ENVIRONMENTAL SETTING OF FIXED SITES IN THE WESTERN LAKE MICHIGAN DRAINAGES, MICHIGAN AND WISCONSIN

By D.J. Sullivan, E.M. Peterson, and K.D. Richards

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BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, Director

For additional information write to:

District Chief
U.S. Geological Survey
6417 Normandy Lane
Madison, WI 53719

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FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for specific contamination problems; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional- and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the U.S. Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

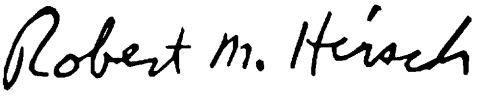
- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 60 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 60 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.



Robert M. Hirsch
Chief Hydrologist

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Multiply	By	To Obtain
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
acre	0.4047	hectare
foot per second (ft/s)	0.3048	meter per second

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

$$°C = 5/9 \times (°F - 32).$$

Abbreviated water-quality units: Chemical concentrations and water temperature are given in metric units. Chemical concentration is given in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million.

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Faith A. Fitzpatrick, Hydrologist, U.S. Geological Survey, Madison, Wis.

Technical Reviewers

David Heimann, Hydrologist, U.S. Geological Survey, Independence, Mo.

Sharon A. Fitzgerald, Research Hydrologist, U.S. Geological Survey, Madison, Wis.

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Editorial and Graphics

Michelle M. Greenwood, Cartographic Aide, U.S. Geological Suvey, Madison, Wis.

Ross E. Bagwell, Office Automation Clerk, U.S. Geological Survey, Madison, Wis.

Environmental Setting of Fixed Sites in the Western Lake Michigan Drainages, Michigan and Wisconsin

By D.J. Sullivan, E.M. Peterson, *and* K.D. Richards

Abstract

This report describes selected environmental-setting features for 11 fixed surface-water sites in the Western Lake Michigan Drainages study unit of the National Water-Quality Assessment Program. The study unit, which includes 10 major river systems draining to Lake Michigan, is bounded on the south by the Illinois State line and extends north to about 31 miles north of Escanaba, Mich. The fixed sites are on the following streams: Peshekee River, Popple River, Menominee River, Pensaukee River, Duck Creek, Tomorrow River, East River, Fox River, North Branch Milwaukee River, Lincoln Creek, and Milwaukee River. Drainage basins above these sites receive runoff from land uses and land covers, bedrock types, and surficial deposits representative of the main types of each of these characteristics in the study unit. Data types collected at the fixed sites include water chemistry; organic compounds and trace elements in streambed sediment and biological tissues; algal, benthic-invertebrate, and fish communities; and aquatic habitat. Field measurements include water temperature, pH, specific conductance, alkalinity, and dissolved oxygen. Results of water-quality field measurements indicate little variation in temperature among the fixed sites. Specific conductance and alkalinity were generally higher at sites underlain by carbonate bedrock than at sites underlain by igneous/metamorphic bedrock. Differences in pH among the fixed sites were less than those for specific conductance and alkalinity, but pH seemed to increase slightly from north to south. Dissolved-oxygen concentration varied more at agricultural sites than at forested and urban sites, perhaps because of higher nutrient inputs at agricultural sites. The information included in this report has been assembled as reference material for ongoing studies at the fixed sites.

INTRODUCTION

In 1991, the U.S. Geological Survey (USGS) began full-scale implementation of the National Water-Quality Assessment (NAWQA) Program. The objectives of the NAWQA Program are to (1) describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers, (2) describe trends in water quality over time, and (3) improve understanding of the primary natural and human factors that affect water-quality conditions. This information will be useful for planning future management actions and examining their likely consequences. In all, 60 study units are planned to begin activities on a staggered time scale. The Western Lake Michigan Drainages was selected as one of the first 20 study units to begin data collection and analysis in 1991.

The study-unit design for streamwater quality includes data collection at fixed sites. Eleven fixed sites were established in the Western Lake Michigan Drainages and were sampled from March 1993 through May 1995. During this period, data were collected on water chemistry; organic compounds and trace elements in streambed sediment and biological tissues; algal, benthic-invertebrate, and fish communities; and aquatic habitat.

Purpose and Scope

The purpose of this report is to describe the location and environmental setting of the fixed sites of the Western Lake Michigan Drainages NAWQA study unit. In addition, observed relations among physical and chemical characteristics at each fixed site are discussed. The scope of this report is limited to the 11

fixed sites, which were sampled from March 1993 through June 1995 at selected intervals. For each fixed site, information is given on location, streamflow, general site characteristics, habitat, selected water-quality measurements, physiography, land use, and surficial deposits. This background information is assembled here as reference material for other studies being done in the study unit at the fixed sites.

Western Lake Michigan Drainages

The Western Lake Michigan Drainages NAWQA study unit (fig. 1) encompasses an area draining about 19,900 mi^2 in eastern Wisconsin and parts of the Upper Peninsula of Michigan. The study unit, which includes 10 major river systems draining to Lake Michigan, is bounded on the south by the Illinois State line and extends north to about 31 mi north of Escanaba, Mich. Many of the major natural and anthropogenic features of the basin are described in Setmire (1991); some of the pertinent features are repeated here. The following rivers drain directly to Green Bay: the Escanaba and Ford Rivers in the Upper Peninsula of Michigan; the Menominee River, which forms much of the border between Wisconsin and Michigan; the Oconto and Peshtigo Rivers; and the Fox/Wolf River, the largest system in the study unit. The Manitowoc, Sheboygan, and Milwaukee Rivers all drain directly to the western side of Lake Michigan.

The overall population of the study unit is 2,435,000 (1990). The major cities and their populations are Milwaukee, 636,000; Green Bay, 88,000; Racine, 86,000; and Appleton, 59,000. About 40 percent of the study area is forested, predominantly in the northwestern part. Streams and lakes abound in this area and offer excellent fishing, boating, and other recreation. Agriculture accounts for 37 percent of the land use in the study unit. The dairy industry is a major component of the agricultural activities in the study unit. About 15 percent of the land in the study unit is classified as wetlands. Lake Winnebago, a 137,000-acre lake in the Fox River Basin, is a major surface-water feature of the study unit. The Milwaukee River Basin in the southeastern part of the study unit has the largest human population.

The bedrock of the study unit consists of igneous and metamorphic rocks in the northwest, sandstone in the southwest, and carbonate rocks in the east. Precambrian crystalline rocks are exposed in the Escanaba, Ford, Oconto, Peshtigo, Menominee, and Wolf River Basins; Ordovician and Cambrian sandstones are exposed in the Fox River Basin; and Silurian dolomite is the uppermost bedrock in the Manitowoc, Sheboygan, and Milwaukee River Basins. A small area of shale underlies the East River and the North Branch of the Manitowoc River near the city of Green Bay. Surficial deposits consist primarily of unconsolidated glacial, fluvial, and eolian materials. Diagonally from northwest to southeast (in areas of roughly one-third of the study unit), surficial deposits are generally outwash and ice-contact deposits, glacial lake and ground-moraine deposits, and ground- and end-moraine deposits. The texture of these deposits is classified as predominantly sand or sand and gravel in the western and northern parts of the study unit, clay in the southeast, and loam in the northern and central areas of the study unit. Small peat deposits are scattered throughout the Upper Peninsula of Michigan.

ENVIRONMENTAL SETTING OF FIXED SITES

The selected environmental setting features of the fixed sites that are discussed in this report include large-scale features and site-specific characteristics. Large-scale features are bedrock geology, surficial deposits, and land use in the watershed. Bedrock geology was derived from "Bedrock Geologic Map of Wisconsin" (Mudrey and others, 1982) and "Bedrock Geology of Northern Michigan" (Reed and Daniels, 1987). A description of the texture of surficial deposits throughout the study unit was derived from Quaternary geologic maps, as published in "Quaternary Atlas of the United States" by the USGS (Wisconsin part) (Richmond and Fullerton, 1983), and from "Quaternary Geologic Maps of Northern Michigan" (Michigan part) (Farrand and Bell, 1984). Land-use and land-cover information for the study unit was obtained from high-altitude aerial photographs taken by the USGS during 1971-81 and manually classified according to the system developed by Anderson and others (1976). The drainage areas of the fixed sites were determined by digitizing USGS 1:24,000 topographic maps. Site-specific features of a selected stream reach near the fixed site are the following: a general description of the river at the fixed-site location, including appearance, flow characteristics, and descriptions of unique features at the site; measurement and identification of

