential health risk to anyone who comes into contact with the streamwaters. In addition to protecting human health, the SNP managers want to ensure that recreational activities do not negatively affect the water resources in SNP. The first goal of the SNP Natural Resource Management Program is "…to protect and preserve the natural…resources of the parks" (National Park Service, 2006). Additionally, the SNP Strategic Plan (National Park Service, 2000) contains a goal that water quality be "protected, restored, and maintained in good condition." More comprehensive data would be needed to evaluate whether these management goals are being achieved relative to fecal indicator bacteria.

The U.S. Geological Survey (USGS), in cooperation with the National Park Service (NPS), began an investigation in 2005 to evaluate *E. coli* concentrations in streams and springs throughout SNP. The first study objective was to evaluate the effects of recreational activities on *E. coli* concentrations in selected streams. The second study objective was to evaluate *E. coli* levels in backcountry drinking-water supplies throughout Shenandoah National Park. These drinking-water supplies are used by hikers and campers throughout SNP and generally are located near primitive shelters and huts.

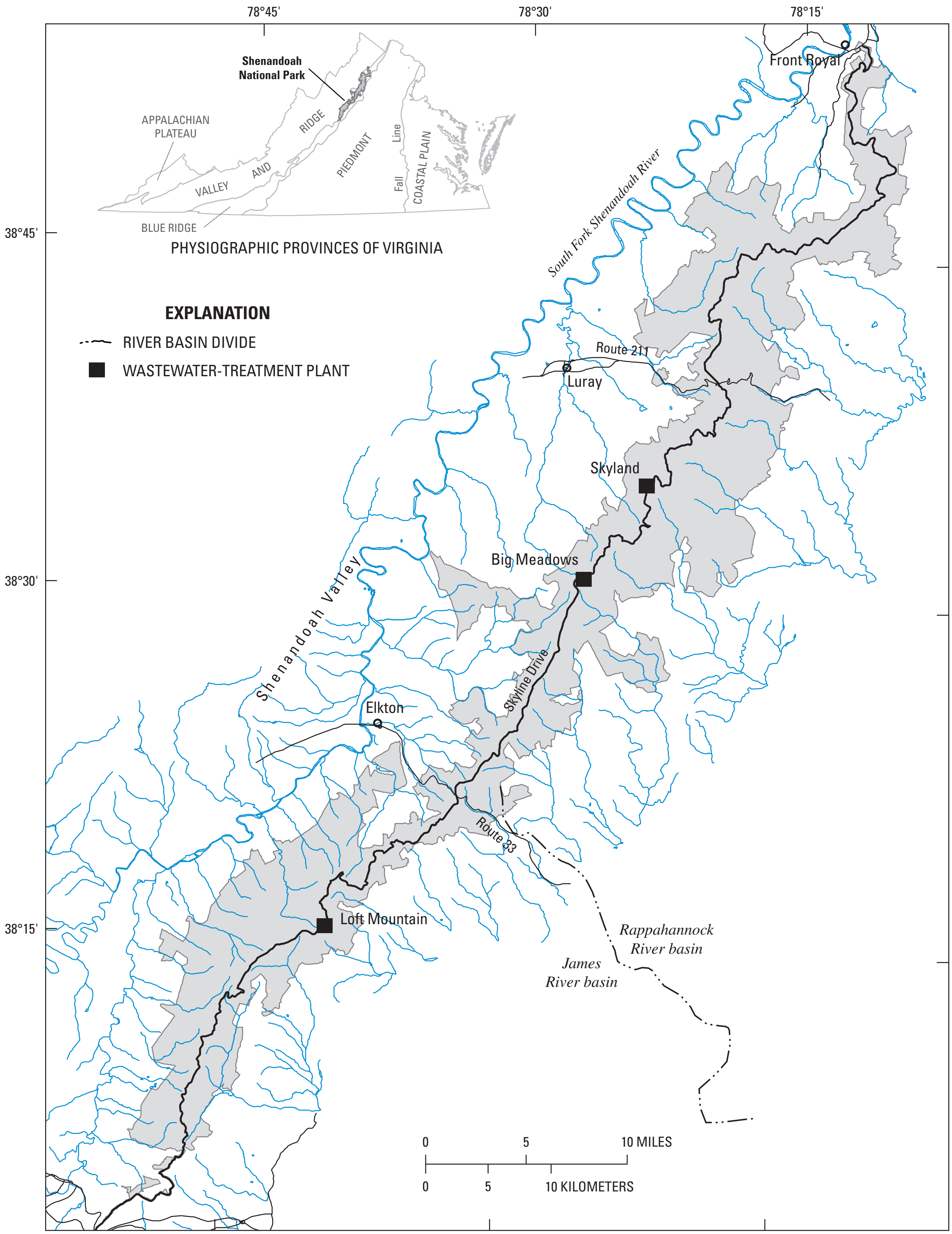
Purpose and Scope

This report documents *E. coli* concentrations at selected streams and springs throughout SNP during 2005–2006. Streamwater samples were analyzed for *E. coli* concentrations in 14 basins with extensive recreational activities, and in 6 control basins with minimal recreational activities. *E. coli* concentrations in backcountry drinking-water supplies were sampled 2 to 6 times at each of 19 primitive shelters throughout SNP. Most water samples were collected under periods of relatively stable, low flow, although a few periods of stormflow runoff were sampled. Sampling of three wastewater-treatment plant outfalls was conducted in 2006 to evaluate their effects on water quality. Outfall samples were analyzed for *E. coli* and a collection of wastewater organic compounds that may be endocrine disruptors. This report will provide SNP management with an important database for managing water quality and assessing possible risks to human health. These data can be used by SNP management to better understand the water quality in the streams throughout SNP and to evaluate changes in water quality in the future. The data and interpretations generated by this study may be applicable to other streams in SNP and potentially to streams in other national parks.

Description of the Study Area

Shenandoah National Park was established in the Blue Ridge Physiographic Province (fig. 1) in 1935 and covers approximately 300 square miles (mi^2; fig. 1). Approximately 95 percent of SNP is forested eastern deciduous woodland (Davis and others, 2006), and the range of elevations, slopes, geology, soils, and vegetation provides a diverse habitat for a variety of flora and fauna. Because SNP is located within 1–2 hours of Baltimore, MD; Washington, DC; and Richmond, VA, it is easily accessible to densely populated areas and is widely used for recreational purposes.

A dominant feature in SNP is Skyline Drive, which runs roughly along the northeast-southwest axis of the Blue Ridge, and provides overlook views of the Virginia Piedmont to the east and the Shenandoah Valley to the west. Most of the development in SNP is along Skyline Drive and provides visitors with a wide range of outdoor recreational activities. In addition, numerous trailheads are scattered along the park boundary and run throughout the park. SNP acts as a headwater system that contains 72 perennial streams, which form the headwaters of the Shenandoah River to the west and the James and Rappahannock Rivers to the east (Davis and others, 2006).



Base from U.S. Geological Survey Virginia Counties, 1980, 1:2,000,000 Digital Line Graph,
Albers Equal-Area Conic projection Standard parallels 29 30'N and 45 30'N,
central meridian 96º 00'W modified to Universal Transverse Mercator Zone 17 NAD 27

Figure 1. Shenandoah National Park in Virginia.

Study Design and Sample Collection

Several types of samples were collected for this study, including:

- Samples for the evaluation of recreational activities on *E. coli* concentrations
- Drinking-water supply samples
- Wastewater-treatment plant samples

Each sample type is defined in the following sections, and the methodologies for site selection and sample collection are described. The methodology for the membrane-filtration analysis of *E. coli* also is presented.

