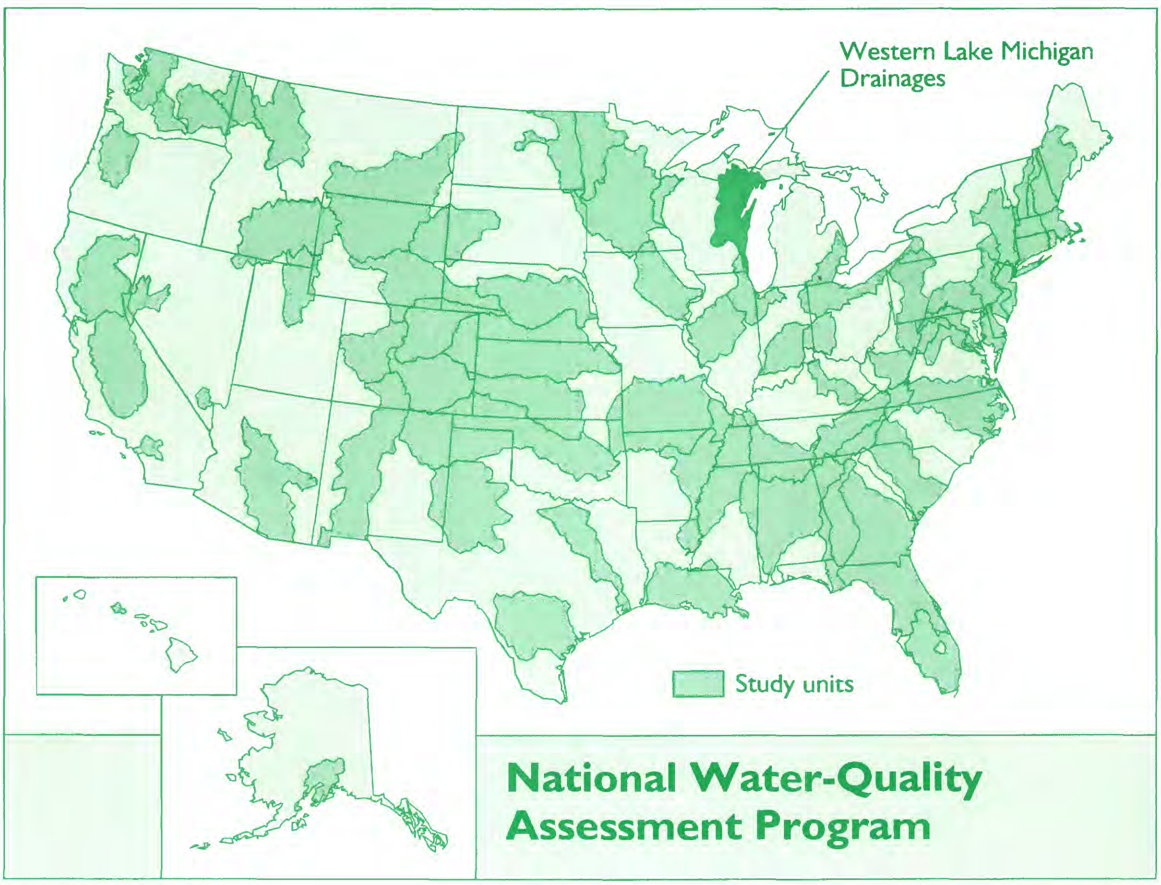
U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 95-4211-B

Stream Habitat Characteristics of Fixed Sites in the Western Lake Michigan Drainages, Wisconsin and Michigan, 1993–95



Stream Habitat Characteristics of Fixed Sites in the Western Lake Michigan Drainages, Wisconsin and Michigan, 1993–95

By Faith A. Fitzpatrick and Elise M. P. Giddings

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NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

science for a changing world

Middleton, Wisconsin
1997

U.S. DEPARTMENT OF THE INTERIOR
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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 59 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 59 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

Robert M. Hirsch
Chief Hydrologist

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CONVERSION FACTORS AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
millimeter (mm)	0.03937	inch
centimeter (cm)	.3937	inch
meter (m)	3.281	foot
kilometer (km)	.6214	mile
meter per kilometer (m/km)	5.280	foot per mile
square centimeter (cm^2)	.1550	square inch
square meter (m^2)	.0929	square foot
hectare	2.471	acre
square kilometer (km^2)	.3861	square mile
centimeter per hour (cm/hr)	.3937	inches per hour
meter per second (m/s)	3.281	feet per second
cubic meter per second (m^3/s)	35.31	cubic foot per second

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

$$°F = 1.8\ (°C) + 32.$$

Abbreviated water-quality units: Chemical concentration given in milligrams per liter (mg/L). Specific conductance of water is expressed in microsiemens per centimeter at 25 degrees Celsius (µS/cm). This unit is equivalent to micromhos per centimeter at 25 degrees Celsius (µmho/cm), formerly used by the U.S. Geological Survey. The abbreviation "pH' represents the negative base 10 logarithm of hydrogen ion activity in moles per liter.

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Stream Habitat Characteristics of Fixed Sites in the Western Lake Michigan Drainages, Wisconsin and Michigan, 1993–95

By Faith A. Fitzpatrick *and* Elise M. P. Giddings

Abstract

Habitat characteristics of 11 fixed sites in the Western Lake Michigan Drainages were examined by the U.S. Geological Survey from 1993 through 1995 as part of the ecological assessment of the National Water-Quality Assessment Program. Evaluation of habitat consisted of more than 75 measurements at three spatial levels: drainage basin, stream segment between major tributaries (length from 1 to 14 kilometers), and stream reach (approximately 150 meters). The 11 fixed sites consisted of 8 "indicator" sites with drainage basins that differ in bedrock type, surficial deposits, and land use; and 3 "integrator" sites with drainage basins that contain a mixture of bedrock type, surficial deposits, and land use. Spatial and temporal variations in habitat characteristics are described and compared. Comparisons are limited to indicator sites except for comparisons among-basin characteristics, which include all fixed sites. Two habitat classification schemes used in Wisconsin and Michigan were used to rank the quality of habitat in indicator streams. Reach-level data were collected at two additional reaches at three of the indicator sites to assess the representativeness of the reach for overall stream conditions.

Although the number of sites is small, statistical analyses indicate that spatial distribution of several characteristics can be related to land use, geology, topography, and width of the riparian zone. Land use and geology, in combination, appeared to be important factors in controlling flood magnitudes. Annual mean flow was correlated with basin shape and drainage density and low flow was correlated with permeability of soils in the basin.

At the reach level, a wide variety of characteristics were observed at the eight indicator sites, with many of the characteristics significantly different between sites. Spatial differences in some reach characteristics can be attributed to the percentage of agriculture in the drainage basin, type of surficial deposits, and width of the riparian zone. Temporal variability in width, depth, and velocity can be attributed to variable flow conditions; whereas temporal variability in streambank measurements are attributed to problematic identification of the boundary between the flood plain and streambanks.

Data from multiple-reach sites indicate that the primary reach adequately represented the variability found within the stream segment for depth, streambank stability index, and canopy angle. However, velocity, dominant substrate type, embeddedness, streambank height, streambank angle, and streambank vegetative stability differed among the multiple reaches at one or more of the three sites.

Correlation analyses of habitat characteristics with median concentrations of four nutrients, pH, and specific conductance indicates that dissolved nitrate plus nitrite concentrations are related to percentage of agriculture in the basin and fine-grained sediment deposition in the reach. Geology and land use appear to be major influences on pH, but their influence on specific conductance, although expected, was not confirmed in this study. Habitat evaluation scores at the eight indicator sites ranged from poor to good. Scores were correlated to the percentage of agricultural or urban land in the drainage basins, width of the riparian zone, and streambank stability index.

Results from this study illustrate the need for collection of habitat data at multiple scales along with water-chemistry data for determining major influences on distribution of aquatic communities. These results also indicate the importance of collecting land use, geological, and geomorphic information at the drainage-basin level to adequately describe how natural and human factors influence local aquatic habitat conditions.

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 (Gilliom and others, 1995; Hirsch and others, 1988). This information will be useful for planning future management actions and examining their likely consequences. In all, 59 study units are planned to begin activities on a staggered time scale. The Western Lake Michigan Drainages (WMIC) was selected as one of the 20 study units to begin data collection and analysis in 1991.

One of the major goals of the NAWQA program is to develop a better understanding of the interaction among physical, chemical, and biological characteristics of streams in selected environmental settings (Gurtz, 1994). Ecological studies are included in the NAWQA program to provide data on biological communities that contribute to the understanding of this interaction. Aspects of the NAWQA ecological studies include (1) investigations of how biological communities and stream habitat differ among selected environmental settings, (2) identification of physical and chemical characteristics that influence biological communities, (3) understanding of how spatial scales affect the relations seen between physical, chemical, and biological characteristics, and (4) investigations of how biological communities affect physical and chemical characteristics (Gurtz, 1994). Stream habitat data, collected at a variety of spatial scales, are useful in expanding the understanding of the interaction among physical, chemical, and biological characteristics.

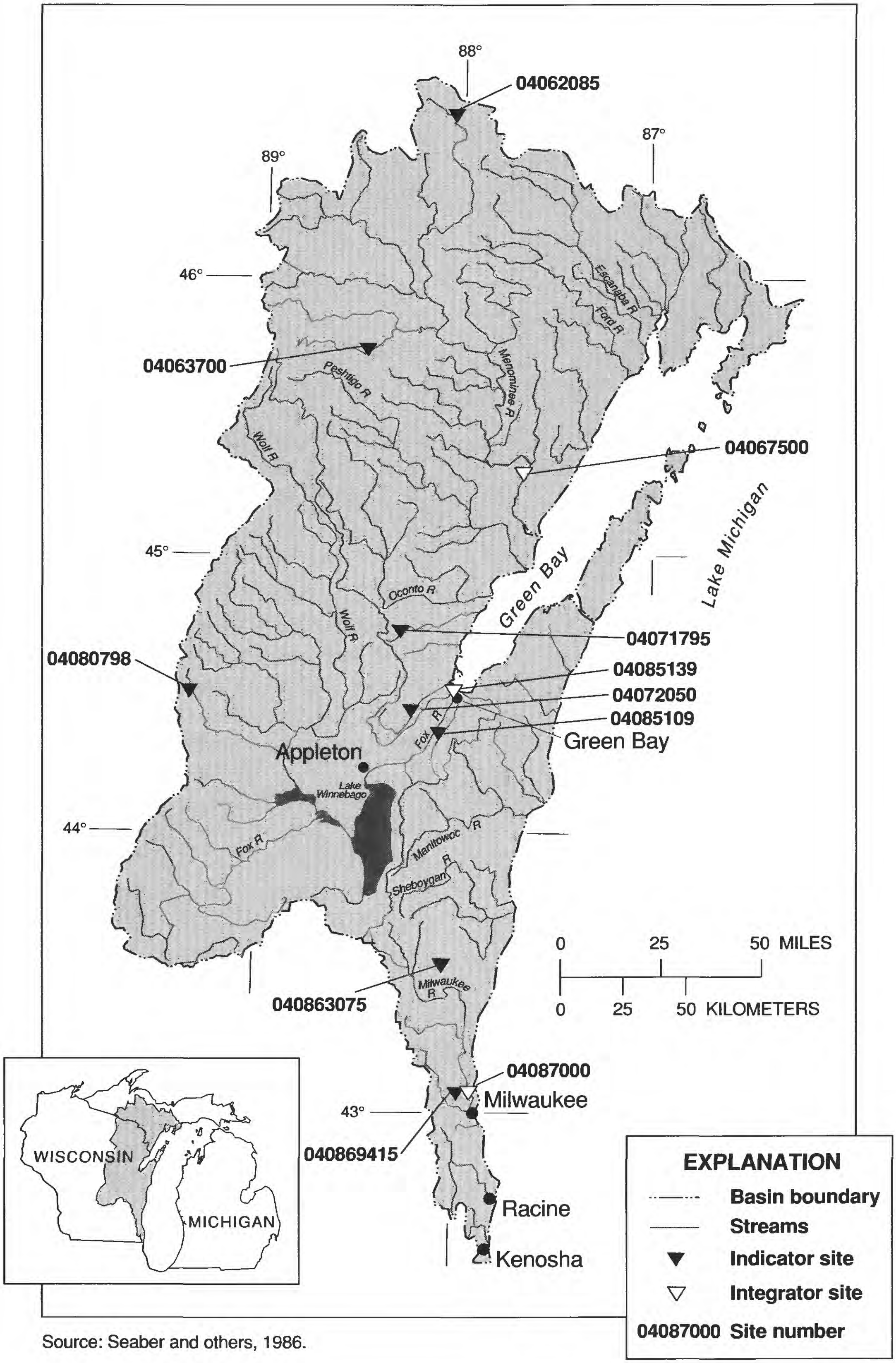
Western Lake Michigan Drainages

The Western Lake Michigan Drainages study unit (fig. 1) encompasses 51,541 km^2 of eastern Wisconsin and the Upper Peninsula of Michigan. Ten major rivers drain the study unit: the Escanaba and Ford Rivers in Michigan; the Menominee River, which partially defines the state boundary between Wisconsin and Michigan; the Peshtigo and Oconto Rivers in northeastern Wisconsin; the Fox/Wolf River complex in east-central Wisconsin, which drains into Green Bay; and the Manitowoc, Sheboygan, and Milwaukee Rivers, which drain the southeastern part of the study unit.

The overall population in the study unit is 2,435,000 (U.S. Bureau of the Census, 1991). Urban land use accounts for less than 4 percent of the study unit. The major cities and their populations are Milwaukee, 628,000; Green Bay, 96,000; Racine, 84,000; Kenosha, 80,000; and Appleton, 66,000. Agriculture makes up 37 percent of the land use in the basin and is devoted almost exclusively to cropland and pasture for dairy production. About 40 percent of the study unit is forested, located mainly in the northwest part of the study unit. Wetlands account for 15 percent of the land use in the study unit. Lake Winnebago, a 55,442-hectare lake in the Fox River Basin, is a major surface-water feature of the study unit.

Sampling Design

The WMIC study unit was subdivided into 28 environmental settings, called relatively homogenous units (RHU's), on the basis of bedrock geology, texture of surficial deposits, and land use/land cover (Robertson and Saad, 1995a). In an effort to isolate the effects of individual factors on stream quality, eight sites (fig. 1) were established on small to medium-sized streams draining eight of the largest RHU's in the WMIC study unit. These sites are called indicator fixed sites because their characteristics are assumed to be indicative of conditions in other streams in the same RHU. Three additional sites (fig. 1) were located on larger streams that drain a variety of RHU's, and they are called integrator fixed sites. All 11 sites are called fixed sites because they were monitored intensively from March 1993 through July 1995 for a variety of chemical, physical, and biological data that included streamflow;



Source: Seaber and others, 1986.

Figure 1. Location of fixed sites in the Western Lake Michigan Drainages study unit.

water chemistry; organic compounds and trace elements in streambed sediment and biological tissues; fish, invertebrate, and algal communities; and stream habitat. Two of the 11 sites will be less intensively monitored for similar constituents from 1996 to 2001. Three years of intensive sampling at the 11 fixed sites is planned for 2002 to 2004 in keeping with the cyclical nature of NAWQA (Gilliom and others, 1995).

General characteristics of the 11 fixed sites, including exact locations, detailed land-use information, and water chemistry, can be found in Sullivan and others (1995). Land use types covered by the eight indicator sites include agriculture (mainly corn and dairy), forest, and urban (Milwaukee, Wis.). Surficial deposits include clayey, loamy, sandy, and sand and gravel types. Bedrock types include igneous/metamorphic, shale, and carbonate.

Purpose and Scope

The purpose of this report is to describe spatial and temporal distribution of habitat characteristics at the drainage-basin, stream-segment, and stream-reach levels at 11 indicator and integrator fixed sites in the WMIC study unit from 1993 through 1995. Data for segment- and reach- level characteristics are limited at integrator sites. Factors that influence spatial and temporal variability of habitat characteristics are discussed. Stream-habitat-evaluation systems (Ball, 1982; Michigan Department of Natural Resources, 1991) are applied to the data, and results are compared in the context of these systems' original goals. Habitat characteristics are compared to several water-chemistry characteristics. The results presented in this report are an integral part of identifying overall stream quality in a variety of land use and geologic settings; they also provide baseline data for characterizing temporal changes in stream quality. Additional biological studies are focusing on the relations between habitat and invertebrate, fish, and algal communities.

METHODS FOR CHARACTERIZING STREAM HABITAT

This section describes collection and analysis techniques for WMIC study unit habitat data. Statistical methods also are described. In addition, methods for two habitat-evaluation systems used extensively in Wisconsin (Ball, 1982) and Michigan (Michigan Department of Natural Resources, 1991) are described.

Collection and Analysis of Habitat-Characteristic Data

The 11 indicator and integrator fixed sites were sampled for stream habitat at a variety of spatial and temporal scales. Habitat data were collected at three spatial scales—drainage basin, stream segment, and stream reach (table 1)—according to methods outlined in Meador and others (1993). All habitat characteristics listed in Meador and others (1993) were measured. Additional basin-level characteristics, important in the analysis of invertebrate, fish, and algae communities, also were included in the analyses. Drainage-basin characteristics include land use, geology, and other geomorphic characteristics such as drainage density and basin shape. Stream segments were located between two major tributaries where geomorphic and habitat conditions are similar along the entire segment. Geomorphic data collected at the stream-segment level were stream order, sinuosity, and gradient.

Stream reaches, between 150 and 300 m long, were selected to represent conditions within the segment and included locations where invertebrates, algae, and fish communities were sampled as part of the integrated biological sampling for NAWQA. Two levels of data were collected at the stream reach. The first level includes quantitative information on channel, bank, and flood plain characteristics. The second level includes more detailed data for the channel cross section, channel substrate particle size, and flood-plain vegetation.

The habitat protocol for stream-reach data collection (Meador and others, 1993) was applicable to wadable streams only. Some data are missing, especially at the segment and reach level for integrator sites, because of the large size of their drainage basins and because part or all of the selected reaches were not wadable.

From 1993 to 1995, habitat data at the stream-reach scale were collected concurrently with invertebrate and algae collections each spring to account for temporal changes and measurement variability. Two additional reaches, adjacent to the original reach but within the stream segment, were sampled in 1994 at three indicator sites to see how representative the original reach was of overall conditions within the stream segment.

Basin Characterization

Basin-level data were collected at the 11 fixed sites to assess the effects of geomorphic and other factors in the watershed on the water quality of the stream. Drainage boundaries for each site were digitized into a geographical information system (GIS) from USGS 1:24,000-scale topographic maps. The drainage boundaries were overlain with thematic maps of bedrock (Mudrey and others, 1982; Reed and Daniels, 1987), surficial deposits (Farrand and Bell, 1984; Wisconsin Geological and Natural History Survey, 1987), soils (U.S. Department of Agriculture, 1991), land use (Anderson, 1970; Fegeas and others, 1983), physiographic province (Fenneman, 1946), ecoregion (Omernik, 1987; Omernik and Gallant, 1988; Albert, 1995), land-resource area (U.S. Department of Agriculture, 1972), and potential natural vegetation (Küchler, 1970). Percentage of drainage area in each category was calculated with the GIS.

Other basin-level data (table 6) were collected by visual inspection of 1:24,000-scale USGS topographic maps. Drainage density was calculated by measuring the cumulative length of all perennial streams in the basin and dividing the cumulative length by the drainage area. Drainage-basin shape (R_f) was calculated by dividing the drainage area (A) by the length of the drainage basin (L) squared:

$$R_f = A/L^2$$

Basin relief is the difference between the highest and lowest elevation in the basin. Basin storage was estimated visually from the maps by use of a grid.

Values for two soil-related characteristics, erodibility factor and permeability rate, were computed from data available through the State Soil Geographic Data Base (STATSGO) (U.S. Department of Agriculture, 1991). The soil erodibility factor quantifies the susceptibility of soil particles to detach and move in water (U.S. Department of Agriculture, 1991); the erodibility factor is used in the Universal Soil Loss Equation. STATSGO provides an erodibility factor for each soil type. Because several soil types were present in the drainage basins, an average erodibility factor for each drainage basin was calculated by weighting the area of each soil type in the drainage basin.

In order to compute average permeability rates for each drainage basin, the STATSGO data were generalized. STATSGO provides minimum and maximum permeability rates for each soil layer. Each soil type is composed of several soil layers that reflect conditions with depth. Thus, the average permeability rate for each stream was calculated by (1) averaging the minimum and maximum permeability rates for each soil layer to calculate the average permeability rate for a given soil type and (2) weighting the average permeability rate for each soil type by the area of the soil type in the drainage basin to calculate the overall permeability rate for the drainage basin.

Two-year flood discharges were estimated by use of Wisconsin flood-frequency equations (Krug and others, 1992). Low-flow discharges (7-day, 2- and 10-year) for Wisconsin streams were calculated by use of equations developed by Holmstrom (1980, 1982). Flood flows and low flow for the Peshekee River in Michigan were estimated by use of equations from Holtschlag and Croskey (1984). Annual mean flows for all fixed sites were calculated by averaging daily flow data for the water years 1993–95 (Holmstrom, Kammerer, and Ellefson, 1994, 1995; Holmstrom, Olson, and Ellefson, 1996). Annual runoff was estimated by use of data from Gebert and others (1987).

Climate data includes average annual precipitation, evaporation, and temperature. Precipitation and temperature data were selected from data published in Wendland and others (1985). Evaporation data were estimated from information in Oakes and Hamilton (1973), Olcott (1968), and Skinner and Borman (1973).

Segment Characterization

Data were collected at the segment level to describe the stream near the reach. Each segment is bounded by the next upstream and next downstream tributary junction and includes all reaches sampled. The segments, which range in length from 2.8 to 15.4 km, are considered discrete stream units that are relatively homogeneous in their characteristics. These data were collected only at indicator sites.

Segment-level data were collected by visual inspection of USGS 1:24,000-scale topographic maps. Stream order was calculated by use of the Strahler method (1954, 1957) with reference to ephemeral and perennial streams marked as blue lines on 1:24,000-scale topographic maps. Channel sinuosity is defined as the ratio of the channel length between two points to the valley length between these points. A high ratio indicates a high degree of sinuosity or meandering. Stream-segment gradient is the overall channel gradient measured from contour lines on the 1:24,000-scale topographic maps. Downstream link number is related to location of the segment within the drainage basin

Table 1. Stream habitat characteristics measured at fixed sites in the Western Lake Michigan Drainages study unit

Basin level	Segment level	First-level reach: Channel	First-level reach: Bottom substrate	First-level reach: Bank and flood plain	Second-level reach
Relatively homogeneous unit	Stream order	Percent riffle	Bottom-substrate type	Bank width	Channel cross section surveys
Drainage area	Downstream link number	Percent pool	Embeddedness	Bank height	Water-surface gradient
Stream length	Channel sinuosity	Percent run	Silt (absence/presence)	Bank angle	Thalweg gradient
Stream gradient	Segment gradient	Channel width	Macrophyte coverage	Bank erosion type	Left and right flood-plain slope
Cumulative stream length	Segment length	Channel depth	Periphyton coverage	Bank shape	Streambed sediment particle size
Drainage density	Upstream elevation	Velocity		Bank substrate	Streambank sediment particle size
Basin shape	Downstream elevation	Aspect		Bank vegetative stability	Wolman[1] pebble counts
Basin relief	Side slope gradient	Amount woody debris		Bank-stability index[2]	Riparian permanent vegetation plots
Basin storage	Springs (absence/presence)	Reach length		Amount undercut banks	
Basin length	Water-management features	Amount rubbish (human)		Amount overhanging vegetation	
Bedrock type		Amount boulders		Bank vegetation	
Surficial deposits		Amount sloughs		Flood-plain vegetation	
Erodibility factor		Bar/shelf/island characteristics		Canopy angle	
Permeability				Flood-plain width	
Land use					
Physiographic province					
Ecoregion					
Potential natural vegetation					
Flood discharge[3]					
Annual mean discharge					
Low-flow estimates[4]					
Annual runoff					
Annual temperature					
Annual precipitation					
Annual evaporation					

[1]Measured according to Wolman (1954).
[2]Bank-stability index combines bank angle, shape, vegetative stability, height, and substrate into one index.
[3]Estimated flood discharges include recurrence intervals of 2, 5, 10, 25, 50, and 100 years; estimated by use of flood frequency equations from Krug and others (1992).
[4]Low-flow estimates calculated for 7-day, 2- and 10-year flows are based on equations from Holmstrom (1980, 1982).

and is measured by counting the number of tributaries above the next downstream tributary. For example, a segment downstream from two headwater tributaries has a downstream link number of 2; if the segment was downstream from another tributary junction it would have a downstream link number of 3. If a low-order stream has a small downstream link number, it is joined by other low-order tributaries just below the segment. However, if it has a large downstream link number, it flows into a larger stream or river just downstream.

First-Level Reach Characterization

The stream reach was the principal sampling unit for collecting physical, chemical, and biological data. Specific sampling reaches were identified from a combination of the following criteria: (1) the reach contains at least two examples each of two geomorphic units (pools, riffles, or runs), (2) minimum reach length is 20 times the average stream width or 150 m, and (3) maximum reach length is 300 m (Meador and others, 1993). An attempt was made to select reaches that were upstream from bridges to limit effects from roads and channel modifications; however, downstream reaches, adequately distanced from bridges, were selected where upstream reaches did not adequately characterize the stream segment.

First-level reach characteristics include channel, substrate, bank, and flood-plain measurements. Most measurements were collected at each of six transects, one at each end of the reach, and the other four at the midpoints of selected geomorphic units. Exact locations of the transects and reach boundaries were measured from established reference points at the nearest bridge crossing. At each of the transects, channel and substrate measurements were made at the thalweg and at two other stream locations equally spaced along the transect. Photos were taken to document each of the reach boundaries and the one transect that best represented the reach. A diagrammatic map of the reach was drawn to depict the location and type of geomorphic channel units, transects, habitat features, bank and flood-plain characteristics, and biotic sampling locations. Reach-level data are limited at the integrator sites because most of the reach was unwadable.

Flood-plain vegetation was characterized by means of the point-centered quarter method (Mueller-Dombois and Ellenberg, 1974). Points were measured in the flood plain at the ends of each transect. The area around each point was divided into four quarters, and the distance from the point to the nearest woody vegetation in each of the quarters was recorded. Density was calculated by averaging the distances from the point to the nearest tree or shrub and calculating the average area occupied by each individual. The species and diameter at breast height of each individual also was recorded, allowing for calculation of frequency and basal area for each species (Mueller-Dombois and Ellenberg, 1974). The nearest woody vegetation over 1.3 m tall was recorded; thus, the sample contained a mixture of trees, saplings and shrubs. If no woody vegetation was present in the flood plain, no value was recorded. Because a value is needed for every quarter for proper calculation, the flood plain width was substituted for distance in these cases. By substituting the flood plain width for distances where no individual was within the flood plain, the result may be biased towards a higher density than is actually present. Therefore, the estimates of density obtained must be interpreted as an upper level of density.

