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Historical Trends and Concentrations of Fecal Coliform Bacteria in the Brandywine Creek Basin, Chester County, Pennsylvania

by Debra A. Town

Water-Resources Investigations Report 01-4026

Prepared in cooperation with the

CHESTER COUNTY WATER RESOURCES AUTHORITY
CHESTER COUNTY HEALTH DEPARTMENT

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

Temperature: Temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by use of the following equation:

$$°F = 1.8 (°C) + 32$$

Concentrations of bacteria are given in colonies per 100 milliliters (col/100 mL), which is the same as colony forming units per 100 milliliters (CFU/100 mL).

Other abbreviations used in report:

mg/L	milligrams per liter
mS/cm	microsiemens per centimeter at 25 degrees Celsius
mL	milliliters
E. coli	*Escherichia coli*, a fecal-indicator bacterium
mTEC	Membrane filter media for Escherichia coli
CWA	Clean Water Act
DMR	Discharge Monitoring Report
USGS	U.S. Geological Survey
USEPA	U.S. Environmental Protection Agency
PaDEP	Pennsylvania Department of Environmental Protection
CCWRA	Chester County Water Resources Authority
CCHD	Chester County Health Department

HISTORICAL TRENDS AND CONCENTRATIONS OF FECAL COLIFORM BACTERIA IN THE BRANDYWINE CREEK BASIN, CHESTER COUNTY, PENNSYLVANIA

by Debra A. Town

ABSTRACT

The Brandywine Creek in Chester County is used for recreation and as an important source of drinking water. For this study, 40 sites were established for collection of water samples for analysis of fecal coliform and Escherichia coli bacteria in 1998-99. Samples were collected during base-flow conditions and during five storms in which rainfall exceeded 0.5 inch. During base-flow conditions, the median concentrations of fecal coliform bacteria exceeded 200 col/100 mL at 26 of the 40 sites (65 percent). During stormflow conditions, the median concentration of fecal coliform bacteria exceeded the Pennsylvania Department of Environmental Protection (PaDEP) criterion of 200 col/100 mL at 30 of 33 sites sampled (91 percent). Trends in fecal coliform bacteria concentrations were downward for the period 1973-99 at three long-term water-quality monitor stations, the result of upgrades in wastewater treatment plants, decreases in point-source discharges, and a decrease in agricultural land. A positive relation exists between streamflow and concentrations of fecal coliform bacteria at two of the long-term stations, but concentrations are elevated in base flow and stormflow at all three stations.

Factors affecting bacteria concentrations in the Brandywine Creek Basin include nonpoint-source contaminants, reservoirs, seasonality, and stormflow. Nonpoint sources of bacterial contamination in the basin include, but are not limited to, land-surface runoff, urbanization, agricultural processes, ground-water contamination, and wildlife. Bacteria concentrations in streams that flow directly from the reservoirs are much lower than the concentrations in the streams flowing into the reservoirs. During March, April, May, October, and November, the Brandywine Creek tends to have lower water temperatures and bacteria concentrations than during June, July, August, and September. The 10-year median concentrations of bacteria at West Branch Brandywine Creek at Modena and East Branch Brandywine Creek below Downingtown exceed the criterion of 200 col/100 mL established by the PaDEP during the swimming season. The 10-year median concentrations of bacteria at Brandywine Creek at Chadds Ford exceed the criterion of 200 col/100 mL only during June. None of the stations exceed the criterion of 2,000 col/100 mL as established by the PaDEP for the remainder of the year.

INTRODUCTION

The aesthetic, recreational, and ecological health of the Brandywine Creek in Chester County may be influenced by high concentrations of fecal coliform bacteria. Chapter 93 of the "Pennsylvania Water Quality Standards" lists the following as uses for the Brandywine Creek: water supply (potable, industrial, and livestock), irrigation, aesthetics, boating and fishing, wildlife water supply, trout stocking, and fishes (warmwater, coldwater, and migratory) (Pennsylvania Department of Environmental Protection, 1999, p. 62). Five public water suppliers in Chester County withdraw water from the Brandywine Creek for domestic, commercial, and industrial use. Three reservoirs on the creek play host to boaters, fishermen, and canoeists (Grieg and others, 1998).

As part of a cooperative program among the Chester County Water Resources Authority (CCWRA), Chester County Health Department (CCHD), and the U.S. Geological Survey (USGS), fecal coliform bacteria, temperature, pH, dissolved oxygen, and specific conductance of the Brandywine Creek are measured at the West Branch Brandywine Creek at Modena (USGS station number 01480617), the East Branch Brandywine Creek below Downingtown (USGS station number 01480870), and the main stem of the Brandywine Creek at Chadds Ford (USGS station number 01481000) (fig. 1). Temperature, pH, dissolved oxygen, and specific conductance are measured hourly, and concentrations of fecal coliform bacteria are measured bi-weekly. Data have been collected from March to November (Wood, 1998) since 1973 at main stem Brandywine Creek at Chadds Ford, since 1980 at East Branch Brandywine Creek below Downingtown, and since 1981 at West Branch Brandywine Creek at Modena.

Data from the long-term water-quality monitor stations show that concentrations of fecal coliform bacteria during storms typically are greater than those during base flow. Water samples containing fecal coliform bacteria typically contain *Escherichia coli* (*E. coli*) bacteria, which indicate the potential presence of water-borne pathogens that may present a public health risk for humans that consume or have bodily contact with contaminated water (Dufour, 1977).

This study supports the objectives and goals of Chester County's Landscapes program (Chester County, 1996, p. 114). The study will help to achieve and sustain a high-quality natural resource system and will help to protect public health and safety. This report also reinforces the Phase I and II results of the Christina River Basin Water Quality Management Strategy (Grieg and others, 1998). The Christina project aims at improving water quality and addressing nonpoint-source pollution reduction; the CCWRA is a local coordinator.

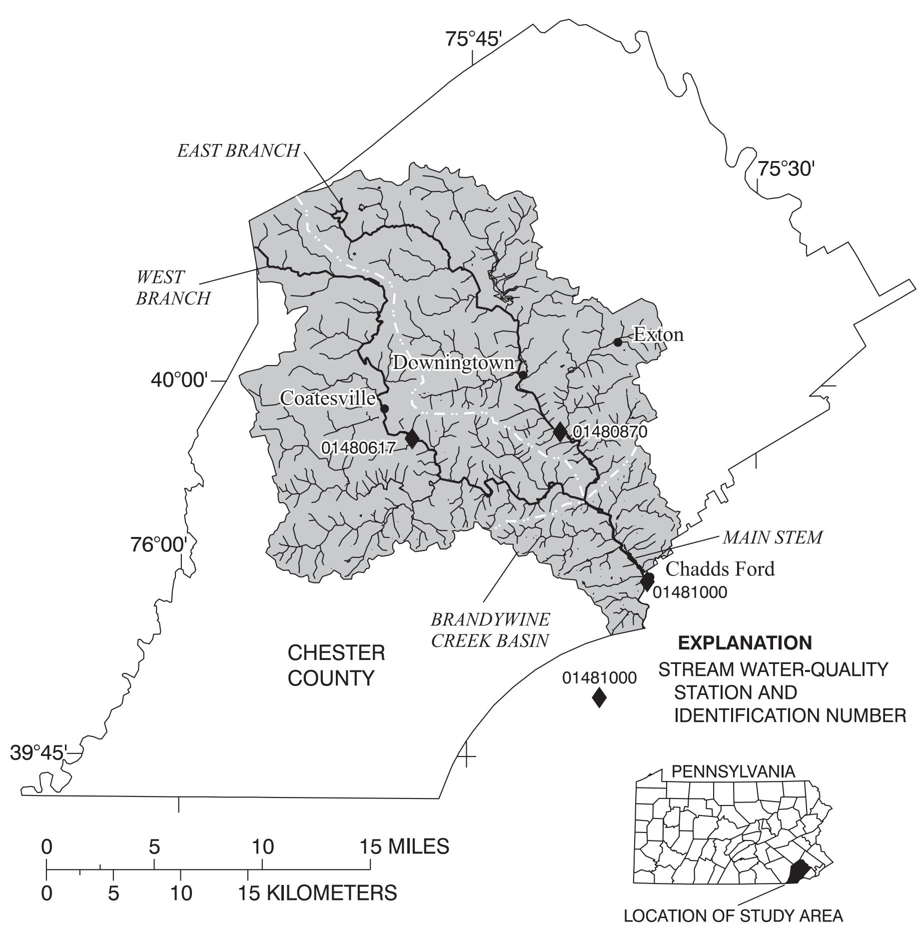


Figure 1. Location of Brandywine Creek Basin, Chester County, Pennsylvania.

Purpose and Scope

This report identifies trends in historical concentrations of fecal coliform bacteria at three USGS long-term water-quality monitor and streamflow-measurement stations on the Brandywine Creek from 1973 to 1999. Relations between concentrations of fecal coliform bacteria and streamflow also are compared for the stations. This report discusses the extent and possible types of sources for fecal coliform and *E. coli* bacteria in the Brandywine Creek Basin. Bacteria data, field chemistry, and streamflow measurements were collected by the USGS at 40 sites on the Brandywine Creek during July through October 1998 and March through September 1999 during base flow and stormflow. Relations between fecal coliform bacteria and field chemistry constituents are determined. Relations between land use and concentrations of fecal coliform bacteria are compared. The effect of the three reservoirs in the basin on bacteria concentrations is evaluated. Other factors, such as the ratio of *E. coli* to fecal coliform bacteria in water samples and seasonality, are discussed. Water-sample analyses are evaluated to determine the current extent of bacterial contamination from the subbasins in the Brandywine Creek Basin.

The length of the study and the number of sites determined that the evaluation of potential sources for bacteria would be limited to the subbasin level within the basin rather than specific sources for bacteria. Bacterial contamination is identified on the basis of the median concentration of fecal coliform bacteria for each subbasin during base flow and stormflow.

Acknowledgments

The author gratefully acknowledges the assistance of Linda Tracey of the CCHD, who was a tremendous asset with the interlaboratory quality assessment of the bacteria analyses. In addition, USGS interns Carrie Gillespie, Tammi Renninger, and Kiley McDaniel contributed a great deal of time and effort to the data-collection phase of the project along with USGS staff members Kevin Grazul, Cynthia Rowland-Lesitsky, and Abdul Mohammad. The cartography in this report was completed by Scott Hoffman of the USGS in Lemoyne, Pa.

Description of the Study Area

The Brandywine Creek Basin drainage area is approximately 325 mi^2, most of which is in Chester County, Pa. The estimated population in 1998 was 197,460 (Greig and others, 1998). The Brandywine Creek is one of four streams that constitute the larger Christina River Basin, which drains to the Delaware River. Land use in the West Branch Brandywine Creek Basin is predominantly agricultural with an urban area around the city of Coatesville. The East Branch Brandywine Creek Basin is predominantly forested with an urban area around the borough of Downingtown. The main stem basin is predominantly agricultural. The Brandywine Creek is lined by forest for most of its length.

The Brandywine Creek Basin lies in the Piedmont Physiographic Province. Typically, diabase, gneiss, and marble are found north of the Great Valley. The borough of Downingtown and the City of Coatesville lie in the Great Valley, which is underlain by limestone and dolomite and cuts a midline through the basin. Schists and gneisses make up the bedrock of the southern part of the basin.

The Brandywine Creek attracts canoeists, fisherman, waders, and even cyclists and hikers who use the paved areas beside the creek to bike and walk. While most of these activities are pursued during the swimming season, recreational use around the creek goes on year-round.

Latitude and longitude locations were established for each of the 40 sampling sites along the Brandywine Creek (table 1). A USGS station-identification number, station name, local alpha-numeric identification number, drainage area of each site's subbasin, and the subbasin's land-use percentages also are listed.

FECAL-INDICATOR BACTERIA AND WATER QUALITY

Fecal coliform bacteria are present in water when bacterial pathogens from fecal contamination are present. Indicator organisms, such as fecal coliform bacteria, are not usually pathogenic but rather indicate the possible presence of pathogenic organisms. Because fecal coliform bacteria are present in higher concentrations than the actual pathogens and because they can survive longer, the bacteria are more likely to be detected. Fecal coliform bacteria

Table 1. *Sites sampled for bacteria, Brandywine Creek Basin, Chester County, Pennsylvania*

[ID, identification number; USGS, U.S. Geological Survey; WB, West Branch; EB, East Branch; MS, main stem]

Local ID	USGS site ID	Site name	Latitude	Longitude	Drainage area (square miles)	Percentage land use			
						Agricultural	Forested	Residential	Urban
WB1	01480269	WB Brandywine Creek at Rockville	40 04 50	75 52 20	5.68	72.0	11.0	9.0	0.5
WBA	01480295	Two Log Run at Birdell	40 04 06	75 52 25	2.75	34.0	54.0	9.9	1.0
WB2	[1]01480300	WB Brandywine Creek near Honey Brook	40 04 22	75 51 40	18.4	68.0	20.0	7.0	1.0
WB3	01480349	WB Brandywine Creek at Brandamore	40 02 39	75 49 51	24.0	58.0	27.0	10.0	1.0
WB4	01480390	Birch Run near Martins Corner	40 01 50	75 52 20	2.48	30.0	54.0	13.0	8.0
WB5	[1]01480400	Birch Run near Wagontown	40 01 38	75 50 43	4.66	31.0	53.0	13.0	2.0
WB6	01480458	Rock Run near Philipsville	40 00 20	75 52 44	2.32	58.0	29.0	10.0	2.0
WBE	01480463	Rock Run at Reservoir near Coatesville	40 00 07	75 51 20	5.11	52.0	26.0	17.0	2.0
WB7	01480466	Rock Run below Coatesville Reservoir	40 00 22	75 51 09	5.56	49.0	26.0	16.0	2.0
WBD	01480470	Rock Run at Rock Run near Coatesville	39 59 34	75 49 53	45.5	47.0	33.0	14.0	2.0
WBB	01480434	WB Brandywine Creek at Rock Run	39 59 36	75 49 41	37.6	48.0	33.0	14.0	1.0
WBC	01480480	WB Brandywine Creek below Rock Run at Coatesville	39 59 28	75 49 52	45.7	47.0	33.0	15.0	2.0
WB8	[1]01480500	WB Brandywine Creek at Coatesville Reservoir	39 59 08	75 49 40	46.0	47.0	33.0	15.0	2.0
WB9	[1]01480617	WB Brandywine Creek at Modena	39 57 42	75 48 06	55.3	42.0	33.0	16.0	4.0
WB10	01480629	Buck Run at Doe Run	39 55 46	75 49 24	21.5	58.0	26.0	11.0	2.0
WB11	014806318	Doe Run above tributary at Springdell	39 54 25	75 49 42	8.76	76.0	15.0	5.1	1.0
WB12	01480634	WB Brandywine Creek near Embreeville	39 56 04	75 45 00	116.0	53.0	30.0	12.0	3.0
WB13	01480637	Little Broad Run near Marshallton	39 57 38	75 42 44	1.02	38.0	27.0	26.0	5.0
WB14	01480638	Broad Run at Northbrook	39 55 49	75 41 06	6.38	37.0	29.0	29.0	3.0
WB15	01480640	WB Brandywine Creek at Wawaset	39 55 34	75 39 47	134.0	52.0	30.0	12.0	3.0
EB1	01480648	EB Brandywine Creek near Cupola	40 05 41	75 51 14	6.86	60.0	25.0	7.0	1.0
EB2	01480653	EB Brandywine Creek at Glenmoore	40 05 48	75 46 44	16.2	53.0	34.0	7.0	.4
EB3	01480658	Indian Run at Springton	40 04 32	75 46 55	4.26	37.0	46.0	12.0	3.0
EB4	[1]01480675	Marsh Creek near Glenmoore	40 05 52	75 44 31	8.53	39.0	46.0	8.0	3.0
EB5	[1]01480685	Marsh Creek near Downingtown	40 03 19	75 43 00	20.1	34.0	38.0	17.0	2.0
EB6	01480660	EB Brandywine Creek at Lyndell	40 03 34	75 44 39	27.1	45.0	39.0	10.0	1.0
EB7	01480662	Culbertson Run at Lyndell	40 03 29	75 45 07	4.41	44.0	33.0	21.0	1.0
EB8	[1]01480700	EB Brandywine Creek near Downingtown	40 02 05	75 42 32	60.0	39.0	37.0	16.0	2.0
EB9	01480775	Beaver Creek near Downingtown	40 00 12	75 43 28	16.5	33.0	29.0	25.0	4.0
EBA	01480800	EB Brandywine Creek at Downingtown	40 00 19	75 42 18	76.4	36.0	36.0	19.0	3.0
EBC	01480840	EB Brandywine Creek at Altor	39 58 33	75 40 59	89.0	34.0	37.0	20.0	3.0
EB13	01480878	Uwchlan Run at Exton	40 01 35	75 39 52	1.50	67.0	16.0	10.0	2.0
EBB	01480887	Valley Creek at Ravine Road near Downingtown	39 59 55	75 39 52	14.4	20.0	31.0	26.0	7.0
EB10	[1]01480870	EB Brandywine Creek below Downingtown	39 58 07	75 40 25	89.7	34.0	37.0	20.0	3.0
EB11	01480905	Valley Creek at Altor	39 58 12	75 39 59	20.6	30.0	33.0	19.0	7.0
EB12	01480930	Taylor Run at Copesville	39 57 19	75 38 55	5.52	23.0	26.0	37.0	4.0
EB14	01480950	EB Brandywine Creek at Wawaset	39 55 35	75 38 54	123.0	31.0	35.0	22.0	4.0
MS1	01480970	Brandywine Creek at Pocopson	39 54 04	75 37 26	264.0	42.0	32.0	17.0	3.0
MS2	01480975	Pocopson Creek at Pocopson	39 54 03	75 38 16	8.57	49.0	21.0	26.0	1.0
MS3	[1]01481000	Brandywine Creek at Chadds Ford	39 52 11	75 35 37	288.0	42.0	32.0	18.0	3.0

[1] USGS streamflow-measurement station.

are easy to culture and typically are harmless to humans; therefore, they were chosen as the primary indicator bacteria. Because fecal coliform bacteria were sampled from 1973 to 1999 in the Brandywine Creek, the historical data could be compared with data collected for this study. The Pennsylvania Department of Environmental Protection (PaDEP) and the U.S. Environmental Protection Agency (USEPA) have the same set of criteria on the basis of water use. For bathing (full-body contact) in recreational freshwater, on the basis of a statistically sufficient number of samples (generally not less than five samples equally spaced over a 30-day period), the geometric mean of the indicated bacterial densities of fecal coliform should not exceed 200 col / 100 mL during the swimming season (May 1 through September 30) and should not exceed 2,000 col / 100 mL for the remainder of the year. (Pennsylvania Department of Environmental Protection, 1999, p. 16). For water supply, bacteria concentrations should not exceed 5,000 col / 100 mL as a monthly average in more than 20 percent of the samples collected during a month and should not exceed 20,000 col / 100 mL in more than 5 percent of the samples (Pennsylvania Department of Environmental Protection, 1999).

E. coli bacteria are found within the fecal coliform group in smaller concentrations than fecal coliform bacteria. *E. coli* were chosen as the secondary indicator of bacterial contamination because they are a specific indicator of fecal pollution. *E. coli* inhabit the gastrointestinal tract of warm-blooded animals and are an indicator of the presence of intestinal pathogens that cause human diseases (Francy and others, 1993). The USEPA (1998) has set a criterion on the basis of water use. For bathing (full-body contact) in recreational freshwater, on the basis of a statistically sufficient number of samples (generally not less than five samples equally spaced over a 30-day period), the geometric mean of the indicated bacterial densities of *E. coli* should not exceed 126 col / 100 mL.

Fecal-indicator bacteria assess the sanitary quality of water and include Enterococci, the coliform group, and the streptococcal group. For this study, the coliform group were used as the indicator organisms of choice. Within the coliform group, total coliforms (of which fecal coliform and *E. coli* are part), fecal coliforms (of which *E. coli* is part), and *E. coli* are the most widely used indicators. Total coliforms, and to some extent fecal coliforms, have been used as indicators of the possible presence of pathogens in surface waters and have been associated with a risk of disease on the basis of epidemiological evidence of gastrointestinal disorders from ingestion of contaminated surface water. Contact with pathogens in contaminated surface water can cause ear or skin infections or respiratory diseases. The pathogens responsible for these diseases can be bacteria, viruses, protozoans, fungi, or parasites that live in the gastrointestinal tract and are shed in the feces of warm-blooded animals. Because it is difficult to analyze for this myriad of pathogens, fecal coliform and *E. coli* bacteria are used as the primary indicators of fecal contamination in recreational waters. *E. coli* is considered to have a high degree of association with outbreaks of certain diseases and are recommended as a fecal-indicator for bacterial water-quality standards by the USEPA (1986).

Bacterial contamination can come from point and nonpoint sources. Point sources are single, identifiable points of origin, such as municipal or industrial discharges. Nonpoint sources are from diffuse origins. Agricultural nonpoint sources include animal waste, the application of manure and biosolids to fields, and crop irrigation from contaminated storage ponds. Urban / residential nonpoint sources include active construction areas, failed waste-disposal systems, residential septic systems, pet waste, litter, and landfill leakage. Wildlife waste also is a nonpoint source. The Brandywine Creek is affected by nonpoint sources of bacterial contamination during base flow and especially during stormflow.

