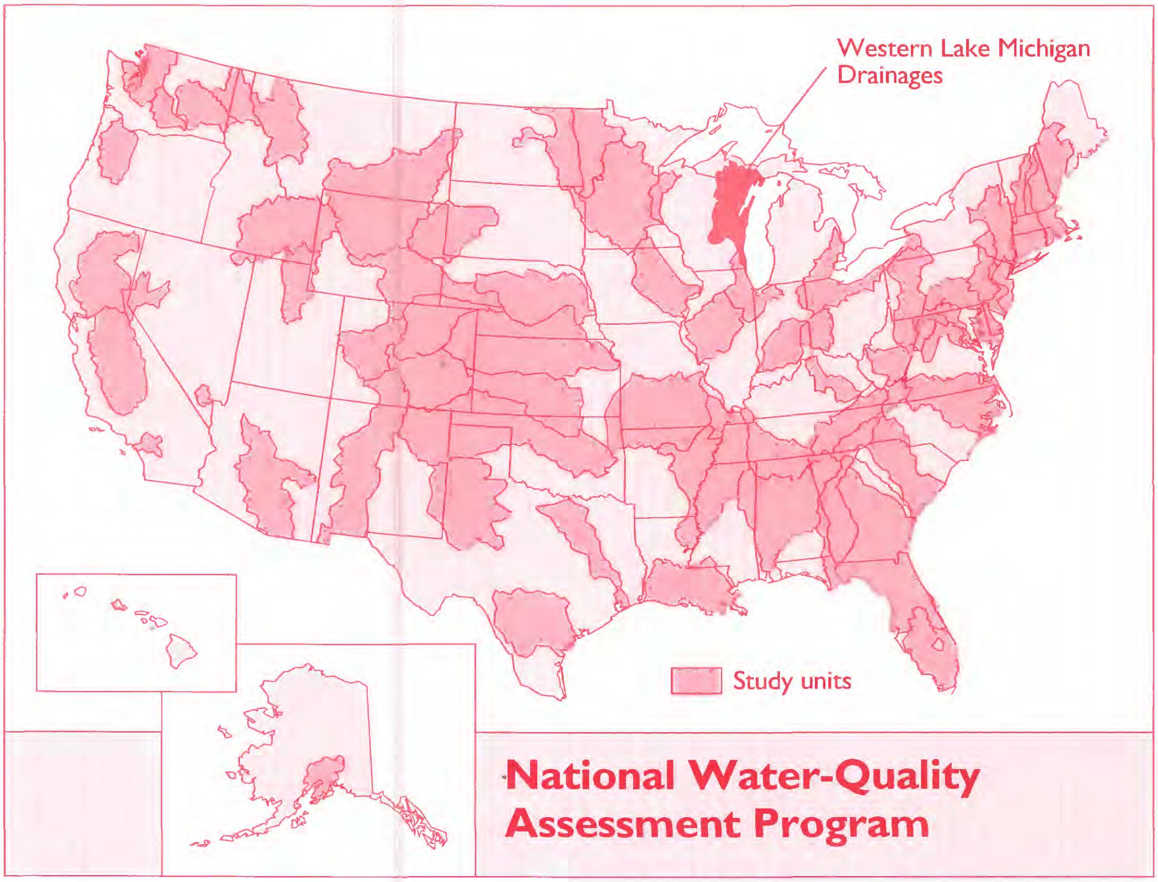
U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 98-4072

Evaluation of the Surface-Water Sampling Design in the Western Lake Michigan Drainages in Relation to Environmental Factors Affecting Water Quality at Base Flow



EVALUATION OF THE SURFACE-WATER SAMPLING DESIGN IN THE WESTERN LAKE MICHIGAN DRAINAGES IN RELATION TO ENVIRONMENTAL FACTORS AFFECTING WATER QUALITY AT BASE FLOW

By Dale M. Robertson

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Water-Resources Investigations Report 98–4072

NATIONAL WATER-QUALITY ASSESSMENT PROGRAM
WESTERN LAKE MICHIGAN DRAINAGES

USGS
science for a changing world

Middleton, Wisconsin
1998

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FOREWORD

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

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

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

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

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

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 59 of the Nation's most important river basins and aquifer systems, which are referred to as Study Units. These Study Units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 59 Study Units, and more than two-thirds of the people served by public water-supply systems live within their boundaries.

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

CONTENTS

FIGURES

FIGURES—Continued

TABLES

CONVERSION FACTORS AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To Obtain
centimeter (cm)	0.3937	inch
meter (m)	3.281	foot
hectare (ha)	2.471	acre
kilometer (km)	0.6214	mile
square kilometer (km^2)	0.3861	square mile
kilogram (kg)	2.205	pound
liter (L)	0.2642	gallon
milligram (mg)	0.000002205	pound
kilogram per hectare (kg/ha)	0.89218	pound per acre
cubic meter per day (m^3/d)	0.1834	gallon per minute
centimeter per hour (cm/h)	0.3937	inch per hour

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

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Evaluation of the Surface-Water Sampling Design in the Western Lake Michigan Drainages in Relation to Environmental Factors Affecting Water Quality at Base Flow

By Dale M. Robertson

Abstract

Eight stream sites (Fixed Sites) were chosen to describe the variability in the water quality of the Western Lake Michigan Drainages (WMIC) Study Unit of the National Water-Quality Assessment program. These sites were chosen in areas (Relatively Homogeneous Units) dominated by unique combinations of the environmental factors thought to be most important in influencing water quality; namely, land use, surficial deposits, and bedrock type. A study was designed to determine (1) the applicability of streamflow, nutrient, and suspended sediment data regularly collected at these eight sites to describing the variability in these characteristics throughout the Study Unit during base-flow conditions and (2) the applicability of the interpretive results made from data collected at these few sites to streams throughout the Study Unit. This was done by sampling the Fixed Sites and an additional 83 sites in Relatively Homogeneous Units throughout the Study Unit during summer base-flow conditions.

Data collected at the Fixed Sites described the range in water-quality characteristics (streamflow and concentrations of nutrients and suspended sediment) in the WMIC Study Unit and, in general, represented the water quality from the Relatively Homogeneous Units from which they were chosen. The results from the eight Fixed Sites agreed with those found for all of the sites; namely, that these water-quality characteristics in streams throughout the WMIC Study Unit during base-flow conditions are influenced primarily by the land use and surficial deposits in their drainage basins. General basin characteristics (bedrock information, topographic gradient, and basin size) were not important factors in explaining the variability in these water-quality characteristics during base-flow conditions, but may be important factors for other characteristics measured at the Fixed Sites, such as major ions, and may be important during higher flow. In general, streams in agricultural areas had the poorest water quality; that is, they contained the highest concentrations of total phosphorus, total Kjeldahl nitrogen, and suspended sediment. Streams in forested areas had the best water quality; that is, they contained the lowest concentrations of total phosphorus, dissolved nitrite plus nitrate, and suspended sediment. Streams in urban and mixed agriculture/forested areas had moderate water quality and usually were not statistically different from one another. Within a specific land-use type, streams in areas with low permeability (clayey deposits) had the poorest water quality, exhibiting the highest concentrations of total phosphorus, total Kjeldahl nitrogen, and suspended sediment, and the lowest base flow. In general, water quality in streams in areas with sandy/sand and gravel deposits and loamy deposits were very similar. Within the forested areas, streams in areas with a higher percentage of forested wetlands had lower base flow, higher concentrations of total Kjeldahl nitrogen, and lower concentrations of dissolved nitrite plus nitrate than streams in areas with a lower percentage of forested wetlands.

