USGS
science for a changing world

In cooperation with the
City of Youngstown, Ohio

Water Quality in the Mahoning River and Selected Tributaries in Youngstown, Ohio

Water-Resources Investigations Report 02 — 4122

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

Cover photo: Mill Creek at Lake Glacier outlet, Youngstown, Ohio.

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

Water Quality of the Mahoning River and Selected Tributaries in Youngstown, Ohio

By Donald M. Stoeckel and S. Alex Covert

Water-Resources Investigations Report 02–4122

In cooperation with the
City of Youngstown, Ohio

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

For additional information write to:

District Chief
U.S. Geological Survey
6480 Doubletree Avenue
Columbus, OH 43229-1111

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286
Denver, CO 80225-0286

Columbus, Ohio
2002

CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
kilometer (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
liter (L)	0.2642	gallon (gal)
cubic meter (m^3)	264.2	gallon (gal)
cubic meter (m^3)	0.0002642	million gallons (Mgal)
	Flow rate	
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
	Mass	
kilogram (kg)	2.205	pound avoirdupois
megagram (Mg)	1.102	ton, short (2,000 lb)
megagram per day (Mg/d)	1.102	ton per day

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

$$°F = (1.8 \times °C) + 32$$

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L). Pore sizes of filters and screens are given in micrometers (µm)

Water Quality of the Mahoning River and Selected Tributaries in Youngstown, Ohio

by Donald M. Stoeckel and S. Alex Covert

Abstract

The lower reaches of the Mahoning River in Youngstown, Ohio, have been characterized by the Ohio Environmental Protection Agency (OEPA) as historically having poor water quality. Most wastewater-treatment plants (WWTPs) in the watershed did not provide secondary sewage treatment until the late 1980s. By the late 1990s, the Mahoning River still received sewer-overflow discharges from 101 locations within the city of Youngstown, Ohio. The Mahoning River in Youngstown and Mill Creek, a principal tributary to the Mahoning River in Youngstown, have not met biotic index criteria since the earliest published assessment by OEPA in 1980. Youngstown and the OEPA are working together toward the goal of meeting water-quality standards in the Mahoning River. The U.S. Geological Survey collected information to help both parties assess water quality in the area of Youngstown and to estimate bacteria and inorganic nitrogen contributions from sewer-overflow discharges to the Mahoning River.

Two monitoring networks were established in the lower Mahoning River: the first to evaluate hydrology and microbiological and chemical water quality and the second to assess indices of fish and aquatic-macroinvertebrate-community health. Water samples and water-quality data were collected from May through October 1999 and 2000 to evaluate where, when, and for how long water quality was affected by sewer-overflow discharges. Water samples were collected during dry- and wet-weather flow, and biotic indices were assessed during the first year (1999). The second year of sample collection (2000) was directed toward evaluating changes in water quality during wet-weather flow, and specifically toward assessing the effect of sewer-overflow discharges on water quality in the monitoring network.

Water-quality standards for *Escherichia coli* (*E. coli*) concentration and draft criteria for nitrate plus nitrite and total phosphorus were the regulations most commonly exceeded in the Mahoning River and Mill Creek sampling networks. *E. coli* concentrations increased during wet-weather flow and remained higher than dry-weather concentrations for 48 hours after peak flow. *E. coli* concentration criteria were more commonly exceeded during wet-weather flow than during dry-weather flow. Exceedances of nutrient-concentration criteria were not substantially more common during wet-weather flow.

The fish and aquatic macroinvertebrate network included Mill Creek and its tributaries but did not include the main stem of the Mahoning River. Persistent exceedances of chemical water-quality standards in Mill Creek and the presence of nutrient concentrations in excess of draft criteria may have contributed to biotic index scores

that on only one occasion met State criteria throughout the fish and aquatic macroinvertebrate sampling network.

Monitored tributary streams did not contribute concentrations of *E. coli,* nitrate plus nitrite, or total phosphorus to the Mahoning River and Mill Creek that were higher than main-stem concentrations, but monitored WWTP and sewer-overflow discharges did contribute. Twenty-four hour load estimates of sewer-overflow discharge contributions during wet-weather flow indicated that sewer-overflow discharges contributed large loads of bacteria and inorganic nitrogen to the Mahoning River relative to the instream load. The sewer-overflow loads appeared to move as a slug of highly enriched water that passed through Youngstown on the rising limb of the storm hydrograph. The median estimated sewer-overflow load contribution of bacteria was greater than the estimated instream load by a factor of five or more; however, the median estimated sewer-overflow load of inorganic nitrogen was less than half of the estimated instream load.

Sewer-overflow discharges contributed loads of *E. coli* and nutrients to the Mahoning River and Mill Creek at a point where the streams already did not meet State water-quality regulations. Improvement of water quality of the Mahoning River, Mill Creek, and tributaries at Youngstown would be facilitated by reducing loads from sewer-overflow discharges within Youngstown, by identifying and reducing other sources of *E. coli* and nutrients within Youngstown, and by reducing discharges of *E. coli,* nitrate plus nitrite, and total phosphorus to the Mahoning River and Mill Creek upstream from Youngstown.

Introduction

The Ohio Environmental Protection Agency (OEPA) characterized the lower reaches of the Mahoning River as "historically. . . one of the most polluted of any stream or river in Ohio" (Ohio Environmental Protection Agency, 1996). Sewer-overflow discharge sites and wastewater-treatment plants (WWTPs) line the Mahoning River and its tributaries and contribute partially treated or untreated wastewater discharges to streamflow during wet weather. The city of Youngstown, Ohio, is on the Mahoning River not far from the Pennsylvania border. Youngstown is served by a combined sewer system in which varying proportions of the flow are stormwater and sanitary sewage. There are 101 known sewer-overflow discharge sites in Youngstown. Sewer-overflow and WWTP discharges have been cited as contributors to impaired water quality in the Mahoning River and its tributaries (Ohio Environmental Protection Agency, 1996).

In 1999, the U.S. Geological Survey (USGS), in cooperation with the city of Youngstown and in collaboration with ms consultants, inc., began a study to investigate the effects of sewer-overflow discharges within Youngstown on water quality of the Mahoning River. The intent of this investigation was to provide data useful to multiple parties involved in assessment of water quality in the Mahoning River. This investigation represents an attempt to directly relate municipal sewer-overflow discharges to changes in receiving-water quality and to quantify those changes.

The Clean Water Act of 1972, reauthorized and amended in 1982, requires states to categorize public waterways into designated aquatic-life uses and non-aquatic-life uses (Ohio Environmental Protection Agency, 2002). Nearly all Ohio waterways are designated for aquatic-life use as warmwater habitat. Other water-use designations include recreation and water supplies. Waterways are characterized as "attaining" or "not attaining" their designated uses by comparison with water-quality regulations. OEPA has issued water-quality regulations based on ecoregions to reflect the geographic diversity in the State.

This investigation was conducted using sites on the Mahoning River and selected tributaries in and around Youngstown. Water quality of the waterways studied was assessed based upon OEPA standards and criteria for primary recreation, non-aquatic-life use and for aquatic-life use as warmwater habitat within the Erie-Ontario Lake Plain (EOLP) ecoregion (Ohio Environmental Protection Agency, 1987). Mill Creek, tributary to the Mahoning River in Youngstown, was chosen for in-depth evaluation because it is further designated as a State resource water. Ohio has more stringent management policies for its State resource waters to help prevent water-quality degradation.

Purpose and scope

This report is an interpretive summary of data collected during a 2-year investigation of a reach on the lower Mahoning River, selected tributaries, and selected municipal discharges. The purpose of this report is to

1. describe a water-quality and streamflow monitoring network developed for the Mahoning River, Mill Creek, and selected tributaries, and an aquatic-

biological index monitoring network developed for Mill Creek and selected tributaries;

2. compare microbiological and chemical quality of the Mahoning River and its tributaries during periods of dry- and wet-weather flow to determine where, when, and for how long sewer-overflow discharges affected surface-water quality;

3. provide basic information about sewer-overflow discharges for future projects in which simulation calculations may be developed; and

4. compute 24-hour bacteria and inorganic nitrogen loads in an effort to quantify effects of these components of sewer-overflow discharges on water quality in the Mahoning River.

The broad scope of the investigation was to improve understanding of the effects of combined-sewer overflows on use-attainment for primary-contact recreation and protection of aquatic life in a heavily urbanized river reach.

Watershed description

The part of the Mahoning River described in this report is in Mahoning County, in northeastern Ohio bordering Pennsylvania (fig. 1). The Mahoning River Watershed drains 2,934 km^2 (1,133 mi^2) into a channel that is 166 km (103 mi) long (Ohio Environmental Protection Agency, 1996). Downstream from the study area, the Mahoning River joins with the Shenango River to form the Beaver River in western Pennsylvania. The Beaver River is, in turn, tributary to the Ohio River. The Mahoning River Valley is in the glaciated part of the Allegheny Plateau (Lessig and others, 1971). In 1988, 87 km (54 mi) of the Mahoning River flowed through urban areas and 31 km (19 mi) of river were impounded (Ohio Environmental Protection Agency, 1996).

Mill Creek is tributary to the Mahoning River at Youngstown. The lower part of Mill Creek flows through Mill Creek Park, a 10-km^2 (4-mi^2) municipal park created in 1891 (Mill Creek Metropolitan Park District, 2001). The area surrounding Mill Creek Park is densely populated. Mill Creek upstream from Mill Creek Park is partially channelized and is surrounded by agriculture and aquaculture facilities. Three dams segment Mill Creek within Mill Creek Park and form (from upstream to downstream) Newport Lake, Lake Cohasset, and Lake Glacier. These reservoirs have considerable water-holding capacity and would be expected to affect hydrology and water quality of Mill Creek. Retention of stream water in reservoirs promotes settling of solids, including bacteria and particulate forms of nutrients, and allows time for nutrient conversions and bacterial decay. Water leaving reservoirs is expected to have lower concentrations of suspended solids, particulate nutrients, and indicator bacteria than water flowing through a hypothetical unmodified stream. Conversion of organic nutrients to inorganic forms and changes in the oxidation state of inorganic nutrients also are expected in the reservoirs.

Youngstown, Ohio, is a small city with a history of heavy industry. In 2000, the population of Youngstown was 82,026 people in an 88-km^2 area (34 mi^2; 2000 census data). Youngstown was the site of the first steel company in the Mahoning Valley, and steel continues to be important to local industry.

Previous studies

Water quality in the lower part of the Mahoning River has been a persistent problem. OEPA did biological and water-quality surveys of the lower part of the Mahoning River in 1980, 1983, 1986, and 1994 (Ohio Environmental Protection Agency, 1996). In the early 1980s, the steel industry thrived in the Mahoning River Valley. The OEPA surveys indicated that part of the steel industry legacy is sediment contamination with toxic metals, phenols, and polycyclic aromatic hydrocarbons. The OEPA reports also indicated that WWTPs in and around Youngstown used only primary treatment before the 1980s. Incomplete treatment of sewage contributed to low dissolved oxygen concentrations (often less than 4 mg/L) and high ammonium concentrations (up to about 3 mg/L), which were reported as important chemical water-quality concerns before 1994 (Ohio Environmental Protection Agency, 1996). Most local WWTPs began using secondary treatment in the late 1980s, and OEPA noted improvements in achievement rates of water-quality standards for dissolved oxygen and ammonium concentrations. Despite improvements in wastewater treatment, however, microbiological water quality in the Mahoning River remained above primary-contact recreation standards throughout 1973–93 downstream from Youngstown at Lowellville (Ohio Environmental Protection Agency, 1996).

Acknowledgments

Appreciation is extended to Joe Catullo of ms consultants, inc., Tom Mirante of the city of Youngstown, and Allen Diebel of the Mahoning County Sanitary Engineering Department, for coordination on all facets of the investigation. The Youngstown wastewater laboratory and Mahoning County Boardman wastewater laboratory kindly allowed use of their facilities during this investigation.

Hydrological and water-quality sampling networks

Two sampling networks were developed in the Mahoning River Watershed in and around Youngstown. One sampling network was developed to monitor streamflow and assess

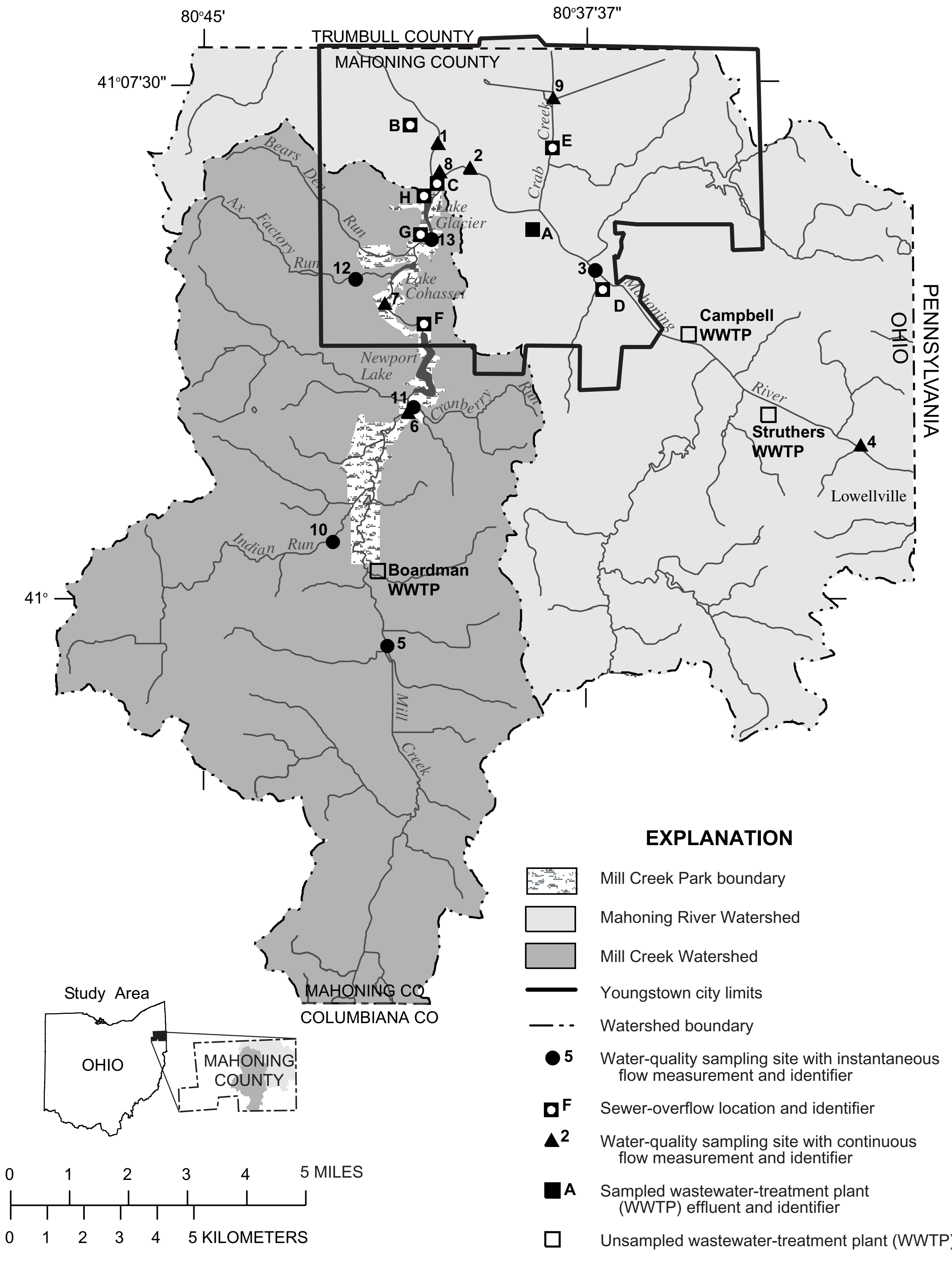

Figure 1. Surface-water quality and hydrology sampling network in the area of Youngstown, Ohio.

microbiological and chemical water quality in the Mahoning River Watershed, including the Mill Creek Subwatershed. An overlapping, second sampling network was used to assess aquatic biological indices for Mill Creek and one of its tributary streams, Indian Run.

Streamflow and water-quality sampling sites and schedule

The first network (fig. 1 and table 1) included seven continuous streamflow-measurement stations: three on the Mahoning River, three on Mill Creek, and one on Crab Creek. Six other water-quality monitoring sites, at which instantaneous streamflow was measured, were located on the Mahoning River, on Mill Creek, and on tributaries to Mill Creek. The first network also included eight municipal-source discharge sites: one at the Youngstown WWTP outflow and seven at sewer-overflow sites on the Mahoning River (three), Crab Creek (one), and Mill Creek (three). The sewers carry combined storm runoff and domestic sewage in varying proportions and would be commonly described as combined-sewer overflows unless flow were dominated by domestic waste. It was not within the scope of this investigation to define which sewers should be characterized as combined sewers and which should be characterized as sanitary sewers. The generic term “sewer-overflow discharge” is used throughout this report.

Water-quality monitoring sites on the Mahoning River (fig. 1) were chosen to assess the quality of surface water entering, passing through, and leaving Youngstown and at Lowellville, Ohio, downstream from Youngstown. Water entering the Mahoning River from its two largest tributary streams in Youngstown (Mill Creek and Crab Creek) and the Youngstown WWTP was sampled to evaluate the effects of these inputs on water quality of the Mahoning River. Mill Creek was chosen for detailed characterization because it is used heavily for recreation within Mill Creek Park and is designated as a State of Ohio resource water within the park. Sites on Mill Creek were selected to measure water quality entering Youngstown, water quality downstream from the Boardman WWTP, water quality midway through Mill Creek Park, and water quality entering the Mahoning River at the mouth of Mill Creek. Additional water-quality monitoring sites were chosen on tributaries to Mill Creek (Indian Run, Cranberry Run, Ax Factory Run, and Bears Den Run) to assess water quality in streams receiving different volumes of sewer-overflow discharge (table 1).

Different goals were addressed during the 2 years of sampling (1999 and 2000) in the water-quality and hydrology network. The first year of sampling was interval-oriented, intended to assess use-attainment in the sampling networks by comparing surface-water-quality data to State regulations. The standard for *Escherichia coli* (*E. coli*) requires at least five samples within a 30-day period, so the first-year schedule called for five water samples collected over each of three 30-day intervals, for a total of 15 samples from each of the 13 surface-water sites and the Youngstown WWTP outflow. The second year of sampling was event-oriented, intended to assess the effects of sewer-overflow discharges on surface-water quality. The second-year schedule called for sample collection after three runoff-producing rains. Water-quality samples and data were collected shortly after the onset of rainfall (nominally 6 hours past peak flow) and at nominally 24 and 48 hours past peak flow during each of three wet-weather flow events in 2000, for a total of nine samples at each site. This strategy was conceived as a means of measuring where, when, and for how long sewer-overflow discharges affected surface-water quality.

Samples collected during 1999 were categorized as wet-weather or dry-weather flow samples on the basis of local rainfall data. Samples from sites that had received at least 0.25 cm (0.1 in.) of rain in the 3 days before sampling were categorized as wet-weather flow. All other samples were categorized as dry-weather flow. USGS personnel sampled the first or second of each set of five samples, and personnel from ms consultants sampled the other four. Water-quality measurements were made instream for pH, dissolved oxygen concentration, specific conductance, and temperature on every occasion. *E. coli* concentration also was measured from samples collected on every occasion. Other water characteristics were evaluated from only the USGS-collected samples (table 2).

During the three wet-weather events in 2000, USGS personnel collected surface-water data and samples, and ms consultants personnel collected sewer-overflow discharge data and samples. Instream measurements were made for pH, dissolved oxygen concentration, temperature, and specific conductance, and *E. coli* concentration was measured from every surface-water sample collected. Other measurements were taken from only the 6-hour sample or from both the 6-hour and the 24-hour sample. (See table 2 for specific analysis schedule.) Samples from WWTP effluent and sewer-overflow discharges were analyzed as outlined in table 2.

Aquatic biological sampling reaches and schedule

The second network included seven 150-m (164-yd) reaches in the Mill Creek Subwatershed: six on Mill Creek and one on Indian Run (fig. 2 and table 3). All reaches in the biological-index network were at or near sites in the water-quality monitoring network. Aquatic biological-monitoring reaches were chosen to assess attainment of biocriteria for fish and aquatic macroinvertebrates in Mill Creek upstream from Youngstown, below the Mahoning County Boardman WWTP, above and below two tributaries that carry sewer-overflow discharges, and at the mouth of Mill Creek.