The width of the riparian buffer area was measured from aerial photographs, using 1992 National Aerial Photography Program (NAPP) photography where available. Three measurements were taken on each of the left and right banks at evenly spaced intervals in the reach area. The buffer width was measured along a perpendicular from the streambank to the edge of continuous noncultivated vegetation. These values were then averaged for analysis.

Second-Level Reach Characterization

Second-level reach characterization focused on detailed measurements of channel geometry and longitudinal profiles of the water surface, channel thalweg, and flood plain; particle-size analyses of channel bottom and streambank substrate; and establishment of permanent vegetation plots. These data were collected only at indicator sites.

Channel geometry and longitudinal profiles were measured according to methods described in Harrelson and others (1994) and Gordon and others (1992) using a level and metric tape. Channel cross sections were measured at three of the six transects in the reach, including the transects at the beginning and end of the reach and one representative transect. Usually, the transect within the geomorphic unit sampled for invertebrates and algae was selected as the third transect to be measured. Sections of concrete reinforcement bar (1.3 m long, 13 mm in diameter) were driven into the ground and used as reference marks at each end of the surveyed transects. Elevation measurements were tied into a benchmark at the reference point. This benchmark, usually a permanent Wisconsin Department of Transportation benchmark or a set of marks engraved on the bridge rail, was the same point used for referencing gage-height elevations from the streamflow continuous recorders. The channel cross sections included flood-plain measurements for calculation of bankfull stage. Longitudinal profiles of the water surface, channel thalweg, and flood plain were constructed using approximately 10 to 20 elevation measurements made at constant intervals within the reach. The U.S. Army Corps of Engineers Hydrologic Engineering Center water-surface profile computation model HEC-2 (BOSS Corporation, 1992) was used to estimate bankfull streamflow through the reach.

Channel bottom substrate particle size was measured by use of two techniques: pebble counts (Wolman, 1954) and quantitative particle-size distributions analyzed from sediment samples submitted to the U.S. Geological Survey, Iowa District, sediment laboratory. For the Wolman pebble counts, one boulder, three cobble, five gravel, and one sand or fines fractions were distinguished. Sediment samples for laboratory analyses of particle size were collected at three points in the same surveyed cross sections. The three point samples were composited from each cross section. Streambank samples also were collected from one or both banks of each channel cross section. The Iowa District laboratory analyzed the samples for five gravel, five sand, four silt, and two clay fractions.

Permanent vegetation plots were established according to Meador and others (1993) at the ends of each channel cross section for a total of six vegetation plots per reach. Plots were 400 m^2 in area and were restricted to the flood plain. For some plots, it was not possible to achieve 400 m^2 without overlapping the adjacent plot. For these, plots of less than 400 m^2 were established and noted. If no flood plain was present, or if the flood plain consisted of managed vegetation such as pasture, field, or lawn, no plot was established. Plots were marked permanently with one concrete reinforcement bar and angle and distance measurements to each corner. All woody plants taller than breast height within a plot were counted, and species and diameter at breast height was recorded. Density, basal area, and importance values for each species were calculated. Calculation of importance values for each species required calculation of relative density, relative dominance, and relative frequency. The importance value for the species is the average of these three determinations:

$$\text{Relative density} = \frac{\text{number of individuals of a species}}{\text{total number of individuals}} \times 100$$

$$\text{Relative dominance} = \frac{\text{dominance of a species}}{\text{dominance of all species}} \times 100$$

$$\text{Relative frequency} = \frac{\text{frequency of a species}}{\text{sum frequency of all species}} \times 100$$

$$\text{Importance value} = \frac{\text{Rel. den.} + \text{Rel. dom.} + \text{Rel. freq.}}{3} \times 100$$

The point intercept technique along a line transect (Mueller-Dombois and Ellenberg, 1974; Bonham, 1989) was used to evaluate canopy coverage of the tree, shrub, and herb layers. Transects were laid through the center of each vegetation plot perpendicular to the aspect of the channel and extended 50 m or to the edge of the natural vegetation. The presence or absence of a tree, shrub, or herb was noted within a 5-cm cylinder at each 0.5-m point. The total number of "hits" for each vegetation layer was divided by the number of points sampled to determine a percentage of cover for that layer (Bonham, 1989).

Habitat Evaluation

Stream habitat classification and evaluation systems currently available typically have a wide range of goals, are used at many spatial scales, and are applicable to a variety of environmental settings. Examples of classification and evaluation systems available are the rapid bioassessment protocol (Plafkin and others, 1989), quantitative evaluation of fish habitat in Wisconsin streams (Simonson and others, 1994), stream reach inventory and channel stability evaluation (U.S. Department of Agriculture, 1975), and the qualitative habitat evaluation index (Rankin, 1989). Two qualitative evaluation systems used by the States of Wisconsin and Michigan were chosen to evaluate stream habitat at the indicator fixed sites (Ball, 1982; Michigan Department of Natural Resources, 1991). Use of these evaluation systems was considered after NAWQA habitat data were collected; however, the detailed quantitative data collected by use of the NAWQA protocols were adequate for fitting into the broader categories contained in each qualitative evaluation system.

The objectives for the Wisconsin qualitative habitat evaluation are to describe potential stream uses and provide background data for management decisions (Ball, 1982). Habitat structure, streamflow, water quality, and stream biota are used to classify each stream to its highest potential. The habitat characterization section of the classification uses 13 categories, or "metrics", to assess habitat potential: watershed erosion, watershed nonpoint source, bank erosion or failure, bank vegetative protection, lower bank channel capacity, lower bank deposition, bottom scouring and deposition, bottom substrate and available cover, average depth of riffles and runs, average depth of pools, flow at representative low flow, pool/riffle or run/bend ratio, and esthetics. Scores are summed for each metric to obtain an overall score. The smaller the score, the better the habitat; the maximum possible score (worst habitat) is 254. Overall scores are broken into four categories: excellent (less than 70), good (71–129), fair (130–200) and poor (greater than 200).

The Michigan Department of Natural Resources, Great Lakes Environmental Assessment Section (GLEAS) Procedure 51 (Michigan Department of Natural Resources, 1991) also was used to qualitatively classify and evaluate stream habitat at the fixed sites. The objectives of the habitat part of the GLEAS evaluation are similar to the Wisconsin evaluation; it is designed to evaluate the effects of nonpoint sources. Criteria in the GLEAS procedure are very similar to those in the rapid biological assessment protocol (Plafkin and others, 1989). The habitat part of the GLEAS procedure measures nine metrics in three categories. The categories and metrics are substrate and instream cover (bottom substrate and available cover, embeddedness, water velocity), channel morphology (flow stability, deposition/sedimentation, pools-riffles-runs-bends), and riparian and bank structure (bank stability, bank vegetation, and streamside cover). Four of these metrics—bank stability, bottom deposition/sedimentation, bottom substrate and available cover, and pools-riffles-runs-bends—are identical to metrics in the Wisconsin rating except in the assignment of scores. Scores for each metric are summed and compared to scores from GLEAS reference sites. In this system, a higher score indicates excellent habitat, opposite of the scoring for the Wisconsin evaluation. A total score of 135 is the highest score possible. The metrics are weighted by category; the maximum score for metrics in the first category is 20, for the second category is 15, and for the third category is 10. In this way, substrate and instream cover is given more importance in the final score than the other metrics. As before, the scores are assigned to four categories: excellent (111–135), good (75–102), fair (39–66), and poor (0–30). In suggested practice, a previously identified reference site is classified and scored. Degraded streams are then scored and compared to the reference stream, which generally is nearby. In this report, scores from the study reaches are used directly as well as compared to reference streams in the same physiographic setting.

Statistical Analysis

The SAS statistical software package (SAS Institute, Inc., 1990) was used for the statistical analyses of habitat data. Boxplots, which are used to compare and contrast reach-level habitat characteristics, show visual summaries of median and means, as well as the distribution of the data and outliers and skewness.

Correlation analysis was used to identify habitat characteristics that followed similar distributions among sites. Although data distributions for some of the habitat characteristics were normal or nearly normal, distributions for other characteristics were normal only when transformed to log scale; data for some characteristics (especially categorical data) were not normal even when log transformed. Thus, all data were rank transformed and correlated by use of Spearman correlations, which do not require the assumption of normal distribution (Johnson and Wichern, 1992; Iman and Conover, 1983). Helsel (1987) describes the advantages of nonparametric statistics for analysis of water-quality data. Rank correlation coefficients, signified by Spearman's rho (ρ), quantify the strength of the monotonic relations between habitat characteristics without requiring the relation to be linear (Johnson and Wichern, 1992; Iman and Conover, 1983). Significant correlations are defined as those with p-values less than 0.05.

The Tukey studentized range test (Neter and others, 1985) was used to identify significant spatial, temporal, and multiple reach differences of reach characteristics at the 95-percent confidence level among indicator sites. Specifically, it was used to indicate whether variance at a reach, at a site, or for a given year was large enough to mask differences between multiple reaches, sites, or years. These tests were run on both raw and rank-transformed data. Significant differences were reported only if both tests showed similar results.

STREAM HABITAT CHARACTERISTICS

Basin-, segment-, and first-level reach characteristics are listed in tables 6–9 (at back of report). Data for several characteristics, including site location, latitude/longitude, mean width, and reach length, and boxplots of water temperature, pH, specific conductance, alkalinity, and dissolved oxygen can be found in Sullivan and others (1995).

Of the eight streams with indicator sites, four have drainage basins that are more than 86 percent agriculture: Pensaukee River, Duck Creek, East River, and North Branch Milwaukee River (table 6). Two streams contain mainly forested land: Peshekee River (88 percent) and Popple River (61 percent). The Tomorrow River contains a mix of agriculture and forest (58 and 31 percent, respectively), whereas the drainage basin of Lincoln Creek is 97 percent urban. The three integrator sites contain a mixture of land uses. The Menominee River is dominated by forest (75 percent) and wetland (16 percent). The Fox River is 54 percent agriculture, 26 percent forest, and 11 percent wetland. The Milwaukee River is 60 percent agriculture and 26 percent urban.

Basin and Segment Characteristics

Indicator and integrator basins cover a wide range of drainage areas and characteristics. Drainage areas ranged from 24.8 to 360 km^2 for the eight indicator sites and from 1,800 to 10,200 km^2 for the three integrator sites. Stream length ranged from 5.6 to 52 km for the indicator sites and 150 to 340 km for the integrator sites. Stream channel gradient was correlated with the ratio of basin relief and drainage area (ρ = 0.81). Basin relief ranged from 43 to 110 m for the indicator-site basins. When weighted by drainage area, Lincoln Creek had the greatest relief of the indicator-site basins; but when weighted by basin length, the North Branch Milwaukee River and the East River had greater relief.

Drainage densities ranged from 0.13 to 0.55. Standard references indicate that drainage densities should range from 1 to 1,000 in nature (Leopold and others, 1964). This discrepancy could account for a lack of expected relations between drainage density and other characteristics. There appeared to be a positive relation between drainage density and basin relief (fig. 2A), although it was not statistically significant. Drainage basins with greater relief often have more closely spaced streams and greater drainage densities. The Peshekee and Popple Rivers, the northernmost basins studied, had a greater drainage density than the other basins. This was not expected because they are in the youngest glacial landscapes, and geologic time is an important factor in the creation of drainage networks. Perhaps the difference in geologic time between the northern and southern basins in not long enough to be significant. The network of the Peshekee River, a linear basin, may be controlled by glacial striations or bedrock fractures in the landscape. Previous research has indicated that networks northeast of the Peshekee were formed by glacial geology (Hack, 1965).

Drainage density and basin shape are negatively correlated (ρ = -0.74) (fig. 2B). Sites with longer, linear basins had greater drainage densities than those with more rounded basins. This relation is probably a reflection of bedrock geology and topography. Basins in the northern part of the study unit are more linear, are underlain by igneous/metamorphic bedrock, and are located in the Superior Upland Physiographic Province, whereas those in the southern part are more rounded, are underlain by sandstone or carbonate bedrock, and are in the Eastern Lake Section of the Central Lowland Physiographic Province. Channelization in the agricultural areas in the southern part of the study unit could reduce drainage density, so the more rounded agricultural basins could have lower densities. There were no statistically significant correlations between bedrock type and drainage density; however, there is a significant correlation between amount of bedrock at the surface in the basin and drainage density (ρ = 0.72).

Soil texture, erodibility, and permeability varied across the basins. Agricultural basins with higher overall stream gradient tended to have higher erodibility than basins with less gradient (fig. 2C). The more forested basins of the Peshekee, Popple, and Tomorrow Rivers, however, had lower erodibility than the agricultural basins regardless of their stream gradient. These three basins also are underlain by igneous/metamorphic bedrock. The mostly forested Menominee River also is underlain by igneous/metamorphic bedrock, and it follows the trend with the agricultural site; thus, the causes and correlations are not completely clear.

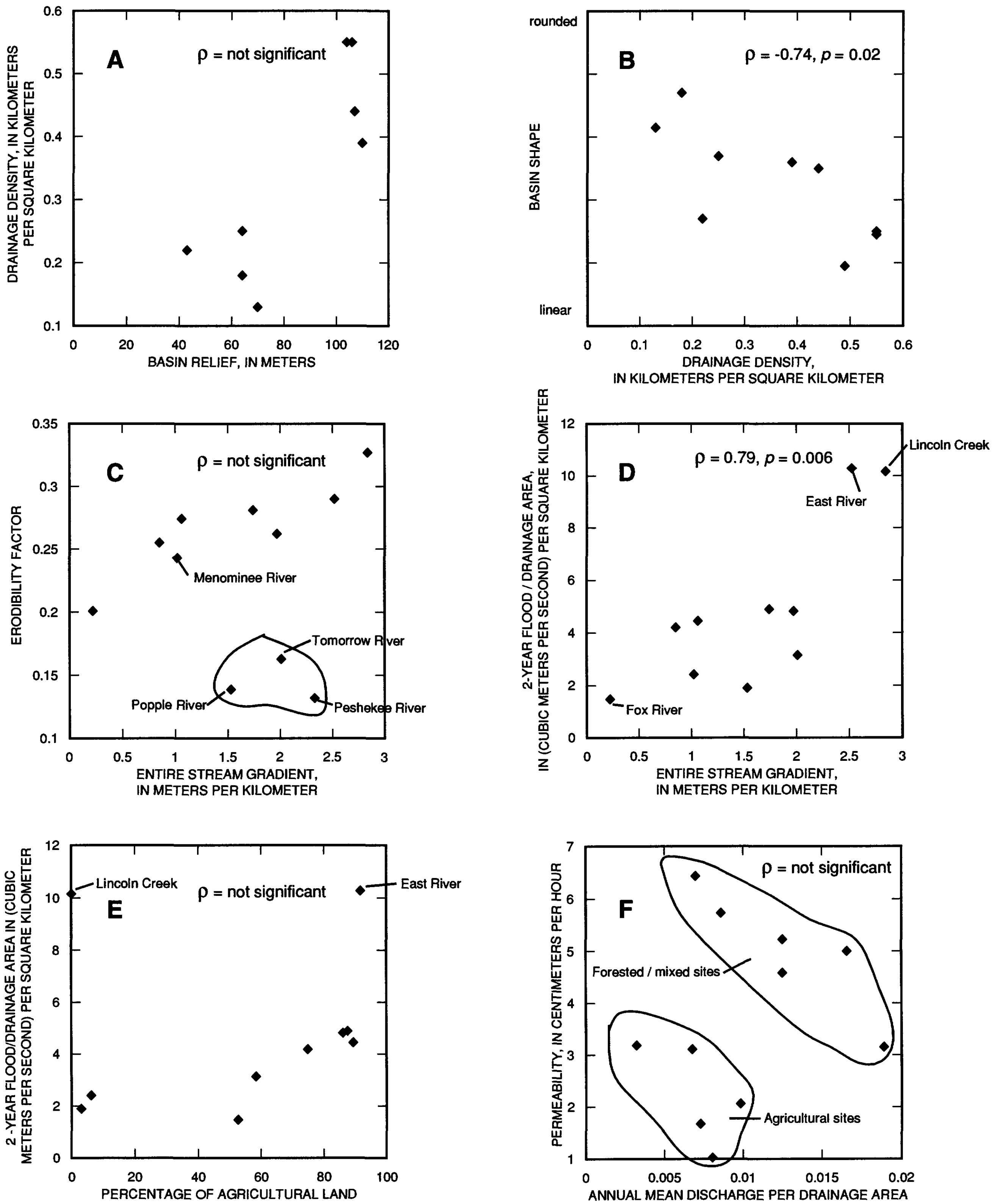


Figure 2. Correlations among selected basin characteristics of fixed sites in the Western Lake Michigan Drainages study unit (ρ, Spearman's correlation coefficient; *p*, *p*-value for correlation).

Although not statistically significant, basins with higher percentages of agriculture tend to have less permeable soils and higher erodibility than basins with lower percentages of agriculture. This is a reflection of the finer grained soils characteristic of the agricultural part of the WMIC. Thus, the interactions of land use, soil characteristics, and bedrock geology seem to be important for the investigated basins.

Streamflow characteristics are related to drainage-basin patterns and topography. The 2-year flood was calculated using established regression equations for all the study sites except Peshekee River, for which the equations for the 2-year flood were not available. The sites are among three geographic areas with different regression equations. Regression equations for all three areas include drainage area, stream gradient, and soil permeability. Other variables used in one or more areas include rainfall intensity, storage, snowfall, and percentage of forested land (Krug and others, 1992).

The sites seem to break into two groups with respect to stream gradient (fig. 2D) and 2-year flood weighted by drainage area. Sites on Lincoln Creek and the East River have higher stream gradients and larger weighted 2-year floods than the other sites. Stream gradient is a parameter in the regression equations; however, Lincoln Creek and East River are in different flood-frequency areas with different regression equations, coefficients, and exponents. The other sites are lower with respect to gradient and weighted 2-year flood, the Fox River being the lowest of all for both measures. Analysis of the 5-year flood calculations show that Peshekee River falls into the group with Lincoln and East. No linear trend between these two variables is apparent; rather, the sites seem to follow a different relation. Although this grouping is evident for stream gradient, it is not evident with respect to basin relief, which has a positive linear relation with 2-year flood when weighted by drainage area ($\rho = 0.83$).

As expected, land use also plays a role in the magnitude of the 2-year flood (fig. 2E). Those basins with a high percentage of agriculture have larger 2-year floods than forested basins do (ρ = not significant). Lincoln Creek and East River again had much larger 2-year floods than the other basins. Lincoln Creek is a completely urbanized basin, which results in large amounts of runoff and wide, rapid fluctuations in flow. Its steep gradient is partially the result of channelization in the urban environment.

Lastly, there is an expected correlation between soil permeability and 2-year flood ($\rho = -0.80$). Rainfall on drainage basins with high permeability infiltrates quickly, and so surface runoff and flood flows tend to be less than in impermeable basins. The combination of low-permeability soils and steeper gradients in East River seem to cause larger floods in that basin. Duck Creek, also with low permeability but with lower gradient, does not exhibit this high flood peak. Likewise, Tomorrow River has a gradient almost as steep as East River, but permeability is very high in this drainage and floods are small.

The annual mean flow can be used as an estimate of overall flow conditions, combining baseflow characteristics with occasional flood flows. The flow values are based on continuous data from 1993 through 1995 for all sites except East River, which is missing April through September 1994 from the record. Some streams have longer flow records, but only the 1993–95 sampling period was included in this analysis for consistency. One of these years, 1993, was a year of unusually high flow, especially for the basins in the southern part of the study unit; thus, annual mean flows are biased somewhat high.

Annual mean flows correlated with basin shape ($\rho = -0.73$) and drainage density ($\rho = 0.66$) and were correlated to soil permeability. Linear basins had larger mean flows than rounded basins. Basins with larger drainage densities also had larger annual mean flow. (As mentioned previously, basins with larger drainage densities also were more linear.) These three characteristics seem to be intertwined; thus, causality cannot be determined among the three variables.There is a strong relation between permeability and annual mean flows for both agricultural and non-agricultural sites ($\rho = -0.90$ and $\rho = -0.83$, respectively) (fig. 2F). The "agricultural" group consists of sites with greater than 80 percent agriculture, plus Lincoln Creek, the urban site. For both types of sites, basins with higher permeability have smaller mean flows, although agricultural basins have smaller mean flows and lower permeability in general. This shows that the annual mean flow is a reflection of both flooding and base-flow characteristics. The increase in flow with lower permeability reflects the effect of flood flow on the annual mean flow, because less permeable basins produce more runoff and thus more flood flow. However, the fact that, given the same permeability, non-agricultural sites have larger annual mean flows than agricultural sites reflects the effect of base flow on the annual mean flow. Agricultural and urban basins tend to have less infiltration and ground-water recharge; thus, baseflow at agricultural and urban sites is less than at mixed or forested sites.

Two year, 7-day minimum streamflows were also examined to analyze differences in low-flow conditions. Although relations were not statistically significant, there was a trend toward increasing discharge with higher permeability of soils. These type of soils should have higher infiltration rates and should allow more ground-water recharge, which contributes to base flows. The relations may be weak because three agricultural sites had zero flow, and low flows at the rest of the indicator sites were less than 1 m^3/s. For the integrator sites, the Menominee and Fox Rivers had similar low-flow conditions (about 40 m^3/s), whereas the Milwaukee River had flows slightly greater than 1 m^3/s.

Annual precipitation, evaporation, and temperature were less variable among the sites (table 6). Precipitation ranged from 74 to 76 cm and evaporation from 46 to 54 cm, increasing slightly at the southeastern sites. Annual temperature ranged from 5.5°C at the northern sites to 6.7°C in the southeast part of the study unit. Runoff was more variable (21 to 38 cm), with less runoff generally at the southern sites than at the northern sites (due to slightly more evaporation caused by slightly higher temperatures).

Stream-segment characteristics were examined at the eight indicator sites only. Stream order for these sites ranged from second to fifth order, with three second-order, three fourth-order and two fifth-order streams (table 7). Downstream link, an indication of downstream proximity to a much larger stream, ranged from 2 at Lincoln Creek to 53 at the East River. Channel sinuosity ranged from 1.05 to 1.60; thus, all the indicator streams except the East River would be classified as straight by Leopold and others (1964). The East River would be classified as meandering. The ratio of entire stream gradient to segment gradient was 1.5 to 2.5 for most sites (fig. 3). The ratio for the East River was higher (4.3), and that for the Popple River was lower (0.55). This indicates that for most of the sites, the gradient of the segment was less than the gradient of the upstream tributaries. However, for the Popple River, the segment had a higher gradient than that for the entire stream and for the East River, the segment sampled had a much lower gradient than that for the entire stream length. Springs were identified only at forested indicator sites: the Peshekee, Popple, and Tomorrow Rivers.

First-Level Reach Characteristics

Summary graphs of a selected subset of reach characteristics can be found in figures 4–10 for the eight indicator sites. Correlation analyses were performed on the first-level reach characteristics; however, significant correlations were few, and those found are only suggestive of possible relations because of the small number of sites. The most notable correlations ($\rho > 0.80, p < 0.01$) are discussed briefly in the appropriate sections, whereas the main discussion centers on spatial distribution and temporal variations for the most important reach characteristics.

Channel

Water depth, velocity, and streambed substrate are important for determining the type of habitat available for aquatic life and control the type of geomorphic units (riffle, run, pool) present in a stream. All indicator sites but the Popple River contained the three types of geomorphic units (fig. 4A). No pool was present in the Popple River, and most of the reach was composed of run. The Tomorrow River was also characterized by very little riffle and pool and mostly run. Temporal variations measured in the percentage of riffle, pool, and run (fig. 4A) are caused by somewhat different flow conditions at the time of measurement (fig. 5). For example, in 1993, flow at the Peshekee River was the smallest of all three years, and part of what was identified as run at the Peshekee in 1994 and 1995 was identified as pool in 1993. Measurements at the Tomorrow

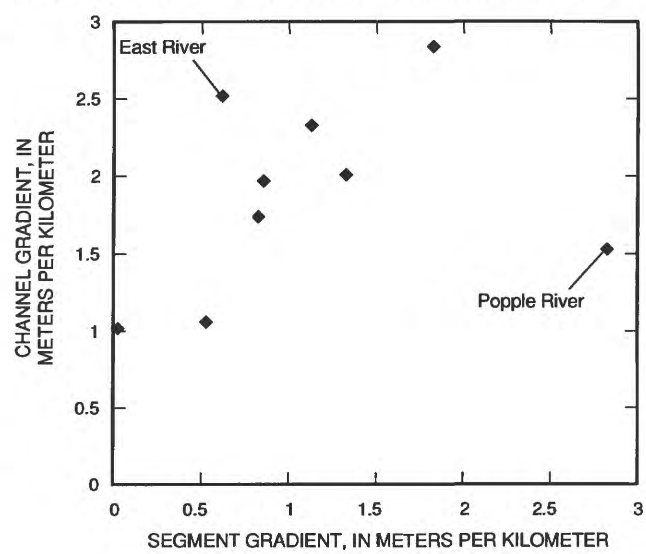


Figure 3. Relation of entire stream gradient for the basin and segment gradient at fixed sites in the Western Lake Michigan Drainages study unit

River and the North Branch Milwaukee River also reflect similar variations in the percentage of geomorphic units caused by variable flow conditions. The multiple reach comparisons of geomorphic units (fig. 4B) indicate that the primary reaches (reach A) at Duck Creek and the Tomorrow River adequately reflect the amount of pool, riffle, and run within the stream segment. In contrast, more variability was seen between the North Branch Milwaukee River reaches, with the primary reach (reach A) containing less run than the other two additional reaches (reaches B and C).

Average width at indicator sites ranged from about 6 to 15 m except for the Popple River site, which had an average width of 21 m. Measurements of width also were dependent on flow conditions because the definitions for width include measurements from the water surface; thus, temporal variability in the data are mainly due to different flow conditions during sampling. As was the case with geomorphic units, year-to-year variability in mean width at the Pensaukee River and Lincoln Creek were small compared to variability at the Peshekee, Tomorrow, and North Branch Milwaukee Rivers. Comparison of data collected at the multiple reaches indicate that, for average width, the primary reach at the Tomorrow River adequately reflects overall conditions in the stream. However, much more variability in average width was observed at the multiple reaches at Duck Creek and North Branch Milwaukee River.