The variability in water quality throughout the WMIC Study Unit during base-flow conditions could be described very well by subdividing the area into Relatively Homogeneous Units and sampling a few streams with drainage basins completely within these homogeneous units. This

subdivision and sampling scheme enabled the differences in water quality to be directly related to the differences in the environmental characteristics that exist throughout the Study Unit.

INTRODUCTION

In 1991, the National Water-Quality Assessment (NAWQA) program was fully implemented by the U.S. Geological Survey (USGS). The goals of the NAWQA program are to (1) provide a nationally consistent description of water-quality conditions for a large part of the Nation's water resources, (2) define long-term trends (or lack of trends) in water quality, and (3) identify, describe, and explain, as possible, the major factors that affect the observed water-quality conditions and trends (Hirsch and others, 1988).

To fulfill the goals of the NAWQA program, the USGS plans to examine approximately 59 areas (Study Units) across the United States on a rotational cycle. The first 20 of these Study Units began intensive investigations in 1991. The Western Lake Michigan Drainages (WMIC) was one of these Study Units. The WMIC Study Unit drains approximately 51,540 km^2 in eastern Wisconsin and the Upper Peninsula of Michigan (fig. 1). During the first intensive phase of these investigations (lasting approximately 5 years), Study-unit staffs examine available historical data and intensively sample surface water and ground water to describe water quality throughout the Study Unit. Most historical stream data collected in the WMIC Study Unit were from relatively large streams that flow through and integrate the effects of varied environmental conditions, rather than from small streams in areas dominated by specific environmental factors (for example, streams in agricultural areas with clayey surficial deposits and carbonate bedrock) (Robertson and Saad, 1996). Therefore, it is difficult to use the historical data to determine how the differences in surface-water quality throughout the Study Unit are related to differences in specific environmental factors.

Two general approaches have been used to define the extent of areas dominated by specific environmental factors: the qualitative approach, which relies on expert judgment to integrate the various factors thought to be important in influencing a suite of response variables, such as general water quality or biological communities; and the explicit, rule-based approach, which identifies the specific controlling factors that, based on process-based rationale, influence the response variable(s). In the qualitative approach, the entire landscape is partitioned into various regions, usually referred to as "ecoregions," based on the relative differences in a suite of environmental factors; each factor is not equally weighted or used independently in defining the ecoregions (Omernik, 1995). In the explicit, rule-based approach, the landscape is partitioned into relatively homogeneous units (RHU's) based on the geographic distributions of the controlling factors; each factor is equally weighted in defining the RHU's (Bailey, 1996). Each of the RHU's represents a unique combination of the controlling environmental factors.

The ecoregion approach is the most commonly used approach to describe the variability in water quality. For example, Omernik and others (1988) used this approach to subdivide the Midwest into ecoregions (based on relative differences in land use/land cover, land-surface form, potential natural vegetation, and soils), then demonstrated differences in concentrations of phosphorus from lakes in the different ecoregions. The ecoregion classification of Omernik and Gallant (1988) divides the WMIC Study Unit into four ecoregions (fig. 1): the Northern Lakes and Forests ecoregion (northern half of the Study Unit), the North Central Hardwood Forests ecoregion (southwest), the Southeastern Wisconsin Till Plains ecoregion (southeast), and the Central Corn Belt Plains ecoregion (extreme south). Differences in land use/land cover were the primary basis for subdividing this area into ecoregions, although differences in many other environmental factors also were included. The ecoregion approach may allow spatial patterns in water quality to be found; however, the approach does not allow the effects of individual environmental factors to be determined because each environmental factor is not equally weighted and is not used independently in defining the ecoregions. Ecoregions, in fact, were not designed for regionalization of particular water-quality or biological characteristics (Omernik and Bailey, 1997). Therefore, to improve the general understanding of how environmental factors affect water quality, the WMIC Study Unit was subdivided into RHU's, a design that should allow differences in water quality to be directly related to the differences in the environmental characteristics used to subdivide the area.

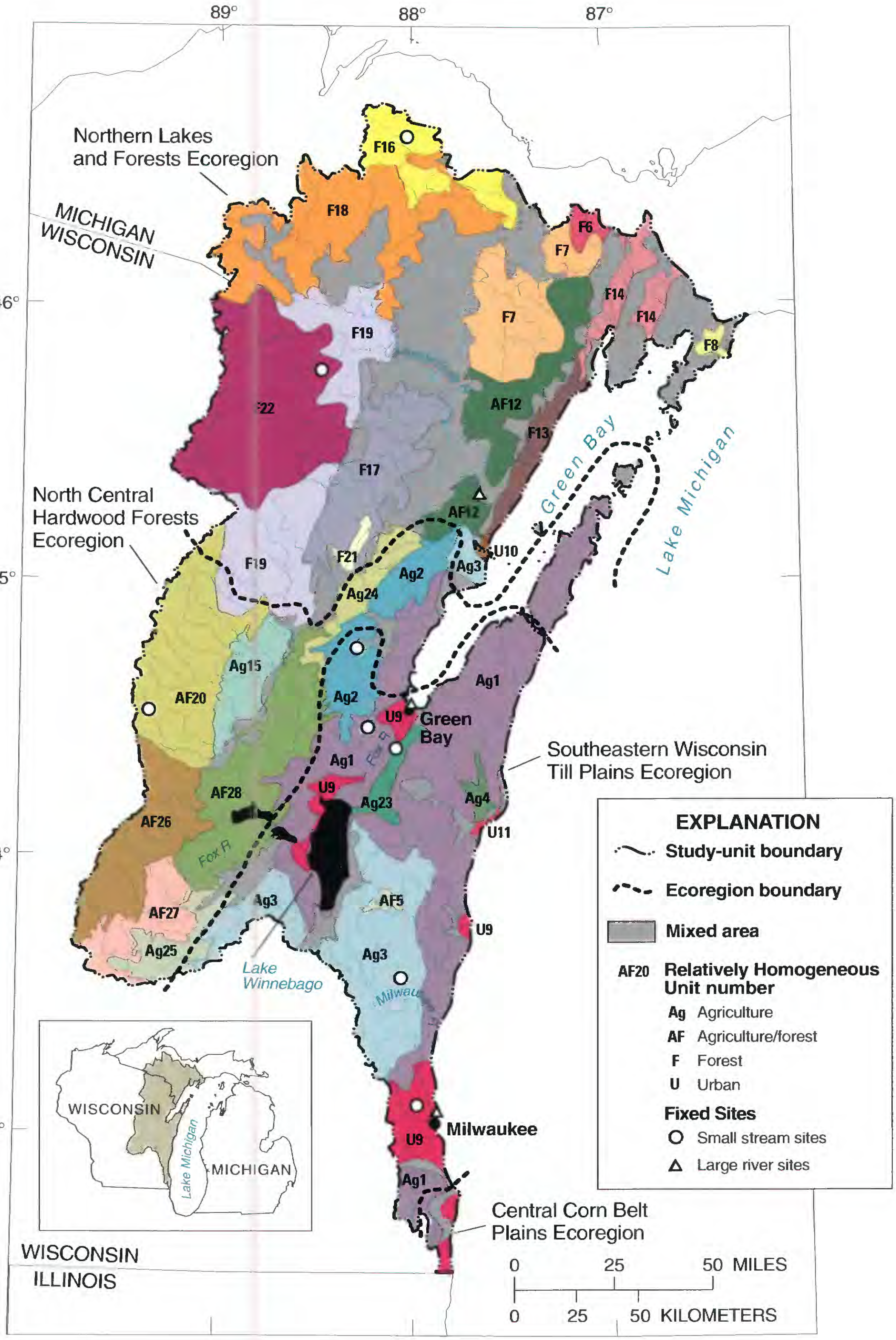

Figure 1. Relatively Homogeneous Units, ecoregions, and Fixed Sites in the Western Lake Michigan Drainages Study Unit. (The environmental characteristics of the Relatively Homogeneous Units and Fixed Sites are given in table 1, and the environmental characteristics of the other sites are given in Appendixes 1 and 2.)