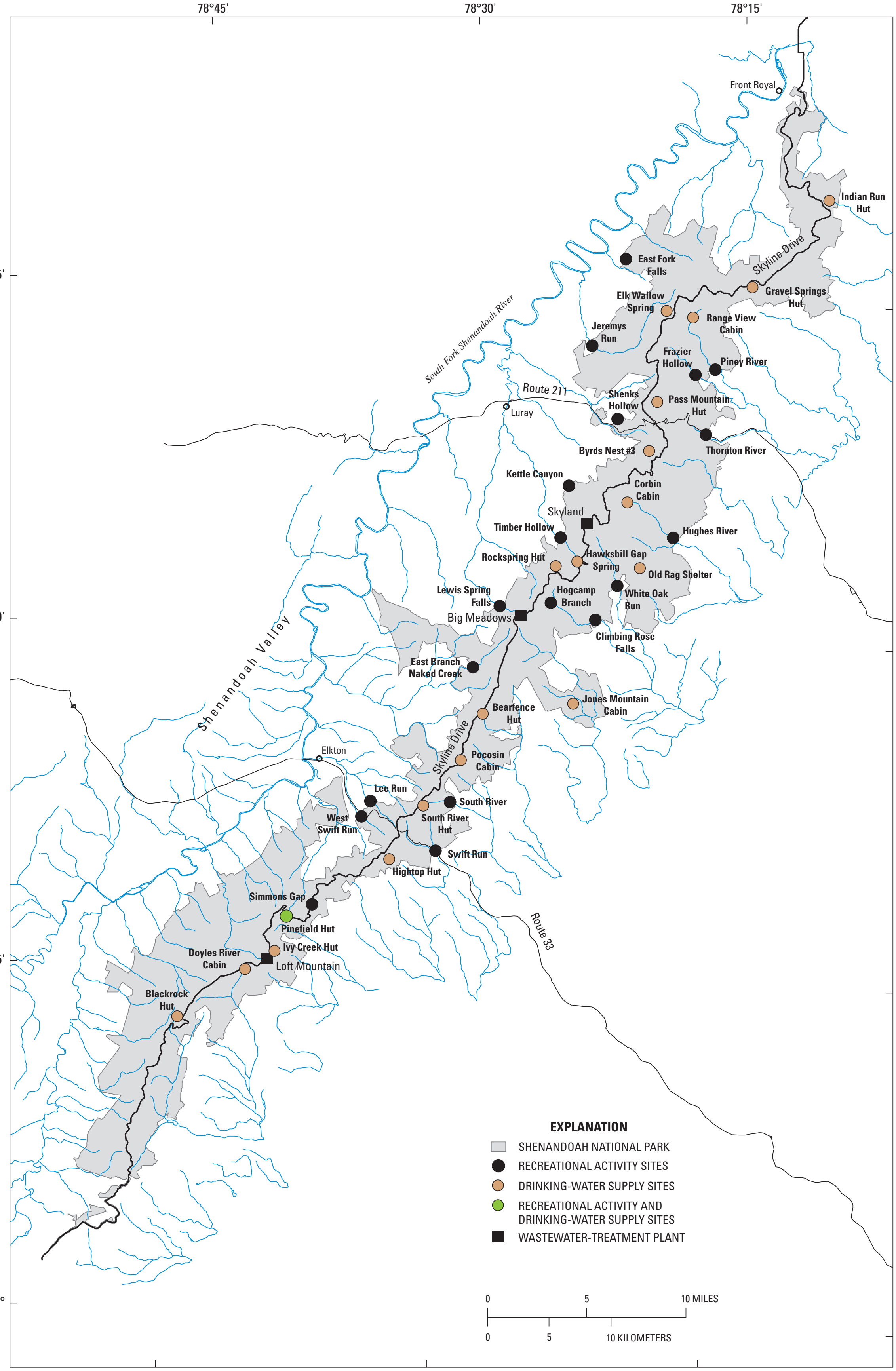
Selection and Sampling of Sites for the Evaluation of Recreational Activities on *E. coli* Concentrations

Sampling sites for the evaluation of the possible effects of recreational activities on *E. coli* concentrations were selected on the basis of detailed discussions with SNP staff about the range and type of recreational activities that occur throughout the different basins in SNP. Sites were selected to represent a variety of different recreational activities and, therefore, a range of possible fecal contributors (table 1; fig. 2). Recreational sites are defined as those sites identified by SNP staff as having significant amounts of recreational activities taking place within the basin (including hiking, fishing, wading into streams, bathing, horseback riding, camping, and other outdoor activities). All these recreational activities may directly or indirectly result in increased fecal loadings to SNP streams that would be manifested as elevated *E. coli*

Table 1. Sampling sites for evaluating the effects of recreational activities on *Escherichia coli* concentrations in surface waters of Shenandoah National Park in Virginia.

[NAD 27, North American Datum of 1927; WWTP, wastewater-treatment plant]

Sampling site (fig. 2)	Station ID	Latitude (NAD 27)	Longitude (NAD 27)	Sampling year	Potential sources of *E. coli* and recreational activities within watershed
Recreational sites					
East Fork Falls	0163060997	38.77952166	78.35309761	2006	Wildlife, WWTP, dump station, camping, horse trails and crossings
Hogcamp Branch	0166578545	38.52641907	78.41131185	2005	Wildlife, stables, camping, dump station, falls, horse trails
Hughes River	0166214930	38.57731824	78.29977197	2006	Wildlife, pit toilet, many trails, much camping
Jeremys Run	0163058255	38.71527169	78.38158899	2006	Wildlife, high visitor use, a few horses, septic system
Kettle Canyon	01629958	38.61245433	78.39838765	2005	Wildlife, stables, WWTP
Lee Run	01628906	38.37689942	78.57171458	2006	Wildlife, septic drain field
Lewis Spring Falls	01629765	38.52287524	78.45875527	2005	Wildlife, WWTP, a few horse trails, falls overlook
Pinefield Hut downstream site	0203254380	38.29049650	78.64558914	2006	Wildlife, pit toilet
Piney River	0166236730	38.70117017	78.26619065	2006	Wildlife, some horse trails, many hiking trails
Simmons Gap	0203254430	38.29982995	78.62227937	2006	Wildlife, septic drain field
South River	01665432	38.37834392	78.49785980	2005	Wildlife, pit toilet or septic drain field, high recreational use
Swift Run	02032589	38.34233730	78.50966218	2005	Wildlife, impaired stream, few trails
Thornton River	01662310	38.65353251	78.27281748	2005	Wildlife, WWTP, visitor use, commuter traffic
White Oak Run	01665709	38.54070093	78.35024291	2005	Wildlife, camping, horse trails, much visitor use, swimming
Control sites					
Climbing Rose Falls	0166579935	38.51514085	78.36941568	2005	Wildlife
East Branch Naked Creek	01629113	38.47733229	78.48141085	2005	Wildlife
Frazier Hollow	0166234875	38.69692525	78.28441566	2006	Wildlife
Pinefield Hut upstream site	0203254380	38.29049650	78.64558914	2006	Wildlife
Shenks Hollow	0163054325	38.66250139	78.35548681	2006	Wildlife
Timber Hollow	0162994975	38.57448766	78.40441417	2005	Wildlife
West Swift Run	01628910	38.36533728	78.57948002	2006	Wildlife



Base from U.S. Geological Survey Virginia Counties, 1980, 1:2,000,000 Digital Line Graph,
Albers Equal-Area Conic projection Standard parallels 29 30'N and 45 30'N,
central meridian 96° 00'W modified to Universal Transverse Mercator Zone 17 NAD 27

Figure 2. Sampling sites in Shenandoah National Park in Virginia, 2005–2006.

concentrations in these streams. In contrast to the recreational basins, control basins also were selected with input from the SNP staff. These control basins had minimal recreational activity within each basin (generally because of a lack of access trails into the basin) and were believed to be similar to the recreational basins in other watershed characteristics. The source of the *E. coli* contributions to the streams in the control basins is likely wildlife inputs; in contrast, the recreational basins will be subject to both wildlife inputs as well as inputs that are caused by or related to recreational activities.

For the evaluation of possible effects of recreational activities on *E. coli* concentrations, a total of 20 streams were selected for sampling during 2005 and 2006. Sampling during low-flow conditions was the focus of the study to allow maximum comparability among the samples from all sites. Low-flow conditions were defined as no rainfall during the 36 hours prior to sampling. The 10 streams that were sampled each year were a combination of 7 recreational basins and 3 control basins. Up to 12 water samples were collected from each sampling site. Stream sampling was weighted toward the summer when recreational use and bacteria survival are greatest.

Stormflow sampling of bacteria is generally important in determining bacteria loadings in a stream, and numerous researchers have identified increased fecal-bacteria concentrations in streams during storms (Bolstad and Swank, 1997; Christensen and others, 2001). However, the current study focused on base-flow sampling because most in-stream recreation occurs during low-flow conditions. During the 2-year study, 3 of the 12 water-quality samples collected at each sampling site were collected during stormflow periods to permit some characterization of *E. coli* concentrations under these conditions.

To better characterize the water samples for the evaluation of possible effects of recreational activities on *E. coli* concentrations, physical properties, including water temperature, specific conductance, pH, dissolved oxygen, and turbidity, were measured using hand-held water-quality monitors. These water-quality monitors were calibrated according to the manufacturer's specifications each morning before they were used. All sampling and analyses were performed according to established USGS field protocols (U.S. Geological Survey, variously dated).