Boxplots of the 18 depth measurements collected at each reach (fig. 6A) display the spatial, temporal, within-reach, and multiple-reach variability at the eight indicator sites. In general, average depth ranged from 0.2 to 0.7 m, the Popple and East Rivers being the deepest sites, and the Peshekee, Pensaukee, and Duck Creek sites the shallowest. Although the Popple River site had the greatest average depth, the Popple River also had the most variability in depth. There was no significant difference between reach differences in depth at the three multiple-reach sites.

Velocities ranged from 0 to 0.91 m/s, with average velocity at most sites in the range of 0 to 0.46 m/s (fig. 6B). There were many significant between-site differences in velocity. Lincoln Creek had the lowest velocity, followed closely by the East River. The Peshekee River had the highest average velocity. Site-specific between-year differences were significant at the Peshekee, Pensaukee, and East Rivers and at Lincoln Creek. At the Pensaukee River, the depth decreased slightly in 1995, yet there was a noticeable decrease in velocity. Beavers created a dam approximately 100 m downstream from the reach sometime

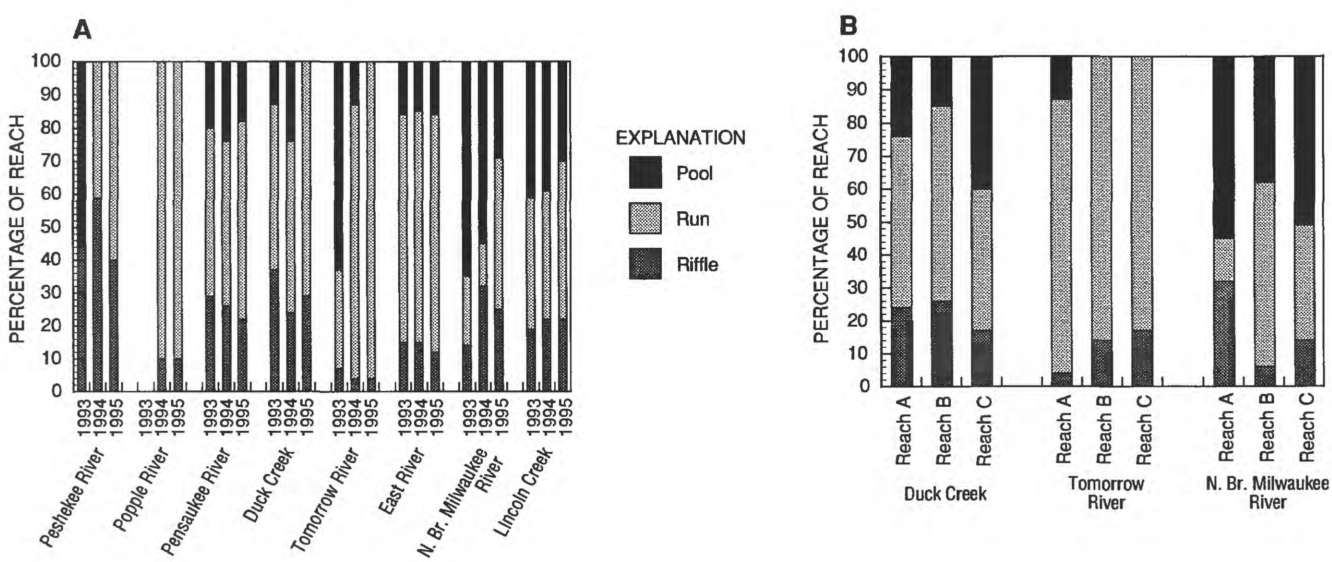


Figure 4. Variability in geomorphic units at indicator sites in the Western Lake Michigan Drainages study unit, 1993–95: (A) spatial and temporal variability, and (B) multiple-reach variability.

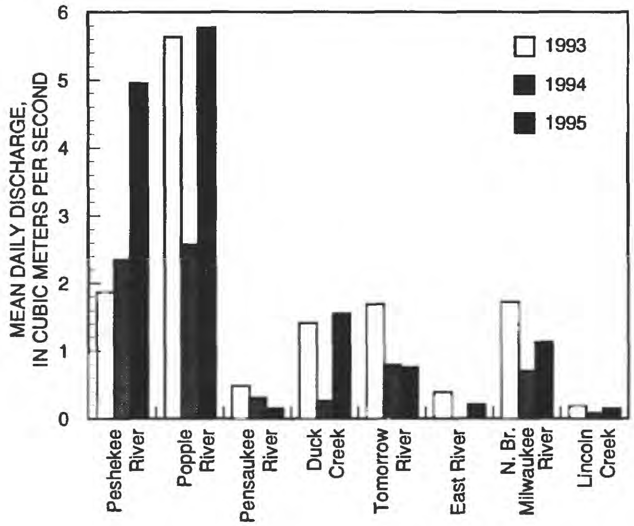


Figure 5. Mean daily discharge at indicator sites on the day of reach-level habitat data collection, 1993–95.

between fall 1994 and late winter 1995 (Kevin D. Richards, U.S. Geological Survey, oral commun., 1997), causing water to back up behind the dam and reducing the velocity considerably within the reach. Velocity in the primary reach at Duck Creek was much higher than the two additional reaches; however, at the Tomorrow River, there were no significant differences among the multiple reaches. Again, temporal variability in both depth and velocity can be attributed to flow conditions at the time of sampling.

Bottom Substrate

Two other factors, crucial elements in the habitat availability for aquatic life, are substrate particle size and embeddedness. Unlike width, depth, and velocity, substrate and embeddedness are not as dependent on minor variations in flow conditions; thus, measurements appear to be more similar from year to year (figs. 7A, B). However, some variability, such as that seen at the East and North Branch Milwaukee Rivers, could be caused by timing of sampling with respect to major floods. Dominant substrate type and embeddedness were correlated ($\rho = -0.88$), indicating that coarse-textured substrate types tended to be less embedded.

Several between-site differences were significant for dominant substrate; in general, dominant substrate at the Peshekee and Popple Rivers was mainly cobble, and at all other indicator sites, the dominant substrate was mainly gravel or sand (fig. 7A). The East River contained the most variability in dominant substrate type from year to year, with significantly smaller particles measured in 1995 than in 1993 and 1994. Substrate at the East River is composed of fine-grained material over gravel. The gravel is exposed during and shortly following major floods. Thus, the gravel may have been closer or farther from the substrate surface depending on the amount of time between the last major flood and when the habitat measurements were made. Results from multiple-reach sampling indicate that the primary reach at Duck Creek had finer grained sediment than reach C and that the substrates at the Tomorrow and North Branch Milwaukee Rivers were adequately represented by the primary reach.

Average subdominant particle sizes were similar to dominant substrate and ranged from cobble and gravel at the Peshekee, Popple, and Duck, to sand and silt at the rest of the indicator sites. The Tomorrow and North Branch Milwaukee Rivers contained the finest-textured subdominant substrates.

A full range of embeddedness was found at the eight indicator sites, from a minimum of 5–25 percent to a maximum of 100 percent embedded (fig. 7B). Many between-site differences were significant. Not all of the 18 sampling points at the Popple, Tomorrow, East, and North Branch Milwaukee River had large particles present to permit measurement of embeddedness. Sites with the least embedded substrate include the Peshekee River, Popple River, Pensaukee River, and Duck Creek. Substrates at the East River, North Branch Milwaukee River, and Lincoln Creek were the most embedded of all the indicator sites.

Although some sites, such as the Tomorrow River, North Branch Milwaukee River, and Lincoln Creek experienced only minor variations in embeddedness from year to year, embeddedness at the Peshekee River, Pensaukee River, Duck Creek, and East River varied significantly from year to year; however, each of the latter sites behaved differently from the rest. The increase in embeddedness in 1995 at the Pensaukee River can be attributed to the beaver activity. Reasons for the steady increase in embeddedness at Duck Creek over the 3-year period are not known, because no significant temporal variations were observed in depth, velocity, or substrate type. The decrease in embeddedness at East River in 1994 corresponds with a slight increase in dominant substrate particle size; however, explanations for both these variations are not known. Embeddedness was adequately represented in the pri-

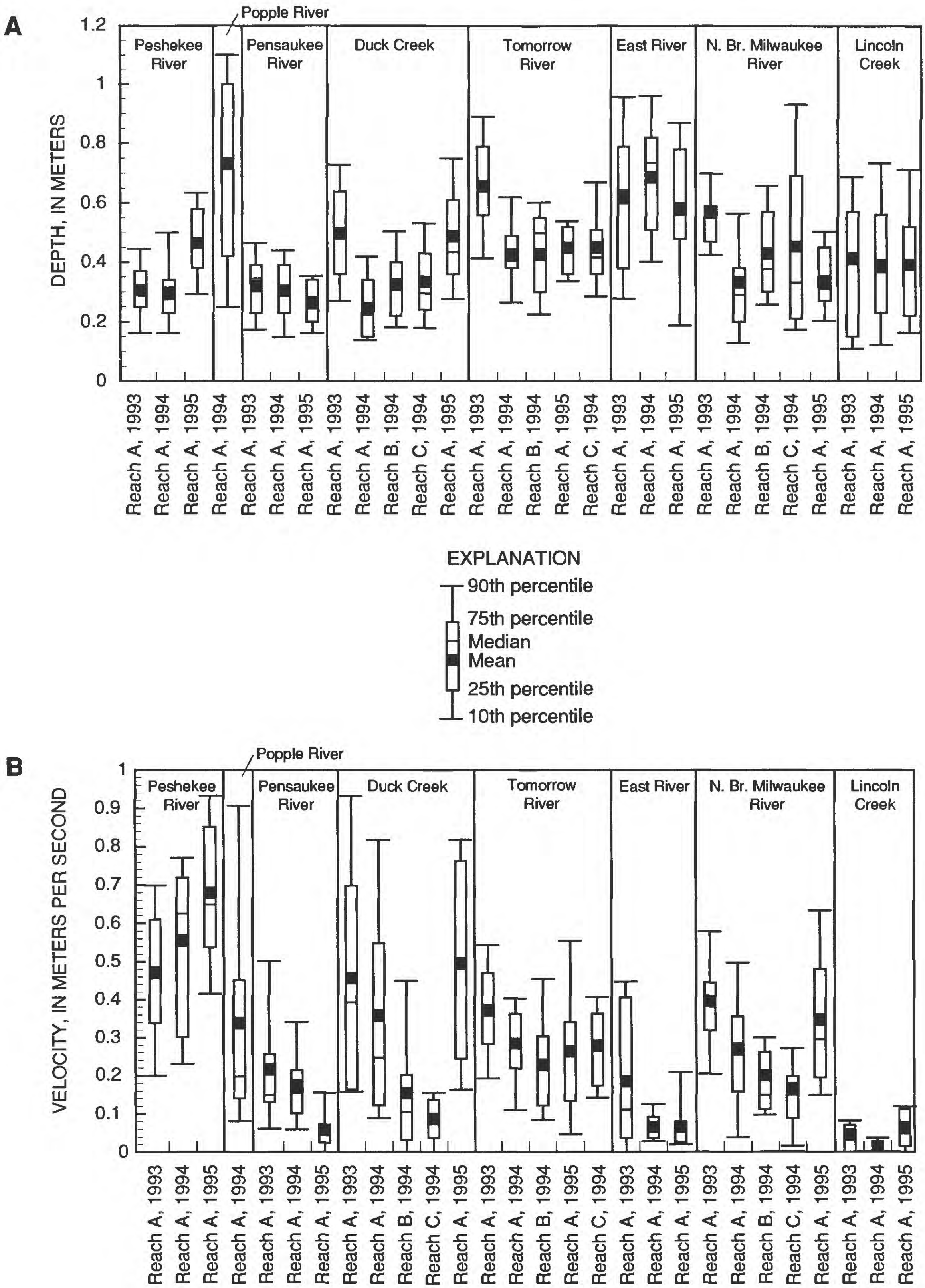


Figure 6. Spatial, temporal, within-reach, and multiple-reach variability of selected channel characteristics at indicator sites in the Western Lake Michigan Drainages study unit, 1993–95: (A) depth, and (B) stream velocity.

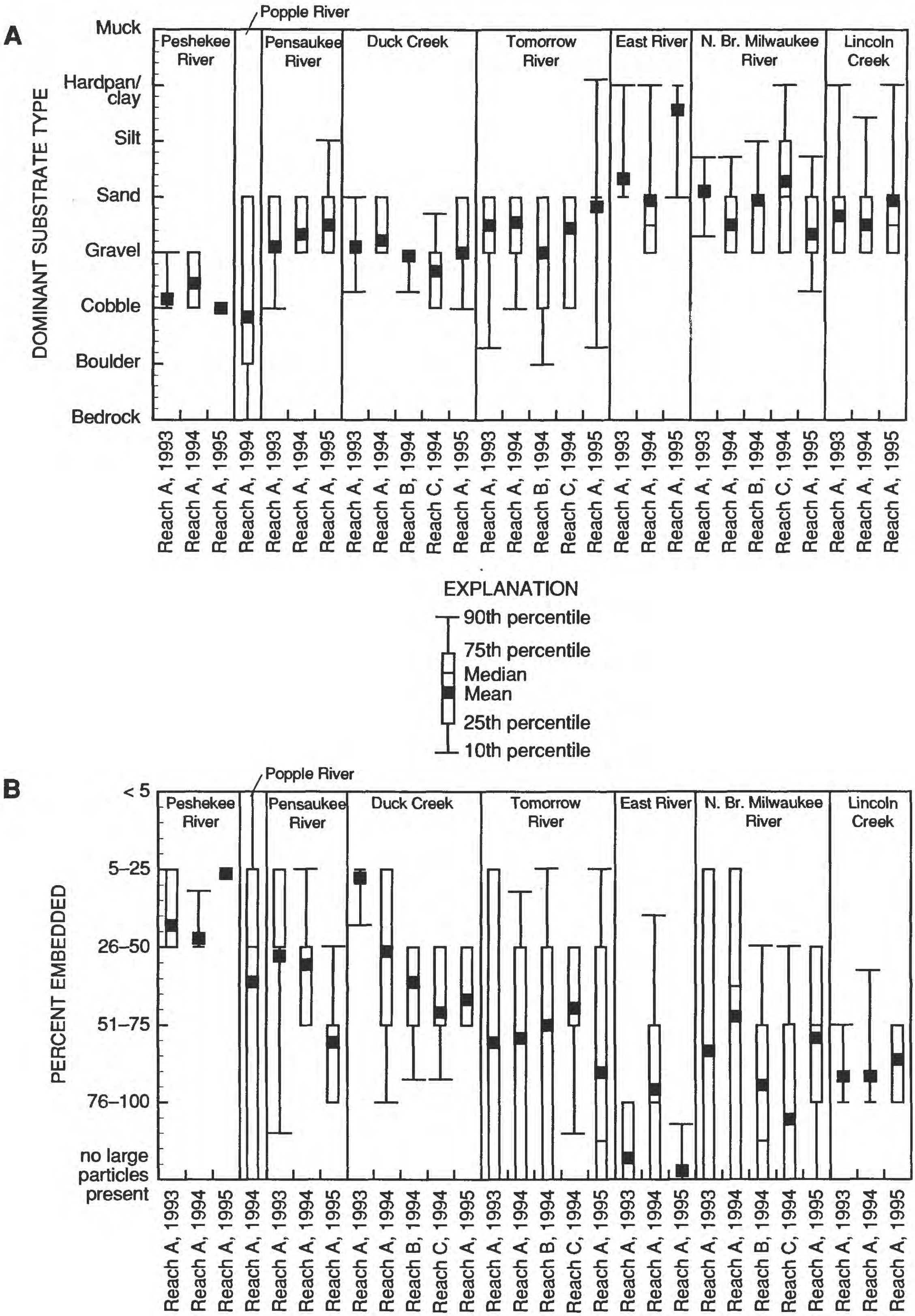


Figure 7. Spatial, temporal, within-reach, and multiple-reach variability of selected bottom substrate characteristics at indicator sites in the Western Lake Michigan Drainages study unit 1993–95: (A) dominant substrate type, and (B) embeddedness.

mary reach at the Tomorrow River; however, at the North Branch Milwaukee River and Duck Creek, Tukey tests indicate that the substrate was less embedded in the primary reach than in reach C.

Comparisons of median suspended-sediment concentrations from 1993 through 1995 with median embeddedness (fig. 8) indicate that, as might be expected, sites with low suspended-sediment concentrations had less embedded substrates than sites with high suspended-sediment concentrations. Even though suspended-sediment concentrations were relatively high at the North Branch Milwaukee and Pensaukee Rivers, the substrate was not as embedded as one would expect. This indicates that the reaches for these streams are located where sediment in the channel is eroded or transported rather than deposited. The preceding discussion illustrates the importance of examining both embeddedness and suspended-sediment concentrations to determine the different roles sediment may play in controlling the quality of aquatic habitat. For those sites where substrate is not buried by fine sediment, scouring by transported sediment may be a limiting factor for aquatic habitat.

Streambank

In general, variations in bank height (fig. 9A) from year to year are minimal compared to other bank measurements. Bank height at the eight indicator sites ranged from 0.2 m to more than 2 m, with the entrenched East River having the highest banks and also the most variability of bank height within the reach. Both the North Branch Milwaukee and Tomorrow Rivers had the lowest and least variable banks. Overall, there was no significant temporal difference in bank height, except for the Peshekee and Tomorrow Rivers. It is not known why measurements of bank height at the additional reaches at the Tomorrow River also were significantly higher than at the primary reach.

Average bank angles ranged from 25 to 75 degrees. Individual measurements were variable within each reach; but overall, only a few between-site differences were significant, and no temporal differences were significant for all sites combined or for individual sites. Bank angles were adequately represented in the primary reaches of the Tomorrow River; however, North Branch Milwaukee River had significant differences among the multiple reaches.

In general, bank vegetative stability was greatest at the Peshekee, Popple, and North Branch Milwaukee Rivers and lowest at Duck Creek, East River, and Lincoln Creek (fig. 9B). Even though this characteristic was measured at the same time each year, some temporal variability is evident at most sites. Specifically, less of the banks were covered by vegetation in 1995 at five of the indicator sites than in 1993 and 1994. This may be due to a cool spring in 1995 that slowed growth of vegetation compared to 1993 and 1994. For multiple reaches, the primary reaches at Tomorrow River and North Branch Milwaukee River were adequate; however, at Duck Creek, reach C had greater bank vegetative stability than the primary reach.

The bank stability index combines five individual streambank characteristics into one index of the susceptibility to erosion. According to this index, streambanks at the indicator sites generally fell into the "at risk" or "unstable" categories (fig. 9C). In general, the stability index scores were higher (more unstable banks) in 1994 than in 1993 and 1995. There were no significant differences among any of the reaches at the three multiple-reach sites. The bank stability index significantly correlated with bank height ($\rho = 0.82$) and bank vegetative stability ($\rho = -0.82$).

Canopy angle reflects the amount of stream shaded by riparian vegetation or anything that blocks the sun. The larger the angle, the more direct sunlight reaches the stream. In general, the North Branch Milwaukee and Popple Rivers had the most open canopies, and Duck Creek and the East River had the most closed canopies. Significant temporal differences were

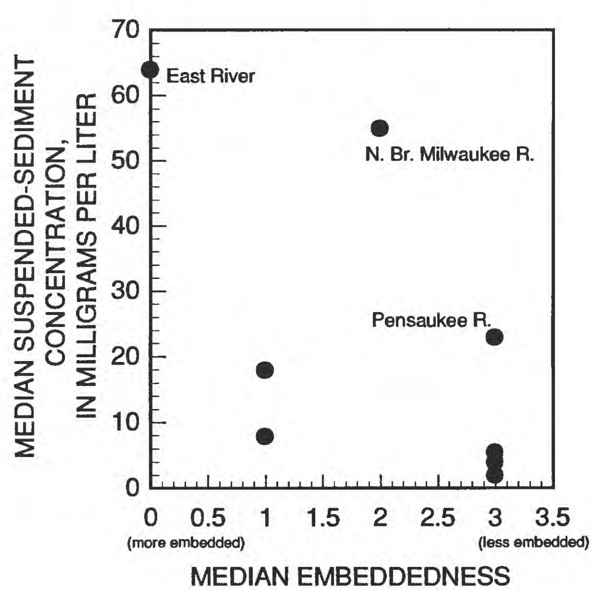


Figure 8. Relation of median suspended-sediment concentration to median substrate embeddedness at indicator sites in the Western Lake Michigan Drainages study unit, 1993–95.

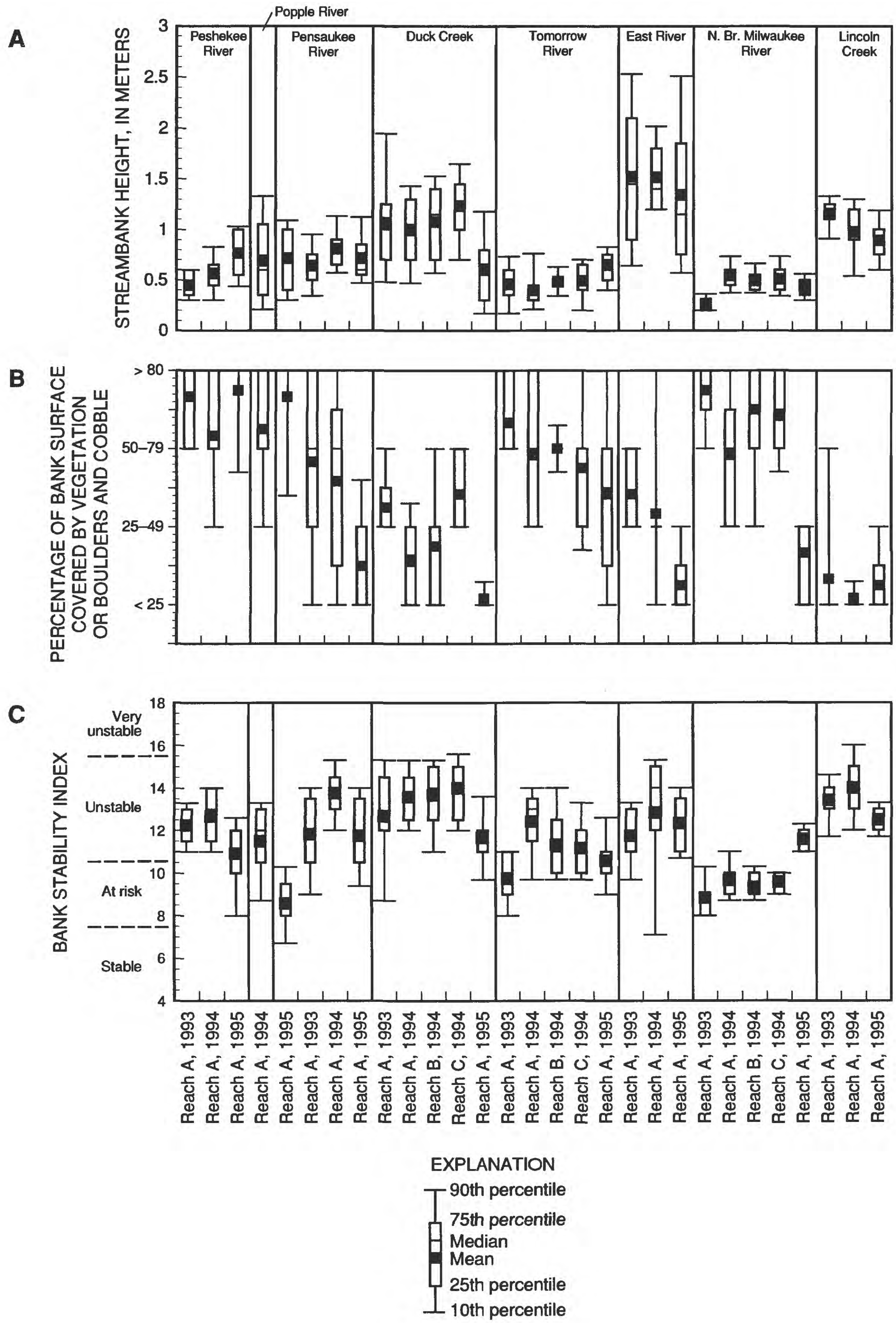


Figure 9. Spatial, temporal, within-reach, and multiple-reach variability of selected streambank characteristics at indicator sites in the Western Lake Michigan Drainages study unit, 1993–95: (A) height, (B) vegetative stability, and (C) bank stability index.

observed at the Peshekee and Tomorrow Rivers, although each site followed a different trend. There were no significant differences among multiple reaches at any of the sites.

Riparian Vegetation

Riparian vegetation at the fixed sites varied widely in density, dominance, and composition. Averages for density and dominance at each site (figs. 10A,B) were calculated for two years (1994 and 1995) on the basis of data collected by use of the point-centered quarter method. Mean density of all species in the reach ranged from a low of less than one tree or shrub per 100 m^2 at the North Branch Milwaukee River to a high of 421 trees or shrubs per 100 m^2 at the Peshekee River; however, densities at most sites were less than 40 trees or shrubs per 100 m^2 (fig. 10A). Mean basal area (dominance) for all species (fig. 10B) also ranged from less than 7 cm^2 (less than 3-cm diameter at breast height (dbh)) at Peshekee River to 817 cm^2 (32-cm dbh) at the North Branch Milwaukee River, reach C.

Some variation in density and dominance or basal area calculations from year to year is evident. The number of points sampled at each reach for the quarter point vegetation (12) is on the low end of the recommended number for an adequate sample (Mueller-Dombois and Ellenberg, 1974). Curtis (1959) found lowland communities to be the most diverse in woody vegetation of all those he examined in Wisconsin. The only site with a very large amount of yearly variation is the Peshekee River. In 1994, an extremely high density of 421 trees and shrubs per 100 m^2 was calculated, but in 1995, this density was down to 49 per 100 m^2. Along this reach in particular the vegetation grows in spatially distinct areas. It is possible that the points sampled in 1994 were in an alder thicket and the points in 1995 were farther away from the water's edge in less dense trees and shrubs. The large differences in canopy angle for this site for these two years also alludes to the possibility that measurements were made at slightly different transect locations.

The Tomorrow River had average densities of 25.5 individuals per 100 m^2 (fig. 10A), the second most dense after the Peshekee River. The Popple, Pensaukee, and East Rivers had similar average densities of 8.5 to 9 individuals per 100 m^2 (fig. 10A). Duck and Lincoln Creeks averaged 5.5 individuals per 100 m^2, whereas density at the North Branch Milwaukee River was the least, at less than one individual per 100 m^2. This site consists of a large reed canary grass (*Phalaris arundinacea*) wetland, with very sparse woody vegetation on the right bank and sparse willows on the left bank.