Sampling Design in the Western Lake Michigan Drainages and Evaluation Approach

Previous studies have shown that sediment and nutrient loss from land to streams is a function of land-use practices and type of surficial deposits (for example, Wischmeier and Smith, 1960; Monteith and Sonzogni, 1981; Clesceri and others, 1986). In addition, ground water entering streams may be chemically altered by the bedrock it contacts. Therefore, the WMIC Study Unit was subdivided into areas dominated by a single type of land use/land cover, surficial deposit, and bedrock (Robertson and Saad, 1995) (fig. 1).

Detailed land-use/land-cover information (hereafter referred to as "land-use information") was obtained from high-altitude aerial photographs collected by the USGS between 1971 and 1981 (Feagus and others, 1983). Land use was interpreted manually from the photographs on the basis of the land-use classification system of Anderson and others (1976). Land use in the Study Unit consists primarily of forested land in the north and agricultural land in the south (fig. 2). Large areas of the forested land are classified as forested wetlands in the northeastern part of the Study Unit and along the northwestern shore of Green Bay. Areas of urban or developed land surround the major cities along Lake Michigan in the southeastern part of the Study Unit, along Green Bay, and around and north of Lake Winnebago.

Surficial deposits in the Study Unit range in thickness from zero to several hundred feet and consist of glacial and postglacial deposits (fig. 3). Sand and gravel deposits are mainly in western and northwestern parts of the Study Unit and are remnants of glacial outwash and ice-contact deposits. Sandy deposits also are interspersed with the sand and gravel in most of these areas. In the southern part of the Study Unit, sandy deposits predominate and are associated with till. Loamy deposits are in the northeastern part of the Study Unit and are also associated with till. Clayey deposits predominate in the central and eastern parts of the Study Unit.

The bedrock underlying the Study Unit is composed of crystalline and sedimentary rock (fig. 4). Bedrock dips southeast toward Lake Michigan. Within the Study Unit, the oldest rock at the bedrock surface is in the northwest and the youngest is in the southeast. For WMIC study purposes, bedrock was divided into four categories that were based on the type of rock at the bedrock surface: igneous/metamorphic, sandstone, carbonate, and shale. Igneous/metamorphic bedrock is present in the northwestern third of the Study Unit, carbonate bedrock in the eastern half, and sandstone bedrock in the southwestern corner and between the igneous/metamorphic and carbonate bedrock.

The WMIC Study Unit was divided into RHU's by overlaying generalized digital coverages of each of these three environmental factors by use of a Geographic Information System (GIS) (Robertson and Saad, 1995). This approach resulted in 28 RHU's in the Study Unit in addition to the mixed areas (fig. 1); a description of each RHU is given in table 1. Eight of the RHU's represent agriculture on different combinations of bedrock and surficial deposits, 11 represent forests on different combinations of bedrock and surficial deposits (six represent forests with a high percentage of forested wetlands and five represent forests with a low percentage of forested wetlands), six represent a mixture of agriculture and forested areas, and three represent urban areas.

The RHU subdivision was used to design the surface-water sampling network of the WMIC Study Unit. The network consisted of 11 sites established to describe the variability in streamflow characteristics; concentrations and loads of nutrients, major ions, and suspended sediment; and biological communities that exist in the WMIC Study Unit. These sites are referred to as "Fixed Sites." Eight of these Fixed Sites have drainage basins entirely in one RHU (fig. 1 and table 1). The selection of these sites was based primarily on differences in land use. Of these eight Fixed Sites, four sites were chosen on streams in RHU's representing agricultural areas (Ag1, Ag2, Ag3, and Ag23) with different surficial deposits and bedrock types, two sites on streams in RHU's representing forested areas with different percentages of forested wetlands (F22, wet forest and F16, dry forest) and different surficial deposits, one site on a stream in a RHU representing the mixed agriculture/forest areas (AF20), and one site on a stream in a RHU representing the urban areas (U9). The drainage basin of each of these Fixed Sites was also completely contained in one of three different ecoregions: two sites in the Northern Lakes and Forests, one site in the North Central Hardwood Forests, and five sites in the Southeastern Wisconsin Till Plains (fig. 1). In addition to these eight Fixed Sites, three Fixed Sites on large rivers flowing through several RHU's (the Menominee, Fox, and Milwaukee Rivers) were chosen to represent and quantify water leaving most of the WMIC Study Unit (fig. 1).