Selection and Sampling of Drinking-Water Supply Sites

For the evaluation of drinking-water supplies, SNP staff selected the sampling sites and collected the water-quality samples, which were analyzed for *E. coli* concentrations by USGS. Many of the water supplies that are associated with primitive shelters in SNP were evaluated (table 2; fig. 2). Most of the water supplies are springs that are located very close to the shelters; in a few cases, the water supply was a nearby stream. Because some stream and spring sampling sites were extremely shallow (flow less than 0.2 foot deep), sampling protocols occasionally had to be modified to collect a representative water sample from these locations. When possible, a grab sample was collected from the approximate center of flow in what appeared to be a well-mixed region. When flow was too low to permit a grab sample (about 10 percent of the time), clean, sterile, disposable syringes were used to collect a sample of the flowing water. Using the syringe for sampling allowed the collection of samples from sites with extremely low flow while preventing the collection of bottom sediments.

Sampling of Wastewater-Treatment Plants

Near the end of the study, outfalls for three WWTPs in SNP were sampled once for *E. coli*, physical properties, and wastewater organic compounds. This additional sampling was conducted to further evaluate how human and recreational activities may be affecting water quality in SNP. Samples for *E. coli* were collected in the same manner as the drinking-water supply sites. Samples for analysis of wastewater organic compounds were collected in 1-liter (L) baked amber-glass bottles. These samples were packed in ice and shipped by overnight courier to the USGS National Water-Quality

Table 2. Sampling sites for the evaluation of drinking-water supplies in Shenandoah National Park in Virginia.

[NAD 27, North American Datum of 1927]

Sampling site (fig. 2)	Latitude (NAD 27)	Longitude (NAD 27)	Site type
Bearfence Hut	38.44363738	78.47062797	Spring
Blackrock Hut	38.21428861	78.74298869	Spring
Byrds Nest 3 Shelter	38.63618127	78.32005528	Spring
Corbin Cabin	38.60181028	78.34351955	Stream
Doyles River Cabin	38.25058183	78.68178459	Spring
Elk Wallow Spring	38.74280523	78.31358665	Spring
Gravel Springs Hut	38.76220176	78.23420595	Spring
Hawksbill Gap Spring	38.55749697	78.38804989	Spring
Hightop Hut	38.33496136	78.55217108	Spring
Indian Run Hut	38.82740954	78.16543926	Spring
Ivy Creek Hut	38.26464380	78.65533207	Spring
Jones Mountain Cabin	38.45334797	78.38715188	Spring
Old Rag Shelter	38.55434377	78.32981252	Spring
Pass Mountain Hut	38.67609982	78.31931332	Spring
Pinefield Hut	38.29049650	78.64558914	Stream
Pocosin Cabin	38.40928505	78.48932345	Spring
Range View Cabin	38.73873989	78.28863708	Spring
Rockspring Hut	38.55358730	78.40786614	Spring
South River Hut	38.37509609	78.52263586	Spring

Laboratory in Denver, Colorado, where the samples were processed according to standard analytical methodology (Zaugg and others, 2002). One unique aspect of the wastewater organic compound analyses is that the detection method used is an "information rich" method; that is, the presence of a specific compound can be verified at concentrations that are below the defined minimum reporting level (Steven Zaugg, U.S. Geological Survey, oral commun., 2000). When the presence of a compound is verified at a concentration below the minimum reporting level (which actually represents a level of quantification), the reported concentration is noted with an "E" for estimated. Samples from the WWTP outfalls were submitted for analyses of suspected endocrine disruptors, which are compounds that can either stimulate or inhibit the endocrine system by mimicking or blocking the effects of natural hormones (U.S. Environmental Protection Agency, 2006). Although only three samples were collected, they represent the first application of this new analysis in SNP. The analytical results of these samples will aid in understanding the potential for the presence of endocrine disruptors in SNP streams.

Analytical Technique for *E. coli*

E. coli was selected as the bacterial indicator for this study because *E. coli* is used by the Commonwealth of Virginia as the bacterial water-quality standard for freshwaters. Furthermore, *E. coli* may be a better indicator than fecal coliform bacteria because *E. coli* is a definitive indicator of fecal pollution, whereas fecal coliform bacteria are a more general indicator that is not necessarily specific to fecal contamination. Because the standard methods for *E. coli* analysis require no more than a 6-hour holding time before processing the samples by membrane filtration (U.S. Geological Survey, variously dated), field technicians collected all samples, and automated samplers were not used. Clean, sterile glass bottles were used to collect samples.

Approximately 10 percent of the samples for *E. coli* concentrations were analyzed as sequential replicates, in which separate streamwater samples were collected, and membrane filtration was performed on each sample by a single analyst. The median *E. coli* concentration for all sequential replicate samples was 19 col/100 mL. Because most of the bacterial concentrations in the replicates were relatively low, a typical percent-difference calculation was not appropriate for all these data. For example, if a paired *E. coli* analysis determined concentrations of 10 and 14 col/100 mL, this pair would have a percent difference of approximately 33 percent between measurements, providing an inappropriately elevated measure of variability in the replicate samples. Instead of a percent-difference computation involving all sequential replicate samples, the replicate *E. coli* results were plotted (fig. 3) relative to a line of one-to-one correspondence to provide a demonstration of analytical variability. Distance off the one-to-one line represents the variability in these sequential replicate analyses. As a further measure of the variability in the replicates analyses, the median absolute difference in concentration between all paired replicate analyses was 4 col/100 mL. For the nine sequential replicate stream samples that had *E. coli* concentrations greater than 100 col/100 mL, the median percent difference was –6.7 percent, defined as follows:

$$\text{PERCENT DIFFERENCE} = ((\text{SAMPLE 1} - \text{SAMPLE 2}) / ((\text{SAMPLE 1} + \text{SAMPLE 2}) / 2) \times 100) \quad (1)$$

All measures of variability for the replicate bacterial samples indicated satisfactory agreement between the paired samples and demonstrated that acceptable method performance was achieved using the membrane filtration technique.

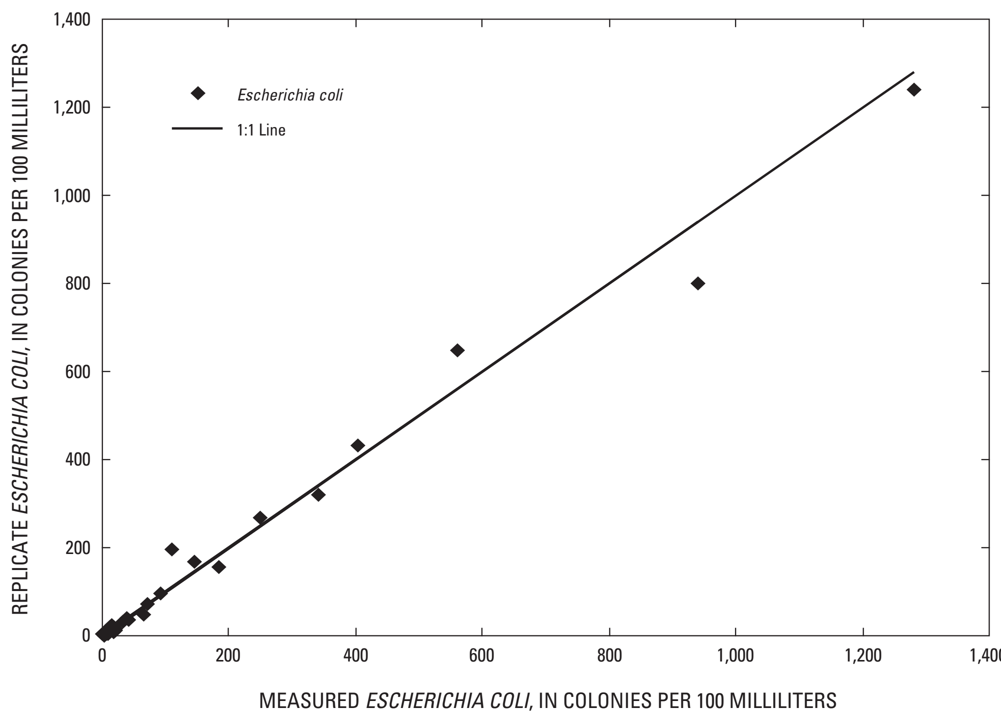


Figure 3. Analytical results of sequential replicate *Escherichia coli* samples, plotted relative to a 1:1 line, from streams in Shenandoah National Park in Virginia, 2005–2006.