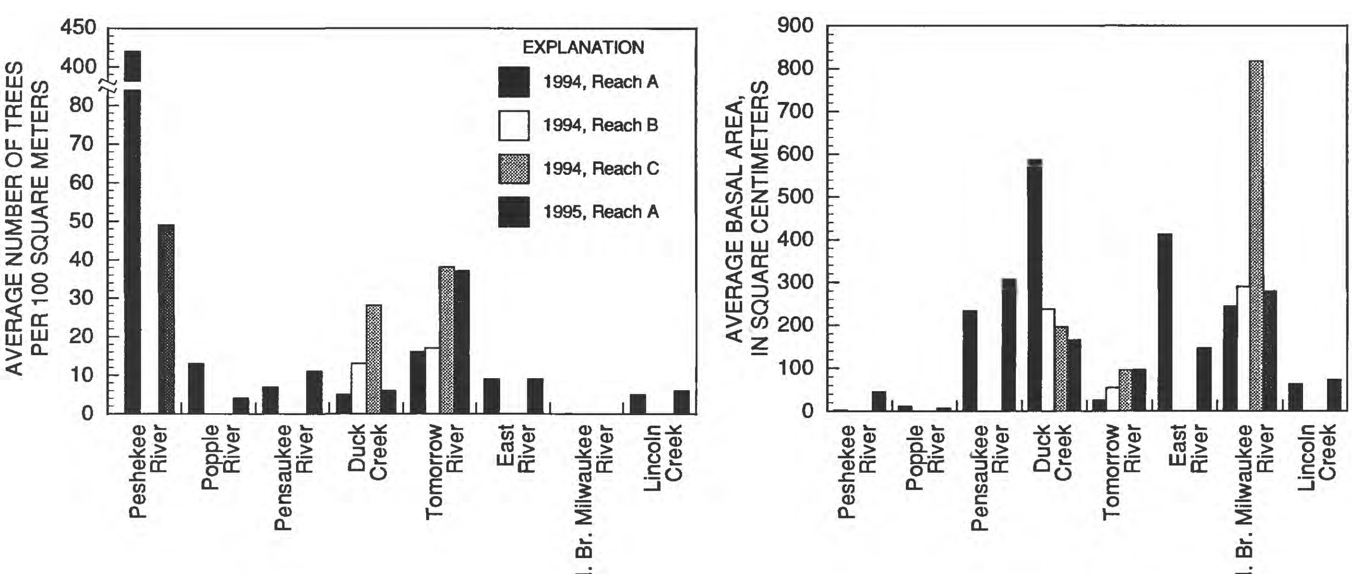


Figure 10. Vegetation densities (A) and average basal area (B) calculated from point-quarter data for all species at indicator sites in the Western Lake Michigan Drainages study unit, 1994–95.

Calculations for basal area included trees that were less than 3 cm dbh by using an average basal area of 1.8 cm^2. Average basal areas for the sites grouped into sites characterized by large trees (greater than 250 cm^2) and those characterized by smaller trees and shrubs (less than 100 cm^2). The large-tree sites were Pensaukee River, Duck Creek, East River, and North Branch Milwaukee River (fig. 10B). The small-tree sites were the Peshekee River, Popple River, Tomorrow River, and Lincoln Creek.

When examined together, the variation in density and basal area reflect the diversity of riparian vegetation and the type of canopy cover affecting the stream. For example, at Duck Creek, East River, and the Pensaukee River, the vegetation consists of widely spaced large trees in the flood plain and a shaded stream. However, vegetation at the Peshekee River is characterized by many small trees spaced closely together, resulting in high density but small basal area and less shading of the stream.

Second-Level Reach Characteristics

Second-level reach measurements at the indicator sites provided baseline information on channel stability, sedimentation, and vegetation changes that will be used in the next high phase of NAWQA. Channel cross-section data provided information necessary for determining bankfull width, depth, and discharge estimates.

Channel Geometry

Channel cross sections and longitudinal profiles of the water surface, channel bottom, and flood plain show the relative differences in channel shape and size and various gradients among the eight indicator sites (fig. 11). In general, the Popple, Peshekee, and North Branch Milwaukee Rivers have relatively wide and shallow channels. These are reflected by larger bankfull width/depth ratios compared to the East River and Lincoln Creek (table 2). Wide, shallow streams with low banks are indications that low magnitude, high-frequency floods commonly spill out into the flood plain in these streams. Wetland vegetation is common in the riparian zone along all three streams with large width/depth ratios. In contrast, the East River and Lincoln Creek have incised channels with high banks and little or no flood plain; these streams are capable of routing flood flows quickly downstream without spilling out into adjacent land. Bankfull width/depth ratios at the Pensaukee River ranged from 12.5 to 37.6 and at Duck Creek ranged from 9.6 to 23.9. This variability at the measured cross sections indicates that the width/depth ratio is highly influenced by where it is measured.

The bankfull width/depth ratios are slightly different than the width/depth ratios calculated from the reach Level I data because the Level I data reflect channel width and depth from the water's edge (varies with flow conditions) rather than the top of the bank. Table 2 shows that, in general, the bankfull width/depth ratios are smaller than the reach Level I width/depth ratios based on the location of the water's edge. The differences in the ratio among the sites can be attributed to different bank shapes and angles.

Water-surface gradient for each indicator site (table 2) were computed from the longitudinal profiles of the water surface (fig. 11). Water-surface gradients are used to estimate the energy gradient of a stream (Chang, 1992), and the energy gradient is one of three important variables that affect stream power, or the ability of a stream to erode and transport sediment. The East River had the lowest gradient of all indicator sites (table 2), and the Peshekee River had the highest gradient. These results are somewhat different from the segment gradients discussed earlier (fig. 3). Ratios between water-surface gradient and segment gradient ranged from 0.098 at the East River to 2.8 at the Peshekee and Duck Creek. Ratios greater than 1 indicate that the reach gradient is higher than the segment gradient. This was the case for the Peshekee River, Pensaukee River, Duck Creek, and North Branch Milwaukee River and perhaps is an indication that the reach contains more riffle or run than the rest of the segment. The Pensaukee River, Duck Creek, North Branch Milwaukee River, and Lincoln Creek all had similar water-surface gradients. The low gradient at the East River indicates that the reach is in a depositional part of the stream and accounts for the high embeddedness percentages. The relatively high gradients of the Pensaukee River, Duck Creek, North Branch Milwaukee River, and Lincoln Creek indicate the potential for erosion and (or) transport of sediment, which allows the embeddedness to remain low even though suspended-sediment concentrations are relatively high.

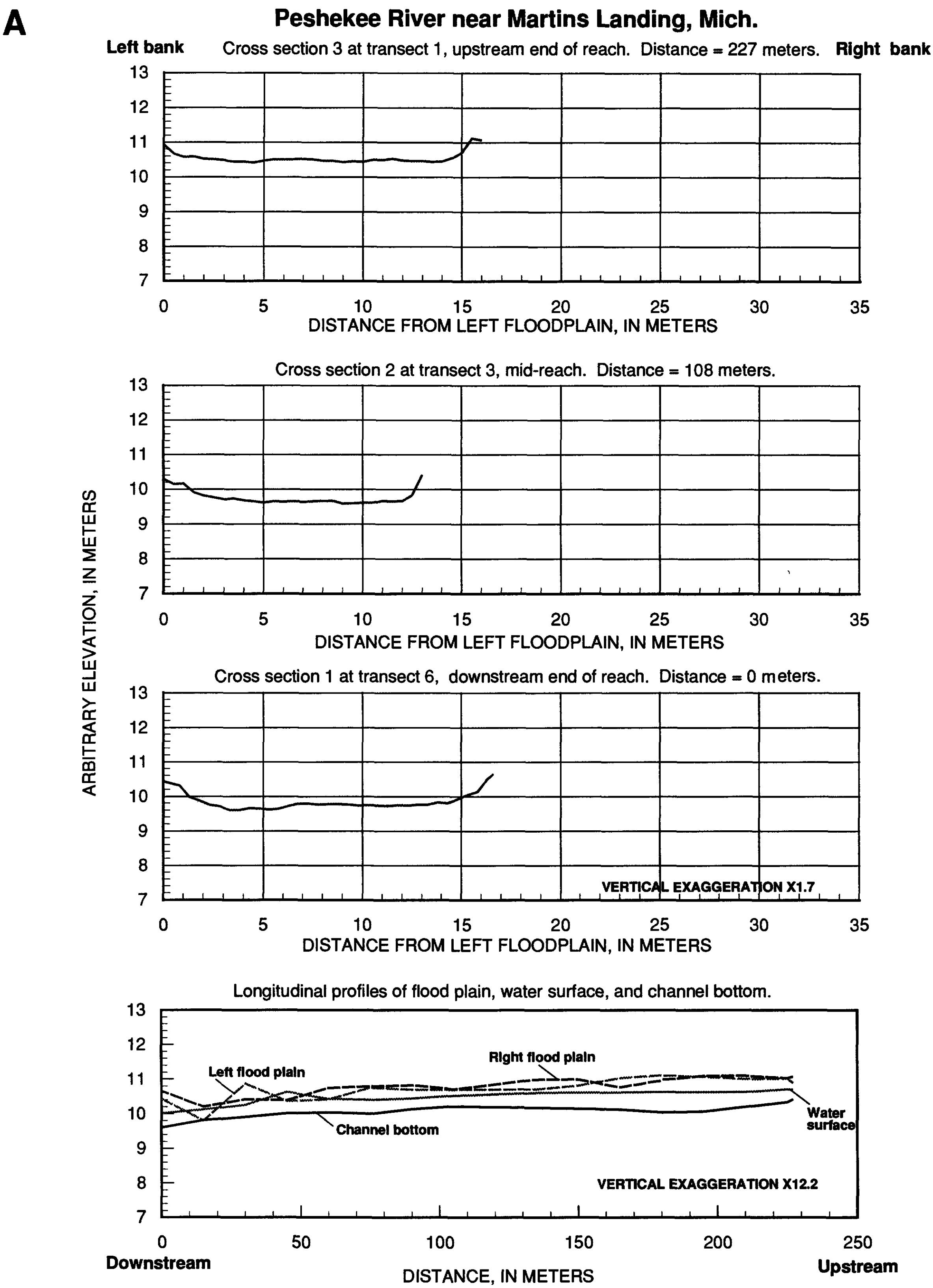


Figure 11. Channel cross-sections and longitudinal profiles of indicator sites in the Western Lake Michigan Drainages study unit.

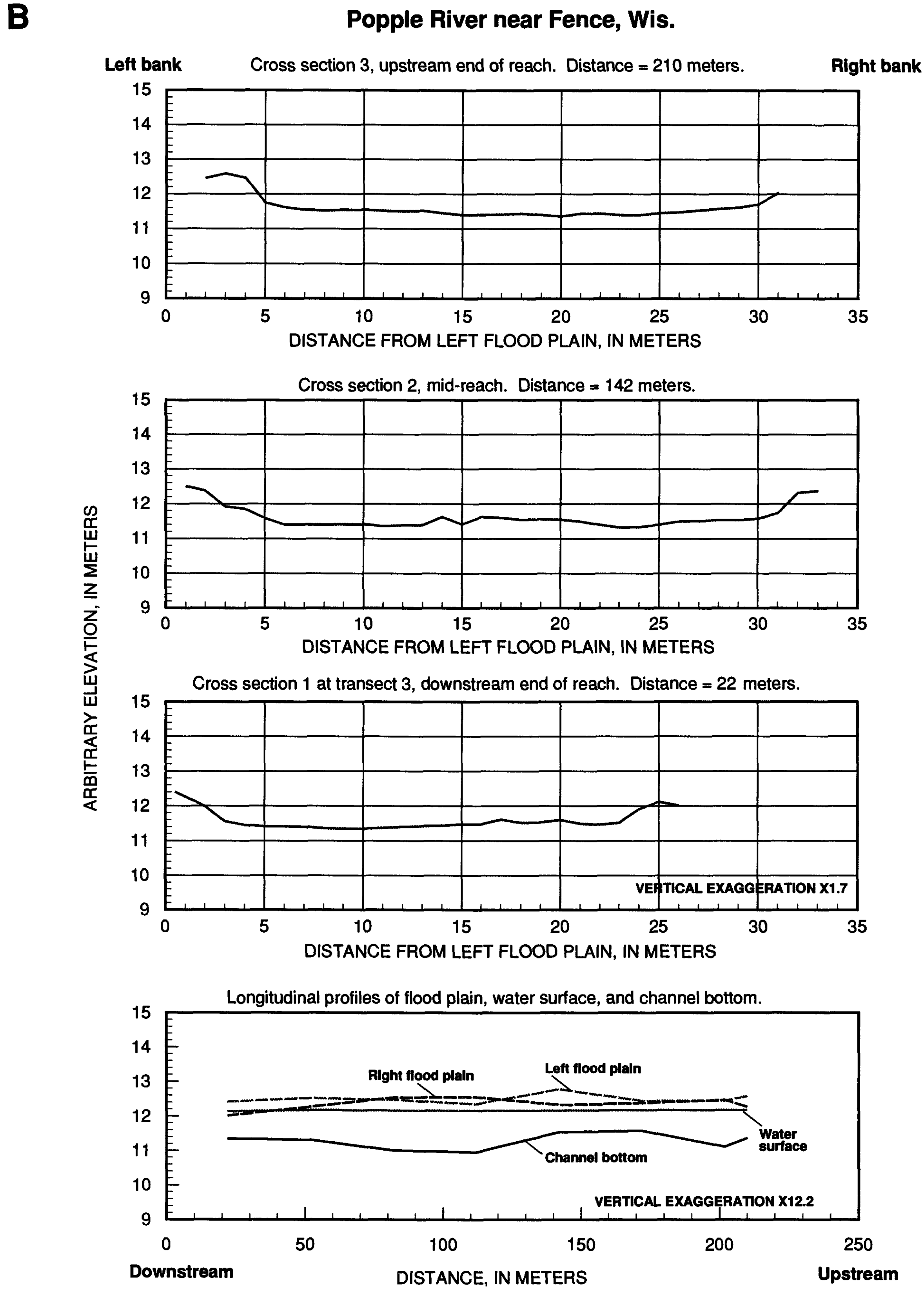


Figure 11. Channel cross-sections and longitudinal profiles of indicator sites in the Western Lake Michigan Drainages study unit—Continued.

C

Pensaukee River near Krakow, Wis.

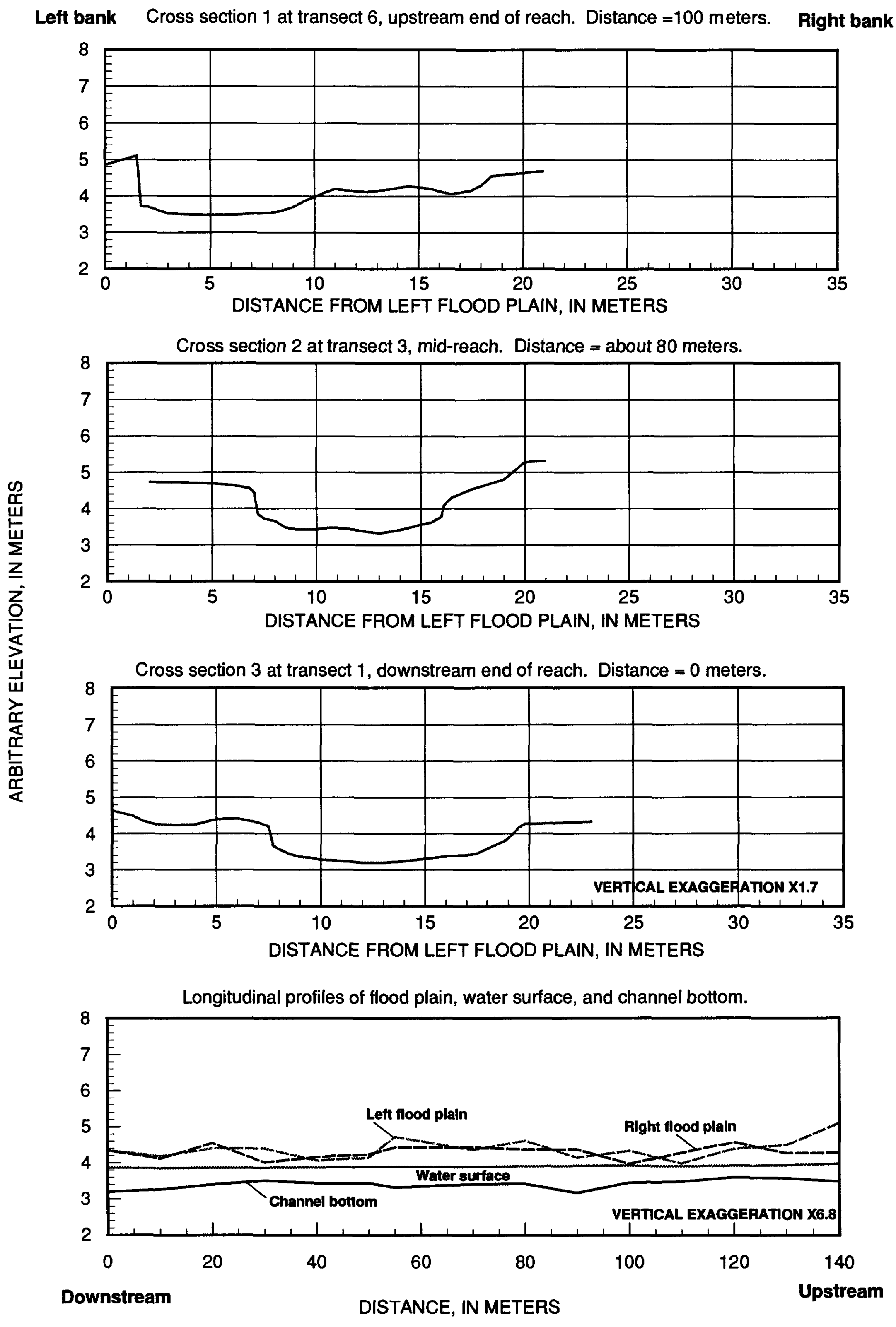


Figure 11. Channel cross-sections and longitudinal profiles of indicator sites in the Western Lake Michigan Drainages study unit—Continued.

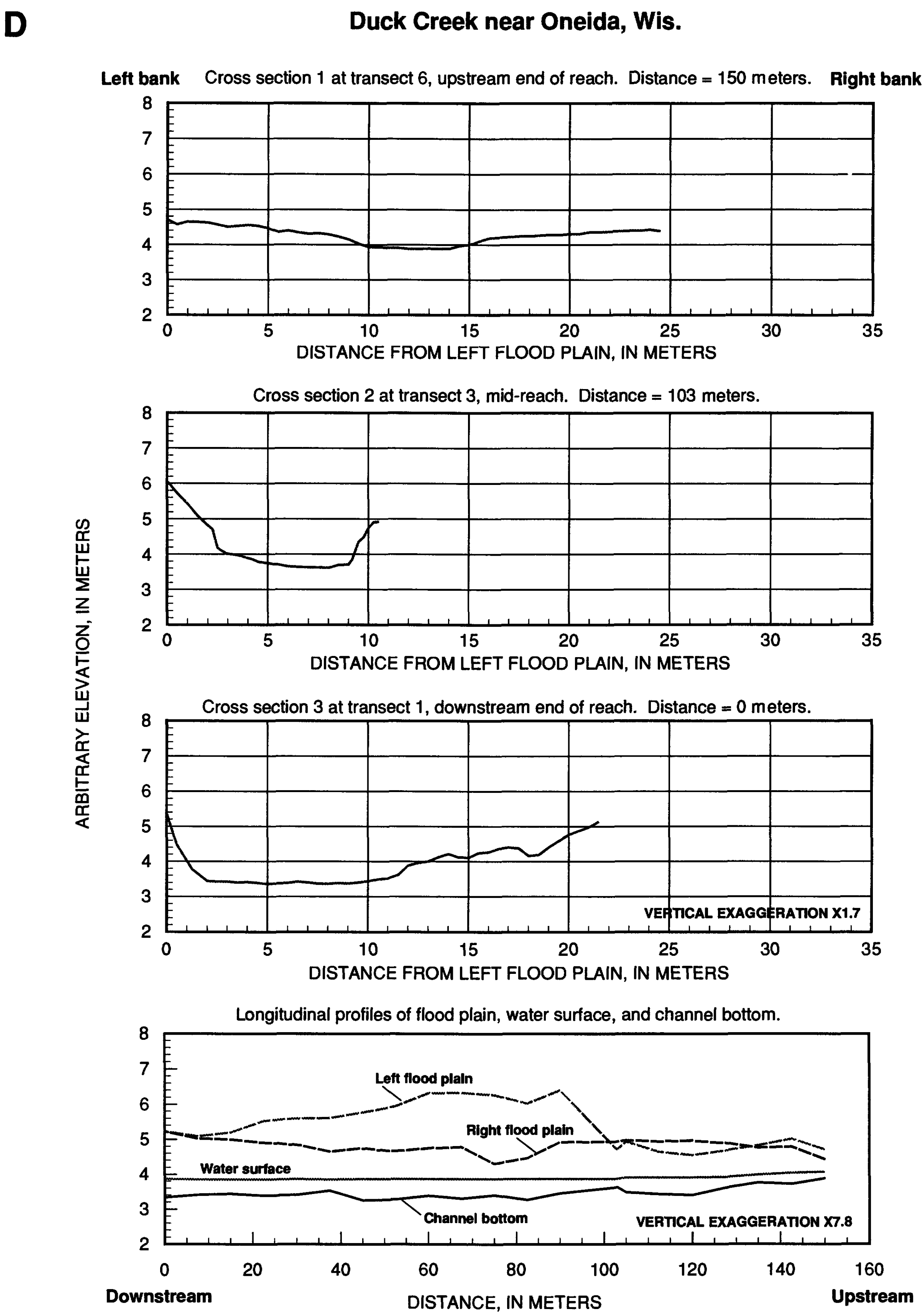


Figure 11. Channel cross-sections and longitudinal profiles of indicator sites in the Western Lake Michigan Drainages study unit—Continued.

E

Tomorrow River near Nelsonville, Wis.

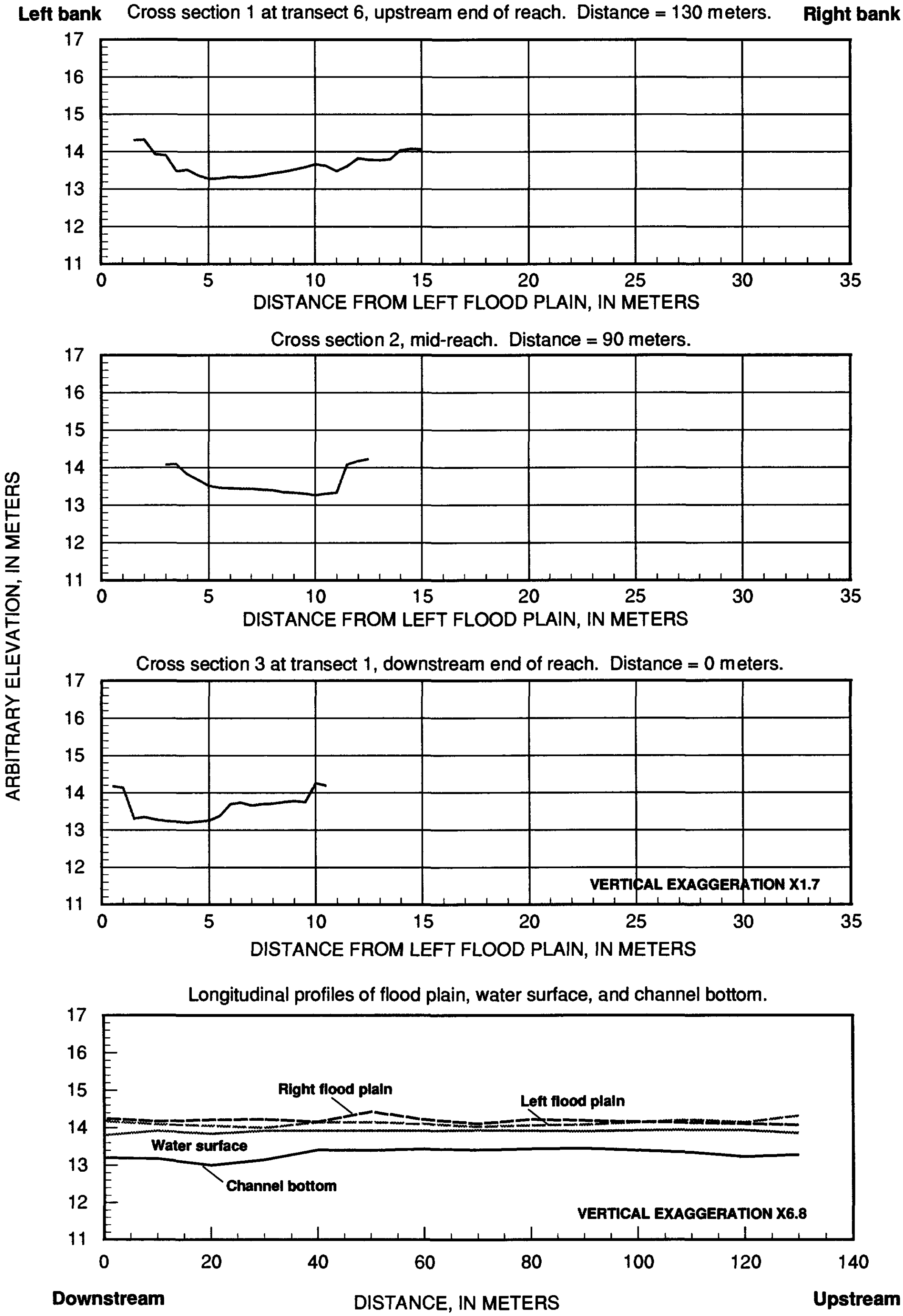


Figure 11. Channel cross-sections and longitudinal profiles of indicator sites in the Western Lake Michigan Drainages study unit—Continued.

