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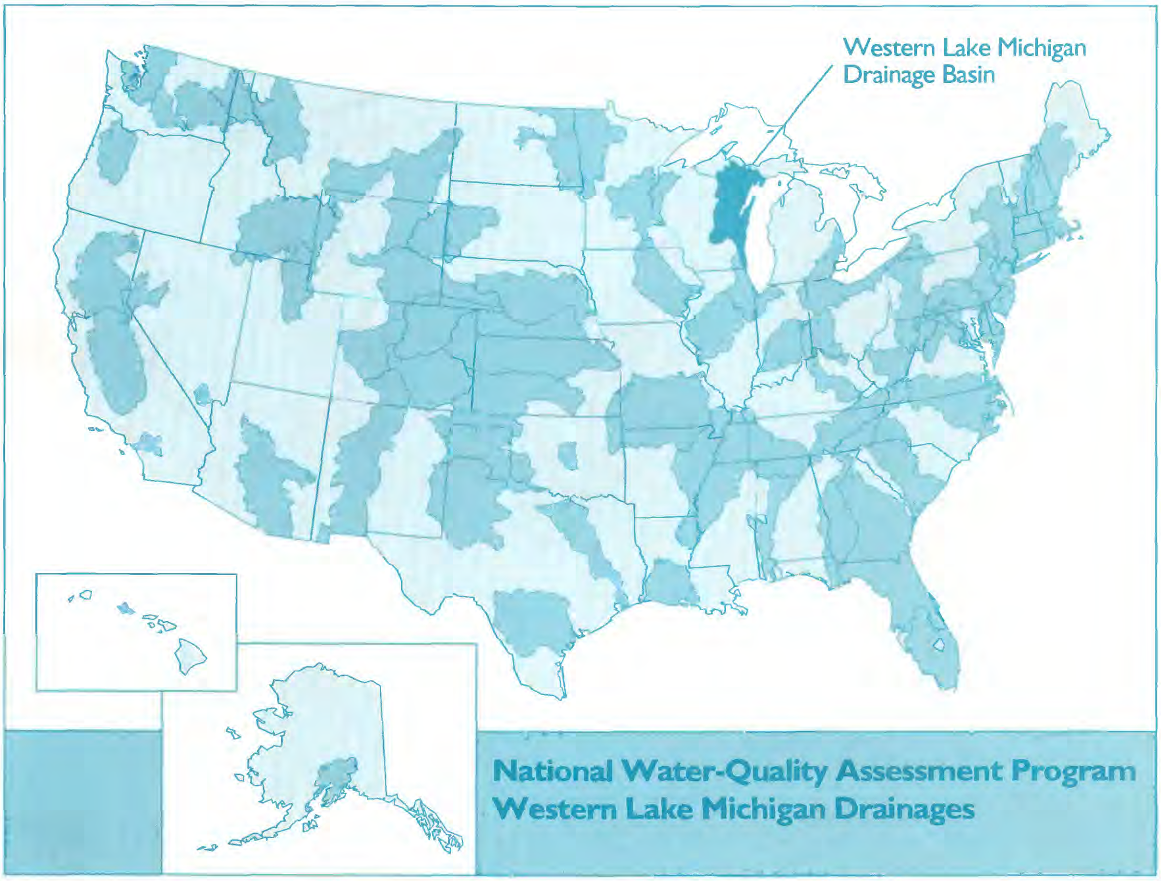
Habitat Characteristics of Benchmark Streams in Agricultural Areas of Eastern Wisconsin



National Water-Quality Assessment Program
Western Lake Michigan Drainages

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By Faith A. Fitzpatrick, Elise M. Peterson, and Jana S. Stewart

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BRUCE BABBITT, ***Secretary***

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

For additional information write to:

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

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FOREWORD

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

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

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

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

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

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

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

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

Robert M. Hirsch

Robert M. Hirsch
Chief Hydrologist

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CONVERSION FACTORS AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
centimeter (cm)	0.3937	inch
meter (m)	3.281	foot
kilometer (km)	0.6214	mile
square kilometer (km^2)	0.3861	square mile
meter per kilometer (m/km)	5.280	foot per mile
hectare	2.471	acre
meter per second (m/s)	3.281	foot per second
cubic meter per second (m^3/s)	35.31	cubic foot per second

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

°F = 1.8 (°C) + 32.

Abbreviated water-quality units used in this report: 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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Technical Reviewers

Charles A. Peters, Supervisory Hydrologist, U.S. Geological Survey, Madison, Wis.
Mitchell A. Harris, Ecologist, U.S. Geological Survey, Urbana, Ill.
Bernard N. Lenz, Hydrologist, U.S. Geological Survey, Madison, Wis.

Editorial and Graphics

Michael Eberle, Technical Publications Editor, U.S. Geological Survey, Columbus, Ohio
Karen R. Barr, Secretary, U.S. Geological Survey, Madison, Wis.
Michelle M. Greenwood, Cartographic Aide, U.S. Geological Survey, Madison, Wis.

Approving Official

Michael Yurewicz, Supervisory Hydrologist, U.S. Geological Survey, Reston, Va.

Habitat Characteristics of Benchmark Streams in Agricultural Areas of Eastern Wisconsin

By Faith A. Fitzpatrick, Elise M. Peterson, *and* Jana S. Stewart

Abstract

Stream habitat characteristics were measured at twenty sites in agricultural areas of eastern Wisconsin by the U.S. Geological Survey in May and June, 1993 as part of the National Water-Quality Assessment Program Western Lake Michigan Drainages study unit. These "benchmark" stream sites were selected for study to represent standards of reference for comparison to other streams in similar physical settings that appear to be more detrimentally affected by agriculture. The agricultural benchmark streams were selected from four physical settings, or relatively homogeneous units (RHU's), that differ in bedrock type and texture of surficial deposits. Habitat characteristics at streams in these four physical settings are described and compared to each other, and a habitat classification scheme was used to rank the quality of habitat in these streams. Additional aquatic information was collected along with the habitat data: water-quality data and population surveys of fish, invertebrates, and algae. Habitat data were collected at three levels: drainage basin, stream segment between major tributaries (length from 1 to 14 km), and stream reach (approximately 150 m).

Results of statistical analyses show that, in general, most correlations are among basin-level habitat characteristics. Few correlations were observed among reach- and basin-level characteristics. Principal components analysis (PCA) on basin-level data resulted in principal components that reflect RHU, land use or latitude, and basin size. Groupings of habitat characteristics at the reach level are less clearly attributed to some outside environmental factor. Streams that have undergone habitat restoration for fisheries group closely together on PCA ordination plots.

Less than half of the habitat characteristics were found to be significantly different between one RHU and the other three. Characteristics that differed between RHU's were mainly at the basin level but also included some reach-level characteristics.

Stream-habitat characteristics were classified according to the Michigan Department of Environmental Quality, Great Lakes Environmental Assessment Section (GLEAS) Procedure 51. No relation was found between GLEAS scores and RHU or the percentage of agricultural land in the drainage basins above the benchmark-stream sites. GLEAS scores were varied in each RHU. Streams with high GLEAS scores (rated good or excellent) can be considered benchmark or reference streams as far as habitat is concerned. Of the 20 streams sampled, 16 met this criterion.

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 (Hirsch and others, 1988). This information will be useful for planning future management actions and examining their likely consequences. In all, 60 study units are planned to begin activities on a staggered time scale. The Western Lake Michigan Drainages (WMIC) was selected as one of the 20 study units to begin data collection and analysis in 1991.

The Western Lake Michigan Drainages study unit (fig. 1, inset map) 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 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, most forested areas being 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.

Agriculture accounts for the major land use in the southern half of the WMIC, and many studies have focused on the effect of agriculture on water quality in this area. Although many agriculturally affected streams have been measured in terms of aquatic biota and habitat, few studies have focused on the composition of healthy stream communities that have been largely unaffected by human activity. By identifying the community composition for a healthy stream, a benchmark can be developed for hydrologic researchers to (1) determine the community and habitat potential for streams in similar geographic settings and (2) measure the effect of improvements or the extent of degradation in community composition and stream habitat resulting from changes in agricultural practices.

In response to this need for a benchmark or standard of reference for comparison, the WMIC study-unit team identified 20 stream sites (fig. 1) where physical and chemical conditions appear to be minimally affected by the agricultural activity that generally dominates land use in the drainage basins above the sites. Data were collected from May 1993 to July 1995 to describe the physical and chemical conditions, habitat, and fish, invertebrate, and algal communities of these streams. The environmental settings of these relatively unaffected, or benchmark, streams are presented in the first of a series (Rheaume and others, 1996) of reports on benchmark streams in agricultural areas. This report, the second in the series, briefly describes the habitat data collected at these benchmark streams and relations among habitat characteristics. Some of the stream habitat characteristics are also described in Rheaume and others (1996). Additional studies of the benchmark streams are focusing on invertebrates, fish, and algae characteristics.

Purpose and Scope

The purpose of this report is to (1) provide a list of habitat characteristics measured as part of the WMIC NAWQA ecological synoptic survey of agricultural benchmark streams in eastern Wisconsin, (2) describe habitat characteristics as they relate to benchmark streams, (3) compare habitat characteristics from four physical settings, and (4) evaluate the suitability of these as benchmark streams or reference sites for agricultural areas. More than 80 habitat characteristics were measured as part of the ecological synoptic survey; of these, a subset was deemed important in the analysis of invertebrate, fish, and algae data and is discussed here. These habitat data were collected from streams in four physical settings in agricultural areas in eastern Wisconsin (fig. 1): (1) clayey surficial deposits over carbonate bedrock, (2) sandy surficial deposits over carbonate bedrock, (3) sandy/sand and gravel surficial deposits over igneous/metamorphic bedrock, and (4) sandy/sand and gravel surficial deposits over sandstone bedrock.

Study Design

To isolate the effects of individual environmental factors on water quality, the study unit was subdivided into 28 physical settings—called RHU's—on the basis of bedrock geology, texture of surficial deposits, and land use/land cover (Robertson and Saad, 1995). These three environmental factors are important determinants of ambient water quality. Four of the largest RHU's (fig. 1) in the study unit (1, 3, 20, and 26) are in areas of widespread agricultural land use and were selected as the focus for this study (Rheaume and others, 1996). The selected RHU's differ geologically by bedrock

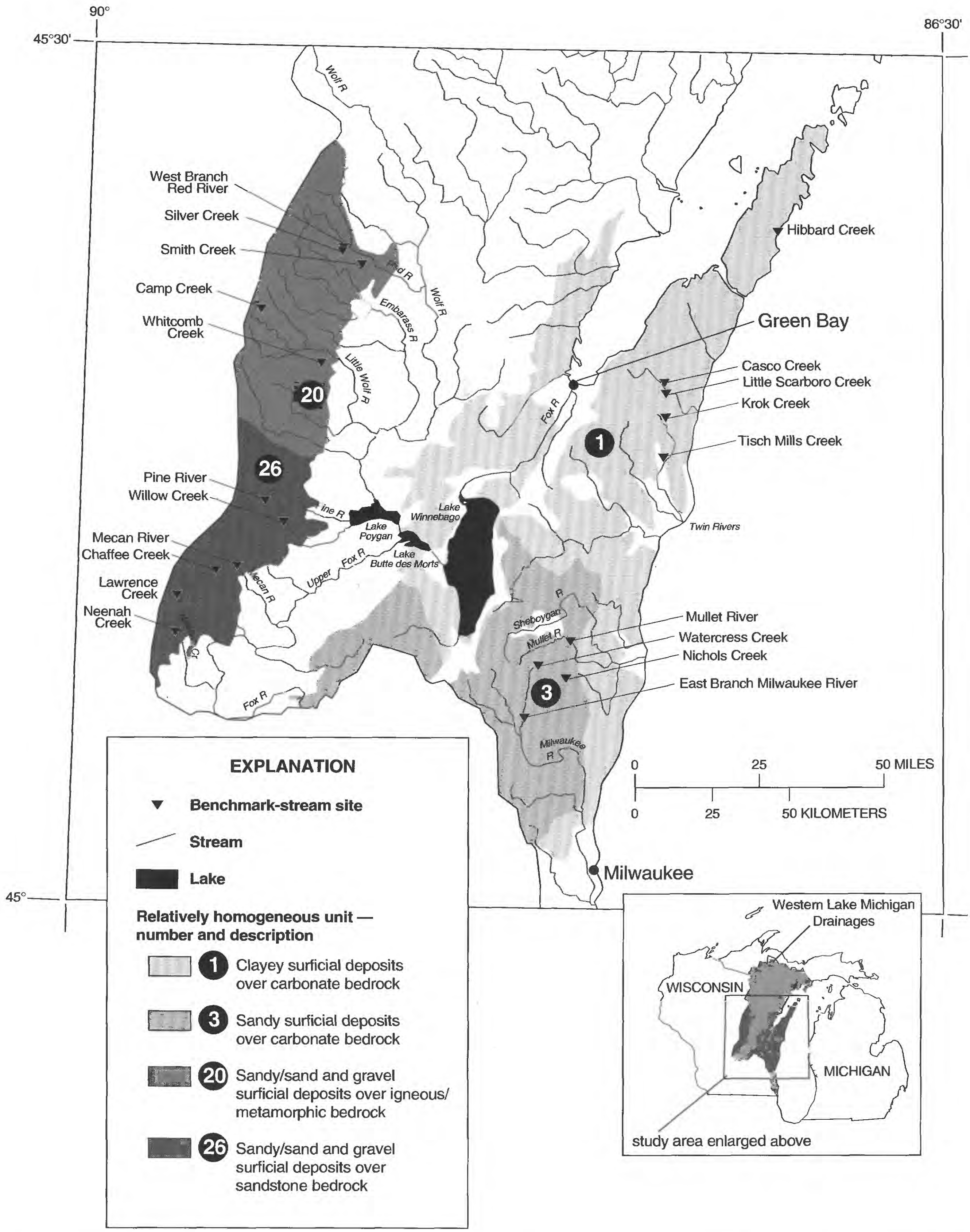

Figure 1. Location of agricultural benchmark-stream sites and four relatively homogeneous units in the Western Lake Michigan Drainages study unit.

type and by composition and texture of surficial deposits. RHU 1 (clayey surficial deposits over carbonate bedrock) and RHU 3 (sandy surficial deposits over carbonate bedrock) are in adjacent areas dominated by agricultural land use. RHU 20 (sandy/sand and gravel surficial deposits over igneous/metamorphic bedrock) and RHU 26 (sandy/sand and gravel surficial deposits over sandstone bedrock) are in adjacent areas of mixed agricultural land use and forest.