METHODS OF SITE SELECTION, DATA COLLECTION, AND DATA ANALYSIS

Data were collected by the USGS from July to October 1998 as part of a reconnaissance sampling of the Brandywine Creek Basin under base-flow conditions to determine preliminary base-flow concentrations of fecal coliform bacteria. This information, along with data from the PaDEP and the CCHD, were used to determine the location of base-flow sampling sites. Site locations also were selected on the basis of land use, known point discharges, and areas where recreational use was evident. Thirty-two sites initially were selected for sample collection. All nine USGS streamflow-measurement stations in the basin were used as sampling sites. Eight additional sampling sites were added midway through the study to pinpoint potential sources of elevated bacteria measured during monthly sampling (fig. 2).

Data Collection

Water samples were collected for analysis for fecal coliform and *E. coli* bacteria at the sites established as a result of the reconnaissance sampling. Sampling frequency was approximately monthly from March to September 1999 to provide sufficient temporal variation and different flow regimes for the evaluation of bacterial contamination. Fecal coliform bacteria were measured monthly at all 40 sites during base flow, and *E. coli* bacteria were measured monthly at a subset of those 40 sites during base flow. During the course of the study, each of the initial 32 sites was sampled for *E. coli* bacteria at least once during base flow.

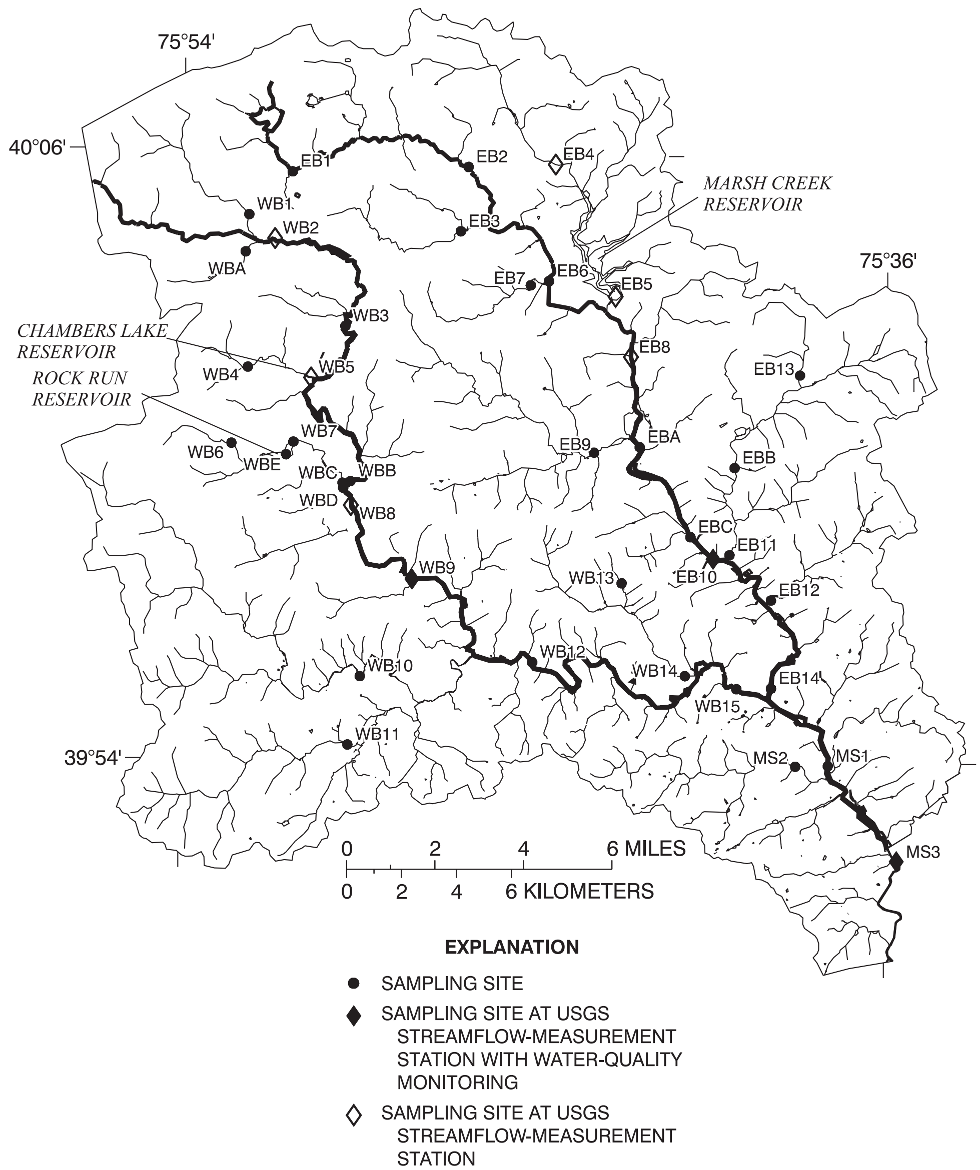


Figure 2. Sampling sites in the Brandywine Creek Basin, Chester County, Pennsylvania, 1998-99. (See table 1 for full names and characteristics of sampling sites.)

Storm sampling also was conducted as a part of this study. Data were collected during five storms in which rainfall exceeded 0.5 in. Most of the USGS streamflow-measurement stations were sampled during every storm. The selection of these stations as sampling sites eliminated the need for current-meter measurements of streamflow. During storms, only specific conductance, temperature, and gage height were measured at the time the sample was collected. In addition, for each storm, five sites not at streamflow-measurement stations were sampled.

All water samples were analyzed for fecal coliform and *E. coli* bacteria by use of the membrane filtration method described in Myers and Wilde (1997) (table 2). Water samples were collected as grab samples, by use of individually labeled sterile 250-mL plastic bags. The plastic bag was submerged in the stream at the center of flow and opened to allow water to enter. It was then sealed and placed in a cooler for transportation to the laboratory. Samples were incubated immediately after filtration. CCHD samples were collected in 250-mL plastic bottles. The bottles were submerged in the stream in the same place as the plastic bags, opened and filled with water, and sealed and placed in a cooler for transportation to the CCHD laboratory.

Field chemistry measurements and streamflow measurements were made for all base-flow samples collected. Field chemistry included dissolved oxygen, pH, specific conductance, and water temperature. Dissolved oxygen was measured by use of the Winkler Method (Clesceri and others, 1998). The pH, specific conductance, and water temperature were measured with meters.

Quality assurance was conducted by USGS and CCHD personnel by use of guidelines from Clesceri and others (1998). Quality-assurance methods were used in the field and the laboratory and for the equipment and media. Quality control was conducted according to guidelines from Clesceri and others (1998). Quality control for variability was conducted by use of interlaboratory comparisons of sequential replicate samples. Duplicate samples were analyzed by the CCHD laboratory. Quality-control results are shown in table 3. Quality control for bias was conducted by use of membrane filter equipment blanks with sterile buffered water filtered and plated before every sample to test for contamination.

Data Analysis

Bacteria concentrations in samples collected from July to October 1998 and from March to September 1999 from the Brandywine Creek Basin were compared to maximum acceptable concentrations established by the PaDEP (1999).

Median concentrations of fecal coliform bacteria were calculated for all 40 sites. A limited number of samples were analyzed for *E. coli* bacteria at each site; therefore, median concentrations of *E. coli* bacteria were not determined for either base flow or stormflow.

Graphical analyses (boxplots) were used to evaluate water-quality measurements and bacteria concentration during base flow and stormflow. The water-quality measurements and bacteria-concentration data collected during base flow and stormflow are listed in tables 6-11 at the end of this report. Graphical analyses also were used to evaluate historical data at three USGS long-term water-quality monitoring and streamflow-measurement stations on Brandywine Creek.

Table 2. *Indicator bacteria, filter size, ideal count range, holding times, and incubation time and temperature for collected bacteria samples (from Myers and Wilde, 1997)*

[m-FC, fecal coliform media; M-TEC, *Escherichia coli* media; °C, degrees Celsius]

Indicator bacteria (and media type)	Filter size (microns)	Ideal count range (colonies per filter)	Holding time	Incubation time and temperature
Fecal coliform bacteria (m-FC media)	0.65	20-60	6 hours	22 to 26 hours at 44.5°C
Escherichia coli bacteria (m-TEC media)	.45	20-80	6 hours	2 hours at 35.0°C and then 22 to 24 hours at 44.5°C (filter then transferred to urea substrate broth for 15 to 20 minutes before counting).

***Table 3.** Quality-control results for fecal coliform and E. coli bacteria, Brandywine Creek Basin, Chester County, Pennsylvania, 1998-99*

[ID, identification number; —, no data collected; FC, fecal coliform; EC, *E. coli*; E, estimated; >, greater than; col/100 mL, colonies per 100 milliliters; CCHD, Chester County Health Department; USGS, U.S. Geological Survey]

Date	Local ID	Site ID	FC Concentrations (col/100 mL)		EC Concentrations (col/100 mL)	
			CCHD	USGS	CCHD	USGS
05/04/99	EB4	01480675	23 E	12 E	15 E	2 E
05/04/99	EB8	01480700	170	160	150	170
05/04/99	EB13	01480950	180	200	150	150
07/19/99	WB2	01480300	25,000	> 6,000	2,700	> 8,000
07/19/99	WB13	01480637	1,500	2,000 E	1,100	—
07/20/99	EB1	01480648	2,000	> 1,200	890 E	—
08/03/99	EB1	01480648	220	260	180	240
08/16/99	WB1	01480269	4,000	5,100	2,700	5,900
08/16/99	WB3	01480349	500	590	460	—
08/16/99	WB10	01480629	270	310	170	260
08/17/99	EB7	01480662	280	300	210	340
08/26/99	WB8	01480500	7,600	9,200	2,600	1,400 E
09/13/99	WB14	01480638	460	470	530	320
09/14/99	EB6	01480660	200	140 E	140	100 E
09/15/99	MS2	01480975	220	140	190	180
09/16/99	WB6	01480458	> 6,000	540,000 E	>1,600 E	16,000 E

Relations between bacteria, chemical constituents, and streamflow for data collected in 1998-99 were evaluated statistically by use of Spearman Rank correlations significant at the 95-percent confidence interval. Relations were evaluated at base-flow and stormflow conditions. Relations between bacteria concentrations and land use were evaluated statistically by use of the Kruskal-Wallis test.

Spatial Analysis

A geographical information system (GIS) spatial analysis was used to determine the land-use percentages of the subbasins within the Brandywine Creek Basin. Land use was divided into four categories: agricultural, forested, residential, and urban. The agricultural category consists of cropland, livestock, and pasture. Forested areas are defined as those with more than 50 percent cover of deciduous, coniferous, and mixed woody vegetation. The residential category consists of areas of single- and multi-family residences. Urban areas include institutions, transportation/utilities, commercial businesses, and industries. All other categories—examples would be mining, water, vacant/barren, public and private open space—constituted a very low percentage of land use and were not used in the spatial analysis. The Brandywine Creek Basin was divided into 40 subbasins relative to each sampling site. An individual subbasin usually extended from each sampling site to the sampling site immediately upstream from it. Where sampling sites were clustered (as in the supplemental sites), a subbasin included both the initial sites and supplemental sites. A land-use coverage obtained from the Water Resources Agency for New Castle County was used to determine the percentages of each type of land use within each subbasin. Subbasins with greater than 50 percent of one type of land use were designated as predominantly that type of land use. Subbasins with less than 50 percent of one type of land use were assigned a “mixed” designation. Although the urban category was used to differentiate land use during the GIS spatial analysis and did not appear as a predominant land use, it is an indicator of areas of nonpoint source land-surface runoff.

Twenty-five sites were identified as being in subbasins of mixed land use (table 1), 11 sites were identified as being in predominantly agricultural subbasins, 3 sites were identified as being in predominantly forested subbasins, and 1 site was identified as being in a predominantly residential subbasin. Although urban land use ranged from 1-7 percent, no subbasin was identified as predominantly urban. Each subbasin was examined as an individual entity with regards to impact on the Brandywine Creek's bacteria concentration.

HISTORICAL TRENDS IN FECAL COLIFORM BACTERIA

Data from East Branch Brandywine Creek below Downingtown (EB10), West Branch Brandywine Creek at Modena (WB9), and Brandywine Creek at Chadds Ford (MS3) were evaluated for historical trends (fig. 3). All three USGS long-term water-quality monitoring and streamflow-measurement stations show decreased bacteria concentrations since the beginning of record collection. The data were collected at these sites bi-monthly, usually between March to November, regardless of flow conditions. Only MS3 shows median concentrations of bacteria below 200 col / 100 mL for most of the time from 1992 to 1999. All three sites show elevated median concentrations of bacteria in 1980, 1983, and 1989. The elevated median concentrations are on both branches and the main stem of Brandywine Creek.

From 1980 to 1999, the median bacteria concentrations at EB10 have decreased by a factor of 1,000, showing the most dramatic and consistent improvement of the three stations. The median bacteria concentrations at MS3 have decreased by at least a factor of 10 from a peak in 1980. Since data collection began in 1973, the median bacteria concentrations at MS3 increased until 1980 and then progressively decreased to below the PaDEP criterion of 200 col / 100 mL. The median bacteria concentrations at WB9 showed a peak in 1981, decreased to the PaDEP criterion in 1987, and increased until 1999 to one-tenth of its highest recorded median bacteria concentration.

In 1972, the U.S. Congress enacted landmark legislation, in the form of a statute, to protect the Nation's waters. The Federal Water Pollution Control Act Amendments of 1972 (referred to as the Clean Water Act of 1972 or CWA), expanded and built upon existing laws designed to control and prevent water pollution. The CWA may have contributed to the decrease in bacteria concentrations between 1972 and 1987. The Clean Water Act of 1977 and the Water Quality Act of 1987, which

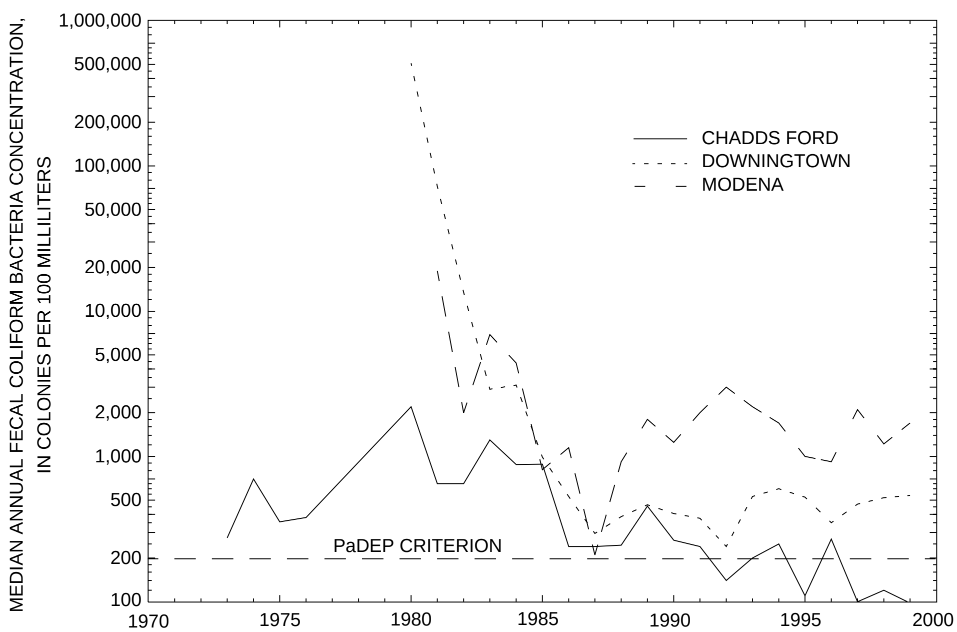


Figure 3. Annual median concentrations of fecal coliform bacteria at Brandywine Creek at Chadds Ford, East Branch Brandywine Creek below Downingtown, and West Branch Brandywine Creek at Modena, Pennsylvania, 1973-99.

are successive amendments to the 1972 CWA, have continued to strengthen that law. Concentrations of bacteria decreased dramatically from 1980 to 1987, rose and fell between 1987 and 1996, and then stabilized from 1996 to 1999. Possible factors that would lower bacteria concentrations are the addition and upgrade of wastewater treatment plants, an expansion of collection systems, decreases in point-source discharges, and decreases in agricultural land use in the basin.

Comparisons between streamflow and concentrations of fecal coliform bacteria during base flow and stormflow for sites MS3, EB10, and WB9 are shown in figure 4. There is a general relation between streamflow and concentrations of fecal coliform bacteria at sites MS3 and WB9. When streamflow is elevated, bacteria concentrations tend to be elevated. A relation between streamflow and concentrations of fecal coliform bacteria is not apparent at EB10.

Median concentrations of fecal coliform bacteria were highest at WB9 and lowest at MS3 (fig. 5). EB10 had the greatest range in bacteria concentrations.

FACTORS AFFECTING BACTERIA CONCENTRATIONS

Numerous factors affect bacteria concentrations in the Brandywine Creek. Land use, the chemical and physical properties of stream water, seasonality, and reservoirs are all factors that can affect the concentration of bacteria. Land-use differences in the Brandywine Creek do not appear to affect bacteria concentrations to a statistically significant extent. A moderate positive relation exists between water temperature and fecal coliform and *E. coli* bacteria during base flow. Seasonal changes in water temperature can either promote or inhibit bacteria growth. Water flowing from reservoirs is low in bacteria concentration.

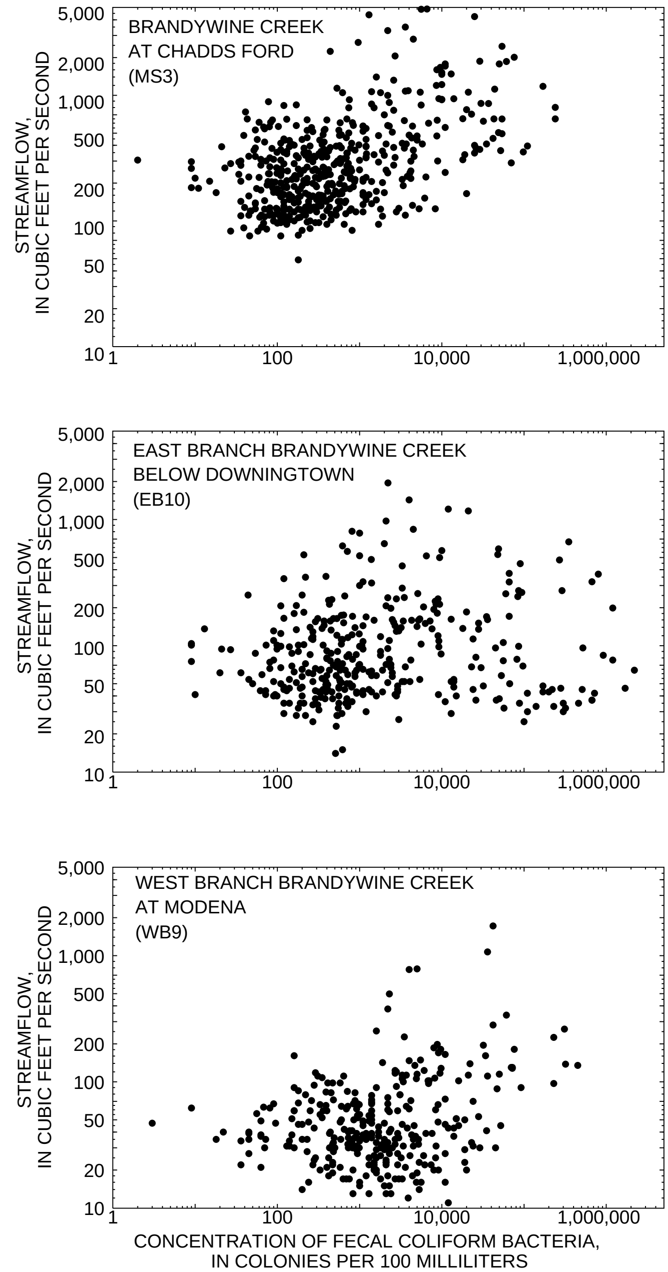


Figure 4. Relation between streamflow and concentration of fecal coliform bacteria, Brandywine Creek at Chadds Ford, East Branch Brandywine Creek below Downingtown, and West Branch Brandywine Creek at Modena, Pennsylvania, 1973-99.