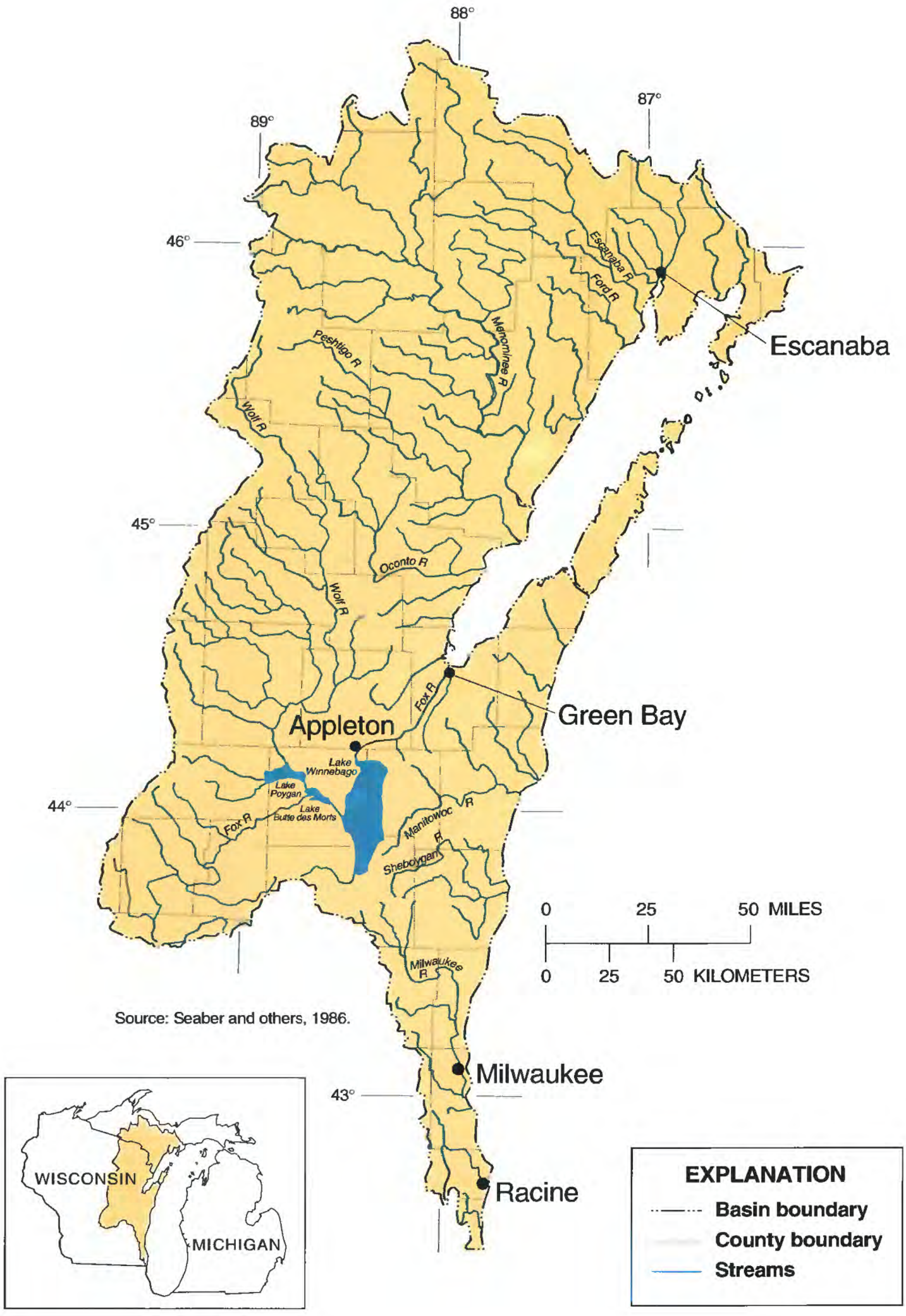


Figure 1. Western Lake Michigan Drainages study unit of the National Water-Quality Assessment Program.

geomorphic units; visual examination of bank stability; identification of dominant bank and flood-plain vegetation; measurement of reach length; and visual examination of predominant substrate type at six transects. Site-specific habitat features were measured according to methods described in Meador and others (1993).

Using a Geographic Information System (GIS), NAWQA investigators subdivided the Western Lake Michigan Drainages study unit on the basis of an overlay of the boundaries of the large-scale features previously mentioned. This overlay revealed subunits with unique combinations of bedrock geology, surficial deposits, and land use. These subunits are referred to as "relatively homogeneous units" (RHU's) (fig. 2). There are 28 RHU's in the Western Lake Michigan drainages; a complete description of each RHU is given in Robertson and Saad (1995).

Eleven fixed sites were selected to represent the status of and trends in water quality in the study unit. Of these, eight fixed sites were selected to represent conditions in eight selected RHU's (fig. 2). These fixed sites are referred to as "indicator fixed sites" because the water quality at these sites is assumed to be indicative of average conditions throughout the RHU in which each site is located. The locations of the three other fixed sites were selected to represent a large part of the total flow from the study unit to western Lake Michigan. These sites are referred to as "integrator fixed sites" because the drainage basin of each contains more than one RHU, thereby integrating the effects of several RHU's. Three sites, two indicator and one integrator, were selected for intensive sampling, which entailed more frequent sample collection as well as analysis of samples for selected pesticides. These sites are referred to as "intensive (indicator or integrator) fixed sites." Selected information on the fixed sites is presented in table 1.

Site-specific habitat features were measured at the fixed sites once a year during 1993-95. Qualitative descriptions of some of these features are included in this report. Water-quality data were collected at various frequencies at each site. Intensive fixed sites were sampled monthly throughout the year, and weekly during the growing season in 1993 and 1994. All other fixed sites were sampled monthly from April 1993 through May 1995. Additional samples were collected at some of the fixed sites in response to storms or in conjunction with other hydrologic studies.

The following sections of this report give information on large-scale and site-specific features at each of the 11 fixed sites. Ancillary information, such as sampling efforts by other agencies, land-management information, and other pertinent information, is given where applicable and known.

Peshekee River near Martins Landing, Michigan

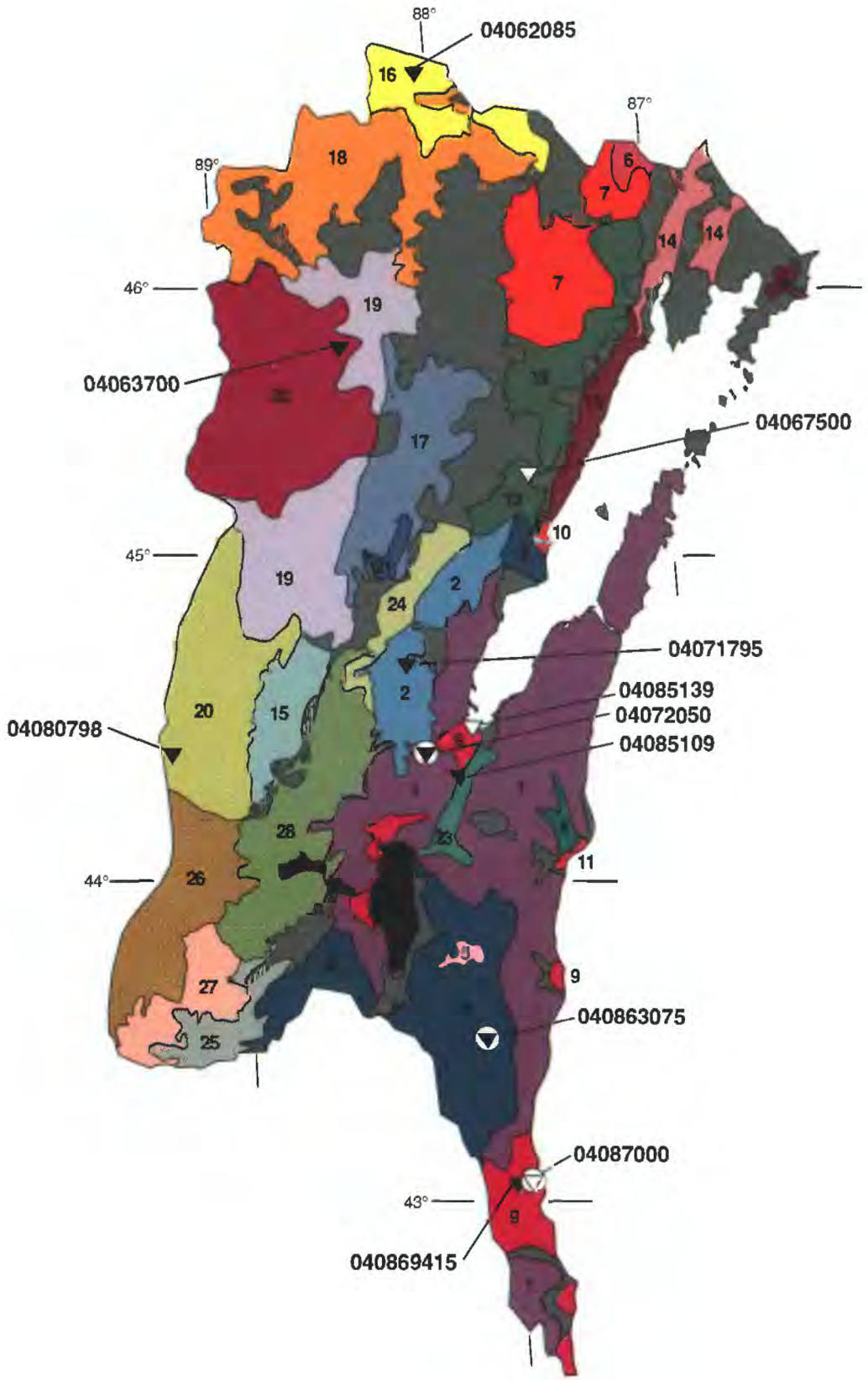
The Peshekee River is in the extreme northwestern part of the study unit, in the Menominee River Basin (fig. 3). The stream reach at the fixed site is best described as a meandering, rock-bottomed, stained-water stream flowing through dense forests of mixed coniferous and deciduous trees, that are typical of the Upper Peninsula of Michigan. Hilly topography results in the regular occurrence of riffles along the stream reach.

The surficial deposits in the basin are thin, and bedrock outcrops are common. Streamflow fluctuations are limited by recharge from ground water and wetlands in the headwaters of the basin. Tannins from vegetation stain the water, giving it the appearance of tea. Clearcutting for pulpwood began in 1994; prior to this, most of the basin was undisturbed forest and wetland.

The stream reach in the vicinity of the sampling site has a firm substrate of cobbles and gravel. The banks are highly stable because of heavy vegetative cover and near-surface bedrock in many places. The primary bank and flood-plain vegetation consists of *Alnus rugosa* (speckled alder), *Prunus pennsylvanica* (pin cherry), *Picea mariana* (black spruce), and grasses and sedges.

Popple River near Fence, Wisconsin

The Popple River drains forested lands in the northwestern part of the study unit just south of the Wisconsin-Michigan border, in the Menominee River Basin (fig. 4). The character of the Popple River is best described as a stained-water stream flowing through dense forests of mixed deciduous and coniferous trees. The river is slow-moving along much of the reach, although bedrock outcrops create riffles and even waterfalls in some places.