Twenty benchmark streams in these four RHU's were selected for sampling. Benchmark streams are defined as those that show minimal adverse effects from human activity, and they were selected on the basis of field reconnaissance and the following criteria: (1) available invertebrate or fisheries data that indicated good to excellent water quality, (2) instream habitat restoration for fisheries enhancement, and (3) land management to protect riparian vegetation (Rheaume and others, 1996). Four to six streams were selected for sampling in each of the four RHU's.

Goals of Stream-Habitat Data Collection

The goals for the collection of stream-habitat data were numerous. The main objective was to measure habitat characteristics at multiple scales that include drainage-basin level, stream segment, and stream reach. These habitat measures will be used in the analyses of invertebrate, fish, and algae communities. Another goal was to identify significant differences among habitat characteristics at individual streams sampled in the survey and among the four RHU's. Classification systems were used to evaluate whether all the streams selected for this study are suitable as benchmark streams in agricultural areas of eastern Wisconsin. If the benchmark streams suitably represent streams in agricultural areas of eastern Wisconsin that are minimally affected by agricultural practices, they can be used to establish expected baseline conditions at affected streams or as a goal to reach by implementation of best-management practices. Lastly, the habitat data will be used to expand the national NAWQA data base on ecological characteristics of streams across the Nation.

METHODS

Data Collection

Data were collected by use of methods described by Meador and others (1993) as part of a national NAWQA protocol. Data were collected at three spatial levels: basin, stream segment between tributaries, and stream reach. All the habitat characteristics listed in Meador and others (1993) were measured; however, only some of them, based on whether they will be used in the analysis of benchmark-stream studies of invertebrates, algae, and fish, are listed and discussed in this publication (table 1). Additional basin-level characteristics, also thought to be important in the analysis of invertebrate, fish, and algae communities but not specifically listed in Meador and others (1993), were included in the analyses.

Basin

Data were collected at the basin level (table 6, at back of report) to assess the effects of 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), 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 data (table 6) were collected by visual inspection of 1:24,000-scale USGS topographic maps in accordance with guidelines in Meador and others (1993). 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 storage was estimated visually from the maps by use of a grid.

Values for several characteristics were computed from data available through the State Soil Geographic

Table 1. Habitat characteristics measured at agricultural benchmark streams in the Western Lake Michigan Drainages study unit

[All characteristics measured are listed; characteristics in bold are discussed in this report]

		Reach level			
Basin level	Segment level	Channel	Bank and flood plain	Bottom substrate	Water quality
Relatively homogeneous unit	**Stream order**	**Percent riffle**	**Bank-stability index**[1]	**Bottom-substrate type**	**pH**
Drainage area	**Channel sinuosity**	**Percent pool**	**Bank vegetation**	**Embeddedness**	**Specific conductance**
Stream length	**Segment slope**	**Percent run**	**Flood-plain vegetation**	**Silt (absence/presence)**	**Discharge**
Stream slope	Segment length	**Canopy angle**	**Amount undercut banks**	**Macrophyte coverage**	**Flood discharge**[2]
Drainage density	Upstream river mile	**Channel width**	Bank width	**Periphyton coverage**	**Low-flow estimates**[3]
Basin shape	Downstream river mile	**Channel depth**	Bank height		**Organic plus ammonia nitrogen, total**
Basin relief	Upstream elevation	**Velocity**	Bank erosion type		**Nitrate plus nitrite, dissolved**
Bedrock type	Downstream elevation	**Aspect**	Bank shape		**Ammonium, dissolved**
Surficial deposits	Side slope gradient	**Amount woody debris**	Bank substrate		**Phosphorus, total**
Erodibility factor	Downstream link number	Reach length	Bank angle		**Orthophosphate, dissolved**
Soil drainage	Springs (absence/presence)	Amount rubbish (human)	Bank vegetative stability		**Triazine screening results**
Permeability	Water-management features	Amount boulders	Amount overhanging vegetation		Temperature
Basin storage		Amount sloughs	Flood-plain width		Dissolved oxygen
Land use		Bar/shelf/island characteristics			
Annual runoff					
Annual temperature					
Annual precipitation					
Annual evaporation					
Basin length					
Perennial-stream length					
Drainage texture					
Physiographic province					
Ecoregion					
Land resource area					
Potential natural vegetation					

[1]Bank-stability index combines bank angle, shape, vegetative stability, height, and substrate into one index.
[2]Estimated flood discharges include recurrence intervals of 2, 5, 10, 25, 50, and 100 years; estimated by use of flood-frequency equations from Gebert and others (1987).
[3]Low-flow estimates calculated for 7-day, 2- and 10-year flows are based on equations from Holmstrom (1980, 1982).

Database (STATSGO) (U.S. Department of Agriculture, 1991). These characteristics included soil drainage, soil erodibility factor, and permeability rate. The soil drainage class identifies the natural drainage condition of the soil and refers to the frequency and duration of periods when the soil is free from saturation (U.S. Department of Agriculture, 1991). The soil erodibility factor quantifies the susceptibility of soil particles to detachment and movement by water (U.S. Department of Agriculture, 1991). The erodibility factor is used in the Universal Soil Loss Equation. STATSGO provides a soil drainage class and erodibility factor for each soil type. Because several soil types were present in the drainage basins, an average soil drainage class and erodibility factor for each drainage basin was calculated by weighting the area of each soil type in the drainage basin.

In order that average permeability rates could be computed for each drainage basin, the STATSGO data needed to be further 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.

Segment

Data were collected at the segment level (table 6) to describe the stream near the reach. Each segment includes the reach that was sampled and is bounded by the next upstream and next downstream tributary junction. The segments, which range in length from 1 to 14 km, are considered discrete units that are relatively homogeneous in their characteristics (Meador and others, 1993).

Data-collection methods for segment-level data were not modified from Meador and others (1993). Data were collected by visual inspection of USGS 1:24,000-scale topographic maps (table 6). Stream order was calculated by use of the Strahler (1954, 1957) method, with reference to ephemeral and perennial streams marked as blue lines on 1:24,000-scale topographic maps. Stream-segment slope is the overall channel slope measured from contour lines on the 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 (Meador and others, 1993). A high number indicates a high degree of sinuosity or meandering.

Reach

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) at least two types of geomorphic units (pools, riffles, or runs) occur repetitively in the selected reach, (2) minimum reach length is 20 times the average stream width, and (3) maximum reach length is 300 m. An attempt was made to select reaches that were upstream from bridges to limit effects from roads and channel modifications; however, in certain places where upstream reaches did not adequately characterize the stream segment, downstream reaches were selected (Meador and others, 1993).

Data that were collected to describe stream reaches included channel, substrate, bank, and flood-plain measurements and measurements of physical properties and chemical constituents of the water (table 1). Most measurements were collected at each of six transects (table 8, at back of report), one at each end of the reach and the other four at the midpoints of selected geomorphic units. 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.

At the time of habitat sampling in May 1993, pH, specific conductance, temperature, dissolved oxygen, and discharge were measured. Flood discharges (recurrence intervals of 2, 5, 10, 25, 50, and 100 years) were estimated by use of flood-frequency equations for streams in Wisconsin (Krug and others, 1992). Low-flow discharges (7-day, 2- and 10-year) were calculated by use of equations developed by Holmstrom (1980, 1982). Samples were collected in April 1995 for nutrients analysis and an immunoassay analysis to screen for triazines. The immunoassay analysis has a detection limit of 0.1 μg/L and is designed to be most sensitive to atrazine but may detect other triazines.

Statistical Analysis

This section is a brief overview of the numerous statistical techniques used to analyze the habitat data. Where possible, references are provided for details on specific procedures. The SAS statistical software package (SAS Institute, Inc., 1990) was used for all the statistical analyses of habitat data.

The first level of analyses involved checking the habitat data for univariate normal distributions. Techniques included Tukey modified boxplots (Tukey, 1977), stem and leaf plots (Iman and Conover, 1983), normal probability plots (Johnson and Wichern, 1992), and the Shapiro-Wilk test (SAS Institute, Inc., 1990). 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 analyzed by use of nonparametric statistical methods, which do not require the assumption of normal distribution. Helsel (1987) describes the advantages of nonparametric statistics for analysis of water-quality data.

Correlation analysis was used to identify habitat characteristics that followed similar distributions among sites. 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 0.1. Habitat characteristics that were significantly correlated were plotted against each other by site identification number to identify site groupings.

Correlation analysis was followed by principal components analysis (PCA), an objective exploratory technique invented by Pearson (1901) and Hotelling (1933). PCA was used to explain the overall variance seen in the combination of habitat characteristics through linear combinations of individual habitat characteristics (Johnson and Wichern, 1992). Plots of two principal components axes can be used to identify groupings of sites along the two axes. The use of PCA does not require a multivariate normal assumption for the data (Johnson and Wichern, 1992); however, the principal components should be normally distributed and uncorrelated (Hotelling, 1933). Gauch (1982) states that field data sets rarely meet the requirements exactly.

The PCA was done on a subset of 37 habitat characteristics (chosen because data were available at most of the sites) from basin, segment, and reach levels. Raw and rank-transformed data were analyzed and compared, and similar results were found. Next, PCA was done separately on rank-transformed data including: (1) 20 habitat characteristics from all levels (3 water quality, 10 reach, and 7 basin and segment), (2) 16 basin and segment characteristics, (3) 13 reach characteristics, and finally (4) 8 water-quality characteristics.

The Kruskal-Wallis test (Iman and Conover, 1983), a nonparametric analysis of variance (ANOVA) on rank-transformed data, was used to identify significant differences between RHU's with respect to habitat characteristics; specifically, it was used to indicate whether variance among the sites in an RHU was large enough to mask differences between RHU's. The Tukey studentized range test (Neter and others, 1985) was used to identify which groups from the Kruskal-Wallis test were similar among the RHU's at the 95 percent confidence level.

Stream Classification

The Michigan Department of Natural Resources GLEAS Procedure 51 (Michigan Department of Natural Resources, 1991) was used to characterize the habitat data and to help determine the suitability of the streams in this study as benchmark streams. The GLEAS procedure consists of qualitative methods for describing biological and habitat data. The habitat portion measures nine characteristics, or "metrics": bottom substrate and available cover, embeddedness, water velocity, flow stability, deposition/sedimentation, pools-riffles-runs-bends, bank stability, bank vegetation, and streamside cover. Scores for each metric are summed and compared to scores from GLEAS reference sites. A total score of 135 is the highest score possible. The scores are broken into four categories: excellent (111–135), good (75–102), fair (39–66), and poor (0–30). In normal 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. Although not exactly the same as GLEAS protocols, the NAWQA habitat protocols included all the information needed to apply the data to the GLEAS procedure.

HABITAT CHARACTERISTICS

Basin-, segment-, and reach-level habitat characteristics for the 20 benchmark streams are listed in tables 6–8 (at back of report). Several characteristics, including site location, latitude/longitude, ecoregion, Anderson (1970) Level II land use, water temperature, dissolved-oxygen and nutrient concentrations, and triazine screening results, are not listed in this report but can be found in Rheaume and others (1996). Reach-level data are listed in tables 7 and 8. Table 7 contains average data for the reach, whereas table 8 contains detailed data collected at each of six transects within a reach.