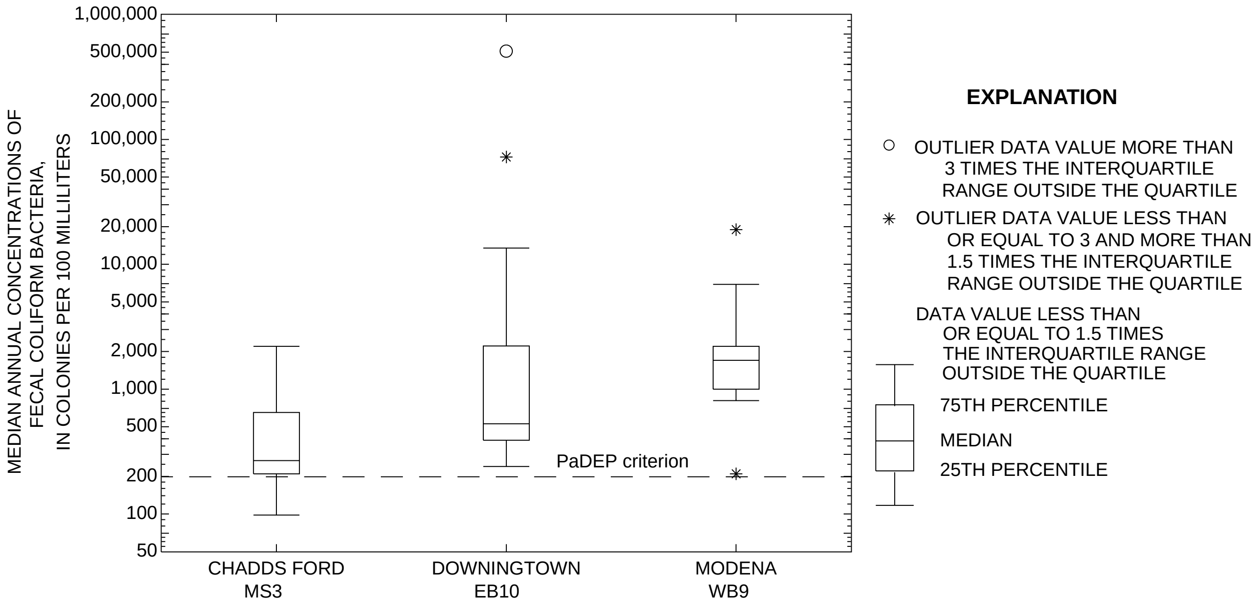


Figure 5. Distribution of annual median concentrations of fecal coliform bacteria at three USGS long-term water-quality monitor and streamflow-measurement stations during base flow and stormflow, Brandywine Creek Basin, Chester County, Pennsylvania, 1973-99.

Land Use

Bacteria concentrations in water samples from subbasins with agricultural, forested, residential, and mixed land-use settings were compared. The Kruskal-Wallis test was used to test for statistically significant differences in the ranks of concentrations of fecal coliform bacteria between land-use categories at the 95-percent confidence level for all base-flow and stormflow samples. The test was run twice, once for three categories of land use (agricultural, forested, and residential) and once for four categories (agricultural, forested, residential, and mixed). In both cases, the Kruskal-Wallis test showed no statistically significant difference for concentrations of fecal coliform bacteria among the three predominant land-use groups (agricultural, forested, and residential) or the second group that included the mixed category for base flow and stormflow.

While there seems to be no direct relation between land use and bacteria concentrations within a subbasin, bacteria concentrations in base flow and stormflow are different. The base-flow bacteria concentrations for all four categories are lower than stormflow concentrations by a factor of approximately 10. During base flow and stormflow, the agricultural, forested, residential, and mixed subbasins have approximately the same median bacteria concentration. However, the forested subbasins show a much wider range of bacteria concentrations (fig. 6).

Field-Measured Properties of Water and Streamflow

Relations among bacteria concentrations, field-measured properties of water, and streamflow were evaluated statistically by use of Spearman-rank correlations. Statistically significant relations (for $p < 0.05$) were found to exist. Spearman-rank correlations significant at the 95-percent confidence interval are given in table 4.
A moderate positive correlation exists between temperature and concentration of fecal coliform bacteria ($r_s = 0.346$) and *E. coli* bacteria ($r_s = 0.351$). Concentrations of bacteria are lower when water temperatures are less than approximately 15°C (usually during March and April) than when water temperatures are greater than approximately 15°C (usually from June to September). A weak negative

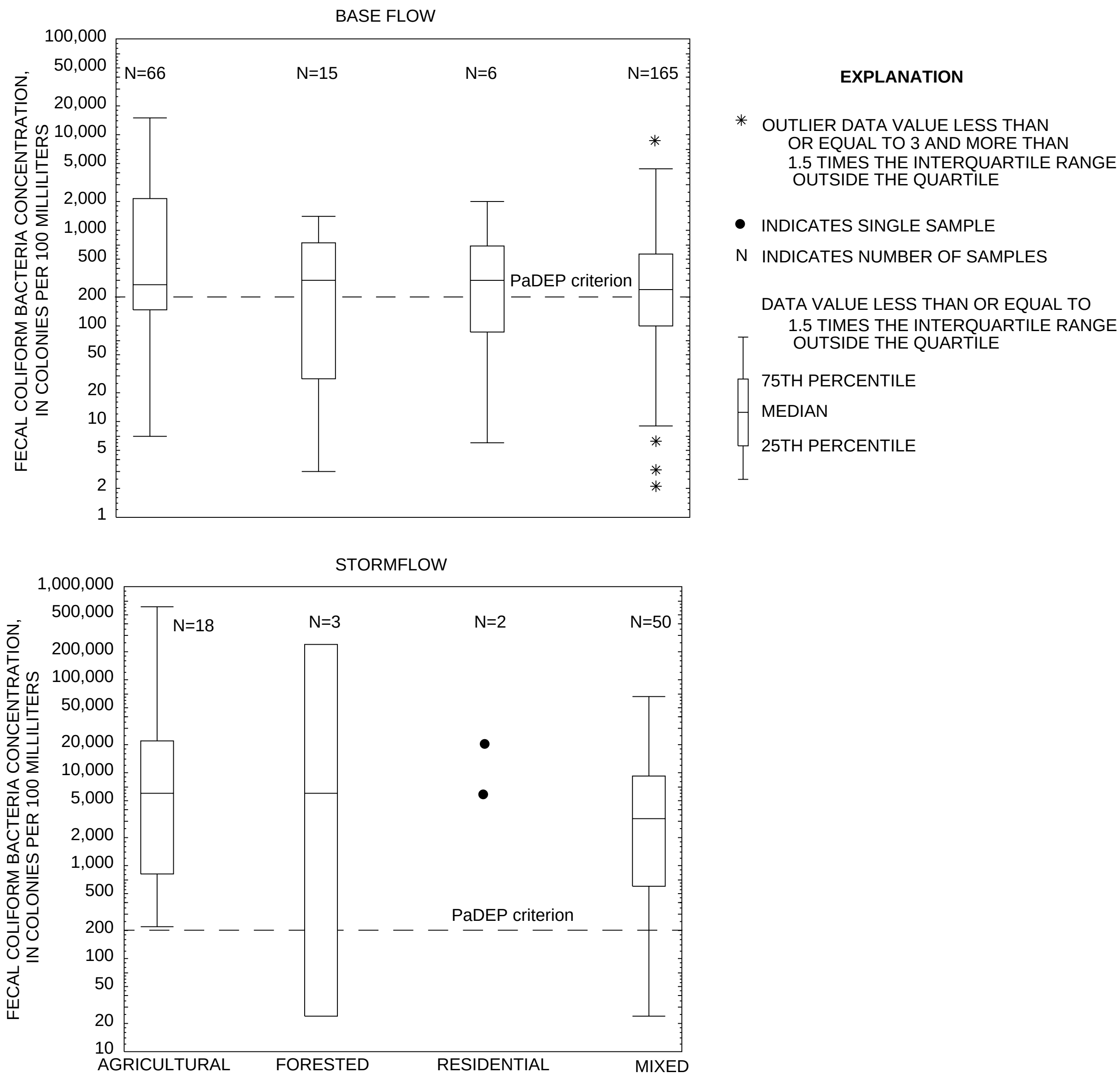


Figure 6. Distribution of concentrations of fecal coliform bacteria during base flow and stormflow at sites in agricultural, forested, residential, and mixed subbasins, Brandywine Creek Basin, Chester County, Pennsylvania, 1998-99.

Table 4. *Spearman rank correlations significant at the 95-percent confidence interval for base-flow and stormflow samples*

[n, number; r_s, Spearman Rho coefficient; p-value, significance value]

Correlation	n	r_s	p-value
Base flow			
Temperature - dissolved oxygen	209	-0.553	0.0001
Fecal coliform - dissolved oxygen	208	-.309	.0001
E. coli - dissolved oxygen	69	-.267	.0263
Fecal coliform - water temperature	251	.346	.0001
E. coli - water temperature	76	.351	.0018
Fecal coliform - streamflow	219	-.212	.0016
E. coli - streamflow	72	-.231	.0505
Fecal coliform - specific conductance	243	.250	.0001
E. coli - specific conductance	76	.257	.0251
Fecal coliform - *E. coli*	76	.745	.0001
Stormflow			
Fecal coliform -*E. coli*	32	.612	.0002

correlation exists between dissolved oxygen and concentration of fecal coliform bacteria (r_s = -0.309) and *E. coli* bacteria (r_s = -0.267). When water temperatures are higher, dissolved oxygen concentrations are lower (r_s = -0.553). The weak correlation between bacteria concentrations and dissolved oxygen probably is the result of the correlation between water temperature and dissolved oxygen and not low dissolved oxygen causing an increase in bacteria concentration. A weak negative correlation exists between streamflow and concentration of fecal coliform bacteria (r_s = -0.212) and *E. coli* bacteria (r_s = -0.231). A weak positive correlation exists between specific conductance and concentration of fecal coliform bacteria (r_s = 0.250) and *E. coli* bacteria (r_s = 0.257). As expected, a strong positive correlation exists between fecal coliform and *E. coli* bacteria (r_s = 0.745). When concentrations of fecal coliform bacteria are elevated, concentrations of *E. coli* bacteria also are elevated.

During stormflow, a strong positive correlation exists between fecal coliform bacteria and *E. coli* bacteria (r_s = 0.612). When concentrations of fecal coliform bacteria are elevated, concentrations of *E. coli* bacteria also are elevated (table 4).

Seasonality

Seasonality in this region of temperate climate affects bacteria concentrations in the Brandywine Creek through water temperature variations. USGS water-quality monitor stations do not collect data between December and February. Base flow and stormflow water temperatures from 1990 to 1999 at West Branch Brandywine Creek at Modena (WB9), East Branch Brandywine Creek below Downingtown (EB10), and Brandywine Creek at Chadds Ford (MS3) are grouped by month and shown in figure 7. At all three stations water temperatures are lower during spring (March, April, and May) and fall months (September, October, and November) than during summer months (June, July, and August).

Fecal coliform bacteria concentrations roughly follow the same rise and fall as water temperatures (fig. 8). The PaDEP criterion defines the swimming season as May 1 through September 30. While none of the three stations are completely below the PaDEP criterion during the swimming season, bacteria concentrations are lowest at MS3. The 10-year median concentration of bacteria at WB9 always exceeds the PaDEP criterion of 200 col / 100 mL during the swimming season and commonly exceeds the higher PaDEP criterion of 2,000 col / 100 mL, the criterion that pertains to the remainder of the year. However, during March, April, October, and November, some individual bacteria samples do exceed the PaDEP criterion. The 10-year median concentration of bacteria at EB10 exceeds the PaDEP swimming season criterion. The remainder of the year at EB10, the 10-year median concentration of bacteria does not exceed the PaDEP criterion. The 10-year median concentration of bacteria at MS3 exceeds the PaDEP swimming season criterion only in June.

Effect of Reservoirs

Three reservoirs are located in the Brandywine Creek Basin: Chambers Lake Reservoir (also known as Birch Run Reservoir), Rock Run Reservoir (also known as Coatesville Reservoir), and Marsh Creek Reservoir. Samples were collected above and below each reservoir. A comparison of the bacteria concentrations at sites above and below each reservoir during base flow and stormflow is shown in figure 9. Bacteria concentrations in streams that flow out of the reservoirs are much lower than the bacteria concentrations in the streams that flow into the

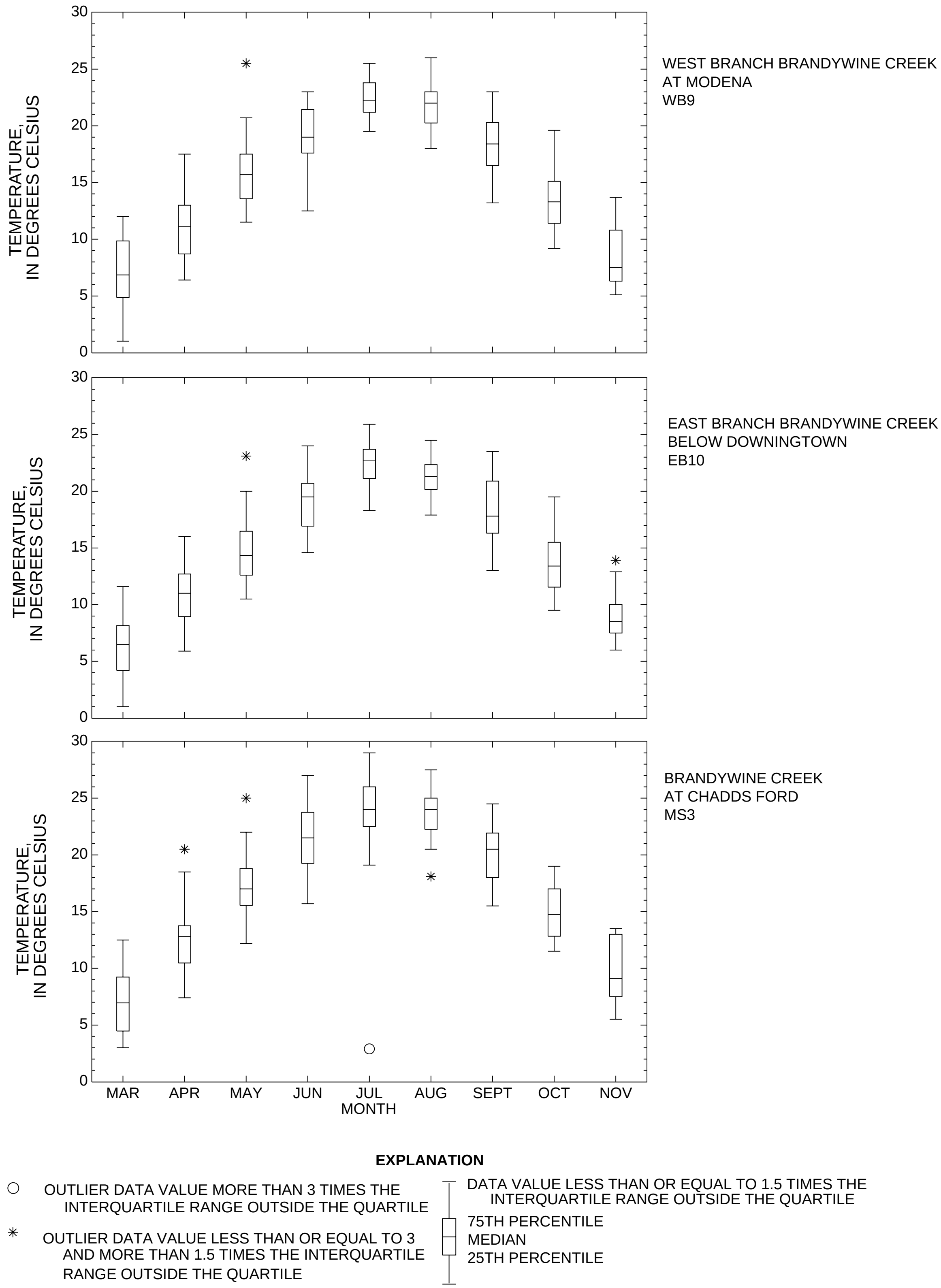


Figure 7. Distribution of monthly water temperatures during base flow and stormflow at West Branch Brandywine Creek at Modena, East Branch Brandywine Creek below Downingtown and Brandywine Creek at Chadds Ford, Pennsylvania, 1990-99.

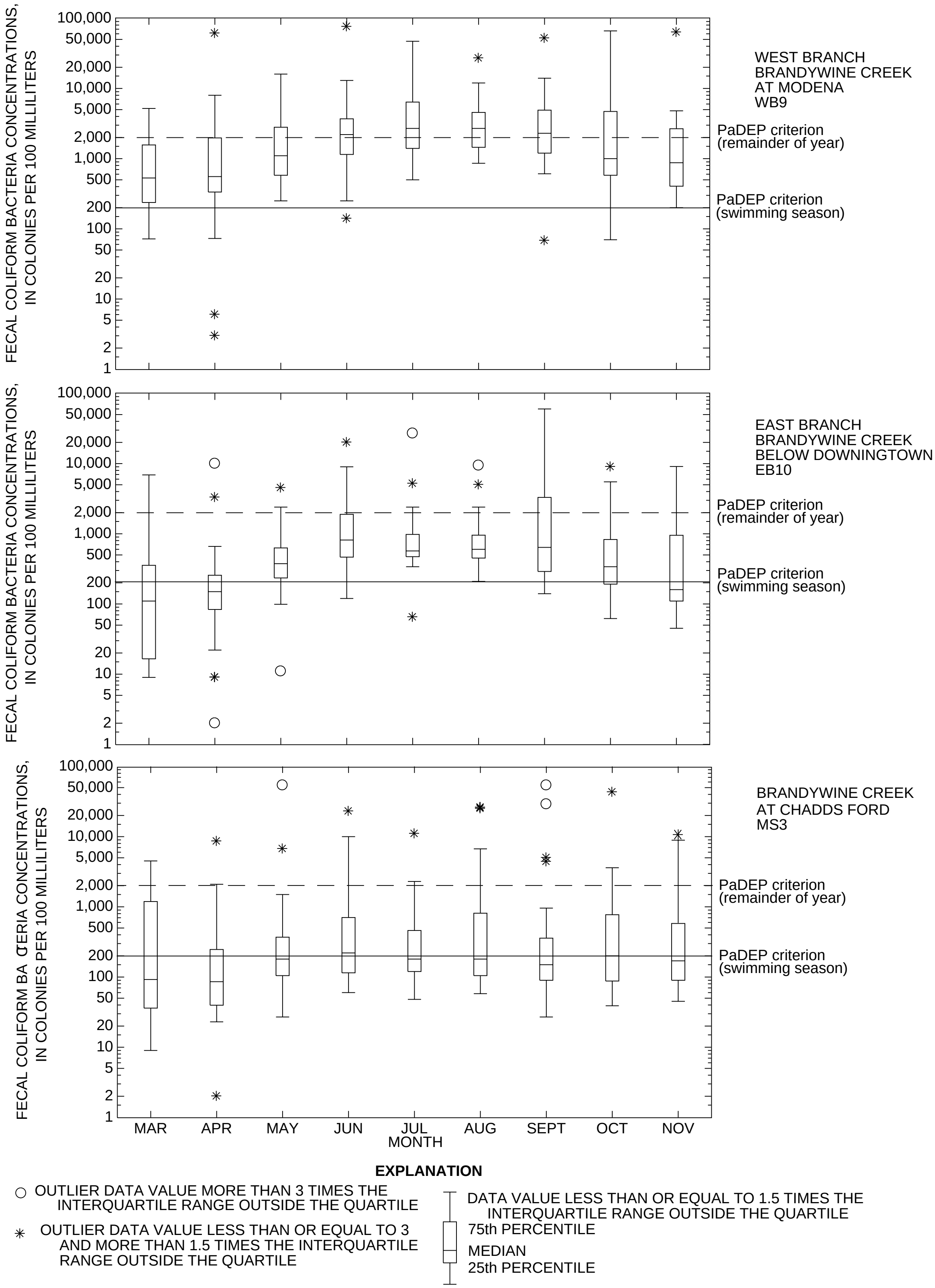


Figure 8. Distribution of monthly fecal coliform bacteria concentrations for base flow and stormflow, West Branch Brandywine Creek at Modena, East Branch Brandywine Creek below Downingtown, and Brandywine Creek at Chadds Ford, Pennsylvania, 1990-99.

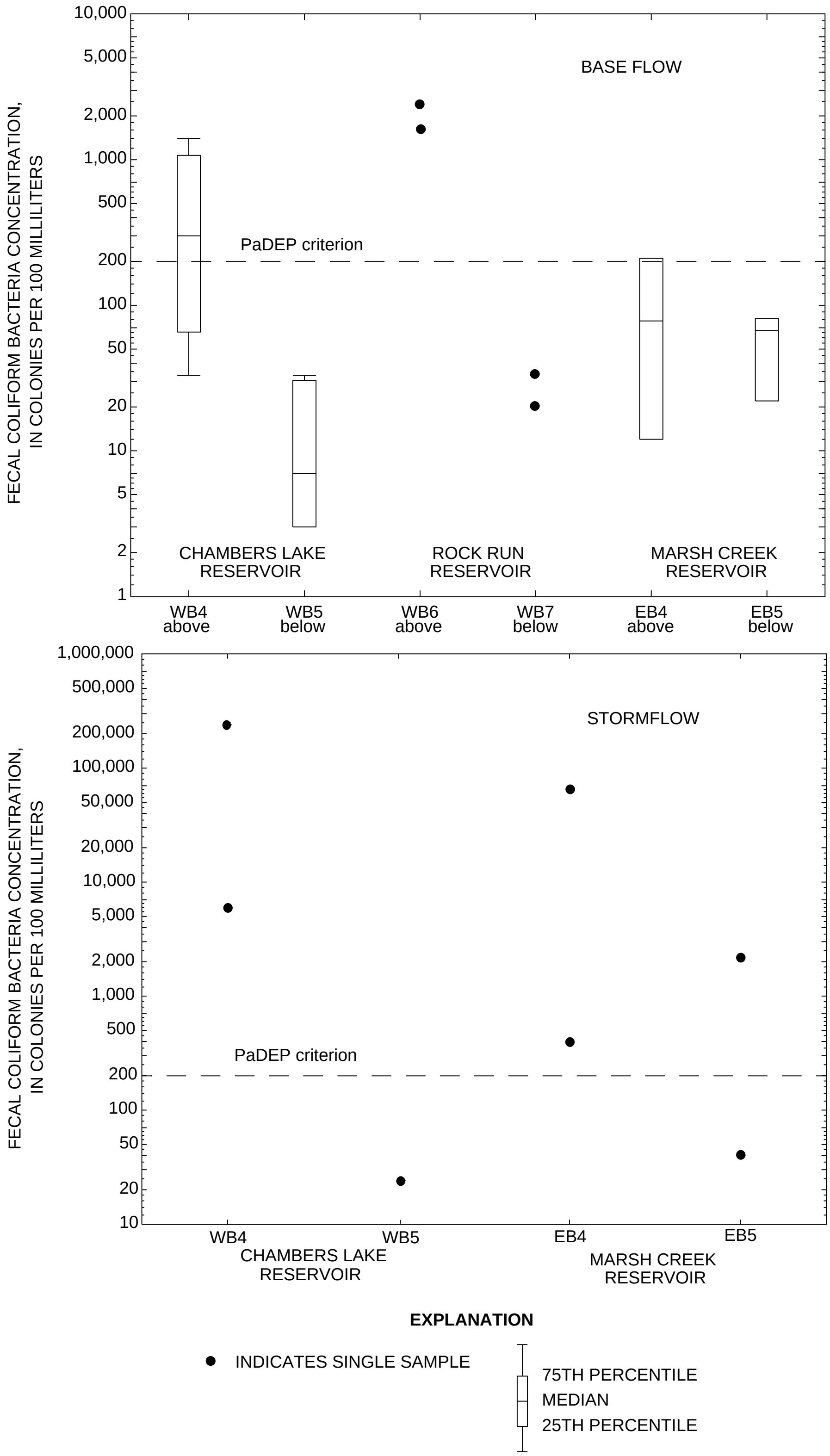


Figure 9. Distribution of concentrations of fecal coliform bacteria during base flow and stormflow at sampling sites above and below Chambers Lake Reservoir, Rock Run Reservoir, and Marsh Creek Reservoir, Chester County, Pennsylvania, 1998-99.

reservoirs. Because the volume of water flowing into the reservoir is very small compared to the volume of water already residing in the reservoir, the bacteria concentrations in the streams below the reservoirs reflect bacteria concentrations in the reservoirs, and not the bacteria concentrations in the streams that flow into the reservoirs.