Table 1. Name and location of each site in the streamflow and water-quality monitoring network, arranged by site category, in and around Youngstown, Ohio

[mi^2, square miles; 10^6 gal, million gallons; NA, not applicable; WWTP, wastewater-treatment plant]

Site identifier	Site name	Location relative to reservoirs	Location relative to overflows	Drainage area (mi^2)	Sewer overflow (10^6 gal/yr)	Receiving water	River mile
Main-stem sites							
1	Mahoning River at Youngstown	NA	Downstream	900	2.6	NA	22.5
2	Mahoning River below West Avenue	NA	Downstream	980	280	NA	21.2
3	Mahoning River at Center Street	NA	Downstream	980	470	NA	18.0
4	Mahoning River at Lowellville	NA	Downstream	1,100	1,400	NA	12.0
5	Mill Creek at Western Reserve Road	Upstream	Upstream	28	0	NA	11.6
6	Mill Creek at Shields Road at Boardman	Upstream	Upstream	54	0	NA	5.6
7	Mill Creek at Youngstown	Downstream	Downstream	66	67	NA	2.6
8	Mill Creek at Price Road at Youngstown	Downstream	Downstream	78	99	NA	0.1
Tributary-stream sites							
8	Mill Creek at Price Road at Youngstown	Downstream	Downstream	78	99	Mahoning	21.6
9	Crab Creek at Youngstown	NA	Downstream	20	180	Mahoning	19.5
10	Indian Run near Canfield	NA	Upstream	15	0	Mill Creek	7.7
11	Cranberry Run at Boardman	NA	Downstream	3.7	38	Mill Creek	5.4
12	Ax Factory Run at Youngstown	NA	Upstream	3.2	0	Mill Creek	2.1
13	Bears Den Run at Youngstown	NA	Downstream	3.9	.23	Mill Creek	1.3
Municipal sources							
A	Youngstown WWTP	NA	NA	NA	NA	Mahoning	19.4
B	Overflow at Waverly Avenue (RC24)	NA	NA	NA	NA	Mahoning	22.1
C	Overflow Salt Springs, Price Road (OF19)	NA	NA	NA	NA	Mahoning	21.6
D	Overflow east of Poland Avenue (RC111)	NA	NA	NA	NA	Mahoning	17.5
E	Overflow McGuffey, Willow Street (RC65)	NA	NA	NA	NA	Crab Creek	1.1
F	Overflow Park Drive near Kiawatha (RC8)	NA	NA	NA	NA	Mill Creek	3.6
G	Overflow at Orchard Meadows (OFMH)	NA	NA	NA	NA	Mill Creek	1.3
H	Overflow at Price and Halls Heights (RC18)	NA	NA	NA	NA	Mill Creek	.2

Table 2. Sampling schedule during interval sampling (1999) and wet-weather flow (event-oriented) sampling (2000), in and around Youngstown, Ohio

[WWTP, wastewater-treatment plant; X, sample collected each visit; M, sample collected during one visit per 30-day interval; --, constituent not sampled for; DO, dissolved oxygen concentration; $cBOD_5$, 5-day carbonaceous biochemical oxygen demand; COD, chemical oxygen demand; $NO_3 + NO_2$, nitrate plus nitrite; NH_4, ammonium; Ca, calcium; Mg, magnesium; Fe, iron; Mn, manganese; K, potassium; Na, sodium; Cl, chlorine; F, fluorine; SO_4, sulfate; SiO_2, silica]

Constituent	Interval (1999)	Wet-weather flow (2000)									
	All sites	Mahoning River and tributaries			Mill Creek and tributaries			Municipal sources WWTP			Overflows
		Nominal hours past peak flow									
		6	24	48	6	24	48	6	24	48	0-6
Fecal-contamination indicators:											
E. coli	X	X	X	X	X	X	X	X	X	X	X
C. perfringens	M	--	--	--	X	--	--	X	--	--	X
Coliphage	M	--	--	--	X	--	--	X	--	--	X
Caffeine	M	--	--	--	X	--	--	--	--	--	--
Physicochemical:											
Temperature, pH, DO, specific conductance	X	X	X	X	X	X	X	--	--	--	--
Suspended solids	M	X	X	--	X	X	--	X	X	--	X
Alkalinity	M	X	--	--	X	--	--	X	--	--	--
Nutrients:											
$cBOD_5$ and COD	M	X	X	--	X	X	--	X	X	--	X
Nitrogen forms (total, dissolved, Kjeldahl, NH_4, and NO_3+NO_2)	M	X	X	--	X	X	--	X	X	--	X
Phosphorus forms (total, dissolved, and orthophosphate)	M	X	X	--	X	X	--	X	X	--	X
Anions and cations:											
Ca^{++}, Mg^{++}, Fe^{++}, Mn^{++}, K^{+}, Na^{+}, Cl^{-}, F^{-}, SO_4^{--}, SiO_2	X	X	--	--	X	--	--	X	--	--	X

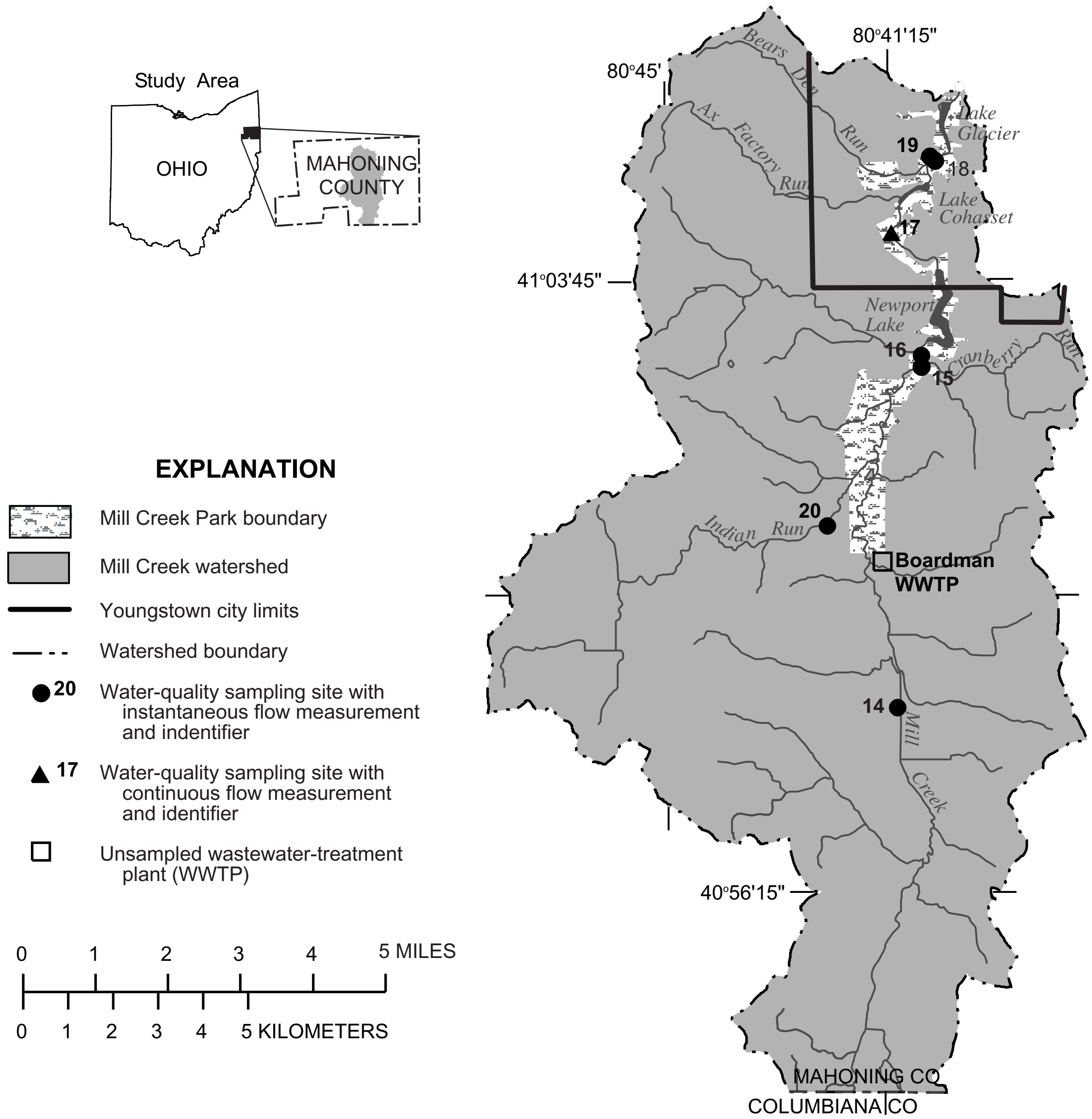

Figure 2. Biological-index sampling network in the area of Youngstown, Ohio.

A reach on Indian Run, which is not affected by sewer-overflow discharges (table 3), was included for comparison with reaches on Mill Creek.

Fish-community samples were collected and habitat-quality measurements made by USGS and ms consultants personnel at the seven reaches of the biological monitoring network (fig. 2) in July through September 1999. Aquatic-macroinvertebrate community samples were collected in September 1999 (quantitative) and November 1999 (qualitative) by personnel from the Ohio Biological Survey. The qualitative macroinvertebrate sample was scheduled for September, but collection was postponed because of inclement weather.

Field and laboratory methods

Standard USGS hydrologic and analytical methods were used throughout this investigation. All analyses were done by USGS-trained personnel, USGS-approved laboratories, and contractors or, if no appropriate USGS-approved facility was available, with OEPA-certified contractors.

Table 3. Name and location of each reach in the biological monitoring network, arranged by location on the main stem or tributary stream, in and around Youngstown, Ohio

[Mgal/yr, million gallons per year]

Reach identifier	Reach name	Location relative to overflows	Sewer overflow (Mgal/yr)	River mile
Mill Creek reaches				
14	Near Calla Road	Upstream	0	15
15	Upstream from Cranberry Run	Upstream	0	5.6
16	Downstream from Cranberry Run	Downstream	38	5.5
17	At Youngstown	Downstream	67	2.6
18	Upstream from Bears Den Run	Downstream	78	1.4
19	Downstream from Bears Den Run	Downstream	82	1.3
Tributary reach				
20	Indian Run near Canfield	Upstream	0	7.7

Streamflow measurement

Two types of streamflow measurements were made in the monitoring network. The seven continuous streamflow-measurement stations measured stage at 15-minute intervals and recorded data to dataloggers. Stage was recorded at all other sites when water samples were collected by reading the stage height from staff gages or wire-weight gages. Instantaneous-streamflow measurements were made by the method of Rantz and others (1982a) at each of the Mill Creek and tributary sites. Streamflow measurements made on at least five occasions and representing a wide range of flows were used to develop stage-discharge rating curves by the method of Rantz and others (1982b). Rating curves already were available for the Mahoning River sites except for site 3, at Center Street, for which no rating curve was developed.

Flow at Center Street was estimated as the sum of the flows calculated at Mahoning River below West Avenue (site 2), Crab Creek at Youngstown (site 9), and estimates of both inputs from Crab Creek between site 9 and the mouth and flow from the Youngstown WWTP (source A), assuming no other gains or losses across the reach. Rating curves for the other three Mahoning River sites were validated by at least three instantaneous-flow measurements over the course of the investigation.

Sample collection and processing

Surface-water samples, municipal-source-water samples, and aquatic-biological-community samples were collected by the application of the methods described below.

Surface-water samples. All surface-water samples were collected by the depth-width-integration method using isokinetic samplers (Webb and others, 1999). Samples collected into multiple containers were composited with a churn splitter (Wilde and Radtke, 1999). Whole-water subsamples for measurement of total nonfilterable residue (total suspended solids), 5-day carbonaceous biochemical oxygen demand ($cBOD_5$), chemical oxygen demand (COD), nitrogen, and phosphorus were removed from the churn splitter first. Water was filtered through a 0.45-µm capsule filter, and subsamples were collected for measurement of caffeine, alkalinity, dissolved solids, dissolved nitrogen, dissolved phosphorus, and cation and anion concentrations. All subsamples were chilled, acidified, or both chilled and acidified according to requirements identified in following sections for each analysis type. Samples for microbiological analyses were collected separately in autoclaved 1-L bottles with isokinetic samplers.

Samples of effluents from municipal sources. Sewer-overflow-discharge samples were collected with automatic samplers installed into sewerlines for this project. Samplers were activated upon diversion of flow from the main sewer to the overflow discharge outlet. As many as 24 discrete samples were collected into a composite sample bottle at 15- to 30-minute intervals during discharge (Joe Catullo, ms consultants, written commun., July 2001). Samples were retrieved as soon as was practical after collection, chilled, and held on ice for analysis. Samples from the Youngstown WWTP effluent were collected as grab samples from the discharge flume. Youngstown WWTP effluent is dechlorinated before discharge, so WWTP effluent samples were not dechlorinated before microbiological analysis.

Aquatic-biological-community samples. Fish were collected by USGS and ms consultants personnel by electrofishing with pulsed-DC current (Meador and others, 1993; Ohio Environmental Protection Agency, 1989) from each of the seven reaches (fig. 2) on two separate dates. One electrofishing pass was done over each reach on each date. Fish were identified, weighed, and checked by field personnel for external anomalies such as parasites, lesions, and skeletal deformities. Most fish were returned to the stream after processing. Voucher specimens were retained from each sample collected.

Aquatic macroinvertebrates were collected from the same reaches (fig. 2) by means of methods described by OEPA (1989). The aquatic-macroinvertebrate community sample consists of a quantitative sample and a qualitative sample, both of which are required to be collected between June 15 and September 30. The Ohio Biological Survey did sample collection for this investigation and was able to collect quantitative samples within the required timeframe. Inclement weather prevented collection of qualitative samples within the required timeframe. Implications of late collection of the qualitative sample on the aquatic macroinvertebrate community index are discussed in the results section of this report. Quantitative and qualitative samples were transferred to plastic containers and preserved in the field with 10 percent formalin and shipped to the analyzing laboratory (Pennington and Associates, Inc., Cookeville, Tenn.) for macroinvertebrate identification.

Onsite physicochemical measurements

Physicochemical measurements were made to characterize water quality and to assess designated-use attainment. The pH, dissolved oxygen concentration, temperature, and specific conductance of water were measured by use of multimeters, which were calibrated each day. Alkalinity samples were held on ice and analyzed within 12 hours of collection by means of the incremental titration inflection point method (Radtke and others, 1999).

Chemical constituents rationale, methods, and analytical laboratories

Caffeine was measured as an alternative indicator of fecal contamination because human waste can be an important source of caffeine to surface water. Total nonfilterable residue, $cBOD_5$, and COD are regulated under National Point-source Discharge Elimination System (NPDES) permits. Nutrient concentrations were measured because standards and draft criteria have been developed for surface-water nitrate plus nitrite and total phosphorus concentrations. Anions and cations were measured to help assess the similarity between the chemistry of municipal source discharges and receiving surface waters. Various laboratories, identified under headings for each method, were used to analyze these constituents in surface-water and municipal-source samples.

Caffeine. Filtered samples for caffeine analysis were shipped on ice to the USGS National Water Quality Laboratory (Denver, Colo.) for analysis by high-pressure liquid chromatography with a mass-spectroscopic detector as used in schedule 2060. The detection limit for caffeine by this method is 0.0096 μg/L.

Total nonfilterable residue. Total nonfilterable residue samples were chilled and transported on ice to the OEPA Division of Environmental Sciences Laboratory (Columbus, Ohio) for analysis within 48 hours by methods published by OEPA (1997a). The detection limit for total nonfilterable residue is 2 mg/L.

Five-day carbonaceous biochemical oxygen demand. Samples for analysis of $cBOD_5$ were chilled and transported on ice to the OEPA Division of Environmental Sciences Laboratory (Columbus, Ohio) for analysis within 48 hours by methods published by OEPA (1997b). The detection limit for $cBOD_5$ is 2 mg/L.

Chemical oxygen demand. Samples were collected for COD analysis into baked glass bottles, acidified with 4.5-*N* sulfuric acid to a pH less than 2, and shipped at 4°C to the USGS National Water Quality Laboratory (Denver, Colo.) for analysis by procedure 2144, described in Fishman and Friedman (1989). The detection limit for this procedure is 10 mg/L.

Nutrients. Nutrient samples were collected into polyethylene bottles. Total (unfiltered) nutrient samples were preserved by acidification with 4.5-*N* sulfuric acid to a pH less than 2 and shipped at 4°C. Dissolved (filtered) nutrient samples were not acidified and also were shipped at 4°C. Nutrient samples were analyzed at the USGS National Water Quality Laboratory (Denver, Colo.) for inorganic and organic forms by methods used in schedule 2702.

Anions and cations. Samples for anions and cations were filtered and collected into polyethylene bottles. Samples were acidified with 6-*N* nitric acid to a pH less than 2 and shipped at ambient temperature to the USGS National Water Quality Laboratory (Denver, Colo.) for analysis by methods used in schedule 2701.

Microbiological rationale, methods, and analytical laboratories

The State of Ohio has developed *E. coli* concentration standards for primary-contact recreational waters based on U.S. Environmental Protection Agency (USEPA) criteria. *E. coli,* coliphage, and *Clostridium perfringens* (*C. perfringens*) concentrations were used as indicators of health risk caused by fecal contamination. *E. coli* was used as a general indicator of human health risk, whereas coliphage is thought to be a better indicator of health risks posed by enteric pathogenic viruses, and *C. perfringens* is thought to be a better indicator for enteric pathogenic endospore-forming bacteria and protozoa (Rose and Grimes, 2001; Sorensen and others, 1989). More details for the following methods can be found in Francy and others (2001).

Escherichia coli. Samples for analysis of *E. coli* concentrations were carried on ice from the collection site to the Youngstown wastewater laboratory (1999 and 2000) or the Boardman wastewater laboratory (2000) for processing. Samples for *E. coli* analysis were held at 4°C for not more than 6 hours and analyzed by means of the mTEC-agar membrane-filtration method (U.S. Environmental Protection Agency, 1985). Plates were incubated at 35°C for 2 hours, then at 44.5°C for 22 to 24 hours in aluminum-block incubators. Yellow, presumptive *E. coli* colonies were tested by placing the membrane on a urea-phenol red soaked filter pad: *E. coli* colonies remain yellow when exposed to the urea-phenol red solution.

Coliphage. Samples for analysis of coliphage concentrations were chilled and shipped on ice to the USGS Ohio District Microbiology Laboratory (Columbus, Ohio) where they were held at 4°C until analysis. Analysis was initiated within 48 hours of sample collection. Concentrations of coliphage were measured by means of a modification of the β-galactosidase induction single-agar layer method (Ijzerman and Hagedorn, 1992). Coliphage concentrations were measured by incubating raw water in the presence of a host *E. coli* strain—analysis for F-specific coliphage involved the *E. coli* F-amp host. In this method, *E. coli* host bacteria grow everywhere on the agar plate except where an infectious coliphage is present. The result of incubation is confluent growth of *E. coli* interrupted by circular plaques (zones of lysis where *E. coli* were killed by coliphage). Plaques were counted after 22-24 hours incubation at 35°C.

Clostridium perfringens. Samples for analysis of *C. perfringens* concentrations were chilled and shipped on ice to the USGS Ohio District Microbiology Laboratory (Columbus, Ohio) where they were held at 4°C for analysis within 48 hours. Concentrations of *C. perfringens* were measured by means of the mCP-agar membrane-filtration method with incubation in an anaerobic environment (U.S. Environmental Protection Agency, 1996). Samples were incubated at 41°C for 22 to 24 hours, and colonies that turned pink in an atmosphere of ammonium hydroxide were counted as *C. perfringens*. Concentrations in raw-water samples represent both vegetative and dormant (endospore) populations of *C. perfringens*.

Quality control for water-quality measurements

Quality-control samples were particularly important for this investigation given that samples and onsite water-quality data were collected by both USGS and ms consultants personnel and that non-USGS laboratories did some analyses. Seven types of quality-control samples were collected: field equipment blanks, membrane-filtration equipment blanks, membrane-filtration procedure blanks, positive control samples, negative control samples, replicate samples, and spiked replicate samples. Each of these sample types was used to assess the consistency of data collection among the various individuals and laboratories collecting and analyzing samples. Preservation and maximum holding time requirements for each method were strictly adhered to. Chain-of-custody procedures were maintained for $cBOD_5$ and total nonfilterable residue samples.

Blanks were used to assess sample contamination from equipment and to assess quantitative recovery of sample from equipment. Field equipment blanks were collected monthly during interval-oriented sampling in 1999 (three blanks collected) to measure possible contamination in the analysis of caffeine, anions and cations, nutrients, $cBOD_5$, and COD. Membrane-filtration equipment blank tests were done to measure possible residual bacterial contamination after decontamination of reusable membrane-filtration equipment; these tests were done with each set of microbiological samples analyzed, for an estimated total of 180 *E. coli* analysis blanks, 54 coliphage analysis blanks, and 54 *C. perfringens* analysis blanks. Membrane-filtration procedure blank tests were used to assess quantitative recovery of microorganisms from membrane-filtration equipment after sample filtration; these tests were done weekly during periods of analysis.