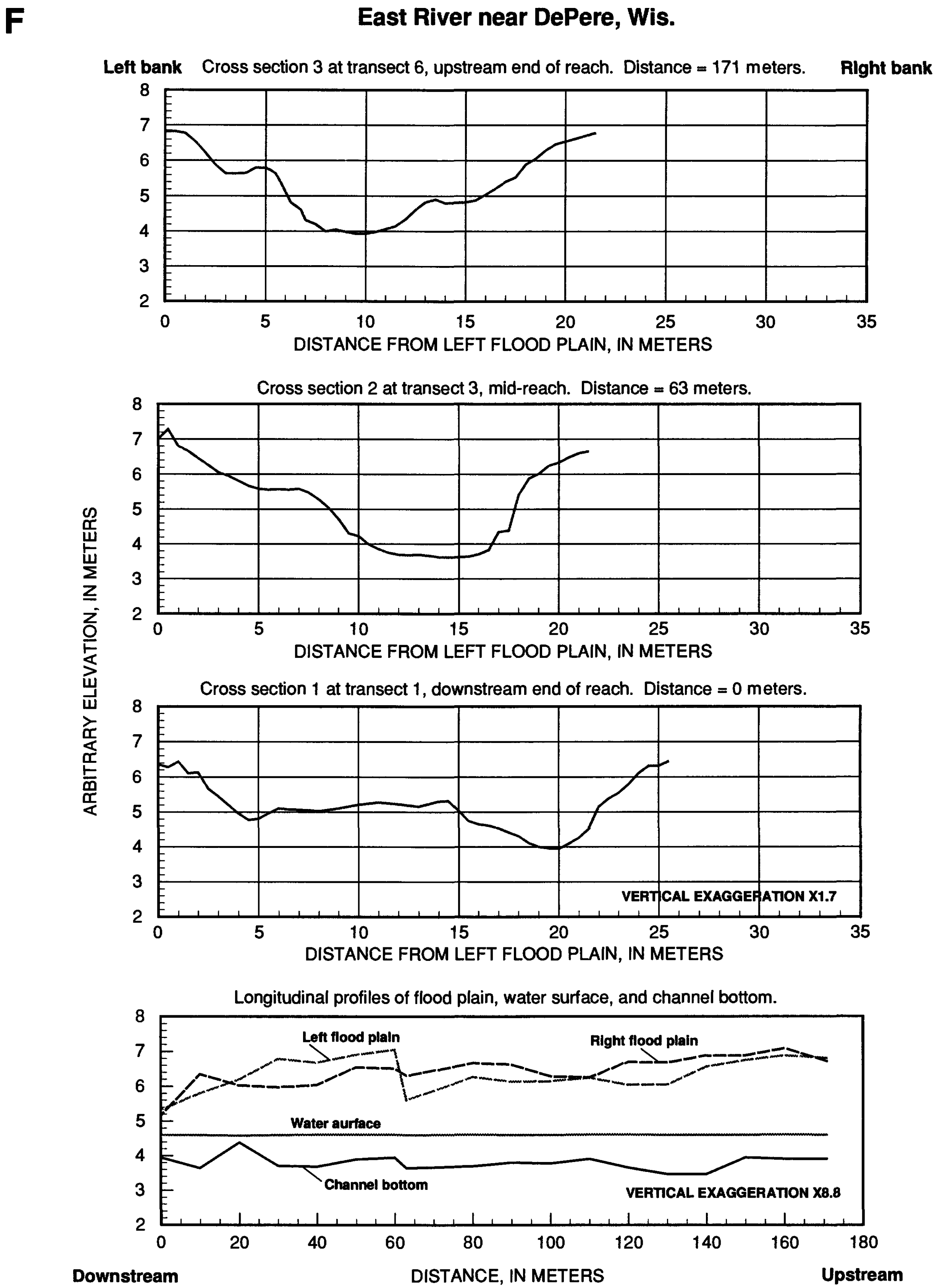


Figure 11. Channel cross-sections and longitudinal profiles of indicator sites in the Western Lake Michigan Drainages study unit—Continued.

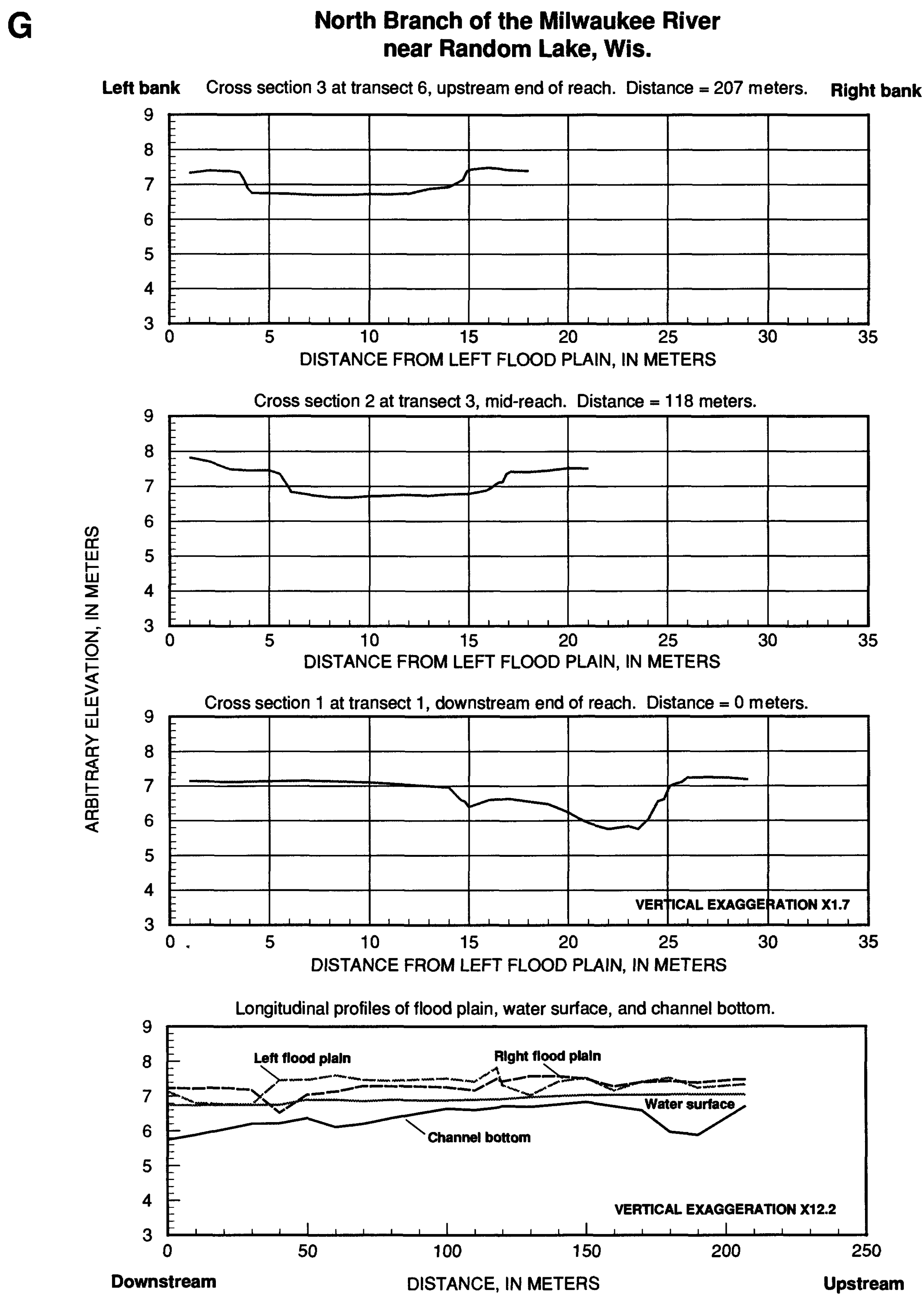


Figure 11. Channel cross-sections and longitudinal profiles of indicator sites in the Western Lake Michigan Drainages study unit—Continued.

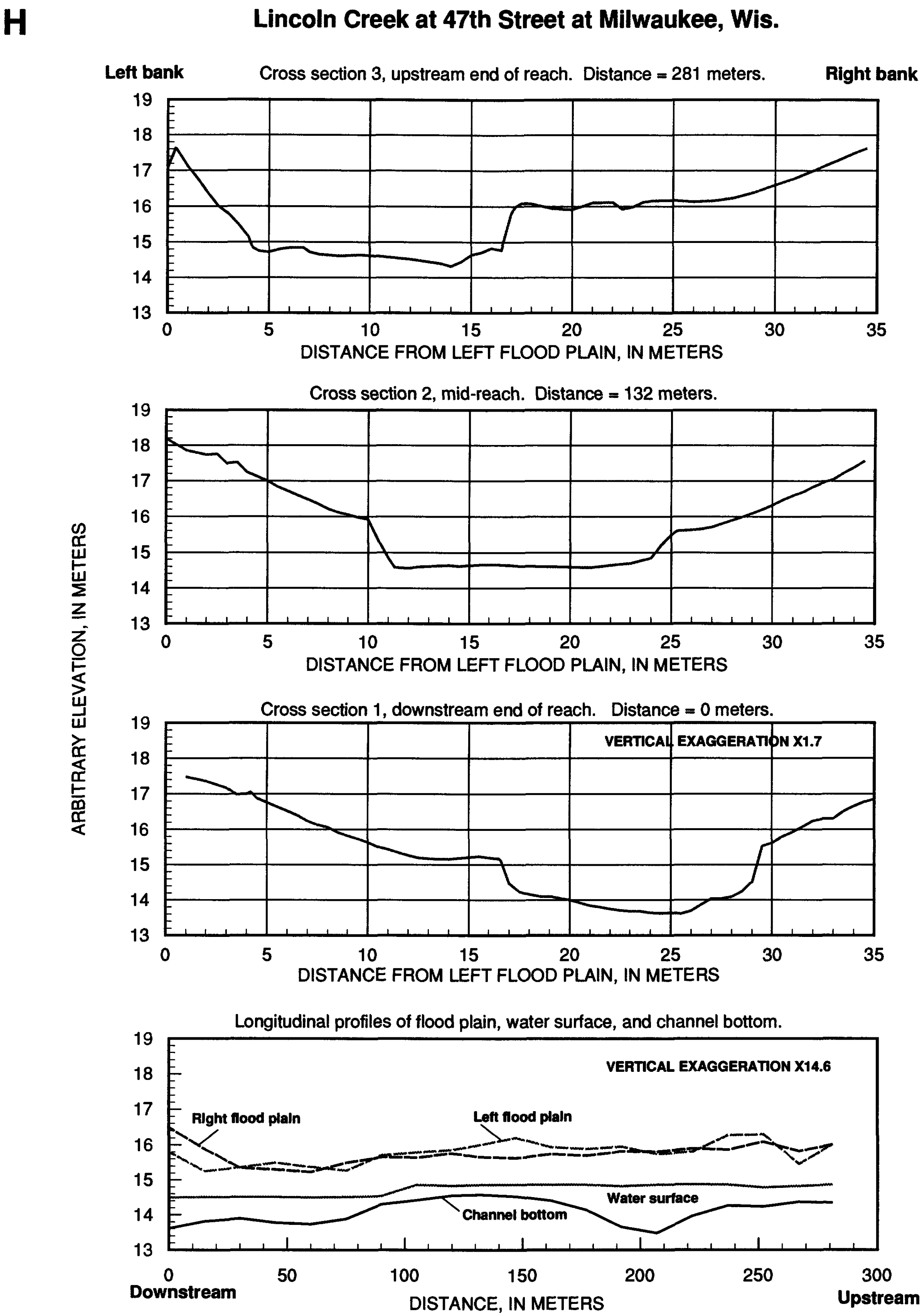


Figure 11. Channel cross-sections and longitudinal profiles of indicator sites in the Western Lake Michigan Drainages study unit—Continued.

Table 2. Channel characteristics and estimated bankfull flow at indicator sites in the Western Lake Michigan Drainages study unit

[m, meters; km, kilometers; km^2, square kilometers, m^3/s, cubic centimeters per second; Q_2, estimated 2-year flood (from Krug and others, 1992)]

Indicator site	Mean bankfull width/ depth ratio	Mean reach Level I width/ depth ratio	Water-surface gradient (m/km)	Downstream bankfull elevation (m)	Estimated bankfull flow[1] (m^3/s)	Bankfull flow/ drainage area ((m^3/s)/km^2)	Bankfull flow/Q_2
Peshekee River	31	43	3.1	10.3	9[2]	0.071	--[3]
Popple River	38	44	.11	12.3	5	.014	.26
Pensaukee River	29	31	1.2	4.5	5	.054	.38
Duck Creek	17	22	1.4	4.2	20[2]	.081	.64
Tomorrow River	21	20	.33	13.8	2	.018	.20
East River	17	21	.058	5.6	5	.041	.14
North Branch Milwaukee River	25	34	1.4	7.3	5	.038	.28
Lincoln Creek	16	36	1.3	15.5	6	.240	.86

[1]Bankfull flow was estimated using the step backwater method (BOSS Corporation, 1992) and verified using U.S. Geological Survey gaging-station rating information.

[2]NAWQA site not collocated with gaging station; bankfull flow not verified.

[3] Q_2 not available.

In contrast to the linear nature of the water-surface longitudinal profile, the channel bottom and flood-plain longitudinal profiles contain dips and rises (fig. 11). Variations in the elevation and gradient of the channel bottom reflect position of geomorphic units. Riffles are reflected by a rise in the channel bottom elevation; pools are reflected by dips in the channel bottom elevation. Variations in flood-plain elevations on the longitudinal profiles are caused by several factors, including the entrance of a tributary stream and intersection of the streambank with a terrace or bluff.

Bankfull Flow

Estimated bankfull flows (table 2) at the indicator sites from HEC-2 modeling ranged from 2 m^3/s at the Tomorrow River to 20 m^3/s at Duck Creek. The bankfull flows at the elevations specified in table 2 were verified at all but two sites using USGS gaging-station flow data and rating tables. The gaging stations at the Peshekee River and Duck Creek are not near the NAWQA reaches; thus, the NAWQA habitat surveys could not be connected with the gaging-station reference points. Elevations used to calculate bankfull flow are given in table 2 and can be matched up with the cross sections shown in figure 11.

Bankfull flow is of interest because it is defined as the channel-forming flow (Leopold and others, 1964), or the flow at which the most sediment can be eroded and transported. Once the bankfull flow is exceeded, additional flow spills out into the flood plain and does not contribute as much to the channel shape (Chang, 1992). Leopold and others (1964) found that bankfull flow of streams in equilibrium have a recurrence interval of 1.5 years. However, subsequent studies, including Williams (1978) and Andrews (1980), have shown that the recurrence interval corresponding to bankfull flow can be quite varied for many streams.

Standardizing the estimated bankfull flow by drainage area (table 2) shows the variability in channel-forming flow caused by other physical and (or) human factors once the influence of basin size is removed. The bankfull flow/drainage area for the Popple River was the smallest of all indicator sites, and that for Lincoln Creek was the largest. Large ratios indicate high banks and large 2-year floods for the given drainage-basin size. It is not surprising that Lincoln Creek has the largest ratio because its drainage area is completely urban and it receives input from many sewer outfalls. Small bankfull flows/drainage area indicate a greater possibility that flows spill out over the banks and into the flood plain more often than once every 1.5 years.

The wetland riparian vegetation at the Popple and Tomorrow Rivers may be the result from small bankfull flow/drainage area ratios, low banks, and lower gradients at these sites.

The ratio of estimated bankfull flow to the calculated Q_2 indicates how well the bankfull flow compares with the flood having a recurrence interval of 2 years, as estimated by using equations in Krug and others (1992). For all but Duck Creek and Lincoln Creek, the bankfull flow was well below 50 percent of the calculated Q_2. This may be an indication of two possibilities: (1) the regression equations used to calculate Q_2 overestimate the actual Q_2 at these sites, and (2) the bankfull flow happens much more frequently than every 2 years. One study has shown that the regression equations in Krug and others (1992) typically overestimate the 2-year flood for smaller streams because the equations are based on data from gaged streams, which are typically much larger than most of the WMIC indicator streams (University of Wisconsin, Department of Civil Engineering, 1995). On the other hand, the wetland vegetation in their flood plains indicates the Popple and Tomorrow Rivers may flood more often than every 2 years. The Popple River is the only site that has a streamflow record long enough (1964–present) to adequately calculate the 2-year flood. The 2-year flood at the Popple River, as calculated from the gaging station data, is 19 m^3/s. This substantiates the second hypothesis that flow at the Popple River exceeds the banks and spills out into the flood plain much more often than once every 2 years.

Channel Bottom Substrate and Streambank Particle Size

Wolman pebble counts were done once at each indicator site, including multiple reaches, in 1994. The general variability of larger particle sizes (boulder, cobble, and gravel) among the sites is indicated in figure 12A. Pebble counts were not done at the East River because it was too deep. The Popple River was the only site where bedrock and large boulders were found. The Peshekee contained the most cobble, whereas the Pensaukee River, Duck Creek, North Branch Milwaukee River, and Lincoln Creek contained the most gravel of all the indicator sites. The Tomorrow River contained a mix of cobble and fines.

In general, results from the Wolman pebble counts are similar to the results from the reach Level I substrate measurements. Exceptions, however, were found for the Popple and the North Branch Milwaukee Rivers. At the Popple River, Wolman pebble counts resulted in a higher percentage of bedrock and boulder than the Level I measurements (fig. 7A). At the North Branch of the Milwaukee River, Wolman pebble counts resulted in a higher percentage of gravel than

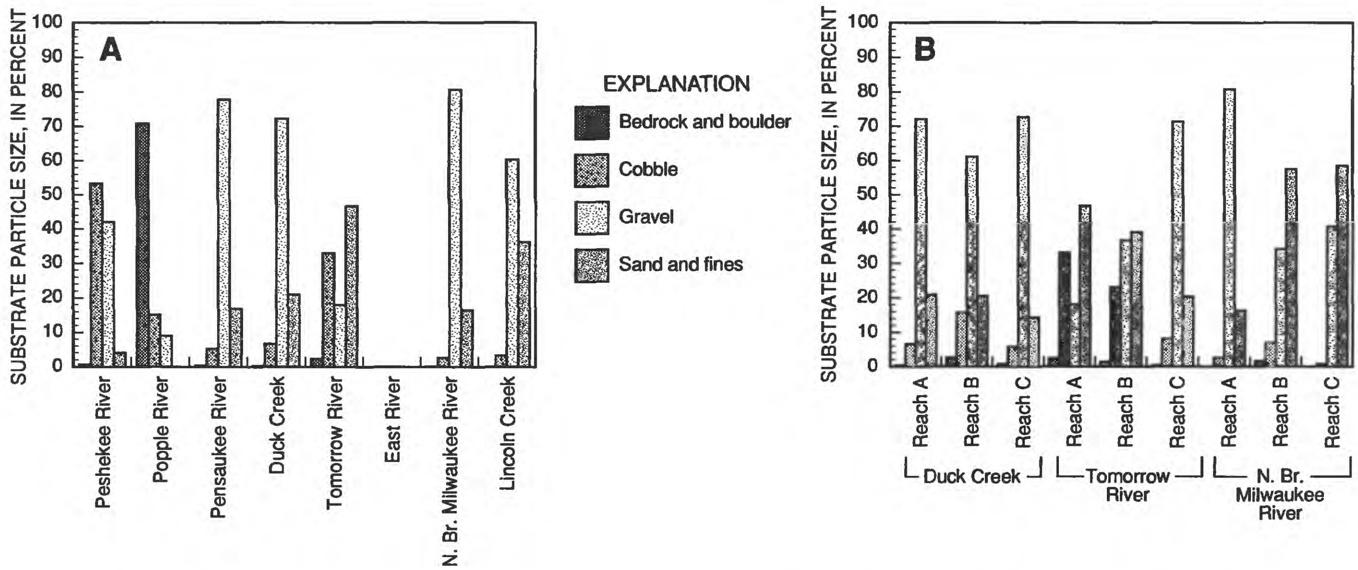


Figure 12. Mean particle-size distribution of large streambed substrate, based on Wolman pebble counts, from indicator sites in the Western Lake Michigan Drainages study unit, 1993–94: (A) site-by-site comparison, and (B) multiple-reach comparison.

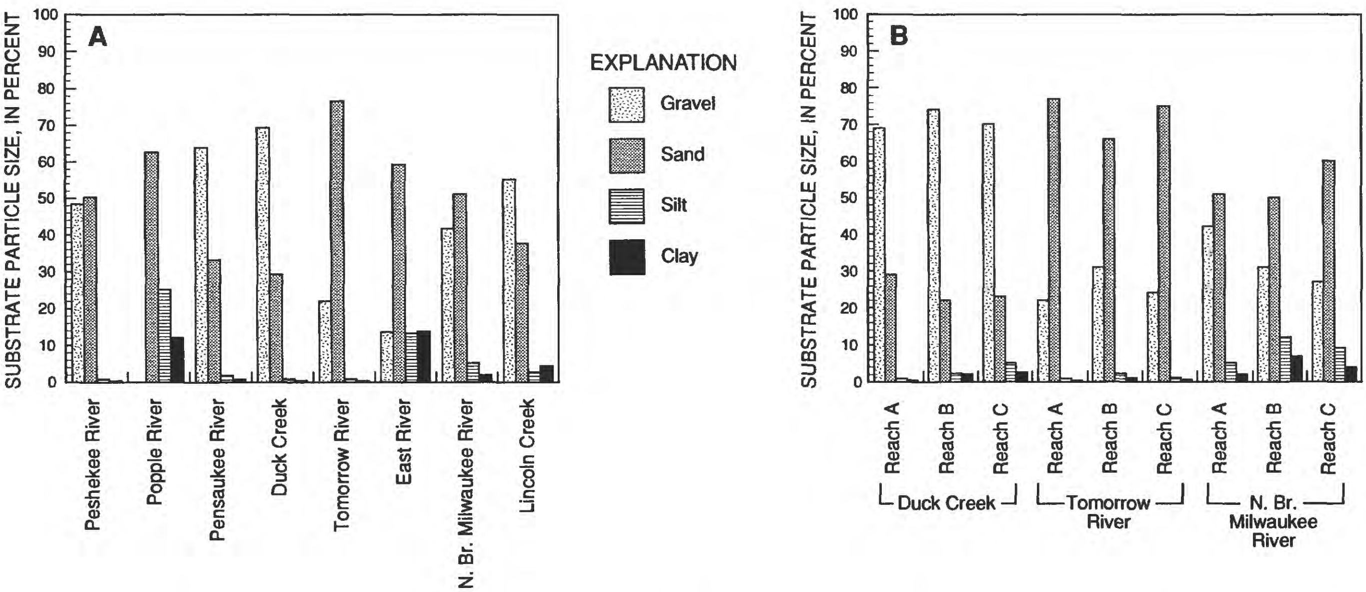


Figure 13. Mean particle-size distribution of streambed substrate, based on laboratory analyses of streambed sediment from indicator sites in the Western Lake Michigan Drainages study unit, 1993–94: (A) site-by-site comparison, and (B) multiple-reach comparison.

the Level I measurements. These differences probably resulted from Wolman pebble counts having been done at only three of the six transects. As stated earlier, two out of the three measurements were done at the reach boundaries. The third transect measured at both of these streams was located in a riffle where invertebrates were collected, causing overall particle size to be coarser than if measurements were done at all six transects. The pebble-count data for the multiple reaches also show slightly different results than the Level I measurements (fig. 12B), perhaps due to the same reasons.

The second type of Level II analyses of substrate and streambank particle size, quantitative laboratory analyses of particle size, are illustrated in figures 13 and 14. Gravel makes up a large proportion of the streambed sediment at five indicator sites (fig. 13). Figure 13 does not show any gravel for the Popple River; however, the pebble counts (fig. 12) indicated that bedrock and boulders make up a significant part of the streambed. Streambed sediment at the Tomorrow and East River are dominated by sand. Multiple-reach comparisons of streambed sediment (fig. 13B) show similar size characteristics at all three reaches for each indicator site, especially Duck Creek and the Tomorrow River.

For streambank substrate, the comparison among mean particle-size distributions at the indicator sites (fig. 14A) indicates that the streambanks at Pensaukee River and Duck Creek contained the most gravel of all the indicator sites, whereas banks at the Peshekee River were almost entirely composed of sand. Streambanks at the Popple River, North Branch Milwaukee River, and Lincoln Creek contained the most fines of all the indicator sites. Streambanks at the Tomorrow River and East River contained a mixture of sand, silt, and clay. As expected, particle size of streambank sediment is generally finer than that of streambed sediment.

Multiple-reach data for particle size of streambanks (fig. 14B) indicate that streambank sediment was similar at all three reaches at the North Branch Milwaukee River; however, Duck Creek and the Tomorrow River had notable differences among the reaches. At Duck Creek, the amount of sand in the streambanks was similar among all transects and was the dominant particle size; however, streambanks at reach A contained more gravel, reach B contained more fine sediment, and reach C contained almost entirely sand. Streambank sediment at reaches A and B at the Tomorrow River were very similar; however, streambank sediment at reach C contained less sand and more silt and clay than reach A and B.

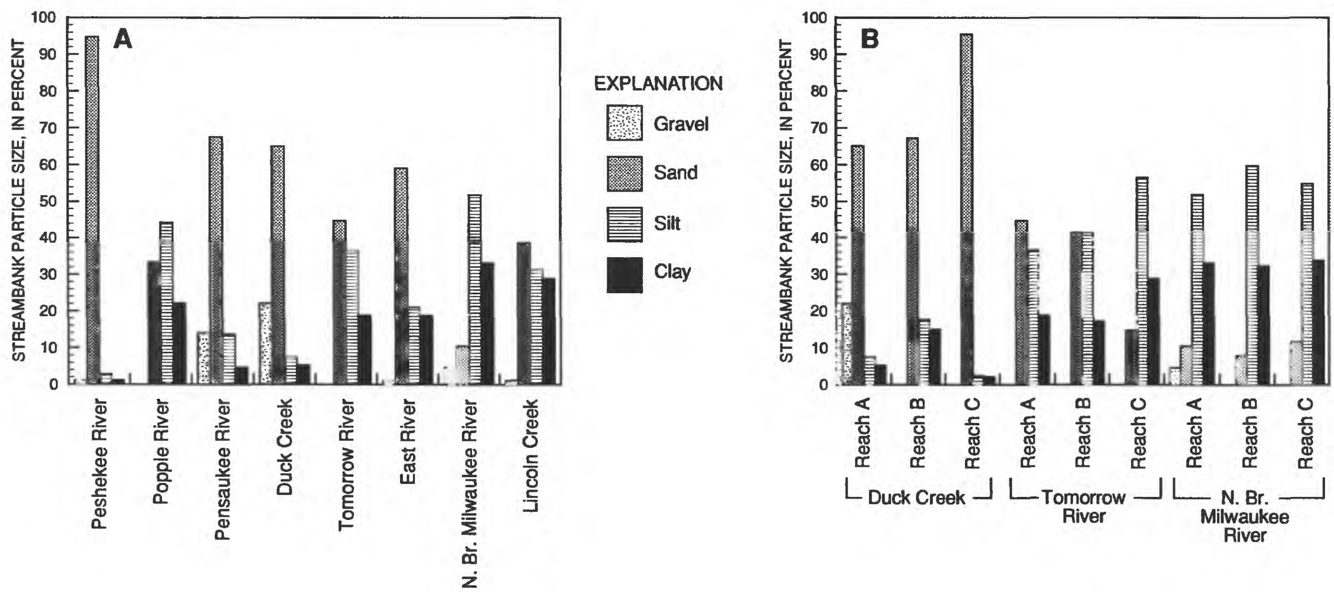


Figure 14. Mean particle-size distribution in streambank sediment from indicator sites in the Western Lake Michigan Drainages study unit, 1993–94: (A) site-by-site comparison, and (B) multiple-reach comparison.