On the West Branch, Chambers Lake Reservoir and Rock Run Reservoir typically release water from the bottom. The chemistry of the water released from the bottom of a reservoir is different than the water entering from a source above the reservoir. The water at the bottom of a reservoir is usually colder (between 1 to 5°C), anoxic, and may have become stratified. In addition, the residence time of the water in a reservoir is long and allows for natural die-off of bacteria. On the East Branch, Marsh Creek Reservoir releases water on a multi-level basis. Typically, Marsh Creek Reservoir releases water from the middle of the reservoir.

In most cases, during storms at all three reservoirs, water flows over the top of the reservoir, reducing residence time. During large storms, such as Hurricane Floyd on September 16, 1999, water also is released from the bottom. A sample collected on July 20, 1999, during a storm at EB5 (below Marsh Creek Reservoir) had a concentration of fecal coliform bacteria of 40 col / 100 mL. No sample was collected from the site above the reservoir. On September 16, 1999, a sample collected during Hurricane Floyd from EB4 (above Marsh Creek Reservoir) had a fecal coliform bacteria concentration of 66,000 col / 100 mL. The sample collected at EB5 (below the reservoir) had a fecal coliform bacteria concentration of 2,200 col / 100 mL. The bacteria concentration below the reservoir reflects a mixture of the older-residence time water being released from the bottom and the younger-residence time water, which was the result of the hurricane.

COMPARISON OF BACTERIA CONCENTRATIONS DURING BASE FLOW AND STORMFLOW

Comparisons were made between bacteria concentrations observed during base flow and stormflow. Bacteria concentrations at five sites where at least four samples at each site were collected during both base flow and stormflow are listed in table 5. A comparison of bacteria concentrations during base flow and stormflow is shown in figure 10. For all five sites, bacteria concentrations were higher during stormflow than during base flow.

Storm runoff contains elevated concentrations of bacteria. Rainfall flushes the land surface and causes bacteria to be transported into Brandywine Creek, thereby increasing the bacteria concentration. Consequently, storms accelerate the influx of bacteria from any given source through land-surface runoff. In all analyses, Brandywine Creek tributaries have higher bacteria concentrations during stormflow than during base flow. During stormflow, median concentrations of fecal coliform bacteria at sites on 14 of 15 tributaries (93 percent) to Brandywine Creek were greater than 200 col / 100 mL.

***Table 5.** Range and median concentrations of fecal coliform bacteria concentrations during base flow and stormflow for five sites in the Brandywine Creek Basin, Chester County, Pennsylvania, 1998-99*

[FC, fecal coliform; col/100 mL, colonies per 100 milliliters; ID, identification number]

Local ID	U.S. Geological Survey site ID	Site name	Base flow range of FC concentration (col/100 mL)	Base flow FC median concentration (col/100 mL)	Stormflow range of FC concentration (col/100 mL)	Stormflow FC median concentration (col/100 mL)
WB2	01480300	West Branch Brandywine Creek near Honey Brook	63 - 10,000	4,500	1,100 - 610,000	12,000
WB8	01480500	West Branch Brandywine Creek at Coatesville Reservoir	2 - 1,800	410	3,700 - 16,000	7,200
WB9	01480617	West Branch Brandywine Creek at Modena	6 - 4,400	940	2,700 - 15,000	6,000
EB10	01480870	East Branch Brandywine Creek below Downingtown	80 - 8,000	590	1,400 - 12,000	4,500
MS3	01481000	Brandywine Creek at Chadds Ford	2 - 2,200	110	160 - 6,700	2,200

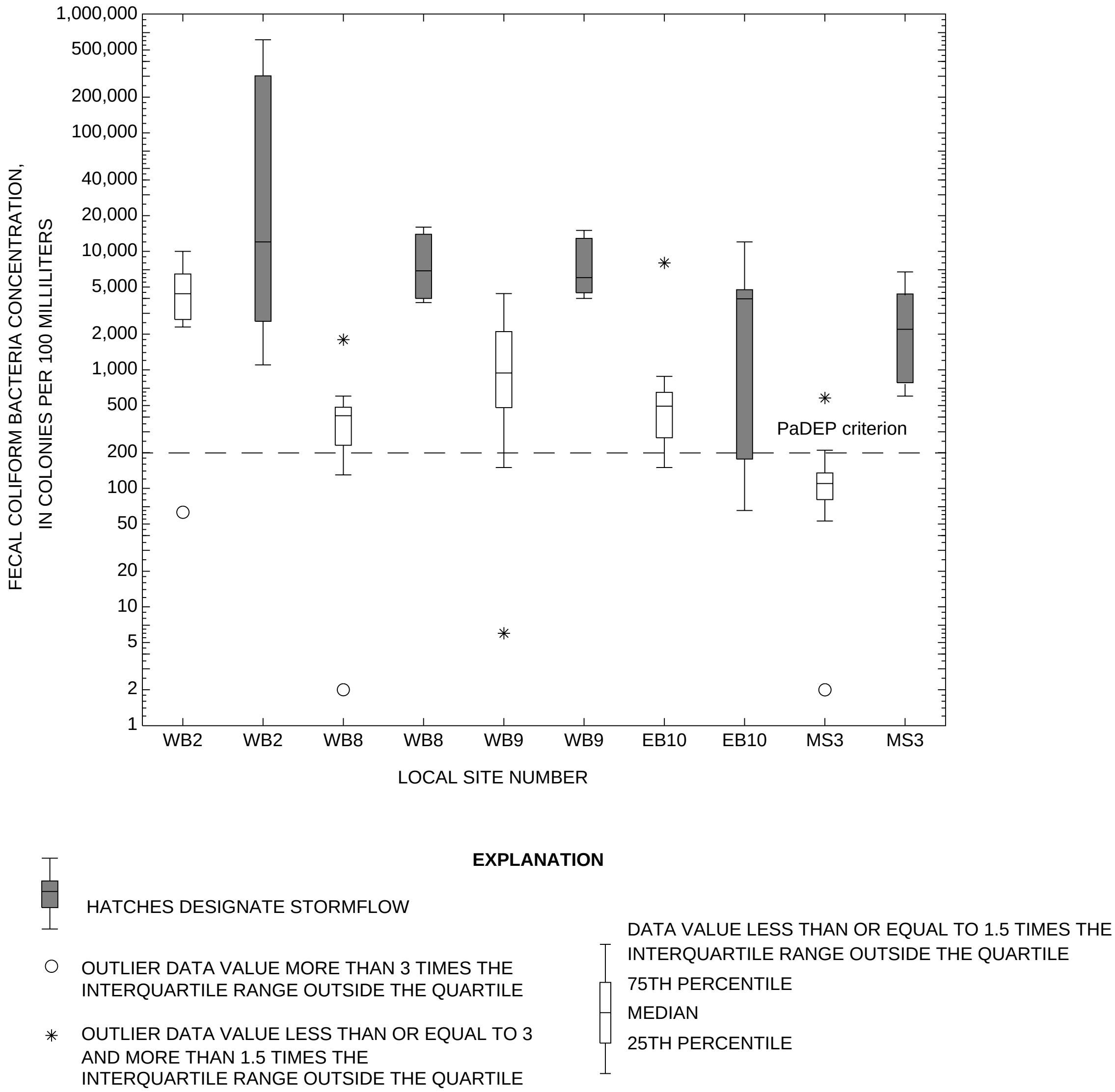


Figure 10. Distribution of fecal coliform bacteria concentrations during base flow and stormflow at selected sampling sites in the Brandywine Creek Basin, Chester County, Pennsylvania, 1998-99.

EXTENT AND POTENTIAL SOURCES OF FECAL AND *ESCHERICHIA COLI* BACTERIA

Bacteria sources were identified by examining bacterial counts in downstream sequence. An increase in bacteria concentration at a sampling site compared to the concentration at the closest upstream sampling site indicates a bacteria source between the two sites. Data on concentrations of *E. coli* bacteria are noted in this section; however, the fecal coliform bacteria data provided a more comprehensive picture of the extent and potential source of bacteria and were used for primary analysis. During base flow, 91 percent of the 24 non-estimated water samples contained *E. coli* / fecal coliform bacteria ratios greater than 1:2. During storms, 37 percent of the eight non-estimated water samples contained *E. coli* / fecal coliform bacteria ratios greater than 1:2. The data given in tables 6 to 11 at the back of the report are field chemistry measurements and bacteria concentrations during base flow and stormflow conditions.

Bacteria concentration and land use were compared at each of the 40 sites on the Brandywine Creek. Data for the branches and the main stem were examined individually. Median concentrations of fecal coliform bacteria were used for a comparison between the branches and main stem during base flow and stormflow and are shown in figures 11 and 12, respectively. Typically, elevated bacteria concentrations during base flow and stormflow indicate pollution from point and nonpoint sources. During base flow, elevated bacteria concentrations in the Brandywine Creek appear to come from nonpoint sources such as contaminated ground water, or from farm animals and wildlife entering and leaving waste in the stream. During stormflow, land-surface runoff, a nonpoint source, is the causal agent for the elevated bacteria concentrations in all of the subbasins.

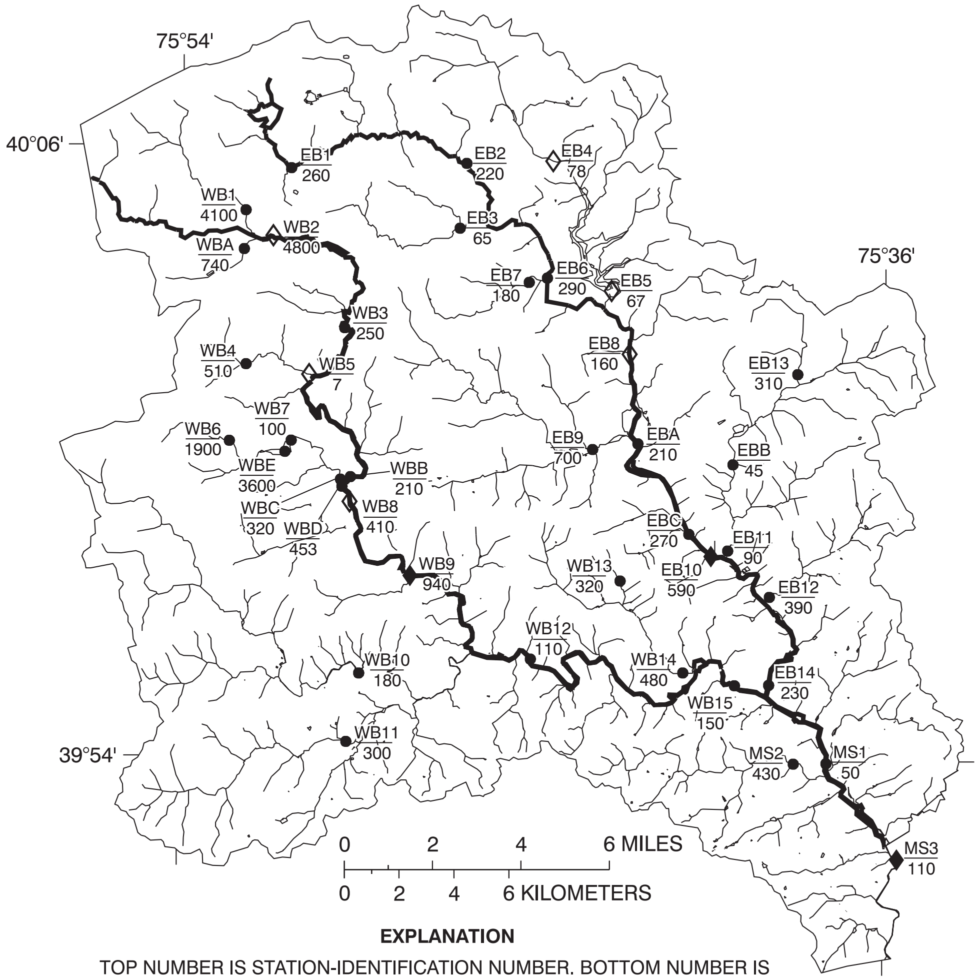
At base flow, the median concentrations of fecal coliform bacteria at sites on the West Branch exceed 200 col / 100 mL at 15 of the 20 sites (75 percent). The median concentrations of fecal coliform bacteria at sites on the East Branch exceed 200 col / 100 mL at 10 of the 17 sites (58 percent). The median concentrations of fecal coliform bacteria at sites on the main stem exceed 200 col / 100 mL at one of the three sites (33 percent). During stormflow, the median concentrations of fecal coliform bacteria at sites on the West Branch exceed 200 col / 100 mL at 12 of the 13 sites (92 percent). The median concentrations of fecal coliform bacteria at sites on the East Branch exceed 200 col / 100 mL at 15 of the 17 sites (88 percent). The median concentrations of fecal coliform bacteria at sites on the main stem exceed 200 col / 100 mL at all 3 sites.

Samples analyzed for *E. coli* bacteria were limited in number at each site; therefore, median concentrations of *E. coli* bacteria were not determined for either base flow or stormflow.

West Branch Brandywine Creek

Distributions of fecal coliform bacteria concentrations in the West Branch Brandywine Creek during base flow and stormflow are shown in figure 13. During base flow, 75 percent of the sites had bacteria concentrations above the PaDEP criterion of 200 col / 100 mL. During storms, 92 percent of the sites had bacteria concentrations above the PaDEP criterion. Of the 20 sites sampled, 11 sites were on tributaries. During base flow, Birch Run, Rock Run, and Buck Run had median bacteria concentrations below 200 col / 100 mL. During stormflow, only Birch Run below the Reservoir had a median bacteria concentration that was below 200 col / 100 mL.

In the headwaters of the West Branch Brandywine Creek, fecal coliform concentrations at West Branch Brandywine Creek at Rockville (WB1) at base flow ranged from 200 to 5,500 col / 100 mL; the median was 4,100 col / 100 mL. Three samples were analyzed for *E. coli;* the concentrations were greater than 600, 1,000 and 5,900 col / 100 mL. No samples were collected at WB1 during stormflow. West Branch Brandywine Creek at Rockville (WB1) and West Branch Brandywine Creek near Honey Brook (WB2) are very close to one another and have similar land uses; WB2 is at a USGS streamflow-measurement station. Because base-flow samples at both sites were similar in bacteria concentration, stormflow sampling was done at WB2, and the sample was considered to be representative for both sites. WB1 is located in a subbasin that is predominantly agricultural (72 percent). Cows and horses are pastured in an area upstream of WB1 that has an unfenced creek, causing a nonpoint source for bacteria during base flow and stormflow. Farms that support crops and livestock are within 0.5 mi upstream of WB1.



EXPLANATION

TOP NUMBER IS STATION-IDENTIFICATION NUMBER. BOTTOM NUMBER IS MEDIAN FECAL COLIFORM BACTERIA CONCENTRATION IN COLONIES PER 100 MILLILITERS.

● WB11/300 SAMPLING SITE

◆ MS3/300 SAMPLING SITE AT USGS STREAMFLOW-MEASUREMENT STATION WITH WATER QUALITY MONITOR

◇ WB8/300 SAMPLING SITE AT USGS STREAMFLOW-MEASUREMENT STATION

Figure 11. Median concentrations of fecal coliform bacteria during base flow, Brandywine Creek Basin, Chester County, Pennsylvania, 1998-99.

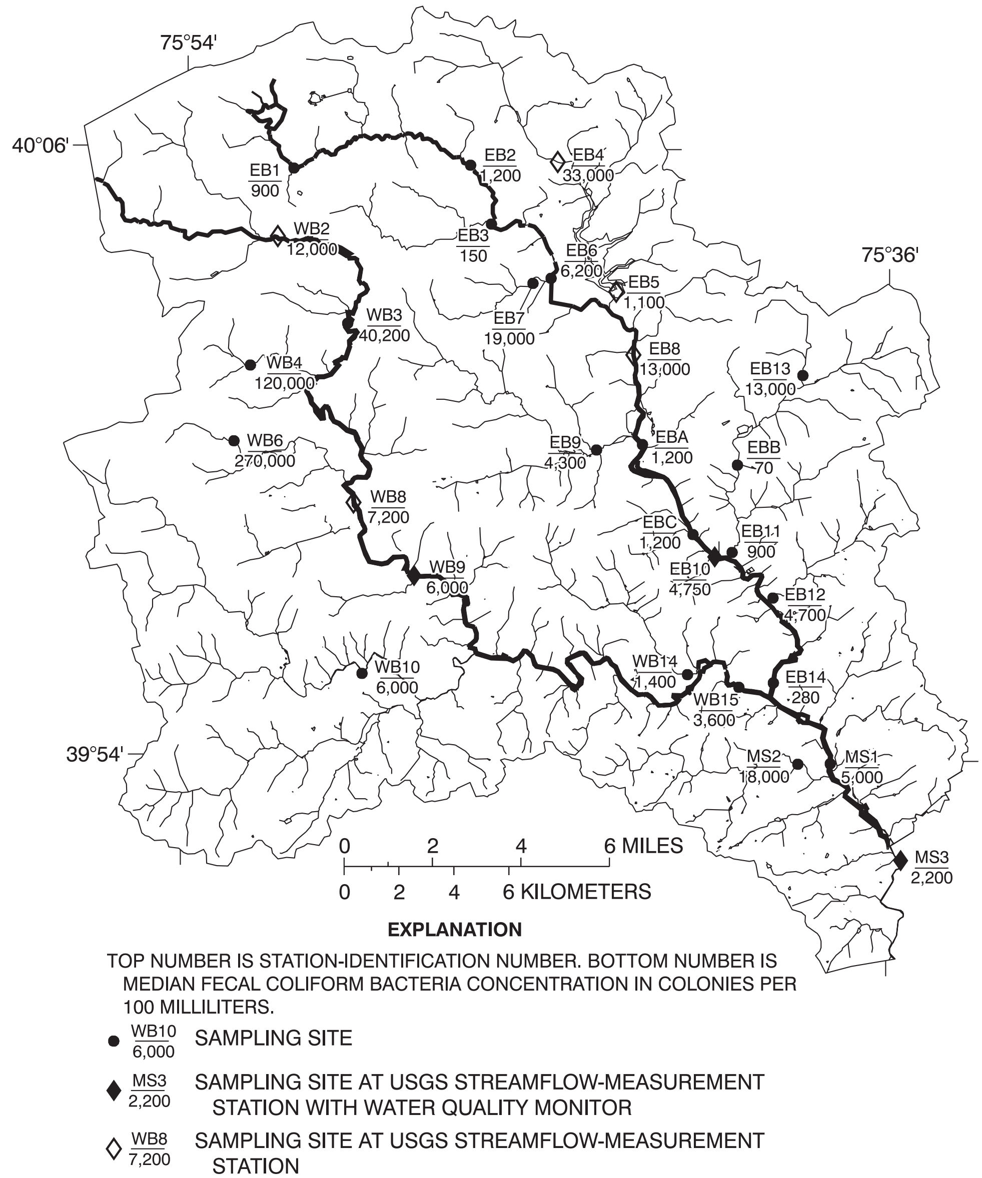


Figure 12. Median concentrations of fecal coliform bacteria during stormflow, Brandywine Creek Basin, Chester County, Pennsylvania, 1998-99.