EXPLANATION

Relatively Homogenous Unit (RHU) and number —

Characteristics listed for each RHU are bedrock, land use, and surficial deposit, separated by commas. Abbreviations are as follows: Carb, carbonate; IgMet, igneous and/or metamorphic; Shle, shale; Snds, sandstone; Ag, agriculture

- Mixed areas
- (1) Carb, Ag, clayey
- (2) Carb, Ag, loamy
- (3) Carb, Ag, sandy
- (4) Carb, Ag, sand and gravel
- (5) Carb, Ag/wet forest, sandy/ sand and gravel
- (6) Carb, dry forest, loamy
- (7) Carb, wet forest, loamy
- (8) Carb, wet forest, sandy
- (9) Carb, urban, clayey
- (10) Carb, urban, sandy
- (11) Carb, urban, sand and gravel
- (12) Carb, Ag/wet forest, loamy
- (13) Carb, wet forest, sandy
- (14) Carb, wet forest, sandy/sand and gravel
- (15) IgMet, Ag, loamy/sand and gravel
- (16) IgMet, dry forest, loamy
- (17) IgMet, dry forest, loamy/sand and gravel
- (18) IgMet, dry forest, sandy
- (19) IgMet, dry forest, sandy/sand and gravel
- (20) IgMet, dry forest/Ag, sandy/ sand and gravel
- (21) IgMet, wet forest, clayey
- (22) IgMet, wet forest, sandy/sand and gravel
- (23) Shle, Ag, clayey
- (24) Snds, Ag, loamy
- (25) Snds, Ag, sandy
- (26) Snds, dry forest/Ag, sandy/sand and gravel
- (27) Snds, wet Ag, clayey/sandy
- (28) Snds, wet Ag, clayey
- Open water

Type of site

- ▼ Indicator site
- ▽ Integrator site
- ⊛ Intensive fixed site
- ⊜ Integrator site and intensive fixed site

Figure 2. Boundaries of relatively homogeneous units in the Western Lake Michigan Drainages study unit and location of fixed sites.

Table 1. Selected information for the fixed sites in the Western Lake Michigan Drainages study unit

[Mean daily discharge calculated through September 1994; USGS, U.S. Geological Survey; mi^2, square miles; ft^3/s, cubic feet per second; --, no measurement made; ft, feet; m, meters; co, cobble; gr, gravel; sa, sand; bo, boulder; cl, clay]

Site name	USGS number	Latitude-longitude	Drainage area (mi^2)	Mean discharge (ft^3/s)	Stream type	Mean width (ft)	Reach length (ft [m])	Percent of each in reach		
								Riffle	Run	Pool
Peshekee River near Martins Landing, Mich.	04062085	88°01′20" 46°36′35"	49.0	73[1]	Meandering	39	745 [227]	44	0	56
Popple River near Fence, Wis.	04063700	88°27′50" 45°45′50"	139	119	Meandering	69	1,090 [332]	10	45	45
Menominee River at McAllister, Wis.	04067500	87°39′40" 45°19′20"	3,930	3,470	Meandering	--	110 [360]	0	100	0
Pensaukee River near Krakow, Wis.	04071795	88°16′35" 44°45′09"	35.8	12	Meandering	23	508 [155]	29	51	20
Duck Creek near Oneida, Wis.	04072050	88°13′08" 44°27′57"	95.5	53[2]	Meandering	30	492 [150]	37	50	13
Tomorrow River near Nelsonville, Wis.	04080798	89°20′16" 44°31′28"	44.0	31	Meandering	30	469 [143]	7	30	63
East River near De Pere, Wis.	04085109	88°04′47" 44°23′12"	47.0	60[3]	Meandering	16	564 [172]	15	69	16
Fox River at Green Bay, Wis.	04085139	88°00′16" 44°32′22"	6,332	5,330	Channelized	--	--	0	0	100
North Branch Milwaukee River near Random Lake, Wis.	040863075	88°03′10" 43°33′25"	51.4	35	Meandering	36	705 [215]	14	21	65
Lincoln Creek at 47th Street at Milwaukee, Wis.	040869415	87°58′20" 43°05′49"	9.56	8.5	Channelized	37	922 [281]	19	40	41
Milwaukee River at Milwaukee, Wis.	04087000	87°54′32" 43°06′00"	696	431	Channelized	--	--	--	--	--

Table 1. Selected information for the fixed sites in the Western Lake Michigan Drainages study unit–Continued

Site name	Site designation	Bedrock type	Surficial deposits	Predominant substrate type	Land use[4]			
					Level I		Level II[5]	
					Classification	Percentage of total	Clasaification	Percentage of level I
Peshekee River near Martins Landing, Mich.	Indicator	Igneous/ metamorphic	Loamy	co, gr	Forest	87.9	41	4.5
							42	18.0
							43	77.5
					Water	2.3	52	100
					Wetland	9.8	61	100
Popple River near Fence, Wis.	Indicator	Igneous/ metamorphic	sa/sa & gr	sa, bo	Urban	.1	11	100
					Agricultural	3.0	21	100
					Forest	61.1	41	18.4
							42	9.9
							43	71.7
					Water	.6	52	100
					Wetland	35.1	61	95.8
							62	4.2
Menominee River at McAllister, Wis.	Integrator	Mixed	Mixed	--	Urban	.6	11	52.0
							12	11.0
							13	2.9
							14	5.1
							15	.1
							16	15.5
							17	13.4
					Agricultural	6.1	21	99.9
							22	<.1
							24	<.1
					Forest	75.0	41	22.3
							42	20.2
							43	57.4

Table 1. Selected information for the fixed sites in the Western Lake Michigan Drainages study unit–Continued

Site name	Site designation	Bedrock type	Surficial deposits	Predominant substrate type	Land use[4]			
					Level I		Level II[5]	
					Classification	Percentage of total	Classification	Percentage of level I
Menominee River at McAllister, Wis.--Continued					Water	2.3	51	8.2
							52	67.2
							53	24.6
					Wetland	15.6	61	96.5
							62	3.5
					Barren	.3	75	100
Pensaukee River near Krakow, Wis.	Indicator	Carbonaceous	Loamy	gr, sa, co	Urban	.2	11	12.5
							16	87.5
					Agricultural	86.0	21	100
							24	<.1
					Forest	4.4	41	100
					Wetland	9.2	61	100
					Barren	<.1	76	100
Duck Creek near Oneida, Wis.	Intensive indicator	Carbonaceous	Clayey	gr, sa	Urban	.6	11	73.0
							12	23.0
							16	4.0
					Agricultural	89.3	21	100
							24	<.1
					Forest	4.6	41	98.0
							43	2.0
					Wetland	4.8	61	100
					Barren	.6	75	69.0
							76	31.0
Tomorrow River near Nelsonville, Wis.	Indicator	Igneous/ metamorphic	sa/sa & gr	sa, gr, co, bo	Urban	.2	11	67.0
							16	33.0

Table 1. Selected information for the fixed sites in the Western Lake Michigan Drainages study unit–Continued

Site name	Site designation	Bedrock type	Surficial deposits	Predominant substrate type	Land use[4]			
					Level I		Level II[5]	
					Classification	Percentage of total	Classification	Percentage of level I
Tomorrow River near Nelsonville, Wis.--Continued					Agricultural	58.3	21	100
					Forest	31.4	41	5.6
							42	13.3
							43	81.1
					Water	1.2	52	100
					Wetland	8.8	61	73.6
							62	26.4
East River near De Pere, Wis.	Indicator	Shale	Clayey	sa, cl	Urban	.8	11	38.0
							12	10.0
							14	18.0
							17	33.0
Fox River at Green Bay, Wis.	Integrator	Mixed	Mixed	--	Agricultural	91.7	21	100
					Forest	5.1	41	73.0
							43	27.0
					Wetland	2.3	61	100
					Barren	.1	75	100
					Urban	2.8	11	53.9
							12	18.6
							13	7.4
							14	7.2
							15	.7
							16	2.7
							17	9.5
					Agricultural	52.6	21	99.9
							22	<.1
							23	<.1
							24	<.1

Table 1. Selected information for the fixed sites in the Western Lake Michigan Drainages study unit–Continued

Site name	Site designation	Bedrock type	Surficial deposits	Predominant substrate type	Land use[4]			
					Level I		Level II[5]	
					Classification	Percentage of total	Classification	Percentage of level I
Fox River at Green Bay, Wis.--Continued					Forest	26.2	41	49.5
							42	7.5
							43	43.0
					Water	5.4	51	.5
							52	93.0
							53	6.5
							54	<.1
					Wetland	12.8	61	70.0
							62	30.0
					Barren	.3	75	63.0
							76	37.0
North Branch Milwaukee River near Random Lake, Wis.	Intensive indicator	Carbonaceous	Sandy	sa, gr	Urban	1.0	11	18.0
							12	3.6
							14	27.4
							16	51.0
					Agricultural	87.5	21	100
					Forest	6.2	41	49.0
							43	51.0
					Water	.3	52	100
					Wetland	4.9	61	97.0
							62	3.0
					Barren	.1	75	100
Lincoln Creek at 47th Street at Milwaukee, Wis.	Indicator	Carbonaceous	Clayey	gr, cl, sa	Urban	100	11	58.1
							12	18.4
							15	3.0
							17	20.5

Table 1. Selected information for the fixed sites in the Western Lake Michigan Drainages study unit–Continued

Site name	Site designation	Bedrock type	Surficial deposits	Predominant substrate type	Land use[4]			
					Level I		Level II[5]	
					Classification	Percentage of total	Classification	Percentage of level I
Milwaukee River at Milwaukee, Wis.	Intensive integrator	Carbonaceous	Mixed	co, gr	Urban	11.0	11	55.2
							12	20.8
							13	2.6
							14	4.5
							15	.4
							16	2.1
							17	14.4
					Agricultural	74.8	21	99.9
							23	<.1
							24	<.1
					Forest	8.3	41	78.5
							42	1.5
							43	19.9
					Water	1.1	52	73.8
							53	26.2
					Wetland	4.4	61	88.4
							62	11.6
					Barren	.3	75	85.3
							76	14.7

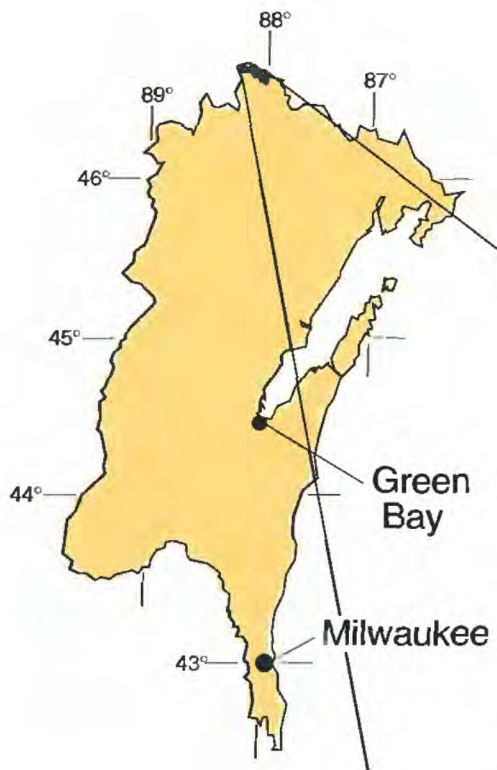
[1]Mean discharge for station 04062085 was calculated from drainage-area ratio and discharge record from station 04062100 (66.5 mi^2 drainage area).