Positive- and negative-control samples were used to assess sterility and proper function of microbiological media and incubation conditions. Positive-control samples, from which microorganisms were expected to grow, were done with each set of coliphage and *C. perfringens* analyses. Negative-control samples, which evaluate the selectivity of a test, were done with each set of coliphage analyses.

Replicate samples were used to assess variability in sample results. Two extra samples were collected and tested each month in 1999 (six samples) to measure response variability in microbiological analyses (*E. coli*, coliphage, *C. perfringens*) and chemical analyses (anions and cations, nutrients, $cBOD_5$, chemical oxygen demand, and total nonresidual solids). Additionally, spiked caffeine replicates (six samples) were tested to ensure that this nonconserved constituent persisted in samples for the duration of the holding time before analysis.

Each of the analyzing laboratories had its own quality-control procedures. USGS laboratories have published quality-control manuals: the Ohio District Microbiology Laboratory quality-control manual (Francy and others, 2001) can be accessed online, and the National Water Quality Laboratory publishes results of its quality-control program (National Water Quality Laboratory, 2001). Quality-control practices and procedures for the laboratory that analyzed aquatic-macroinvertebrates are available from Pennington and Associates (1997). Ohio EPA quality-control procedures were published with method procedures (Ohio Environmental Protection Agency, 1997a)

Biotic index rationale, methods, and analytical laboratories

Three biotic indices are calculated for assessment of biological use-attainment by OEPA. Two of the indices relate to fish communities, and the third relates to aquatic-macroinvertebrate communities. A habitat index also can be calculated to evaluate whether nonattainment based on fish indices is related to shortage of physical habitat or unfavorable chemical water quality.

Fish community indices. Individuals collected during electrofishing passes were identified, weighed, and checked for external anomalies such as parasites, lesions, and skeletal deformities onsite and released back to the stream (Ohio Environmental Protection Agency, 1989). Numbers of individuals, taxa, and biomass were used to calculate two indices of fish-community health.

The index of biotic integrity (IBI) developed by Karr (1981) is based on structural and functional characteristics of fish communities. Fish communities in study streams are compared to reference fish communities in similar-sized basins considered least affected by human activity within the same ecoregion. The comparison allows a score between 1 and 5 to be assigned to each of 12 metrics (listed in table 4). The IBI is calculated as the sum of the 12 metric scores; therefore, the range of possible values for the IBI is 12 to 60. Higher values indicate more healthy aquatic ecosystems than lower values do. The IBI used by OEPA includes metrics that are tailored specifically to the surface waters of Ohio (Ohio Environmental Protection Agency, 1987).

The index of well-being (Iwb) was developed by Gammon (1976) and includes the Shannon diversity index. The Shannon diversity index is based on the numbers and weights of fish and takes into account species richness and proportion of each species within the local aquatic community (Shannon and Weaver, 1949). The OEPA uses a modified index of well-being (MIwb) that excludes fish considered to be "highly tolerant" from the Iwb calculation. A high score indicates a healthier aquatic ecosystem. The MIwb score always is greater than 0, but there is no theoretical upper limit.

Habitat index. Habitat was assessed by USGS personnel at the same time that fish communities were inventoried. The qualitative habitat evaluation index (QHEI) is a measure of habitat features that affect fish communities. This habitat index incorporates six metrics: channel substrate, instream cover, channel morphology, riparian and bank condition, pool and riffle quality, and gradient (Ohio Environmental Protection Agency, 1989). The QHEI is not used as a criterion to determine the attainment of aquatic-life use designations; however, narrative interpretations of QHEI scores were derived from correlation of QHEI scores with fish-index scores. A high score should indicate that the capability of the available physical stream habitat to support a healthy aquatic community also is high. The result of a higher QHEI should, therefore, be more healthy fish communities (high IBI and MIwb scores).

Aquatic-macroinvertebrate index. The invertebrate community index (ICI) was developed by OEPA to measure the health of aquatic-macroinvertebrate communities (Ohio Environmental Protection Agency, 1987). This index is similar to the IBI for fish. Macroinvertebrate communities in study streams are compared to reference macroinvertebrate communities in similar-sized basins within the same ecoregion. There are 10 metrics for macroinvertebrate communities, scoring between 0 and 6, resulting in an overall ICI value between 0 and 60. A high score indicates a healthy community of aquatic macroinvertebrates.

Macroinvertebrate samples were preserved and shipped to Pennington and Associates, Inc., for analysis. All benthic samples were placed on a 120-μm mesh screen. After washing, the macroinvertebrates were removed from the detritus under × 5 magnification and preserved in 85 percent ethanol. The organisms were identified to the lowest practical taxonomic level with available keys (Pennington and Associates, 1997) and counted. Initial identifications were made with a stereomicroscope (× 7-60).

Slide mounts were made of the chironomids, simuliids, oligochaetes, and small crustaceans for identification with a compound microscope. The chironomids, simuliids, and oligochaetes were cleared for 24 hours in refrigerated 10 percent potassium hydroxide. Temporary mounts were made in glycerin, and the organisms were returned to 80 percent ethanol after identification. When permanent mounts were desired, the organisms were transferred to 95 percent ethanol for 30 minutes and mounted in euperol. The procedures used for taxonomic identification and enumeration followed methods described by OEPA (1989).

Table 4. Twelve metrics composing the modified index of biotic integrity used by the Ohio Environmental Protection Agency for wading-water and headwater sites

[IBI, index of biotic integrity; DELT, deformities, eroded fins, lesions, tumors]

IBI metric	Wading water	Headwater
1	Total number of species	Total number of species
2	Number of darter species	Number of darter species
3	Number of sunfish species	Number of headwaters species
4	Number of sucker species	Number of minnow species
5	Number of intolerant species	Number of sensitive species
6	Percent tolerant individuals	Percent tolerant individuals
7	Percent omnivorous individuals	Percent omnivorous individuals
8	Percent insectivorous individuals	Percent insectivorous individuals
9	Percent top carnivore individuals	Percent pioneer individuals
10	Relative number of individuals (density)	Relative number of individuals (density)
11	Percent lithophils	Number of lithophilic individuals
12	Percent DELT anomalies	Percent DELT anomalies

Estimation of *Escherichia coli* and inorganic nitrogen loads

Loads were calculated for *E. coli* and inorganic nitrogen carried by the Mahoning River and sewer-overflow discharges during the first 24 hours of wet-weather flow, defined to begin 6 hours before peak flow at the Mahoning River at West Avenue (site 2) for this computation. This definition of the beginning of wet-weather flow was adopted to include both the onset of sewer-overflow discharge and the peak flow at all sites. Sewer overflows discharged only during a portion of each 24-hour interval.

Surface-water 24-hour load. The 24-hour wet-weather loads at the Mahoning River at Youngstown (site 1) and the Mahoning River at Lowellville (site 4) were calculated for each of the three wet-weather events sampled in 2000. Streamflow volume over the 24-hour period was calculated by summing incremental flow volumes for the first 24 hours of wet-weather flow. The 24-hour wet-weather flow load was estimated from continuously monitored streamflow measurements and a regression analysis of concentration with flow. The regression analysis included *E. coli* and inorganic nitrogen concentrations measured at each site over a range of streamflow during the course of this investigation. Constituent concentrations were estimated for each streamflow measurement by means of the regression equations. Total 24-hour loads were calculated by summing incremental loads (estimated constituent concentrations multiplied by the volume of water passing the site over each 15-minute interval in 24 hours). Load estimates obtained by this method were increased by a smearing-estimator bias factor as recommended and described by Duan (1983; in USGS Office of Surface Water Technical Memorandum No. 93.08, 1992) for linear regression analysis on log-transformed data.

Sewer-overflow load. Sewer-overflow sites were identified and mapped by ms consultants (Youngstown, Ohio). The personal-computer version of the Storm Water Management Model (XP-SWMM), produced by the USEPA, was used by ms consultants to estimate discharges from 101 sewer-overflow sites in Youngstown, Ohio. The XP-SWMM model was calibrated and verified twice in 1999 and further verified by comparing a 5-year discharge simulation based on National Climatic Data Center rainfall data to historic discharge data from 1981–85 (Joe Catullo, ms consultants, written commun., 2001). Multiday simulations of discharges during the three wet-weather events sampled in 2000 were computed. Simulations generated flow-rate values on a 15-minute-interval basis, which in turn were used to estimate the discharge volume from each sewer-overflow site during each time interval. Discharge volume to the Mahoning River was estimated as the sum of discharge volumes from all modeled sewer-overflow sites.

Concentrations measured in samples collected from seven monitored sewer-overflow discharge sites in 2000 were used to estimate concentrations of *E. coli* and inorganic nitrogen forms in each of the 101 modeled sewer-overflow discharges. The characteristics of the seven monitored sewer-overflow sites were not assumed to be an adequate representation of all 101 sites; therefore, minimum, median, and maximum concentration values were used to present an expected range of concentration estimates. These concentration estimates were multiplied by XP-SWMM discharge-volume estimates for each 15-minute discharge interval for all sewer-overflow sites. The sum of loads from all 101 overflows was used as an estimate of the 24-hour load attributable to sewer-overflow discharges in Youngstown.

Hydrology of the Mahoning River and selected tributaries

The intent of hydrologic data summarization was to characterize streamflow in the study area and to present a context for wet-weather event magnitudes and timing of sample collection. These data also were used to estimate water volumes entering and leaving Youngstown in the Mahoning River, Mill Creek, and tributaries, which were necessary for calculating loads.

Streamflow

Hydrographs from centrally located, continuous streamflow-measurement stations on the Mahoning River and Mill Creek portions of the monitoring network for May through October 1999 and 2000 are shown in figure 3. As evident from the hydrographs, the Mahoning River carries larger amounts of water and maintains more consistent dry-weather flow than Mill Creek does. The instantaneous peak wet-weather flow that is exceeded on average once every 2 years was calculated to be 367,000 m^3/s (10,400 ft^3/s) for the Mahoning River below West Avenue and 71,000 m^3/s (2,010 ft^3/s) for Mill Creek at Youngstown by use of the method described by Koltun and Roberts (1990). Wet-weather events sampled in this investigation can be characterized as small to moderate because the 2-year flow was not reached on either stream during the months evaluated in this investigation.

The hydrographs in figure 3 include superimposed symbols on dates when samples were collected. Water samples were collected during wet-weather flow and dry-weather flow in 1999 (fig. 3). Samples were collected only during wet-weather flow in 2000. Early summer 2000 was wetter than early summer 1999 had been. The three flow peaks that were sampled in 2000 came in late summer when the hydrograph, similar to the 1999 hydrograph, was characterized by steady dry-weather flow punctuated by wet-weather flow peaks. Dry-weather concentration estimates based on 1999 data should be relevant to late-summer 2000 on the basis of this hydrologic observation.

Wet-weather events

One-week hydrographs from August, September, and October 2000 at three continuous streamflow-monitoring stations on the Mahoning River (fig. 4) and Mill Creek (fig. 5) were abstracted from the continuous record for water year 2000. As mentioned previously, wet-weather events were initiated by precipitation greater than 0.25 cm (0.1 in.). Wet-weather flow was defined to begin 6 hours before peak flow, and a wet-weather event was defined to end 48 hours after peak flow for the purposes of analysis in this investigation. Situations involving a secondary flow peak—most pronounced during the August 2000 event—were still treated as a single wet-weather flow event.

Discharge intervals for monitored sewer overflows (three to the Mahoning River, one to Crab Creek, and three to Mill Creek) were superimposed on the hydrographs (figs. 4 and 5). Discharge intervals shown in figures 4 and 5 do not necessarily represent the discharge intervals of all sewer overflows in the sampling network because only 7 of the 101 modeled sewer-overflow sites were monitored. All discharges occurring during a wet-weather flow event were considered to be part of the same discharge event. Data depicted in figures 4 and 5 clearly show that discharges at individual overflow sites could be discontinuous. It was not possible to measure the actual intervals during which each of the unmonitored sewer-overflow sites upstream from a water-quality monitoring site was actively discharging.

Surface-water samples were expected to reflect the effect of sewer-overflow discharges on receiving waters because monitored sewer overflows discharged before surface-water sample collection during all three sampled wet-weather events. The August 2000 event, however, included dual streamflow peaks, and sewer overflows discharged not only before the first surface-water sample collection but also between the first and second surface-water sample collections. The volume of the second discharge was 79,000 m^3 (21 Mgal) compared with 450,000 m^3 (119 Mgal) for the first discharge. Total model simulated sewer-overflow discharges for the first 24-hour interval of each wet-weather event were 450,000 m^3 (119 Mgal) on August, 6 and 7 144,000 m^3 (38 Mgal) on September, 20 and 21 and 64,300 m^3 (17 Mgal) on October, 5 and 6 (Joe Catullo, ms consultants, written commun., 2001). According to the 5-year XP-SWMM simulation, 92 percent of sewer-overflow volume was discharged to the Mahoning River and tributary streams outside the Mill Creek Subwatershed, and the remaining 8 percent of discharge volume went into the Mill Creek Subwatershed.

Water quality of the Mahoning River and selected tributaries

Surface-water quality in the study area was evaluated to determine where, when, and for how long *E. coli* concentrations exceeded primary-contact recreational-use standards. Chemical water-quality constituents were evaluated to determine where and when standards and draft criteria for the protection of aquatic life were not met. OEPA uses biotic indices to assess whether Ohio public waterways achieve their designated use as warmwater habitat; therefore, Mill Creek biotic-index data were compiled for assessment of this long-term indicator of water quality (relative to instantaneous chemical concentration data). Finally, an attempt was made to quantify the effects of sewer-overflow

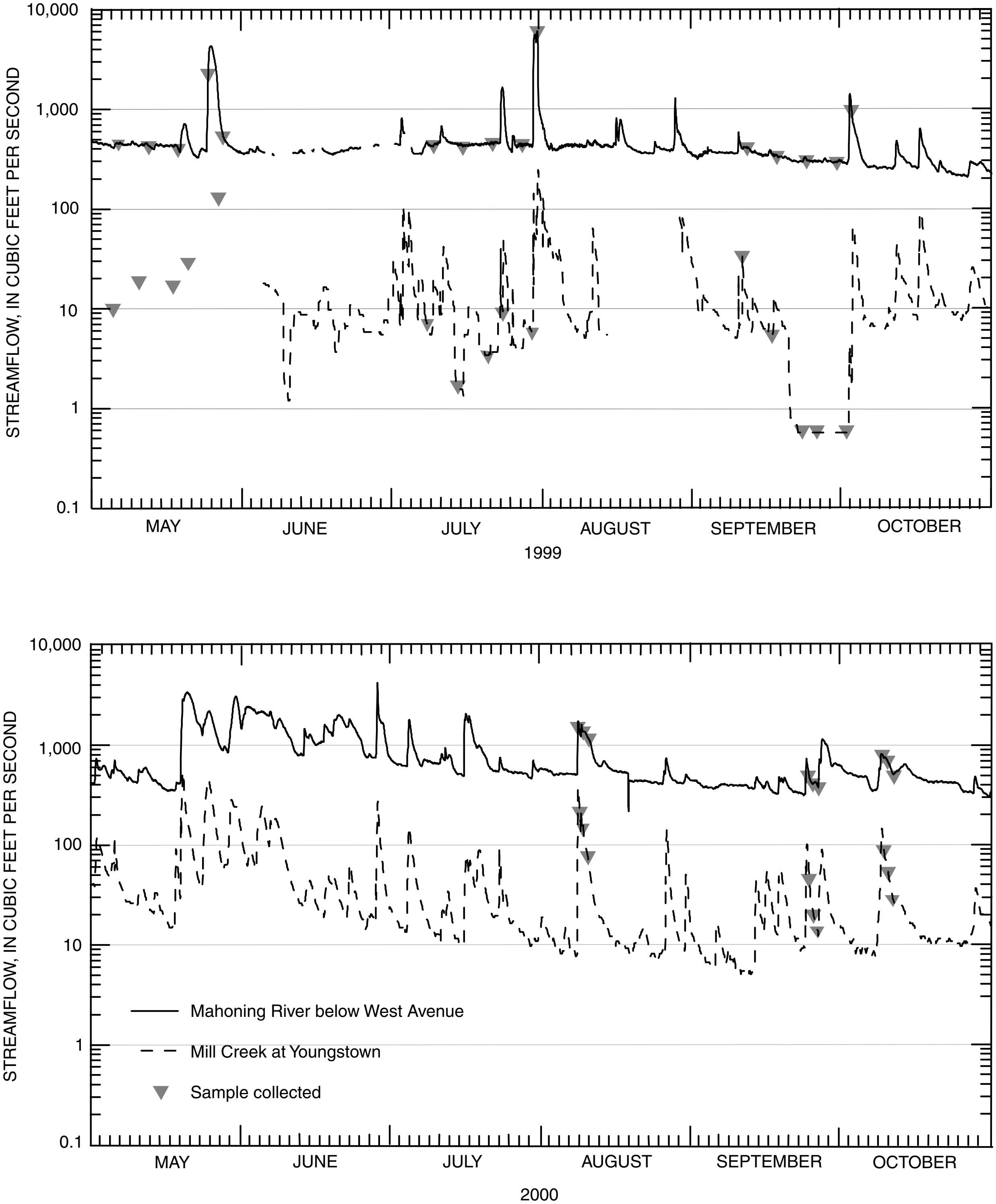

Figure 3. Streamflow and sample collection for two sites in Youngstown, Ohio, during summer 1999 and 2000. (Discontinuities in graph line show where data are missing from record.)

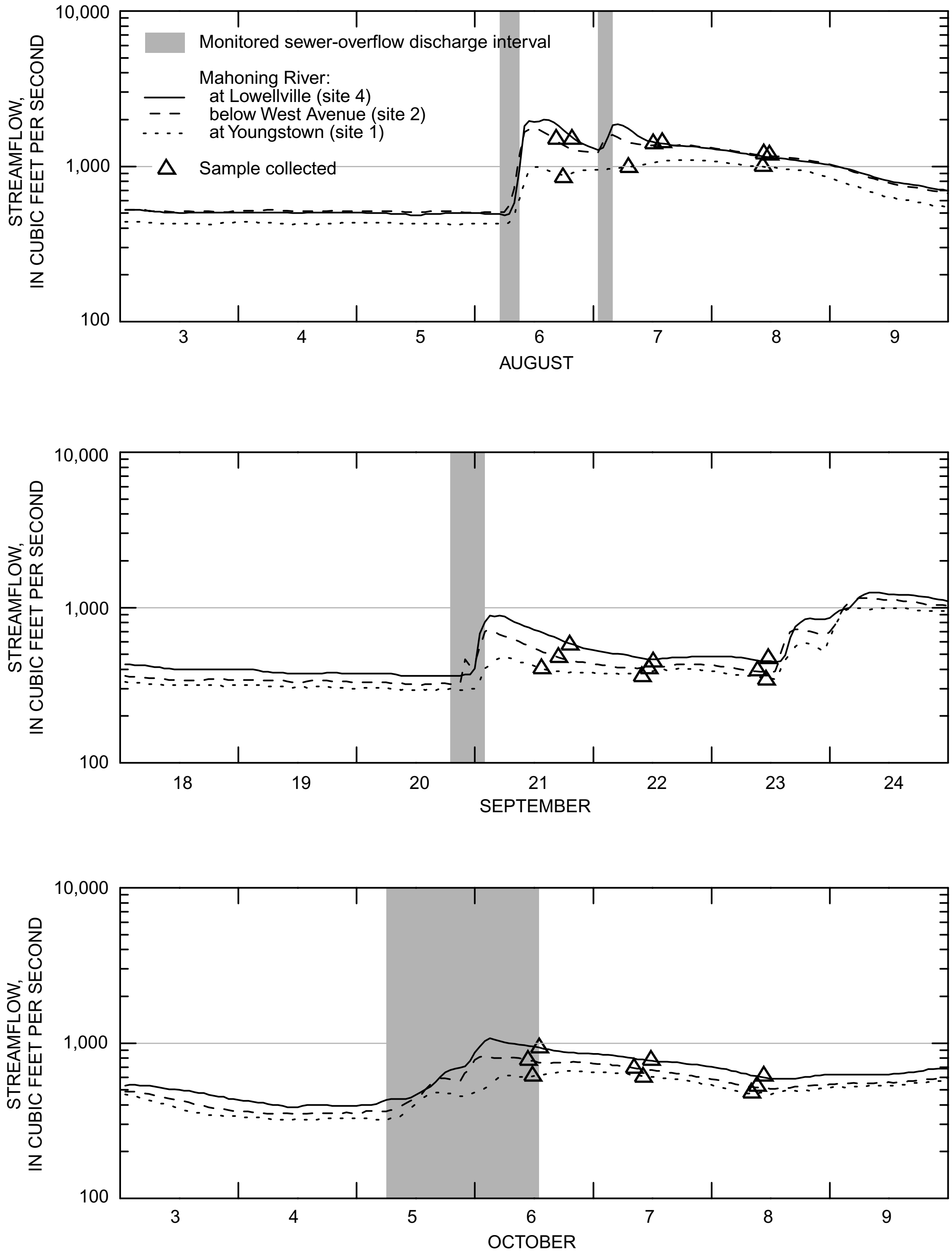

Figure 4. Streamflow and sample collection for three sites on the Mahoning River, Ohio, during three wet-weather flow events sampled, August-October 2000.