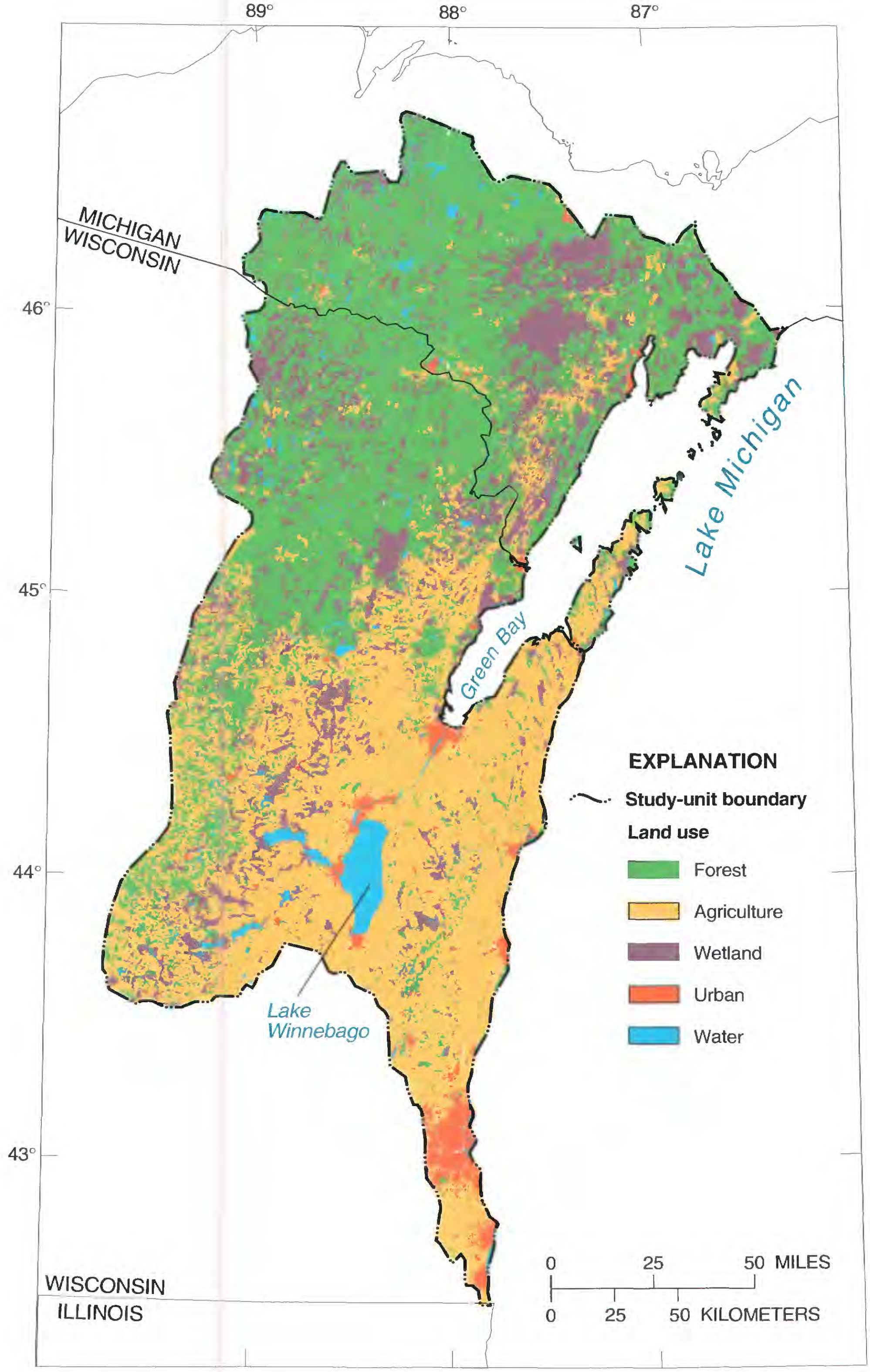

Figure 2. Land use/land cover of the Western Lake Michigan Drainages Study Unit.

Table 1. Description of Relatively Homogeneous Units (RHU's) and basins of the Fixed Sites within the Western Lake Michigan Drainages

[km², square kilometers; S and G, sand and gravel; Ig/Met, igneous/metamorphic]

RHU or Fixed Site	Area (km²)	Percentage of land use in RHU or basin						Percentage of surficial deposit type in RHU or basin				Bedrock type
		Agriculture	Forest	Forested wetland	Open wetland	Urban	Water	S and G	Sand	Loam	Clay	
Agriculture												
Ag1	7,531	80.2	9.1	4.8	0.8	3.1	1.2	3.6	0.5	0.2	95.7	Carbonate
Duck Creek	247	89.3	4.6	4.8	0	.6	0	0	0	23.9	76.1	Carbonate
Ag2	1,356	79.3	10.4	8.7	.4	.9	.1	3.3	.2	95.2	1.3	Carbonate
Pensaukee River	87	86.1	4.4	9.3	0	.2	0	.8	0	99.2	0	Carbonate
Ag3	3,548	79.6	10.7	3.7	1.8	2.9	1.0	13.8	85	.2	1	Carbonate
North Br. Milwaukee River	133	88	6.4	3.9	.2	1.1	.3	9.9	89	0	1.1	Carbonate
Ag4	142	77.9	13.8	3.3	0	3.6	.3	80	0	0	20	Carbonate
Ag15	835	66.6	18.5	12.4	.7	1.2	.5	32.3	.1	65.2	2.4	Ig/Met
Ag23	304	84.2	6.6	1.8	3.8	2.6	.2	13.2	1.3	0	85.5	Shale
East River	122	91.5	5	2.3	.2	.8	0	3.6	.9	0	95.4	Shale
Ag24	650	67.3	15.9	13.8	.6	.6	1.4	2.3	0	94.8	2.9	Sandstone
Ag25	667	72.2	12.9	1.5	6.5	1.6	5.0	8.5	77.6	0	13.9	Sandstone
Agriculture/forest												
AF5	81	30.7	6.2	51.5	8.7	.8	1.9	65.9	34.1	0	0	Carbonate
AF12	1,642	31.3	34.0	30.4	.2	.5	.4	3.8	.3	94.7	0	Carbonate
AF20	2,519	44.4	41.9	11.0	.8	.9	.8	67.5	32	.4	.1	Ig/Met
Tomorrow River	114	58.3	31.5	6.5	2.3	.2	1.2	50.6	49.4	0	0	Ig/Met
AF26	1,854	52.3	40.0	3.3	1.6	.8	1.8	62.6	30.7	0	6.7	Sandstone
AF27	956	52.4	15.3	8.9	17.7	1.2	4.4	.4	22.6	0	77.1	Sandstone
AF28	2,480	57.7	8.2	18.2	9.7	1.6	4.3	.3	1.1	1.2	97.4	Sandstone

Table 1. Description of Relatively Homogeneous Units (RHU's) and basins of the Fixed Sites within the Western Lake Michigan Drainages—Continued

[km^2, square kilometers; S and G, sand and gravel; Ig/Met, igneous/metamorphic]

RHU or Fixed Site	Area (km^2)	Percentage of land use in RHU or basin						Percentage of surficial deposit type in RHU or basin				Bedrock type
		Agriculture	Forest	Forested wetland	Open wetland	Urban	Water	S and G	Sand	Loam	Clay	
Dry Forest												
F6	155	2.7	85.4	11.7	0	.1	.1	0	0	100	0	Carbonate
F16	995	.4	84.3	5.7	.3	.5	6.4	3.1	3	92.4	0	Ig/Met
Peshekee River	44	0	87.7	10	0	0	2.3	0	0	100	0	Ig/Met
F17	1,900	5.6	77.5	13.9	.4	.5	1.9	59.3	.3	39.8	.6	Ig/Met
F18	3,098	2.7	81.0	12.3	.8	.1	2.4	10.2	86.3	2	0	Ig/Met
F19	3,160	5.8	81.6	9.1	.3	.3	2.3	61.4	35.8	2.8	0	Ig/Met
Wet Forest												
F7	1,832	3.8	47.2	47.4	.3	0	.1	.6	0	93.1	0	Carbonate
F8	103	.7	42.3	54.2	.3	0	2.4	0	100	0	0	Carbonate
F13	543	4.8	63.4	26.7	1.7	1.0	1.9	1.3	85.3	12.6	0	Carbonate
F14	719	5.2	67.9	22.7	1.0	.9	1.9	55.1	35.4	2.8	0	Carbonate
F21	140	8.9	23.8	58.7	8.0	.5	.1	7.1	0	1.8	91.1	Ig/Met
F22	3,701	4.4	65.1	26.6	1.0	.3	2.6	61.3	38.7	0	0	Ig/Met
Popple River	140	3	61.1	33.6	1.4	.1	.6	76.3	23.7	0	0	Ig/Met
Urban												
U9	1,227	19.4	1.5	.2	.6	68.9	8.1	2.5	.9	0	96.6	Carbonate
Lincoln Creek	25	3.3	0	0	0	96.8	0	0	0	0	100	Carbonate
U10	40	10.9	16.1	4.8	0	50.1	17.0	1.2	94.3	2.1	2.4	Carbonate
U11	35	6.8	.1	2.2	0	62.7	28.1	71.2	0	0	28.8	Carbonate