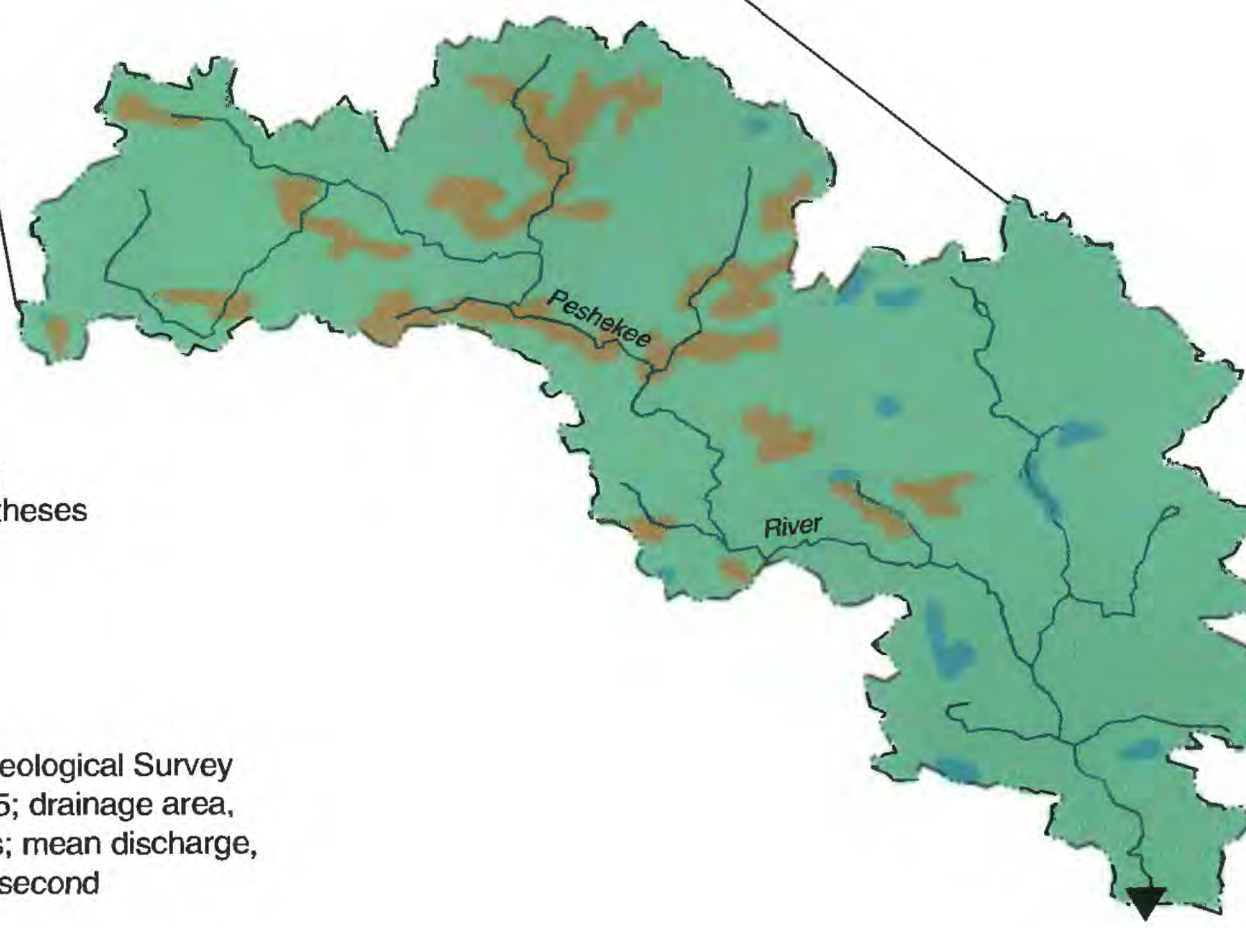
[2]Mean discharge for station 04072050 was calculated from drainage-area ratio and discharge record from station 04072150 (108 mi^2 drainage area).

[3]Mean discharge calculated from average of monthly mean discharge owing to missing record).

[4]Based on Anderson and others (1976) classification system; percentages estimated from digital line graph land use/land cover from high-altitude photography taken from 1972-81 and interpreted according to methods in Fegeas and others (1983).

[5]Level II classification: 11, residential; 12, commercial and services; 13, industrial; 14, transportation, communications, and utilities; 15, industrial and commercial complexes; 16, mixed urban or built-up land; 17, other urban; 21, cropland and pasture; 22, orchards, groves, vineyards, nurseries, and ornamental horticultural areas; 23, confined feeding operations; 24, other agricultural land; 41, deciduous forest land; 42, evergreen forest land; 43, mixed forest land; 51, streams and canals; 52, lakes; 53, reservoirs; 54, bays and estuaries; 61, forested wetland; 62, nonforested wetland; 75, strip mines, quarries, and gravel pits; 76, transitional areas.





EXPLANATION

Land use — percentage of total area given in parentheses

- Forest (87.87)
- Water (2.28)
- Wetland (9.85)
- ▼ Fixed site — U.S. Geological Survey number 04062085; drainage area, 49.0 square miles; mean discharge, 73 cubic feet per second

0 2.5 5 MILES

0 2.5 5 KILOMETERS

Figure 3. Map of Peshekee River Basin above the fixed site and photo showing typical character of the stream.

Figure 4. Map of Popple River Basin above the fixed site and photo showing typical character of the stream.

Extensive forested wetlands cover much of the sand and sand and gravel surficial deposits in the drainage basin. The wetlands help to limit flow extremes throughout the year, and tannins from them impart a tea-like appearance to the water.

The stream reach in the vicinity of the sampling site has a substrate consisting predominantly of boulders and bedrock in riffle areas, and sand and boulders in slow-moving areas. The sampling reach consists of a long run/pool complex with a single riffle at the downstream terminus. The banks are very stable as a result of the combination of vegetative cover and near-surface bedrock. The primary bank and flood-plain vegetation consists of *Salix* sp. (willow), *Alnus* sp. (alder), and grasses and sedges. Large beds of submergent and emergent macrophytes are evident in the stream.

The sampling site has been a benchmark site in the USGS National Stream Quality Accounting Network (NASQAN) since 1964 (Holmstrom and others, 1994). This designation is given to stream sites in the NASQAN sampling network where water quality is primarily representative of natural conditions.

Menominee River near McAllister, Wisconsin

The Menominee River flows through several RHU's in predominantly forested land before discharging about 22 mi downstream from the fixed site to the northern part of Green Bay at the twin cities of Marinette, Wis., and Menominee, Mich. (fig. 5). The Menominee River can be described as a river flowing through thick forests over shallow bedrock. In general, the stream channel is primarily runs interspersed with isolated pools and rocky riffle areas.

The flow in the Menominee River is regulated along much of its lower reaches by a series of hydroelectric dams. The drainage area of the Menominee River at the fixed site, an integrator site, accounts for about 20 percent of the total drainage area of the study unit.

The stream reach in the vicinity of the sampling site is wide and fairly shallow, and flow velocities are moderate. Bedrock is close to the land surface in the area and is exposed in parts of the stream bottom. Banks are very stable, in part a result of the near-surface bedrock and in part as a result of extensive woody vegetation. Primary bank and flood-plain vegetation consists of *Fraxinus pennsylvanica* (green ash), *Populus balsamifera* (Balsam poplar), *Salix* sp. (willow), and *Carex* sp. (sedge).

Much of the land in the basin is under the management of the U.S. Department of Agriculture, Forest Service. Several state forests and parks in Michigan and Wisconsin also are in the basin. Urban areas are generally small, and farms are few. The small amount of agricultural land in the basin is primarily used for small grains and forage crops. In some reaches in the lower part of the stream, locally severe sediment-contamination problems have been associated with historical industrial pollution.

The WDNR and USGS operate a water-quality sampling site at the mouth of the Menominee River as part of a Lake Michigan tributary-monitoring study.

Pensaukee River near Krakow, Wisconsin

The Pensaukee River drains an agricultural area used for small-grain and forage-crop production, pasture land for dairy cattle, and vegetable raising. The Pensaukee River can be described as a shallow stream flowing over a cobble substrate with brushy riparian vegetation. In summer, the streambed is covered with algae. The depth is often only a few inches or less, and flow is dispersed across a 20-ft-wide channel in riffle areas. In some years, including 1995, the streamflow was zero for several weeks in the summer.

The fixed site on the Pensaukee River is in the east-central part of the study unit, about 25 mi north of the city of Green Bay (fig. 6). Streamflows at the site vary widely, the result of tightly packed loam surficial deposits that limit infiltration and ground-water discharge to the stream channel.

The stream reach in the vicinity of the sampling site has a firm substrate composed primarily of sand and gravel with some cobbles. At low flow, the stream consists of shallow riffles and runs and a few deep pools. The stream banks are fairly stable, although some undercutting can be seen on the outside of bends. The primary bank and flood-plain vegetation consists of *Acer negundo* (boxelder) and *Carex* sp. (sedge).

Figure 5. Map of Menominee River Basin above the fixed site and photo showing typical character of the stream.

Figure 6. Map of Pensaukee River Basin above the fixed site and photo showing typical character of the stream.

Duck Creek near Oneida, Wisconsin

Duck Creek drains an agricultural area in east-central Wisconsin before discharging to lower Green Bay immediately northwest of the city of Green Bay (fig. 7). In general, Duck Creek is a small, turbid, slow-moving (less than 0.5 ft/s) stream draining agricultural land, much of which is used for corn production.

The low permeability of the clayey surficial deposits in the basin results in considerable surface runoff and restricts ground-water discharge to the stream. As a result, stage rises rapidly in response to rainfall and snowmelt. During dry periods, the absence of ground-water discharge results in very low flows; in extremely dry periods, zero flow has been observed. Agriculture in the Duck Creek basin is primarily pasture and cropland. Much of the land adjoining the main stem and most tributaries is cultivated very near to the banks. Several wetlands are in the headwaters and near the mouth of the stream.

The stream reach in the vicinity of the sampling site has a substrate dominated by gravel and sand. The banks, which are covered with rooted vegetation over about half their surface area, are fairly stable. The primary bank and flood-plain vegetation consists of *Fraxinus pennsylvanica* (green ash), *Acer saccharum* (sugar maple), *Acer negundo* (boxelder) and *Carex* sp. (sedge).