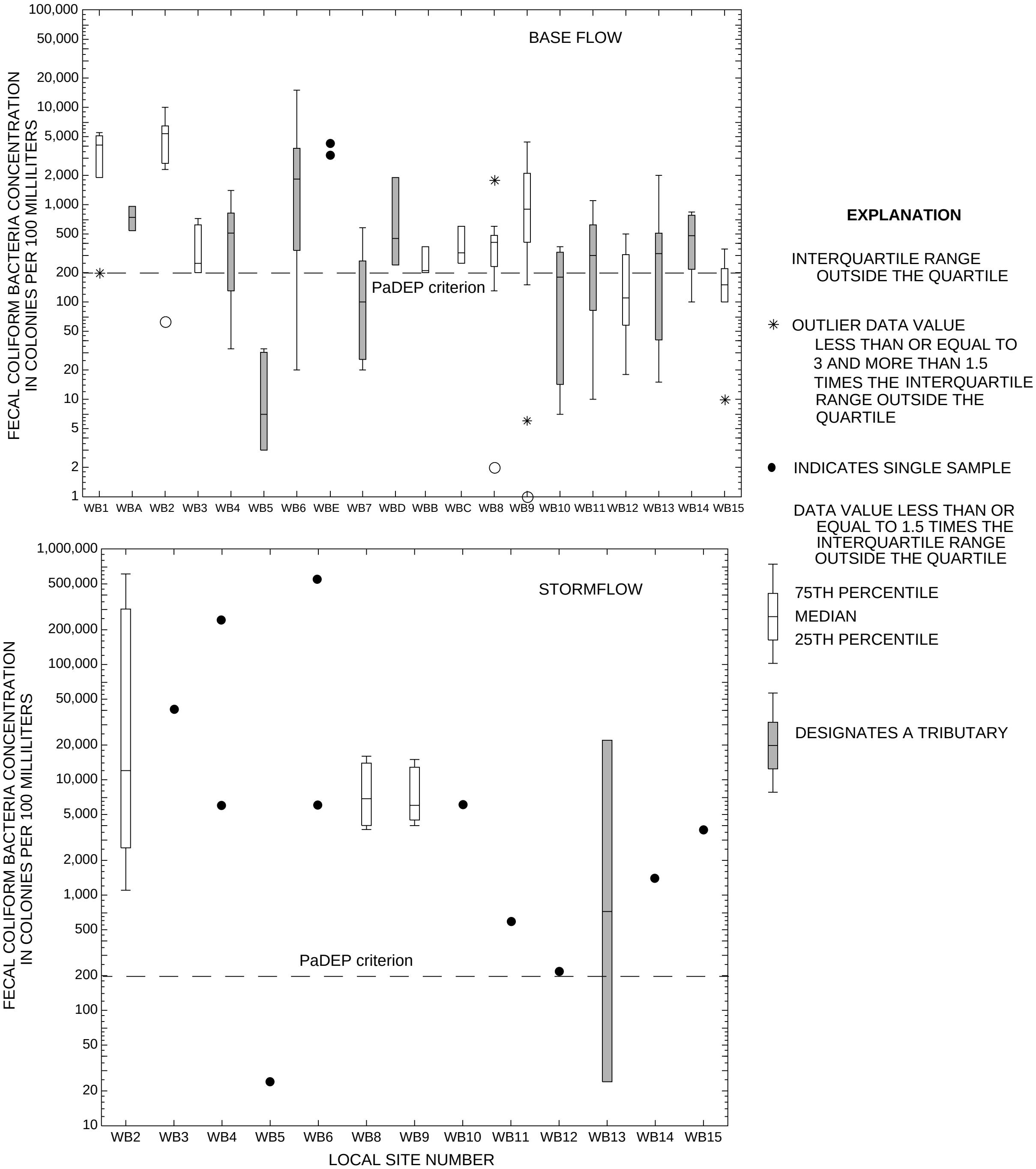


Figure 13. Distribution of concentrations of fecal coliform bacteria during base flow and stormflow at sampling sites on West Branch Brandywine Creek, Chester County, Pennsylvania, 1998-99.

Fecal coliform bacteria concentrations at Two Log Run at Birdell (WBA) during base flow were measured three times. Concentrations were 540, 740, and 960 col / 100 mL. No stormflow or *E. coli* bacteria samples were collected at this site. The subbasin is predominantly forested (54 percent). Cropland is within 0.5 mi upstream of WBA. This site, which is on a tributary below WB1 and above WB2, was added midway through the study to collect additional data to evaluate the bacteria contribution of this tributary to elevated bacteria concentrations measured at WB2. Although the median concentration of fecal coliform bacteria at WBA is lower than at WB2, the median concentration of bacteria at WBA still exceeds the PaDEP criterion of 200 col / 100 mL. Two Log Run contributes elevated bacteria concentrations to West Branch Brandywine Creek.

At West Branch Brandywine Creek near Honey Brook (WB2), concentrations of fecal coliform bacteria at base flow ranged from 63 to 10,000 col / 100 mL; the median concentration was 4,800 col / 100 mL. Three samples were analyzed for *E. coli* bacteria; concentrations were less than 1,900, 6,600, and greater than 8,000 col / 100 mL. During stormflow, the concentrations of fecal coliform bacteria at WB2 ranged from 1,100 to 610,000 col / 100 mL; the median concentration was 12,000 col / 100 mL. Three samples were analyzed for *E. coli* bacteria; concentrations were 8,000, 16,000 and 250,000 col / 100 mL. The maximum bacteria concentrations during stormflow for fecal coliform and *E. coli* were measured during Hurricane Floyd and are not considered to be normal storm event bacteria concentrations. The subbasin is predominantly agricultural (68 percent). Within 0.5 mi upstream of WB2 is cropland, and horses are in a pasture that contains an unfenced stream.

Concentrations of fecal coliform bacteria at West Branch Brandywine Creek at Brandamore (WB3) during base flow ranged from 200 to 720 col / 100 mL; the median concentration was 250 col / 100 mL. One sample was collected for *E. coli* bacteria; the concentration was 470 col / 100 mL. One stormflow sample was collected and analyzed for *E. coli* bacteria; the concentration was 1,000 col / 100 mL. No stormflow samples were measured for fecal coliform bacteria. The subbasin is predominantly agricultural (58 percent). The lower base-flow concentrations at WB3 may be attributable to the site's distance from WB2. The long reach of stream between the two sites allows die-off of bacteria by deposition (into the streambed), ultra-violet inactivation (sunlight), grazing (by protozoa and other microorganisms), or simply natural attenuation of the bacteria resulting in a decrease in concentration.

Concentrations of fecal coliform bacteria at Birch Run near Martins Corner (WB4) during base flow ranged from 33 to 1,400 col / 100 mL; the median concentration was 510 col / 100 mL. Two samples were collected for analysis of *E. coli* bacteria; concentrations were 180 and 230 col / 100 mL. Two samples were collected during stormflow for analysis of fecal coliform and *E. coli* bacteria. Concentrations of fecal coliform bacteria were greater than 6,000 and greater than 240,000 col / 100 mL, and concentrations of *E. coli* bacteria were greater than 8,000 and greater than 320,000 col / 100 mL. The maximum bacteria concentrations during stormflow for fecal coliform and *E. coli* were measured during Hurricane Floyd and are not considered to be normal storm event bacteria concentrations. The subbasin is predominantly forested (54 percent), and the stream for 0.5 mi above WB4 is forested. This site is above the Chambers Lake Reservoir. Birch Run contributes elevated bacteria concentrations to Chambers Lake Reservoir.

Concentrations of fecal coliform bacteria at Birch Run near Wagontown (WB5) during base flow ranged from 3 to 33 col / 100 mL; the median concentration was 7 col / 100 mL. Both *E. coli* bacteria sample concentrations were less than 3 col / 100 mL. One stormflow sample was collected; the concentration of fecal coliform bacteria was 24 col / 100 mL. No *E. coli* bacteria sample was collected at stormflow. The subbasin is predominantly forested (53 percent). Because this site is below the Chambers Lake Reservoir, it has low bacteria concentrations. The outflow from the reservoir does not contribute elevated bacteria concentrations to the West Branch Brandywine Creek.

Concentrations of fecal coliform bacteria at Rock Run near Philipsville (WB6) during base flow ranged from 20 to 15,000 col / 100 mL; the median concentration was 1,900 col / 100 mL. Three samples were analyzed for *E. coli* bacteria; concentrations were 1,400, 1,500, and 1,600 col / 100 mL. Two samples were analyzed for fecal coliform and *E. coli* bacteria during stormflow. Concentrations of fecal coliform bacteria were 6,000 and 540,000 col / 100 mL; *E. coli* bacteria concentrations were 8,000 and 16,000 col / 100 ml. The maximum bacteria concentrations during stormflow for fecal coliform and *E. coli* were measured during Hurricane Floyd and are not considered to be normal storm event bacteria concentrations. The subbasin is predominantly agricultural (58 percent). This site is above the Rock Run Reservoir. Forest and cropland is within 0.5 mi upstream of WB6. Rock Run contributes elevated bacteria concentrations to Rock Run Reservoir.

Concentrations of fecal coliform bacteria at Rock Run at Coatesville (Rock Run) Reservoir near Coatesville (WBE) were measured twice during base flow. The bacteria concentrations were 3,300 and 3,900 col / 100 mL. No stormflow or *E. coli* bacteria samples were collected. The subbasin is predominantly agricultural (52 percent). This site was added midway through the study to collect additional data between sites WB6 and WB7. The right side of the creek is forested within 0.5 mi upstream of WBE. On the left side, the creek runs past cropland, cattle pasture, and an open field. Site WBE is downstream from site WB6, and bacteria concentrations increase from site WB6 to site WBE. Rock Run is usually about 20 ft in width. During the drought in 1999 when samples were collected, Rock Run was only 4 to 5 ft wide. A possible cause for the increased concentration of bacteria is the decrease in streamflow in Rock Run because of the drought.

Concentrations of fecal coliform bacteria at Rock Run below Coatesville (Rock Run) Reservoir (WB7) during base flow ranged from 20 to 580 col / 100 mL; the median concentration was 100 col / 100 mL. Two samples were collected for *E. coli* bacteria; concentrations were 93 and 97 col / 100 mL. No stormflow samples were collected. The land use in the subbasin is mixed—49 percent agriculture, 26 percent forested, and 16 percent residential. Because this site is below the Rock Run Reservoir, bacteria concentrations are lower than at sites WB6 and WBE, which are above the reservoir.

Concentrations of fecal coliform bacteria for Rock Run at Rock Run near Coatesville (WBD) were measured three times during base flow. The concentrations were 240, 453, and 1,900 col / 100 mL. No stormflow or *E. coli* bacteria samples were collected. The land use in the subbasin is mixed—47 percent agriculture, 33 percent forested, and 15 percent residential. This site was added midway through the study to collect additional data between sites WB7 and WB8. Bacteria concentrations at site WBD, which is just upstream from the confluence of Rock Run and the Brandywine Creek, are much higher than at upstream site WB7, which is below the Rock Run Reservoir. The land is forested and residential within 0.5 mi upstream of WBD. Concrete banks line Rock Run at the sample site. Disposable diapers and rodents were present in Rock Run at times when samples were collected. A nonpoint source for bacteria during base flow is the surrounding urbanized area. Rock Run contributes elevated bacteria concentrations to the West Branch Brandywine Creek.

Concentrations of fecal coliform bacteria at West Branch Brandywine Creek at Rock Run (WBB) were measured three times during base flow. Concentrations were 200, 210, and 370 col / 100 mL. No stormflow or *E. coli* bacteria samples were collected. The land use in the subbasin is mixed—48 percent agricultural, 33 percent forested, and 14 percent residential. Residences and forest line the creek within 0.5 mi upstream of WBB. This site was added midway through the study to collect additional data between WB7 and WB8. The Brandywine Creek above WBB has a lower bacteria concentration than at WBC, which is below WBB, and receives water with elevated bacteria concentrations from Rock Run. The bacteria concentrations at WBB were only slightly above the PaDEP criterion.

Concentrations of fecal coliform bacteria at West Branch Brandywine Creek below Rock Run at Coatesville (WBC) during base flow were measured three times; concentrations were 250, 320, and 600 col / 100 mL. No stormflow or *E. coli* bacteria samples were collected. The land use in the subbasin is mixed—47 percent agricultural, 33 percent forested, and 15 percent residential. This site was added mid-way through the study to collect additional data between WB7 and WB8. Residences are on both sides of the creek within 0.5 mi upstream of WBC. WBC is downstream from site WBB, and bacteria concentrations are higher at WBC than at site WBB.

Concentrations of fecal coliform bacteria at West Branch Brandywine Creek at Coatesville (Rock Run) Reservoir (WB8) during base flow ranged from 2 to 1,800 col / 100 mL; the median concentration was 410 col / 100 mL. Three samples were analyzed for *E. coli* bacteria; concentrations were 100, 240 and 500 col / 100 mL. Fecal coliform bacteria concentrations during stormflow ranged from 3,700 to 16,000 col / 100 mL; the median concentration was 7,200 col / 100 mL. Two samples were analyzed for *E. coli* bacteria during stormflow; concentrations were 1,400 and 12,000 col / 100 mL. The maximum bacteria concentrations during stormflow for fecal coliform and *E. coli* were measured during Hurricane Floyd and are not considered to be normal storm event concentrations. The land use in the subbasin is mixed—47 percent agricultural, 33 percent forested, 15 percent residential, and 2 percent urban (around the city of Coatesville). Residences and forested areas line both sides of the creek within 0.5 mi upstream of WBB. Site WB8 is in an industrial area of Coatesville. Bacteria concentrations increase between WBB and WB8. A nonpoint source for the elevated bacteria concentrations during base flow is the urbanized area between WBB and WB8.

Concentrations of fecal coliform bacteria at West Branch Brandywine Creek at Modena (WB9) during base flow ranged from 6 to 4,400 col / 100 mL; the median concentration was 940 col / 100 mL. Concentrations of *E. coli* bacteria ranged from 100 to 800 col / 100 mL. Fecal coliform bacteria concentrations during stormflow ranged from 4,000 to 15,000 col / 100 mL; the median concentration was 6,000 col / 100 mL. Three samples were analyzed for *E. coli* bacteria; concentrations were 600, 2,900, and greater than 8,000 col / 100 mL. The land use in the subbasin is mixed—42 percent agricultural, 33 percent forested, 16 percent residential, and 4 percent urban. Approximately 1 mi upstream of WB9 is an industrial plant with a wastewater treatment plant and a storm sewer outfall. Immediately upstream of WB9 are residences and forested areas on the right side of the creek and an urban / industrial area on the left side of the creek. Bacteria concentrations increase substantially between WB8 and WB9. Nonpoint sources for bacteria contamination are the urban area surrounding the creek.

Concentrations of fecal coliform bacteria at Buck Run at Doe Run (WB10) during base flow ranged from 7 to 370 col / 100 mL; the median concentration was 180 col / 100 mL. Two *E. coli* bacteria samples were collected; concentrations were 69 and 260 col / 100 mL. One sample was collected during stormflow; the concentration of fecal coliform bacteria was greater than 6,000 col / 100 mL, and the *E. coli* bacteria concentration was greater than 8,000 col / 100 mL. The land use in the subbasin is predominantly agricultural (58 percent); however, 28 percent of the subbasin is forested and 11 percent is residential. At base flow, Buck Run does not contribute elevated bacteria concentrations to Doe Run to which it is a tributary.

Concentrations of fecal coliform bacteria at Doe Run above tributary at Springdell (WB11) during base flow ranged from 10 to 1,100 col / 100 mL; the median concentration was 300 col / 100 mL. Two samples were collected and tested for *E. coli* bacteria; concentrations were 110 and 690 col / 100 mL. One sample was collected during stormflow; the fecal coliform bacteria concentration was 580 col / 100 mL. No *E. coli* bacteria samples were collected during stormflow. The land use in the subbasin is predominantly agricultural (76 percent). Within 0.5 mi upstream of WB11 is cropland on the right side and horses in a fenced pasture on the left side of Doe Run. Doe Run contributes elevated bacteria concentrations to the West Branch Brandywine Creek.

Concentrations of fecal coliform bacteria at West Branch Brandywine Creek near Embreeville (WB12) during base flow ranged from 18 to 500 col / 100 mL; the median concentration was 110 col / 100 mL. Two water samples were collected and tested for *E. coli* bacteria; concentrations were 68 and 120 col / 100 mL. One sample was collected during stormflow and analyzed for fecal coliform and *E. coli* bacteria; concentrations were 220 and 190 col / 100 mL, respectively. The subbasin surrounding WB12 is predominantly agricultural (53 percent). Bacteria concentrations decrease between WB9 and WB12. The long reach between the two sites and the consequent die-off of bacteria through deposition, UV inactivation, grazing, or natural attenuation account for the decrease in bacteria concentration.

Concentrations of fecal coliform bacteria at Little Broad Run near Marshallton (WB13) during base flow ranged from 15 to 2,000 col / 100 mL; the median concentration was 320 col / 100 mL. Three samples were analyzed for *E. coli* bacteria; concentrations were 200, 330, and 330 col / 100 mL. Three samples were analyzed for fecal coliform bacteria during stormflow; concentrations were 24, 720, and 22,000 col / 100 mL. One *E. coli* bacteria sample was collected during stormflow; the concentration was 670 col / 100 mL. The land use in the subbasin is mixed—38 percent residential, 27 percent forested, and 26 percent agricultural. Within 0.5 mi upstream of WB13 is riparian forest 75-120 ft wide; the remainder of the area is residential. Little Broad Run contributes elevated bacteria concentrations of bacteria to Broad Run.

Concentrations of fecal coliform bacteria during base flow at Broad Run at Northbrook (WB14) ranged from 100 to 840 col / 100 mL; the median concentration was 480 col / 100 mL. Two water samples were collected and tested for *E. coli* bacteria; concentrations were 46 and 320 col / 100 mL. One sample was collected during stormflow; the fecal coliform bacteria concentration was 1,400 col / 100 mL, and the *E. coli* bacteria concentration was 1,300 col / 100 mL. The land use in the subbasin is mixed—37 percent agricultural, 29 percent forested, and 29 percent residential. Dense riparian forest approximately 90-120 ft wide is on both sides of Broad Run within 0.5 mi upstream of WB14. Open, uncut fields extend out from the forest on both sides. A few residences are scattered on either side of the creek upstream. Broad Run contributes elevated concentrations of bacteria to the West Branch Brandywine Creek.

Concentrations of fecal coliform bacteria at West Branch Brandywine Creek at Wawaset (WB15) during base flow ranged from 10 to 350 col / 100 mL; the median concentration was 150 col / 100 mL. Three samples were analyzed for *E. coli* bacteria; concentrations were 60, 200, and 260 col / 100 mL. One sample was collected during stormflow; the fecal coliform bacteria concentration was 3,600 col / 100 mL, and the *E. coli* bacteria concentration was 1,300 col / 100 mL. The land use in the subbasin is predominantly agricultural (52 percent). Bacteria concentrations increase between sites WB12 and WB15 as a result of Broad Run's elevated bacteria concentrations. However, WB15's median bacteria concentration is below the PaDEP criterion.

East Branch Brandywine Creek

Fecal coliform bacteria concentrations on East Branch Brandywine Creek during base flow and stormflow are shown in figure 14. During base flow, bacteria concentrations at 58 percent of the sites exceeded the PaDEP criterion of 200 col / 100 mL. During storms, bacteria concentrations at 88 percent of the sites exceeded the PaDEP criterion. Of the 17 sites on the East Branch Brandywine Creek, 9 sites are located on tributaries. Four tributaries, Indian Run, Marsh Creek, Culbertson Run, and Valley Creek, had median bacteria concentrations below 200 col / 100 mL during base flow. Only the median bacteria concentrations at Indian Run remained below 200 col / 100 mL during stormflow.

Concentrations of fecal coliform bacteria in the headwaters of the East Branch Brandywine Creek at East Branch Brandywine Creek near Cupola (EB1) during base flow ranged from 31 to 1,200 col / 100 mL; the median concentration was 260 col / 100 mL. Two samples were analyzed for *E. coli* bacteria; the concentrations were 86 and 240 col / 100 mL. Two stormflow samples were collected and analyzed for fecal coliform bacteria; concentrations were 600 and greater than 1,200 col / 100 mL. No stormflow samples were collected for analysis of *E. coli* bacteria. Land use in the subbasin surrounding EB1 is predominantly agricultural (60 percent). Within 0.5 mi upstream of EB1 on one side is fenced farmland with cows and chickens. On the opposite side are residences. Cropland is further upstream.

Concentrations of fecal coliform bacteria at East Branch Brandywine Creek at Glenmoore (EB2) during base flow ranged from 63 to 330 col / 100 mL; the median concentration was 220 col / 100 mL. Two samples were collected and analyzed for *E. coli* bacteria; the concentrations were 110 and 170 col / 100 mL. Three samples were analyzed for fecal coliform bacteria during stormflow; concentrations were 450, greater than 1,200, and greater than 12,000 col / 100 mL. One sample was collected during stormflow and analyzed for *E. coli* bacteria; the concentration was greater than 16,000 col / 100 mL. EB2 is in a predominantly agricultural subbasin (53 percent). Cropland is on the right side and forest on the left side of the creek within 0.5 mi upstream of EB2. Bacteria concentrations decrease between EB1 and EB2. One possible reason for the decrease is the change in land use. Farm animals are replaced by forest at EB2. Overall the subbasin becomes less agricultural and more forested than the subbasin above EB1.