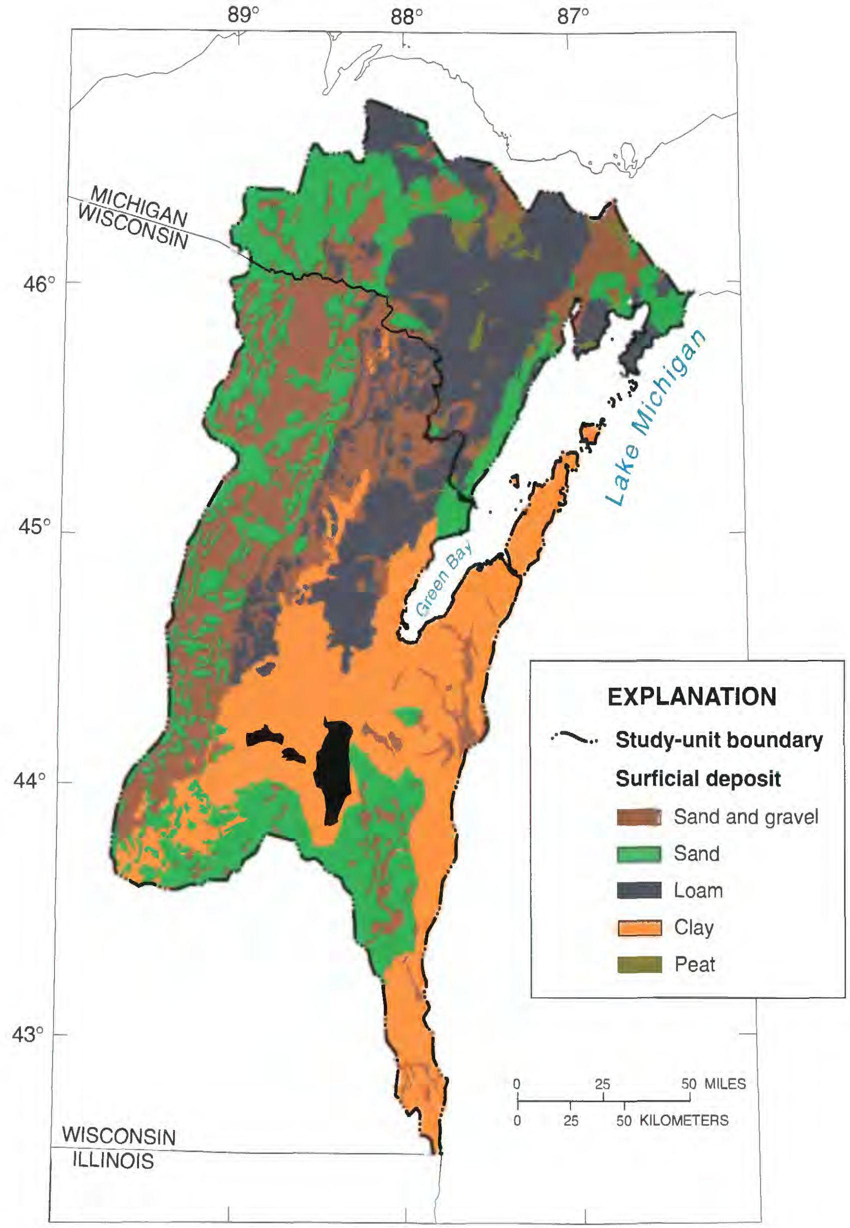

Figure 3. Texture of surficial deposits in the Western Lake Michigan Drainages Study Unit. The digital coverage was constructed from Quaternary geologic maps published by Richmond and Fullerton (1983) and Farrand and Bell (1982).

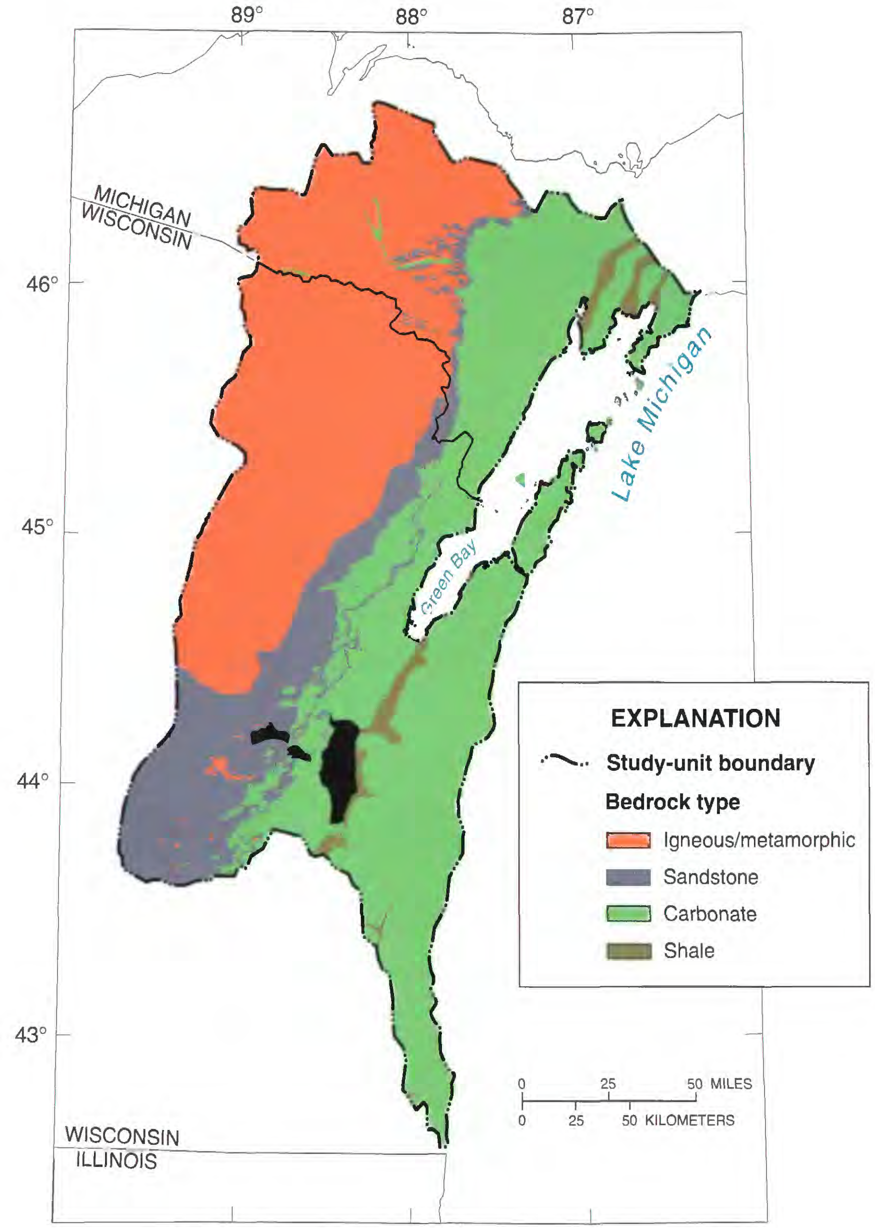

Figure 4. Bedrock types in the Western Lake Michigan Drainages Study Unit. The digital coverage was derived from maps by Mudrey and others (1982) and Reed and Daniels (1987).