Evaluating the Effect of Recreational Activities on *E. coli* Concentrations

In the evaluation of the potential effects of recreational activities on *E. coli* concentrations, stream samples were collected during both low-flow and stormflow conditions at 20 sites in SNP. Additionally, multiple sites were sampled at Pinefield Hut (fig. 2), at the request of SNP management, to evaluate water-quality concerns associated with a pit toilet.

Low-Flow Conditions

During 2005–2006, 10 streams were sampled each year during low streamflow conditions (no rainfall during the 36 hours before sampling). Because of variable flow conditions and occasional site-access problems (closed roads and trails occasionally prevented the collection of some samples), between 6 and 9 samples were collected during low-flow conditions at each of the sampling sites. Median *E. coli* concentrations at the 20 sites ranged from as low as 3 col/100 mL to as high as 58 col/100 mL (table 3). The distribution of *E. coli* concentrations that was observed at each site is presented in figures 4 and 5. During 2005 only one low-flow sample (from Hogcamp Branch) exceeded Virginia's instantaneous *E. coli* standard of 235 colonies/100 mL. During 2006, six samples exceeded Virginia's instantaneous water-quality standard, including one sample from Shenks Hollow, two samples from West Swift Run, two samples from Lee Run, and one sample from the Pinefield Hut pit toilet site. Three of the samples that exceeded the water-quality standard during 2006 were collected from two of the control sites (Shenks Hollow and West Swift Run). Possible future investigations of the sites with two samples that exceeded water-quality standards (Lee Run

Table 3. Median *Escherichia coli* concentrations during low-flow and stormflow conditions and the number of samples collected at each stream site in Shenandoah National Park in Virginia.

[col/100 mL, colonies per 100 milliliters; C, control; R, recreational]

Sampling site (fig. 2)	Site type	Low-flow median (col/100 mL)	Number of low-flow samples	Stormflow median (col/100mL)	Number of stormflow samples
2005					
Climbing Rose Falls	C	12	8	34	4
East Branch Naked Creek	C	4	7	432	3
Timber Hollow	C	9	8	129	4
Hogcamp Branch	R	5	8	16	2
Kettle Canyon	R	12	8	118	4
Lewis Spring Falls	R	10	7	300	3
South River	R	9	6	63	2
Swift Run	R	18	6	142	6
Thornton River	R	23	8	176	4
White Oak Run	R	6	8	2	3
2006					
Frazier Hollow	C	9	8	807	2
Pinefield Hut upstream site	C	10	8	143	3
Shenks Hollow	C	58	9	340	3
West Swift Run	C	43	9	208	3
East Fork Falls	R	6	8	100	3
Hughes River	R	3	9	145	3
Jeremys Run	R	7	9	90	3
Lee Run	R	14	9	210	3
Pinefield Hut downstream site	R	17	6	85	3
Pinefield Hut pit toilet site	R	29	6	173	3
Piney River	R	3	9	216	2
Simmons Gap	R	30	8	253	3

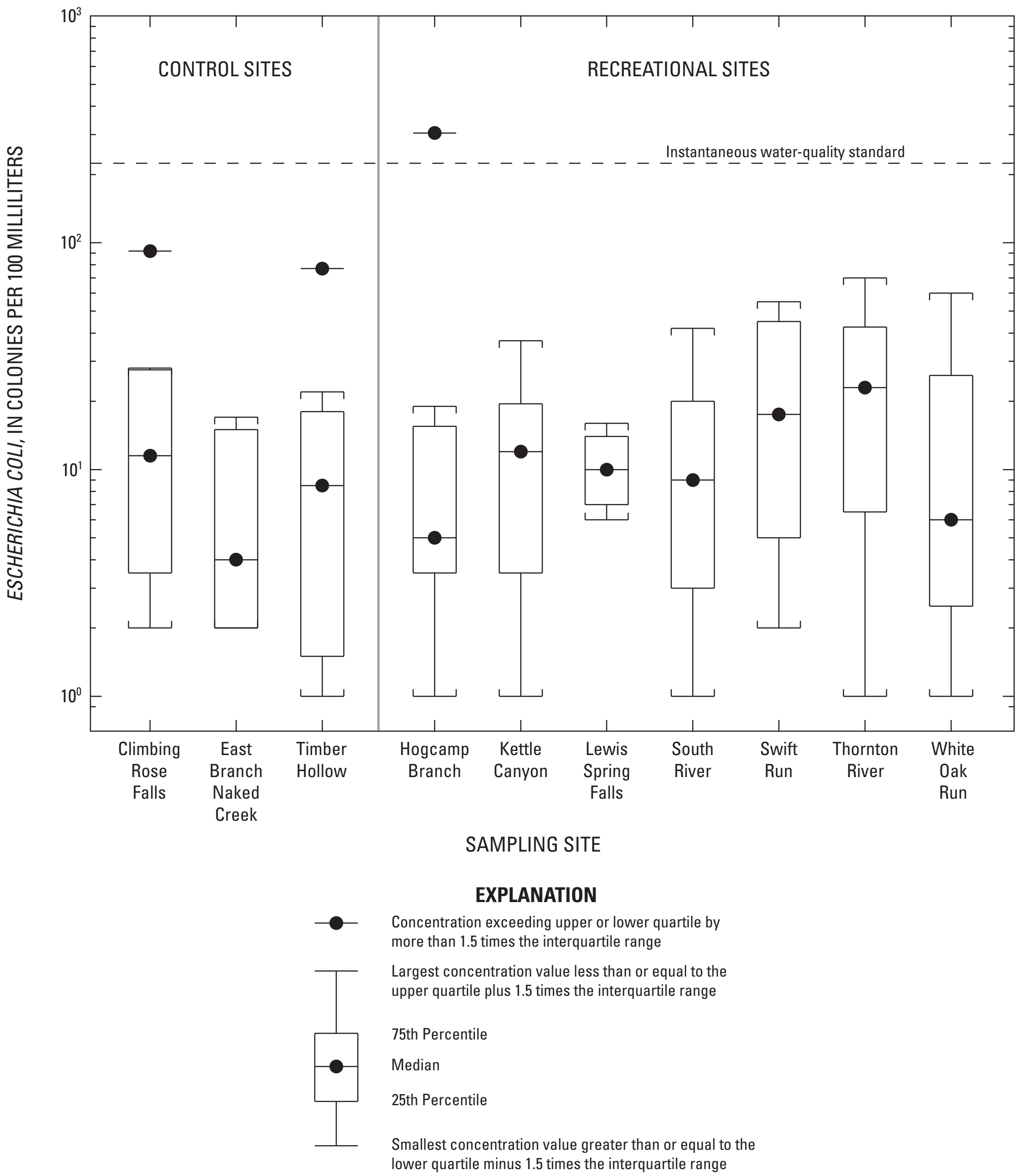


Figure 4. *Escherichia coli* concentrations in streamwater at low-flow conditions at 10 sites in Shenandoah National Park in Virginia, 2005.

and West Swift Run) could include an inspection of the septic system in the Lee Run watershed (table 1) and a sanitary survey of both watersheds to determine possible sources for the observed bacteria levels.

Statistical comparisons were conducted to evaluate whether the recreational basin sites had relatively elevated concentrations of *E. coli* compared to the control basins. These statistical comparisons were conducted by using a Wilcoxon rank-sum test (Helsel and Hirsch, 2002, p. 118) to compare the distribution of *E. coli* concentrations in the control basins against the recreational basins for each year of the study. The hypotheses tested are:

H_0: median *E. coli* concentration in recreational basins = median *E. coli* concentration in control basins

H_1: median *E. coli* concentration in recreational basins > median *E. coli* concentration in control basins

In both 2005 and 2006, the water samples collected from the recreational basins did not have statistically significantly elevated ($p < 0.05$) concentrations of *E. coli* relative to the samples collected from the control basins. The two sites