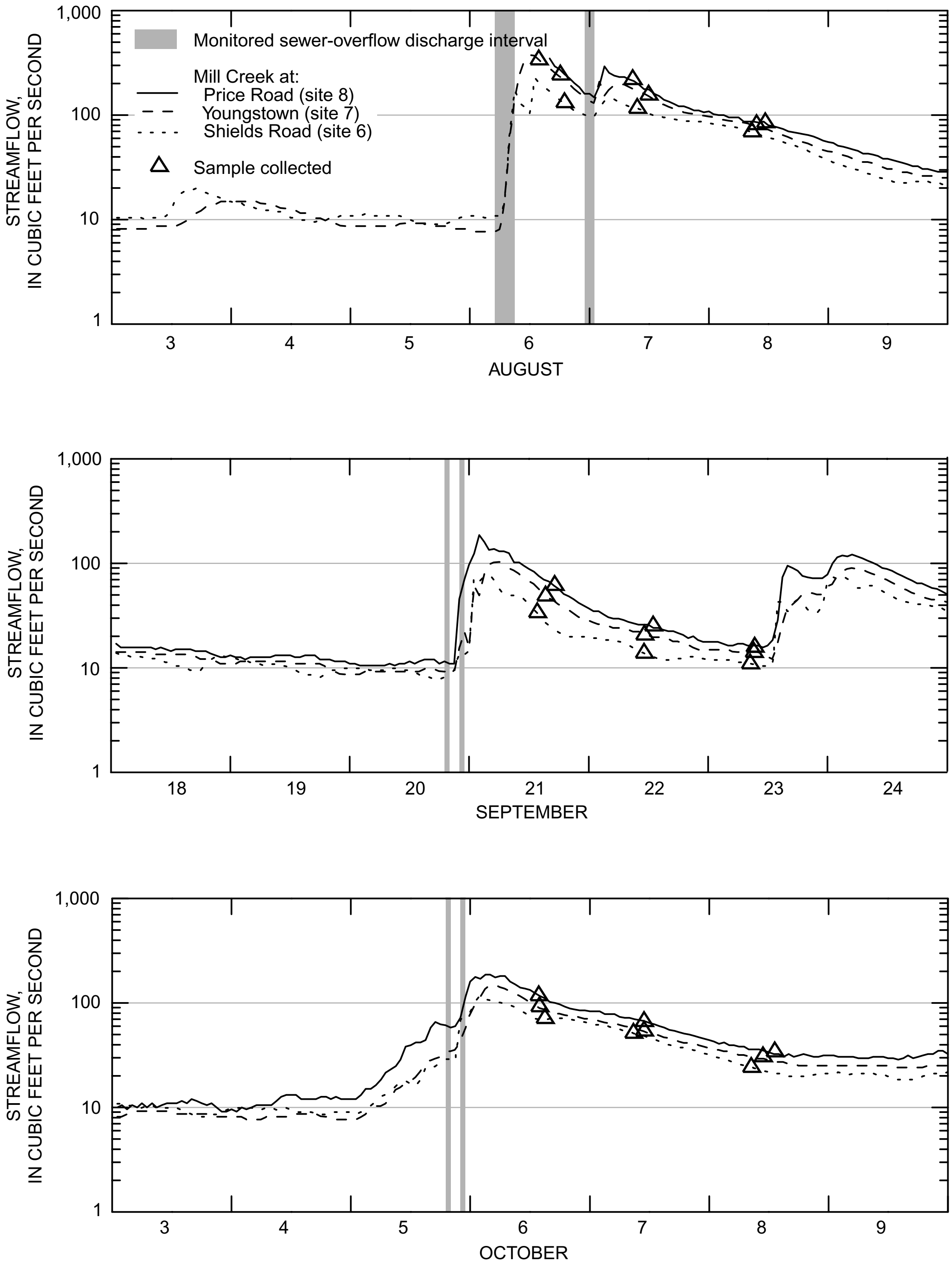

Figure 5. Streamflow and sample collection for three sites on Mill Creek, Ohio, during three wet-weather flow events sampled during, August-October 2000. (Discontinuities in graph line show where data are missing from record.)

discharges on surface-water loads of constituents relevant to water quality in the study area.

Many constituents were evaluated in an attempt to relate surface-water quality to possible municipal sources of impairment (table 2). Analysis of various constituents did not lead to conclusions that were relevant to the objectives of this report. Data for surface-water concentrations of total suspended solids, $cBOD_5$, COD, and anions and cations have been published elsewhere (Shindel and others, 2000 and 2001). Data for the aforementioned constituents in sewer-overflow discharges, when collected, are included in this report as appendix A.

Quality control was important in the evaluation of this data set because the analytical scope of this investigation required cooperation from multiple parties. Blank samples never showed unacceptable levels of contamination with water-quality constituents. Positive control samples always showed the presence of measured constituents, and negative control samples always showed the absence of measured constituents. Replicate analyses agreed within 10 percent, and caffeine-spiked samples showed acceptable recovery.

Primary-contact recreational use

Ohio law states that, for primary-contact recreational waters, "geometric mean *E. coli* content . . . based on not less than 5 samples in a 30-day period shall not exceed 126 (CFU) per 100 mL and *E. coli* content . . . shall not exceed 298 (CFU) per 100 mL in more than 10 percent of the samples taken during any 30-day period" (Ohio Environmental Protection Agency, 2002). *E. coli* concentration data collected during interval-oriented sampling in 1999 were used to calculate 5-sample, 30-day geometric mean values for comparison to the standard (table 5). At least one part of the two-part standard was exceeded in 35 of 37 instances. The two instances for which *E. coli* concentrations met the complete standard both occurred in September 1999, at Mill Creek at Price Road (site 6) and Indian Run near Canfield (site 10). In two other instances, both in May 1999, geometric-mean *E. coli* concentrations were less than 126 colony-forming units per 100 mL (CFU/100 mL), but in each case one of the five samples (20 percent) had an *E. coli* concentration higher than 298 CFU/100 mL. *E. coli* concentrations frequently were higher than Ohio's standard for primary-contact recreational waters throughout the sampling network.

E. coli concentrations during dry- and wet-weather flows were compared to evaluate whether streamflow condition influenced microbiological water quality. *E. coli* carried by dry-weather flows are contributed by some or all of the following: municipal WWTP effluent, leaking municipal sewerlines, septic-system leachate, and direct fecal inputs from domestic animals and wildlife. If only those sources contributed *E. coli* to the stream during wet-weather flow, and if the contributions were at the same rate as during dry-weather flow, then *E. coli* concentrations should have decreased during wet-weather flow because of dilution with rainwater runoff. On the other hand, *E. coli* concentrations could remain constant or increase during wet-weather flow because of increased contributions from dry-weather sources (faster flow through septic systems may allow breakthrough or less effective treatment, less contact time in WWTPs). Additional contributions of fecal material to the stream during wet-weather flow can come from additional human sources (sewer-overflow discharges, partially treated WWTP effluent) or domestic animal (overflows from waste-treatment lagoons) and wildlife sources (feces carried with surface runoff).

E. coli concentration data from both years of this study are summarized as boxplots in figure 6. Sites were placed into seven categories for figure 6 on the basis of site and location characteristics. (See also table 1.) Site categories were divided further by flow condition. *E. coli* concentrations were higher during wet-weather flow than during dry-weather flow in all site categories.

E. coli concentration observations for dry-weather flow (fig. 6) show that in three of five site categories, 75 percent or more of concentrations were less than 298 CFU/100 mL. This finding indicates that, within some site categories, surface water in the study area could be expected to meet Ohio *E. coli* standards during periods of extended dry weather. In every surface-water site category, *E. coli* concentrations from more than 75 percent of wet-weather flow samples were greater than 298 CFU/100 mL; thus, if no changes are made to the watershed, the water-quality standard usually will be exceeded during periods that include wet-weather flow.

To evaluate how long wet-weather flow affects microbiological water quality, *E. coli* concentrations measured during wet-weather events (sampled in 2000) were compared with expected dry-weather flow concentrations based on 1999 data (table 6). The geometric mean of concentrations measured at time intervals during wet-weather events (nominally up to 48 hours past peak flow) were all higher than geometric-mean concentrations during dry-weather flow. *E. coli* concentrations in the Mahoning River were generally less than three times higher than dry-weather flow concentrations within 48 hours after peak flow; however, at Mill Creek and other tributary sites, *E. coli* concentrations generally remained more than four times higher than dry-weather flow concentrations at 48 hours after peak flow. By comparison, WWTP effluent *E. coli* returned to near-normal concentrations within 24 hours after peak flow in the Mahoning River (table 6).

Table 5. Five-sample geometric mean *Escherichia coli* concentrations and percentage of samples exceeding the standard of 298 colony-forming units per 100 milliliters during three 30-day periods in May, July, and September 1999

[--, data not collected; Geo mean, geometric mean; std, standard of 298 colony-forming units per 100 milliliters]

Site location and identifier	May 1999		July 1999		September 1999	
	Geo mean	Percent over std	Geo mean	Percent over std	Geo mean	Percent over std
Mahoning River:						
At Youngstown (1)	89	20	220	20	160	20
Below West Avenue (2)	420	40	310	20	350	40
At Center Street (3)	--	--	720	40	820	60
At Lowellville (4)	850	60	2,000	100	930	40
Mill Creek:						
At Western Reserve Rd. (5)	580	60	550	100	620	100
At Shields Road (6)	940	60	400	60	590	100
At Youngstown (7)	240	40	500	40	290	20
At Price Road (8)	54	20	220	40	53	0
Tributaries:						
Crab Creek at Youngstown (9)	160	20	1,700	80	400	40
Indian Run near Canfield (10)	260	20	240	40	61	0
Cranberry Run at Boardman (11)	780	60	500	100	440	60
Ax Factory Run at Youngstown (12)	--	--	300	40	550	40
Bears Den Run at Youngstown (13)	130	40	690	60	230	40

The Mahoning River and Mill Creek failed to meet designated recreational uses because of microbiological water quality in and around Youngstown during summer 1999 (table 6). A longitudinal view of geometric-mean concentrations (fig. 7) was prepared to look at spatial distributions across Youngstown. *E. coli* concentrations increased in the Mahoning River as the river passed through Youngstown (figs. 7a, b). Monitored sources to the Mahoning River (Mill Creek, Crab Creek, and the Youngstown WWTP) did not carry substantially greater concentrations of *E. coli* than did the Mahoning River; although they certainly added a bacterial load to the Mahoning River, they could not have increased main-stem *E. coli* concentrations. Dry-weather flow increases in *E. coli* concentrations across the reaches between Mahoning River at Youngstown (site 1) and Mahoning River below West Avenue (site 2) and between site 2 and Mahoning River at Center Street (site 3) were not explained by additions from monitored sources (fig. 7a). During wet-weather flow, sewer overflows contributed discharge with high *E. coli* concentrations and may help explain increases in *E. coli* concentration across the same reaches (fig. 7b).

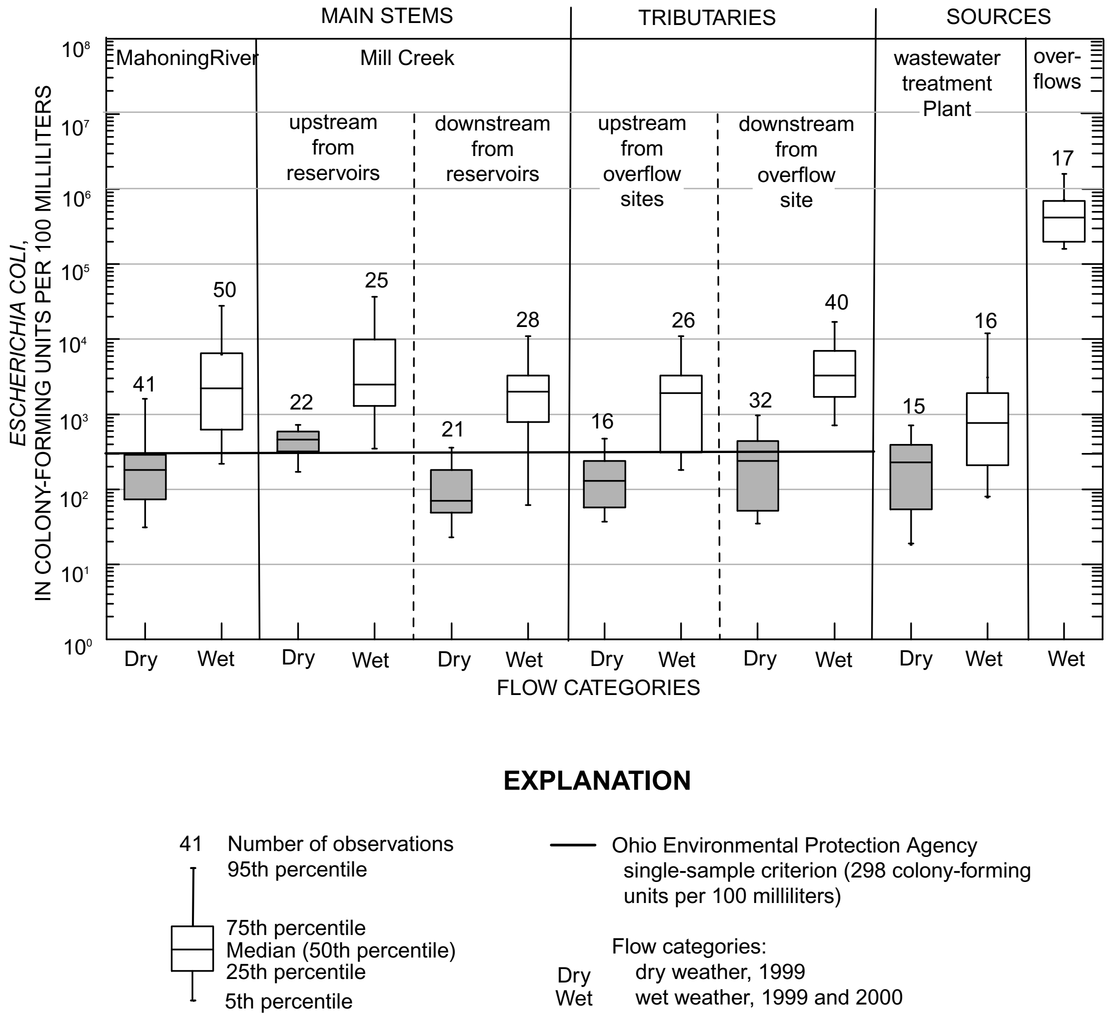

Figure 6. Summary of *Escherichia coli* concentration data by site type, relative location, and flow category for summer 1999 and 2000 in the Mahoning River, Ohio, and selected tributaries and sources.

Concentrations of *E. coli* in Mill Creek (fig. 7c, d) were constant between Western Reserve Road (site 5) and Shields Road (site 6); then, as Mill Creek passed through reservoirs in Mill Creek Park to Youngstown (site 7) and Price Road (site 8), concentrations decreased. This decrease may have been caused by settling in the reservoirs and the time it took the water to pass through the reservoirs. *E. coli* bacteria commonly are associated with suspended material that falls as sediment in reservoirs. The residence time of each reservoir is not known, but because *E. coli* do not reproduce outside of the body in temperate climates (Clesceri and others, 1998), then some *E. coli* should die off in the reservoirs. Sampled tributaries to Mill Creek carried *E. coli* at similar concentrations to those in Mill Creek; therefore, tributaries neither substantially reduced nor increased *E. coli* concentrations in Mill Creek. Relatively *E. coli*-rich additions from overflows, however, might have increased *E. coli* concentrations at Youngstown (site 7) and at Price Road (site 8) and may have increased *E. coli* concentrations compared with what they would otherwise have been (fig. 7d).

Aquatic-life use

The State of Ohio has developed regulations for the protection of aquatic life, particularly fish and aquatic macroinvertebrates (Ohio Environmental Protection Agency, 2002). These regulations vary according to the surrounding ecoregion and aquatic-life use designation of the stream. Youngstown, Ohio, lies within the Erie-Ontario Lake Plain

Table 6. Geometric-mean *Escherichia coli* concentrations during dry-weather flow (1999) and at nominal times after wet-weather flow peaks (2000). (All data are in colony-forming units per 100 milliliters)

[WWTP, wastewater-treatment plant]

Site location and identifier	Dry-weather flow (1999)	Wet-weather flow (2000) Nominal hours after peak flow		
		6	24	48
Mahoning River:				
At Youngstown (1)	52	800	790	160
Below West Avenue (2)	110	2,100	1,800	300
At Center Street (3)	330	4,100	2,400	1,100
At Lowellville (4)	490	7,900	2,400	880
Mill Creek:				
At Western Reserve Road (5)	410	9,200	6,300	1,500
At Shields Avenue (6)	270	7,200	6,000	1,400
At Youngstown (7)	130	2,700	1,300	580
At Price Road (8)	44	2,800	3,200	520
Tributaries:				
Crab Creek at Youngstown (9)	160	6,500	3,200	2,000
Indian Run near Canfield (10)	100	7,000	3,500	600
Cranberry Run at Boardman (11)	310	7,700	3,400	1,900
Ax Factory Run at Youngstown (12)	160	2,600	1,600	390
Bears Den Run at Youngstown (13)	100	5,900	2,200	1,300
Municipal sources:				
Youngstown WWTP (source A)	130	2,400	200	320

(EOLP) ecoregion, and all streams in the study area are designated as warmwater habitat. The associated State criteria are listed in table 7. Water-quality data from the entire 2-year study were summarized as a series of boxplots (figs. 8 and 9) for comparison with State regulations. Observations were separated by site category and flow condition before summarization to allow evaluation of where and when water quality did not meet criteria. Even sporadic failure to meet chemical water-quality regulations may result in failure to support aquatic biota within the study area because aquatic organisms integrate the effects of water quality in their habitat.

Water-quality standards for pH, dissolved oxygen concentration, and temperature were met in more than 75 percent of all instances (fig. 8). Specific cases where standards were not met are listed in table 8. The pH standards were not met when pH exceeded 9.0, usually during dry weather (fig. 8). The pH standard was exceeded at least once in all five tributaries and at half of the Mahoning River and Mill Creek sample sites (table 8). Dissolved oxygen concentrations generally met the State standard (fig. 8); those concentrations that did not meet standards were documented only during dry-weather flow (table 8). Mill Creek at Western Reserve (site 5) did not meet the dissolved oxygen concentration standard on two sampling dates (one on May 11, 1999, and the other on July 27, 1999), and Bears Den Run (site 13) did not meet the dissolved oxygen concentration standard on July 28, 1999.