The majority of streams (14) were second-order streams; four were first-order streams, one was a third-order stream, and one was a fourth-order stream. Drainage basins ranged in size from 2.3 km^2 for Little Scarboro Creek to 138.0 km^2 for the East Branch of the Milwaukee River.

Eight of the 20 streams have undergone habitat restoration for trout fisheries. Typical restoration or enhancement techniques used on these streams include bank covers, current deflectors, stream bank debrushing, half logs, boulders, low dams, and brush bundles. Although information on restoration history is not available for all eight streams, restoration information on three of the eight streams (Hunt, 1988) indicates that restorations have been ongoing since the early 1960's.

Regional climatic data indicate that climatic factors are similar for all the streams; climatic conditions were not measured specifically at each site. Average annual precipitation in the area ranges from 74 to 76 cm (Wendland and others, 1985), annual average temperature from 5.8 to 6.7°C (Wendland and others, 1985), class A pan evaporation from 46 to 54 cm (Olcott, 1968; Oakes and Hamilton, 1973; and Skinner and Borman, 1973), and average annual runoff from 20 to 25 cm (Gebert and others, 1987).

Some of the streams sampled near the end of the synoptic survey were at overbank flow when invertebrates and algae were sampled and habitat characteristics were measured; all streams in RHU 20 were in flood condition. Because there was a limited window of time available for collection of invertebrates (after snowmelt runoff and before insect emergence), and 1993 was a particularly wet year in southern Wisconsin, these sites were still sampled even though flow conditions were not at an optimum. A ratio (Q/Q_2) of the measured discharge (Q) at time of sampling in 1993 divided by the estimated 2-year flood discharge (Q_2) was included in the analysis to account for differences in flow that might have affected the habitat characteristics and measurements of biota.

Correlations Among Habitat Characteristics

Several strong correlations were found among the 39 basin-level, segment-level, reach-level, and water-quality characteristics evaluated by means of nonparametric correlation (Spearman) and graphical analyses (table 2). Some of the highest correlation coefficients, indicating the strongest relations, were found among basin-level characteristics. In particular, many basin-level characteristics associated with RHU were correlated (table 2). This is to be expected because site selection was based on RHU. Some of the more notable results of the correlation analyses indicate that streams flowing over carbonate bedrock have higher percentages of agricultural land in their basins than streams flowing over sandstone and igneous/metamorphic rocks (fig. 2A). As would be expected, basins with high percentages of agricultural land have higher erodibility factors and less wetland than do less agricultural basins. Basins where sandy surficial deposits dominate have high soil drainage and permeability; these basins also contain less forested land than do basins where surficial deposits are less sandy.

Few correlations were found among other geomorphic-related basin- and segment-level characteristics not related to RHU, such as drainage area, drainage density, basin shape, basin relief, stream order, channel sinuosity, and segment slope (table 2). Drainage area and stream order would be expected to correlate; however, these sites were in recently glaciated and geologically young landscapes, so stream networks are not yet well defined (fig. 2B). Drainage density correlated negatively with soil drainage ($\rho = -0.75$), an indication that well drained areas have minimally developed stream networks. Streams with steep segment slopes tended to have substantial sand in their basins, good soil drainage, and considerable sinuosity.

Correlations among reach characteristics are negligible or generally below $\rho = 0.60$. Some of the

Table 2. Spearman rank correlation coefficients for habitat characteristics of agricultural benchmark streams in the Western Lake Michigan Drainages study unit

[--, correlation not significant at 90-percent confidence level and therefore not reported]

Level	Habitat characteristic	Basin													Segment	
		Drainage area	Drainage density	Basin shape	Basin relief	Bedrock type	Percent sand	Erodibility factor	Soil drainage	Permeability	Basin storage	Percent agriculture	Percent forest	Percent wetland	Channel sinuosity	Segment slope
Basin	Drainage area	1.00														
	Drainage density	--	1.00													
	Basin shape	--	--	1.00												
	Basin relief	.83	--	--	1.00											
	Bedrock type	--	--	--	.61	1.00										
	Percent sand	--	--	--	.68	.54	1.00									
	Erodibility factor	--	--	--	-.63	-.78	-.68	1.00								
	Soil drainage	.61	-.75	--	.57	--	.78	--	1.00							
	Permeability	--	--	--	--	--	--	-.59	.60	1.00						
	Basin storage	--	--	--	--	--	--	--	--	--	1.00					
	Percent agriculture	--	--	--	-.52	-.94	--	.76	--	--	--	1.00				
	Percent forest	--	--	--	-.57	--	-.82	.67	-.71	-.92	--	--	1.00			
	Percent wetland	--	--	--	.64	.88	--	-.77	--	--	--	-.93	--	1.00		
Segment	Channel sinuosity	--	--	--	--	--	--	--	--	--	--	--	--	--	1.00	
	Segment slope	--	--	--	-.56	--	-.82	--	-.82	--	--	--	--	--	-.74	1.00

Table 2. Spearman rank correlation coefficients for habitat characteristics of agricultural benchmark streams in the Western Lake Michigan Drainages study unit—Continued

Level	Habitat characteristic	Basin													Segment	
		Drainage area	Drainage density	Basin shape	Basin relief	Bedrock type	Percent sand	Erodibility factor	Soil drainage	Permeability	Basin storage	Percent agriculture	Percent forest	Percent wetland	Channel sinuosity	Segment slope
Reach	Percent pool	--	--	--	--	--	-0.78	0.67	-0.54	-0.61	--	--	0.61	--	--	0.59
	Mean canopy angle	--	--	--	.66	.71	.71	-.87	-.53	--	--	-.68	-.71	.71	--	--
	Mean width/depth ratio	.57	--	--	--	--	--	--	--	.55	--	--	--	--	--	--
	Velocity	--	--	-.66	--	--	.67	--	.69	--	--	--	--	--	--	-.79
	Bank-stability index	--	--	--	--	-.52	--	.85	--	-.57	--	.55	--	-.61	--	--
	Amount undercut banks	--	--	--	.54	--	.54	-.68	.55	--	--	--	-.63	.67	--	--
	Bottom-substrate type	--	--	.74	--	--	--	-.57	--	--	--	--	--	--	--	--
	Embeddedness, in riffle	--	--	-.62	--	--	--	.68	--	--	--	--	--	--	--	--
	Macrophyte coverage	--	--	--	--	--	--	-.48	--	--	--	--	--	--	--	--
	Periphyton coverage	--	-.67	--	--	-.68	--	.59	--	--	--	.74	--	-.58	--	--
	pH	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Specific conductance	--	--	--	-.60	-.94	--	.65	--	--	-.55	.94	--	-.87	--	.54
	[1]Q_2	.79	--	--	.61	--	--	--	.53	--	--	--	--	--	--	--
	[2]Q/Q_2	--	.70	--	--	.65	--	--	--	--	--	--	--	--	--	--
	Organic plus ammonia nitrogen, total	-.76	.64	--	--	--	--	--	-.68	--	--	--	--	--	-.55	--
	Nitrate plus nitrite, dissolved	--	--	--	--	-.56	--	--	--	--	-.61	.63	--	--	--	--
	Ammonium, dissolved	--	--	--	--	--	--	--	--	-.62	.54	--	--	--	--	--
	Phosphorus, total	-.54	.78	--	--	--	--	--	-.61	--	--	--	--	--	--	--
	Triazine screening results	--	--	--	--	--	--	--	--	.64	--	--	--	--	--	--

Table 2. Spearman rank correlation coefficients for habitat characteristics of agricultural benchmark streams in the Western Lake Michigan Drainages study unit—Continued

Level	Habitat characteristic	Reach																				
		Percent riffle	Percent pool	Mean canopy angle	Mean width/depth ratio	Velocity	Amount woody debris	Bank-stability index	Amount undercut banks	Bottom-substrate type	Embeddedness, in riffle	Macrophyte coverage	Periphyton coverage	pH	Specific conductance	[1]Q_2	[2]Q/Q_2	Organic plus ammonia nitrogen, total	Nitrate plus nitrite, dissolved	Ammonium, dissolved	Phosphorus, total	Triazine screening results
Reach	Percent riffle	1.00																				
	Percent pool	--	1.00																			
	Mean canopy angle	--	-.74	1.00																		
	Mean width/depth ratio	--	--	--	1.00																	
	Velocity	--	--	--	--	1.00																
	Amount woody debri	--	--	--	--	--	1.00															
	Bank-stability index	--	.54	-.74	--	--	--	1.00														
	Amount undercut banks	--	--	.78	--	.60	--	-.71	1.00													
	Bottom-substrate type	--	--	--	--	--	--	-.70	--	1.00												
	Embeddedness, in riffle	--	--	-.56	--	--	--	.82	--	-.93	1.00											
	Macrophyte coverage	--	-.50	.57	--	--	--	-.74	--	.49	-.54	1.00										
	Periphyton coverage	--	--	--	--	--	--	--	--	-.60	.65	--	1.00									
	pH	.63	--	--	--	--	-.53	--	--	--	--	.52	--	1.00								
	Specific conductance	--	--	-.60	--	--	--	--	--	--	--	--	.59	--	1.00							
	[1]Q_2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.00						
	[2]Q/Q_2	--	--	--	--	--	--	--	--	--	--	--	--	--	-.64	--	1.00					
	Organic plus ammonia nitrogen, total	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-.59	--	1.00				
	Nitrate plus nitrite, dissolved	--	--	--	--	--	--	--	--	--	--	--	.54	--	.62	--	--	--	1.00			
	Ammonium, dissolved	--	--	--	--	--	.58	--	--	--	--	--	--	--	--	--	--	--	--	1.00		
	Phosphorus, total	--	--	--	-.66	--	--	--	--	--	--	--	-.66	--	--	-.52	--	.77	--	--	1.00	
	Triazine screening results	.64	-.64	--	--	--	--	--	--	--	--	.51	--	--	--	--	--	--	--	--	--	1.00

[1]Estimated 2-year flood discharge (Gebert and others, 1987).
[2]Discharge measured in May and June 1993 divided by the estimated 2-year flood discharge.

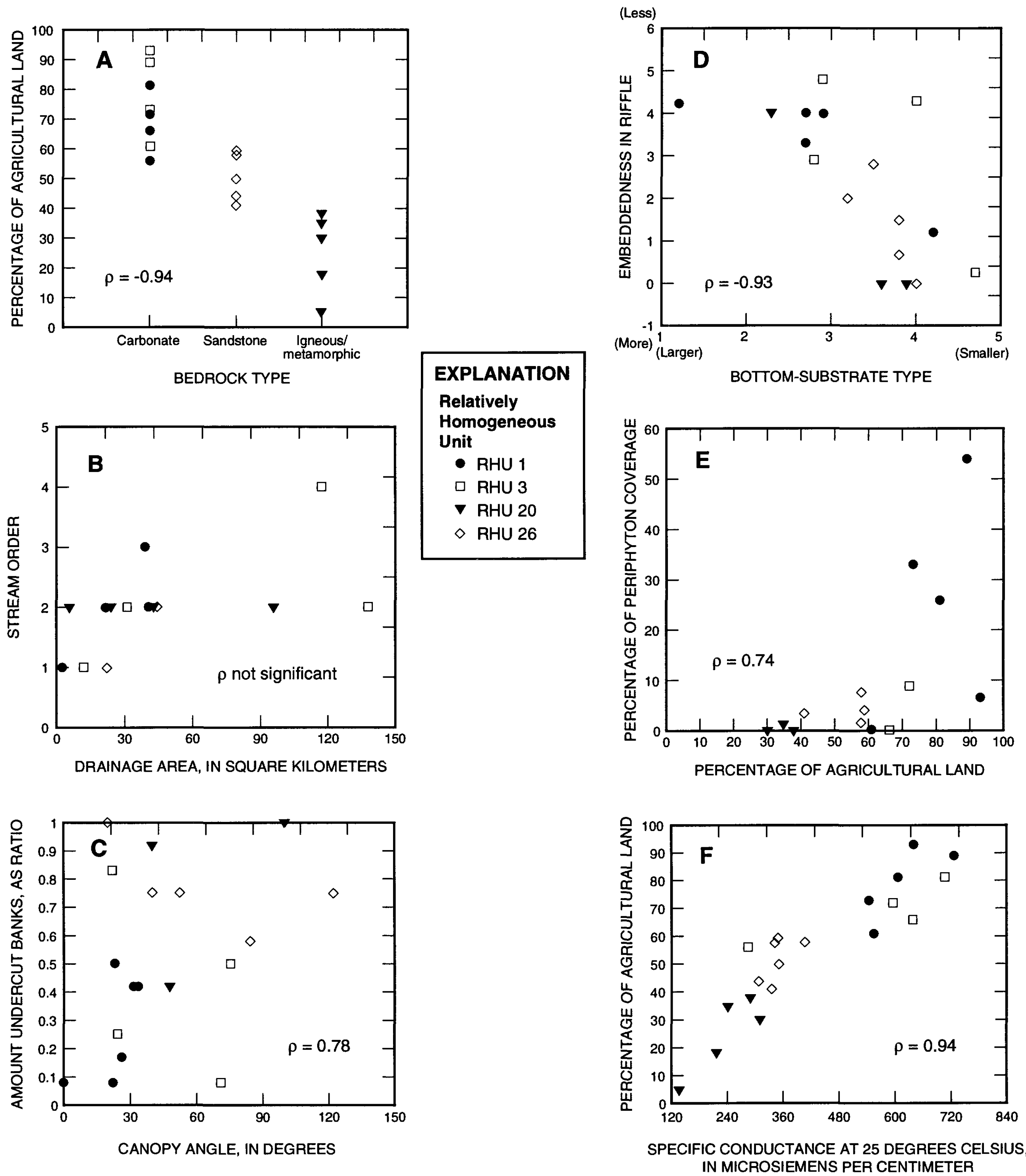

Figure 2. Correlations among selected habitat characteristics of agricultural benchmark streams in the Western Lake Michigan Drainages study unit.

more notable correlations indicate that streams with open canopy have less stable banks but more undercut banks than closed-canopy streams do (fig. 2C). Streams with stable banks tend to have smaller particle sizes in bottom substrate, greater macrophyte coverage, and more undercut banks than do streams with unstable banks. Streams where riffle substrates are not greatly embedded have more stable banks and larger particle sizes than do streams where riffle substrates are more embedded (fig. 2D).