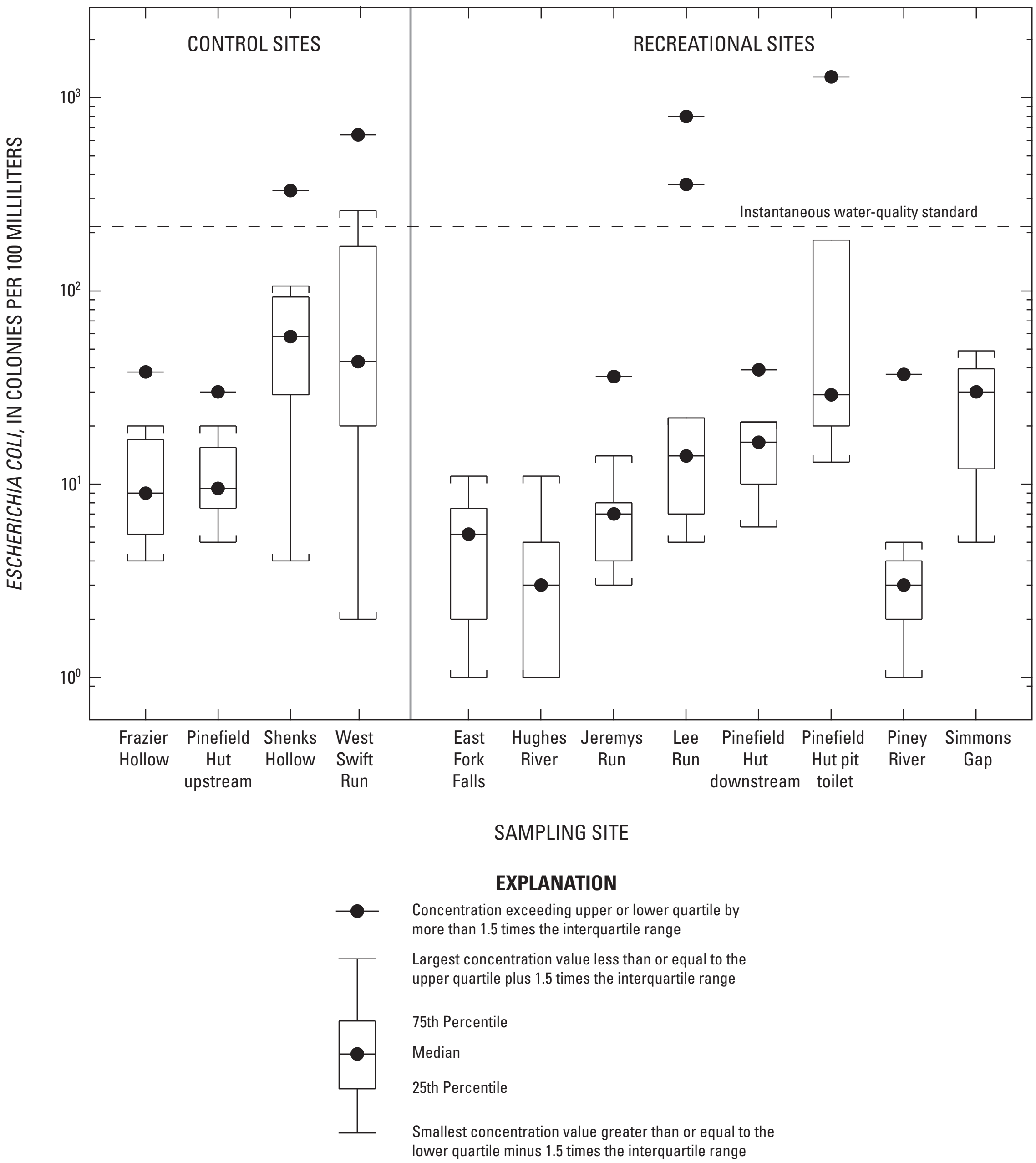


Figure 5. *Escherichia coli* concentrations in streamwater at low-flow conditions at 10 sites in Shenandoah National Park in Virginia, 2006.

with the greatest median *E. coli* concentrations were two of the control sites—Shenks Hollow (median concentration of 58 col/100 mL), and West Swift Run (median concentration of 43 col/100 mL). It is unknown why the bacterial concentrations in these two control basins were at the upper end of the median concentrations. Based on the above, it appears that recreational activities do not have a significant effect on *E. coli* concentrations in SNP streams under low-flow conditions.

Stormflow Conditions

Stormflow samples are critically important for understanding the effects of storms on the *E. coli* concentrations in SNP streams. Two to six stormflow samples were collected from each of the sampling sites during 2005–2006 (table 3). Stormflow conditions are defined as conditions during and up to 12 hours following rainfall (while streamflow was still falling after the storm). In most cases, streamflows increased noticeably and stream turbidity levels increased relative to low-flow conditions. During stormflow conditions, *E. coli* concentrations as great as 2,233 col/100 mL were observed in SNP streams. The median *E. coli* concentration observed during stormflow conditions was 143 col/100 mL, as opposed to a median concentration of 10 col/100 mL that was observed during low-flow conditions. The *E. coli* concentrations in SNP streams increased by at least one order of magnitude during stormflow periods. For comparison, stormflow *E. coli* concentrations are presented in figure 6 relative to the low-flow streamwater concentrations for the control and the recreational basins. The stormflow *E. coli* concentrations frequently exceeded the instantaneous water-quality standards for Virginia. The stormflow *E. coli* concentrations in the control and recreational basins are statistically significantly elevated ($p < 0.05$) relative to the *E. coli* concentrations during low-flow conditions.

The mechanisms by which elevated *E. coli* concentrations are occurring during stormflow periods in SNP streams remain largely unresolved; however, these patterns are not unusual and several possible explanations are presented. These patterns are observed commonly in agricultural and urban watersheds (Hyer and Moyer, 2004), even though the initial *E. coli* concentrations during low-flow conditions in SNP streams generally were much less than those in agricultural and urban streams. Even in a relatively undisturbed forested watershed such as South Fork Quantico Creek (USGS station number 01658500, in Prince William County, Virginia; National Park Service, 1999), bacterial concentrations have been observed to increase significantly during stormflow periods. Mechanistically, elevated stormflow concentrations typically are interpreted as a combination of flushing response (whereby bacteria deposited near the stream are washed off the land surface and into the stream) and resuspension of streambed sediments containing bacteria (McDonald and Kay, 1981; Hunter and others, 1992). Because streambed sediments in the relatively high-gradient SNP streams generally are composed of sand and larger particulates, resuspension of bacteria-laden streambed sediments likely is less important than washoff. Another potentially important mechanism causing elevated bacterial concentrations during stormflow periods includes the direct washoff of animal scat from exposed rocks within the stream channel. During sampling, animal scat commonly was observed on exposed rocks; as streamflows increased during or following rainfalls, the scat was either washed into the stream or the streamflow increased sufficiently to overtop the rocks, which resulted in direct contributions of fecal matter to the streams.

Although less in-stream recreation (such as wading and fishing) occurs during stormflow periods than during low-flow