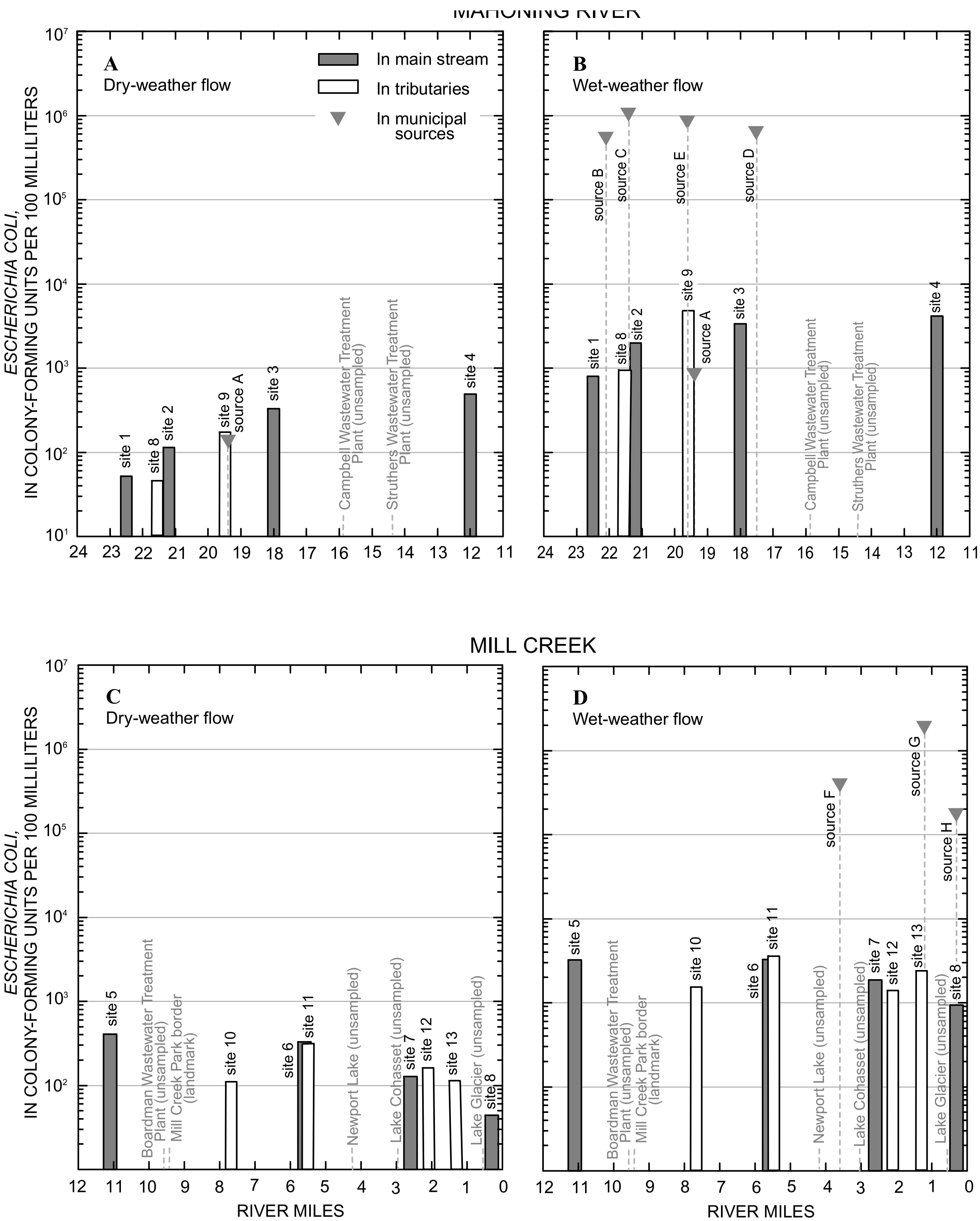

Figure 7. Geometric mean *Escherichia coli* concentrations in the (A and B) Mahoning River and (C and D) Mill Creek, Ohio, parts of the water-quality sampling network during dry-weather flow (1999) and wet-weather flow (1999 and 2000).

Table 7. State of Ohio regulations for the protection of aquatic life in designated warmwater-habitat streams in the Erie-Ontario Lake Plain ecoregion

[Regulations are standards (Ohio Administrative Code 3745-1-07) except nitrate plus nitrite and total phosphorus, which are draft criteria (Robert Miltner, U.S. Environmental Protection Agency, written commun., 1999). Min, regulation minimum; Max, regulation maximum; mg/L, milligrams per liter; degrees C, degrees Celsius; NA, not applicable; mi^2, square miles]

Criterion	Units	Min	Max	Application
pH	Standard units	6.5	9.0	All seasons, statewide.
Dissolved oxygen	mg/L	4.0	NA	All seasons, statewide.
Temperature	degrees C	NA	22.8	May 16–31
		NA	25.0	June 1–15
		NA	29.4	June 16–Sept. 15
		NA	25.6	Sept. 16–30
		NA	22.8	Oct. 1–15
Ammonium, instantaneous	mg/L	NA	1.1–13.0	March to November, statewide. Value is dependent on pH and temperature.
Ammonium, 30-day average	mg/L	NA	0.1–2.3	March to November, statewide. Value is dependent on pH and temperature.
Nitrate plus nitrite	mg/L	NA	1.0	Drainage area less than 200 mi^2, statewide.
		NA	1.5	Drainage area 200 or more mi^2, statewide.
Total phosphorus	mg/L	NA	.08	Drainage area less than 20 mi^2, statewide.
		NA	.10	Drainage area 20 to less than 200 mi^2, statewide.
		NA	.17	Drainage area 200 to less than 1000 mi^2, statewide.

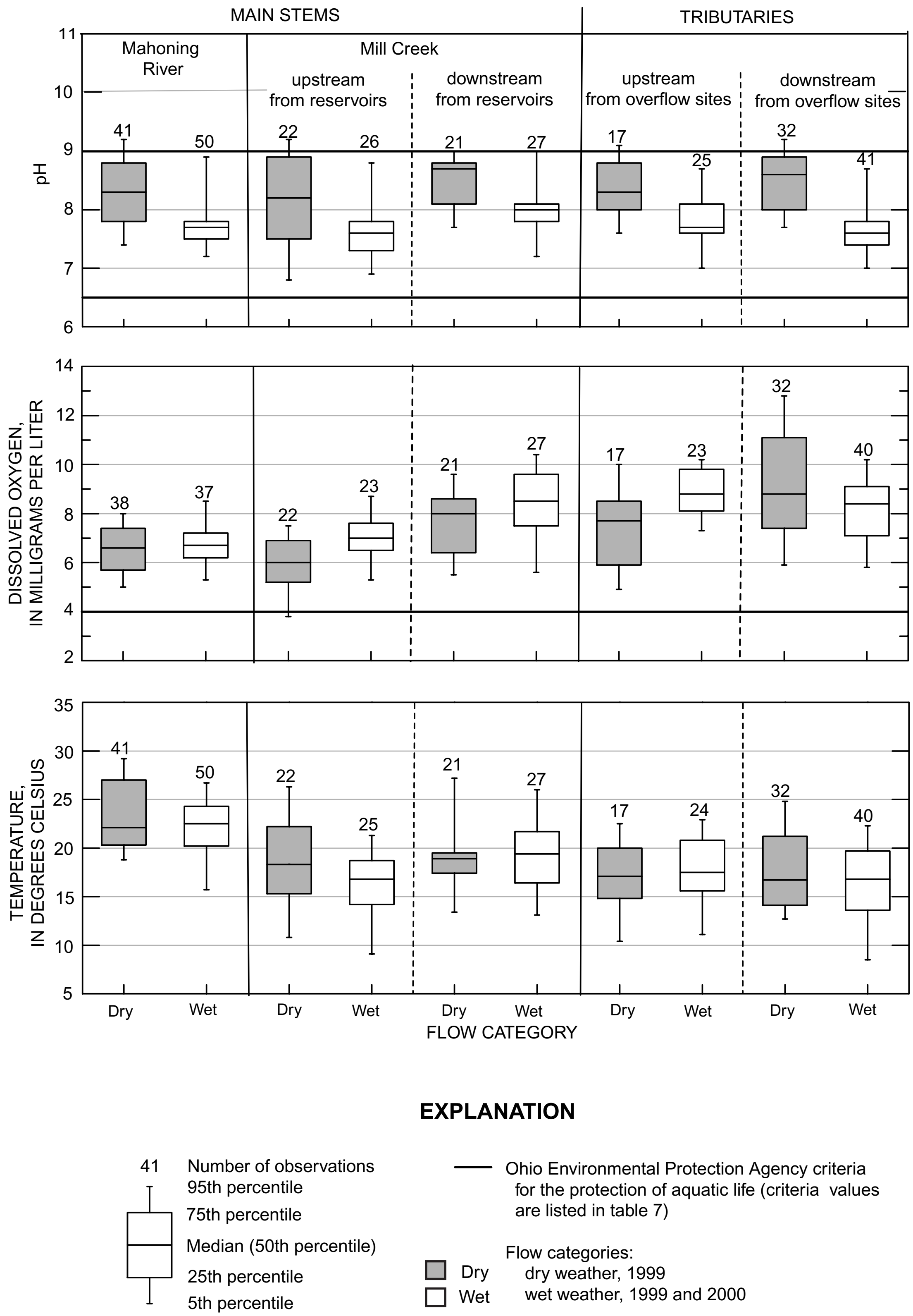

Figure 8. Summary of pH, dissolved oxygen concentration, and temperature data by site

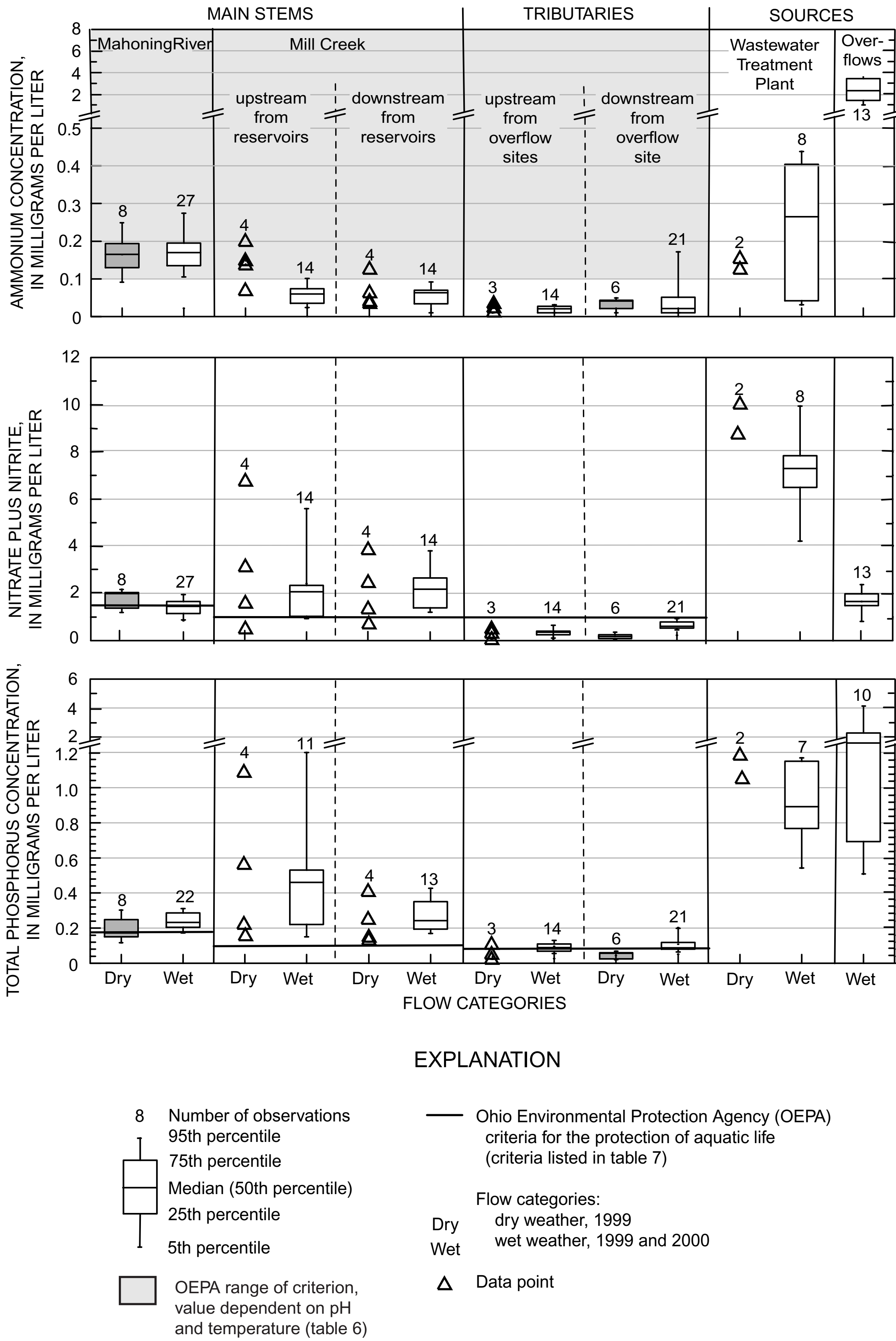

Figure 9. Summary of ammonium, nitrate plus nitrite, and total phosphorus concentrations by site type, relative location, and flow category in the area of Youngstown, Ohio.

Table 8. Observations for which surface-water quality did not meet one or more Ohio physical or chemical water-quality standards for the protection of aquatic life (sites at which all chemical water-quality standards were met are not listed), in or around Youngstown, Ohio

[^{o}C, degrees Celsius; DO, dissolved oxygen; mg/L, milligrams per liter]

Site	Standard	Date	Measured value
Mahoning River at Youngstown (site 1; 24 total measurements)	Temperature	7/20/99	30.2 ^{o}C
		9/21/99	27.4 ^{o}C
		10/06/00	23.0 ^{o}C
	pH	7/26/99	9.1
		9/21/99	9.3
		9/27/99	9.3
Mahoning River below West Avenue (site 2; 24 total measurements)	pH	5/24/99	9.2
		9/27/99	9.2
Mill Creek at Western Reserve Road (site 5; 25 total measurements)	DO	5/11/99	3.8 mg/L
		7/27/99	3.7 mg/L
	pH	5/25/99	9.1
		9/13/99	9.5
		9/22/99	9.2
Mill Creek at Price Road (site 8; 24 total measurements)	pH	9/14/99	9.3
		9/29/99	9.4
Crab Creek at Youngstown (site 9; 24 total measurements)	Ammonium (30-day)	9/9/99	0.7 mg/L
	pH	5/10/99	9.1
		5/17/99	9.1
		5/26/99	9.1
		9/14/99	9.8
		9/23/99	9.2
		9/29/99	9.6

Table 8. Observations for which surface-water quality did not meet one or more Ohio physical or chemical water-quality standards for the protection of aquatic life (sites at which all chemical water-quality standards were met are not listed), in or around Youngstown, Ohio —Continued

[^{o}C, degrees Celsius; DO, dissolved oxygen; mg/L, milligrams per liter]

Site	Standard	Date	Measured value
Indian Run near Canfield (site 10; 31 total measurements)	pH	7/12/99	9.1
		9/13/99	9.3
Cranberry Run at Boardman (site 11; 24 total measurements)	pH	9/13/99	9.1
Ax Factory Run at Youngstown (site 12; 23 total measurements)	pH	9/14/99	9.1
Bears Den Run at Youngstown (site 13; 30 total measurements)	DO	7/28/99	3.9 mg/L
	pH	5/17/99	9.4
		9/14/99	9.2

Ohio standards for temperature and ammonium vary with time of year (table 7). The ammonium standard is dependent on pH and temperature because the solubility of ammonium is controlled by both factors. Furthermore, an instantaneous standard and a 30-day average standard are in effect for ammonium (table 7). Data for temperature (fig. 8) and ammonium (fig. 9) were not, therefore, compared to a single-value standard. Value-by-value interpretation indicated that temperatures met State standards in all site categories except for three observations from Mahoning River at Youngstown. All measured ammonium concentrations met both the instantaneous and 30-day average criteria except for one observation from Crab Creek in September 1999; this observation met the instantaneous criterion but was higher than the 30-day average criterion. Because only one sample was collected during September 1999 for ammonium, in a regulatory setting this observation would not be considered an exceedance but would be grounds for additional sampling for ammonium concentrations at the site (Steve Tuckerman, Ohio Environmental Protection Agency, oral commun., 2000).

Waters in the sampling network met State standards for the protection of aquatic life in most instances; however, current (2002) State standards do not cover nitrate plus nitrite or total phosphorus in warmwater habitat. OEPA has drafted nutrient criteria for legislative consideration (Robert Miltner, Ohio Environmental Protection Agency, written commun., 1999). These draft criteria were included for comparison in table 7. Boxplots were produced (fig. 9) to allow evaluation of measured concentrations against the nitrate plus nitrite and total phosphorus draft criteria.

Data presented in figure 9 indicate that, in general, nutrient concentrations did not change from dry-weather flow to wet-weather flow in the Mahoning River and Mill Creek. Wet-weather flow concentrations may have been higher than concentrations measured during dry-weather flow in tributaries downstream from overflow sites. Nutrient concentrations in Youngstown WWTP effluent (source A) appeared to decrease during wet-weather flow. Mahoning River sites tended to have nitrate plus nitrite and total phosphorus concentrations at or near the draft criteria. Mill Creek sites, both upstream and downstream from reservoirs, tended to have nutrient concentrations in excess of the draft criteria. Tributaries tended to have nitrate plus nitrite concentrations lower than the draft criteria but total phosphorus concentrations at or above the draft criteria.

Concentrations of nitrate plus nitrite and total phosphorus increased during wet-weather flow at tributaries downstream from overflow sites (Bears Den Run, Crab Creek, Cranberry Run); this observation may indicate an influence of sewer-overflow discharge on water quality, or it may be related to greater urbanization of the watersheds that also include sewer-overflow sites (Driver and Tasker, 1990).

Warmwater-habitat use

The attainment of aquatic-life use designations is determined from three biotic indices: index of biotic integrity (IBI), modified index of well-being (MIwb), and invertebrate community index (ICI). A fourth index, the qualitative habitat evaluation index (QHEI), can be used as a comparison to evaluate whether nonattainment based on IBI or MIwb scores is related to chemical water quality or availability and quality of physical stream habitat. Criteria vary with the surrounding ecoregion and aquatic-life use designation of the stream; criteria for the EOLP ecoregion warmwater habitat aquatic-life use are presented in table 9.

The total fish catch for the six sites of the biological monitoring network on Mill Creek consisted of 2,343 individuals representing 25 species. Common carp accounted for 90 percent of the biomass. Bluntnose minnows, common carp, and green sunfish, all tolerant of anthropogenic disturbances, were the dominant species making up 29 percent, 24 percent, and 11 percent of the total fish catch, respectively. The reach on Indian Run (reach 20) yielded 371 fish comprising 16 species and 1 hybrid. The IBI score from Indian Run (reach 20), a reach with little or no sewer-overflow discharge (fig. 10), is higher than IBI scores for any of the Mill Creek reaches. The high IBI score is attributed mostly to the higher number of total species, higher number of darter species, and higher percentage of insectivorous individuals within Indian Run. The MIwb cannot be calculated in streams that drain less than 32 km^2 (20 mi^2); therefore, no MIwb score is presented for Indian Run.

Fish-index data (IBI) showed no clear longitudinal trend within Mill Creek from upstream to downstream despite increased influence from sewer-overflow discharges at downstream sites. The IBI scores all fell within the OEPA range of "insignificant departure"— 4 or fewer IBI points apart from each other (Ohio Environmental Protection Agency, 1987). In other words, a difference of 4 or fewer IBI points could be accounted for by expected data variability. The IBI and MIwb scores were all associated with the fish-community narrative descriptions of "poor to very poor." No reach in the biological monitoring network met designated-use criteria on the basis of IBI or MIwb scores.

Nonattainment of designated-use criteria on the basis of fish indices was despite QHEI scores that improved in Mill Creek from upstream to downstream sites: QHEI scores met or exceeded the Ohio Environmental Protection Agency (1987) reference value for warmwater-habitat sites at all sites except Mill Creek near Calla Road (reach 14), where the stream was channelized and lacked riparian vegetation comparable to vegetation at downstream reaches.

The longitudinal comparison of Mill Creek fish and habitat indices along a gradient of increasing sewer-overflow discharges (fig. 10) showed no visual relation between fish index scores and either habitat quality or sewer-overflow discharge volume. This does not mean that habitat quality or sewer-overflow discharge had no effect on aquatic life in Mill Creek and Indian Run. The fish and macroinvertebrate communities are depressed in both systems, and further cumulative effects may be difficult to isolate for investigation. Longitudinal improvements to aquatic habitat in Mill Creek, as indicated by QHEI scores, may have been offset by increasing pressure from corresponding increases in annual volumes of sewer-overflow discharge, flow alteration at reservoirs, or other factors.

QHEI scores indicated that healthier fish communities than those observed should be present in Indian Run and the part of Mill Creek within Mill Creek Park. Some other limiting factor, possibly nutrient stress or flow alteration at reservoirs, may have contributed to nonattainment of biological criteria. As discussed in the previous section, no aquatic-life use-designation standards are yet in effect for concentrations of nitrate plus nitrite or total phosphorus; however, draft criteria have been written (Robert Miltner, Ohio Environmental Protection Agency, 1999). Nitrate plus nitrite concentrations were well above draft criteria at all sites downstream from the Boardman WWTP, and total phosphorus concentrations were above draft criteria for all sites on Mill Creek (fig. 9).

ICI values were calculated and compared with warmwater-habitat criteria within the EOLP ecoregion (table 9). Observed ICI narrative scores from six of the seven reaches corresponded to a "fair" rating. The ICI narrative score of the remaining site, Mill Creek downstream from the confluence with Cranberry Run (reach 16), was rated as "good." Mill Creek did not meet the ICI warmwater-habitat criterion for most of the network sites and Indian Run (fig. 10). Owing to the late collection of qualitative macroinvertebrate samples, the ICI scores may have been slightly higher than those reported. This potential bias should be kept in mind when viewing longitudinal trends in ICI scores for Mill Creek. Late collection of the qualitative sample may have changed one ICI metric; namely, the total number of qualitative Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa. If the measured scores were substituted with 6, the maximum score for this metric, two additional ICI scores would have met the warmwater-habitat criteria besides reach 16: reach 15, on Mill Creek above Cranberry Run and reach 20, on Indian Run (fig. 10). The ICI scores at the remaining four sites on Mill Creek would still indicate a "fair" narrative rating.