Correlations between reach characteristics and basin characteristics also were few (table 2). Expected correlations that were observed include positive correlations between drainage area and Q_2 (estimated 2-year flood volume is based on a regression equation in which drainage area is the main explanatory variable). Drainage density also correlated positively with Q/Q_2 ($\rho = 0.70$), indicating that drainages with dense stream networks were more likely to be under flood conditions when sampled in 1993. Streams draining basins with high percentages of agricultural land tended to have the most dense algal coverage (fig. 2E). Streams draining basins with the highest percentages of wetland tended to have the greatest canopy angles (large canopy angles equate with open riparian vegetation), and streams draining forested land had smaller canopy angles than most other streams. Other correlations are not easily explained: long/narrow drainage basins tended to have fine particle sizes in bottom substrate, stream reaches in carbonate bedrock tend toward closed canopy, and basins where the erodibility factor is high tend toward stable banks but also toward open canopy.

The only correlation among the set of water-quality characteristics was a positive correlation between total phosphorus and total organic plus ammonia nitrogen concentrations ($\rho = 0.77$). However, several water-quality characteristics correlated with basin- and reach-level characteristics. For example, specific conductance correlated positively with percentage of agriculture (fig. 2F) but correlated negatively with percentage of wetland. Specific conductance correlated positively with carbonate bedrock (percentage of agricultural land also correlated positively with carbonate bedrock). Total organic plus ammonia nitrogen concentrations correlated negatively with drainage area but correlated positively with drainage density. Total phosphorus concentrations also positively correlated with drainage density.

Principal Components Analyses

Principal components analyses were performed on rank-transformed data consisting of 16 basin and segment characteristics, 13 reach characteristics, and 8 water-quality characteristics. Two sites, Smith and Casco Creeks, were dropped from the analysis because of missing data. The first three principal components explained 54 percent of the total variance. The first principal component accounted for 22 percent of the variance, the second for 17 percent of the variance, and the third for 14 percent of the variance. Habitat characteristics that loaded on each component (that is, had significantly high correlation coefficients) are listed in table 3. The first principal component (PC1) appears to be related to bedrock type. Characteristics that loaded most heavily on PC2 can be related to basin characteristics such as relief and land use, specifically forest. An ordination plot of PC1 and PC2 (fig. 3A) shows that sites can be grouped by RHU. Along the PC1 axis, scores for sites in RHU 20 and 26 are similar and sites in RHU 1 and 3 are even more similar. This again indicates a weighting toward bedrock type. Along the PC2 axis, however, scores for sites in RHU 20 and 1 are similar and those for RHU 26 are the most dissimilar. Many, but not all, sites with low scores for PC2 are in the northern part of the study area, suggesting latitude may play a role. A plot of PC1 and PC3 scores (not shown) again indicates the dependence of PC1 on bedrock type; PC3 seems to be most closely related to drainage-basin size.

A subset of 20 habitat characteristics were selected for PCA analysis to identify additional or different spatial distributions or relations among a mixture of habitat characteristic from different levels. These characteristics were selected because they either were found to load heavily on one of the principal components from the analyses with 37 characteristics or were thought to be most important in their effects on fish, invertebrates, or algae. Habitat characteristics included in the analysis were 7 basin and segment characteristics (drainage area, bedrock type, permeability, basin storage, percent forest, percent wetland, and slope), 10 reach characteristics (percent riffle, percent pool, canopy angle, width/depth ratio, velocity, woody debris, bank-stability index, undercut banks, bottom substrate, and riffle substrate embeddedness) and 3 water-quality characteristics (specific conductance, total organic plus ammonia nitrogen, and total phosphorus). The first three principal components explained 58 percent of the

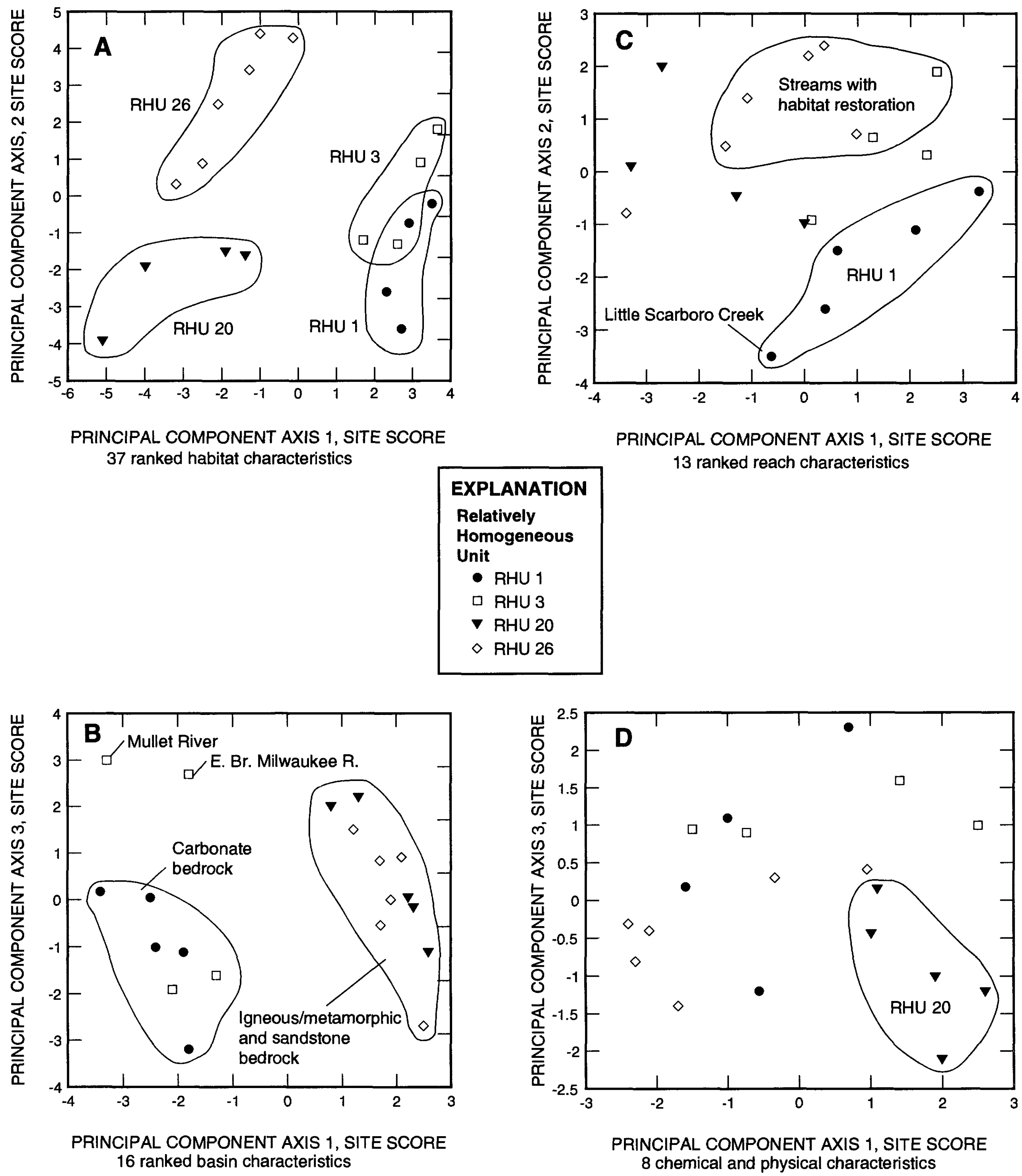

Figure 3. Principal components ordination diagrams for selected habitat characteristics of agricultural benchmark streams in the Western Lake Michigan Drainages study unit.

Table 3. Loadings of habitat characteristics on the first three principal components of data for agricultural benchmark streams in the Western Lake Michigan Drainages study unit
[PC, principal component; coefficients are ≥ 0.70 for PC1, ≥ 0.60 for PC2, and ≥ 0.50 for PC3]

PC1		PC2		PC3	
		37 habitat characteristics			
Erodibility factor	0.94	Percent forest	-0.76	Basin storage	0.84
Bedrock type	-.92	Organic plus ammonia nitrogen, total	-.72	Drainage area	.77
Percent agriculture	.87	Soil drainage	.70	Nitrate plus nitrite, dissolved	-.74
Percent wetland	-.84	Permeability	.68	Stream order	.69
Percent sandy surficial deposits	-.76	Percent pool	-.62	Basin relief	.57
Specific conductance	.74	Basin relief	.60	Width/depth ratio	.56
Embeddedness, in riffle	.71			Canopy angle	.50
		20 selected habitat characteristics			
Percent wetland	0.89	Percent forest	0.71	Basin storage	0.83
Bedrock type	.86	Percent riffle	-.70	Drainage area	.68
Undercut banks	.75	Percent pool	.64	Width/depth ratio	.58
		Organic plus ammonia nitrogen, total	.60	Canopy angle	.54
		16 basin and segment characteristics			
Erodibility factor	-0.93	Percent forest	-0.78	Drainage area	0.82
Bedrock type	.89	Drainage density	-.71	Basin storage	.78
Percent wetland	.86	Soil drainage	.69	Basin relief	.70
Percent agriculture	-.83			Stream order	.63
Percent wetland	.81				
		13 reach characteristics			
Percent riffle	0.78	Canopy angle	0.86	Bottom substrate	-0.76
Embeddedness, in riffle	.75	Bank-stability index	-.73	Velocity	.75
Width/depth ratio	.72	Percent pool	-.72		
		8 water-quality characteristics			
Organic plus ammonia nitrogen, total	0.77	Orthophosphate, dissolved	0.77	Phosphorus, total	0.54
Ammonium, dissolved	.75			pH	.53
				Specific conductance	.50

total variance, similar to PCA results on all 37 characteristics, and variances explained by each principal component also were similar. In addition, similar characteristics loaded heavily on the same principal components (table 3).

Relations between habitat characteristics and other possible spatial relations were explored by applying PCA to subsets of habitat characteristics from the same level. Separate PCA's were done on 16 basin and segment characteristics, 13 reach characteristics, and 8 water-quality characteristics. For basin and segment characteristics, the first three principal components explained 68 percent of the total variance, with 30 percent explained by PC1, 20 percent by PC2, and 18 percent by PC3. All 20 sites were included in the analysis. Similar to the results of the previously described PCA's, PC1 relates to RHU, PC2 to land use (or possibly latitude), and PC3 relates to basin size. Ordination plots of PC1 and PC3 (fig. 3B) show that the sites group by bedrock type and that the sites with the largest drainage areas (East Branch of the Milwaukee River and the Mullet River) plot as outliers.