Most of the land in the Duck Creek Basin, with the exception of the headwaters, is within the reservation of the Oneida Nation of Native Americans. They have recently completed a 150-year plan for the watershed, which includes measures for extensive rehabilitation of the stream corridor, upland erosion control, integrated pest management, organic farming, and other means of improving the water quality and biotic integrity of the stream (Finney, 1995). In addition, the Duck Creek Basin was declared a Priority Watershed in 1995 by the Wisconsin Department of Natural Resources (WDNR) (R. McLennan, Wisconsin Department of Natural Resources, oral commun., 1995). This designation targets the basin for (1) cost sharing with landowners to institute land-management practices designed to improve water quality in the stream, and (2) studies of current water quality.

Tomorrow River near Nelsonville, Wisconsin

The Tomorrow River drains an area of sandy surficial deposits and mixed forest and agricultural land in the eastern part of the study unit in the Fox River Basin (fig. 8). In general, the Tomorrow River is a cold, tannin-stained stream flowing quickly (1.0-2.0 ft/s) over sandy runs and rocky riffles with intermittent pools, surrounded by a wide riparian forest.

Streamflow at this site has a large ground-water component which, combined with the highly permeable sandy soils and large wetland areas in the headwaters, results in a fairly constant flow. The land use is a mix of pasture, forest, and cropland.

The stream reach in the vicinity of the sampling site has a firm substrate of sand and gravel; soft humic material and silt deposits are present on the stream margins. The bank stability at this site is high, owing to vegetative cover and the absence of extreme high flows that would scour the banks. The primary bank and flood-plain vegetation consists of *Alnus rugosa* (speckled alder), *Fraxinus pennsylvanica* (green ash), *Larix laricina* (tamarack), and *Phalaris arundinacea* (reed canary grass).

The Tomorrow River Basin was declared a Priority Watershed in 1993 (Wisconsin Department of Natural Resources, 1995), primarily because of high nitrate concentrations in ground water (J. Klosiewski, Wisconsin Department of Natural Resources, oral commun., 1994). Much of the land along the stream corridor is owned by the state of Wisconsin and is administered by the WDNR as public hunting and fishing land.

East River near De Pere, Wisconsin

The East River drains an agricultural area in east-central Wisconsin and discharges to the Fox River in the city of Green Bay (fig. 9). The character of the East River is similar to that of Duck Creek: a small, usually turbid stream flowing slowly (less than 0.5 ft/s) through flat land primarily used for farming. Large amounts of suspended materials are evident even at summer low flow.

The East River Basin, like the Duck Creek Basin, is underlain by clayey surficial deposits. Thus, streamflow of the East River is highly variable, and stream

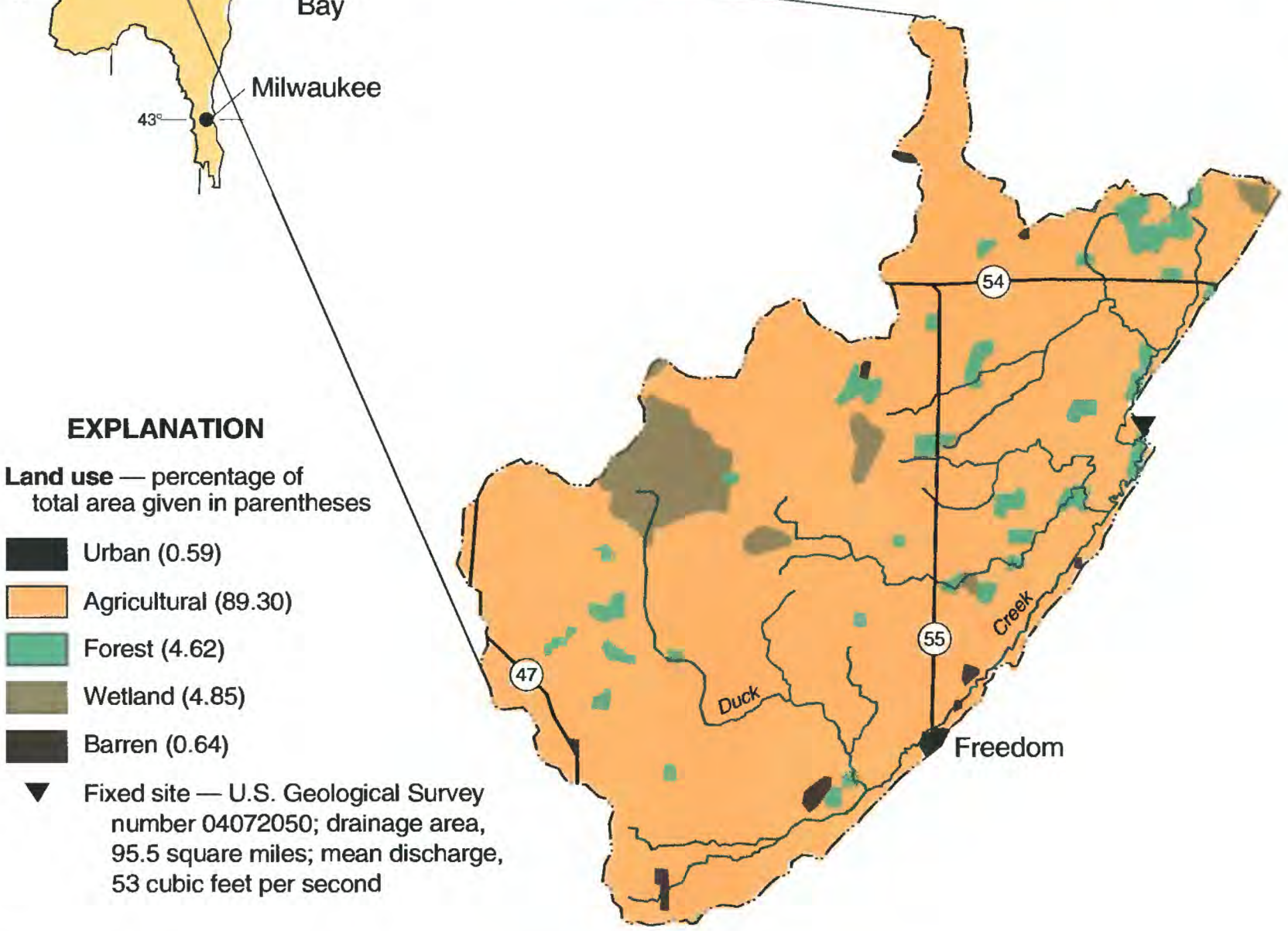


Figure 7. Map of Duck Creek Basin above the fixed site and photo showing typical character of the stream.

Figure 8. Map of Tomorrow River Basin above the fixed site and photo showing typical character of the stream.

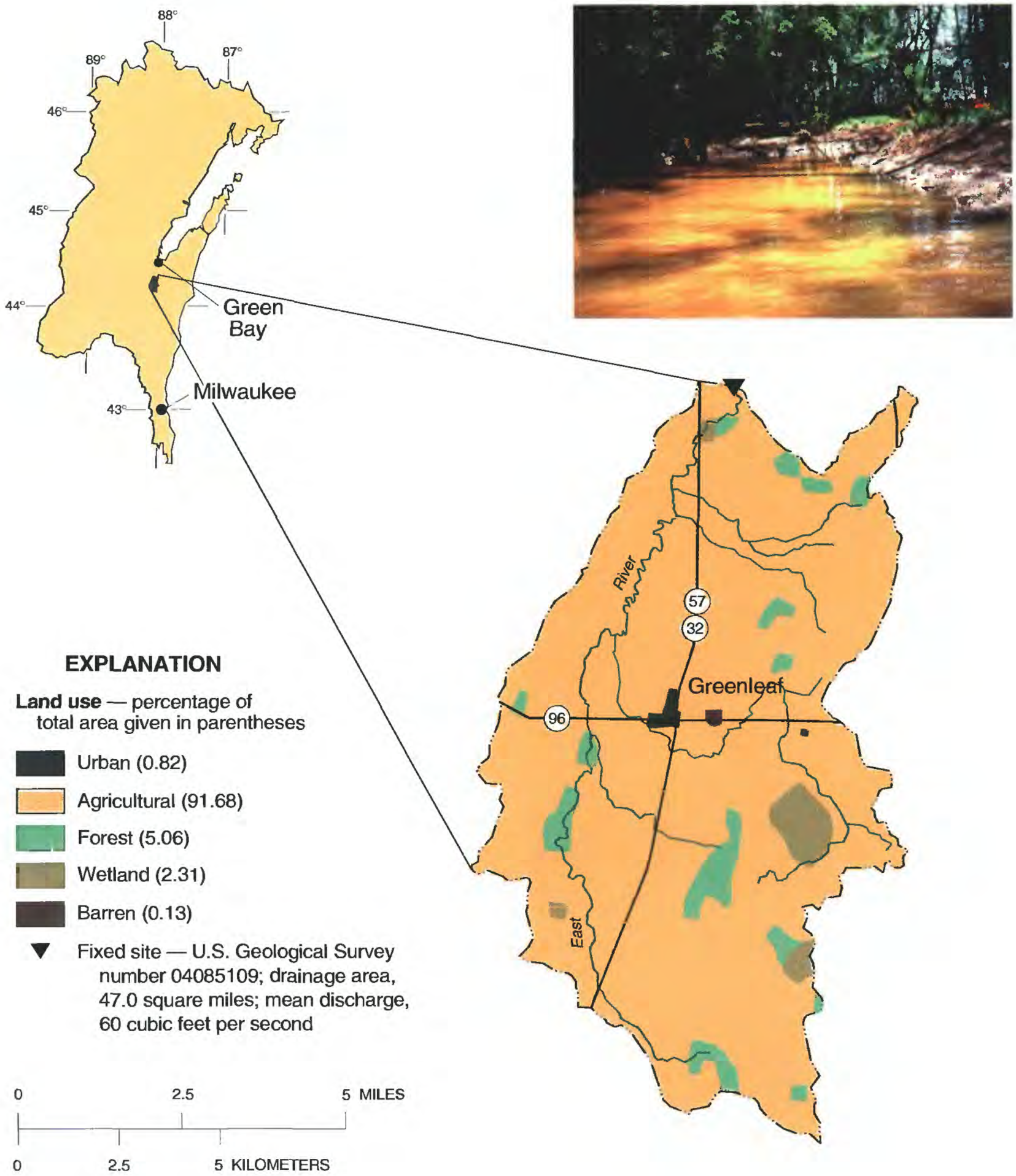


Figure 9. Map of East River Basin above the fixed site and photo showing typical character of the stream.

stage is subject to rapid rises. Agricultural activities, including crop raising and pasturing, are the primary land-use activities in the basin.