Reliable longitudinal trend analysis of Mill Creek ICI scores was not feasible because of the late collection of 1 of its 10 metrics. The remaining nine ICI metrics, however, were evaluated individually along a gradient of increasing sewer-overflow discharge volumes in Mill Creek. The percentage of pollution-sensitive caddisflies was higher at upstream sites (reaches 15 (29 percent) and 16 (71 percent)) than at downstream reaches (reaches 18 (6 percent) and 19 (3 percent)). The percentage of tolerant organisms was highest at the two most downstream reaches (reaches

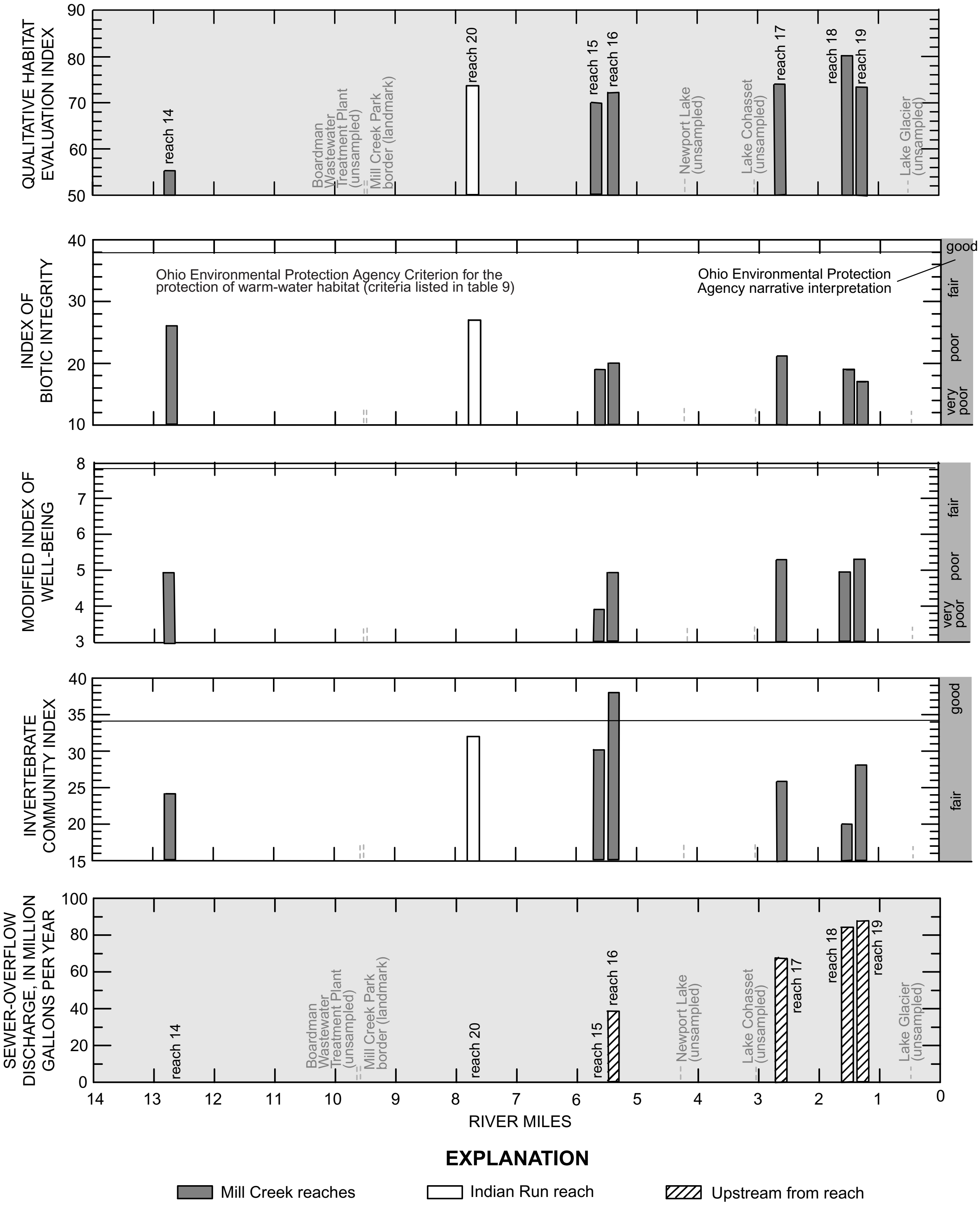

Figure 10. Index of biotic integrity, modified index of well-being, and invertebrate community index (average of two observations) from the biological-index monitoring network during summer 1999. Qualitative habitat evaluation index (QHEI) and annual discharge volume estimates from sewer-overflow sites are presented for comparison. A QHEI score above 70 has been demonstrated by OEPA (1987) to support warmwater-habitat aquatic life.

Table 9. Fish and macroinvertebrate warmwater-habitat biocriteria used by the Ohio Environmental Protection Agency (1987) in the Erie-Ontario Lake Plain ecoregion

Category	Index Type	Numeric value for criterion achievement
Fish	Index of biotic integrity, wading sites	38
	Modified index of well-being, wading sites	7.9
Macroinvertebrates	Invertebrate community index	34

18 (35 percent) and 19 (17 percent)). These results indicated healthier aquatic-macroinvertebrate communities at the upstream sites than at the downstream sites.

OEPA collected fish and macroinvertebrates from Mill Creek in 1994 (Ohio Environmental Protection Agency, 1996). All IBI and MIwb scores and six of eight ICI scores from 1994 fell within the narrative range of "very poor" to "fair." similar to results of this investigation. OEPA also evaluated a suite of chemical water- and sediment-quality characteristics. Toxic metals were found in Mill Creek at above-background levels, adding another possible causative factor for the observed nonattainment of the biological criteria.

No improvements in the fish communities of Mill Creek are evident between the OEPA observations in 1994 and this data collection in 1999. It is not possible to estimate how long these communities have been degraded; and, barring major changes in the Mill Creek Watershed, the fish communities do not have much chance to improve. The physical structure of Mill Creek is complex. Three reservoirs and a waterfall on Mill Creek are within the study area, all restricting fish movement to upstream areas. Even if potential fish stressors such as high pH, low dissolved oxygen concentrations, high nutrient concentrations, toxic metals in sediment, and sewer-overflow discharges were absent from Mill Creek, healthy fish communities may not reappear because of restricted movement. Restricted movement is not an issue for the aquatic macroinvertebrates, which can fly as adults. Because of the complexity of Mill Creek's physical structure, more data would be needed to fully understand the biological communities. This investigation was unable to separate the effects of municipal sources from effects of reservoirs and other factors on the fish and aquatic-macroinvertebrate communities of Mill Creek.

Effects of sewer-overflow discharges on receiving-water quality

Municipal sources of *E. coli,* nitrogen, and phosphorus may adversely affect the water quality of the Mahoning River and Mill Creek. These constituents sometimes exceeded concentration-based regulations in the Mahoning River and Mill Creek in 1999 and 2000. Establishing a relation between impaired surface-water quality and municipal sources, however, requires evaluation of discharge volumes from municipal sources and estimation of how much those discharges can affect surface-water quality. Sewer overflows known to discharge within the city of Youngstown release an estimated 5.3 million cubic meters (1,400 Mgal) per year to surface water in the study area (Joe Catullo, written commun., 1999). This annual volume would account for 2.6 percent of the water volume added to the Mahoning River between Niles, Ohio, just upstream from Youngstown and Lowellville, Ohio, during water year 1999 (Shindel and others, 2000). During the three wet-weather events characterized in this investigation, sewer-overflow discharges contributed 7 to 33 percent of the 24-hour discharge-volume increase in the Mahoning River across Youngstown.

Longitudinal concentration evaluation. Degradation of water quality as the Mahoning River passes through Youngstown has anecdotally been attributed to contributions from Mill Creek, Crab Creek, and the Youngstown WWTP to the Mahoning River. Contrary to that viewpoint, results of this investigation indicate that, during wet weather, sewer overflows were the only sources among those monitored that could have substantially increased *E. coli* concentration in the Mahoning River through Youngstown. Although *E. coli* concentrations increased longitudinally in the Mahoning River during dry-weather flow, neither the monitored tributaries nor the Youngstown WWTP added high *E. coli* concentrations during dry-weather flow (fig. 7a). Crab Creek was the only monitored tributary that contributed to the increase in *E. coli* concentration in the Mahoning River, on the reach between West Avenue (site 2) and Center Street (site 3). Concentrations in Crab Creek were not, however, high enough to account for the entire increase in concentration at Center Street.

Similarly, longitudinal assessment of inorganic nitrogen and total phosphorus concentrations (figs. 11 and 12) indicated that municipal sources were the only monitored inputs contributing higher concentrations of nutrients than were present in the main stem. Median nutrient concentrations in effluent from the Youngstown WWTP were considerably higher than those in receiving waters; thus, the Youngstown WWTP partially contributed to the nitrogen- and phosphorus-concentration increases in the Mahoning River during both dry- and wet-weather flow (figs. 11a and b and 12a and b). Sewer-overflow nutrient concentrations also were higher than receiving-water nutrient concentrations (figs. 11b and 12b). Nutrient concentrations in Mill Creek (site 8) and Crab Creek (site 9), the two monitored tributaries to the Mahoning River, always were the same as or lower than main-stem concentrations (figs. 11a and b and 12a and b).

In Mill Creek, *E. coli* concentrations decreased as the stream passed through Youngstown (figs. 7c and d) despite high-concentration additions from sewer overflows during wet-weather flow (fig 7d). Median concentrations of inorganic nitrogen and total phosphorus increased just downstream from the Boardman WWTP, from which water samples were not collected, during both dry- and wet-weather flow (figs. 11c and d and 12c and d) but then declined with passage through the system of reservoirs before discharge to the Mahoning River. The Boardman WWTP was identified by OEPA as a major source of nutrients to Mill Creek in past studies (Ohio Environmental Protection Agency, 1996). Observed reductions in concentration of *E. coli*, inorganic nitrogen, and total phosphorus as Mill Creek passed through reservoirs complicated assessment of sources that may have caused increases in constituent concentrations. No tributaries to Mill Creek contributed median concentrations of nutrients higher than concentrations in the receiving water. During wet-weather flow, all sewer overflows contributed discharges that had median *E. coli*, inorganic nitrogen, and total phosphorus concentrations higher than median concentrations in the receiving water (figs. 7d, 11d, and 12d). Sewer-overflow discharges may have countered some of the bacteria- and nutrient-removal effects of the reservoirs, but quantification of this effect was not possible with the available data.

Concentration data were sufficient to indicate that sewer-overflow discharges degraded water quality in the Mahoning River and Mill Creek, but the data were insufficient to indicate the extent that observed water-quality problems could be attributed to municipal sources of *E. coli* and nutrients. Both streams did not meet *E. coli* criteria and draft criteria for nitrate plus nitrite and total phosphorus during dry weather, when sewer-overflow discharges were not active. Exceedances of *E. coli* criteria were more pronounced during wet-weather flow than during dry-weather flow.

Loading-estimate evaluation. This investigation was designed to provide basic information describing water quality of sewer-overflow discharges for future model simulation. In addition to addressing this design goal, loads of constituents carried by sewer-overflow discharges in Youngstown also were estimated. Water-quality measurements from seven sewer overflows in Youngstown were used to estimate the range of constituent concentrations expected in sewer-overflow discharge. The concentrations were used to estimate a range of loads—or the total amount of each constituent flowing past a site over a period of time—to receiving water.

The load estimate was used to determine how much of each constituent entered the Mahoning River in Youngstown during the first 24 hours of wet-weather flow. Sewer-overflow discharges were not the only sources of constituent loads to the Mahoning River. Other possible sources include tributary streams, separate storm sewer discharges (as opposed to combined sewer discharges), overland flow, effluents from unmonitored WWTPs, and septic-system leachates. The estimate of sewer-overflow load calculated for this evaluation was not used to estimate the percentage of total loads entering the Mahoning River in Youngstown that originated with sewer-overflow discharges, nor was it taken to be a reliable estimate of the contaminant load leaving Youngstown during wet-weather flow events.

Sewer overflow loads were compared with surface-water loads during the first 24-hour interval of wet-weather flow to provide some context. The regression plots used to estimate *E. coli* and inorganic nitrogen concentrations at the Mahoning River at Youngstown (site 1) and Lowellville (site 4) during the three monitored wet-weather events are shown in figure 13. Results of the linear regression analysis and associated bias correction calculation are presented in table 10. Regressions were not statistically significant ($p>0.1$) for total phosphorus relations (data not shown) or for inorganic nitrogen at site 1. Loads were not calculated in instances where the regression was not significant.

Sewer-overflow discharge is a combination of domestic sewage and storm runoff in varying proportions. The effect that sewer-overflow discharges have on receiving-water quality depends, in part, on the proportion of domestic sewage in the composition of each discharge. Concentrations of selected constituents compared with typical values for domestic sewage and storm-runoff water are listed in table 11 (Tchobanoglous and Burton, 1991). Data in table 11 indicate that constituent concentrations in five of the seven sewer-overflow discharges were intermediate between weak sewage and storm runoff; however, in the other two sewer-overflow discharges (source C and source G), concentrations of total suspended solids, chemical oxygen demand, nitrogen, and phosphorus indicated a greater

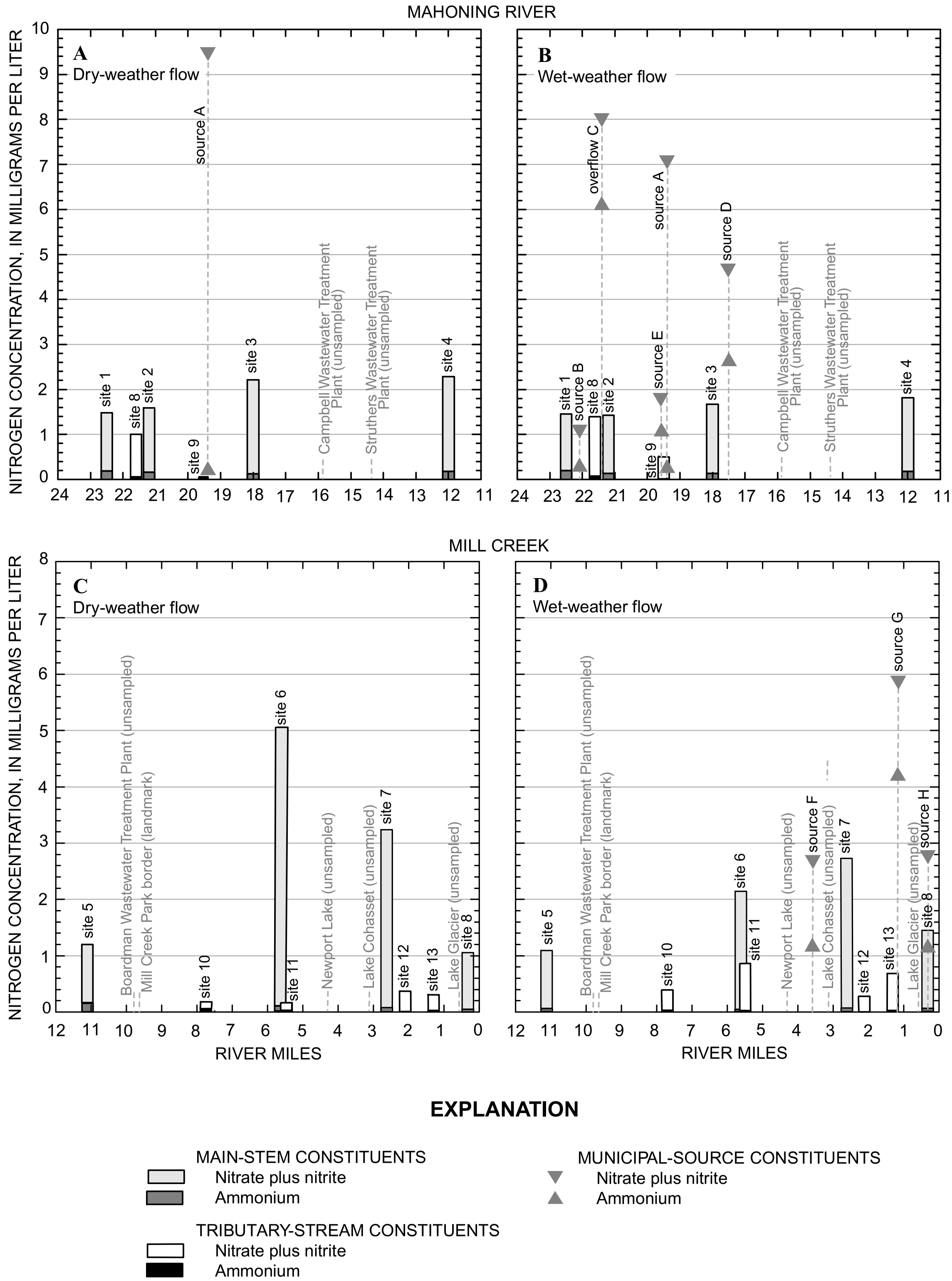

Figure 11. Nitrogen-form concentrations in the Mahoning River and Mill Creek, Ohio, parts of the water-quality monitoring network during dry-weather flow (1999) and wet-weather flow (1999 and 2000).

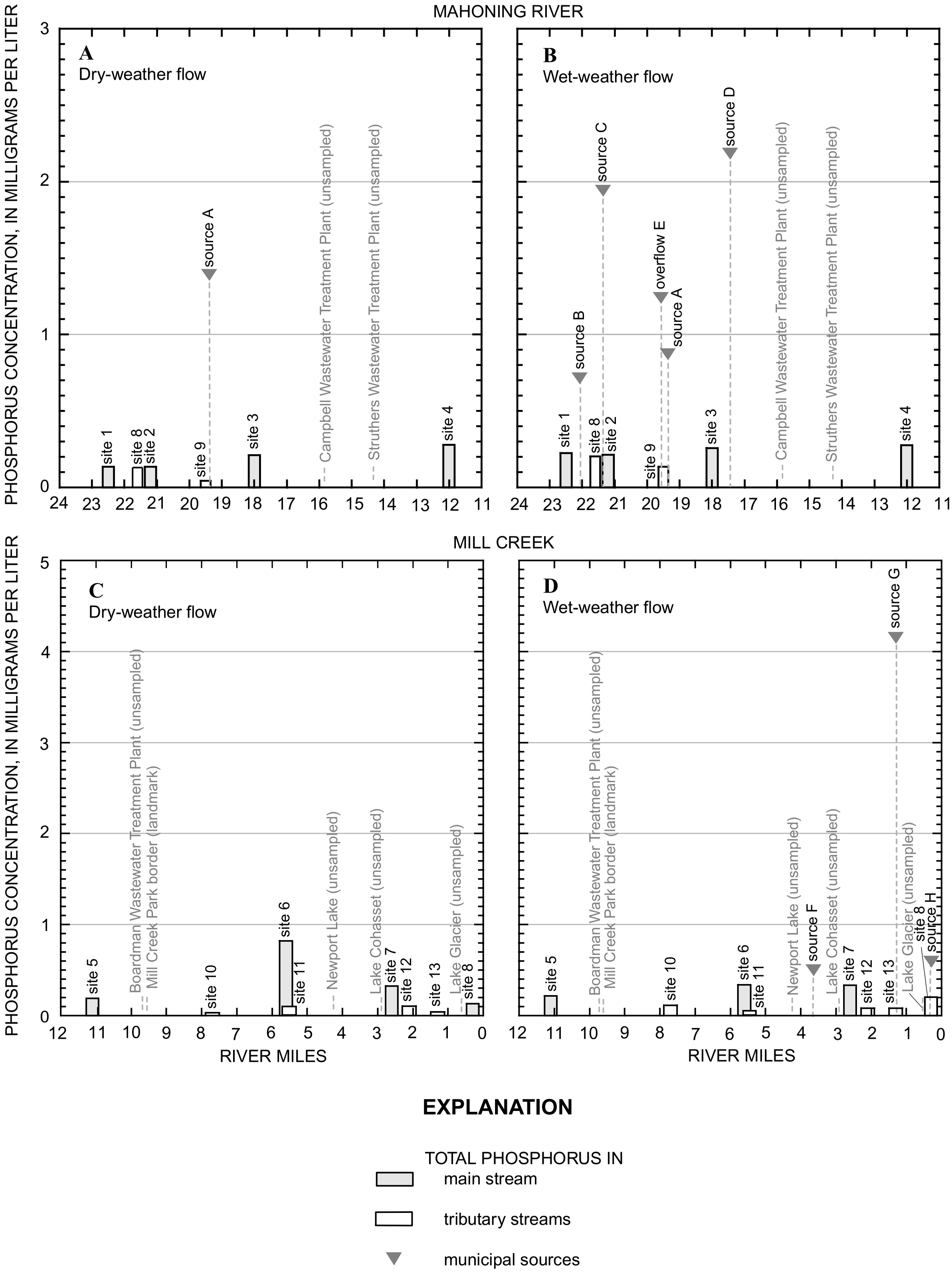

Figure 12. Total phosphorus concentrations in the Mahoning River and Mill Creek, Ohio, parts of the water-quality monitoring network during dry-weather flow (1999) and wet-weather flow (1999 and 2000).