Riparian Vegetation

Herbs and trees dominated in the flood plain at most indicator sites (fig. 15). The East River had the lowest cover of herbs, at 55 percent of points sampled; the Peshekee River was 74 percent covered, and all other sites were greater than 80 percent covered with herbs. A presence of herbs indicates an understory that consists of vegetation instead of bare ground, litter, or debris. Densely growing shrubs and heavy shade can reduce the amount of herb coverage. Tree cover was high at Pensaukee River, Duck Creek, Tomorrow and East Rivers (all greater than 70 percent), and shrub coverage was correspondingly low (less than 30 percent). Lincoln Creek had a moderate tree coverage of 57 percent and only 1 percent shrub coverage. These results may indicate to some extent that tree and shrub cover are inversely proportionate. At none of the sites did shrubs dominate over trees. In the riparian areas, shrubs were mostly found close to the channel, in back-channel areas, or in other open areas where disturbance is frequent or where hydrologic conditions prevent the establishment of trees. At most of the sites, the flood plain is narrow and trees are common.

At the Peshekee and Popple Rivers, trees and shrubs were about equal in coverage. An open flood plain in the upper reach of the Popple River and old channels and backwaters by the Peshekee support more shrubs than trees; thus, shrubs dominate the riparian vegetation at these sites more than at others. The North Branch Milwaukee River had 17 percent tree cover and 15 percent shrub cover. As mentioned earlier, the density of woody vegetation at this site is extremely low, and herbs (primarily) are dominant.

Permanent vegetation plots were established at the indicator sites to monitor changes in vegetation over time. These plots can be used to further describe the vegetation at each site and can be used as a base of information for later comparisons. The relative density, basal area, and importance value of the major species of each site are listed in table 3. A complete list of species per site is in table 4. The Tomorrow River was the most diverse site, with 25 species of trees and shrubs recorded. The North Branch Milwaukee was the least diverse, with 11 species. The rest of the sites were similarly diverse with 14 to 17 species.

Plots at Duck Creek, East River, and the North Branch Milwaukee River were composed of tree species classified by Curtis (1959) as members of the southern lowland forest community. The major codominant species were boxelder (*Acer negundo*), silver maple (*Acer saccharinum*), green ash (*Fraxinus pennsylvanica*), cottonwood (*Populus deltoides*), slippery elm (*Ulmus rubra*) and willow (*Salix* sp.). The development of flood-plain forests is minimal at these sites when compared to larger rivers because the riparian areas are typically narrow because of smaller channel sizes. Curtis found that development of a flood plain forest along streams flowing into Lake Michigan generally was minor, owing to high stream gradients. The composition of plots at the WMIC sites shows similarities to both the southern lowland forest and the upland forest types. For example, the Pensaukee River plot contains some species that resemble the southern lowland forest, but it also has a high importance of a number of shrub species more characteristic of upland southern forest types.

Lincoln Creek, an urban stream, is composed of many species that are considered part of a weed community. These include a high concentration of boxelder and exotics such as asian honeysuckle (*Lonicera* sp.), russian olive (*Eleagnus angustifolia*) and buckthorn (*Rhamnus cathartica*). These species tend to be opportunistic and occur in areas with high degrees of disturbance. Rapid and wide fluctuations in flow of Lincoln Creek, a reflection of its urban nature, likely affect the riparian vegetation, in addition to other human disturbances. Other species with high importance at this stream are green ash and black walnut (*Juglans nigra*).

The Tomorrow River site in the central part of Wisconsin has vegetation that resembles both the southern and northern lowland forests. Northern lowland forests are rare along streams in Wisconsin because of poorly developed flood plains in this region (Curtis, 1959). The Tomorrow River riparian area contains some species typical of the northern lowland forest, such as tamarack (*Larix laricina*) and balsam fir (*Abies balsamea*), but it also contains species more typical of the southern forests, such as slippery elm and swamp white oak (*Quercus bicolor*). This mix might be suspected because the Tomorrow River is located just outside of the Tension Zone, an area in which a majority of species in the State find their northernmost or southernmost limit (Curtis, 1959). However, Duck Creek, Pensaukee River, and East River are also located near this zone, and they exhibit vegetation more characteristic of the southern communities.

The northern two sites, Peshekee and Popple Rivers, are very different in their vegetational characteristics than sites on the southern streams. The Peshekee River, in Michigan's Upper Peninsula, contains vegetation similar to the boreal forest (Curtis, 1959). This includes balsam fir, paper birch (*Betula papyrifera*), white spruce (*Picea glauca*), red maple (*Acer rubrum*), and white pine (*Pinus strobus*). The narrow flood plain of the Peshekee grades quickly into the characteristically boreal forest, and thus very little lowland vegetation is present. The Popple River riparian vegetation also includes some species from the boreal forest, including its major dominants, balsam fir and balsam poplar.

Alder (*Alnus rugosa*) has a high importance at the three sites exhibiting vegetation typical of the northern communities (Peshekee, Popple, and Tomorrow Rivers). Typically, alders are found in thickets along the streambank near flowing water. Alders are not common or not present in any of the sites characteristic of southern Wisconsin comminutes. This finding is consistent with Curtis's observations (1959) that alder is the predominant streambank vegetation in the northern part of the state, whereas willows, dogwoods (*Cornus* sp.) and viburnums (*Viburnum* sp.) dominate in the south. In this study willows and viburnums were found in both the north and the south, but dogwoods were limited to the south.

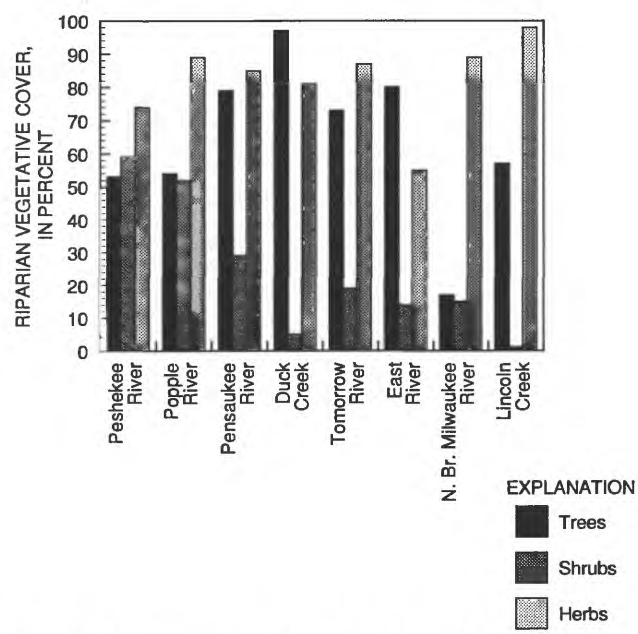


Figure 15. Percentages of tree, shrub, and herb cover of indicator sites in the Western Lake Michigan Drainages study unit, 1995. Data from the point-intercept technique.

Table 3. Relative density, basal area, and importance value of riparian vegetation from permanent vegetation plots at indicator sites in the Western Lake Michigan Drainages study unit, 1995

Species[1]	Percent density	Percent basal area	Importance value
Peshekee River			
Balsam fir *(Abies balsamea)*	71	24	38
White birch *(Betula papyrifera)*	2	48	20
Black cherry *(Prunus serotina)*	10	5	11
White spruce *(Picea glauca)*	5	9	10
Red maple *(Acer rubrum)*	5	1	5
White pine *(Pinus strobus)*	0.5	13	5
Popple River			
Balsam poplar *(Populus balsamifera)*	66	63	48
Balsam fir *(Abies balsamea)*	8	14	13
Speckled alder *(Alnus rugosa)*	10	2	9
Black cherry *(Prunus serotina)*	1	7	5
Pensaukee River			
Black ash *(Fraxinus nigra)*	17	58	29
Nannyberry *(Viburnum lentago)*	20	5	12
Boxelder *(Acer negundo)*	8	15	11
Gray dogwood *(Cornus racemosa)*	23	1	9
Hawthorn *(Crataegus* sp.*)*	8	4	8
American Hornbeam *(Carpinus caroliniana)*	7	4	7
Slippery elm *(Ulmus rubra)*	3	6	6
Prickly ash *(Xanthoxylum americanum)*	7	1	3
Duck Creek			
Cottonwood *(Populus deltoides)*	7	44	20
Silver maple *(Acer saccharinum)*	20	27	20
Green ash *(Fraxinus pennsylvanica)*	23	6	15
Boxelder *(Acer negundo)*	22	2	14
Slippery elm *(Ulmus rubra)*	6	1	7
Willow *(Salix* sp.*)*	6	6	6
Swamp white oak *(Quercus bicolor)*	2	7	4
Tomorrow River			
Larch *(Larix laricina)*	27	55	31
Black ash *(Fraxinus nigra)*	22	11	16
Slippery elm *(Ulmus rubra)*	9	8	10
Balsam fir *(Abies balsamea)*	11	5	7
Speckled alder *(Alnus rugosa)*	9	1	7
White birch *(Betula papyrifera)*	6	2	6
Scotch pine *(Pinus sylvestris)*	3	12	6
Swamp white oak *(Quercus bicolor)*	2	5	3
East River			
Cottonwood *(Populus deltoides)*	21	51	27
Boxelder *(Acer negundo)*	34	23	26
Green ash *(Fraxinus pennsylvanica)*	11	20	16
Hawthorn *(Crataegus* sp.*)*	15	2	12
Slippery elm *(Ulmus rubra)*	8	8	7
Staghorn sumac *(Rhus typhina)*	6	0.5	4
North Branch Milwaukee River			
Willow *(Salix* sp.*)*	67	75	59
Slippery elm *(Ulmus rubra)*	21	10	14
American elm *(Ulmus americana)*	5	10	12
Lincoln Creek			
Boxelder *(Acer negundo)*	70	65	54
Green ash *(Fraxinus pennsylvanica)*	15	8	15
Black walnut *(Juglans nigra)*	3	14	10
Buckthorn *(Rhamnus cathartica)*	6	2	7
Russian olive *(Eleagnus angustifolia)*	1	10	6

[1]Only species with a relative density or relative basal area greater than 5 percent are included.

Table 4. Number of occurrences of tree and shrub species in permanent vegetation plots of indicator sites in the Western Lake Michigan Drainages study unit, 1995

Species	Peshekee River	Popple River	Pensaukee River	Duck Creek	Tomorrow River	East River	North Branch Milwaukee River	Lincoln Creek
Trees								
Balsam fir *(Abies balsamea)*	468	18	--	--	36	--	--	--
Boxelder *(Acer negundo)*	--	--	26	35	--	107	--	78
Red maple *(Acer rubrum)*	68	4	1	1	--	--	--	--
Silver maple *(Acer saccharinum)*	--	1	--	27	--	--	--	--
Sugar maple *(Acer saccharum)*	1	--	--	--	9	--	--	--
White birch *(Betula papyrifera)*	11	--	--	--	14	--	--	--
Ironwood *(Carpinus caroliniana)*	--	--	24	1	--	--	--	--
Hackberry *(Celtis occidentalis)*	--	--	--	17	--	1	--	1
Hawthorn *(Crataegus* sp.*)*	--	--	28	--	--	51	--	--
Russian olive *(Eleagnus angustifolia)*	--	--	--	--	--	--	--	1
Black ash *(Fraxinus nigra)*	--	--	56	16	137	4	--	--
Green ash *(Fraxinus pennsylvanica)*	--	26	--	25	10	37	12	27
Black walnut *(Juglans nigra)*	--	--	--	--	--	--	--	4
Larch *(Larix laricina)*	--	--	--	--	53	--	--	--
Ironwood *(Ostrya virginiana)*	--	4	--	--	1	--	6	--
White spruce *(Picea glauca)*	23	5	--	--	--	--	--	--
White pine *(Pinus strobus)*	2	--	--	--	--	--	--	--
Scotch pine *(Pinus sylvestris)*	--	--	--	--	6	--	--	--
Balsam poplar *(Populus balsamifera)*	--	345	--	--	--	--	--	--
Cottonwood *(Populus deltoides)*	--	--	--	8	--	44	--	--
Quaking aspen *(Populus tremuloides)*	--	1	1	--	1	--	--	--
Black cherry *(Prunus serotina)*	55	15	6	--	4	1	--	--
Mountainash *(Pyrus americana)*	1	--	--	--	--	--	--	--
White oak *(Quercus alba)*	--	--	2	--	--	--	--	--
Swamp white oak *(Quercus bicolor)*	--	--	--	2	1	1	--	--
White cedar *(Thuja occidentalis)*	--	--	--	--	1	--	--	--
American basswood *(Tilia americana)*	--	--	6	4	4	3	1	--
American elm *(Ulmus americana)*	--	--	1	1	1	--	3	--
Slippery elm *(Ulmus rubra)*	--	3	10	8	22	31	10	2
Prickly ash *(Xanthoxylum americanum)*	--	--	57	--	--	--	--	--
Shrubs and small trees								
Speckled alder *(Alnus rugosa)*	232	174	2	--	127	--	--	--
Downy juneberry *(Amelanchier arborea)*	36	--	--	--	--	--	--	--
Juneberry *(Amelanchier canadensis)*	--	2	--	--	--	--	--	--
Leatherleaf *(Chameadaphne calyculata)*	75	--	--	--	--	--	--	--
Alternate leaf dogwood *(Cornus alternifolia)*	--	--	--	--	1	--	--	--
Gray dogwood *(Cornus racemosa)*	--	--	307	--	3	--	25	8
Redosier dogwood *(Cornus stolonifera)*	3	--	--	--	5	--	8	--
American hazelnut *(Corylus americana)*	224	--	--	--	--	--	--	--
Beaked hazelnut *(Corylus cornuta)*	--	--	--	28	--	--	--	--
Winterberry holly *(Ilex verticilata)*	--	11	--	--	--	--	--	--
Honeysuckle *(Lonicera* sp.*)*	3	--	--	--	2	--	37	8
Ninebark *(Physocarpus opulifolius)*	--	--	--	--	3	--	--	--
Chokecherry *(Prunus virginiana)*	60	132	--	26	16	1	--	--
Buckthorn *(Rhamnus cathartica)*	--	--	--	--	--	--	--	12
Staghorn sumac *(Rhus typhina)*	--	--	--	--	--	15	--	--
Currant *(Ribes* sp.*)*	--	--	--	--	2	--	200	1
Blackberry *(Rubus* sp.*)*	--	--	--	--	--	--	202	1
Willow *(Salix* sp.*)*	35	140	--	110	14	3	43	1
Elderberry *(Sambucus canadensis)*	--	--	--	--	3	--	--	--
Wayfaring tree *(Viburnum lantana)*	--	--	--	--	--	--	--	1
Nannyberry *(Viburnum lentago)*	--	12	126	2	--	--	--	--
Highbush cranberry *(Viburnum trilobum)*	2	4	--	--	--	--	--	1
Grape *(Vitis riparia)*	--	--	18	5	--	8	--	1

Habitat Evaluation

The GLEAS and WDNR habitat evaluation systems rated the indicator streams similarly, although there were some minor differences (table 5). Using the qualitative ratings, the Peshekee, Popple and Tomorrow Rivers were rated "good" by both systems. The WDNR rated North Branch Milwaukee and Pensaukee Rivers as "fair" whereas the GLEAS placed these streams between the good and fair ratings. Duck Creek, East River, and Lincoln Creek were rated "poor" by the WDNR system, whereas Duck Creek and East River were "fair" and Lincoln Creek was between fair and poor under the GLEAS rating. Individual metric scores ranged widely from poor to excellent conditions from stream to stream. Average pool depth in the WDNR evaluation was the only metric that did not vary considerably: all streams scored very low. Either pools were scarce, as in the Peshekee River, or their overall depth was not sufficient.

The GLEAS evaluation was also done on 20 additional agricultural sites in part of the study unit to assess their use as reference streams (Fitzpatrick and others, 1996). Sixteen of these streams rated well enough to be considered as reference streams for their combination of land use and geologic setting. The GLEAS rating can be used by comparing streams to known reference streams and assessing quality based on a percentage. If a stream is 90 to 100 percent similar to the reference, it is considered excellent; 75 to 89 percent similar is good, 60 to 74 percent similar is fair, and less than 60 percent similar is poor. Therefore, areas that are limited by their geologic setting can be rated in relation to other limited streams. Comparison of fixed-site scores with the reference streams in the same geologic setting resulted in almost the same evaluation for the streams as when the habitat scores were used directly. The Tomorrow River (score 86) is 81 percent of the reference score at Silver Creek (score 106), the highest ranking of four reference streams in that setting. This is still classified as "good." When compared with the average score of 88 for reference streams in that setting, however, the Tomorrow River moves up a category to "excellent" with 97-percent similarity.

Similar comparisons were done with Duck Creek and North Branch Milwaukee River. Duck Creek is 66 percent similar to the highest reference in the area (Little Scarboro Creek at 99) and 69 percent similar to the average (97). These are both in the "fair" category. The North Branch Milwaukee is 62 percent similar to Nichols Creek (score 108) and 66 percent similar to the average (103), both in the "fair" range. If these reference sites are used for the other agricultural sites, which are in similar but not exactly the same geologic setting, the East River moves down to the poor category (45 percent similar) and Pensaukee River remains on the border of good and fair (67-74 percent similar, depending on the reference site chosen). No reference sites are available with which to compare the forested and urban sites. However, the Ford River, a forested reference site in the Upper Peninsula of Michigan, received a rating of "good" (William H. Taft, Michigan Department of Environmental Quality, Great Lakes Environmental Assessment Section, written commun., 1996). Based on this, it is possible that the Peshekee and Popple Rivers, both with "good" ratings, would move to the "excellent" category if compared by use of percentages, as did the Tomorrow River.

The WDNR and GLEAS habitat scores were compared with basin and other reach characteristics not directly used in the evaluation systems. Because WDNR and GLEAS scores were highly correlated ($\rho = -0.93$) (fig. 16A), WDNR scores are used in the following examples.

Except for Lincoln Creek, which had no agricultural land, lower WDNR scores (better habitat) corresponded with those streams with less agricultural land in their basins (fig. 16B). The scores seem to remain stable until agriculture reaches about 80 percent of the basin, at which point they rise sharply, perhaps indicating a threshold after which the amount of agriculture affects the stream quality.

Low WDNR scores also correlated with large riparian widths (fig. 16C), indicating that sites with narrow buffer zones had worse scores in both evaluations. For example, the East River has a narrow riparian zone and a poor score compared to the North Branch Milwaukee River, which has a wide riparian zone and a moderate score. Both of these stream have greater than 85 percent agriculture in their drainage basins.

The WDNR scores seemed to relate to the NAWQA Bank Stability Index (BSI) in two groups (fig. 16D). Three of the four agriculture sites and Lincoln Creek had BSI's greater than 12 (unstable) and WDNR scores greater than 175 (fair to poor). The forested sites, Tomorrow River and North Branch Milwaukee River had BSI's less than 12 (stable) and WDNR scores less than 175 (good to excellent). The North Branch Milwaukee River has very stable banks because it flows through a large reed canary grass wetland, and so it falls in the group with the forested sites

Table 5. Habitat evaluation results for indicator sites in the Western Lake Michigan Drainages study unit

	Peshekee River	Popple River	Pensaukee River	Duck Creek	Tomorrow River	East River	North Branch Milwaukee River	Lincoln Creek
Great Lakes Environmental Assessment scores								
Bottom substrate	18	15	16	18	12	8	10	10
Embeddedness	14	14	10	11	12	5	11	4
Velocity	8	6	13	9	12	8	10	10
Flow stability	11	11	7	5	11	5	7	3
Bottom deposition	13	10	5	2	10	2	2	2
Pools-riffles-runs-bends	13	6	9	9	10	6	9	3
Bank stability	9	9	3	3	6	2	8	2
Bank vegetative stability	7	7	4	2	5	2	6	0
Streamside cover	9	6	6	7	8	7	4	3
Overall score[1]	102	84	73	66	86	45	67	37
	Good	Good	Good/fair	Fair	Good	Fair	Good/fair	Fair/poor
Wisconsin Department of Natural Resources scores								
Watershed erosion	8	8	14	14	10	16	14	14
Watershed nonpoint source	8	10	14	14	10	14	14	14
Bank erosion	4	8	16	16	8	20	8	20
Bank vegetative protection	9	9	18	18	15	18	9	18
Lower bank channel capacity	14	16	10	10	10	8	10	10
Lower bank deposition	9	9	15	18	15	18	18	18
Bottom scouring and deposition	4	8	16	20	8	20	20	20
Bottom substrate/available cover	2	5	5	2	7	17	12	12
Average depth riffles and runs	3	0	18	24	0	24	6	18
Average depth pools	24	18	24	24	24	24	24	24
Flow at low flow	0	0	18	24	0	24	0	18
Pool-riffle, run-bend ratio	4	16	12	12	8	16	12	18
Aesthetics	8	10	14	10	10	14	14	16
Overall score[2]	97	117	194	206	125	233	161	220
	Good	Good	Fair	Poor	Good	Poor	Fair	Poor

[1]Highest score possible is 135. Scores ranked as 111–135 excellent;75–102 good; 39–66 fair; 0–30, poor.
[2]Lowest score possible is 58. Scores ranked as <70, excellent; 71–129 good; 130–200 fair; >200, poor.

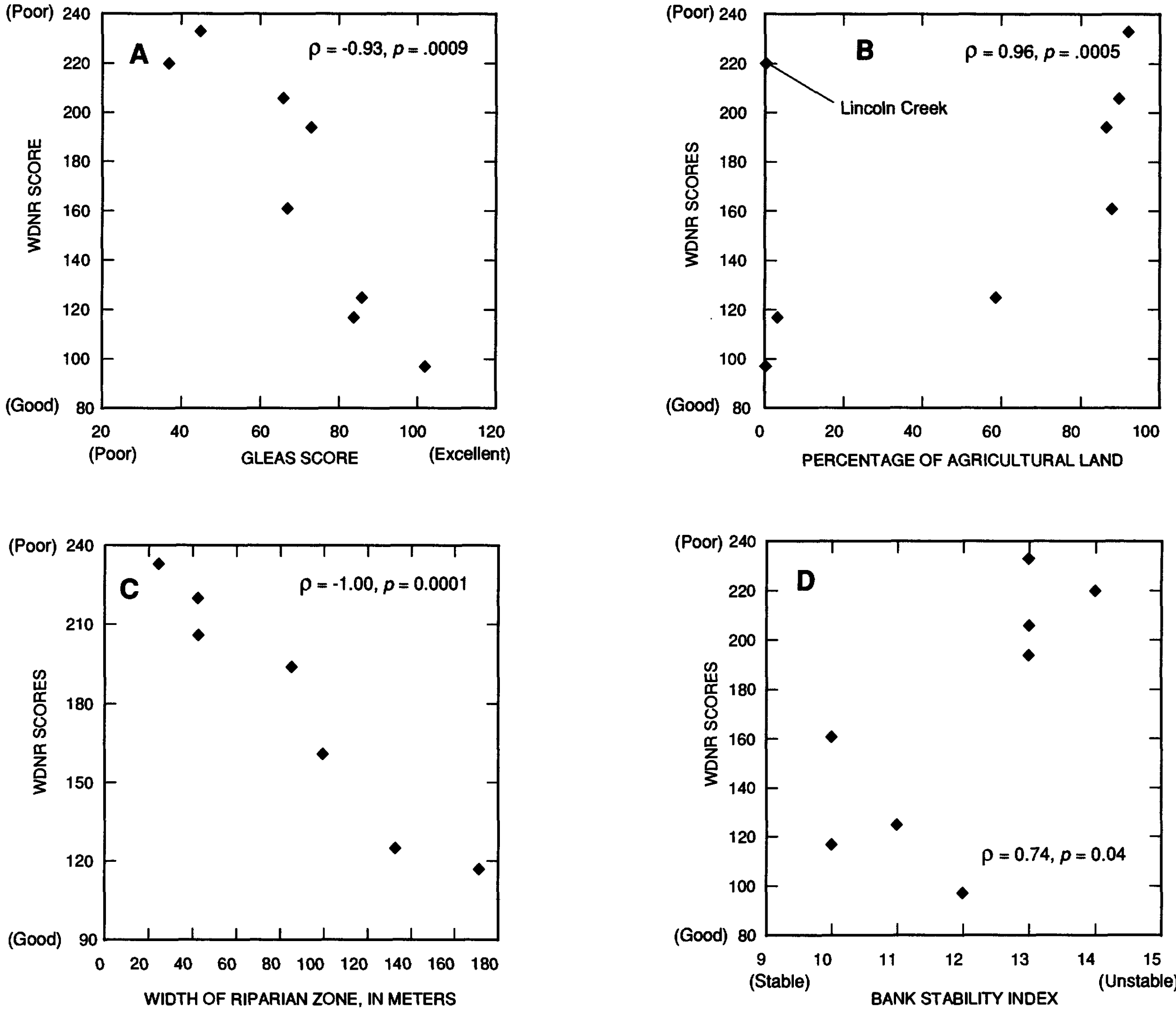


Figure 16. Correlations among Wisconsin Department of Natural Resources (WDNR) habitat evaluation scores and selected basin and reach characteristics for indicator sites in the Western Lake Michigan Drainages study unit (ρ, Spearman's correlation coefficient; *p*, *p*-value for correlation; GLEAS, Michigan Great Lakes Environmental Assessment Section).

rather than with the other agricultural sites. The GLEAS scores were not as well correlated to the BSI as WDNR scores were, perhaps because of the down-weighting of bank characteristics in the GLEAS rating (substrate and instream cover and channel morphology metrics were weighted higher than bank and riparian structure).