The stream reach in the vicinity of the sampling site has a substrate of soft sand and clay. At low flow, much of the reach is classified as a low-velocity run with short sections of riffles and pools. The channel is somewhat unstable because of the intensive agriculture and rapid runoff from the clayey surficial deposits. The primary bank and flood-plain vegetation consists of *Populus deltoides* (cottonwood), *Fraxinus pennsylvanica* (green ash), *Acer negundo* (boxelder), and grasses.

Watershed-modeling research aimed at calibrating hydrologic and chemical models with data from the East River Basin is being done by University of Wisconsin-Green Bay researchers in coordination with the USGS (D.M. Robertson, U.S. Geological Survey, oral commun., 1995). The East River has been a WDNR Priority Watershed since 1986 (Wisconsin Department of Natural Resources, 1994).

Fox River at Green Bay, Wisconsin

The Fox River at its mouth (fig. 10) drains about 32 percent of the total area of the Western Lake Michigan Drainages NAWQA study unit. The stream near the mouth is a large, turbid, channelized river whose flow is sometimes reversed by wind-driven rises in the water level of Green Bay. Industry and other commercial enterprises line the stream. The stream is deep, and suspended sediments often lend a brownish tint to the water.

The water quality of the stream at the mouth where the fixed site is located integrates effects from forested, agricultural, and urban/industrial areas. Many streams tributary to the upper Wolf River are pristine, cold water trout streams. In contrast, the area surrounding the lower Fox River between Lake Winnebago and its mouth at Green Bay (fig. 1) contains the highest density of papermills in the world. Streams in the upper Fox and lower Wolf River Basins drain a combination of forested and agricultural lands.

The stream at the sampling site is a large, channelized reach flowing through urban and industrial land. The stream at this point serves as a shipping channel. The channel is stable because much of it is riprapped or reinforced along the banks with concrete.

A proposal to operate a copper mine near the headwaters of the Wolf River is undergoing environmental-impact assessments. The headwaters of the Wolf River flow through parts of several Native American reservation lands, including the Stockbridge-Munsee and the Menominee Reservations. Several subbasins of the Fox River are WDNR Priority Watersheds (Wisconsin Department of Natural Resources, 1994).

North Branch Milwaukee River near Random Lake, Wisconsin

The North Branch Milwaukee River drains an area of sandy surficial deposits and agricultural land in the southeastern part of the study unit (fig. 11). The North Branch is a slow-moving stream that flows through rolling agricultural land. The water in the stream commonly has a turbid appearance because of suspended materials.

Water quality varies widely within the North Branch Milwaukee River Basin, from coldwater trout stream tributaries to a warmwater stream at the fixed site. The highly permeable surficial deposits allow rain to infiltrate rapidly, limiting maximum streamflow and maintaining base flows.

The stream reach in the vicinity of the sampling site has a substrate of sand and gravel overlain in most places by a layer of silt. Many pools are partially filled with silt; thus, a fairly uniform depth of water is maintained throughout most of the stream reach. A few gravel riffles remain uncovered. The primary bank and flood-plain vegetation consists of grasses and *Salix* sp. (willow).

The North Branch Milwaukee River has been a WDNR Priority Watershed since 1984 (Wisconsin Department of Natural Resources, 1994). Because of the highly permeable surficial deposits, the state of Wisconsin places restrictions on atrazine use in the watershed (Wisconsin Department of Agriculture, 1994).

Lincoln Creek at 47th Street at Milwaukee, Wisconsin

Lincoln Creek is a small urban stream that flows through Milwaukee, the largest urban area in the study unit, before it discharges to the Milwaukee River about

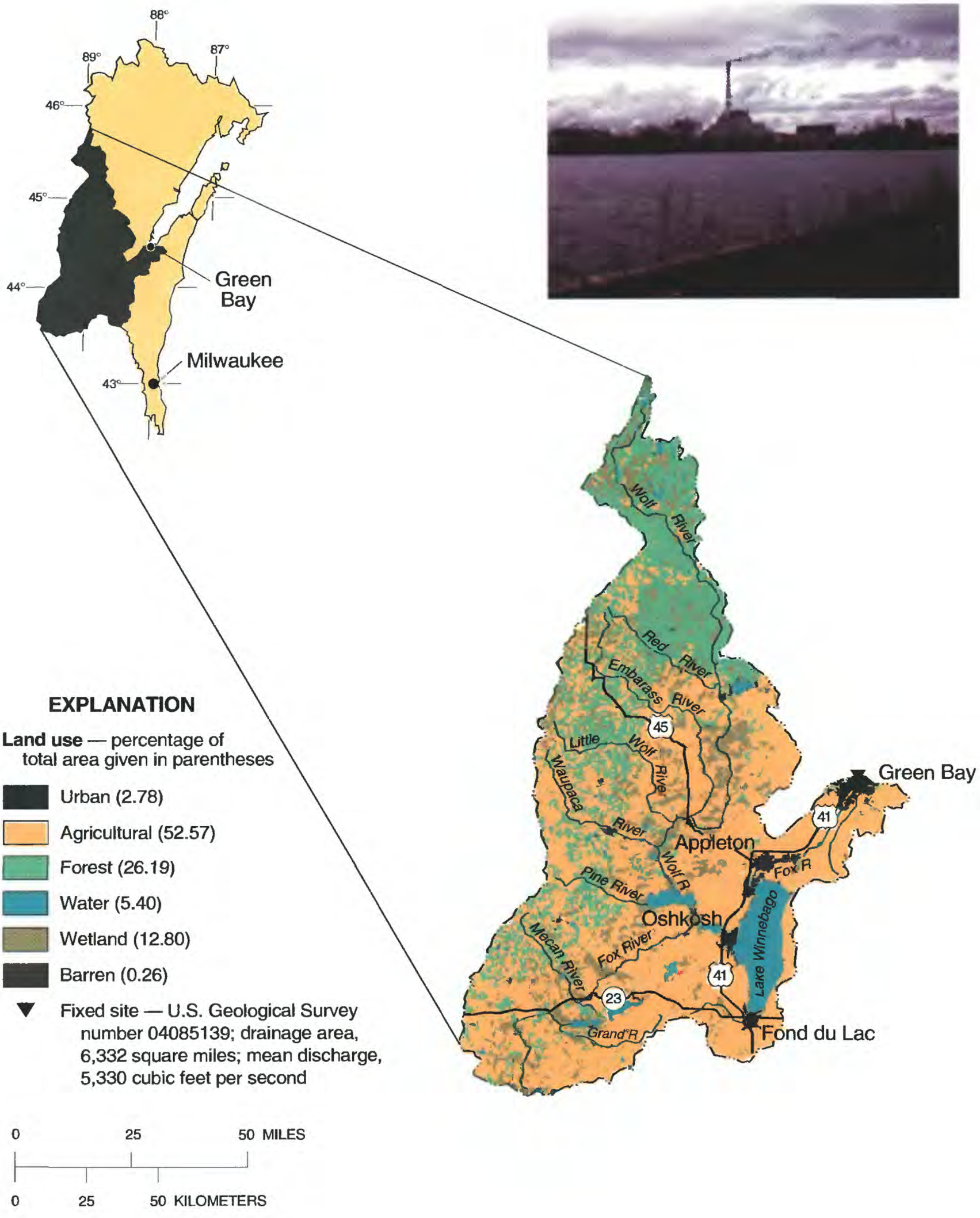


Figure 10. Map of Fox River Basin above the fixed site and photo showing typical character of the stream.

Figure 11. Map of North Branch Milwaukee River Basin above the fixed site and photo showing typical character of the stream.

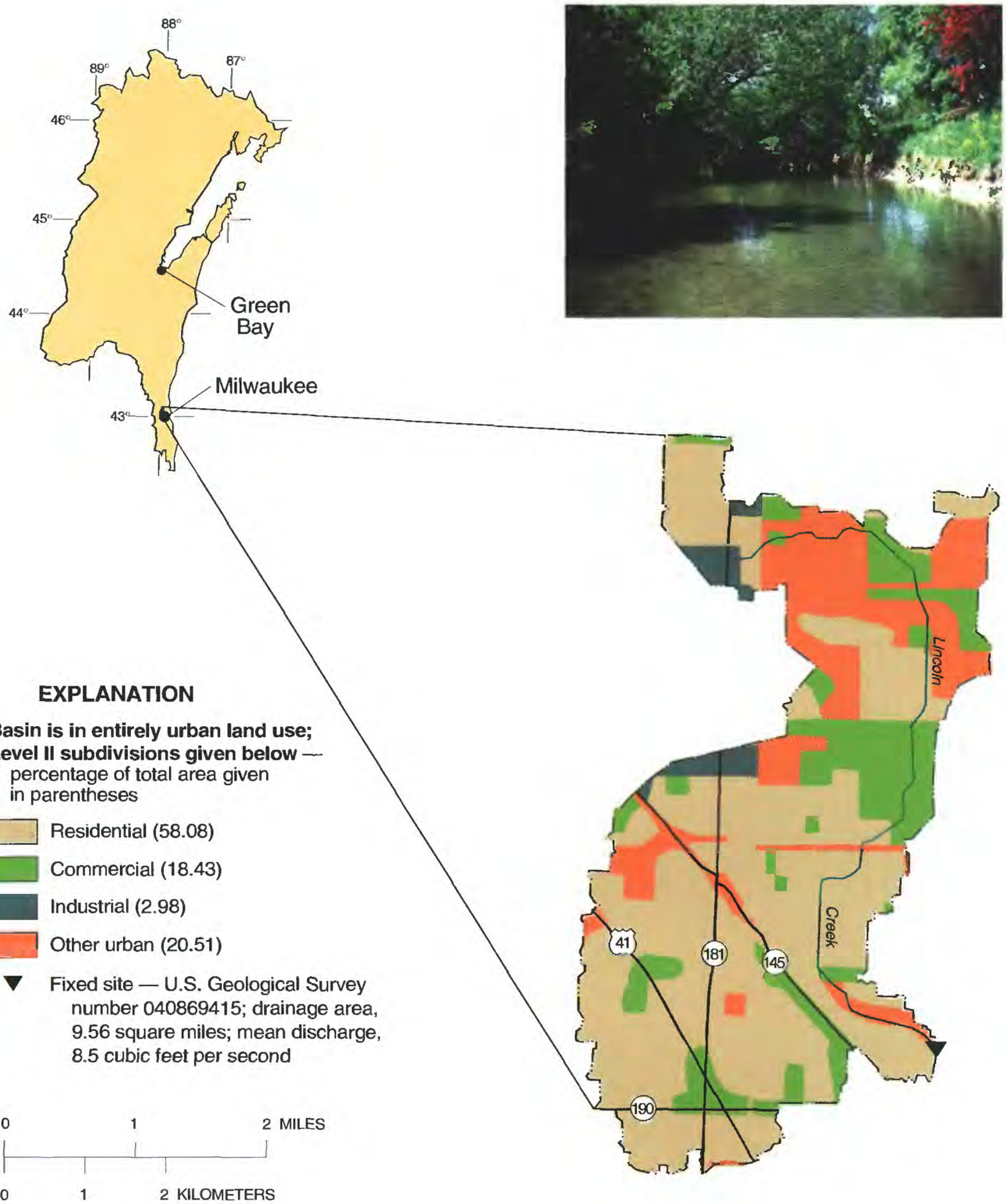


Figure 12. Map of Lincoln Creek Basin above the fixed site and photo showing typical character of the stream.