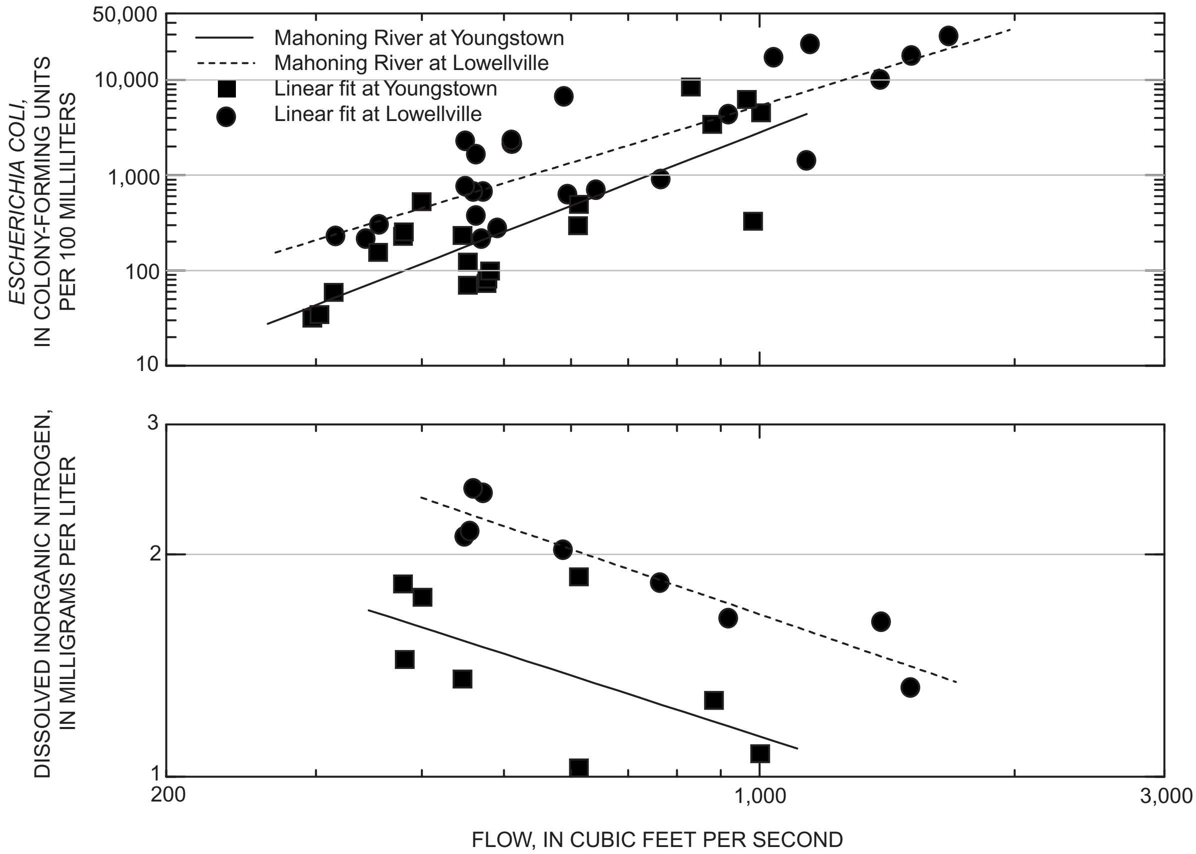

Figure 13. Data and regression lines used to estimate *Escherichia coli* and inorganic nitrogen concentrations at two sites on the Mahoning River, Ohio, during three wet-weather flow events in 2000. All data were collected during 1999 and 2000.

amount of domestic sewage than in the other five. Comparison with stormwater-quality data collected in an urban stormwater-quality report from Wisconsin (Bannerman and others, 1996) also indicated that Youngstown sewer-overflow discharge carries increased sewage relative to stormwater.

A range of concentrations for each constituent was observed among the seven sewer overflows. Within each source, proportions of constituents also differed (table 11). This variability means that use of a single concentration value to represent all 101 sewer-overflows could result in misleading conclusions. Therefore, loads were estimated by means of a range of values: sewer-overflow load calculations were computed from the minimum, median, and maximum concentrations for the seven monitored sewer overflows from the total of 19 samples collected. Sewer-overflow discharge volumes and loads of *E. coli* and inorganic nitrogen (ammonium, nitrate, and nitrite), along with estimates of stream-carried loads entering Youngstown (site 1) and downstream from Youngstown (site 4), are listed in table 12. Inorganic nitrogen forms were considered as a group because ammonium can change to nitrate and back over a period of hours (Peterson and others, 2001).

The volume of sewer-overflow discharge to the Mahoning River during the first 24 hours of the three monitored wet-weather events contributed 3 to 14 percent of the 24-hour discharge passing Lowellville (site 4) and 7 to 33 percent of the increase in discharge between sites 1 and 4 (table 12). The 24-hour load of *E. coli* contributed by sewer overflows, from 52 to 8,400 x 10^{12} CFU (depending on event and full range of concentration estimates), dwarfed the 24-hour loads of *E. coli* estimated to enter Youngstown (2 to 66 x 10^{12} CFU) and to pass site 4 (12 to 230 x 10^{12} CFU). On the other hand, loads of inorganic nitrogen added by sewer-overflow discharge in Youngstown (63 to 4,200 kg, depending on event and full range of concentration estimates) were always substantially smaller than the loads estimated to pass site 4 (3,200 to 5,200.) Sewer-overflow discharges appeared to have a much greater effect on bacterial than on nitrogen-assessed water quality. In contrast, the

Table 10. Linear regression analysis results for the relation between log-transformed flow and log-transformed concentration of *Escherichia coli* and inorganic nitrogen at two sites on the Mahoning River

[r, Pearson's correlation coefficient; p, significance probability; CFU/100 mL, colony-forming units per 100 milliliters; mg/L, milligrams per liter; <, less than; >, greater than]

Constituent	Y-intercept	Slope	r	p	Bias factor
Mahoning River at Youngstown (site 1)					
E. coli (CFU/100 mL)	-6.95	3.47	0.82	<0.0001	1.50
Inorganic nitrogen (mg/L)	1.17	-.371	.61	>.1	1.01
Mahoning River at Lowellville (site 4)					
E. coli (CFU/100 mL)	-4.37	2.70	.83	<.0001	1.42
Inorganic nitrogen (mg/L)	4.69	-1.32	.94	.0002	1.00

Youngstown WWTP appeared to have a greater effect on nitrogen loads than bacterial loads (table 12).

The timing of sewer-overflow discharges is critical in evaluating the effects of sewer-overflow discharges on water quality in Youngstown. Wet-weather-flow hydrographs at the Mahoning River at Youngstown (site 1), the Mahoning River at West Avenue (site 2), and the Mahoning River at Lowellville (site 4) were superimposed on summed XP-SWMM-simulated flow from all sewer-overflow discharges in Youngstown (fig. 14). Peak flow at sites 2 and 4 did not lag behind peak flow at site 1 as would be expected but rather preceded peak flow at site 1 by 2 to 6 hours during all three wet-weather flow events. Modeled sewer-overflow discharges preceded peak flows at all three surface-water sites. The amount of flow coming from all of the sewer-overflow discharges was enough to partially account for the accelerated timing of peak flow at sites 2 and 4.

Sewer-overflow sites, which were distributed throughout the watershed and had asynchronous discharge, were not expected to act as a single discharge to the Mahoning River. Other factors that could have affected the timing of peak flows include local runoff, rainwater discharge through separate storm sewers, discharges from tributary streams, and differences in rainfall at different areas of the watershed. For a short time on the rising limb of the hydrograph, sewer-overflow discharge could be a large component of streamflow in Youngstown (fig. 14). Timing of sample collection at the three water-quality monitoring sites is also depicted in figure 14. Water samples were collected on the falling limb of the hydrograph during all three events and probably reflected only residual effects of sewer-overflow discharges. This hypothesis is consistent with *E. coli* data in table 11. The 24-hour load estimate at site 4 was always much lower than the estimate of sewer-overflow load entering the Mahoning River in Youngstown. If the slug of sewer-overflow discharge was not present at Lowellville at the time of sample collection, then the regression analysis presented in figure 13 and table 10 would not be representative of concentrations when the major flow of sewer-overflow discharge was present. As a result, the load of constituents contributed by sewer-overflow discharge probably was not included in 24-hour load estimates at Lowellville (table 12). In-stream processes such as deposition, *E. coli* die-off, and conversion of inorganic nitrogen to gaseous or organic forms also may have prevented some of the sewer-overflow discharge loads to the Mahoning River in Youngstown from ever reaching the Lowellville station.

Alternate indicators of fecal contamination. *E. coli* is used as a surrogate indicator for fecal contamination from warmblooded animals. Alternate indicators also were monitored in an independent attempt to assess fecal contamination in the sampling network. Comparison of concentrations in municipal-source discharges with surface-water concentrations was used to infer whether fecal loading was related to domestic sewage entering the stream (municipal sources) or diffuse loading from multiple sources with runoff. The three alternate indicators evaluated were coliphage, *C. perfringens*, and caffeine. Mill Creek and its tributaries were sampled for coliphage and *C. perfringens*, and the entire sampling network was sampled for caffeine.

Coliphage and *C. perfringens* have been proposed as better surrogates than *E. coli* for certain pathogens (Rose and Grimes, 2001). F-specific coliphage are RNA-based viruses, like the waterborne pathogens hepatitis A, coxsackievirus, Norwalk virus, and poliovirus. Viruses have different survival characteristics from bacteria in the environment, so F-specific coliphage may be a better indicator of human-health risk from viral pathogens than *E. coli*.

Table 11. Sewer-overflow discharge characteristics observed in and around Youngstown, Ohio, and published characteristic values for raw sewage and stormwater runoff

[Sewage and runoff data adapted from Tchobanoglous and Burton, 1991; TDS, total dissolved solids; mg/L, milligrams per liter; -- , no data available; TSS, total suspended solids; $cBOD_5$, 5-day carbonaceous biochemical oxygen demand; COD, chemical oxygen demand; N, nitrogen; CFU/100 mL, colony-forming units per 100 milliliters]

Constituent	Units	Sewage		Median values, this study							Runoff
		Strong	Weak	Source B	Source C	Source D	Source E	Source F	Source G	Source H	
TDS	mg/L	850	250	--	--	--	--	149	208	223	--
TSS	mg/L	350	100	170	244	131	154	234	364	99	67-101
$cBOD_5$	mg/L	400	110	9	53	17	27	13	31	10	8-10
COD	mg/L	1,000	250	58	300	144	130	84	320	61	40-73
Organic N	mg/L	35	8	2.3	4.92	3.12	4.25	2.21	14.8	2.38	.4-1.0
Ammonium	mg/L	50	12	.28	6.1	2.9	1.1	1.2	4.2	1.3	--
Nitrate plus nitrite	mg/L	0	0	.81	1.98	2.05	.72	1.49	1.69	1.53	.5-0.9
Total N	mg/L	85	20	3.4	13.0	8.11	6.02	4.89	20.7	5.23	.9-2
Organic P	mg/L	5	1	.61	1.22	1.57	1.03	0.31	3.80	.33	--
Orthophosphate	mg/L	10	3	.13	.75	.61	.16	.20	.34	.29	--
Total P	mg/L	15	4	.74	1.96	2.21	1.19	0.51	4.14	.63	.7-1.7
Chloride	mg/L	100	30	--	--	--	--	19	28	31	--
Sulfate	mg/L	20	50	--	--	--	--	26.5	44.2	32.9	--
Total coliforms	CFU/100-mL	10^7-10^9	10^6-10^7	--	--	--	--	--	--	--	10^3-10^4
Escherichia coli†	CFU/100-mL	--	--	4.6×10^5	9.0×10^5	5.9×10^5	5.2×10^5	3.8×10^5	1.6×10^5	1.6×10^5	--

† - *E. coli* is one species in the total coliform group; therefore, *E. coli* concentrations are lower than total coliform concentrations in the same amount of raw sewage.

Table 12. Twenty-four-hour discharge volumes, loads of *Escherichia coli*, discharge-weighted average concentrations of *E. coli*, and loads of inorganic nitrogen (nitrite plus nitrate and ammonium) at two surface-water sites and all modeled sewer-overflow discharges in and around Youngstown, Ohio, during three events in 2000

[WWTP, wastewater-treatment plant; CFU/100, colony-forming units per 100 milliliters; kg, kilogram; NA, not applicable; DWA, discharge-weighted average concentration]

Discharge, load, or concentration	Mahoning River at Youngstown (site 1)	Mahoning River at Lowellville (site 4)	Youngstown WWTP (source A)	All sewer-overflow discharges		
				Minimum	Median	Maximum
August 6-7, 2000						
Discharge volume (10^6 liters)	2,100	3,700	160		530	
E. coli (10^{12} CFU)	66	230	18	470	1,800	8,400
E. coli (CFU/100 mL, DWA)	3,100	6,200	11,000	90,000†	350,000	1,600,000
Inorganic nitrogen (kg)	NA	5,200	1,100	570	2,100	4,200
September 20-21, 2000						
Discharge volume (10^6 liters)	1,000	1,700	130		140	
E. coli (10^{12} CFU)	2.0	12	0.34	130	500	2,300
E. coli (CFU/100 mL, DWA)	200	710	260	90,000	350,000	1,600,000
Inorganic nitrogen (kg)	NA	3,200	860	160	580	1,200
October 5-6, 2000						
Discharge volume (10^6 liters)	1,400	2,200	150		58	
E. coli (10^{12} CFU)	9.6	40	18	52	200	930
E. coli (CFU/100 mL, DWA)	690	1,800	12,000	90,000	350,000	1,600,000
Inorganic nitrogen (kg)	NA	3,800	960	63	240	470

Similarly, *C. perfringens* is an endospore-forming bacterium, and endospores have similar survival characteristics to cysts and oocysts. Cysts and oocysts are resistant forms of protozoa that can survive chlorination by routine sewage-treatment processes. The survival characteristics of cyst- and oocyst-forming pathogens like *Giardia lamblia* and *Cryptosporidium parvum* may be better approximated by endospore-forming bacteria like *C. perfringens* than by bacteria like *E. coli* that do not form resistant endospores (Sorensen and others, 1989). Caffeine generally is associated with human waste; thus, caffeine might be effective as a general, chemical indicator of human-origin wastewater.

Results for concentrations of alternate indicators of fecal pollution are summarized as boxplots in figure 15. F-specific coliphage were not detected in surface waters except during wet-weather events (fig. 15) but were present in most WWTP and overflow samples. Sewer-overflow discharges were, therefore, sources of fecal-origin coliphage viruses to Mill Creek during wet-weather flow. Although the Boardman WWTP effluent was not sampled it is likely, because the Youngstown WWTP effluent carried coliphage, that the Boardman WWTP effluent also contributed viruses of fecal origin to Mill Creek. Viruses were not detected during dry weather downstream from Boardman WWTP, possibly because of die-off and settling during residence time in Newport Lake.

Unlike coliphage concentrations, *C. perfringens* endospore concentrations did not increase consistently with wet-weather flow despite the observation that *C. perfringens* concentrations were higher in municipal-source discharges than in surface water (fig. 15). *C. perfringens* was also detected in tributary streams upstream from any municipal source. Municipal sources were, therefore, not the sole source of *C. perfringens* to Mill Creek.

The primary source of caffeine to streamflow during dry-weather flow was assumed to be sanitary discharge

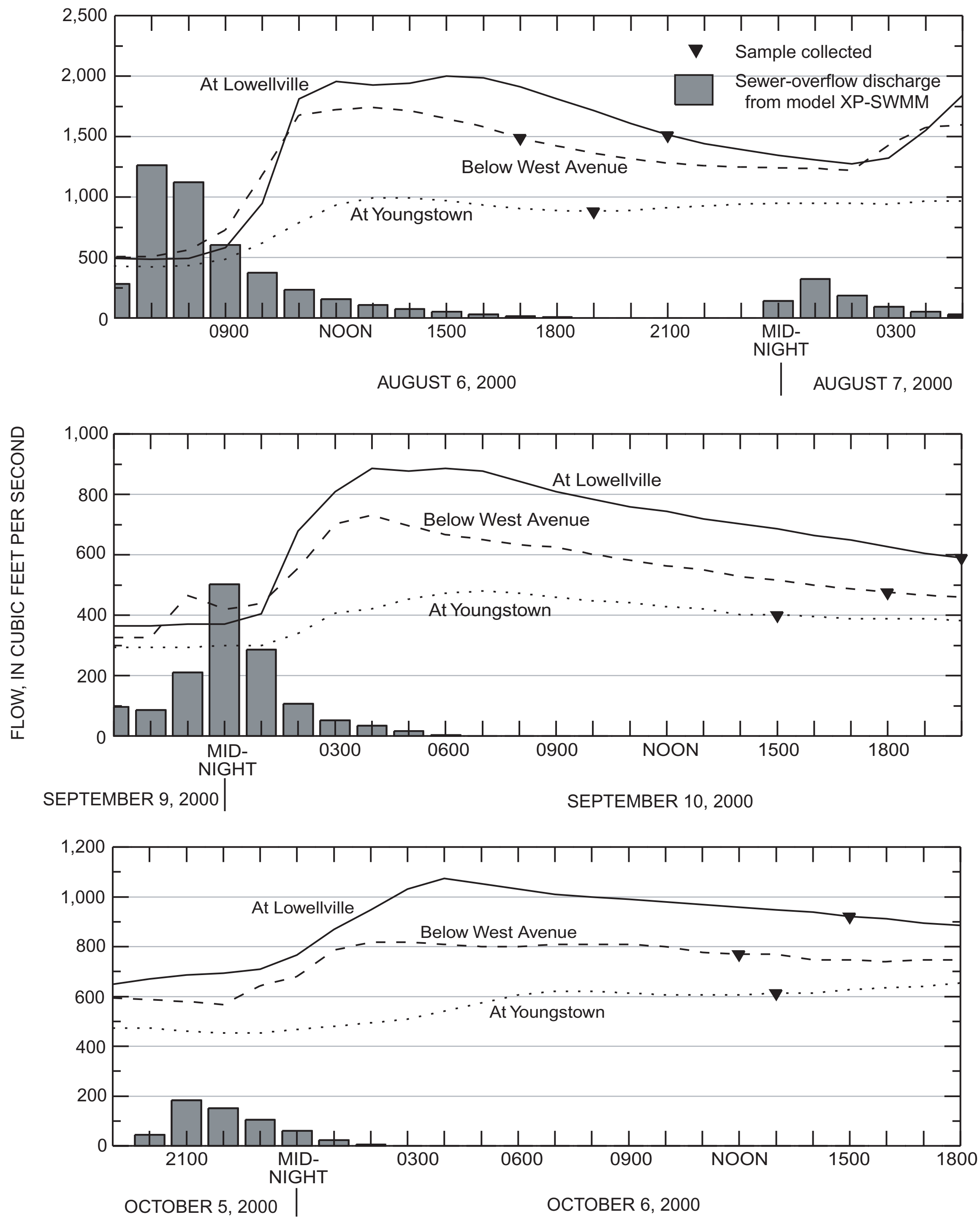

Figure 14. Streamflow and sample collection times for three sites on the Mahoning River, plotted with modeled cumulative sewer-overflow discharge in Youngstown, Ohio, over the first 24-hour interval of three wet-weather flow events.