Concentrations of fecal coliform bacteria at Indian Run at Springton (EB3) were measured three times during base flow. The concentrations were 11, 65, and 71 col / 100 mL. One sample was collected and analyzed for *E. coli* bacteria; the concentration was 90 col / 100 mL. One sample was collected at stormflow; the fecal coliform bacteria concentration was 150 col / 100 mL. No *E. coli*

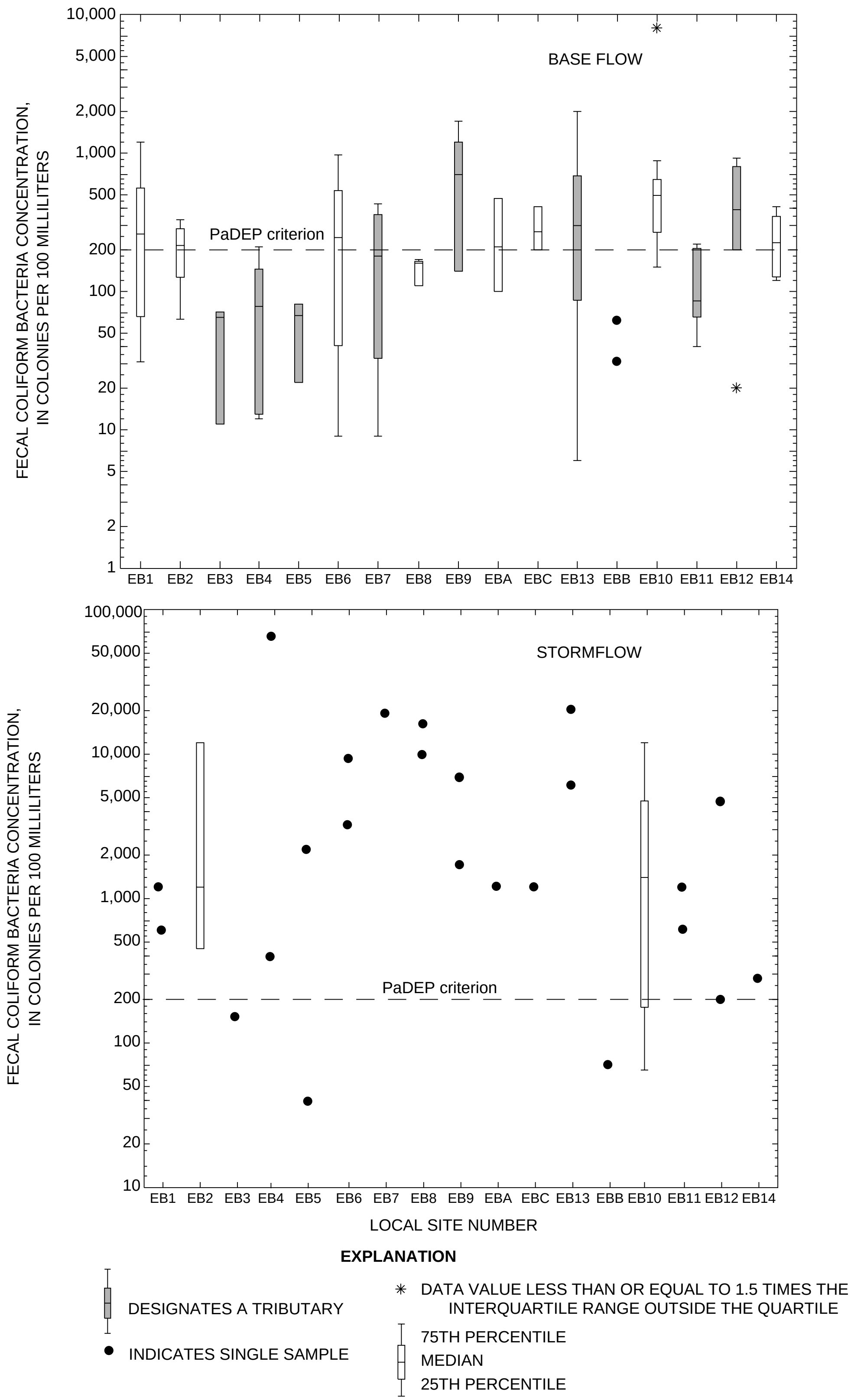


Figure 14. Distribution of concentrations of fecal coliform bacteria during base flow and stormflow at sampling sites on East Branch Brandywine Creek, Chester County, Pennsylvania, 1998-99.

bacteria samples were collected at stormflow. The land use in the subbasin is mixed—46 percent forested, 37 percent agricultural, and 12 percent residential. Forested areas become prevalent over agricultural areas between the subbasin above EB2 and the subbasin above EB3. Median bacteria concentrations decrease between the two subbasins. Indian Run does not contribute elevated concentrations of bacteria to East Branch Brandywine Creek.

Concentrations of fecal coliform bacteria during base flow at Marsh Creek near Glenmoore (EB4), which is above the Marsh Creek Reservoir, ranged from 12 to 200 col / 100 mL; the median concentration was 78 col / 100 mL. Two samples were collected and analyzed for *E. coli* bacteria; the concentrations were 2 and 230 col / 100 mL. Two samples were collected during stormflow and analyzed for fecal coliform bacteria; the concentrations were 400 and 66,000 col / 100 mL. One sample was collected and analyzed for *E. coli* bacteria; the concentration was 2,500 col / 100 mL. The second stormflow sample analyzed for fecal coliform and *E. coli* bacteria was collected during Hurricane Floyd and is not considered to be a bacteria concentration for a normal storm event. The land use in the subbasin is mixed—46 percent forested, 39 percent agricultural, and 8 percent residential. At base flow, Marsh Creek does not contribute elevated concentrations of bacteria to the Marsh Creek Reservoir.

Concentrations of fecal coliform bacteria at Marsh Creek near Downingtown (EB5) during base flow were measured three times. The concentrations were 22, 67, and 81 col / 100 mL. One *E. coli* bacteria sample was collected at base flow; the concentration was 75 col / 100 mL. Samples were collected twice during stormflow and analyzed for fecal coliform bacteria; the concentrations were 40 and 2,200 col / 100 mL. One sample was collected during stormflow and analyzed for *E. coli* bacteria; the concentration was 2,400 col / 100 mL. The land use in the subbasin is mixed—38 percent forested, 34 percent agricultural, and 17 percent residential. This site is below Marsh Creek Reservoir. Bacteria concentrations decrease between EB4 and EB5. The second stormflow sample analyzed for fecal coliform and E. coli bacteria was collected during Hurricane Floyd and is not considered to be a normal storm event bacteria concentration. During base flow, Marsh Creek does not contribute elevated bacteria concentrations to the East Branch Brandywine Creek.

Concentrations of fecal coliform bacteria at East Branch Brandywine Creek at Lyndell (EB6) during base flow ranged from 9 to 970 col / 100 mL; the median concentration was 290 col / 100 mL. Two samples were collected at base flow and analyzed for *E. coli* bacteria; concentrations were 100 and 120 col / 100 mL. Two samples were collected during stormflow and analyzed for fecal coliform bacteria; concentrations were 3,200 and 9,200 col / 100 mL. One sample was collected during stormflow and analyzed for *E.coli* bacteria; the concentration was 2,200 col / 100 mL. The land use in the subbasin is mixed—45 percent agriculture, 39 percent forested, and 10 percent residential. Forested area is on the left side of the creek within 0.5 mi of EB6. Approximately 150 ft upstream of EB6 is a campground. A pond on the campground property supports fish and geese. Bacteria concentrations increase between EB2 and EB6. During base flow, nonpoint sources for bacteria include wildlife and possibly several small tributaries between EB2 and EB6 that were not included in this study.

Concentrations of fecal coliform bacteria at Culbertson Run at Lyndell (EB7) during base flow ranged from 9 to 430 col / 100 mL; the median concentration was 180 col / 100 mL. Two samples were collected during base flow and analyzed for *E. coli* bacteria; concentrations were 200 and 340 col / 100 mL. One sample was collected during stormflow; the concentration of fecal coliform bacteria was 19,000 col / 100 mL, and the concentration of *E. coli* bacteria was 960 col / 100 mL. The land use in the subbasin is mixed—44 percent agricultural, 33 percent residential, and 21 percent forested. Residences are on both sides of Culbertson Run within 0.5 mi upstream of EB7. At base flow, Culbertson Run does not contribute elevated concentrations of bacteria to East Branch Brandywine Creek.

Concentrations of fecal coliform bacteria at East Branch Brandywine Creek near Downingtown (EB8) during base flow ranged from 110 to 170 col / 100 mL; the median concentration was 160 col / 100 mL. Two samples were analyzed for *E. coli* bacteria; concentrations were 110 and 170 col / 100 mL. Two samples were collected during stormflow and analyzed for fecal coliform bacteria and *E. coli*. Concentrations of fecal coliform bacteria were 9,800 and 16,000 col / 100 mL, and concentrations of *E. coli* bacteria were 4,000 and 4,400 col / 100 mL. The maximum bacteria concentrations during stormflow for fecal coliform and *E. coli* were measured during Hurricane Floyd and are not considered to be normal storm event bacteria concentrations. The land use in the subbasin is mixed—39 percent agricultural, 37 percent forested, and 16 percent residential. Bacteria concentrations decrease between EB6 and EB8.

Concentrations of fecal coliform bacteria at Beaver Creek near Downingtown (EB9) during base flow ranged from 140 to 1,700 col / 100 mL; the median concentration was 700 col / 100 mL. Two samples were collected at base flow and analyzed for *E. coli* bacteria; concentrations were 210 and 1,000 col / 100 mL. Two samples were collected during stormflow and analyzed for fecal coliform bacteria; concentrations were 1,700 and 6,800 col / 100 mL. No sample was collected during stormflow for analysis of *E. coli* bacteria. The land use in the subbasin is mixed—33 percent agricultural, 29 percent forested, and 25 percent residential. An open field, a park, and a pumping station are within 0.5 mi upstream from EB9. Beaver Creek contributes elevated bacteria concentrations to East Branch Brandywine Creek.

Concentrations of fecal coliform bacteria at East Branch Brandywine Creek at Downingtown (EBA) during base flow were measure three times. The concentrations were 100, 210, and 470 col / 100 mL. Two samples were collected at base flow and analyzed for *E. coli* bacteria; concentrations were 340 and 350 col / 100 mL. One sample was collected during stormflow; the concentration of fecal coliform bacteria was greater than 1,200 col / 100 mL, and the concentration of *E. coli* bacteria was greater than 800 col / 100 mL. The land use in the subbasin is mixed—36 percent agricultural, 36 percent forested, and 19 percent residential. A paper board company and the center of the borough of Downingtown is within 0.5 mi upstream of EBA. This site was added midway through the study to collect additional data between EB8 and EB10. Bacteria concentrations increase between EB8 and EBA. A tributary draining a pond in the center of Downingtown flows into the East Branch Brandywine Creek above EBA. Resident geese abound on this pond and may contribute to the slightly elevated bacteria concentrations at EBA. During storms, the nonpoint source is land-surface runoff, exacerbated by the urban areas of Downingtown. The paper board company discharges into the local sewer system and, therefore, is not considered to be a point source for bacterial contamination.

Concentrations of fecal coliform bacteria at East Branch Brandywine Creek at Altor (EBC) during base flow were analyzed three times. The concentrations were 200, 270, and 410 col / 100 mL. No samples were collected for analysis of *E. coli* bacteria during either base flow or stormflow. One sample was collected during stormflow; the concentration of fecal coliform bacteria was greater than 1,200 col / 100 mL. The land use in the subbasin is mixed—37 percent forested, 34 percent agricultural, and 20 percent residential. Forest, cropland, residences, and an unmanned wastewater treatment plant are within 0.5 mi upstream of EBC. Another wastewater treatment plant is approximately 1.4 mi upstream from EBC, and a paper plant is approximately 1.8 mi upstream. This site was added midway through the study to collect additional data between EBA and EB10. Bacteria concentrations increase between EBA and EBC.

Fecal coliform bacteria concentrations at Uwchlan Run at Exton (EB13) during base flow ranged from 6 to 2,000 col / 100 mL; the median was 310 col / 100 mL. Two samples were analyzed for *E. coli* bacteria; concentrations were 150 and 220 col / 100 mL. Two fecal coliform bacteria samples were collected during stormflow; concentrations were 6,000 and 20,000 col / 100 mL. No *E. coli* bacteria samples were collected during stormflow. Uwchlan Run was dry during July and August 1999 and was not sampled. The land use in the subbasin is predominantly residential (67 percent). A mixture of townhouses, open fields, forest, and urban area is within 0.5 mi upstream of EB13. Uwchlan Run contributes elevated concentrations of bacteria to Valley Creek.

Samples were collected twice at Valley Creek at Ravine Road near Downingtown (EBB) during base flow for analysis of fecal coliform bacteria; concentrations were 31 and 60 col / 100 mL. No samples were collected for analysis of *E. coli* bacteria. One sample was collected during stormflow; the concentration of fecal coliform bacteria was 70 col / 100 mL. No sample was collected during stormflow for analysis of *E. coli* bacteria. The land use in the subbasin is mixed—31 percent forested, 26 percent residential, and 20 percent agricultural. This site was added midway through the study to collect additional data between EB13 and EB11. Bacteria concentrations were below the PaDEP criterion of 200 col / 100 mL. An instream discharge facility is located between EB13 and EBB. The instream discharge is made by a quarry and consists of ground water pumped from the quarry. Ground water contains little or no bacteria, and the addition of ground water to the stream probably dilutes bacteria concentrations in Valley Creek.

Concentrations of fecal coliform bacteria at East Branch Brandywine Creek below Downingtown (EB10) during base flow ranged from 80 to 8,000 col / 100 mL; the median concentration was 590 col / 100 mL. One sample was collected during base flow and analyzed for *E. coli* bacteria; the concentration was 110 col / 100 mL. Concentrations of fecal coliform bacteria during stormflow ranged from 1,400 to 12,000 col / 100 mL; the median concentration was 4,500 col / 100 mL. Two samples were collected during stormflow and analyzed for *E. coli* bacteria; the concentrations were 1,000 and 16,000 col / 100 mL. The maximum concentrations for both fecal coliform and *E. coli* bacteria were measured during Hurricane Floyd and are not considered to be normal storm event bacteria concentrations. The land use in the subbasin is mixed—37 percent forested, 34 percent agricultural, and 20 percent residential. Forest lines both sides of the creek within 0.5 mi upstream of EB10.

Concentrations of fecal coliform bacteria at Valley Creek at Altor (EB11) during base flow ranged from 40 to 220 col / 100 mL. One sample was collected during base flow and analyzed for *E. coli* bacteria; the concentration was 290 col / 100 mL. Two samples were collected during stormflow and analyzed for fecal coliform bacteria; concentrations were 1,200 and 3,600 col / 100 mL. One sample was collected during stormflow and analyzed for *E. coli* bacteria; the concentration was 1,600 col / 100 mL. The land use in the subbasin is mixed—33 percent forested, 30 percent residential, and 19 percent agricultural. Bacteria concentrations slightly increased between EBB and EB11; however, Valley Creek does not contribute elevated concentrations of bacteria to East Branch Brandywine Creek.

Concentrations of fecal coliform bacteria at Taylor Run at Copesville (EB12) during base flow ranged from 20 to 920 col / 100 mL; the median concentration was 390 col / 100 mL. Two samples were collected at base flow and analyzed for *E. coli* bacteria; the concentrations were 130 to 390 col / 100 mL. One sample was collected during stormflow and analyzed for fecal coliform bacteria; the concentration was 4,700 col / 100 mL. No sample was collected for analysis of *E. coli* bacteria. The land use in the subbasin is mixed—37 percent residential, 26 percent forested, and 23 percent agricultural. The site is surrounded by hayfields. Taylor Run contributes elevated concentrations of bacteria to East Branch Brandywine Creek.

Concentrations of fecal coliform bacteria at East Branch Brandywine Creek at Wawaset (EB14) during base flow ranged from 120 to 410 col / 100 mL; the median concentration was 230 col / 100 mL. Three samples were analyzed for *E. coli* bacteria; concentrations were 81, 360, and 410 col / 100 mL. One sample was collected during stormflow and analyzed for fecal coliform bacteria; the concentration was 280 col / 100 mL. No sample was collected during stormflow for analysis of *E. coli* bacteria. The land use in the subbasin is mixed—35 percent forested, 31 percent agricultural, and 22 percent residential. An open field and a fenced pasture containing livestock is within 0.5 mi upstream of EB14. Bacteria concentrations decrease between EB10 and EB14 because of the distance between sites and the natural die-off of the bacteria during stream transport.

Main Stem Brandywine Creek

Bacteria concentrations on the main stem of the Brandywine Creek during base flow and stormflow are shown in figure 15. At base flow, the median bacteria concentration exceeded 200 col / 100 mL only at MS2 on Pocopson Creek, which is a tributary to the main stem. During stormflow, the median concentrations of fecal coliform bacteria exceeded 200 col / 100 mL at all three sites.

Concentrations of fecal coliform bacteria at Brandywine Creek at Pocopson (MS1) during base flow ranged from 2 to 85 col / 100 mL; the median concentration was 50 col / 100 mL. Two samples were analyzed for *E. coli* bacteria; concentrations were 70 and 93 col / 100 mL. Two samples were collected during stormflow and analyzed for fecal coliform bacteria; concentrations were 4,400 and 5,500 col / 100 mL. One sample was collected during stormflow for analysis of *E. coli* bacteria; the concentration was 180 col / 100 mL. The land

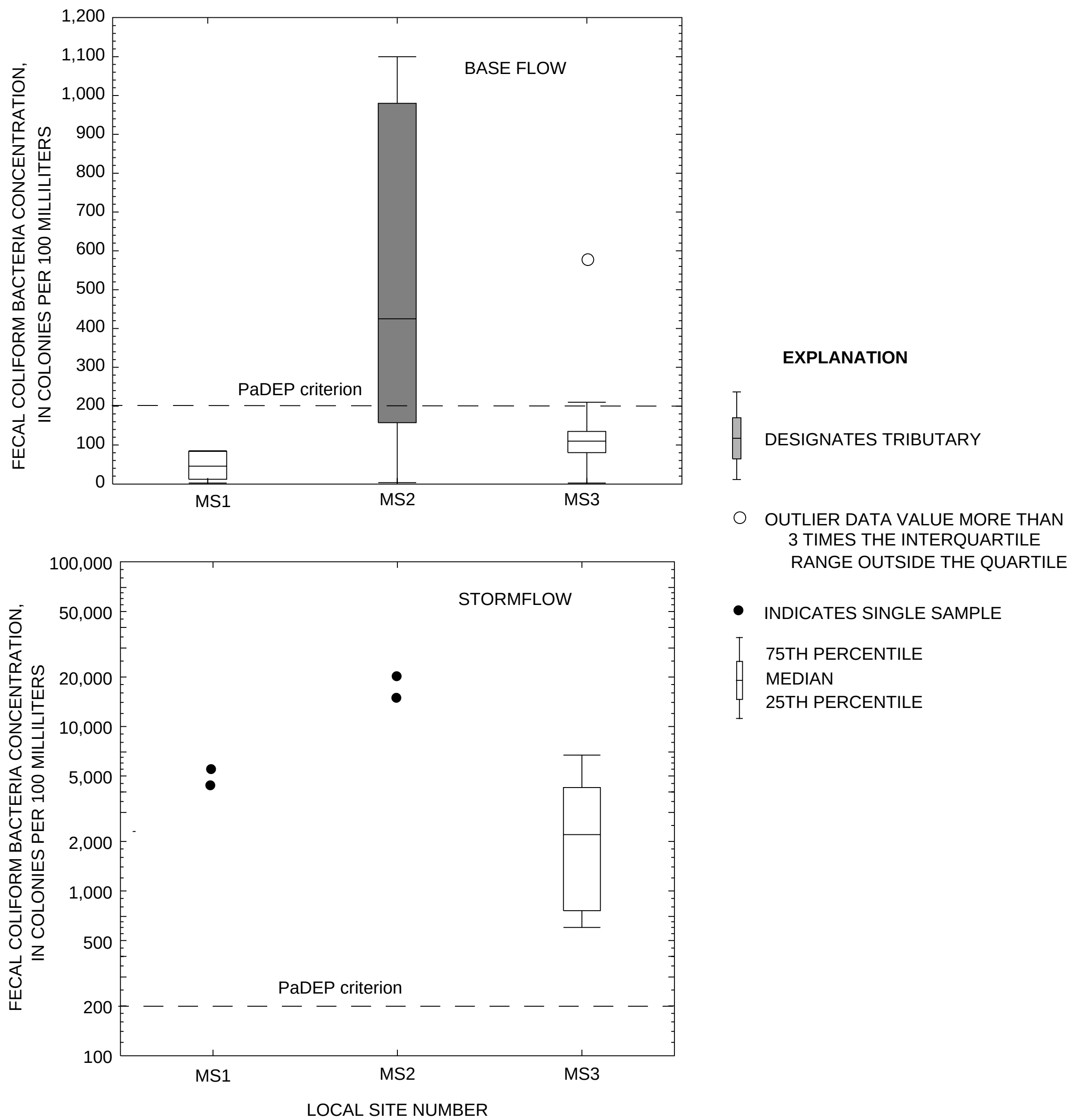


Figure 15. Distribution of concentrations of fecal coliform bacteria during base flow and stormflow at sampling sites on main stem Brandywine Creek, Chester County, Pennsylvania,1998-99.

use in the subbasin is mixed—42 percent agricultural, 32 percent forested, and 17 percent residential. Bacteria concentrations decrease between EB14 on the East Branch and WB15 on the West Branch and MS1. This decrease in concentration is due to the distance between sites and the natural die-off of the bacteria.