In the PCA for 13 reach characteristics, the first three principal components explained 63 percent of the total variance, with PC1 explaining 28 percent, PC2 explaining 20 percent, and PC3 explaining 15 percent. Smith Creek was not included in the analysis because of missing data. Loadings for each principal component are given in table 3. The characteristics that loaded on the first three principal components are (1) percent

Table 4. Great Lakes Environmental Assessment Section scores for habitat characteristics of agricultural benchmark streams in the Western Lake Michigan Drainages study unit

Site name	Relatively homogeneous unit	Substrate and instream cover			Channel morphology			Riparian and bank structure			Overall score[1]
		Bottom substrate	Embeddedness	Velocity	Flow stability	Bottom deposition	Pools, riffles, runs, bends	Bank stability	Bank vegetative stability	Stream side cover	
Tisch Mills Creek at Tisch Mills, Wis.	1	16	16	13	11	10	8	7	8	8	97
Krok Creek near Ellisville, Wis.	1	5	14	3	11	9	10	5	4	10	71
Little Scarboro Creek near Casco, Wis.[2]	1	18	17	8	11	13	13	5	7	7	99
Casco Creek at Casco, Wis.	1	18	17	6	11	10	10	5	9	7	93
Hibbard Creek near Jacksonport, Wis.	1	18	17	11	11	7	12	5	5	7	93
East Branch Milwaukee River near New Fane, Wis.	3	8	14	13	11	9	10	9	9	8	91
Nichols Creek near Cascade, Wis.	3	18	19	8	11	12	11	9	10	10	108
Mullet River near Plymouth, Wis.	3	20	14	8	11	13	10	9	9	9	103
Watercress Creek near Dundee, Wis.	3	6	2	3	11	3	6	5	3	7	46
Whitcomb Creek near Big Falls, Wis.	20	8	0	8	11	7	10	9	8	7	68
West Branch Red River near Bowler, Wis.	20	10	13	13	11	8	9	7	8	10	89
Silver Creek near Bowler, Wis.	20	18	17	11	11	12	13	8	8	8	106
Smith Creek near Bowler, Wis.	20	13	0	8	11	10	10	7	8	8	75
Camp Creek near Galloway, Wis.	20	14	5	3	11	12	9	9	10	9	82
Lawrence Creek near Lawrence, Wis.	26	10	4	6	11	12	8	9	10	4	74
Neenah Creek near Oxford, Wis.	26	12	9	8	11	12	9	7	8	4	80
Chaffee Creek near Neshkoro, Wis.	26	8	0	6	11	12	13	9	10	6	75
Mecan River near Richford, Wis.	26	12	10	8	11	11	12	7	9	6	86
Willow Creek near Mount Morris, Wis.	26	13	12	13	11	10	11	9	9	8	96
Pine River near Wild Rose, Wis.	26	12	14	8	11	9	10	7	8	7	86

[1]Highest overall score possible is 135. Scores are ranked as 111–135 (excellent), 75–102 (good), 39–66 (fair), and 0–30 (poor).
[2]Streams in bold have undergone habitat restoration.

riffle, width/depth ratio, and embeddedness, (2) percent pool, canopy angle, and bank stability index, and (3) average velocity and bottom substrate. Ordination plots of PC1 and PC2 (fig. 3C) indicate that sites in RHU 1 group separately from those for the other RHU's. Streams that have undergone habitat restoration for fisheries also group closely together, except for Little Scarboro Creek, which is in RHU 1. Ordination plots of PC2 and PC3, and PC1 and PC3 (not shown) indicate no grouping of any of the four RHU's; however, sites that have undergone habitat restoration group together. Little Scarboro Creek is an outlier on the plot of PC2 and PC3 but not on the plot of PC1 and PC3.

The first three principal components for eight water-quality characteristics explained 71 percent of the variance; however, loadings and ordination plots did not reveal any relation to spatial distributions or site groupings. Sites among the four RHU's were scattered in ordination plots of PC1 and PC2, and PC2 and PC3. No groupings were found for streams that have undergone habitat restoration. In the ordination plot of PC1 and PC3 (fig. 3D), sites in RHU 20 grouped separately from those in the other three RHU's. Thus, something about nutrient concentrations, specific conductance, and pH in streams within RHU 20 seems to set them apart from streams in the other three RHU's.

Great Lakes Environmental Assessment Section Classification

The GLEAS scores for the 20 agricultural benchmark streams ranged from a low of 46 at Watercress Creek to a high of 108 at Nichols Creek (table 4). Three streams were rated between excellent and good: Nichols Creek, Mullet River, and Silver Creek. Watercress Creek was rated fair. Normally, the GLEAS procedure is used to compare scores of impaired streams to the score of a known GLEAS reference stream. For rough comparison, the closest known reference site in Michigan received a score of good (William H. Taft, Michigan Department of Environmental Quality, Great Lakes Environmental Assessment Section, written commun., 1996).

A breakdown in individual scores for each of the 9 rating categories (table 4) provides some insight on what habitat features effectively influenced overall GLEAS ratings. Top individual scores possible for the three categories in substrate and instream cover were 20 points compared to 15 points for the three channel morphology categories and 10 points for the three riparian and bank-structure categories. This means that the overall GLEAS score is weighted more toward substrate and instream cover than it is toward other habitat features. Riparian and bank features affected the GLEAS score the least.

Individual scores for substrate and instream cover were the most varied. Scores ranged from 0 to 20. Bottom-substrate scores ranged considerably among the four RHU's. A high score in this category indicates a variety of substrate material and habitat types capable of supporting a large variety of fish and invertebrates. A wide range of embeddedness scores also were found in all but RHU 1; all streams in RHU 1 scored as excellent or good. Streams that were rated fair to poor in embeddedness include Watercress Creek, Lawrence Creek, Neenah Creek, Chaffee Creek, Mecan River, Whitcomb Creek, Smith Creek, and Camp Creek. A score of 0 for embeddedness at Chaffee Creek, Whitcomb Creek, and Smith Creek indicates an absence of gravel or larger bottom substrate. The surficial deposits in these drainage basins contain negligible amounts of gravel or larger rocks. Velocity/depth scores were the least varied; most sites scored from good to poor because few sites had the variety of velocity/depth combinations needed to provide good habitat. In general, most streams were too shallow or too slow.

Channel-morphology scores were less varied than were substrate and instream-cover scores. All streams were given a score of 11 (good) for flow stability. A good score is defined as having constant low flow with seasonal high flows. Only three streams (Watercress Creek, Whitcomb Creek, and Hibbard Creek) were rated less than good for bottom-deposition conditions (30 to 50 percent of the bottom substrate was affected by deposition, and some filling of pools with sediment was evident). Although Watercress Creek is considered a Class II brook trout stream, it has been identified as having heavy instream siltation (Wisconsin Department of Natural Resources, 1989). All streams, except for Watercress Creek, had a variety of riffles, pools, runs, and bends.

Riparian and bank-structure scores were generally good to excellent. Watercress Creek and some streams in RHU 1 were rated fair in bank stability and bank vegetative stability; all other streams scored good or better. Streamside cover was rated fair at two streams in RHU 26; all other streams scored good or excellent.

Table 5. Tukey studentized range test ($p \leq 0.05$) for ranked habitat characteristics of agricultural benchmark streams in the Western Lake Michigan Drainages study unit

RHU[1]	Number of observations	Bedrock type		Percent sand surficial deposits		Erodibility factor		Soil drainage		Permeability		Percent agriculture		Percent wetland		Percent forest	
		<x>[2]	<gp>[3]	<x>	<gp>	<x>	<gp>	<x>	<gp>	<x>	<gp>	<x>	<gp>	<x>	<gp>	<x>	<gp>
1	5	5.0	a	7.2	c	16	a	6.6	b	5.6	b	17	a	3.0	a	13	ab
3	4	5.0	a	2.5	d	16	a	8.8	b	10	b	14	a	8.0	b	8.0	ab
20	5	18	b	12	b	7.0	b	7.4	b	7.4	b	3.0	b	17	c	15	b
26	6	13	c	18	a	4.8	b	18	a	18	a	9.0	c	13	d	6.2	a
		Percent riffle[4]		Average velocity		Undercut banks[4]		Embedded-ness, in riffle		Specific conductance		Q/Q_2 ratio[5]		Nitrate plus nitrite, dissolved[6]		Triazine screening results	
		<x>	<gp>	<x>	<gp>	<x>	<gp>	<x>	<gp>	<x>	<gp>	<x>	<gp>	<x>	<gp>	<x>	<gp>
1	5	11	ab	8.0	ab	5.0	a	14	a	16	a	7.6	b	13	ab	9.5	ab
3	4	14	a	6.1	b	8.3	ab	15	ab	14	ac	6.0	b	7.0	ab	11	ab
20	5	4.0	b	9.9	ab	12	ab	5.6	b	3.6	b	16	a	5.2	b	5.5	b
26	6	10	ab	16	a	14	b	8.7	ab	9.3	bc	11	ab	14	a	16	a

[1]Relatively homogeneous unit.
[2]<x> is the mean of ranks for the relatively homogeneous unit.
[3]<gp> indicates which means can be grouped together; means with the same letter(s) for each habitat characteristic in the RHU are not significantly different at the 95-percent confidence level.
[4]Number of observations in RHU 20 = 4.
[5]Ratio of measured discharge at time of sampling divided by the estimated 2-year flood discharge.
[6]Number of observations in RHU 1 = 4.

Overall GLEAS scores were correlated with habitat characteristics to explore possible relations between certain habitat characteristics and high GLEAS scores. Significant correlations (p-values < 0.10) between GLEAS scores and other habitat characteristics included bottom substrate (ρ = -0.81), embeddedness (ρ = 0.77), sinuosity (ρ = 0.54), drainage shape (ρ = -0.53), erodibility factor (ρ = 0.52), and average width/depth ratio (ρ = 0.41). Because of the weighting of the GLEAS scores toward substrate and instream cover, one would expect that bottom substrate and embeddedness would correlate significantly. Although still significant, correlations between GLEAS scores and basin shape, erodibility factor, channel sinuosity, and average width/depth ratio had much lower correlation coefficients; therefore, interpretation of these correlations was not attempted.

IMPLICATIONS OF NATURAL AND ANTHROPOGENIC EFFECTS ON HABITAT CHARACTERISTICS

Comparison of Habitat Among Four Relatively Homogeneous Units

Kruskal-Wallis statistical analyses were done to distinguish habitat characteristics that were significantly different among RHU's. The 39 habitat characteristics from all levels were examined, as well as GLEAS scores. Less than half of the characteristics were significantly different ($p \leq 0.05$) for one or more of the RHU's. Of 16 basin characteristics, 8 were significantly different in at least 1 RHU with respect to the others: bedrock type, percent sand in surficial deposits, erodibility factor, soil drainage, permeability, percent agriculture, percent wetland, and percent forest. Of 15 reach characteristics, 4 were significantly different: percent riffle, average velocity, amount of undercut banks, and embeddedness in riffle. Of eight physical and chemical characteristics, four were significantly different in at least one RHU with respect to the others: specific conductance, Q/Q_2 ratio, nitrate plus nitrite concentration, and triazine screening results.

The 16 habitat characteristics for which significant differences ($p \leq 0.05$) were found among RHU's were further analyzed by use of the Tukey studentized range test on rank-transformed data (table 5). These results indicate that two habitat characteristics were significantly different for all four RHU's: percent sand in surficial deposits and percent wetland. This is a direct result of site selection based on RHU. Basins in RHU 26 had the most sand in surficial deposits, and basins in RHU 20 contained the highest percentages of wetland. Soil drainage and permeability were significantly different in RHU 26 compared to the other three RHU's, which were not significantly different from each other with respect to these characteristics. As mentioned earlier, the percentage of agriculture correlated with bedrock type. The results from the Tukey tests show that the percentage of agriculture was not significantly different between RHU's 1 and 3 (again a direct result of the site selection), both RHU's are underlain by carbonate bedrock. The percentage of agriculture, percentage of sand, and permeability differed significantly between RHU's 20 and 26; however, erodibility factor, which is closely associated with these characteristics, did not differ significantly between RHU 20 and 26. It is not known why the erodibility factor is not significantly different between these two RHU's. Perhaps the percentage of agriculture, percentage of sand, and permeability in RHU's 20 and 26 (although significantly different) are below a certain threshold needed for the difference in erodibility factor to be significant.

Significant differences ($p \leq 0.05$) among RHU's for other habitat characteristics are more complex. For example, patterns of differences in percent forest, concentrations of dissolved nitrate plus nitrite, and triazine screening results were similar: RHU's 20 and 26 differed significantly from each other, but RHU 3 and RHU 1 did not differ significantly from each other or from RHU's 20 and 26. Stream-water samples from RHU 26 contained the highest dissolved nitrate plus nitrite concentrations and had the most triazine detections and contained the most sandy surficial deposits, possibly due to high percentages of agricultural land or ground-water contributions. RHU 20 contained the second largest amount of sandy surficial deposits, but produced the lowest dissolved nitrate plus nitrite concentrations and fewest triazine detections in stream water, possibly because it has the highest percentage of forested land. Highest specific conductances were measured in RHU 1, which significantly differed from RHU's 20 and 26 where specific conductances were lowest. As mentioned earlier, specific conductance correlated with bedrock type, percentage of agricultural land, and percentage of wetland. For Q/Q2, RHU 20 differed significantly from RHU's 1 and 3 due to sampling during flood conditions; no other differences with respect to this ratio were significant.

As noted earlier, sites in RHU 20 grouped separately from the sites in the other RHU's on the ordination plot of principal components related to nutrients, specific conductance, and pH (concentrations of nutrients tended to be lower in RHU 20 than elsewhere). The Tukey tests show that RHU 20 differs significantly from the other RHU's with respect to the percentages of forested land and wetland. This finding indicates that the lower concentrations of nutrients, specific conductance, and pH in streams in RHU 20 relate to the percentage of non-agricultural land in basins within RHU 20.