3.4 mi downstream from the sampling site (fig. 12). Large segments of the banks and streambed of Lincoln Creek are lined with concrete and riprap. The stream course is controlled along its entire length by a series of weirs.

Direct overland runoff from the urban environment may be attenuated somewhat by a corridor of park land that flanks the stream; however, many storm sewers empty directly into Lincoln Creek. The stream stage rises very quickly in response to rainfall, owing to rapid runoff from the surrounding concrete and asphalt. Low flow is maintained by ground-water discharge.

The stream reach in the vicinity of the sampling site has a firm substrate of gravel, clay, and sand. The reach consists of pools and runs and a few riffles. Banks are highly stable as a result of artificial controls. The primary bank vegetation consists of *Acer negundo* (boxelder), *Viburnum* sp. (viburnum), and grasses.

The Lincoln Creek Basin is a WDNR Priority Watershed (Wisconsin Department of Natural Resources, 1994). Many of the water-quality samples were collected in cooperation with other USGS and WDNR researchers. Numerous research projects have been done at the site by researchers from WDNR and the University of Wisconsin-Stevens Point (S.R. Corsi, U.S. Geological Survey, oral commun., 1995).

Milwaukee River at Milwaukee, Wisconsin

The Milwaukee River fixed site (fig. 13) is in Estabrook Park, a Milwaukee County Park, about 6.8 mi upstream from the mouth at Lake Michigan. The sampling site is about 300 ft downstream from a small impoundment. The river flows over a bedrock outcrop, which creates a small waterfall just downstream from the fixed site. The area surrounding the stream at this point is a combination of dense forest and open, grassy park land, which creates a riparian corridor of varying widths, beyond which lies the urban environment of Milwaukee.

The water quality at the fixed site integrates the effects of several RHU's, including the effects of agricultural and urban land uses. This site has the smallest drainage area of the three integrator sites, amounting to only about 3 percent of the total area of the study unit.

The stream reach at the sampling site has a firm substrate of cobbles and gravel. The reach is bounded on either end by bedrock riffles. The bank stability is high; bank and flood-plain vegetation consists of *Salix* sp. (willow), *Acer negundo* (boxelder), *Lonicera* sp. (honeysuckle), and *Carex* sp. (sedge).

The Milwaukee River at Milwaukee was a USGS NASQAN site from January 1973 through September 1994 (Holmstrom and others, 1994). Polychlorinated biphenyls in streambed sediments are being monitored at the site in a study by USGS and WDNR investigators (S.A. Fitzgerald, U.S. Geological Survey, oral commun., 1995). Multi-agency sampling has been done at the site under the auspices of the U.S. Environmental Protection Agency's (EPA) Interagency Task Force on Monitoring (P.A. Kammerer, U.S. Geological Survey, oral commun., 1995).

EFFECTS OF ENVIRONMENTAL SETTING ON WATER QUALITY

General water-quality conditions at the fixed sites may be attributed, at least in part, to geology, surficial deposits, and land use. In this section, some observations are presented that relate water quality to these factors. The water-quality factors considered include field measurements of temperature, pH, specific conductance, alkalinity, and dissolved oxygen; these measurements are summarized in table 2.

Only three significant differences in mean temperature were found among the fixed sites: the Peshekee River was significantly colder ($p<0.05$) than the Milwaukee River, Duck Creek, and the North Branch Milwaukee River. Boxplots of the temperature data are shown in figure 14. The maximum water temperature among all the fixed sites was observed at the Pensaukee River. This high temperature is probably due to the very low flows in the summer at this site and a minimal ground-water component resulting from the tightly packed loamy soils in the basin. The absence of many significant differences among sites may reflect timing of measurements as well as environmental effects. Variables such as time of day when data were collected, cloud cover, and other factors may have greater effect on temperature variation computed from monthly measurements than that computed from more frequent measurements. Continuous temperature monitoring,

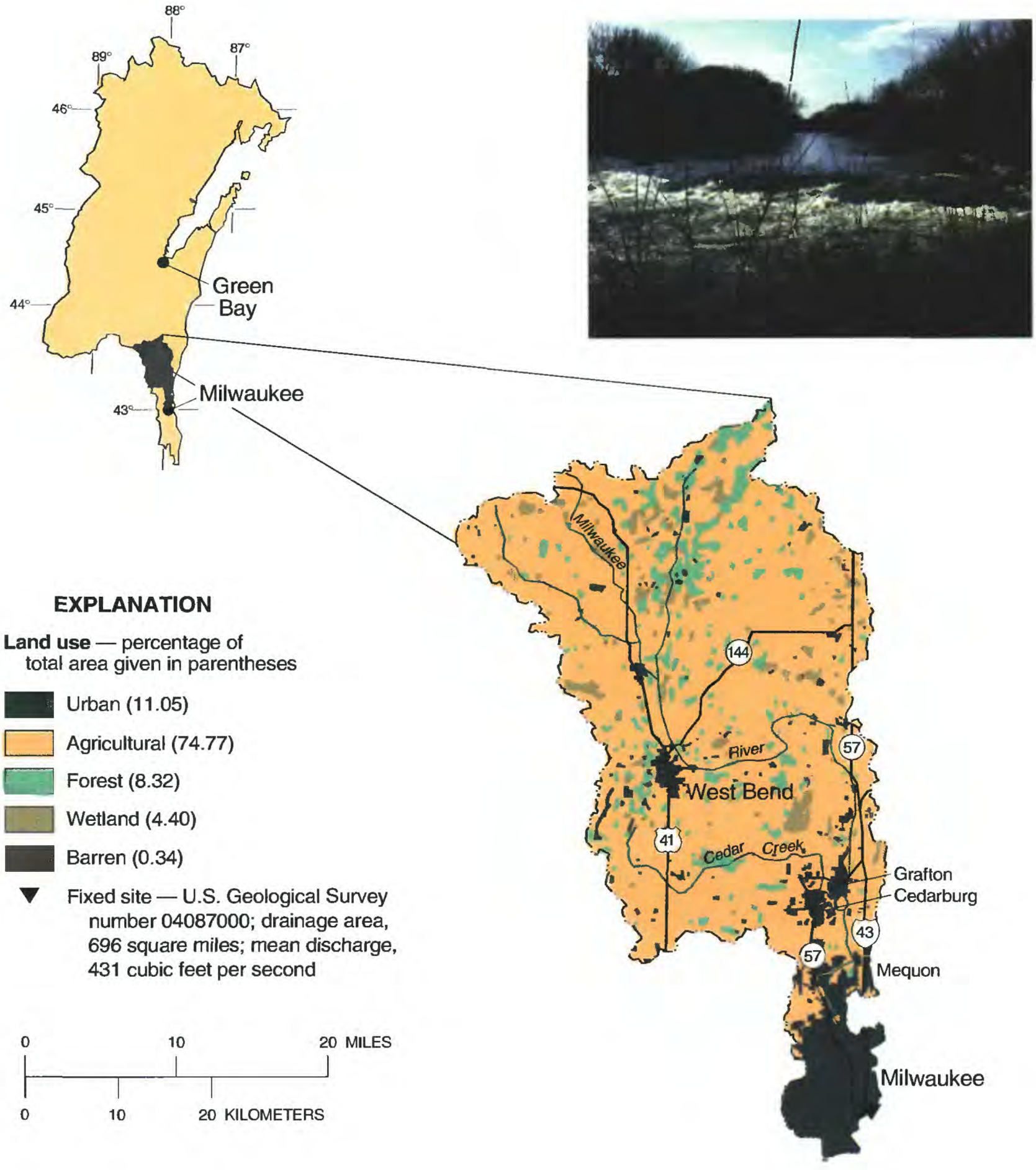


Figure 13. Map of Milwaukee River Basin above the fixed site and photo showing typical character of the stream.