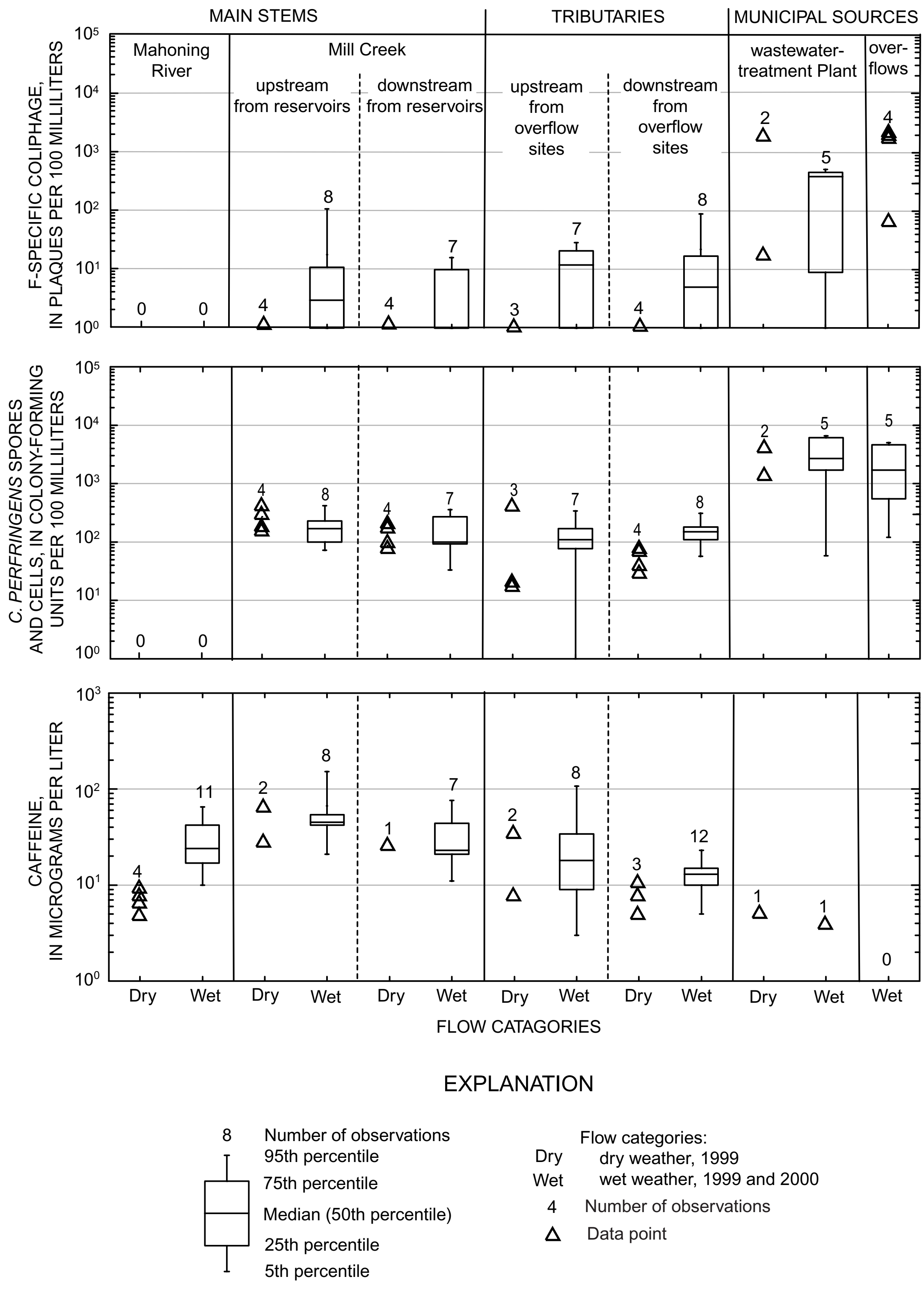

Figure 15. Concentrations of alternate indicators of fecal pollution by site type, relative location, and flow category for summer 1999 and 2000 in Mahoning River and selected tributaries and sources, Ohio.

(septic-field leachate and WWTP effluents); during wet-weather flow, additional sources may have included runoff from discarded beverages and leachate from other garbage in addition to increased septic-system and sewer-overflow discharges. Caffeine was detected in all samples analyzed. The small number of samples analyzed made it impossible to say with certainty whether wet-weather flow had any effect on caffeine concentrations. Caffeine concentrations were not obtained for sewer-overflow discharges. Data indicate that waste of human origin was present in the monitoring network during wet-weather and dry-weather flow (fig. 15). Even tributaries without sewer-overflow sites upstream seemed to be affected by domestic sewage. The presence of caffeine is not incontrovertible evidence of contamination by domestic sewage, given that caffeine can originate from sources other than human feces and urine (Seiler and others, 1999).

Summary and Conclusions

Degraded water quality has historically been a widespread problem in the Mahoning River Watershed in and around Youngstown, Ohio. In 1999, the U.S. Geological Survey (USGS), in cooperation with the city of Youngstown and in collaboration with ms consultants, inc., began a study to investigate the effects of sewer-overflow discharges within Youngstown on water quality of the Mahoning River. This report describes surface-water quality of a monitoring network in the area around Youngstown during dry- and wet-weather flow in 1999 and 2000 and discusses when, where, and for how long water quality was affected by sewer-overflow discharges. Results of sewer-overflow measurements are presented to provide baseline information about sewer-overflow discharges and a measure of the affects of sewer-overflow discharges on surface-water quality within the network.

Areas of nonattainment

The Mahoning River, Mill Creek, and other tributaries in the study area did not meet designated-use criteria as warmwater habitat within the Erie-Ontario Lake Plains ecoregion, as primary-contact recreational waters, or both. Nonattainment of designated-use regulations resulted from from *E. coli* concentrations above State standards (all monitored streams) and low biotic index scores (Mill Creek and Indian Run). Chemical water quality (pH, dissolved oxygen concentration, temperature, and ammonium) frequently met standards; but 46 of 71 samples (65 percent) from the Mahoning River and Mill Creek did not meet draft criteria for nitrate plus nitrite concentrations, and 58 of 63 samples (92 percent) did not meet draft criteria for total phosphorus concentrations. Crab Creek (tributary to the Mahoning River) and Indian Run, Cranberry Run, Ax Factory Run, and Bears Den Run (tributary to Mill Creek) did not meet draft criteria for nitrate plus nitrite concentrations in 1 of 44 samples (2 percent) and the draft total phosphate concentration criterion in 25 of 44 samples (57 percent).

Mahoning River water entering Youngstown had lower concentrations of nutrients and bacteria than Mahoning River water entering Lowellville after passage through the urban areas of Youngstown, Campbell, and Struthers. Mill Creek water entering Youngstown (site 5) had a similar concentration of *E. coli* and lower concentrations of nutrients than Mill Creek just downstream from Boardman WWTP (site 6). Within Mill Creek Park (sites 7, 8, and 9), processes such as settling, inactivation, and transformation —as well as dilution by tributary streams and other water sources—had the net effect of decreasing *E. coli* and nutrient concentrations by the time water reached the Mahoning River. Water quality deteriorated in the Mahoning River as it passed through Youngstown, but water quality improved in Mill Creek as it passed through Mill Creek Park in Youngstown.

Timing of nonattainment

Wet-weather flow was associated with changes in water quality within the sampling network. Concentrations of *E. coli* were greater throughout the sampling network during wet-weather flow than during dry-weather flow. Increases in *E. coli* concentrations contrasted with increased attainment of standards for pH, dissolved oxygen, and temperature during wet-weather flow. Nutrient concentrations remained virtually unchanged during wet-weather flow compared with dry-weather flow in the Mahoning River and Mill Creek. Nitrogen concentrations also remained similar during wet-weather flow compared to dry-weather flow in tributary streams. Tributary streams met draft total phosphate concentration criterion in all but 1 of 9 samples (11 percent) during dry-weather flow but did not meet the criterion in 24 of 35 samples (69 percent) during wet-weather flow.

Duration of nonattainment

Microbiological water quality during wet-weather flow was assessed over time to see whether increases in *E. coli* concentrations would last for more than 48 hours. *E. coli* remained elevated in Mill Creek and most tributaries for over 48 hours after moderate (less than 2-year floodflow) wet-weather flow events but returned to near dry-weather flow concentrations within 48 hours in the Mahoning River and Indian Run. Duration of water-quality changes was not assessed for other properties and constituents.

Effect of sewer-overflow discharges

Three avenues of analysis were followed to evaluate the effects of sewer overflows on water quality in the monitoring network. First, concentrations in municipal-source discharges were compared with longitudinal concentration trends from upstream to downstream sites in both the Mahoning River and Mill Creek. Second, the range of sewer-overflow discharge concentrations was compiled and used for a load-based evaluation of the degree to which constituents in sewer-overflow discharges affected water quality in receiving waters. Third, alternate indicators of fecal pollution were used to evaluate whether an effect by sewer-overflow discharges was detectable.

Concentration data indicated that contributions of *E. coli* and nutrients by tributary streams did not increase concentrations of *E. coli* and nutrients in the Mahoning River. The exception was Crab Creek, which had higher concentrations of *E. coli* than did the Mahoning River during wet-weather flow. Streams tributary to Mill Creek carried *E. coli* concentrations similar to concentrations in Mill Creek and, as such, dilution by tributary streams does not account for the observed decline in *E. coli* concentrations as Mill Creek passed through Mill Creek Park. The decline in nutrient concentrations in Mill Creek, however, may have been caused partially by dilution with tributary streamflow because tributary streams had lower nutrient concentrations.

Municipal sources (sewer-overflow discharges and WWTP effluent) generally were the only monitored sources of *E. coli*, nitrogen, and phosphorus that could have contributed to concentration increases in receiving waters during wet-weather flow. This investigation was limited in its capacity to measure sources of bacteria and nutrients other than sewer-overflow discharges and WWTP effluent.

The magnitude of the effects of sewer-overflow loading on receiving-water quality was evaluated for the Mahoning River entering Youngstown (site 1) and downstream from Youngstown (site 4). The range of probable *E. coli* loads to the Mahoning River through Youngstown from sewer overflows was wide but indicated that sewer-overflow discharges probably had a major effect on bacterial water quality in the Mahoning River during limited times while discharges occurred. Loading estimates for inorganic nitrogen indicated that sewer-overflow discharges had a lesser effect on nutrient water quality than on bacterial water quality but that sewer-overflow discharges added a substantial nutrient load relative to the estimated 24-hour load at site 4. The magnitude of sewer-overflow discharge effects on surface-water quality could not be detected directly because of the timing of sample collection.

Alternate indicators of fecal contamination provided some additional information about fecal loading by sewer overflows. Patterns of F-specific coliphage detection indicated a risk of human-pathogenic viruses in surface water during wet-weather flow from sewer-overflow discharges and WWTP effluent. Patterns of *C. perfringens* and caffeine concentrations, on the other hand, indicated a background of *C. perfringens* and human-origin contamination (either sewage or septic leachate) in the monitoring network during both wet- and dry-weather flow that was independent of Youngstown sewer-overflow and WWTP discharges.

Sewer-overflow discharges contributed to streamflow and to bacterial and nutrient loads carried by the Mahoning River in Youngstown, Ohio; however, sewer-overflow discharges were not the only factor affecting water quality in the area. Improvement of water quality in the lower reaches of the Mahoning River and Mill Creek to the point that each water body meets its designated-use criteria will likely require an integrated approach that includes not only abatement of sewer-overflow loadings but also identification and remediation of other loadings within Youngstown and improvement of water quality entering Youngstown.

References

Bannerman, R.T., Legg, A.D., and Greb, S.R., 1996, Quality of Wisconsin stormwater, 1989-94: U.S. Geological Survey Open-File Report 96-458, 26 p.

Clesceri, L.S., Greenberg, A.E., and Eaton, A.D., 1998, Standard methods for the examination of water and wastewater: Washington, D.C., American Public Health Association, American Water Works Association, and Water Environment Federation, pages 9-46 to 9-78.

Driver, N.E., and Tasker, G.D., 1990, Techniques for estimation of storm-runoff loads, volumes, and selected constituent concentrations in urban watersheds in the United States: U.S. Geological Survey Water-Supply Paper 2363, 44 p.

Duan, N., 1983, Smearing estimate—a nonparametric retransformation method: Journal of the American Statistical Association, v. 78, no. 383, p. 605-610.

Fishman, M.J., and Friedman, L.C., 1989, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 545 p.

Francy, D.F., Stoeckel, D.M., Bushon, R.N., and Kephart, C.M., 2001, Quality assurance, quality control manual, Ohio District Microbiology Laboratory: U.S. Geological Survey accessed August 06, 2001, at URL http://oh.water.usgs.gov/micro/qcmanual/manual.html

Gammon, J.R., 1976, The fish populations of the middle 340 km of the Wabash River: Purdue University Water Resources Research Center Technical Report 86, 73 p.

Ijzerman, M.M., and Hagedorn, C., 1992, Improved method for coliphage detection based on β-galactosidase induction: Journal of Virological Methods, v. 40, p. 31-36.

Karr, J.R., 1981, Assessment of biotic integrity using fish communities: Fisheries, v. 6, p. 21-27.

Koltun, G.F., and Roberts, J.W., 1990, Techniques for estimating flood-peak discharges of rural, unregulated streams in Ohio: U.S. Geological Survey Water-Resources Investigations Report 89-4126, 68 p.

Lessig, H.D., Hale, W.F., Reese, P.W., and Post, G.J., 1971, Soil survey of Mahoning County: Washington, D.C., Natural Resources Conservation Service (formerly Soil Conservation Service), 124 p.

Meador, M.R., Cuffney, T.F., and Gurtz, M.E., 1993, Methods for sampling fish communities as part of the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 93-104, 40 p.

Mill Creek Metropolitan Park District, 2001, Mill Creek Park homepage: accessed on July 30, 2001, at URL http://www.cboss.com/millcreek/

National Water Quality Laboratory, 2001, Technical information: U.S. Geological Survey accessed on August 06, 2001, at URL http://wwwnwql.cr.usgs.gov/USGS/USGS_tech.html

Ohio Environmental Protection Agency, 1987, Biological criteria for the protection of aquatic life – Volume II, Users' manual for biological field assessment of Ohio surface waters: Division of Water Quality Monitoring and Assessment, Surface Water Section, p. 4-2 to 4-66 and 5-1 to 5-19.

Ohio Environmental Protection Agency, 1989, Biological criteria for the protection of aquatic life – Volume III, Standardized biological field sampling and laboratory methods for assessing fish and macroinvertebrate communities: Division of Water Quality Monitoring and Assessment, Surface Water Section, p. V-1-2 to V-1-15 and V-4-1 to V-4-18.

Ohio Environmental Protection Agency, 1996, Biological and water quality study of the Mahoning River basin: Division of Water Quality Monitoring and Assessment, Surface Water Section, 239 p.

Ohio Environmental Protection Agency, 1997a, Method 130.3, Total nonfilterable residue *in* Manual of laboratory analytical procedures and field practices – Vol. 1, Conventional parameters: Columbus, Ohio, p. 130.3-1 to 130.3-5.

Ohio Environmental Protection Agency, 1997b, Method 310.1, Biochemical oxygen demand, five day *in* Manual of laboratory analytical procedures and field practices – Vol. 1, Conventional parameters: Columbus, Ohio, p. 310.1-1 to 310.1-8.

Ohio Environmental Protection Agency, 2002, Laws and Rules: Division of Surface Water, accessed June 3, 2002, at URL http://www.epa.state.oh.us/dsw/rules/index.html

Pennington and Associates, 1997, Standard operating procedures for processing, identification and enumeration of invertebrate samples: Cookeville, Tenn., Pennington and Associates, Inc., unpublished working document, 85 p.

Peterson, B.J., Wollheim, W.M., Mullholland, P.J., Webster, J.R., Meyer, J.L., Tank, J.L., Martí, E., Bowden, W.B., Valett, H.M., Hershey, A.E., McDowell, W.H., Dodds, W.K., Hamilton, S.K., Gregory, S., and Morrall, D.D., 2001, Control of nitrogen export from watersheds by headwater streams: Science, v. 292, p. 86-90.

Radtke, D.B., Wilde, F.D., Davis, J.V., and Popowski, T.J., 1999, Alkalinity and acid neutralizing capacity: U.S. Geological Survey, Techniques of Water-Resources Investigations, book 9, chap. 6.6, variously paginated.

Rantz, S.E., and others, 1982a, Measurement and computation of streamflow – Measurement of stage and discharge: U.S. Geological Survey Water-Supply Paper 2175, v.1, 284 p.

Rantz, S.E., and others, 1982b, Measurement and computation of streamflow – Computation of discharge: U.S. Geological Survey Water-Supply Paper 2175, v. 2, 346 p.

Rose, J.B., and Grimes, D.J., 2001, Reevaluation of microbial water quality: Washington, D.C., American Academy of Microbiology, 26 p.

Seiler, R.L., Zaugg, S.D., Thomas, J.M., and Howcraft, D.L., 1999, Caffeine and pharmaceuticals as indicators of waste water contamination in wells: Ground Water, v. 37, no. 3, p. 405-410.

Shannon, C.E., and Weaver, W., 1949, The mathematical theory of communication: Urbana, Ill., University of Illinois Press, p. 19-27.

Shindel, H.L., Mangus, J.P., and Trimble, L.E., 2000, Water resources data , Ohio, water year 1999 – St. Lawrence River Basin and statewide project data: U.S. Geological Survey, p. 484-515.

Shindel, H.L., Mangus, J.P., and Trimble, L.E., 2001, Water resources data, Ohio, water year 2000 – St. Lawrence River Basin and statewide project data: U.S. Geological Survey, p. 359-390.

Sorensen, D.L., Eberl, S.G., and Kicksa, R.A., 1989. *Clostridium perfringens* as a point source indicator in non-point polluted streams: Water Research, v. 23, no. 2, p. 191-197.

Tchobanoglous, G., and Burton, F.L., 1991, Wastewater engineering, treatment, disposal, and reuse: New York, McGraw Hill, 1,334 p.

U.S. Environmental Protection Agency, 1985, Test method 1103.1 for *Escherichia coli* in water by the membrane filter procedure: Cincinnati, Ohio, EPA/600/4-85-076, 12 p.

U.S. Environmental Protection Agency, Office of Research and Development, 1996, ICR microbial laboratory manual, section XI, membrane filter method for *C. perfringens*: Washington D.C., EPA/600/R-95/178, 15 p.

Webb, W.E., Radtke, D.B., and Iwatsubo, R.T., 1999, Surface-water sampling, collecting methods at flowing-water and still-water sites: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. 4.1, variously paginated.

Wilde, F.D., and Radtke, D.B., 1999, Techniques to prevent sample contamination: U.S. Geological Survey Techniques for Water-Resources Investigations, book 9, chap. 4.0, variously paginated.

Appendix A. Additional water-quality data from sewer-overflow discharges, calendar year January 2000 to December 2000, in Youngstown, Ohio

[mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; --, no data; <, concentration or value reported is less than indicated; E, estimated value]

DATE	TIME	BOD OXYGEN DEMAND, BIOCHEM CARBON. 5 DAY (mg/L)	OXYGEN DEMAND, CHEMICAL (HIGH LEVEL) (mg/L)	RESIDUE TOTAL AT 105 DEG. C SUSPENDED (mg/L)	SOLIDS, RESIDUE AT 180 DEG C DISSOLVED (mg/L)	ALKALINITY WAT DIS TOT IT FIELD (mg/L AS $CaCO_3$)
Overflow at Waverly Ave. and Greenwood Ave. (Source B)						
AUG 6	1132	9.4	58	190	--	--
SEP 21	1055	6.3	--	205	--	--
OCT 6	0210	--	11	--	104	--
Overflow at Salt Springs Price Rd. at Youngstown (Source C)						
AUG 6	1035	32	--	305	--	--
SEP 21	1115	59	--	274	--	--
OCT 5	2300	69	300	153	--	--
Overflow east of Poland Ave and south of Center (Source D)						
AUG 6	0835	16	--	307	--	--
AUG 6	1035	18	89	82	--	--
AUG 24	0220	--	59	--	--	--
SEP 21	1030	E13	--	164	--	--
OCT 5	2030	24	370	100	--	--
OCT 6	2300	15	58	<5	--	--
Overflow at McGuffey Rd and Willow St. (Source E)						
AUG 6	0835	27	130	154	--	--
Overflow at Park Dr. near Kiawatha Dr at Youngstown, Ohio (Source F)						
AUG 6	1056	13	--	234	--	--

Appendix A. Additional water-quality data from sewer-overflow discharges, calendar year January 2000 to December 2000, in Youngstown, Ohio —Continued

[mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; --, no data; <, concentration or value reported is less than indicated; E, estimated value]

DATE	TIME	BOD OXYGEN DEMAND, BIOCHEM CARBON. 5 DAY (mg/L)	OXYGEN DEMAND, CHEMICAL (HIGH LEVEL) (mg/L)	RESIDUE TOTAL AT 105 DEG. C SUSPENDED (mg/L)	SOLIDS, RESIDUE AT 180 DEG C DISSOLVED (mg/L)	ALKALINITY WAT DIS TOT IT FIELD (mg/L AS $CaCO_3$)
AUG 24	0300	--	84	--	149	--
			Overflow at Lilly Pond at Mill Creek Park (Source G)			
AUG 6	0721	31	320	364	208	--
			Overflow at intersection of Price and Halls Heights (Source H)			
AUG 6	1230	11	53	110	308	--
AUG 24	0315	--	68	--	190	63
OCT 6	2300	9.3	63	88	172	--