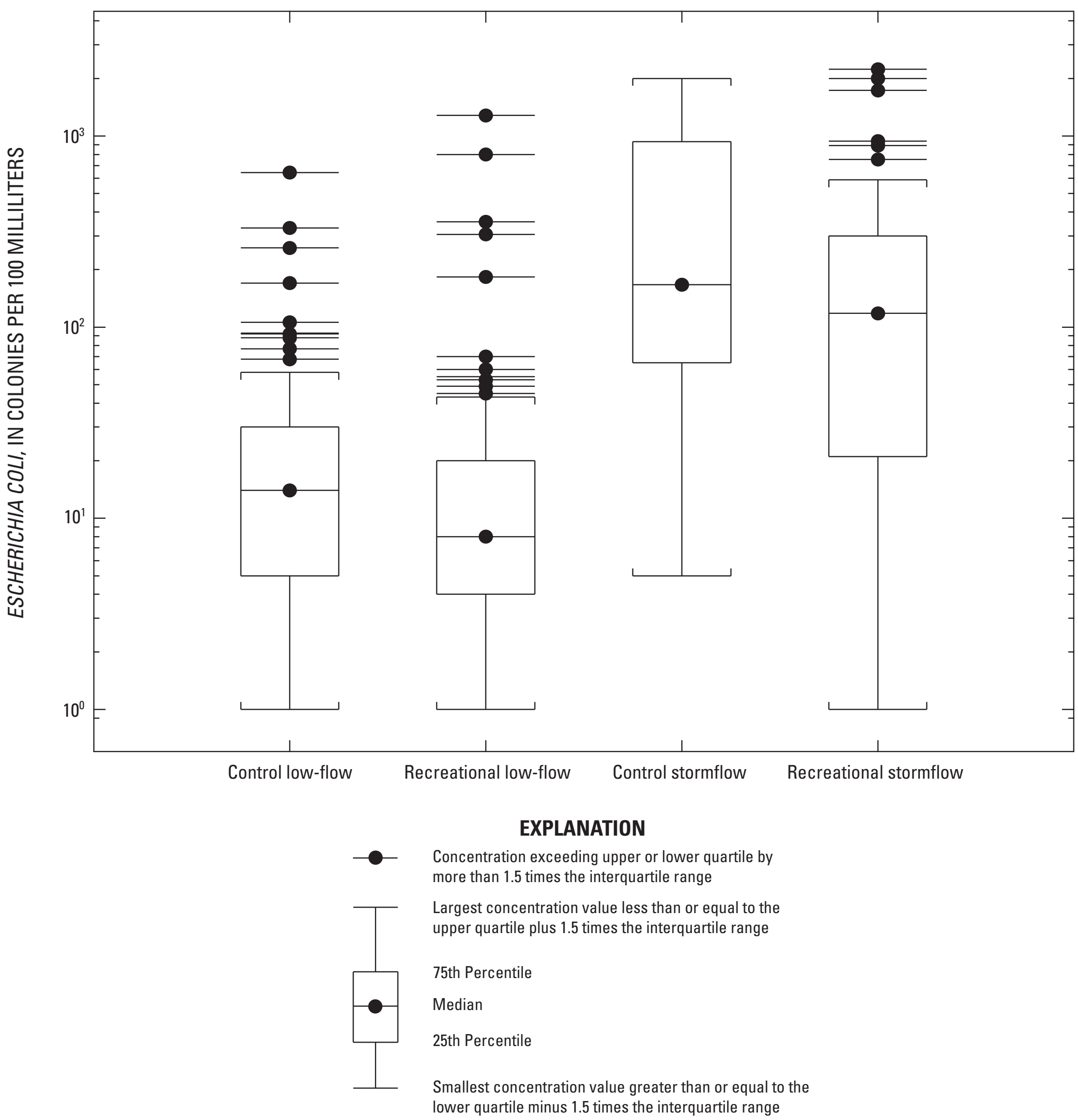


Figure 6. *Escherichia coli* concentrations in streamwater at low-flow and stormflow conditions in the control and recreational basins of Shenandoah National Park in Virginia, 2005–2006.

periods, it is important to recognize that the risk to human health is greater during water recreation in stormflow conditions. Furthermore, the grab samples collected during this study cannot be used to establish how long the elevated *E. coli* concentrations persist, and the sample concentrations cannot be used to identify the maximum concentrations of *E. coli* that are likely to occur during storm events.

Pinefield Hut Samples

The Pinefield Hut site was sampled by USGS during the second year of the study (2006) at the request of SNP managers who were concerned about water-quality in relation to a pit toilet that is approximately 10 ft from an unnamed ephemeral tributary (fig. 7). Based on the site layout, three sampling sites were selected—a station on the perennial stream upstream from the ephemeral tributary on which the pit toilet is located, a site on the ephemeral tributary, and a site about 40 ft downstream from the confluence of the perennial stream and the ephemeral tributary. During several sampling events, the ephemeral tributary was dry and no sample could be collected; in these cases, the other two sampling sites on the perennial stream were sampled. During two sampling events, hikers were observed washing laundry in the perennial stream between the upstream and downstream sampling sites; in these cases, a downstream sample was not collected because it was known to be influenced by the hikers' activities.

The sampling dates and *E. coli* concentrations observed at the Pinefield Hut site are listed in table 4. Three of the 11 sampling events occurred during somewhat elevated stormflow conditions, and the *E. coli* concentrations in these stormflow samples generally are elevated relative to the low-flow conditions. To evaluate whether the pit toilet was adversely affecting the water-quality at this site during low-flow conditions, *E. coli* concentrations in the samples from the most upstream

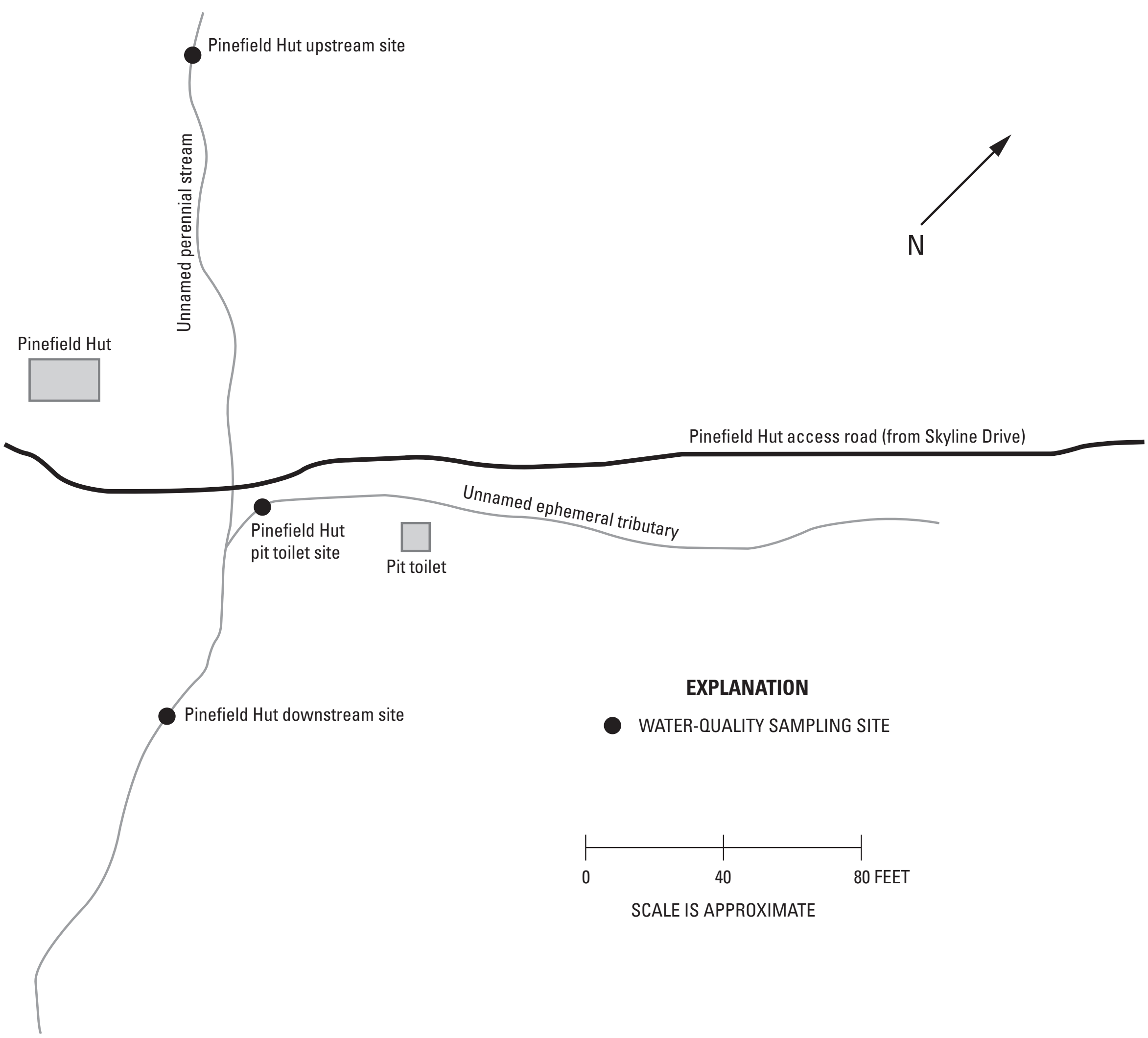


Figure 7. Generalized map of the Pinefield Hut site in Shenandoah National Park in Virginia (see figure 2 for location of site).

Table 4. Sampling dates and *Escherichia coli* concentrations associated with the Pinefield Hut site in Shenandoah National Park in Virginia, 2006.