Concentrations of fecal coliform bacteria for Pocopson Creek at Pocopson (MS2) during base flow ranged from 3 to 1,100 col / 100 mL; the median concentration was 430 col / 100 mL. Three samples were analyzed for *E. coli* bacteria; concentrations were 20, 80, and 390 col / 100 mL. Two samples were collected during stormflow and analyzed for fecal coliform bacteria; concentrations were 15,000 and 20,000 col / 100 mL. No samples were collected during stormflow for analysis of *E. coli*. The land use in the subbasin is mixed—49 percent agricultural, 26 percent residential, and 21 percent forested. A hayfield is on the upstream right side and horses are pastured on the left side. Approximately 300 ft upstream is riparian forest 90-120 ft wide on both sides of the creek. Pocopson Creek contributes elevated bacteria concentrations to the main stem Brandywine Creek.

Concentrations of fecal coliform bacteria at Brandywine Creek at Chadds Ford (MS3) during base flow ranged from 2 to 2,200 col / 100 mL; the median concentration was 120 col / 100 mL. Two samples were collected at base flow and analyzed for *E. coli* bacteria; concentrations were 44 and 180 col / 100 mL. Concentrations of fecal coliform bacteria during stormflow ranged from 160 to 6,700 col / 100 mL; the median concentration was 2,200 col / 100 mL. Two samples were collected during stormflow and analyzed for *E. coli* bacteria; concentrations were 440 and 620 col / 100 mL. Bacterial concentrations increase between sites MS1 and MS3; however, the median concentration does not exceed the PaDEP criterion. A nonpoint source for the increase in bacteria concentration during base flow is Pocopson Creek, a tributary between sites MS1 and MS3 with elevated bacteria concentrations.

Point Discharges

Eighteen point discharges are known in the Brandywine Creek Basin. The point discharges are identified as wastewater treatment plants and instream discharge facilities. Instream discharge facilities are commercial and industrial, such as paper mills and steel plants. The quality of the water being discharged from the wastewater treatment plants and the instream discharge facilities at the time of sampling was not determined. Each wastewater treatment plant must submit a Discharge Monitoring Report (DMR) to the PaDEP and resolve any exceedance in bacteria concentrations. It was beyond the scope of this project to research and evaluate each facility's record of DMR's. While any one of the point discharges in the Brandywine Creek Basin occasionally could be a point source for bacteria contamination, they are not viewed as causal agents because of their regulation by the PaDEP.

SUMMARY AND CONCLUSIONS

Concentrations of fecal coliform bacteria at three USGS long-term water-quality monitoring stations in the Brandywine Creek Basin show a general downward trend for 1973-99. Implementation of regulations stemming from of the Clean Water Act of 1972 contributed to the decrease of bacteria concentrations between 1973 and 1987. With the upgrade in wastewater treatment plants, a decrease in point-source discharges, and the general decrease of agricultural land use in the basin, bacteria concentrations decreased dramatically and then stabilized. Concentrations of fecal coliform bacteria were highest at West Brandywine Creek at Modena and lowest at Brandywine Creek at Chadds Ford. Streamflow and concentrations of fecal coliform bacteria were positively related at both sites, that is, bacteria concentrations increase as streamflow increases. Concentrations of fecal coliform bacteria are elevated—they exceed the regulatory criterion of 200 colonies per 100 milliliters—during both base flow and stormflow conditions at all three monitoring stations.

The concentrations of fecal coliform and *E. coli* bacteria in the Brandywine Creek Basin were assessed on the basis of data collected at 40 stream sites. Thirty-two sampling sites were selected on the basis of historical data, land use, known point discharges of bacteria, and areas where recreational use was evident; nine of these sites were at established U.S. Geological Survey (USGS) streamflow-measurement stations. Eight additional sampling sites were added midway through the study to collect additional data between established sites with elevated bacteria concentrations measured during monthly sampling. Sampling was conducted at base flow approximately monthly from March to September

1999. Sampling also was conducted during five storms where rainfall exceeded 0.5 in. Samples were collected at all of the USGS streamflow-measurement stations during every storm, and five selected sites were sampled during each storm.

During 1998-99, the median concentration of fecal coliform bacteria in the water samples collected during base flow in the Brandywine Creek Basin exceeded 200 col / 100 mL at 26 sites (65 percent). The median concentration of fecal coliform bacteria at sites sampled on the West Branch exceeded 200 col / 100 mL at 15 of the 20 sites (75 percent). The median concentration of fecal coliform bacteria at sites sampled on the East Branch exceeded 200 col / 100 mL at 10 of the 17 sites (58 percent). The median concentration of fecal coliform bacteria on the main stem exceeded 200 col / 100 mL at one of the three sites (33 percent). During 1998-99, the median concentration of fecal coliform bacteria in the water samples collected during stormflow exceeded 200 col / 100 mL at 30 of 33 sites (91 percent). The median concentration of fecal coliform bacteria at sites on the West Branch exceeded 200 col / 100 mL at 12 of 13 sites sampled (92 percent). The median concentration of fecal coliform bacteria at sites on the East Branch exceeded 200 col / 100 mL at 15 of the 17 sites sampled (88 percent). The median concentration of fecal coliform bacteria on the main stem exceeded 200 col / 100 mL at all three sites sampled.

Every water sample analyzed contained *E. coli* bacteria. During base flow, in 21 of 24 samples (91 percent of non-estimated measurements) the ratio of *E. coli* to fecal coliforms was greater than 1:2. During stormflow, in 2 of 8 samples (37 percent of non-estimated measurements) the ratio of *E. coli* to fecal coliforms was greater than 1:2.

The Kruskal-Wallis test for statistically significant differences in bacteria concentrations at the 95-percent confidence level showed no significant differences between fecal coliform concentrations in agricultural, forested, residential or mixed subbasins during base flow and stormflow. However, sites in forested subbasins had a greater range in bacteria concentrations than did sites in agricultural, residential, or mixed subbasins.

Factors affecting bacteria concentrations in the Brandywine Creek Basin include nonpoint sources, stormflow, reservoirs, and seasonality. Nonpoint sources may include agriculture, ground-water contamination (residential septic systems or leaking landfills), urban / residential activities, resident wildlife, and land-surface runoff.

Bacteria concentrations are higher in stormflow than in base flow. Rainfall flushes the land surface, and overland runoff transports bacteria into the stream. The bacteria concentrations at five sites where at least four samples were collected during both base flow and stormflow were compared. For all five sites, bacteria concentrations were substantially higher during storms than during base flow. During stormflow, sites on 14 of 15 tributaries (93 percent) to Brandywine Creek had median concentrations of fecal coliform bacteria greater than 200 col / 100 mL.

Sites above and below each of the three reservoirs in the Brandywine Creek Basin (Chambers Lake, Rock Run, and Marsh Creek Reservoirs) were sampled. Bacteria concentrations in the streams that flow from the reservoirs are lower than bacteria concentrations in the streams that flow into the reservoirs. The bacteria concentration in the water flowing out of the reservoir is reflective of the bacteria concentration in the reservoir, not the stream flowing into the reservoir. The volume of water in the incoming stream is very small compared to the volume of water in the reservoir.

Seasonality plays a role in the concentration of bacteria in Brandywine Creek. During March, April, May, October, and November, water temperatures and bacteria concentrations are lower in the Brandywine Creek than during June, July, August, and September. The 10-year median concentrations of bacteria at West Branch Brandywine Creek at Modena and East Branch Brandywine Creek below Downingtown exceeded the criterion of 200 col / 100 mL established by the PaDEP for the swimming season. The 10-year median concentrations of bacteria at Brandywine Creek at Chadds Ford exceeded criterion of 200 col / 100 mL only during June. None of the three stations exceeded the criterion of 2,000 col / 100 mL established by the PaDEP for the remainder of the year.

Tributaries on the West Branch that contribute elevated bacteria concentrations to Brandywine Creek during base flow include Birch Run, Rock Run, Doe Run, Little Broad Run, Broad Run, and Two Log Run. During stormflow, Buck Run also contributes elevated bacteria concentrations.

Tributaries on the East Branch that contribute elevated bacteria concentrations to Brandywine Creek during base flow include Beaver Creek, Uwchlan Run, and Taylor Run. During stormflow, Marsh Creek, Culbertson Run, and Valley Creek also contribute elevated bacteria concentrations. Pocopson Creek, the only tributary on the main stem that was evaluated, contributes bacteria concentrations to the Brandywine Creek during base flow and stormflow.

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Table 6. *Streamflow, physical and chemical properties, and fecal coliform and E. coli bacteria concentrations during base flow, West Branch Brandywine Creek Basin, Chester County, Pennsylvania, July 1998 to September 1999*

[°C, degrees Celsius; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; E, estimated; >, greater than; <, less than; —, no data; mL, milliliter]

Date	Discharge (ft^3/s)	Oxygen, dissolved (mg/L)	pH (standard units)	Specific conductance (µS/cm)	Tempera-ture (°C)	Fecal coliform (colonies per 100 mL)		*E. coli* (colonies per 100 mL)	
WB1 West Branch Brandywine Creek at Rockville (01480269)									
08-04-98	—	—	—	291	20.5	5,500		—	
04-09-99	—	12.4	7.3	274	11.5	200		—	
05-05-99	3.5	10.9	7.0	271	13.5	1,900	E	—	
06-04-99	3.1	8.2	7.0	279	20.0	5,000		—	
07-19-99	.60	7.1	7.4	293	24.5	3,100		>600	
08-16-99	.72	6.5	7.1	286	23.5	5,100		5,900	
09-13-99	.93	7.5	7.0	302	17.0	4,100		1,000	
WBA Two Log Run at Birdell (01480295)									
07-19-99	1.1	8.5	7.8	276	20.0	540		—	
08-16-99	—	9.6	7.3	278	17.5	960		—	
09-13-99	—	9.2	7.4	294	16.5	740		—	
WB2 West Branch Brandywine Creek near Honey Brook (01480300)									
07-29-98	3.3	—	—	280	23.0	6,600	E	—	
08-04-98	2.7	—	—	308	21.0	4,100		—	
04-09-99	5.9	9.8	7.0	288	12.0	63		—	
05-05-99	5.3	10.3	7.3	—	14.5	2,300	E	—	
06-04-99	2.0	7.2	7.1	327	19.0	4,800		—	
07-19-99	.70	—	7.7	405	25.0	>6,000		>8,000	
08-16-99	.70	6.5	7.6	382	23.0	>6,000		6,600	
09-13-99	.87	7.8	7.4	372	19.0	10,000		1,900	E
WB3 West Branch Brandywine Creek at Brandamore (01480349)									
07-29-98	9.9	—	—	246	23.0	270		—	
09-24-98	—	—	—	254	14.0	230		—	
05-04-99	17	10.8	7.6	237	15.0	200		—	
06-02-99	11	8.1	7.1	210	20.5	200		—	
07-19-99	—	8.5	7.8	255	24.0	720		470	
08-16-99	3.0	7.0	7.1	272	21.5	590		—	
WB4 Birch Run near Martins Corner (01480390)									
07-29-98	.81	8.7	7.6	118	19.0	1,400		—	
04-08-99	2.0	9.1	8.2	104	17.0	33		—	
05-04-99	1.8	10.9	7.5	100	14.5	300	E	—	
06-02-99	.86	9.1	6.8	89	17.5	130		180	
07-19-99	—	8.3	7.1	98	22.0	650		—	
08-16-99	.19	8.4	6.8	128	19.5	510		—	
09-13-99	.23	8.8	6.8	151	16.0	820		230	E
WB5 Birch Run near Wagontown (01480400)									
07-29-98	2.0	6.8	7.3	135	18.0	28	E	—	
04-08-99	4.0	9.9	6.9	123	12.5	3	E	—	
05-05-99	3.4	10.0	7.2	127	14.0	3	E	3	E
06-03-99	1.7	8.4	7.0	135	13.0	7	E	1	E
09-13-99	1.7	7.8	6.9	150	20.0	33		—	

Table 6. *Streamflow, physical and chemical properties, and fecal coliform and E. coli bacteria concentrations during base flow, West Branch Brandywine Creek Basin, Chester County, Pennsylvania, July 1998 to September 1999—Continued*

[°C, degrees Celsius; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; E, estimated; >, greater than; <, less than; —, no data; mL, milliliter]

Date	Discharge (ft^3/s)	Oxygen, dissolved (mg/L)	pH (standard units)	Specific conductance (µS/cm)	Tempera-ture (°C)	Fecal coliform (colonies per 100 mL)	*E. coli* (colonies per 100 mL)
WB6 Rock Run near Philipsville (01480458)							
07-29-98	1.2	—	—	180	20.5	2,400	—
04-08-99	1.8	9.5	8.9	165	18.5	20 E	—
05-04-99	1.6	10.8	8.1	164	15.5	1,600 E	—
06-02-99	.98	8.5	7.0	181	20.5	15,000 E	>1,600
07-19-99	—	8.0	7.6	191	22.5	870 E	1,400
08-16-99	.39	8.0	7.2	214	21.0	2,100	1,500 E
WBE Rock Run at Reservoir near Coatesville (01480463)							
08-04-99	—	—	—	—	19.5	3,900	—
08-16-99	—	—	—	232	20.0	3,300	—
WB7 Rock Run below Coatesville Reservoir (01480466)							
07-29-98	1.2	—	—	202	19.5	33 E	—
09-24-98	—	—	—	300	12.5	580	—
05-05-99	1.4	11.4	8.6	192	16.5	20 E	—
05-18-99	.93	8.6	6.8	193	12.0	100	93
09-13-99	1.1	6.8	6.7	215	21.0	120	97
WBD Rock Run at Rock Run near Coatesville (01480470)							
07-19-99	—	—	—	—	21.5	1,900 E	—
08-17-99	—	—	—	—	19.5	453	—
09-13-99	—	—	—	276	16.0	240	—
WBB West Branch Brandywine Creek at Rock Run (01480434)							
07-19-99	—	—	—	—	22.5	370	—
08-17-99	—	—	—	—	23.0	210	—
09-13-99	—	—	—	283	16.0	200	—
WBC West Branch Brandywine Creek below Rock Run at Coatesville (01480480)							
07-19-99	—	—	—	—	23.0	600	—
08-17-99	—	—	—	—	22.5	320	—
09-13-99	—	—	—	270	16.5	250	—
WB8 West Branch Brandywine Creek at Coatesville Reservoir (01480500)							
07-27-98	20	—	—	233	21.5	1,800 E	—
08-04-98	20	—	—	236	19.5	280	100 E
09-24-98	12	—	—	251	13.0	410	—
04-07-99	36	12.1	8.3	213	15.5	2 E	—
05-05-99	32	9.6	7.3	228	13.5	130	—
05-18-99	25	9.8	7.4	221	14.0	410	240
06-01-99	3.7	9.2	7.6	232	22.0	>600	—
07-19-99	8.1	8.3	7.3	236	25.0	420	—
08-16-99	9.8	10.0	7.7	254	23.5	330	—
09-13-99	8.4	9.3	7.2	254	17.5	450	500

Table 6. *Streamflow, physical and chemical properties, and fecal coliform and E. coli bacteria concentrations during base flow, West Branch Brandywine Creek Basin, Chester County, Pennsylvania, July 1998 to September 1999—Continued*

[°C, degrees Celsius; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; E, estimated; >, greater than; <, less than; —, no data; mL, milliliter]

Date	Discharge (ft^3/s)	Oxygen, dissolved (mg/L)	pH (standard units)	Specific conductance (µS/cm)	Tempera-ture (°C)	Fecal coliform (colonies per 100 mL)	*E. coli* (colonies per 100 mL)
WB9 West Branch Brandywine Creek at Modena (01480617)							
07-07-98	38	10.0	7.7	316	21.5	500	—
07-13-98	30	10.2	7.8	313	21.5	820	—
07-27-98	27	9.6	8.3	330	22.5	940	—
08-04-98	26	—	—	337	20.5	1,800	100 E
08-24-98	26	11.8	8.2	338	24.0	1,500 E	—
09-09-98	6.5	10.5	7.6	314	18.0	3,000	—
09-22-98	23	8.5	7.7	359	22.0	2,100	—
03-11-99	46	12.9	8.2	285	4.0	150	—
04-08-99	43	12.0	9.2	301	17.5	6 E	—
04-16-99	59	10.4	7.6	265	11.5	390	—
04-29-99	42	8.3	7.6	283	12.0	240	—
05-03-99	38	8.3	7.8	296	13.5	280	—
05-18-99	33	9.7	7.8	307	16.0	1,400 E	800
05-25-99	43	10.2	7.8	276	17.5	2,800	—
06-02-99	28	10.3	7.8	298	22.5	480	—
06-23-99	23	10.8	8.2	335	22.5	2,000 E	—
06-28-99	19	7.3	7.5	356	23.0	2,100	—
07-15-99	15	11.3	8.2	368	21.0	2,200 E	—
07-19-99	13	8.4	7.8	409	24.5	2,300	—
07-26-99	14	10.2	8.4	395	25.5	750	—
08-03-99	13	9.5	8.0	402	24.5	1,300	—
08-16-99	16	9.1	8.2	380	25.5	860	660
09-08-99	30	7.8	7.6	333	22.5	4,400	—
09-13-99	16	8.1	7.9	433	16.0	610	310
WB10 Buck Run at Doe Run (01480629)							
07-28-98	13	—	—	223	22.0	190	—
04-07-99	23	11.9	7.8	215	12.0	7 E	—
05-04-99	21	11.2	7.5	214	14.0	18 E	—
06-02-99	16	9.1	7.3	217	23.5	170	—
08-16-99	7.1	9.5	7.7	236	23.5	310	260
09-13-99	8.6	9.1	7.1	246	17.0	370	69 E
WB11 Doe Run above Tributary at Springdell (014806318)							
07-29-98	—	—	—	152	19.5	200	—
04-07-99	12	11.6	7.6	153	12.5	10 E	—
05-04-99	11	11.9	7.1	155	13.0	82	—
06-03-99	6.9	8.8	7.0	155	18.5	1,100	690
07-19-99	4.2	8.7	7.3	152	23.0	620	—
08-16-99	2.1	8.9	7.1	148	22.5	360	—
09-13-99	3.8	10.0	7.0	155	16.5	300	110 E

Table 6. *Streamflow, physical and chemical properties, and fecal coliform and E. coli bacteria concentrations during base flow, West Branch Brandywine Creek Basin, Chester County, Pennsylvania, July 1998 to September 1999—Continued*

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Date	Discharge (ft^3/s)	Oxygen, dissolved (mg/L)	pH (standard units)	Specific conductance (µS/cm)	Temperature (°C)	Fecal coliform (colonies per 100 mL)	*E. coli* (colonies per 100 mL)
WB12 West Branch Brandywine Creek near Embreeville (01480634)							
07-28-98	66	—	—	266	22.0	260	—
04-08-99	123	11.3	8.0	240	12.0	18 E	—
05-03-99	112	11.3	8.1	236	13.0	93	—
06-01-99	84	9.4	7.6	262	22.0	500 E	—
07-19-99	38	9.4	7.5	291	24.5	130	120
08-16-99	39	8.2	7.4	297	23.0	85 E	68 E
WB13 Little Broad Run near Marshallton (01480637)							
07-29-98	.37	—	—	251	19.0	450	—
08-04-98	.37	—	—	254	17.0	260	200
04-08-99	.73	11.6	8.0	235	14.0	15 E	—
05-03-99	.63	10.4	6.9	249	12.5	27 E	—
06-01-99	.42	8.5	7.1	250	19.5	140	—
07-19-99	.21	8.8	7.0	254	21.0	2,000 E	—
08-16-99	.35	9.0	7.1	249	20.5	530	330
09-13-99	.09	9.8	7.2	243	15.5	380	330
WB14 Broad Run at Northbrook (01480638)							
07-28-98	4.2	8.7	7.7	195	19.0	480	—
05-18-99	5.4	9.5	7.3	190	15.0	100	46 E
07-19-99	1.2	9.3	7.1	194	20.5	840	—
08-16-99	.80	8.4	7.0	208	20.5	720	—
09-13-99	1.7	9.7	7.2	203	15.0	470	320
WB15 West Branch Brandywine Creek at Wawaset (01480640)							
07-28-98	70	8.9	7.9	254	22.5	350	—
04-08-99	134	10.5	8.7	231	14.5	10 E	—
05-03-99	101	8.9	7.0	226	13.0	120	—
06-01-99	77	9.9	7.1	238	22.5	150	—
07-21-99	40	8.4	7.7	284	23.5	220	200
08-18-99	28	7.2	7.3	288	24.0	200 E	260
09-14-99	36	8.9	7.6	294	19.0	100	60 E

Table 7. *Streamflow, physical and chemical properties, and fecal coliform and E. coli bacteria concentrations during base flow, East Branch Brandywine Creek Basin, Chester County, Pennsylvania, July 1998 to September 1999*

[°C, degrees Celsius; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; E, estimated; —, no data; mL, milliliter]