Environmental factors that contributed to significant differences of some reach characteristics among RHU's were more difficult to identify. Streams in RHU 3 contained the most riffles and streams in RHU 20 had the least, possibly because streams in RHU 20 had high relative flows when habitat was sampled. Riffle substrate embeddedness differed significantly only between RHU's 1 and 20; the large particles sizes in RHU 1 were the least embedded even though RHU 1 has a higher percentage of agricultural land than RHU 20. It is not known why average velocities were highest in RHU 26 and lowest in RHU 3, or why the most undercut banks were present in RHU 26 and the least in RHU 1.

Suitability of Benchmark Streams as Reference Sites

In the NAWQA program, basic fixed sites are established to assess broad-scale spatial and temporal character of stream water in relation to various hydrologic conditions and environmental settings (Gilliom and others, 1995). GLEAS scores were calculated for three WMIC NAWQA basic fixed sites (Sullivan and others, 1995), one each in RHU's 1, 3, and 26; these scores were compared to GLEAS scores at the agricultural benchmark streams in these RHU's (no basic fixed site was available for RHU 20). These particular basic fixed sites are indicator sites; that is, sites chosen to represent drainage from areas of homogeneous land use (primarily agriculture for these sites) and homogeneous physiographic setting. Thus, one would expect those three basic fixed sites to be more affected by agricultural activities than the benchmark-stream sites. Agricultural land in the three fixed-site basins ranged from 58 percent for Tomorrow River near Nelsonville, Wis. (RHU 26) to 87 percent for North Branch of the Milwaukee River near Random Lake, Wis. (RHU 3) and to 89 percent for Duck Creek near Oneida, Wis. (RHU 1). The basic fixed sites at Tomorrow River, North Branch of the Milwaukee River, and Duck Creek were rated good (75-102) with scores of 84, 76, and 78, respectively. Stream reaches at basic fixed sites needed to meet certain selection criteria required for ecological surveys. One criterion was having a variety of geomorphic units (riffle, run, pool) for collecting several types of invertebrate samples required by NAWQA protocols. This criterion may have resulted in inflated scores for the basic fixed sites than would be found for other agricultural streams.

Although the percentage of agricultural land in the benchmark stream basins was as low as 5 percent for some streams, other streams, such as Nichols Creek, Little Scarboro Creek, and Casco Creek drained basins that were more than 80 percent agriculture. The GLEAS scores for these sites were 108, 99, and 93 respectively (table 4). Thus, the percentage of agricultural land in the basin is not affecting the GLEAS ratings of the habitat for these streams (Spearman correlation analyses support this finding). One possible hypothesis is that the width of the riparian zone (not measured in this study), rather than the percentage of agricultural land in the basins, may be more important for influencing habitat ratings.

Habitat characteristics at the benchmark streams are controlled by their physical setting to some degree, and important factors affecting GLEAS scores include availability of large particle sizes for substrate, slopes that are not steep enough to produce adequate velocities, and limited variability of available habitat types. Based only on the high scores from the GLEAS habitat criteria, the best streams in each RHU, as far as available stream habitat is concerned, are Little Scarboro Creek (RHU 1), Nichols Creek (RHU 3), Silver Creek (RHU 20), and Willow Creek (RHU 26). Streams that can be considered GLEAS reference sites are 16 out of the 20 streams with scores of good or better. Those not considered GLEAS reference sites (based on GLEAS scores below 75 for habitat characteristics) are Krok Creek (RHU 1), Watercress Creek (RHU 3), Whitcomb Creek (RHU 20), and Lawrence Creek (RHU 26).

Effects of Stream Restoration on Habitat Characteristics

Although selection of sites where stream habitat has undergone restoration for fisheries was not a major goal of this study, some interesting observations can be made about the characteristics of such sites as compared to other, unrestored streams. Some of the highest GLEAS scores are from streams that have undergone restoration; yet other streams with high GLEAS scores are unrestored. Of the four streams that had the highest GLEAS scores in each RHU, Little Scarboro (GLEAS score = 99) and Nichols Creek (GLEAS score = 108) have undergone the most channel modification, Willow Creek (GLEAS score = 96) has undergone a moderate amount of restoration, and Silver Creek (GLEAS score = 106) has undergone no stream restoration. The GLEAS score for Silver Creek was only 2 points lower than that for Nichols Creek, which was the highest of all the streams sampled in this study.

GLEAS scores for restored streams ranged from 80 to 108. Neenah Creek, the stream where streambank covers and current deflectors failed the most noticeably, had the lowest GLEAS score of all the restored streams. The seven unrestored streams whose GLEAS scores were 80 or above were Tisch Mills Creek, Casco Creek, and Hibbard Creek (RHU 1); East Branch Milwaukee River (RHU 3); and West Branch of the Red River, Silver Creek, and Camp Creek (RHU 20). Thus, streams that have undergone habitat restoration for fisheries do not have higher GLEAS scores for habitat than streams that have not undergone habitat restoration. As mentioned earlier, streams with high GLEAS scores contain large particle sizes for bottom substrate, a variety of velocities, and a wide variety of habitat types. Streams naturally may have these characteristics without undergoing habitat restoration.

The results from the PCA indicate that restored streams sampled in this study group together when plotted along PC1 and PC2 (fig. 3C) and PC2 and PC3 for 13 reach characteristics. Little Scarboro Creek is a noticeable outlier on all three ordination plots. As mentioned previously, percent riffle, width/depth ratio, and embeddedness load on PC1. Percent pool, canopy angle, and bank-stability index load most heavily on PC2, and velocity and bottom substrate on PC3. The close grouping of these streams on the ordination plots (except for Little Scarboro Creek) indicates that reach characteristics such as riffle/pool sequences, velocity, and substrate are less varied for these streams than for other reference streams. This result may reflect the goals for stream-habitat restorations or enhancements that support sport fisheries. Although habitat characteristics after restoration may meet the needs of certain fish species, restored-stream habitats may not be conducive to other native aquatic species that do not do well under such limited habitat characteristics. Streams with high GLEAS scores without habitat restoration tended to show more variability along all three principal components, indicating variability in channel, substrate, and bank conditions, within the bounds of what is considered good habitat according to the GLEAS method.

SUMMARY AND CONCLUSIONS

Habitat characteristics of 20 streams were measured at the basin, segment, and reach level in May and June 1993 as part of an ecological survey of agricultural areas in the WMIC NAWQA study unit. Data were analyzed to meet three main goals: (1) overall description of habitat characteristics, (2) determination of differences among habitat characteristics in four RHU's, and (3) determination of whether these streams represent standards of reference for comparison to other agricultural streams in similar geographic settings.

Overall description of the habitat characteristics was accomplished through correlation analysis and PCA. Most significant correlations were found among basin characteristics, especially among those characteristics that reflected their respective RHU's. For example, streams flowing over carbonate bedrock had drainage basins with the highest percentages of agricultural land and the lowest percentages of wetland.

Correlations among reach characteristics were few and sometimes hard to explain. Streams with undercut banks have open canopies, an indication that these streams have open wetland riparian vegetation. It is not known why stable banks tended to occur in streams with abundant macrophyte coverage; or, why large particle sizes in bottom substrate tended to be less embedded than small particle sizes. Specific conductance correlated positively with percentage of agricultural land, erodibility factor, and carbonate bedrock; and correlated negatively with percentage of wetland. Total organic plus ammonia nitrogen and total phosphorus concentrations correlated positively with drainage density.

The results from several exploratory analyses with PCA indicate the potential for certain groupings among habitat characteristics, as well as groupings of streams whose distributions of habitat characteristics are similar. Results from PCA of a mixture of habitat characteristics from different levels indicate that the first three principal components can be described as most closely associated with (1) RHU, (2) land use or geomorphology, and (3) drainage-basin size. Ordination plots of these PCA results show several groupings of sites by RHU. A PCA on basin-level characteristics only resulted in similar groupings. The results from PCA on reach-level characteristics only did not indicate any groupings of reach characteristics that could be related to other environmental factors. Instead, the most important finding was that streams that have undergone habitat restoration form a distinct group on the ordination plots of the reach-level principal components. This grouping of streams indicates that variability of reach characteristics is reduced when streams are modified by humans to meet the present stream restoration requirements for specific aquatic species.

Out of the 39 habitat characteristics analyzed as part of this report, less than half were significantly different between one RHU and the other three. These characteristics included eight basin-level characteristics and eight reach-level characteristics. The percentages of sandy surficial deposits and wetlands were significantly different among all four RHU's. The percentages of agriculture were not significantly different between RHU's 1 and 3, but those for RHU's 20 and 26 were significantly different from each other and from those in RHU's 1 and 3. Streams in RHU 20 had the lowest dissolved nitrate plus nitrite concentrations and the fewest triazine detections and the largest percentages of forest and wetland. Streams in RHU 20 also contained the least amount of riffle and had the most embedded riffles.

Based on GLEAS scores for habitat criteria, 16 out of 20 agricultural benchmark streams are suitable as reference streams as far as habitat is concerned. No significant difference in GLEAS scores was found between streams that have undergone habitat restoration and those that have not. All RHU's have a similar range in GLEAS scores. Streams with scores of fair and not considered reference sites for habitat characteristics are: Krok Creek (RHU 1), Watercress Creek (RHU 3), Whitcomb Creek (RHU 20), and Lawrence Creek (RHU 26).

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SUPPLEMENTAL TABLES 6–8

Table 6. Basin- and segment-level habitat characteristics of agricultural benchmark streams in the Western Lake Michigan Drainages study unit

[km, kilometers; mi^2, square miles; km^2, square kilometers; m, meters; m/km, meters per kilometer; cm/h, centimeters of rainfall absorbed before saturation per hour unit time; soil drainage classes: 9, excessively drained; 8, somewhat excessively drained; 7, well to somewhat excessively drained; 6, well drained; 5, moderately well drained; 4, somewhat poorly drained; 3, poorly drained; 2, poorly to very poorly drained; 1, very poorly drained]

Site name	Relatively homogeneous unit[1]	Drainage area (km^2, [mi^2])		Stream length[2] (km)	Stream slope[2] (m/km)	Drainage density[2] (km/km^2)	Basin shape[2]	Basin relief[2] (m)
Tisch Mills Creek at Tisch Mills, Wis.	1	42.2	[16.3]	8.4	3.6	0.28	0.59	55
Krok Creek near Ellisville, Wis.	1	22.8	[8.8]	4.0	1.1	.32	1.4	33
Little Scarboro Creek near Casco, Wis.	1	2.33	[0.9]	1.2	9.5	.52	1.6	30
Casco Creek at Casco, Wis.	1	38.8	[15.0]	12	2.0	.32	.25	67
Hibbard Creek near Jacksonport, Wis.	1	42.5	[16.4]	7.2	3.0	.17	.81	67
East Branch Milwaukee River near New Fane, Wis.	3	138	[53.3]	25	.73	.36	.22	91
Nichols Creek near Cascade, Wis.	3	11.9	[4.6]	2.6	8.1	.22	1.8	79
Mullet River near Plymouth, Wis.	3	117	[45.4]	28	1.2	.36	.14	100
Watercress Creek near Dundee, Wis.	3	31.1	[12.0]	2.0	12	.06	7.7	67
Whitcomb Creek near Big Falls, Wis.	20	22.0	[8.5]	7.7	3.4	.67	.37	67
West Branch Red River near Bowler, Wis.	20	95.8	[37.0]	31	2.4	.54	.10	137
Silver Creek near Bowler, Wis.	20	40.9	[15.8]	12	2.5	.45	.28	67
Smith Creek near Bowler, Wis.	20	5.70	[2.2]	1.6	6.6	.28	2.2	43
Camp Creek near Galloway, Wis.	20	12.4	[4.8]	5.3	3.2	.43	.44	46
Lawrence Creek near Lawrence, Wis.	26	21.5	[8.3]	.80	23	.04	33	49
Neenah Creek near Oxford, Wis.	26	63.7	[24.6]	8.8	4.0	.21	.81	85
Chaffee Creek near Neshkoro, Wis.	26	23.8	[9.2]	9.5	4.1	.40	.26	70
Mecan River near Richford, Wis.	26	73.8	[28.5]	16	4.2	.30	.27	123
Willow Creek near Mount Morris, Wis.	26	41.7	[16.1]	11	4.4	.28	.31	94
Pine River near Wild Rose, Wis.	26	55.2	[21.3]	7.7	6.7	.14	.92	104

Table 6. Basin- and segment-level habitat characteristics of agricultural benchmark streams in the Western Lake Michigan Drainages study unit—Continued