Although the objectives of the two evaluation systems were similar, the WDNR system was designed to rate the stream to "its highest potential" rather than its current condition. This information could then be used to provide background information for informed management decisions. The GLEAS evaluation, however, was designed to evaluate the stream's current condition and the effects of nonpoint sources. Both of the evaluations ordered the streams similarly; and using the qualitative wording, the WDNR ratings were slightly lower overall than the GLEAS ratings. Many of the metrics used were the same or similar between the two systems. The similarity in the resulting scores may simply reflect the difficulty in distinguishing current conditions from stream potential. However, the ordering gives extra confidence in interpretation of the scores, considering that results from two different methods were in agreement on the relative condition of the streams.

Relations Among Basin- and Reach-Level Characteristics

Discussion on relations among basin- and reach-level characteristics is limited to those that have correlation coefficients greater than 0.80 and p-values less than 0.05. Several reach characteristics at indicator sites correlated with basin characteristics of land use and surficial deposits (figs. 17A–F). In general, indicator sites with stable streambanks are in basins with high percentage of forests and storage (lakes or wetlands), high percentage of coarse-textured surficial deposits, and low erodibility factors (figs. 17A–D). Three other reach characteristics that correlate with drainage basin erodibility are embeddedness, dominant substrate type, and velocity. High erodibility factors are correlated to highly embedded and fine-textured channel bottom substrates (figs. 17 E and F, respectively) and low velocities. In addition, streams with a high percentage of agriculture have wide flood plains and fine-textured dominant substrate types.

The importance of riparian-zone width is substantiated by some of the correlations observed between riparian-zone width and reach characteristics. For example, streams with large riparian zones had low bank heights and stable banks.

Meaningful correlations between other basin and reach characteristics are few. In general, sites with large runoff estimates tended toward high stream velocity, larger dominant and subdominant substrate size, and high riparian vegetation density. Sites with large 7-day, 2-year low flows had open canopies. Streams with large annual mean flows had high velocities. Long drainage basins tended to have high stream velocities and narrow channels.

RELATIONS AMONG HABITAT CHARACTERISTICS AND WATER CHEMISTRY

Correlation analysis was done on habitat characteristics at all levels and water-chemistry data that included pH, specific conductance, alkalinity, dissolved ammonium, dissolved nitrate plus nitrite, and total and dissolved phosphorus. Median values for water-chemistry data (table 10, at back of report) were used in the correlation analysis and are based on monthly and storm-related samples collected at the fixed sites from April 1993 through May 1995. Actual concentrations for these data and data for many additional constituents are found in Richards and others (1997).

Basin-level habitat characteristics at indicator and integrator sites correlated mainly with pH. Relatively low pH was measured in streams with high drainage density (ρ=-0.77), high relief (ρ=-0.79), high percentage of forest (ρ=-0.75), and igneous/metamorphic bedrock (ρ=-0.67). These correlations indicate that geology and topography in the basin are major factors that affect the pH of streams in the study unit, although land use–which also correlated with pH–is also a potential factor. Most of the forested land in the study unit is underlain by igneous or metamorphic rock, making it difficult to separate land use effects from geological effects.

Only a few habitat characteristics correlated with specific conductance. These included reach-level measurements of flood plain width and basal area of riparian vegetation. For unknown reasons, streams with steep streambanks also had higher specific conductance than streams with less steep streambanks. No relation was found between specific conductance and land use or bedrock geology, even though specific conductance correlated positively with percentage of agriculture and carbonate bedrock at benchmark streams in the WMIC study unit (Fitzpatrick and others, 1996).

Very few habitat characteristics significantly correlated with nutrient concentrations. The principal exception was for dissolved nitrate plus nitrite, for which high concentrations correlated with highly embedded (ρ=-0.69) and fine-grained bottom substrate (ρ=0.86), median suspended sediment concentrations (ρ=.60), large basal area of riparian vegetation (ρ=0.78), and high percentage of agriculture (ρ=0.72). This is the only nutrient of the four nutrients included in the analysis that appears to show some relation to land use and also to habitat characteristics affected by land use. Historically, the highest dissolved nitrate plus nitrite concentrations in the WMIC (Robertson and Saad, 1995b) also correlated with agricultural sites. The additional strong correlations between nitrate plus nitrite and fine-grained substrate, and embeddedness and to a lesser degree median suspended sediment concentrations, indicate the importance of collecting information on the sediment depositional environment in addition to sediment transport for understanding the variability of nutrient concentrations at a site.

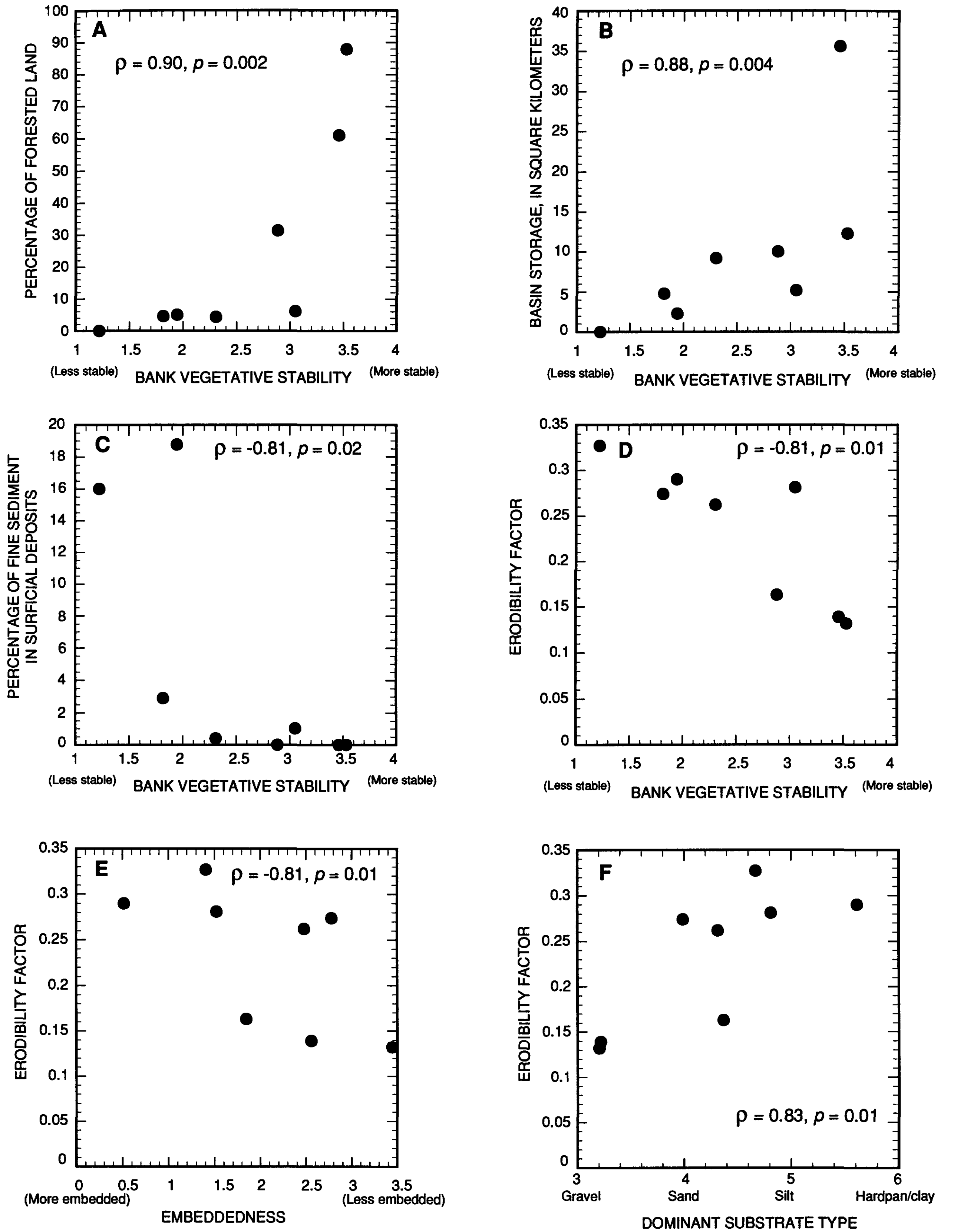


Figure 17. Correlations among basin and reach characteristics for indicator sites in the Western Lake Michigan Drainages study unit (ρ, Spearman's correlation coefficient, *p*, *p*-value for correlation).

The habitat evaluation scores at the indicator sites did not significantly correlate with any of the water-chemistry constituents included in this analysis. This result, along with the paucity of other correlations between habitat characteristics and water-chemistry data, indicate that both chemical and physical (habitat) characteristics of streams need to be examined to determine the limiting factors governing the distribution, frequency, and health of aquatic life.

IMPLICATIONS OF NATURAL AND HUMAN EFFECTS ON HABITAT CHARACTERSTICS

Effects of drainage-basin land use, geology, and topography are apparent on all levels of habitat characteristics. Effects of climate on the variability of habitat characteristics are minimal because there is little variability in temperature, evaporation, and precipitation in the study unit. At the drainage-basin scale, land use, bedrock geology, relief, and soil characteristics are important factors in determining drainage-network density, drainage shape, gradient, base flow, and flood characteristics of streams in the WMIC study unit. The interrelation of land use, geology, and topography with many habitat characteristics make it difficult to identify primary causative factors and indicate that basin-level features are probably determined by a complex interaction of several natural and human factors. For example, annual mean streamflow is related to physical characteristics of basin shape, drainage density, and soil characteristics; however, correlation results also indicate that agricultural streams have less base flow than they would with natural vegetation in their drainage basins. One implication of these results is that improvements to agricultural land use (implementing best management practices, conversion of agricultural land to natural vegetation) in the drainage basins of these streams has the potential for increasing base flow.

Results from the analyses of correlations among basin- and reach-level data at the indicator sites indicate that streambank stability, substrate embeddedness and size, and stream velocity are related to a combination of land use and soil characteristics. The inclusion of these reach characteristics in both habitat evaluation systems is evidence of their known influence on the quality of habitat. This example illustrates the importance of collecting habitat data at different scales (basin, segment, and reach) because even though reach characteristics are direct controls on habitat quality, they, in turn, may be influenced by land use, geology, and topography of the drainage basin.

This study did not look specifically at causal relations between riparian-zone width and overall habitat quality; however, other studies of streams in Wisconsin and Michigan (Wang and others, 1997; Roth and others, 1996) have shown that land use in the drainage basin is more important in determining habitat quality than local riparian zone conditions are. The conclusions from these studies are not all inclusive, especially for drainage basins with grazing or silviculture, where the width and extent of riparian zone have been found to influence habitat quality (Holaday, 1995; Armour and others, 1991).

The relations observed among habitat evaluation scores, streambank characteristics, land use, and riparian zone width are not unique to this study. Wang and others (1997) found similar correlations between amount of agricultural land, riparian width, and two different habitat-quality evaluations (Lyons, 1992; Lyons and others, 1996; and Simonson and others, 1994). Wang and others (1997) suggest that there may be a threshold level where the effects of agriculture do not manifest themselves until the drainage basin is greater than 50 percent agriculture. The limited data from the WMIC study indicate a threshold level of greater than 60 percent agriculture. Wang and others (1997) also found that riparian vegetation, geology, and topography were important factors in affecting habitat quality and, for some streams, sometimes were more important in determining habitat quality than the overall amount of different land uses within the drainage basin.

The WMIC data set may be too small to observe relations between habitat quality and nonpoint sources observed in other studies; however, Johnson and others (1997) also found similar relations between percentage of agriculture and nitrate plus nitrite concentrations. Their data indicate that phosphorus and ammonia concentrations are determined by a complex interaction of land use, geology, and local stream-sediment dynamics, and the importance of these three factors varied seasonally.

Geologic, geomorphic, and land-use data for the entire drainage basin also are important for understanding how a stream will respond to habitat improvements at various levels or scales. For example, if land-use improvements are made in the drainage basin, reach-level habitat characteristics may benefit as long as geologic and geomorphic characteristics are not the limiting factors. In addition, improvements to reach-level habitat characteristics may be only temporarily beneficial if natural and human factors at the basin level are ultimately controlling channel, substrate, and streambank characteristics.

SUMMARY AND CONCLUSIONS

Habitat characteristics of 11 fixed sites in the Western Lake Michigan Drainages were examined by the U.S. Geological Survey from 1993 through 1995 as part of the ecological assessment of the National Water-Quality Assessment Program. Evaluation of habitat consisted of more than 75 measurements at three spatial levels: drainage basin, stream segment between major tributaries, and stream reach; however, segment and reach-level data for the three integrator sites are limited.

Each of the 11 fixed sites has a unique combination of geology and land use; thus, the streams they represent contain the range of habitat characteristics influenced by both natural and human factors in the WMIC study unit. Many stream habitat characteristics differed significantly both spatially and temporally. For basin-level characteristics, significant correlations were found between land use, soil erodibility and permeability, drainage density, basin shape, overall stream gradient, flood characteristics, annual mean flow, and base flow at the 11 fixed sites. Almost all reach characteristics significantly differed among indicator sites. All three geomorphic units of riffle, run, and pool were present at eight indicator sites except for one, and, in general, most streams were dominated by run. Depths at the eight indicator sites were generally less than 1 m and widths generally less than 15 m. Stream velocities were less than 1 m/s. Dominant substrate types mainly consisted of gravel and sand and correlated to soil erodibility in the drainage basin. A full range of embeddedness was observed at the indicator sites and was related to the size of substrate and also to soil erodibility. Suspended-sediment concentrations also correlated to embeddedness, but this relation was confounded by whether the reach was located in a erosional, transport, or depositional setting.

Relations among habitat characteristics at the eight indicator sites were found within each spatial level and among different spatial levels. Bank vegetative stability and the NAWQA bank stability index significantly correlated with several basin-level characteristics including land use, basin storage, and soil texture and erodibility. Thus, a combination of land use, geology, and topography are inferred to be the most important factors that influenced habitat characteristics at all three spatial levels. These significant relations illustrate the importance of understanding how landscape-scale characteristics in the drainage basin ultimately may affect local habitat conditions along a reach.

Most of the temporal variability in reach characteristics is attributed to variable streamflow conditions. Although all indicator streams, except the Popple River, were wadable at the time of sampling and sampled at the same time of year, some variability in streamflow at the sampling dates was expected due to sampling logistics. The temporal variability observed in streambank characteristics stemmed from problems in identifying bankfull stage.

Habitat data from multiple-reach sites indicate that depth, bank stability index, and canopy angle in the primary reach adequately represented the variability found within the stream segment; however, within-segment variability of velocity, embeddedness, streambank angle, bank height, and bank vegetative stability was not completely accounted for at some of the primary reaches. These results indicate a potential for variability in algae, invertebrate, and fish communities among the multiple reaches at some indicator sites.

Bankfull flows at many of the indicator sites were much less than the estimated 2-year flood, an indication that flows spill out of the banks at least once a year and provide the water necessary to sustain the wetland vegetation present at these sites. Overall, the riparian vegetation at the indicator sites cover a wide range of possible types of flood plain vegetation in Wisconsin and Michigan. Riparian-vegetation characteristics affect the type of canopy cover along the stream and indicate how the riparian cover will change over time.

Habitat evaluation scores put stream-habitat quality at indicator sites into perspective with other streams in Wisconsin and Michigan. Even though different criteria were used in the two evaluations for this study, both evaluations produced similar ratings. Habitat ranged from poor at the urban site to good at the forested sites. Weighting scores from the indicator sites with scores from reference sites with the same geologic setting (essentially removing geology as the limiting factor) placed agricultural sites in the same categories (fair to poor) as the unweighted scores. It can be cautiously inferred from correlations among width of the riparian zone, streambank characteristics, and habitat evaluation scores that widening the riparian zone along agricultural streams has some potential for improving channel, substrate, and streambank conditions.

The paucity of correlations among habitat and water-chemistry data may be caused by the temporal variability inherent in the chemical data. Only a few habitat characteristics correlated with water-chemistry characteristics of pH, specific conductance, and nutrient concentrations. Geology and possibly land use correlated with pH; however, relations between geology and land use and specific conductance were not observed. Of the four nutrients included in the analyses, only dissolved nitrate plus nitrite concentrations correlated with the percentage of agriculture. Dissolved nitrate plus nitrite concentrations also correlated with embeddedness and fine-grained substrate, two reach-level characteristics that also correlated with percentage of agriculture and sediment deposition.

These results illustrate the need to collect data for both habitat and chemical characteristics of the stream when conducting an overall assessment of stream quality. Both reach-level habitat and chemical characteristics are ultimately affected by natural and human factors of land use, geology, and topography at the drainage-basin level. Analyses of the factors most important in determining the distribution and health of an aquatic community is strengthened by collecting habitat data at multiple scales—especially at the drainage-basin level—in addition to water-chemistry data.

This report is limited to the habitat part of a wider set of data-collection activities at the fixed sites that include community analyses of algae, invertebrates, and fish. Additional analyses of correlations among habitat characteristics, other aquatic organisms, and water chemistry also are being done by the WMIC NAWQA study team.

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SUPPLEMENTAL TABLES

Table 6. Basin-level habitat characteristics of fixed sites in the Western Lake Michigan Drainages study unit

[--, missing data; km^2, square kilometers; mi^2, square miles; km, kilometers; m, meters; m/km, meters per kilometer; cm/h, centimeters of rainfall absorbed before saturation per hour unit time; m^3/s, cubic meters per second; ft^3/s, cubic feet per second]

	Indicator sites								Integrator sites		
	Peshekee River near Martins Landing, Mich.	Popple River near Fence, Wis.	Pensaukee River near Krakow, Wis.	Duck Creek near Oneida, Wis.	Tomorrow River near Nelsonville, Wis.	East River near DePere, Wis.	North Branch Milwaukee River near Random Lake, Wis.	Lincoln Creek at 47th Street at Milwaukee, Wis.	Menominee River at McAllister, Wis.	Fox River at Green Bay, Wis.	Milwaukee River at Milwaukee, Wis.
USGS site number	04062085	04063700	04071795	04072050	04080798	04085109	040863095	040869415	04067500	04085139	04087000
Relatively homogeneous unit[1]	16	22	2	1	20	23	3	9	--	-	--
Drainage area (km^2, [mi^2])	127 [49.0]	360 [139]	92.7 [35.8]	247 [95.5]	114 [44.0]	122 [47.0]	133 [51.4]	24.8 [9.56]	10,200 [3,930]	16,400 [6,330]	1,800 [696]
Stream length[2] (km)	29.0	52	17	32	16	19	22	5.6	340	310	150
Stream gradient (m/km)	2.3	1.5	2.0	1.1	2.0	2.5	1.7	2.8	1.0	.22	.85
Cumulative stream length (km)	69.2	199	17.1	32.8	28.3	53.4	52.3	5.63	--	--	548
Drainage density (km/km^2)	.55	.55	.18	.13	.25	.44	.39	.22	--	--	.49
Basin shape	.30	.30	.74	.63	.54	.50	.52	.34	.28	.36	.19
Basin relief (m)	106	104	64	70	64	107	110	43	1,340	--	650
Basin storage (km^2)	12	36	9.2	4.8	10	2.3	5.2	.0	1,800	3000	100
Basin length (km)	20.8	34.6	11.2	19.8	14.5	15.6	16.0	8.51	150	168.0	76.1
2-year flood (m^3/s, [ft^3/s])	--	19 [680]	13 [450]	31 [1,100]	10 [360]	35 [1,300]	18 [650]	7 [250]	430 [15,000]	420 [15,000]	130 [4,700]
Annual mean flow (m^3/s, [ft^3/s])	2.4 [85]	3.1 [110]	.28 [10]	1.8 [64]	.82 [29]	1.2 [41]	.88 [31]	.24 [8.5]	79 [2,800]	170 [6,000]	14 [500]
2-yr 7-day low flow (m^3/s [ft^3/s])	--	.86 [30]	0 [0]	0 [0]	.49 [17]	0 [0]	.11 [4.0]	.07 [2.3]	41 [1,400]	38 [1,400]	1.5 [55]
Riparian width (m)	--	170	85	43	130	25	100	43	--	--	--
Bedrock type	Igneous/ metamorphic	Igneous/ metamorphic	Carbonate	Carbonate	Igneous/ metamorphic	Shale	Carbonate	Carbonate	Mixed	Mixed	Carbonate

Table 6. Basin-level habitat characteristics of fixed sites in the Western Lake Michigan Drainages study unit—Continued

	Indicator sites								Integrator sites		
	Peshekee River near Martins Landing, Mich.	Popple River near Fence, Wis.	Pensaukee River near Krakow, Wis.	Duck Creek near Oneida, Wis.	Tomorrow River near Nelsonville, Wis.	East River near DePere, Wis.	North Branch Milwaukee River near Random Lake, Wis.	Lincoln Creek at 47th Street at Milwaukee, Wis.	Menominee River at McAllister, Wis.	Fox River at Green Bay, Wis.	Milwaukee River at Milwaukee, Wis.
Surficial deposits (percent)[3]											
Clay	0	0	0	0.74	0	0.08	0	0	0	0.14	0
Fine loam	0	0	.41	2.2	0	19	1.0	16	.01	6.9	3.7
Medium loam	68	20	21	74	2.4	72	94	80	27	27	85
Coarse loam	3	45	57	11	68	1.6	.19	0	24	24	.62
Sand	0	5.0	5.6	1.4	7.7	2.0	.75	0	20	19	1.9
Muck	22	30	15	9.2	22	6.0	4.1	4	26	16	8.6
Bedrock	6	.25	0	0	0	0	0	0	1.8	.02	0
Erodibility factor[3]	.13	.14	.26	.27	.16	.29	.28	.33	.24	.20	.26
Permeability (cm/hr) [3]	3.1	5.7	3.1	1.7	6.4	2.0	3.1	1.0	5.2	5.0	4.6
Land use (percent)											
Agriculture	0	3.0	86	89	58	92	88	3.2	6.2	54	60
Forest	88	61	4.4	4.6	31	5.1	6.4	0	75	26	8.3
Wetland	10	35	9.2	4.8	8.8	2.5	4.0	0	16	11	4.5
Urban	0	.13	.23	.59	.21	.81	1.1	97	.60	2.8	26
Water	2.3	.65	0	0	1.2	0	.33	0	2.5	5.6	1.1
Annual precipitation (cm)	76	76	76	74	76	76	74	74	--	--	--
Annual evaporation (cm)	46	46	46	46	46	46	54	54	--	--	--
Annual runoff (cm)	38	28	23	23	25	22	21	21	27	22	21
Annual temperature (°C)	5.5	5.5	6.0	6.0	6.0	6.0	6.5	6.7	--	--	--

[1]Relatively homogeneous units are described in Robertson and Saad (1995a).
[2]Method for calculation is described in Meador and others (1993); data are derived from 1:24,000 scale U.S. Geological Survey topographic maps.
[3]Percentages of surficial deposits, erodibility factor, and permeability were obtained from U.S. Department of Agriculture (1991).

Table 7. Segment-level habitat characteristics of indicator sites in the Western Lake Michigan Drainages study unit

[--, missing data; m, meters; km, kilometers; Y, yes; N, no; N/A, not applicable]

	Stream order[1]	Down-stream link[2]	Channel sinuosity[2]	Segment gradient[2] (m/km)	Sideslope gradient[2]	Springs	Water-management feature: Type	Water-management feature: Distance from reference point[3] (km)
Peshekee River near Martins Landing, Mich.	2	--	1.12	1.1	0.19	Y	Bridge	0
							Bridge	-4.0
Popple River near Fence, Wis.	4	35	1.20	2.8	.061	Y	Bridge	0
							Artificial riffle	0
							Natural lake	-4.8
							Bridge	-4.8
Pensaukee River near Krakow, Wis.	4	33	1.39	.83	.031	N	Bridge	0
							Water treatment	2.4
							Bridge	-1.6
Duck Creek near Oneida, Wis.	5	47	1.05	.50	.041	N	Bridge	0
							Bridge	7.2
Tomorrow River near Nelsonville, Wis.	2	9	1.10	1.3	.050	Y	Bridge	0
							Streambank stabilization	0
							Artificial riffle	.02
							Impoundment	3.2
East River near DePere, Wis.	5	--	1.60	.59	.038	N	Bridge	0
							Channelized	0
North Branch Milwaukee River near Random Lake, Wis.	4	13	1.12	.80	.052	N	Bridge	0
							Channelized	-.2
							Diversion	0.8
							Artificial riffle	-.2
Lincoln Creek at 47th Street at Milwaukee, Wis.	2	--	N/A[4]	1.8	N/A[4]	N	Storm sewer	-.006
							Lowhead dam	0
							Storm sewer	.003
							Channelized	0

[1]Method for calculating stream order is based on Strahler (1954, 1957); data are derived from blue lines on 1:24,000-scale U.S. Geological Survey topographic maps.
[2]Method for calculation is described in Meador and others (1993); data are derived from 1:24,000-scale U.S. Geological Survey topographic maps.
[3]A positive number indicates feature is downstream, and a negative number indicates feature is upstream.
[4]Manmade channel.

Table 8. First-level reach habitat characteristics of indicator sites in the Western Lake Michigan Drainages study unit

[No data available for integrator sites; --, missing data]

	Date	Reach	Percent riffle	Percent pool	Percent run	Mean canopy angle[1] (degrees)	Mean aspect (degrees)	Mean width/ depth ratio	Bank stability Index[2]	Vegeta-tion density[3]	Mean basal area (cm^2)[4]
Peshekee River near Martins	6/15/93	A	44	56	0	89.7	210	45.0	12	--	--
Landing, Mich.	5/27/94	A	59	0	41	118	199	49.1	13	421	1.77
	5/25/95	A	40	0	60	79.7	206	35.7	10	43.4	44.7
Popple River near Fence, Wis.	6/16/93	A	--	--	--	--	--	--	--	--	--
	5/26/94	A	10	0	90	134	72	43.7	11	13.5	10.7
	5/24/95	A	10	0	90	--	--	--	9	4.32	7.44
Pensaukee River near Krakow,	6/7/93	A	29	20	51	33.8	213	34.6	12	--	--
Wis.	5/25/94	A	26	24	50	74.4	226	28.0	14	7.30	233
	5/22/95	A	22	18	60	60.2	222	31.6	12	10.8	307
Duck Creek near Oneida, Wis.	6/3/93	A	37	13	50	0	143	15.8	13	--	--
	5/20/94	A	24	24	52	2.7	149	29.3	14	5.4	588
	5/21/94	B	26	15	59	35.2	238	37.7	14	13.3	237
	5/21/94	C	17	40	43	28.0	52	38.7	14	28.3	196
	5/17/95	A	29	0	71	22.3	142	21.2	13	6.1	165
Tomorrow River near Nelson-	6/2/93	A	7	63	30	0	152	14.7	10	--	--
ville, Wis.	5/23/94	A	4	13	83	45.5	151	23.8	12	16.1	26.2
	5/23/94	B	14	0	86	66.7	138	19.1	11	17.5	53.6
	5/24/94	C	17	0	83	40.2	148	37.5	11	38.1	96.0
	5/19/95	A	4	0	96	115	150	21.2	10	34.6	96.0
East River near DePere, Wis.	6/3/93	A	15	16	69	0	176	13.4	12	--	--
	5/19/94	A	15	15	70	45.8	229	21.4	13	8.99	411
	5/17/95	A	12	16	72	58.7	223	26.7	14	8.75	146
North Branch Milwaukee River	5/23/93	A	14	65	21	94.0	213	24.0	10	--	--
near Random Lake, Wis.	5/17/94	A	32	55	13	107	220	37.1	10	.15	243
	5/17/94	B	6	38	56	114	210	31.2	10	--	290
	5/18/94	C	14	51	35	93.7	221	43.3	10	--	1,900
	5/16/95	A	25	29	46	124	224	40.0	11	.067	279
Lincoln Creek at 47th Street at	5/19/93	A	19	41	40	85.5	149	33.6	14	--	--
Milwaukee, Wis.	5/16/94	A	22	39	39	75.5	135	36.3	14	4.92	62.9
	5/15/95	A	22	30	48	93.7	134	36.8	13	6.47	72.7

[1]Measured according to Meador and others (1993).