Date	Discharge (ft^3/s)	Oxygen, dissolved (mg/L)	pH (standard units)	Specific conductance (µS/cm)	Temperature (°C)	Fecal coliform (colonies per 100 mL)		*E. coli* (colonies per 100 mL)	
EB1 East Branch Brandywine Creek near Cupola (01480648)									
03-31-99	4.4	10.6	8.3	203	13.5	31	E	—	
05-04-99	3.7	13.3	8.5	220	15.5	140		—	
06-02-99	2.2	8.2	6.5	217	18.5	1,200		—	
08-03-99	.44	8.6	7.3	219	19.0	260	E	240	
08-17-99	.57	7.6	7.3	228	20.0	260		86	E
EB2 East Branch Brandywine Creek at Glenmoore (01480653)									
03-31-99	14	12.2	7.6	191	8.0	63	E	—	
05-04-99	14	11.5	7.4	201	12.5	200		—	
06-02-99	8.0	8.9	6.7	200	21.5	160		170	
08-03-99	—	6.9	7.0	200	20.0	330		—	
08-17-99	2.6	7.7	7.2	209	21.0	270		—	
09-15-99	1.7	7.9	7.0	228	18.0	220	E	110	E
EB3 Indian Run at Springton (01480658)									
03-31-99	5.8	12.3	8.5	158	12.5	11	E	—	
05-04-99	4.2	11.0	8.5	177	14.5	65		—	
06-02-99	3.2	8.9	6.8	183	18.5	71	E	90	
EB4 Marsh Creek near Glenmoore (01480675)									
07-29-98	2.7	8.3	7.6	201	21.0	78		—	
03-31-99	8.2	11.4	7.2	182	9.0	14	E	—	
05-04-99	6.9	10.4	6.9	191	12.5	12	E	2	E
06-02-99	3.0	8.3	6.7	183	20.5	100		—	
08-17-99	.76	7.9	7.1	241	21.5	200		230	
EB5 Marsh Creek near Downingtown (01480685)									
7-29-98	9.0	7.2	8.0	169	26.5	22	E	—	
05-04-99	5.2	10.2	7.2	197	13.5	67		75	
08-03-99	8.7	7.6	6.4	203	10.0	81	E	—	
EB6 East Branch Brandywine Creek at Lyndell (01480660)									
07-27-98	14	—	—	197	20.0	430		—	
03-31-99	29	12.2	8.5	187	13.5	9	E	—	
05-05-99	23	11.2	7.6	223	17.5	67		—	
06-02-99	12	8.6	6.6	197	23.0	970	E	120	
08-03-99	3.6	9.4	7.4	201	20.5	440		—	
09-14-99	5.7	9.4	7.2	217	17.0	140	E	100	E
EB7 Culbertson Run at Lyndell (01480662)									
07-27-98	3.5	—	—	237	20.0	180		—	
03-31-99	5.0	11.9	8.1	228	12.5	9	E	—	
05-05-99	4.9	10.7	7.3	254	13.5	120		—	
08-17-99	.34	8.1	7.2	237	21.5	300		340	
09-14-99	.72	8.8	7.2	257	17.0	430		200	

Table 7. *Streamflow, physical and chemical properties, and fecal coliform and E. coli bacteria concentrations during base flow, East Branch Brandywine Creek Basin, Chester County, Pennsylvania, July 1998 to September 1999—Continued*

[°C, degrees Celsius; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; E, estimated; —, no data; mL, milliliter]

Date	Discharge (ft^3/s)	Oxygen, dissolved (mg/L)	pH (standard units)	Specific conductance (µS/cm)	Temperature (°C)	Fecal coliform (colonies per 100 mL)		*E. coli* (colonies per 100 mL)
EB8 East Branch Brandywine Creek near Downingtown (01480700)								
07-27-98	41	—	—	200	23.0	160		—
08-04-98	38	—	—	203	20.0	170		—
03-31-99	66	12.3	6.6	212	6.5	110		—
05-04-99	39	11.1	7.5	218	13.0	160		170
06-02-99	39	9.0	7.8	206	22.0	110		110
EB9 Beaver Creek near Downingtown (01480775)								
07-28-98	7.7	8.2	—	350	19.0	490		—
03-31-99	18	12.5	7.2	315	8.0	140		—
05-03-99	15	10.2	7.9	312	12.5	740		—
06-02-99	9.0	8.8	7.6	324	21.0	1,700	E	1,000
08-03-99	2.2	9.2	7.7	405	20.5	1,200	E	—
08-17-99	2.3	8.3	7.6	403	20.5	700		—
09-14-99	4.0	9.0	7.6	383	17.5	140	E	210
EBA East Branch Brandywine Creek at Downingtown (01480800)								
08-03-99	17	11.4	8.3	282	23.5	100		350
08-17-99	—	—	8.4	267	23.0	470		340
09-14-99	—	12.5	8.3	285	19.5	210		—
EBC East Branch Brandywine Creek at Altor (01480840)								
08-03-99	19	7.3	7.4	354	21.5	410		—
08-17-99	—	—	7.4	363	23.5	200		—
09-14-99	—	—	7.5	402	20.0	270		—
EB13 Uwchlan Run at Exton (01480878)								
07-29-98	1.5	—	—	401	21.0	480		—
08-04-98	.30	—	—	412	19.0	230		220
03-31-99	1.2	13.5	8.6	415	10.0	6	E	—
05-04-99	.65	11.8	7.8	407	13.5	200		150
06-04-99	.30	8.2	7.2	406	18.5	2000		—
09-14-99	.04	8.1	7.8	417	18.0	390		220
EBB Valley Creek at Ravine Road near Downingtown (01480887)								
08-03-99	1.6	8.5	7.6	584	22.0	60	E	—
08-17-99	—	—	—	575	24.0	31	E	—
EB10 East Branch Brandywine Creek below Downingtown (01480870)								
07-07-98	76	9.0	7.8	286	21.1	480		—
07-13-98	101	9.4	7.4	261	21.5	590		—
07-27-98	65	10.9	8.3	307	23.0	340		—
08-04-98	61	—	—	309	20.5	880		—
08-10-98	59	8.7	7.7	308	24.0	300		—
08-18-98	112	8.4	7.4	220	22.0	> 600		—
08-24-98	68	9.8	7.9	304	24.0	520		—
09-09-98	55	9.3	7.7	304	18.5	640		—
09-22-98	65	8.0	7.4	329	21.0	>8,000		—

Table 7. *Streamflow, physical and chemical properties, and fecal coliform and E. coli bacteria concentrations during base flow, East Branch Brandywine Creek Basin, Chester County, Pennsylvania, July 1998 to September 1999—Continued*

[°C, degrees Celsius; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; E, estimated; —, no data; mL, milliliter]

Date	Discharge (ft^3/s)	Oxygen, dissolved (mg/L)	pH (standard units)	Specific conductance (µS/cm)	Temperature (°C)	Fecal coliform (colonies per 100 mL)		*E. coli* (colonies per 100 mL)	
03-31-99	114	13.8	7.7	265	8.5	80	E	—	
04-29-99	84	10.4	7.5	286	12.5	190		—	
05-03-99	80	11.3	7.7	295	14.0	660		—	
05-18-99	69	9.9	7.8	285	16.0	150		110	
06-02-99	71	6.7	7.7	303	22.0	530		—	
06-23-99	58	9.6	7.9	334	23.5	1,600	E	—	
06-28-99	52	6.2	7.5	342	24.0	390		—	
07-15-99	43	8.5	7.7	386	20.5	390	E	—	
07-19-99	38	6.4	7.4	405	24.0	470		—	
07-26-99	42	8.0	7.7	360	24.5	920		—	
08-03-99	35	6.8	7.4	390	24.0	680		—	
08-16-99	42	6.8	7.6	349	24.5	550		—	
09-08-99	48	6.6	7.3	330	23.0	4,000		—	
09-14-99	49	6.8	7.5	379	20.0	410		—	
EB11 Valley Creek at Altor (01480905)									
07-27-98	9.0	11.8	8.4	400	21.0	83	E	—	
03-31-99	24	10.6	7.5	398	6.5	40	E	—	
05-03-99	18	11.2	8.0	375	12.0	77		—	
06-04-99	11	11.0	8.0	334	22.0	220		290	
08-03-99	2.5	8.0	7.5	332	21.0	88	E	—	
08-17-99	4.7	9.1	7.6	444	22.0	200		—	
EB12 Taylor Run at Copesville (01480930)									
07-28-98	4.7	12.3	8.6	518	25.0	580		—	
03-31-99	7.0	13.0	7.7	500	14.5	20	E	—	
05-03-99	6.8	10.9	7.4	426	12.5	200		—	
06-02-99	4.9	—	7.8	489	22.0	390		—	
08-03-99	2.1	7.4	7.1	706	20.5	920		—	
08-17-99	2.3	7.3	7.0	591	22.5	800		390	
09-14-99	3.0	10.7	7.7	530	19.0	250		130	E
EB14 East Branch Brandywine Creek at Wawaset (01480950)									
07-28-98	56	7.3	7.6	346	22.0	410		—	
05-03-99	—	10.8	7.2	330	13.0	120		—	
06-02-99	59	—	7.4	335	22.0	220		—	
07-21-99	31	7.6	7.2	392	23.0	230		360	
08-18-99	24	6.9	7.4	408	24.0	330		410	
09-14-99	28	9.0	7.4	415	21.5	130	E	81	E

Table 8. *Streamflow, physical and chemical properties, and fecal coliform and E. coli bacteria concentrations during base flow, main stem Brandywine Creek Basin, Chester County, Pennsylvania, July 1998 to September 1999*

[°C, degrees Celsius; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; E, estimated; >, greater than; —, no data; mL, milliliter]

Date	Discharge (ft^3/s)	Oxygen, dissolved (mg/L)	pH (standard units)	Specific conductance (µS/cm)	Temperature (°C)	Fecal coliform (colonies per 100 mL)	*E. coli* (colonies per 100 mL)
MS1 Brandywine Creek at Pocopson (01480970)							
07-28-98	139	—	—	293	23.0	15 E	—
09-24-98	—	8.3	7.8	305	16.0	28 E	—
04-08-99	—	13.0	7.6	265	15.0	2 E	—
06-01-99	146	9.2	6.8	283	22.5	63 E	—
08-18-99	53	8.0	7.4	319	26.0	83	93
09-15-99	43	7.3	7.2	347	20.5	85 E	70
MS2 Pocopson Creek at Pocopson (01480975)							
07-28-98	3.3	—	—	232	21.0	430	—
09-24-98	—	12.1	8.1	222	13.0	620	—
04-08-99	—	11.5	8.0	215	15.0	3 E	—
05-03-99	7.9	10.6	6.9	220	11.0	1,100	—
06-01-99	4.6	9.1	6.8	—	19.5	1,100	—
07-21-99	2.1	8.8	7.5	234	22.0	420	390
08-18-99	.39	8.1	7.3	244	22.5	130 E	80 E
09-15-99	1.7	8.5	7.1	248	19.0	240	20 E
MS3 Brandywine Creek at Chadds Ford (01481000)							
07-07-98	195	8.3	7.5	300	22.0	180	—
07-13-98	222	7.5	7.7	283	21.5	60 E	—
07-27-98	162	8.0	7.5	313	23.0	120	—
08-10-98	122	7.5	7.4	330	25.0	580	—
08-18-98	382	—	7.2	190	23.0	> 600	—
08-24-98	131	7.5	7.2	316	24.0	120	—
09-09-98	131	8.0	7.5	260	19.0	88	—
09-22-98	116	6.6	7.4	341	22.0	210	—
09-24-98	106	5.2	7.6	365	17.0	60 E	—
03-11-99	265	10.0	6.3	267	4.0	27	—
04-07-99	294	12.3	7.9	265	13.5	2 E	—
04-16-99	348	10.0	7.5	229	11.5	52	—
04-29-99	241	9.7	7.4	258	13.5	98	—
05-03-99	219	9.3	7.4	262	14.5	78	—
05-18-99	195	10.1	7.7	275	18.0	94 E	44 E
06-02-99	173	8.2	7.6	277	23.0	110	—
06-23-99	163	10.0	7.4	293	22.0	150 E	—
06-28-99	135	6.5	7.0	303	25.0	100	—
07-15-99	104	8.4	7.5	321	22.0	2,200 E	—
07-19-99	85	6.5	7.4	341	26.5	180	—
07-21-99	104	7.4	7.4	293	25.0	110	—
07-26-99	80	7.1	7.5	338	26.5	120	—
08-03-99	63	6.0	7.4	372	26.0	180	—
08-16-99	92.3	7.8	7.5	316	25.5	105	—
09-08-99	181	7.6	7.4	271	24.5	210	—
09-15-99	99.7	7.8	7.7	335	21.5	140	180

Table 9. *Streamflow, physical and chemical properties, and fecal coliform and E. coli bacteria concentrations during storms, West Branch Brandywine Creek Basin, Chester County, Pennsylvania, July 1998 to September 1999*

[°C, degrees Celsius; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; E, estimated; >, greater than; —, no data; mL, milliliter]

Date	Discharge (ft^3/s)	Oxygen, dissolved (mg/L)	pH (standard units)	Specific conductance (µS/cm)	Temperature (°C)	Fecal coliform (colonies per 100 mL)		*E. coli* (colonies per 100 mL)	
WB2 West Branch Brandywine Creek near Honey Brook (01480300)									
10-08-98	20	—	—	265	16.0	150,000	E	—	
03-22-99	92	10.9	7.2	203	6.5	1,100		—	
08-14-99	10	—	—	294	23.0	>6,000		>8,000	
08-26-99	4	—	—	219	19.01	>12,000		>16,000	
09-16-99	202	—	—	116	17.5	610,000	E	250,000	
WB3 West Branch Brandywine Creek at Brandamore (01480349)									
08-26-99	—	—	—	238	20.0	—		1,000	
WB4 Birch Run near Martins Corner (01480390)									
08-14-99	—	—	—	145	22.0	>6,000		>8,000	
09-16-99	—	—	—	119	17.5	>240,000		>320,000	
WB5 Birch Run near Wagontown (01480400)									
03-22-99	40	12.9	7.1	123	6.0	24	E	—	
WB6 Rock Run near Philipsville (01480458)									
08-14-99	—	—	—	218	23.0	> 6,000		> 8,000	
09-16-99	—	—	—	118	18.0	540,000	E	16,000	E
WB8 West Branch Brandywine Creek at Coatesville Reservoir (01480500)									
10-08-98	40	—	—	209	15.5	3,700		—	
03-22-99	734	12.7	7.71	139	5.0	5,100		—	
08-26-99	25	—	—	172	20.0	9,200		1,400	E
09-16-99	410	—	—	—	18.0	16,000		12,000	
WB9 West Branch Brandywine Creek at Modena (01480617)									
10-08-98	51	—	—	243	17.5	15,000		—	
03-22-99	817	12.7	7.8	146	5.0	5,000		—	
08-14-99	21	5.7	7.7	328	26.0	> 6,000		> 8,000	
08-26-99	38	6.1	7.7	252	20.5	11,000	E	600	E
09-16-99	596	3.1	7.5	410	19.0	4,000		2,900	
09-27-99	30	9.0	8.0	377	17.5	2,700	E	—	
WB10 Buck Run at Doe Run (01480629)									
08-14-99	—	—	—	220	27.0	> 6,000		> 8,000	
WB11 Doe Run above Tributary at Springdell (014806318)									
10-08-98	12	11.6	7.6	153	15.5	580		—	
WB12 West Branch Brandywine Creek near Embreeville (01480634)									
08-14-99	—	—	—	210	26.5	220		190	
WB13 Little Broad Run near Marshallton (01480637)									
10-08-98	2.1	—	—	165	16.5	22,000		—	
03-22-99	2.0	11.1	7.7	209	9.0	24	E	—	
08-14-99	—	—	—	249	24.0	720		670	
WB14 Broad Run at Northbrook (01480638)									
08-14-99	—	—	—	197	23.5	1,400	E	1,300	
WB15 West Branch Brandywine Creek at Wawaset (01480640)									
08-26-99	—	—	—	263	21.0	3,600	E	1,300	

Table 10. *Streamflow, physical and chemical properties, and fecal coliform and E. coli bacteria concentrations during storms, East Branch Brandywine Creek Basin, Chester County, Pennsylvania, July 1998 to September 1999*

[°C, degrees Celsius; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligrams per liter; E, estimated; >, greater than; —, no data; mL, milliliter]

Date	Discharge (ft^3/s)	Oxygen, dissolved (mg/L)	pH (standard units)	Specific conductance (µS/cm)	Temperature (°C)	Fecal coliform (colonies per 100 mL)	*E. coli* (colonies per 100 mL)
EB1 East Branch Brandywine Creek near Cupola (01480648)							
07-30-98	2.4	—	—	224	21.0	600	—
07-20-99	.67	7.6	7.5	227	21.5	> 1,200	—
EB2 East Branch Brandywine Creek at Glenmoore (01480653)							
07-30-98	8.5	—	—	211	21.5	450	—
07-20-99	5.4	6.8	7.1	204	22.0	>1,200	—
08-26-99	—	—	—	173	19.5	>12,000	>16,000
EB3 Indian Run at Springton (01480658)							
07-30-98	2.5	—	—	191	20.0	150	—
EB4 Marsh Creek near Glenmoore (01480675)							
03-22-99	100	12.2	6.7	146	5.5	400 E	—
09-16-99	320	—	—	188	18.0	66,000	2,500
EB5 Marsh Creek near Downingtown (01480685)							
07-20-99	8.5	7.5	7.0	200	9.5	40 E	—
09-16-99	10	—	—	281	12.0	2,200	2,400
EB6 East Branch Brandywine Creek at Lyndell (01480660)							
07-20-99	10	7.6	7.7	185	22.5	3,200	—
08-26-99	—	—	—	158	19.0	9,200	2,200
EB7 Culbertson Run at Lyndell (01480662)							
08-26-99	—	—	—	240	19.5	19,000 E	960 E
EB8 East Branch Brandywine Creek near Downingtown (01480700)							
08-26-99	94	—	—	181	18.0	9,800	>4,000
09-16-99	588	—	—	—	18.0	16,000	4,400
EB9 Beaver Creek near Downingtown (01480775)							
07-20-99	4.0	8.8	7.2	356	21.5	6,800	—
08-26-99	—	—	—	248	19.5	1,700 E	—
EBA East Branch Brandywine Creek at Downingtown (01480800)							
07-20-99	—	9.7	8.4	262	22.0	> 1,200	> 800
EBC East Branch Brandywine Creek at Altor (01480840)							
07/20/99	39	9.4	7.1	388	23.5	>1,200	—
EB13 Uwchlan Run at Exton (01480878)							
10-08-98	6.2	—	—	106	18.0	20,000 E	—
07-20-99	.34	8.9	7.3	285	23.5	> 6,000	—
EBB Valley Creek at Ravine Road near Downingtown (01480887)							
07-20-99	—	6.0	7.4	299	23.0	70 E	—
EB10 East Branch Brandywine Creek below Downingtown (01480870)							
03-22-99	973	11.4	7.4	152	6.5	2,100	—
05-25-99	132	9.4	7.7	244	18.0	4,500	—
07-20-99	59	5.5	7.2	342	24.5	6,500 E	—
08-26-99	142	3.9	7.0	220	20.5	5,000	1,000
09-16-99	1,210	4.2	7.4	166	19.5	12,000	16,000
09-27-99	398	7.0	7.2	232	16.0	1,400 E	—

Table 10. *Streamflow, physical and chemical properties, and fecal coliform and E. coli bacteria concentrations during storms, East Branch Brandywine Creek Basin, Chester County, Pennsylvania, July 1998 to September 1999—Continued*

[°C, degrees Celsius; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligrams per liter; E, estimated; >, greater than; —, no data; mL, milliliter]

Date	Discharge (ft^3/s)	Oxygen, dissolved (mg/L)	pH (standard units)	Specific conductance (µS/cm)	Temperature (°C)	Fecal coliform (colonies per 100 mL)		*E. coli* (colonies per 100 mL)
EB11 Valley Creek at Altor (01480905)								
07-20-99	8.1	9.5	7.0	240	23.5	> 1,200		—
08-26-99	—	—	—	148	21.0	3,600	E	1,600
EB12 Taylor Run at Copesville (01480930)								
07-20-99	3.3	8.2	7.1	516	23.5	4,700		—
EB14 East Branch Brandywine Creek at Wawaset (01480950)								
08-26-99	—	—	—	167	21.0	280	E	—

Table 11. *Streamflow, physical and chemical properties, and fecal coliform and E. coli bacteria concentrations during storms, Main Stem Brandywine Creek Basin, Chester County, Pennsylvania, July 1998 to September 1999*

[°C, degrees Celsius; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; E, estimated; —, no data; mL, milliliter]

Date	Discharge (ft^3/s)	Oxygen, dissolved (mg/L)	pH (standard units)	Specific conductance (µS/cm)	Temperature (°C)	Fecal coliform (colonies per 100 mL)	*E. coli* (colonies per 100 mL)
MS1 Brandywine Creek at Pocopson (01480970)							
10-09-98	—	—	—	200	16.5	4,400	
09-16-99	—	—	—	347	20.5	5,500	180 E
MS2 Pocopson Creek at Pocopson (01480975)							
10-09-98	—	—	—	186	16.0	15,000	—
09-16-99	—	—	—	108	20.0	20,000 E	—
MS3 Brandywine Creek at Chadds Ford (01481000)							
03-22-99	3,620	11.4	7.4	150	6.5	2,200	—
05-25-99	409	8.3	7.4	210	16.0	6,700	—
08-26-99	747	7.3	7.4	300	22.0	2,600	620
09-16-99	8,290	7.4	7.1	125	17.0	960 E	440 E
09-27-99	395	8.8	7.6	257	16.5	160	—