[col/100 mL, colonies per 100 milliliters; L, low-flow; S, stormflow; Shading indicates estimated *E. coli* concentrations; >, greater than]

Site	Date	Flow condition	*E. coli* (col/100 mL)
Pinefield Hut downstream site	6/13/2006	L	19
Pinefield Hut upstream site	6/13/2006	L	8
Pinefield Hut downstream site	6/22/2006	L	14
Pinefield Hut upstream site	6/22/2006	L	20
Pinefield Hut downstream site	7/13/2006	S	21
Pinefield Hut pit toilet site	7/13/2006	S	103
Pinefield Hut upstream site	7/13/2006	S	12
Pinefield Hut downstream site	7/27/2006	L	39
Pinefield Hut pit toilet site	7/27/2006	L	>1,280
Pinefield Hut upstream site	7/27/2006	L	8
Pinefield Hut downstream site	8/10/2006	S	85
Pinefield Hut pit toilet site	8/10/2006	S	173
Pinefield Hut upstream site	8/10/2006	S	143
Pinefield Hut pit toilet site	8/17/2006	L	37
Pinefield Hut upstream site	8/17/2006	L	11
Pinefield Hut downstream site	9/1/2006	S	590
Pinefield Hut pit toilet site	9/1/2006	S	2,233
Pinefield Hut upstream site	9/1/2006	S	967
Pinefield Hut downstream site	9/21/2006	L	21
Pinefield Hut pit toilet site	9/21/2006	L	21
Pinefield Hut upstream site	9/21/2006	L	30
Pinefield Hut downstream site	9/26/2006	L	10
Pinefield Hut pit toilet site	9/26/2006	L	13
Pinefield Hut upstream site	9/26/2006	L	11
Pinefield Hut downstream site	10/4/2006	L	6
Pinefield Hut pit toilet site	10/4/2006	L	183
Pinefield Hut upstream site	10/4/2006	L	7
Pinefield Hut pit toilet site	10/19/2006	L	20
Pinefield Hut upstream site	10/19/2006	L	5

perennial stream site were compared with *E. coli* concentrations in the samples from both the ephemeral tributary site and the downstream perennial stream site (fig. 8). Median *E. coli* concentrations during low-flow conditions were greatest in the ephemeral tributary samples (29 col/100 mL), intermediate in the downstream perennial stream-site samples (17 col/100 mL), and lowest in the upstream perennial stream-site samples (10 col/100 mL), which indicates a possible bacterial source from the pit toilet, although the differences in median concentrations are relatively small. Statistically, the upstream perennial stream-site *E. coli* concentrations were compared to the *E. coli* concentrations from the ephemeral tributary by using a Wilcoxon rank-sum test. The samples from the ephemeral tributary with the pit toilet had statistically significantly elevated *E. coli* concentrations ($p < 0.05$) relative to the concentrations from the upstream perennial stream site, which indicates a likely additional source of bacteria in the tributary, possibly caused by the pit toilet.

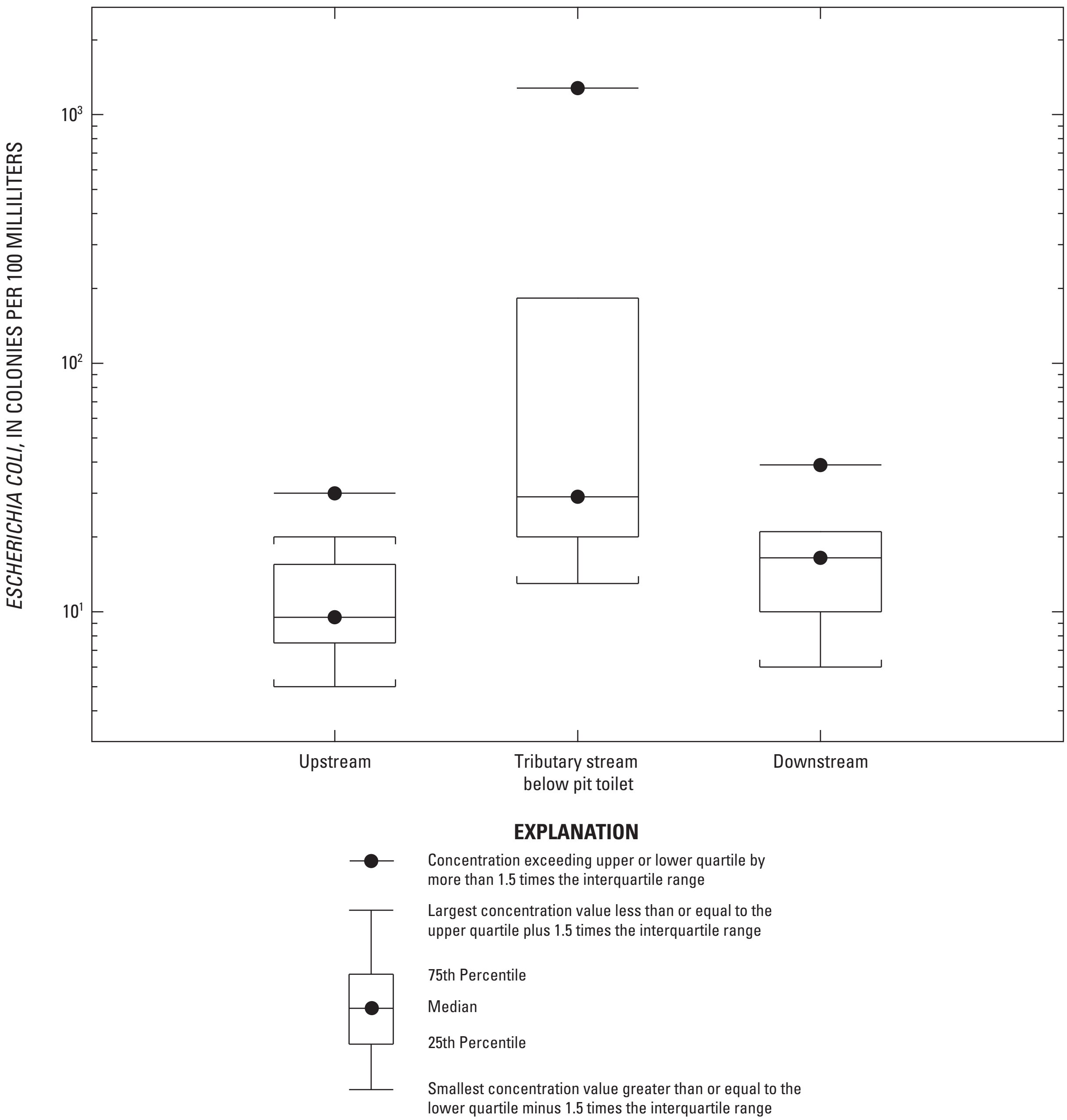


Figure 8. *Escherichia coli* concentrations in streamwater at low-flow conditions at the Pinefield Hut site in Shenandoah National Park in Virginia, 2006.

E. coli Concentrations in Backcountry Drinking-Water Supplies

A total of 19 drinking-water supplies were selected by SNP staff for evaluation of *E. coli* concentrations (table 5). Most of these drinking-water sites were springs located only a short distance from the cabin or hut that they served. Two to six grab samples were collected at each of the sites under relatively steady, low-flow conditions. Overall, *E. coli* concentrations were extremely low at these sites; 12 of the sites had median concentrations of only 1 col/100 mL. The remainder of the sites had median *E. coli* concentrations ranging from 2 to 61 col/100 mL. The maximum observed single-sample *E. coli* concentration was 150 col/100 mL. The median overall *E. coli* concentration for all sites combined was 1 col/100 mL.

Only the samples from the Corbin Cabin site and Pinefield Hut sites had median *E. coli* concentrations greater than 14 col/100 mL. The Corbin Cabin samples were not collected from a spring but instead from the Hughes River (fig. 2), which may explain the different *E. coli* concentrations. The upstream perennial stream site near Pinefield Hut (fig. 7) also was located on a free-flowing stream, possibly explaining why these *E. coli* concentrations are greater than those observed for the other drinking-water sites. The collection of paired upstream and downstream samples by the SNP staff at the Pinefield Hut site permits another evaluation of how this pit toilet may be affecting water quality. The *E. coli* concentrations at the downstream perennial stream site are approximately two times greater than the concentrations observed at the upstream Pinefield Hut site (table 5), further indicating that the ephemeral tributary where the pit toilet is located is a possible source of elevated bacterial concentrations. However, based on only four samples collected by SNP staff from each of the Pinefield Hut sites, the difference in the bacterial concentrations at these two sites is not statistically significant.

Table 5. Median *Escherichia coli* concentrations and the number of samples collected for the evaluation of drinking-water supplies in Shenandoah National Park in Virginia, 2005-2006.