For practical purposes, a Fixed Site could not be located in each of the 28 RHU's, and multiple sites could not be located in specific RHU's. The decision of which RHU's would contain a Fixed Site depended partially on the RHU size; the amount of available data within each RHU; the importance of the RHU and the selected stream to local, state, and Federal agencies; the extent of ongoing and past studies in the RHU; and the importance of the type of area that the RHU describes in the National NAWQA framework. At each of the Fixed Sites on small streams, continuous flow was measured and water samples were collected monthly from April 1993 through July 1995, with generally two to four additional samples collected annually during runoff events (Richards and others, 1998). These data demonstrated significant differences in water quality seasonally and among sites. However, because only one site was sampled in each of eight RHU's, it was not possible to determine whether the water quality measured at each Fixed Site truly represented the water quality in other streams from that RHU; and, because only eight sites were chosen from the entire Study Unit, it was not possible to determine whether the entire range in water quality in this large area was being observed. Therefore, an Applicability Study was designed to determine (1) how well the data collected at the eight Fixed Sites describe the variability in water quality within specific RHU's and throughout the Study Unit and (2) how applicable the interpretive results made from the data collected at these eight Fixed Sites were to streams throughout the Study Unit.

In the design of the Applicability Study, it was not possible to establish more continuously monitored sites in streams in each RHU; therefore, the Applicability Study was designed to examine the variability in water quality within and among RHU's for only one hydrologic condition—base flow during summer. This period was chosen because relatively similar streamflow conditions could be sampled across the Study Unit (in other words, flow-duration values or the percentages of time that streamflow is equaled or exceeded were likely to be similar throughout the Study Unit); therefore, meteorologic effects would be minimal. The summer base-flow period also coincides with field studies in most other water-quality studies; therefore, the results would most likely be comparable to those of other studies.

Purpose and Scope

This report describes the Applicability Study and uses the results of this study to (1) describe how well the data collected at the eight Fixed Sites on small streams represent the water quality during base-flow conditions within the RHU's from which they were chosen, (2) describe how well the data collected at the eight Fixed Sites represent the variability in water quality throughout the entire WMIC Study Unit, (3) determine what environmental factors most affect the variability in specific water-quality characteristics, (4) determine the relative importance of the environmental factors that affect general water quality (community assessment), and (5) determine whether a more appropriate subdivision and choice of Fixed Sites could have been used to describe the water quality of the WMIC Study Unit. A full suite of water-quality characteristics and biological data were collected at the Fixed Sites throughout the year; in this study, however, the variability in streamflow and concentrations of total phosphorus, dissolved nitrite plus nitrate, total Kjeldahl nitrogen, and suspended sediment are examined only for the summer base-flow period.

METHODS OF STUDY

Site Selection

To determine how well data collected at each Fixed Site represent the streamflow and water quality in the RHU, three to eight additional sites were chosen on streams in their respective RHU's. To determine the streamflow and water quality in the RHU's without Fixed Sites, one to four sites were chosen on streams in these RHU's. The drainage basins of these additional 83 sites in Applicability Study were almost completely contained within the RHU from which they were chosen. Watershed boundaries for each site were manually defined and traced from 1:24,000 (7.5-minute) USGS topographic quadrangles. The drainage areas of the additional sites ranged in size from 19 to 332 km^2, and those of the Fixed Sites ranged from 27 to 362 km^2 (fig. 5). Only streams in urban areas had drainage areas less than 37 km^2. Each of the sites was randomly chosen so that the data from these streams truly represented the range in water quality in the Study Unit and did not incorporate a bias into the analyses. In several of the RHU's, only a few indicator sites could not be found without choosing sites with very small drainage basins.

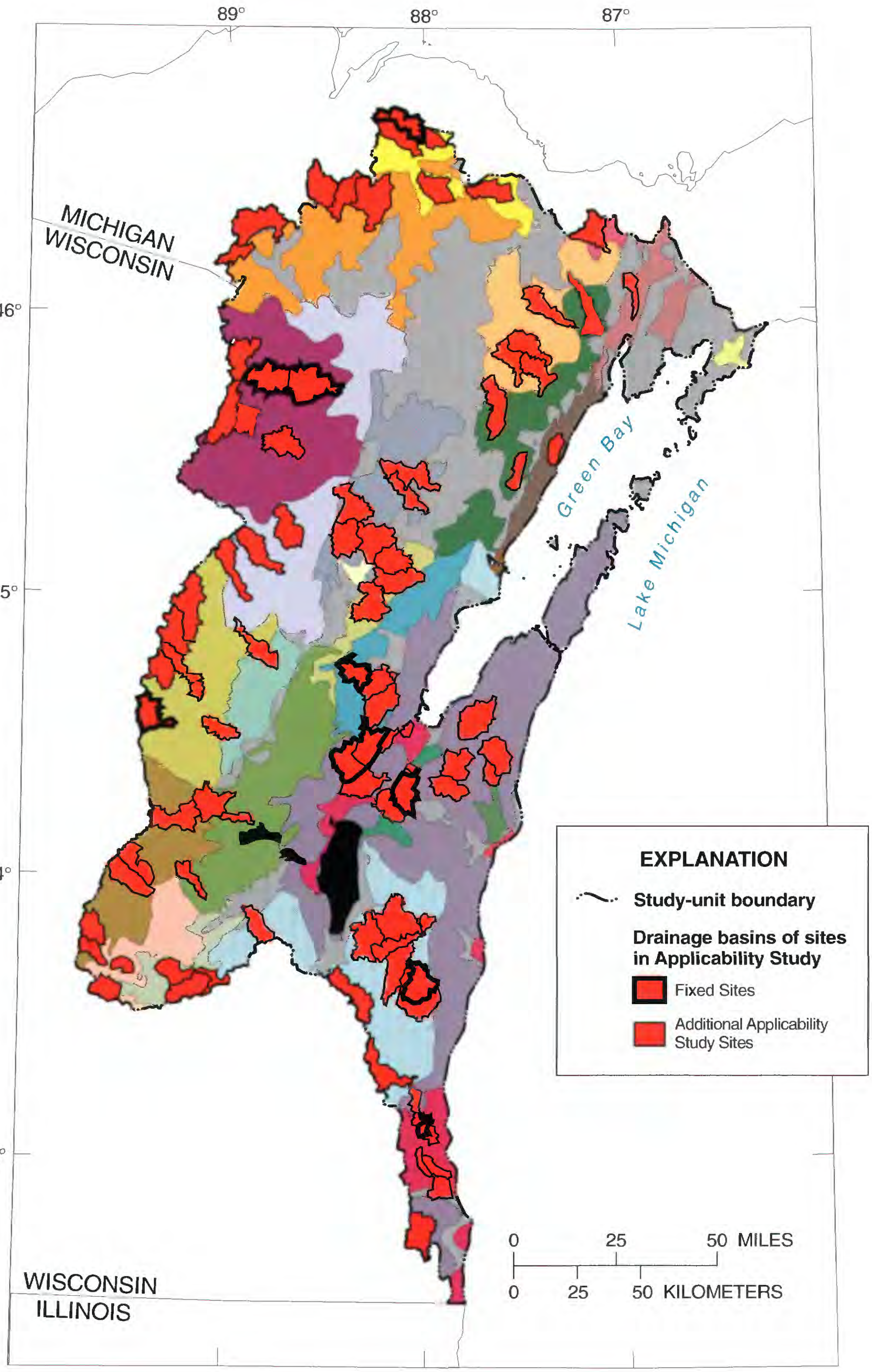

Figure 5. Drainage basins of sites sampled during the Applicability Study superimposed on the Relatively Homogeneous Units of the Western Lake Michigan Study Unit.