[2]Bank-stability index combines bank angle, vegetative stability, height, and substrate into one index. Possible scores from most to least stable range from 4 to 22.

[3]Density is expressed as mean number of trees or shrubs in a 100-square meter area and was calculated using the point centered quarter method (Mueller-Dombois and Ellenberg, 1974).

[4]Basal area is calculated from the point centered quarter method (Mueller-Dombois and Ellenberg, 1974). Trees and shrubs that were less than 3-cm diameter at breast height were included in the calculation using an average diameter of 1.5 cm (1.77 cm^2 basal area).

Table 9. Transect-level habitat characteristics of fixed sites in the Western Lake Michigan Drainages study unit

[Abbreviations: m, meters; m/s, meters per second; RHU, relatively homogeneous unit; gv, gravel; sa, sand; bo, boulder; co, cobble; mu, muck; de, detritus; bd, bedrock; si, silt. Embeddedness codes: 5, less than 5 percent of surface area of gravel, cobble, and boulder particles covered by fine sediment; 4, 5 to 25 percent covered by fine sediment; 3, 26 to 50 percent covered by fine sediment; 2, 51 to 75 percent covered by fine sediment; 1, more than 75 percent covered by fine sediment. N/A, no gravel, cobble or boulder present. --, missing data]

Site name	Reach	Date sampled	Transect	Geomorphic channel unit[1]	Channel width (m)	Depth (m)	Velocity (m/s)	Bottom substrate: Dominant	Bottom substrate: Sub-dominant	Embeddedness	Silt present[2]
Indicator sites											
Peshekee River	A	6/15/93	1	--	14.5	0.25-0.30	0.37-0.61	co	gv	3-4	No
			2	Run/pool	16.1	0.40-0.60	0.17-0.29	co	gv	3	No
			3	Riffle	11.0	0.30-0.35	0.55-0.67	co-gv	co-gv	3	No
			4	Run	12.0	0.22-0.45	0.34-0.61	co-gv	co-gv	3	No
			5	Riffle	14.0	0.070-0.30	0.61-0.73	co-gv	co-gv	3-4	No
			6	--	13.5	0.20-0.37	0.11-0.85	co	gv	3-4	No
Peshekee River	A	5/27/94	1	--	14.3	0.25-0.34	0.30-0.58	gv	co	3	No
			2	Run	17.6	0.40-0.63	0.20-0.30	co	gv-sa	3	No
			3	Riffle	11.6	0.25-0.35	0.67-0.76	co-gv	co-gv	3	No
			4	Run	12.2	0.23-0.33	0.24-0.73	co	gv	3	No
			5	Riffle	13.8	0.10-0.23	0.64-0.76	co-gv	co-gv	3	No
			6	--	12.6	0.16-0.25	0.23-1.07	co-sa	co-gv	3-4	No
Peshekee River	A	5/25/95	1	--	15.4	0.38-0.47	0.61-0.98	co	gv	4	No
			2	Run	16.8	0.59-0.73	0.28-0.46	co	gv	4	No
			3	Riffle	14.2	0.29-0.58	0.67-0.88	co	gv	4	No
			4	Run	11.8	0.31-0.55	0.55-0.85	co	gv	4	No
			5	Riffle	14.6	0.17-0.43	0.82-1.01	co	gv	3-4	No
			6	--	14.2	0.49-0.59	0.52-0.64	co	gv	4	No
Popple River	A	6/16/93[3]	1	--	--	--	--	--	--	--	--
			2	--	--	--	--	--	--	--	--
			3	--	--	--	--	--	--	--	--
			4	--	--	--	--	--	--	--	--
			5	--	--	--	--	--	--	--	--
			6	--	--	--	--	--	--	--	--
Popple River	A	5/26/94	1	--	16.9	0.18-0.42	0.46-0.94	br	br	5	No
			2	Riffle	16.8	0.23-1.0	-0.13-1.16[4]	br-sa	gv-sa	0-5	No-Yes
			3	Riffle/run	21.9	0.40-0.72	0.070-0.55	bo	co-sa	4	No-Yes
			4	Run/pool	20.0	0.90-1.1	0.15-0.21	bo-gv	gv-sa	1-3	Yes
			5	Run/pool	28.4	0.70-0.90	0.17-0.19	sa	si	0	Yes
			6	--	23.0	1.1	0.11-0.18	bo-sa	co-si	0-3	Yes

Table 9. Transect-level habitat characteristics of fixed sites in the Western Lake Michigan Drainages study unit—Continued

Site name	Reach	Date sampled	Tran-sect	Geomorphic channel unit[1]	Channel width (m)	Depth (m)	Velocity (m/s)	Bottom substrate		Embed-dedness	Silt pre-sent[2]
								Dominant	Sub-dominant		
Popple River	A	5/24/95[3]	1	--	--	--	--	--	--	--	--
			2	Riffle	--	--	--	--	--	--	--
			3	Riffle/run	--	--	--	--	--	--	--
			4	Run/pool	--	--	--	--	--	--	--
			5	Run/pool	--	--	--	--	--	--	--
			6	--	--	--	--	--	--	--	--
Pensaukee River	A	6/07/93	1	--	8.0	0.34-0.39	0.094-0.15	sa	gv	0-4	No
			2	Riffle	5.8	0.14-0.19	0.26-0.55	co-gv	gv-sa	4	No
			3	Run	8.3	0.35-0.41	0.12-0.15	co-gv	gv-sa	3-4	No
			4	Riffle	4.9	0.19-0.25	0.16-0.64	gv-sa	gv-sa	2-3	No
			5	Run	9.9	0.23-0.47	0.046-0.26	gv	sa	3-4	No
			6	--	10.3	0.39-0.48	0.00-0.15	gv-sa	gv-sa	2-3	No
Pensaukee River	A	5/25/94	1	--	8.0	0.30-0.45	0.10-0.12	gv	sa	3-4	No-Yes
			2	Riffle	7.6	0.17-0.25	0.16-0.37	gv-sa	gv-sa	3	No-Yes
			3	Run	8.4	0.31-0.39	0.055-0.16	gv-si	gv-sa	2-3	Yes
			4	Riffle	5.3	0.13-0.29	0.17-0.52	sa	gv	1-2	No-Yes
			5	Run	9.5	0.18-0.39	0.00-0.21	gv	sa-si	2-4	Yes
			6	--	10.5	0.31-0.50	0.067-0.15	gv	sa	2-3	No-Yes
Pensaukee River	A	5/22/95	1	--	7.7	0.30-0.31	0.037-0.043	gv	sa	1	Yes
			2	Riffle	7.2	0.16-0.23	0.055-0.12	co-si	gv-sa	0-2	Yes
			3	Run	8.2	0.29-0.34	0.00-0.070	gv-sa	gv-sa	1-3	Yes
			4	Riffle	5.4	0.080-0.20	0.00-0.25	gv-sa	gv-sa	2	Yes
			5	Run	8.1	0.18-0.35	0.030-0.052	gv-sa	gv-sa	2-3	Yes
			6	--	10.6	0.27-0.39	0.00-0.046	gv-si	gv-si	1-2	Yes
Duck Creek	A	6/03/93	1	--	10.3	0.71-0.73	0.16-0.28	sa	gv	4	Yes
			2	Run	10.7	0.47-0.64	0.13-0.49	gv-sa	co-sa	3-4	Yes
			3	Riffle	9.0	0.36-0.51	0.16-0.64	gv	sa	3-4	Yes
			4	Run	7.0	0.51-0.74	0.22-0.43	gv	co-sa	4	Yes
			5	Riffle	8.6	0.27-0.48	0.16-0.76	co-gv	gv-sa	4	Yes
			6	--	7.5	0.22-0.31	0.94-1.01	co-gv	co-sa	4	Yes
Duck Creek	A	5/20/94	1	--	10.5	0.27-0.42	0.10-0.14	sa	gv	1	Yes
			2	Run	8.0	0.22-0.23	0.085-0.28	gv-sa	gv-sa	1-3	Yes
			3	Riffle	4.1	0.08-0.18	0.30-0.67	gv	co-sa	4	No
			4	Run	5.7	0.34-0.47	0.037-0.21	co-sa	gv-sa	2-4	No-Yes
			5	Riffle	4.9	0.15-0.25	0.46-0.98	gv	gv-sa	4	No
			6	--	5.0	0.14-0.25	0.46-0.88	gv	co-sa	4	No

Table 9. Transect-level habitat characteristics of fixed sites in the Western Lake Michigan Drainages study unit—Continued

Site name	Reach	Date sampled	Tran-sect	Geomorphic channel unit[1]	Channel width (m)	Depth (m)	Velocity (m/s)	Bottom substrate		Embed-dedness	Silt pre-sent[2]
								Dominant	Sub-dominant		
Duck Creek	B	5/21/94	1	--	13.7	0.27-0.41	0.027-0.18	gv-sa	co-gv	0-3	Yes
			2	Riffle	5.0	0.18-0.22	0.37-0.55	gv	co-sa	3-4	No-Yes
			3	Run/pool	9.8	0.32-0.40	0.043-0.12	gv	bo-co	3	Yes
			4	Riffle	10.7	0.14-0.31	0.00-0.34	co-gv	bo-gv	3	No-Yes
			5	Pool	13.3	0.47-0.57	0.00-0.058	gv	co	2-3	Yes
			6	--	10.9	0.18-0.32	0.12-0.20	co-gv	co-gv	2-3	Yes
Duck Creek	C	5/21/94	1	--	12.4	0.14-0.27	0.073-0.15	co-gv	co-sa	2	Yes
			2	Run/pool	14.5	0.35-0.43	0.00-0.037	gv-sa	co-gv	1-2	Yes
			3	Pool	13.5	0.30-0.48	0.030-0.076	gv	co-sa	1-2	Yes
			4	Riffle/run	9.3	0.21-0.25	0.076-0.23	co	gv	3	No-Yes
			5	Pool	11.5	0.44-0.62	0.00-0.12	co-gv	bo-co	2-3	Yes
			6	--	10.0	0.17-0.29	0.12-0.14	co-gv	gv-sa	2-3	Yes
Duck Creek	A	5/17/95	1	--	12.6	0.59-0.61	0.027-0.30	sa	gv-sa	0-2	No
			2	Run	8.8	0.53-0.76	0.20-0.43	gv-sa	gv-sa	2-3	No
			3	Riffle	6.4	0.27-0.45	0.61-0.76	gv	co-sa	2	No
			4	Run	6.8	0.41-0.81	0.17-0.52	co-gv	gv-sa	2-3	No
			5	Riffle	6.2	0.36-0.42	0.24-1.01	co-gv	gv-sa	3	No
			6	--	6.0	0.25-0.32	0.61-0.79	bo-gv	co-sa	3	No
Tomorrow River	A	6/02/93	1	--	8.3	0.47-0.85	0.19-0.52	co-sa	gv-de	0-4	No
			2	Riffle	9.2	0.39-0.90	0.13-0.46	sa-mu	gv-sa	0-4	No
			3	Run	8.8	0.56-0.90	0.34-0.43	sa	gv	0	No
			4	Run	11.2	0.57-0.86	0.28-0.46	sa	gv-de	0-4	No
			5	Riffle	5.5	0.37-0.69	0.34-0.61	bo-sa	co-sa	0-4	No
			6	--	11.2	0.57-0.79	0.19-0.55	bo-sa	gv-sa	0-4	No
Tomorrow River	A	5/23/94	1	--	9.6	0.45-0.67	0.18-0.29	sa	sa-si	0-2	No-Yes
			2	Riffle	7.6	0.31-0.65	0.10-0.29	gv-sa	co-si	0-3	No-Yes
			3	Run	8.0	0.30-0.45	0.24-0.37	sa	gv-sa	0-3	No-Yes
			4	Run	7.0	0.40-0.49	0.34-0.40	sa	gv	3	No
			5	Riffle	9.6	0.080-0.38	0.058-0.29	co-sa	gv	1-4	No
			6	--	8.3	0.39-0.54	0.30-0.43	co-sa	co-gv	3-4	No
Tomorrow River	B	5/23/94	1	--	7.5	0.30-0.50	0.00-0.16	bo-sa	sa-de	0-3	No-Yes
			2	Run/riffle	7.0	0.22-0.51	0.10-0.58	bo-sa	bo-de	2-4	No
			3	Run	8.7	0.30-0.60	0.10-0.23	gv-sa	gv-de	0-3	No-Yes
			4	Riffle/run	7.3	0.35-0.60	0.12-0.37	co-sa	gv-de	0-3	No-Yes
			5	Run/pool	7.8	0.50-0.60	0.16-0.34	sa	gv-de	0-1	Yes
			6	--	11.3	0.18-0.55	0.23-0.49	bo-sa	bo-sa	3-4	No-Yes

Table 9. Transect-level habitat characteristics of fixed sites in the Western Lake Michigan Drainages study unit—Continued

Site name	Reach	Date sampled	Tran-sect	Geomorphic channel unit[1]	Channel width (m)	Depth (m)	Velocity (m/s)	Bottom substrate		Embed-dedness	Silt pre-sent[2]
								Dominant	Sub-dominant		
Tomorrow River	C	5/24/94	1	--	10.0	0.43-0.52	-0.030[5]-0.70	co-gv	co-gv	2-3	No-Yes
			2	Riffle	7.6	0.33-0.35	0.043-0.64	co	gv-de	2-3	No-Yes
			3	Run	8.1	0.42-0.65	0.15-0.34	sa	gv-de	0-3	No-Yes
			4	Run	7.0	0.43-0.53	0.13-0.34	sa-de	co-sa	0-3	No-Yes
			5	Riffle	6.7	0.26-0.53	0.25-0.40	co-sa	co-gv	0-3	No-Yes
			6	--	7.5	0.36-0.45	0.094-0.26	co-sa	co-de	0-3	No-Yes
Tomorrow River	A	5/19/95	1	--	7.4	0.43-0.68	0.16-0.30	sa-mu	gv-mu	0-4	No
			2	Riffle	7.1	0.39-0.81	0.12-0.30	sa-mu	gv-mu	0-3	No
			3	Run	8.3	0.26-0.49	0.21-0.37	sa	mu-de	0	No
			4	Run	8.0	0.34-0.42	0.15-0.40	sa	gv-de	0-2	No
			5	Riffle	12.0	0.28-0.37	0.37-0.58	bo-sa	co-de	0-4	No
			6	--	10.3	0.36-0.51	0.14-0.25	bo-sa	gv-sa	1-4	No
East River	A	6/03/93	1	--	5.4	0.22-0.39	0.40-0.43	sa	gv-cl	0	Yes
			2	Riffle	4.0	0.3-0.38	0.27-0.52	sa	gv	0	Yes
			3	Run	5.7	0.52-0.79	0.082-0.10	sa-cl	gv-sa	0	Yes
			4	Pool	11.0	0.74-0.85	0.00	sa	gv	0	Yes
			5	Run	5.4	0.79-1.2	0.00-0.16	sa-cl	gv	1	Yes
			6	--	6.1	0.53-0.74	0.11-0.12	sa	gv-de	0-1	Yes
East River	A	5/19/94	1	--	16.6	0.37-0.82	0.082-0.13	sa-cl	gv-cl	0	Yes
			2	Riffle	6.7	0.25-0.51	0.040-0.12	gv	sa	1-4	Yes
			3	Run	9.4	0.75-0.88	0.027-0.037	gv-sa	sa-cl	0-2	Yes
			4	Pool	11.2	0.54-0.95	0.015-0.052	gv-sa	gv-cl	0-1	Yes
			5	Run	6.3	0.76-0.98	0.058-0.091	gv-cl	sa-cl	0-2	Yes
			6	--	9.1	0.51-0.75	0.046-0.13	gv-cl	sa	0-2	Yes
East River	A	5/17/95	1	--	18.3	0.48-0.62	0.027-0.058	cl	sa	0	Yes
			2	Riffle	13.0	0.14-0.21	0.21-0.23	sa-cl	gv-sa	0-1	No-Yes
			3	Run	7.5	0.64-0.94	0.018-0.021	sa-cl	cl	0	Yes
			4	Pool	10.8	0.56-0.78	0.021-0.024	cl	sa	0	Yes
			5	Run	6.7	0.54-0.82	0.021-0.12	cl	sa	0	Yes
			6	--	5.9	0.45-0.63	0.027-0.046	cl	sa	0	Yes
North Branch Milwaukee River	A	5/23/93	1	--	10.5	0.40-1.1	0.14-0.34	sa-mu	gv-mu	0	Yes
			2	Riffle/run	15.3	0.49-0.56	0.20-0.30	gv-sa	gv-sa	0-4	Yes
			3	Riffle	10.0	0.47-0.58	0.39-0.56	gv-sa	gv-sa	0	Yes
			4	Riffle/run	10.5	0.42-0.48	0.42-0.59	sa	gv	3-4	Yes
			5	Pool	12.9	0.64-0.70	0.32-0.34	sa-si	gv-sa	0-4	Yes
			6	--	10.0	0.55-0.59	0.43-0.45	sa	gv	0-4	No

Table 9. Transect-level habitat characteristics of fixed sites in the Western Lake Michigan Drainages study unit—Continued

Site name	Reach	Date sampled	Tran-sect	Geomorphic channel unit[1]	Channel width (m)	Depth (m)	Velocity (m/s)	Bottom substrate: Dominant	Bottom substrate: Sub-dominant	Embed-dedness	Silt pre-sent[2]
North Branch Milwaukee River	A	5/17/94	1	--	10.3	0.040-0.97	0.00-0.23	sa-si	sa-cl	0	Yes
			2	Riffle/run	15.0	0.22-0.26	0.00-0.41	gv	sa	1-4	No-Yes
			3	Riffle	9.5	0.12-0.38	0.25-0.70	gv	sa	4	No
			4	Riffle/run	10.7	0.16-0.36	0.25-0.43	gv	sa	3-4	No-Yes
			5	Pool	15.5	0.23-0.57	0.13-0.19	sa	gv	0-3	Yes
			6	--	10.4	0.32-0.37	0.26-0.27	gv-sa	gv-sa	1-2	Yes
North Branch Milwaukee River	B	5/17/94	1	--	11.2	0.25-0.68	0.11-0.23	sa-si	gv-ma	0-4	Yes
			2	Riffle	10.0	0.27-0.30	0.26-0.64	gv	sa	2-3	No-Yes
			3	Run	9.9	0.29-0.35	0.26-0.29	gv	sa	0-2	No-Yes
			4	Pool	13.0	0.35-0.57	0.12-0.15	sa-si	si-ma	0-2	Yes
			5	Pool	14.0	0.46-0.60	0.076-0.16	sa	gv-cl	0	Yes
			6	--	14.3	0.25-0.77	0.091-0.11	sa-cl	sa-cl	0	Yes
North Branch Milwaukee River	C	5/18/94	1	--	10.7	0.30-1.0	0.052-0.16	si	sa-cl	0	Yes
			2	Pool	13.6	0.33-0.94	0.00-0.17	cl	sa	0	Yes
			3	Pool	13.6	0.18-0.69	0.00-0.14	sa	cl	0	Yes
			4	Riffle	13.2	0.090-0.21	0.17-0.73	gv	sa	2-3	No-Yes
			5	Run/riffle	17.8	0.25-0.37	0.094-0.29	sa-gv	sa-si	0-3	No-Yes
			6	--	18.7	0.19-0.45	0.052-0.20	sa-si	gv-cl	0-1	Yes
North Branch Milwaukee RIver	A	5/16/95	1	--	10.7	0.14-0.31	0.14-0.29	si	gv-si	0-2	No-Yes
			2	Riffle/run	16.0	0.29-0.33	0.10-0.52	bo-sa	gv-sa	1-3	No
			3	Riffle	10.3	0.19-0.32	0.43-0.76	co-gv	co-sa	2-3	No
			4	Riffle/run	10.9	0.24-0.27	0.37-0.61	gv	sa	3	No
			5	Pool	10.8	0.45-0.52	0.20-0.26	gv	hp	2	No
			6	--	12.0	0.34-0.59	0.25-0.30	gv-hp	sa-hp	0-1	No
Lincoln Creek	A	5/19/93	1	--	11.3	0.40-0.8	0.00	gv-cl	gv-cl	1-2	Yes
			2	Run/pool	12.1	0.38-0.49	0.00-0.23	gv-cl	gv-sa	1-4	Yes
			3	Riffle	12.3	0.10-0.15	0.061-0.070	gv	sa	1	Yes
			4	Pool	10.0	0.57-0.65	0.00-0.23	gv-sa	gv-si	1-2	Yes
			5	Riffle	8.5	0.10-0.45	0.061-0.091	gv-cl	sa-cl	1	Yes
			6	--	12.0	0.14-0.47	0.00-0.073	co-sa	gv-si	1	Yes
Lincoln Creek	A	5/16/94	1	--	12.5	0.38-0.71	0.00	gv-sa	gv-sa	1-3	Yes
			2	Run/pool	12.1	0.35-0.42	0.00	gv-sa	gv-sa	1-2	Yes
			3	Riffle	13.0	0.090-0.15	0.00	gv	sa	1	Yes
			4	Pool	10.2	0.56-0.78	0.00	gv-cl	gv-sa	1	Yes
			5	Riffle	9.5	0.16-0.44	0.00-0.073	gv-cl	sa-cl	1	Yes
			6	--	10.0	0.23-0.31	0.00	gv	sa	1	Yes

Table 9. Transect-level habitat characteristics of fixed sites in the Western Lake Michigan Drainages study unit—Continued

Site name	Reach	Date sampled	Tran-sect	Geomorphic channel unit[1]	Channel width (m)	Depth (m)	Velocity (m/s)	Bottom substrate		Embed-dedness	Silt pre-sent[2]
								Dominant	Sub-dominant		
Lincoln Creek	A	5/15/95	1	--	12.0	0.44-0.80	0.00-0.040	gv-hp	gv-hp	0-2	No
			2	Run/pool	12.8	0.39-0.45	0.00-0.061	gv-sa	gv-sa	1-2	No
			3	Riffle	13.3	0.11-0.17	0.10-0.12	gv-sa	gv-sa	2	No
			4	Pool	11.0	0.52-0.59	0.0091-0.021	gv-cl	gv-sa	1-2	No
			5	Riffle	10.0	0.17-0.35	0.00-0.20	gv-sa	co-sa	1-2	No
			6	--	10.5	0.27-0.37	0.10-0.11	gv-cl	gv-sa	2	No
Integrator sites											
Menominee River	A	5/23/95	1	Run	--	--	--	co	gv	3	No
			2	Run	--	--	--	co	gv	3	No
			3	Run	--	--	--	gv	co	3	No
			4	Run	--	--	--	si	si	0	Yes
			5	Run	--	--	--	bo	co	3	No
			6	Run	--	--	--	--	--	--	--
Fox River[5]	A	--	--	--	150	7	--	cl	si	--	Yes
Milwaukee River	A	5/17/95[6]	1	--	--	--	--	co	gv	3	No
			2	Run	--	--	--	co	gv	3	No
			3	Run	--	--	--	gv	co	3	No
			4	Run	--	--	--	si	si	0	Yes
			5	Pool	--	--	--	bo	co	3	No
			6	--	--	--	--	--	--	--	--

[1]Transects 1 and 6, at the beginning and end of the reach, are between geomorphic channel units.

[2]Silt present or absent recorded as one measurement for entire reach in 1993. In 1994, silt recorded at each point in a transect.

[3]Popple River not wadable on this date.

[4]Flow moving upstream from eddy effects.

[5]Data are from Ball and others (1985) and represent average conditions in reach.

[6]Only one point, instead of three points, was sampled; data limited because of unwadable sections of stream.

Table 10. Median values of selected water-chemistry characteristics of fixed sites in the Western Lake Michigan Drainages study unit

[μs/cm, microsiemens per centimeter; °C, degrees Celsius; mg/L, milligrams per liter; N, nitrogen; P, phosphorus; $CaCO_3$, calcium carbonate]

Site	Indicator sites								Integrator sites		
	Peshekee River near Martins Landing, Mich.	Popple River near Fence, Wis.	Pensaukee River near Krakow, Wis.	Duck Creek near Oneida, Wis.	Tomorrow River near Nelsonville, Wis.	East River near DePere, Wis.	North Branch Milwaukee River near Random Lake, Wis.	Lincoln Creek at 47th Street at Milwaukee, Wis.	Menominee River at McAllister, Wis.	Fox River at Green Bay, Wis.	Milwaukee River at Milwaukee, Wis.
Specific conductance (μS/cm at 25°C)	38	148	628	733	381	770	684	768	248	394	682
pH (standard units)	7.0	7.6	8.0	8.1	8.0	8.0	8.3	8.0	8.0	8.4	8.4
Ammonium, dissolved, mg/L as N	.04	.03	.065	.085	.03	.10	.07	.08	.02	.12	.035
Nitrate plus nitrite, dissolved, mg/L as N	.073	.057	.78	.84	1.8	1.0	1.6	.54	.096	.32	.76
Phosphorus, total, mg/L as P	.008	.02	.16	.15	.02	.24	.14	.045	.02	.12	.11
Phosphorus, dissolved, mg/L as P	.007	.008	.095	.10	.005	.18	.085	.025	.01	.05	.05
Alkalinity, mg/L as $CaCO_3$	16	68	280	260	190	270	310	160	110	160	260