[col/100 mL, colonies per 100 milliliters; ≥, greater than or equal to; <, less than]

Sampling site (fig. 2)	Number of samples	Median *E. coli* concentration (col/100 mL)	Maximum *E. coli* concentration (col/100 mL)	Number of samples with *E. coli* concentration ≥ 1 col/100 mL
Bearfence Hut	6	14	75	5
Blackrock Hut	3	1	1	2
Byrds Nest 3 Shelter	2	1	<1	0
Corbin Cabin	5	43	60	5
Doyles River Cabin	3	1	16	2
Elk Wallow Spring	3	1	1	1
Gravel Springs Hut	5	5	135	4
Hawksbill Gap Hut	3	1	<1	0
Hightop Hut	4	1	1	2
Indian Run Shelter	3	1	20	2
Ivy Creek Hut	3	3	12	2
Jones Mountain Cabin	3	1	2	2
Old Rag Shelter	3	1	2	2
Pass Mountain Hut	3	1	2	1
Pinefield Hut downstream site	4	61	130	4
Pinefield Hut upstream site	4	34	150	4
Pocosin Cabin	3	1	1	2
Range View Cabin	3	1	5	2
Rockspring Hut	3	5	13	3
South River Hut	3	2	10	2

Water Quality of Wastewater-Treatment Plant Releases

After determining that recreational activities in SNP did not have a statistically significant effect on the low-flow *E. coli* concentrations, an additional concern was raised regarding the quality of the water releases from the WWTPs in the park. Because most of the sampling sites were well downstream from the WWTP outfalls, it was decided to directly sample the discharge from several WWTPs in SNP. On September 5, 2006, the end-of-pipe discharge was sampled from three WWTPs, including the facilities at Skyland, Big Meadows, and Loft Mountain (fig. 1). Outfall samples were analyzed for *E. coli*, turbidity, specific conductance, pH, and wastewater organic compounds. The wastewater organic-compound analysis was conducted to look for known or suspected endocrine-disrupting compounds, an issue of special concern for SNP managers.

Results from the sampling of the WWTP outfalls (table 6) indicated a range of *E. coli* concentrations from 35 col/100 mL in the Big Meadows sample to 18,700 col/100 mL in the Loft Mountain sample. Concentrations of *E. coli* in the Loft Mountain (18,700 col/100 mL) and Skyland (1,070 col/100 mL) samples were greater than *E. coli* concentrations generally observed in the streams and springs of SNP, and the concentrations measured at Big Meadows were relatively low (35 col/100 mL). Between 9 and 13 wastewater organic compounds were detected in the samples from each of the WWTPs, though nearly all detections were at the submicrogram per liter level. The detected compounds include three known and five suspected endocrine-disrupting compounds. Because analytical chemistry capabilities have outpaced our environmental toxicology knowledge, the overall effect of these chemicals being released into SNP streams is unknown. Further research into the spatial and temporal occurrence and distribution of these compounds in the SNP streams and WWTP effluents may be warranted.

Summary and Conclusions

The U.S. Geological Survey, in cooperation with National Park Service, conducted this study during 2005 and 2006 to evaluate *E. coli* concentrations in streams and springs in SNP. A total of 20 streams in SNP were sampled to evaluate how recreational activities may be affecting *E. coli* concentrations in the streams. Of the 20 streams sampled in SNP, 14 are in areas where extensive recreational activities occur, and 6 are located in control basins that have minimal recreational activity. Water-quality sampling was conducted during low-flow conditions during the relatively warm months because this is when recreation in SNP and bacterial survivorship are greatest. Although most sampling was conducted during low-flow conditions, approximately three stormflow samples were collected at each site. An additional study objective was to evaluate *E. coli* levels in backcountry drinking-water supplies throughout SNP. Nineteen springs and streams throughout the park were sampled two to six times by SNP staff and analyzed by USGS to evaluate *E. coli* levels.

Results indicated that relatively low *E. coli* concentrations occurred during low-flow conditions, and no statistically significant increase in *E. coli* concentrations was observed in the recreational streams relative to the control streams. During stormflow conditions, *E. coli* concentrations were observed to increase by nearly a factor of 10, and the Virginia instantaneous water-quality standard for *E. coli* (235 col/100 mL) frequently was exceeded.

The sampling results from drinking-water supplies throughout SNP indicated that the springs that were sampled had relatively low *E. coli* concentrations. Several of the streams that were sampled had slightly higher *E. coli* concentrations, but none of them exceeded the Virginia instantaneous water-quality standard. Although the bacterial concentrations in all the drinking-water supplies were relatively low, SNP management continues to stress that all hikers must treat drinking water from all streams and springs prior to consumption.

After determining that recreational activities in SNP did not have a statistically significant effect on low-flow *E. coli* concentrations, an additional concern was addressed regarding the quality of the water releases from the WWTPs in SNP. Sampling of three treatment-plant outfalls was conducted to evaluate how effluent releases may affect water quality in SNP streams. Outfalls from the three WWTPs were sampled in 2006 and analyzed for bacteria and a collection of wastewater organic compounds that may be endocrine disruptors. Relatively elevated *E. coli* concentrations were observed in two of the three samples, and between 9 and 13 wastewater organic compounds were detected, including three known and five suspected endocrine-disrupting compounds.

Although the results of the low-flow sampling and the sampling of the drinking-water sites indicated relatively low *E. coli* concentrations throughout SNP, additional investigation would be needed to determine the source of the elevated *E. coli* concentrations that were detected in the stormflow samples (both the maximum observed *E. coli* concentrations, and the duration of the elevated concentrations). Additional investigation would also be needed to better understand the discharges of *E. coli* and possible endocrine-disrupting compounds from the WWTPs in SNP.

Table 6. *Escherichia coli* concentrations, physical properties, and wastewater organic-compound concentrations in samples from three wastewater-treatment plant outfalls in Shenandoah National Park in Virginia, and the endocrine-disrupting potential of each wastewater organic compound detected.

[FNU, formazin nephelometric units; µS/cm, microsiemens per centimeter at 25 degrees Celsius; col/100 mL, colonies per 100 milliliters; µg/L, micrograms per liter; —, not determined; S, suspected; K, known; nd, not detected; Shading indicates estimated concentration]

Sampling data	Skyland	Big Meadows	Loft Mountain
Station identification	383531078230501	383116078264701	381539078395001
Date	Sept. 5, 2006	Sept. 5, 2006	Sept. 5, 2006
Time	1320	1152	0845
Turbidity (FNU)	2.5	0.1	2
pH	8.2	7.8	7.7
Specific conductance (µS/cm)	401	509	548
***E. coli* (col/100 mL)**	1,070	35	18,700

Compound	Skyland	Big Meadows	Loft Mountain	Endocrine-disrupting potential[a]	Possible use, application, source, or occurrence
	Concentration (µg/L)				
5-Methyl-1H-benzotriazole	3.59	nd	nd	—	Antioxidant in antifreeze and deicers.
Acetyl-hexamethyl-tetrahydro-naphthalene (AHTN, Tonalide)	0.633	0.246	2.29	—	Musk fragrance, persistent, widespread in ground water, concern about bioaccumulation and toxicity.
Benzophenone	0.0732	0.115	0.316	S	Fixative for perfumes and soaps.
beta-Sitosterol	0.259	nd	nd	—	Plant sterol.
Bisphenol A	0.143	nd	nd	K	Manufacturing polycarbonate resins, antioxidant, fire retardant.
Cholesterol	1	nd	0.209	—	Often a fecal indicator, also a plant sterol.
N,N-Diethyl-meta-toluamide (DEET)	0.0804	0.0732	0.102	—	Insecticide, urban uses, mosquito repellent.
Nonylphenol, diethoxy- (total, NPEO2)	nd	nd	1.18	K	Nonionic detergent.
Nonylphenol, monoethoxy- (total NPEO1)	nd	nd	0.461	K	Nonionic detergent.
Hexahydrohexamethyl-cyclopenta-benzopyran (HHCB, Galaxolide)	0.127	0.0799	0.434	—	Musk fragrance, persistent, widespread in ground water, concern about bioaccumulation and toxicity.
Tributyl phosphate	nd	nd	0.0811	—	Antifoaming agent, flame retardant.
Triclosan	0.16	0.0853	0.151	S	Disinfectant, antimicrobial (concern about acquired microbial resistance).
Triethyl citrate (ethyl citrate)	nd	0.0787	0.0828	—	Cosmetics, pharmaceuticals.
Tri(2-butoxyethyl) phosphate	nd	0.115	0.299	—	Flame retardant.
Tri(2-chloroethyl) phosphate	nd	0.116	0.601	S	Plasticizer, flame retardant.
Tri(dichloroisopropyl) phosphate	0.0835	0.0975	0.368	S	Flame retardant.
1,4-Dichlorobenzene	0.0136	nd	nd	S	Moth repellent, fumigant, deodorant.
Total Detections	**11**	**9**	**13**		

[a]Zaugg and others, 2002.

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