The environmental characteristics of each drainage basin (computed by overlaying geographic coverages of each of the environmental factors using a GIS) are summarized in Appendixes 1 and 2. The sites were distributed among three of the ecoregions in the Study Unit, enabling differences among ecoregions to also be evaluated and compared with differences found using the RHU subdivision. No sites were selected in the Central Corn Belt Plains ecoregion in the extreme southern part of the Study Unit because it represented only a small part of the Study Unit.

Sampling and Analytical Methods

All 91 streams (8 Fixed Sites plus the 83 additional sites) were sampled during the 5-day period July 10–14, 1995. During this period, base-flow conditions were similar throughout the Study Unit. Flow-duration values were about 85 percent (ranging from 54 to 94 percent; these high and low endpoint values were both from streams near Wauwatosa, Wis.) (B. Holmstrom, U.S. Geological Survey, written commun., 1995). Therefore, the streamflow when samples were collected should be exceeded about 85 percent of the time at all of the sites sampled, so meteorological effects should have been minimal.

At each site, streamflow was measured using standard USGS flow meters. Water samples, later analyzed for total phosphorus as phosphorus, total Kjeldahl nitrogen as nitrogen, and dissolved nitrite plus nitrate as nitrogen, were collected with a DH81 sampler, and those analyzed for suspended sediment were collected with a DH48 sampler (Shelton, 1994). All samples were collected by use of the equal-width-increment (EWI) method described by Guy and Norman (1970), except when no flow was apparent and grab samples were collected from the middle of the stream/pool. All chemical analyses were done by the USGS National Water-Quality Laboratory in accordance with standard NAWQA analytical procedures described by Fishman and Friedman (1989) and Patton and Truitt (1992). All streamflow and water-quality data are presented on WMIC base maps later in this report to demonstrate spatial patterns. In each of these maps, the data are subdivided into groupings based on the following quantile ranges: 0 to 10 percent, >10 to 25 percent, >25 to 50 percent, >50 to 75 percent, >75 to 90 percent, and >90 percent. All of the streamflow and water-quality data are listed in Appendix 3.

Statistical Analyses

This section gives a brief overview of how censored data were handled and which statistical techniques were used to analyze the data from the Applicability Study. The SAS statistical software package (SAS Institute, Inc., 1989) was used for all statistical analyses except for the redundancy analyses, which were done by use of the CANOCO statistical software package (ter Braak, 1991).

For each water-quality constituent, except suspended sediment, some data were reported as less than the minimum detection limit (MDL). These censored data were set to one half of the MDL prior to all statistical analyses and summaries.

To determine whether any apparent differences among groupings of data (such as groupings shown in boxplots) were statistically significant, the nonparametric Kruskal-Wallis rank analysis of variance test was used and was followed by a Tukey multiple-comparison procedure (SAS Institute, Inc., 1989). For all statistically significant differences, the probability of their occurring by chance is less than 5 percent ($p < 0.05$).

All data for each variable were normalized before statistical analyses in an attempt to obtain linear relations between the water-quality characteristics (streamflow, total phosphorus, dissolved nitrite plus nitrate, total Kjeldahl nitrogen, and suspended sediment) and the environmental factors and to normalize the residual variance. The Box-Cox power transformation that maximized the Shapiro-Wilk statistic (SAS Institute, Inc., 1989) was used to find the best normalizing transformation. The best normalizing transformations are listed in table 2; in many cases, the raw data maximized the Shapiro-Wilk statistic, and therefore no transformation was used.

To determine linear relations between each water-quality characteristic and the environmental factors, Pearson correlation analyses were done and were followed by stepwise regression analyses (SAS Institute, Inc., 1989). Correlation analyses describe how much of the linear variability in each water-quality characteristic is explained by each environmental factor. Forward stepwise regression analyses (with 5-percent probability level for entry significance) were used to determine the direction and magnitude of the interaction between the environmental factors and individual water-quality characteristics. Only normalized data were used in the correlation and regression analyses.

Table 2. Selected water-quality characteristics and environmental factors and best normalizing transformations, Western Lake Michigan Drainages

Characteristic	Abbreviation	Transformation
Water-quality characteristic		
Streamflow	Q	$Q^{0.5}$
Total phosphorus	TP	log(TP)
Dissolved nitrite plus nitrate	NO_{2+3}	$\log(NO_{2+3})$
Total Kjeldahl nitrogen	KJ	log(KJ)
Suspended sediment	SS	$SS^{-0.2}$
Land use		
Percentage of agricultural area	Ag	Ag
Percentage of forested area	For	For
Percentage of urban area	Urban	Urban
Surficial deposits		
Erodibility of surficial deposits	Erod	log(Erod)
Permeability of surficial deposits	Perm	$Perm^{0.4}$
Percentage of clay deposits	Clay	Clay
Bedrock		
Bedrock permeability	B.Perm	B.Perm
Percentage of carbonates	Carb	Carb
Percentage of sandstone	Sands	Sands
Percentage of shale	Shale	Shale
Basin size and slope		
Area	Area	$Area^{0.4}$
Topographic gradient	Grad	$Grad^{0.2}$

Redundancy and cluster analyses were used to simultaneously examine all the water-quality characteristics and determine the influence of multiple environmental factors. Before doing these analyses, it was necessary to standardize all of the water-quality and environmental data so that all of the variables had similar variances; otherwise, variables with relatively large variances would bias the results. Standardization was done by transforming all normalized data for each variable into standard z-scores. A standard z-score is calculated by subtracting the average value for the variable from the raw value or normalized value and dividing by the standard deviation of that variable.

Redundancy analysis (RDA) is a form of direct gradient analysis that describes the variation between two multivariate data sets (ter Braak and Prentice, 1988). In the RDA, the site scores from a principal component analysis are regressed on a specified set of environmental variables with each iteration, and the fitted values of the regression become new site scores; therefore, the principal component analysis is constrained by the environmental variables (Jongman, and others, 1987). RDA was used here to quantify the variation in the response variables (water-quality characteristics) explained by the predictor variables (environmental factors) and to determine which environmental variables had the most influence in explaining the variability in water quality. In addition, partial RDA was used to determine what fraction of the variance in the water-quality characteristics was explained by specified groups of the environmental factors (Richards and others, 1996). Monte Carlo permutation tests with 99 iterations, the default number of iterations in CANOCO, were used to determine the validity of the total and partial RDA results. Monte Carlo tests were done by randomly permutating the assignment of the predictor (environmental) data to the water-quality data and reperforming the ordinations (Richards and others, 1996; Johnson and others, 1997).

Cluster analyses were used to determine whether certain types of streams were present in the Study Unit and how well the chosen Fixed Sites represent these general types of streams. This type of analysis is based on the agglomerative hierarchical clustering procedure in which each stream starts in a group or cluster by itself. Then, the two most similar groups are joined. This procedure is continued until only one group remains. To determine the similarity among the groups, the complete linkage method was used (SAS Institute, Inc., 1989).