Table 2. Selected water-quality data for the fixed sites in the Western Lake Michigan Drainages study unit

[°C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per Liter; $CaCO_3$, calcium carbonate; N, number of samples; max, maximum observed value or concentration; min, minimum observed value or concentration; med, median observed value or concentration]

Site name	Water temperature (°C)				Specific conductance (µS/cm at 25°C)				Alkalinity (mg/L as $CaCO_3$)				pH (standard units)				Dissolved oxygen (mg/L)			
	N	max	min	med	N	max	min	med	N	max	min	med	N	max	min	med	N	max	min	med
Peshekee River near Martins Landing, Mich.	30	22.5	0.0	3.7	30	69	16	38	30	33	3	12	30	7.8	6.4	7.0	30	13.1	6.6	11.6
Popple River near Fence, Wis.	31	23.5	.0	12.0	31	257	67	140	31	122	28	62	31	8.3	7.1	7.6	30	12.9	6.3	9.7
Menominee River at McAllister, Wis.	27	25.5	.0	9.0	27	309	163	245	27	120	73	97	27	8.4	7.7	8.0	27	14.6	7.4	11.8
Pensaukee River near Krakow, Wis.	32	30.6	.0	13.0	31	863	261	628	32	618	114	283	32	8.7	7.2	8.0	30	20.0	3.4	11.2
Duck Creek near Oneida, Wis.	52	24.9	.2	16.6	52	1,380	277	712	50	452	70	258	52	8.5	7.3	8.0	50	13.6	3.7	8.8
Tomorrow River near Nelsonville, Wis.	30	18.0	.2	10.9	30	478	201	380	30	240	92	179	30	8.8	7.5	8.0	29	14.0	6.8	10.7
East River near De Pere, Wis. [1]	37	25.3	.0	16.4	35	1,350	243	754	38	603	72	264	38	8.3	7.5	8.0	35	17.0	1.2	6.6
Fox River at Green Bay, Wis.	19	28.0	.0	12.8	18	515	343	392	19	190	134	162	19	8.9	7.9	8.3	18	14.2	6.7	11.2
North Branch Milwaukee River near Random Lake, Wis.	46	27.1	.0	16.2	44	828	391	684	44	360	176	306	45	8.6	7.6	8.3	44	14.8	3.7	8.5
Lincoln Creek at 47th Street at Milwaukee, Wis.	27	22.7	.2	11.7	27	6,640	272	768	28	266	46	158	28	8.7	7.4	8.0	26	13.2	5.6	10.0
Milwaukee River at Milwaukee, Wis.	40	27.3	.2	16.6	41	1,880	386	675	40	378	178	264	41	9.2	7.6	8.4	40	16.8	5.5	9.9

[1] Data collected at station 04085108, 1 mile upstream, from 04/94 through 08/94 because of bridge construction at site.

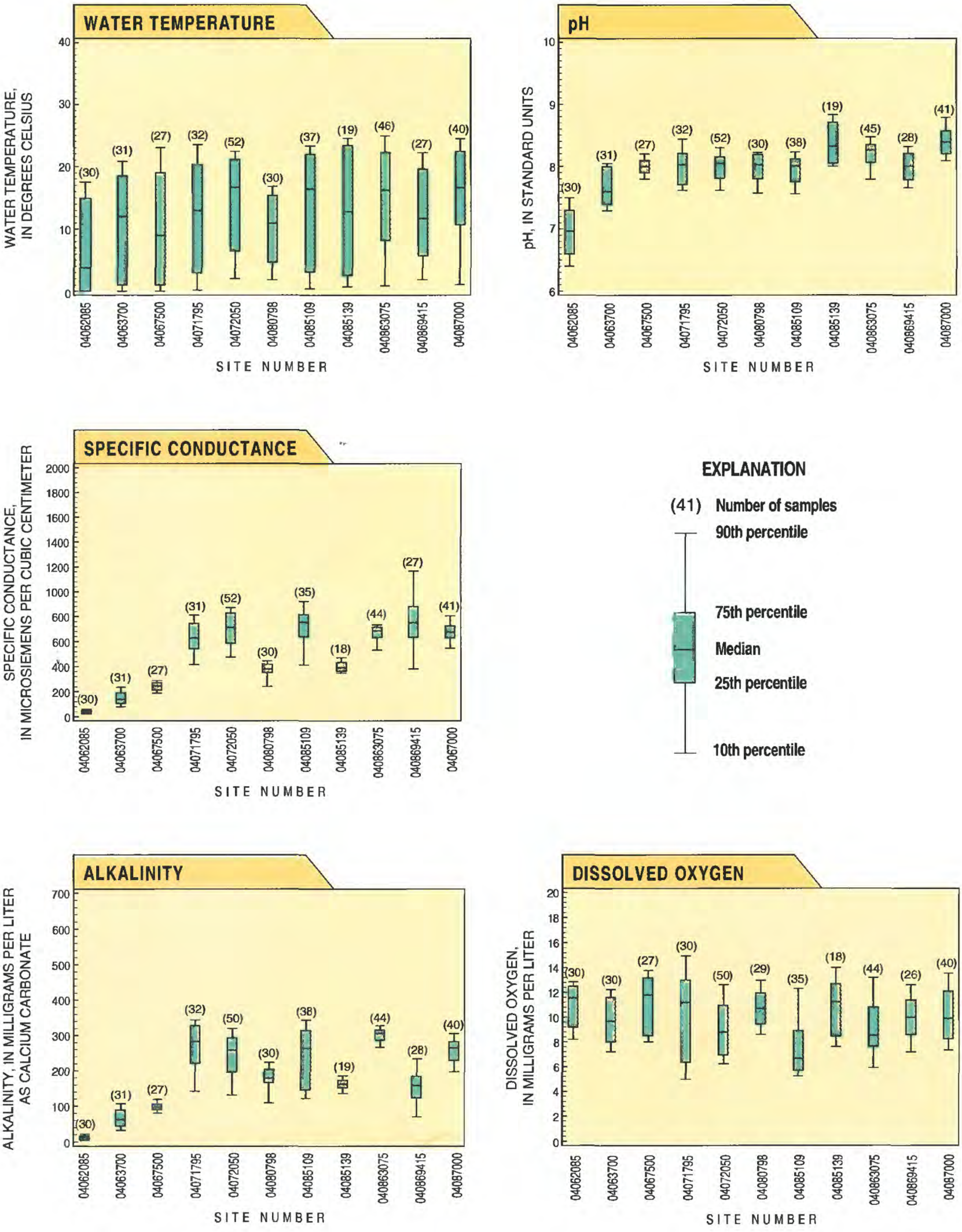


Figure 14. Boxplots of water-quality measurements at the fixed sites in the Western Lake Michigan Drainages study unit, 1993-95 (site data given in tables 1 and 2).

which began in 1995, will provide greater resolution and may reveal additional differences between sites.

Four sites underlain entirely or primarily by igneous/metamorphic bedrock–Peshekee, Popple, Tomorrow, and Menominee Rivers–had lower mean specific conductance and alkalinity ($p<0.05$) than most of the other fixed sites, which are underlain primarily by carbonate or a combination of carbonate and igneous/metamorphic bedrock. Mean specific conductance at the Peshekee River site, for example, was lower ($p<0.05$) than at all other sites except those on the Popple and Menominee Rivers. Additional factors contributing to lower specific conductance and alkalinity at these sites may include their locations in the northern part of the basin and less weathered surficial deposits. Boxplots of specific conductance and alkalinity are shown in figure 14.

Observations of pH indicate patterns similar to those for specific conductance and alkalinity, but less distinct (fig. 14). The north-south gradient is more apparent in the data than are differences between bedrock types.

The mean dissolved-oxygen concentration at the northern sites was not significantly different ($p<0.05$) than at most of the southern fixed sites. However, the variability in dissolved-oxygen concentrations at some of the southern sites appears to be greater than at the northern sites, as indicated by higher maximum values and lower minimum values among the southern sites (fig. 14). Of particular note are the minimum values observed at the agricultural indicator sites, including the Pensaukee River, Duck Creek, East River, and North Branch Milwaukee River. These data indicate that greater nutrient input to these agricultural streams, the result of runoff from cropland, may increase algal activity and thus respiration/photosynthesis activities, which cause dissolved-oxygen concentrations to vary.

The environmental setting features of the fixed sites described in this report, along with other variables, affect the water quality observed at the fixed sites. Ongoing studies are planned to determine whether these environmental factors affect biotic communities and water chemistry, and whether these effects can be quantified.

SUMMARY

The USGS began full-scale implementation of the NAWQA Program in 1991. The goals of the NAWQA Program are to describe current conditions, status and trends, and the natural and human factors that affect the water quality of a large part of the Nation's freshwater streams.

The Western Lake Michigan Drainages encompasses an area draining 19,900 mi^2 in eastern Wisconsin and the Upper Peninsula of Michigan. Ten major river systems are in the study unit. The overall population of the study unit is 2,435,000. About 40 percent of the study unit is forested, 37 percent of the study unit is in agricultural land use, and 15 percent is wetlands.

The Western Lake Michigan Drainages NAWQA study unit was subdivided on the basis of an overlay of the boundaries of large-scale environmental settings features. This was accomplished through the use of a GIS. This process resulted in 28 subunits, referred to as "relatively homogeneous units" (RHU's). Each RHU is a unique combination of bedrock geology, surficial deposits, and land use.

Eleven fixed sites were sampled to determine the status and trends in water quality in the Western Lake Michigan Drainages NAWQA study unit. Eight of the fixed sites were selected to represent conditions in eight selected RHU's and are referred to as "indicator sites." The other three fixed sites were selected to represent a large part of the total flow from the study unit to Western Lake Michigan; they are referred to as "integrator sites" because their drainage basin covers more than one RHU. Three fixed sites, two indicator and one integrator, were sampled more frequently at selected periods of the year and are additionally referred to as "intensive sites."

The fixed sites were sampled from April 1993 through May 1995. Data were collected per NAWQA protocols on water chemistry; organic compounds and trace elements in streambed sediment and biological tissues; algal, benthic-invertebrate, and fish communities; and aquatic habitat.

General water-quality conditions at the fixed sites may be related to geology, surficial deposits, and land use. The water-quality measurements considered in this report include field measurements of temperature,

pH, specific conductance, alkalinity, and dissolved oxygen. Among the relations determined thus far are the following:

- Few significant differences were found in stream temperature at the fixed sites, although timing of measurements may have masked some of the environmental effects. Variables such as time of day when data were collected, cloud cover at the time of data collection, and other factors may have a greater effect on temperature variation computed from monthly measurements than that computed from more frequent measurements.
- Specific conductance and alkalinity were lowest at the sites underlain by igneous/metamorphic bedrock and highest at sites underlain by carbonate bedrock.
- The pH's at the fixed sites have a weaker relation to bedrock types than do specific conductance and alkalinity. A slight north-south effect is apparent in the data.
- The most notable aspect of the dissolved-oxygen data is the greater variation at the agricultural land-use sites. At these sites, lower minimum and higher maximum dissolved-oxygen concentrations were found than at the mostly forested and urban sites. These data indicate that greater nutrient input to these streams, the result of runoff from cropland, may increase algal activity and thus respiration/photosynthesis activities, which cause dissolved-oxygen concentrations to vary.

The environmental-setting features of the fixed sites described in this report, along with other variables, affect the water quality observed at the fixed sites. Ongoing studies are planned to determine whether these environmental-setting features affect biotic communities and water chemistry and whether these effects can be quantified.

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