Site name	Bedrock type	Surficial deposits[3] (percent)					Erodibility factor[3]	Soil drainage[3]	Permea-bility[3] (cm/h)
		Sand	Loam and clay	Silt	Muck	Other deposits			
Tisch Mills Creek at Tisch Mills, Wis.	Carbonate	40	8	47	0	5	0.28	5.5	13
Krok Creek near Ellisville, Wis.	Carbonate	26	17	20	35	2	.20	3.8	11
Little Scarboro Creek near Casco, Wis.	Carbonate	60	11	11	17	1	.20	4.7	19
Casco Creek at Casco, Wis.	Carbonate	26	32	33	0	9	.30	5.1	5.6
Hibbard Creek near Jacksonport, Wis.	Carbonate	29	44	14	4	9	.29	5.4	7.4
East Branch Milwaukee River near New Fane, Wis.	Carbonate	6	26	60	7	1	.22	5.5	19
Nichols Creek near Cascade, Wis.	Carbonate	2	27	65	4	2	.28	5.1	10
Mullet River near Plymouth, Wis.	Carbonate	3	25	60	10	2	.25	5.0	14
Watercress Creek near Dundee, Wis.	Carbonate	6	27	61	6	0	.21	5.6	21
Whitcomb Creek near Big Falls, Wis.	Igneous/metamorphic	72	0	0	26	2	.15	4.9	13
West Branch Red River near Bowler, Wis.	Igneous/metamorphic	74	0	0	24	2	.16	5.0	12
Silver Creek near Bowler, Wis.	Igneous/metamorphic	77	0	0	19	4	.17	5.1	11
Smith Creek near Bowler, Wis.	Igneous/metamorphic	78	0	0	20	2	.14	5.6	20
Camp Creek near Galloway, Wis.	Igneous/metamorphic	80	0	0	15	5	.02	5.3	9.9
Lawrence Creek near Lawrence, Wis.	Sandstone	96	0	0	4	0	.16	7.5	28
Neenah Creek near Oxford, Wis.	Sandstone	96	0	0	3	1	.16	7.5	28
Chaffee Creek near Neshkoro, Wis.	Sandstone	96	0	0	4	0	.16	7.5	28
Mecan River near Richford, Wis.	Sandstone	91	0	0	8	1	.16	7.2	28
Willow Creek near Mount Morris, Wis.	Sandstone	93	0	0	6	1	.16	7.3	25
Pine River near Wild Rose, Wis.	Sandstone	96.4	0	0	2.9	.6	.16	7.5	28

Table 6. Basin- and segment-level habitat characteristics of agricultural benchmark streams in the Western Lake Michigan Drainages study unit—Continued

Site name	Basin storage[2] (km^2)	Land use[4] (percent of basin)			Segment characteristics		
		Agriculture	Wetland	Forest	Stream order[5]	Channel sinuosity[2]	Segment gradient[2] (m/km)
Tisch Mills Creek at Tisch Mills, Wis.	1.3	81	11	7.8	2	1.00	42.4
Krok Creek near Ellisville, Wis.	9.1	61	37	2.7	2	1.11	12.7
Little Scarboro Creek near Casco, Wis.	.15	93	6.5	0	1	1.17	84.9
Casco Creek at Casco, Wis.	2.0	89	2.1	7.0	3	1.26	63.7
Hibbard Creek near Jacksonport, Wis.	2.7	73	12	14	2	1.24	16.1
East Branch Milwaukee River near New Fane, Wis.	19	56	7.8	32	2	1.66	6.5
Nichols Creek near Cascade, Wis.	.35	81	0	19	1	1.28	47.7
Mullet River near Plymouth, Wis.	15	72	7.6	15	4	1.37	22.2
Watercress Creek near Dundee, Wis.	.94	66	3.2	31	2	1.14	14.9
Whitcomb Creek near Big Falls, Wis.	2.6	30	6.2	63	2	1.00	15.3
West Branch Red River near Bowler, Wis.	13	38	10	51	2	1.13	31.2
Silver Creek near Bowler, Wis.	6.3	35	19	45	2	1.29	29.1
Smith Creek near Bowler, Wis.	1.3	5.0	35	59	2	1.20	47.3
Camp Creek near Galloway, Wis.	3.8	18	28	54	1	1.10	31.6
Lawrence Creek near Lawrence, Wis.	.86	50	0	46	1	1.10	37.1
Neenah Creek near Oxford, Wis.	3.0	58	.38	38	2	1.28	24.6
Chaffee Creek near Neshkoro, Wis.	.24	44	17	26	2	1.05	27.5
Mecan River near Richford, Wis.	2.3	59	1.4	40	2	1.24	10.6
Willow Creek near Mount Morris, Wis.	2.3	41	4.0	52	2	1.14	24.8
Pine River near Wild Rose, Wis.	.22	58	0	42	2	1.20	36.9

[1]Relatively homogeneous units are described in Robertson and Saad (1995).
[2]Method for calculation is described in Meador and others (1993) and data are derived from 1:24,000-scale U.S. Geological Survey topographic maps.
[3]Percentages of surficial deposits, erodibility factor, soil drainage and permeability were obtained from STATSGO (U.S. Department of Agriculture, 1991).
[4]Based on Anderson (1970) classification system; percentages estimated from digital line graph land use/land cover from high-altitude photography taken from 1972–81 and interpreted according to methods in Fegeas and others (1983).
[5]Method for calculating stream order is based on Stahler (1954, 1957) and data are derived from blue lines on 1:24,000-scale U.S. Geological Survey topographic maps.

Table 7. Reach-level habitat characteristics of agricultural benchmark streams in the Western Lake Michigan Drainages study unit

[μS/cm, microsiemens per centimeter at 25 degrees Celsius; m^3/s, cubic meters per second; ft^3/s, cubic feet per second; --, missing data]

Site name	Percent riffle	Percent pool	Percent run	Mean canopy angle[1]	Mean aspect	Amount woody debris (percent)	Mean width/depth ratio	Bank-stability index[2]	Amount undercut banks (percent)	Macro-phyte coverage (percent)	Periphyton coverage (percent)
Tisch Mills Creek at Tisch Mills, Wis.	36	33	31	32	236	4	20	8.8	42	0	26
Krok Creek near Ellisville, Wis.	49	14	37	22	187	12	19	7.7	8	14	<1
Little Scarboro Creek near Casco, Wis.	14	37	49	0	79	12	10	9.7	8	0	7
Casco Creek at Casco, Wis.	57	2	41	26	207	0	52	7.8	17	<1	54
Hibbard Creek near Jacksonport, Wis.	10	41	49	23	83	18	23	10	50	0	33
East Branch Milwaukee River near New Fane, Wis.	38	25	37	71	190	2	29	6.9	8	65	--
Nichols Creek near Cascade, Wis.	52	0	48	22	98	8	17	6.8	83	20	--
Mullet River near Plymouth, Wis.	74	0	26	74	146	8	118	7.0	50	8	9
Watercress Creek near Dundee, Wis.	16	5	79	24	189	19	12	7.8	25	0	0
Whitcomb Creek near Big Falls, Wis.	7	7	86	100	182	9	9.9	6.1	100	11	0
West Branch Red River near Bowler, Wis.	9	18	73	48	73	15	18	7.2	42	<1	0
Silver Creek near Bowler, Wis.	28	5	67	33	104	9	11	9.0	42	0	1
Smith Creek near Bowler, Wis.	--	--	--	2	75	18	10	--	--	<1	--
Camp Creek near Galloway, Wis.	7	8	85	40	208	15	9.4	7.4	92	--	--
Lawrence Creek near Lawrence, Wis.	25	0	75	122	109	0	5.8	7.5	75	--	--
Neenah Creek near Oxford, Wis.	41	0	59	84	140	8	13	7.0	58	8	8
Chaffee Creek near Neshkoro, Wis.	24	51	25	20	113	10	7.2	7.4	100	13	--
Mecan River near Richford, Wis.	33	4	63	52	148	13	23	6.5	75	2	4
Willow Creek near Mount Morris, Wis.	21	14	65	40	167	15	14	6.8	75	<1	3
Pine River near Wild Rose, Wis.	35	0	65	73	129	12	15	8.5	50	1	2

Table 7. Reach-level habitat characteristics of agricultural benchmark streams in the Western Lake Michigan Drainages study unit—Continued

Site name	pH	Specific conductance[3] (µS/cm)	Discharge[4] Measured (m^3/s, [ft^3/s])		Discharge[4] 2-year flood (m^3/s, [ft^3/s])	
Tisch Mills Creek at Tisch Mills, Wis.	8.2	606	.31	[11]	7.4	[260]
Krok Creek near Ellisville, Wis.	8.0	553	.16	[5.5]	2.2	[77]
Little Scarboro Creek near Casco, Wis.	7.9	640	.11	[3.9]	.84	[30]
Casco Creek at Casco, Wis.	7.9	726	.31	[11]	5.2	[184]
Hibbard Creek near Jacksonport, Wis.	7.8	543	.27	[9.6]	8.1	[286]
East Branch Milwaukee River near New Fane, Wis.	8.1	283	1.1	[32]	10	[360]
Nichols Creek near Cascade, Wis.	7.9	706	.20	[7.0]	4.2	[148]
Mullet River near Plymouth, Wis.	8.5	596	.75	[26]	13	[448]
Watercress Creek near Dundee, Wis.	7.8	638	.01	[0.25]	10	[368]
Whitcomb Creek near Big Falls, Wis.	7.9	310	.48	[17]	2.7	[97]
West Branch Red River near Bowler, Wis.	7.9	291	2.0	[70]	9.1	[320]
Silver Creek near Bowler, Wis.	7.7	242	1.6	[56]	4.4	[155]
Smith Creek near Bowler, Wis.	7.1	137	.25	[9.0]	.98	[35]
Camp Creek near Galloway, Wis.	7.5	218	.70	[25]	1.6	[58]
Lawrence Creek near Lawrence, Wis.	7.7	350	.46	[16]	20	[726]
Neenah Creek near Oxford, Wis.	8.0	343	.77	[27]	6.5	[230]
Chaffee Creek near Neshkoro, Wis.	7.8	308	.67	[24]	1.7	[59]
Mecan River near Richford, Wis.	7.9	349	1.7	[59]	4.5	[158]
Willow Creek near Mount Morris, Wis.	7.8	335	.65	[22]	4.9	[173]
Pine River near Wild Rose, Wis.	8.0	407	.21	[7.6]	7.8	[276]

[1]Measured according to Meador and others (1993).
[2]Bank-stability index combines bank angle, shape, vegetative stability, height and substrate into one index.
[3]Data were collected during ecological synoptic, May 1993; see Rheaume and others (1996).
[4]Flood discharges calculated from equations developed by Gebert and others (1987).

Table 8. Transect-level habitat characteristics of agricultural benchmark streams in the Western Lake Michigan Drainages study unit

[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 are: 5.0, less than 5 percent of surface area of gravel, cobble, and boulder particles covered by fine sediment; 4.0, 5 to 25 percent covered by fine sediment; 3.0, 26 to 50 percent covered by fine sediment; 2.0, 51 to 75 percent covered by fine sediment; 1.0, more than 75 percent covered by fine sediment; 0.0, no gravel, cobble or boulder present; --, missing data; *, depth and velocity range is from 2 points; ^, depth and velocity range is from 4 points]

Site name	Transect	Geomorphic channel unit[1]	Channel width (m)	Depth (m)	Velocity (m/s)	Bottom substrate: Dominant	Bottom substrate: Subdominant	Embeddedness[2]	Silt present
				RHU 1					
Tisch Mills Creek at Tisch Mills, Wis.	1	--	4.3	0.32–0.40	0.0068–0.51	gv-sa	bo-co	4.0	No
	2	Riffle	6.5	0.20–0.26	0.031–0.037	sa	co	4.0	No
	3	Run	7.0	0.30–0.40	0.015–0.022	co-sa	co-gv	4.0	No
	4	Riffle	5.6	0.32–0.42	0.015–0.040	bo	sa	4.0	No
	5	Run	7.3	0.22–0.28	0.017–0.028	bd-gv	bd-gv	4.0	No
	6	--	8.1	0.29–0.43	0.012–0.020	gv	sa	4.0	No
Krok Creek near Ellisville, Wis.	1	--	5.7	0.27–0.33	0.0096–0.022	sa-mu	sa-mu	0.0	No
	2	Run/riffle	4.7	0.19–0.24	0.013–0.018	sa-mu	sa-de	0.0	No
	3	Riffle	5.3	0.20–0.35	0.015–0.024	sa-mu	sa-mu	0.0	No
	4	Sandy run	4.8	0.21–0.32	0.014–0.023	sa-mu	de-mu	0.0	No
	5	Riffle	5.2	0.23–0.28	0.0091–0.023	sa	co-de	3.5	No
	6	--	5.0	0.23–0.35	0.0088–0.027	bo-mu	sa-de	3.0	No
Little Scarboro Creek near Casco, Wis.	1	--	2.0	0.27–0.47	0.014–0.031	bo-sa	bo-sa	3.5	No
	2	Riffle	3.0	0.14–0.21	0.016–0.048	sa	gv	4.0	No
	3	Sandy run	3.3	0.27–0.36	0.014–0.028	bo-gv	gv-sa	0.0	No
	4	Run	2.5	0.16–0.20	0.019–0.042	gv-sa	gv-sa	4.0	No
	5	Riffle	2.1	0.18–0.24	0.040–0.051	bo-gv	bo-gv	4.0	No
	6	--	2.6	0.21–0.28	0.014–0.065	gv	bo	4.0	No
Casco Creek at Casco, Wis.	1	--	10	0.14–0.24	0.015–0.031	bo	co-gv	4.0	No
	2	Run	8.6	0.14–0.31	0.0099–0.042	bo	gv	4.0	No
	3	Riffle	6.8	0.13–0.28	0.027–0.037	bo	co-gv	4.0	No
	4	Run	7.6	0.15–0.22	0.018–0.027	bo-co	gv	4.0	No
	5	Riffle	15	0.13–0.29	0.012–0.034	bo	gv-sa	4.3	No
	6	--	8.7	0.03–0.22	0.020–0.045*	bo-co	gv	4.0	No

Table 8. Transect-level habitat characteristics of agricultural benchmark streams in the Western Lake Michigan Drainages study unit—Continued

Site name	Transect	Geomorphic channel unit[1]	Channel width (m)	Depth (m)	Velocity (m/s)	Bottom substrate		Embeddedness[2]	Silt present
						Dominant	Subdominant		
RHU 1—Continued									
Hibbard Creek near Jacksonport, Wis.	1	--	5.6	0.30–0.46	--	sa	co-sa	1.5	No
	2	Pool	6.5	0.55–0.62	--	sa	co-sa	3.0	No
	3	Riffle	9.1	0.17–0.20	0.018–0.034	bo-co	gv-sa	4.0	No
	4	Pool	5.7	0.24–0.32	0.015–0.027	co-gv	co-gv	3.6	No
	5	Riffle	6.5	0.09–0.14	0.037–0.059	co-gv	co-gv	4.0	No
	6	--	6.5	0.10–0.17	0.025–0.051	bo-co	co-gv	4.0	No
RHU 3									
East Branch Milwaukee River near New Fane, Wis.	1	--	12	0.32–0.41	0.019–0.031	gv-sa	co-gv	4.0	No
	2	Riffle	22	0.22–0.35	0.016–0.042	gv-sa	co-sa	3.6	No
	3	Run	17	0.38–0.53	0.010–0.019	sa	gv	3.3	No
	4	Sandy run	22	0.25–0.72	0.0071–0.017	sa-mu	co-gv	2.5	No
	5	Pool	14	0.64–0.87	0.0045–0.015	sa-mu	mu	0.0	No
	6	--	10	0.78–1.0	0.011–0.015	sa-mu	co-sa	0.0	No
Nichols Creek near Cascade, Wis.	1	--	4.1	0.11–0.39	0.012–0.024	bo-sa	co-sa	2.0	No
	2	Riffle	3.9	0.15–0.22	0.037–0.057	gv-sa	co-gv	5.0	No
	3	Riffle	4.9	0.15–0.24	0.019–0.042	gv	co-gv	5.0	No
	4	Riffle	4.4	0.22–0.40	0.0091–0.023	co-sa	gv	4.6	No
	5	Run	3.4	0.26–0.35	0.021–0.028	bo-co	co-sa	4.6	No
	6	--	7.2	0.24–0.30	0.0–0.048	gv-mu	gv-mu	3.0	No
Mullet River near Plymouth, Wis.	1	--	54	0.13–0.28^	0.023–0.042^	co-sa	gv-sa	3.2	No
	2	Riffle	50	0.10–0.20^	0.027–0.054^	gv-sa	co-sa	4.0	No
	3	Shallow riffle	22	0.23–0.25	0.027–0.045	gv	sa	2.6	No
	4	Riffle	16	0.18–0.30	0.028–0.045	co-gv	bo-sa	3.3	No
	5	Deep run/riffle	16	0.25–0.30	0.0042–0.031	co-gv	sa	4.0	No
	6	--	9.3	0.29–0.31	0.012–0.042	co-sa	gv-sa	3.3	No

Table 8. Transect-level habitat characteristics of agricultural benchmark streams in the Western Lake Michigan Drainages study unit—Continued

Site name	Tran-sect	Geomorphic channel unit[1]	Channel width (m)	Depth (m)	Velocity (m/s)	Bottom substrate: Dominant	Bottom substrate: Sub-dominant	Embed-dedness[2]	Silt present
RHU 3—Continued									
Watercress Creek near Dundee, Wis.	1	--	2.9	0.13–0.18*	0.019–0.023*	mu-sa	sa-de	0.0	Yes
	2	Run	2.3	0.17–0.28*	0.011–0.016*	mu	gv-de	0.0	Yes
	3	Run	2.0	0.22–0.23*	0.017–0.017*	mu	de	0.0	Yes
	4	Riffle	1.9	0.19–0.23*	0.010–0.014*	sa	gv-sa	0.0	Yes
	5	Run	2.8	0.14–0.21*	0.010–0.018*	mu	de	0.0	Yes
	6	--	3.1	0.26–0.28*	0.0074–0.0079*	sa-mu	si-mu	0.0	Yes
RHU 20									
Whitcomb Creek near Big Falls, Wis.	1	--	5.1	0.49–0.61	0.021–0.028	sa	sa	0.0	No
	2	Riffle	6.5	0.42–0.68	0.021–0.034	sa	sa	0.0	No
	3	Run	6.8	0.26–0.61	0.028–0.034	sa	sa	0.0	No
	4	Sandy run	3.6	0.62–0.71	0.016–0.031	sa	sa	0.0	No
	5	Sandy riffle	5.4	0.44–0.66	0.020–0.037	sa	sa	0.0	No
	6	--	5.4	0.50–0.59	0.024–0.034	sa	sa	0.0	No
West Branch Red River near Bowler, Wis.	1	--	9.2	0.33–0.61	0.028–0.037	gv-sa	gv-sa	0.0	No
	2	Run	8.3	0.55–0.71	0.016–0.051	sa	gv	0.0	No
	3	Riffle/run	10	0.20–0.45	0.0074–0.018	sa	gv-mu	0.0	No
	4	Run	8.6	0.33–0.61	0.013–0.017	sa-mu	gv-sa	0.0	No
	5	Run/pool	9.1	0.58–0.71	0.018–0.027	gv-sa	gv-sa	0.0	No
	6	--	13	0.47–0.70	0.0093–0.021	co-mu	gv-sa	0.0	No
Silver Creek near Bowler, Wis.	1	--	7.5	0.50–0.87	0.016–0.074	bo	gv	4.0	No
	2	Riffle	13	0.38–0.49	0.034–0.048	co-sa	bo-gv	4.0	No
	3	Riffle	12	0.47–0.52	0.76–0.048	bo	gv-sa	4.0	No
	4	Run	8.4	0.52–0.74	0.023–0.071	bo-sa	bo-gv	4.0	No
	5	Deep run	5.9	0.59–0.88	0.034–0.042	gv	sa	0.0	No
	6	--	11	0.46–0.68	0.015–0.037	gv-sa	gv-sa	0.0	No

Table 8. Transect-level habitat characteristics of agricultural benchmark streams in the Western Lake Michigan Drainages study unit—Continued

Site name	Transect	Geomorphic channel unit[1]	Channel width (m)	Depth (m)	Velocity (m/s)	Bottom substrate: Dominant	Bottom substrate: Subdominant	Embeddedness[2]	Silt present
				RHU 20—Continued					
Smith Creek near Bowler, Wis.	1	--	6.0	0.38–0.46	0.0079–0.015	sa	mu	0.0	No
	2	Run	5.0	0.32–0.50	0.022–0.028	sa	mu	0.0	No
	3	--	3.2	0.34–0.49	0.016–0.019	sa	mu	0.0	No
	4	--	6.4	0.38–0.49	--	sa	mu	0.0	No
	5	--	3.7	0.50–0.65	--	sa	mu	0.0	No
	6	--	4.0	0.41–0.57	--	sa	mu	0.0	No
Camp Creek near Galloway, Wis.	1	--	4.1	0.48–0.69	0.034 (1 point)	gv	sa	0.0	No
	2	Riffle	4.8	0.38–0.59	0.023–0.051	gv-sa	sa	0.0	No
	3	Run	4.7	0.50–0.59	0.012–0.042	sa	gv-mu	0.0	No
	4	Run	4.7	0.49–0.61	0.034–0.037	sa	gv	0.0	No
	5	Run	6.2	0.44–0.70	0.028–0.042	gv-de	sa	0.0	No
	6	--	6.0	0.48–0.61	0.021–0.034	gv-sa	gv-de	0.0	No
				RHU 26					
Lawrence Creek near Lawrence, Wis.	1	--	2.8	0.52–0.62	0.016–0.045	sa	gv-mu	2.0	No
	2	Riffle	3.3	0.52–0.69	0.020–0.026	sa	gv-sa	0.0	No
	3	Run	2.8	0.20–0.60	0.0031–0.034	bo-sa	sa-mu	3.0	No
	4	Run	2.4	0.22–0.66	0.019–0.034	sa	sa	0.0	No
	5	Riffle	2.7	0.52–0.58	0.023–0.051	sa	gv-sa	0.0	No
	6	--	3.0	0.34–0.41	0.034–0.054	sa	gv-sa	0.0	No
Neenah Creek near Oxford, Wis.	1	--	5.0	0.29–0.59	0.027–0.068	sa	gv-sa	2.0	No
	2	Run	4.2	0.54–0.55	0.022–0.045	sa	gv-sa	4.0	No
	3	Riffle	5.0	0.24–0.41	0.054–0.065	gv	sa	1.6	No
	4	Run	3.8	0.28–0.46	0.031–0.062	sa	gv-sa	3.5	No
	5	Riffle	6.4	0.29–0.35	0.042–0.057	sa	gv-sa	2.0	No
	6	--	5.0	0.31–0.34	0.031–0.082	gv-sa	gv-sa	3.0	No

Table 8. Transect-level habitat characteristics of agricultural benchmark streams in the Western Lake Michigan Drainages study unit—Continued

Site name	Tran-sect	Geomorphic channel unit[1]	Channel width (m)	Depth (m)	Velocity (m/s)	Bottom substrate: Dominant	Bottom substrate: Sub-dominant	Embed-dedness[2]	Silt present
				RHU 26—Continued					
Chaffee Creek near Neshkoro, Wis.	1	--	3.8	0.28–0.69	0.031–0.034	sa	sa	0.0	No
	2	Pool	3.5	0.73–1.10	0.027–0.034	sa	sa	0.0	No
	3	Riffle	4.1	0.43–0.68	0.031–0.034	sa	sa	0.0	No
	4	Pool	4.4	0.51–0.75	0.031–0.034	sa	sa	0.0	No
	5	Run	4.4	0.42–0.66	0.034–0.034	sa	sa	0.0	No
	6	--	5.0	0.30–.053	0.020–0.042	sa	sa	0.0	No
Mecan River near Richford, Wis.	1	--	7.8	0.34–0.52	0.034–0.057	gv-sa	co-sa	2.5	No
	2	Run	9.9	0.36–0.67	0.33–0.042	sa	gv-sa	3.0	No
	3	Shallow riffle	12	0.13–0.44	0.019–0.068	gv-sa	gv-sa	3.0	No
	4	Shallow riffle	13	0.10–0.43	0.0–0.057	gv-mu	sa-mu	1.5	No
	5	Run	9.2	0.29–0.48	0.059–0.14	gv-sa	sa	2.0	No
	6	--	7.4	0.18–0.81	0.012–0.099	sa	gv-sa	2.0	No
Willow Creek near Mount Morris, Wis.	1	--	7.0	0.32–0.54	0.027–0.12	bo-sa	sa-de	3.0	No
	2	Riffle	8.7	0.23–0.42	0.051–0.10	gv-sa	gv-sa	3.0	No
	3	Pool	5.4	0.34–0.45	0.031–0.076	sa	gv-sa	3.0	No
	4	Run	5.6	0.19–0.67	0.028–0.085	sa	sa-de	0.0	No
	5	Deep riffle	2.7	0.43–0.60	0.091–0.14	bo	sa	3.3	No
	6	--	8.7	0.32–0.50	0.048–0.14	sa	bo-de	3.0	No
Pine River near Wild Rose, Wis.	1	--	3.4	0.21–0.31	0.012–0.051	gv-sa	gv-de	4.0	No
	2	Run/riffle	3.6	0.24–0.43	0.015–0.034	bo-sa	co-sa	1.6	No
	3	Sandy run	4.0	0.14–0.32	0.012–0.034	sa	sa	0.0	No
	4	Riffle	3.6	0.16–0.17	0.034–0.059	co-sa	co-gv	4.0	No
	5	Run	4.5	0.25–0.35	0.0068–0.048	sa	gv-sa	3.0	No
	6	--	3.4	0.22–0.25	0.022–0.034	gv-sa	gv-sa	3.0	No

[1]Transects 1 and 6, at the beginning and end of the reach, are between geomorphic channel units.
[2]Categorical data were averaged to obtain an average embeddedness for each transect; therefore, the given number may fall between two categories.