Selection of Environmental Factors Used in the Analyses

Each environmental factor can be described by specific characteristics and (or) percentages of specific attributes. Percentages of each land-use, surficial-deposit, and bedrock type for each site were computed from the digital geographic coverages previously described. These percentages are listed in table 1 for the Fixed Sites and in Appendixes 1 and 2 for the remainder of the sites. Because the percentages of the various types of environmental factors sum to 100, it is not necessary to include all of the attributes in the statistical analyses; therefore, a subset of the attributes was used. The land use of a basin was characterized on the basis of the percentages of agricultural and urban land. The percentage of forested land was strongly correlated with the percentage of agricultural land (table 3) and therefore was not included in the statistical analyses. To determine whether significant differences in water quality existed among streams from areas with different types of land uses, each of the basins was classified as a specific land-use category: urban, if its drainage basin had more than 35 percent of the area classified as urban; agriculture, if its drainage basin had more than 60 percent of the area classified as agriculture; mixed agriculture/forest, if its drainage basin had more than 30 percent and less than 60 percent of the area classified as agriculture; and forest, if its drainage basin had less than 30 percent of the area classified as agriculture. Forested basins were further subdivided into wet forests, if the percentage of forested wetlands in the basin was greater than 25 percent, or dry forests if the percentage of forested wetlands in the basin was less than or equal to 25 percent.

The surficial deposits in each basin were described by average erodibility and permeability and by the percentage of the basin with clayey deposits. The percentage of the basin with clayey deposits was included because of the affinity for clay particles to adsorb negatively charged ions, such as phosphate. Average basin erodibility and permeability were computed from data in the State Soil Geographic Database (STATSGO) (U.S. Department of Agriculture, 1991). Within STATSGO, each soil type is assigned an erodibility (k factor), and each soil type is composed of several soil layers that describe conditions with depth. The average erodibility was calculated by weighting the erodibility of each soil type in the surface layer by the percentage of the area the soil type represents in the drainage basin. STATSGO provides minimum and maximum permeability rates for each soil layer. The average permeability for each basin was computed by first averaging the minimum and maximum rates for each soil layer to get the average permeability rate for a given soil type and then weighting these average rates by the area each soil type represents in the basin. To determine whether the surficial deposits in a basin affect a stream's water quality, each of the streams classified as being agricultural basins was further classified as having a specific surficial-deposit type based on the dominant surficial deposit (Appendix 2). Preliminary data analyses indicated that land use was usually an important environmental variable influencing water quality; therefore, agricultural sites were examined independently to determine the effects of surficial deposits, and forested sites were examined independently to determine the effects of different amounts of wetlands (wet forest and dry forest).

The percentages of a basin with sandstone and shale bedrock and estimates of relative bedrock permeability were used to describe the bedrock characteristics of each basin. The percentages of the basin with igneous/metamorphic and carbonate bedrock were highly correlated with relative bedrock permeability (table 3); therefore, the percentages of the basin with igneous/metamorphic and carbonate bedrock were not included in the statistical analyses. Average bedrock permeability of each basin was computed by weighting the relative permeability of each bedrock type by the percentage of the area of each type underlying the basin. Relative bedrock permeabilities for each bedrock type were rated by R. Schmidt and K. Kessler (Wisconsin Department of Natural Resources, Bureau of Water Resources Management, written commun., 1987) on the basis of how well water passes through it (shale = 1

Table 3. Pearson correlation coefficients for water-quality characteristics and environmental factors for streams in the Applicability Study, Western Lake Michigan Drainages

[All data were transformed (table 2) prior to statistical analysis. Ig/Met, Igneous/Metamorphic]

Characteristic (Abbreviation)	Q	TP	NO_{2+3}	KJ	SS	Ag	For	Urban	Erod	Perm	Clay	B.Perm	Carb	Sands	Shale	Ig/Met	Grad	Area
Streamflow (Q)	1.00																	
Total phosphorus (TP)	-0.40	1.00																
Nitrite plus nitrate (NO_{2+3})	.18	.17	1.00															
Kjeldahl nitrogen (KJ)	-.64	.72	-.07	1.00														
Suspended sediment (SS)	.19	-.62	-.23	-.55	1.00													
Percent agriculture (Ag)	-.33	.72	.52	.48	-.48	1.00												
Percent forest (For)	.31	-.70	-.51	-.39	.41	-.82	1.00											
Percent urban (Urban)	-.02	.03	.00	-.10	.08	-.22	-.37	1.00										
Erodibility (Erod)	-.43	.65	.31	.47	-.32	.64	-.85	.44	1.00									
Permeability (Perm)	.41	-.46	.05	-.44	.19	-.23	.46	-.44	-.68	1.00								
Percent clay (Clay)	-.37	.52	.09	.31	-.27	.35	-.63	.52	.62	-.52	1.00							
Bedrock permeability (B.Perm)	-.45	.23	.11	.29	.00	.29	-.45	.34	.66	-.45	.27	1.00						
Percent carbonate (Carb)	-.55	.33	.01	.39	-.09	.32	-.48	.35	.72	-.55	.35	.96	1.00					
Percent sandstone (Sands)	.30	-.03	.40	-.16	-.06	.27	-.20	-.14	-.06	.36	.00	-.21	-.38	1.00				
Percent shale (Shale)	-.25	.45	-.17	.36	-.41	.30	-.24	-.06	.27	-.27	.37	-.27	-.03	-.11	1.00			
Percent Ig/Met (Ig/Met)	.40	-.43	-.25	-.37	.25	-.60	.69	-.23	-.76	-.36	-.46	-.74	-.72	-.31	-.17	1.00		
Topographic gradient (Grad)	.28	-.10	.08	-.23	.28	-.10	.13	-.08	-.26	.35	-.15	-.37	-.36	.19	.14	.18	1.00	
Area (Area)	.05	.15	-.09	.19	-.12	.12	.18	-.49	-.17	.10	-.32	-.13	-.10	-.16	.03	.21	-.19	1.00

(least permeable); igneous/metamorphic = 5; sandstone = 6; and carbonate = 10).

Quality Control

Quality control for data collected during this study included analyzing blank and duplicate samples. Eight blank samples and 11 duplicate samples were collected and analyzed. Concentrations in the blank samples were usually below the MDL and never more than twice the MDL. The mean absolute difference in the duplicate samples collected for total phosphorus was 10 µg/L, with a maximum difference of 40 µg/L for a pair of samples with high concentrations. The mean absolute difference for dissolved nitrite plus nitrate was 10 µg/L, with a maximum difference of 100 µg/L for a pair of samples with high concentrations. The mean absolute difference for total Kjeldahl nitrogen was 80 µg/L, with maximum difference of 300 µg/L for a pair of samples with high concentrations.

EFFECTS OF ENVIRONMENTAL FACTORS ON WATER QUALITY AT BASE FLOW

The Applicability Study was designed to examine variability in specific water-quality characteristics (streamflow, total phosphorus, dissolved nitrite plus nitrate, total Kjeldahl nitrogen, and suspended sediment) during base-flow conditions, whereas the Fixed Sites were sampled during a full range of flow conditions. Therefore, data collected during the Applicability Study are compared only with data collected at the Fixed Sites during base-flow conditions.

Effects on Individual Water-Quality Characteristics

Streamflow

From April 1993 through July 1995, each of the Fixed Sites were sampled from 20 to 35 times during what was classified as base-flow conditions (fig. 6A). For graphic purposes, all the measurements of no apparent flow were set to 1 cubic meter per square kilometer per day. Within each land-use category in figure 6 (and the following similar type of figures), the sites are ordered from those with the least permeable surficial deposits to those with the most permeable deposits. Streamflow (as a flow per unit area) at a particular Fixed Site appears to be related primarily to the permeability of the surficial deposits in the basin. In general, streams with basins having poorly permeable clayey and loamy deposits (Duck Creek, Ag1; East River, Ag23; and Pensaukee River, Ag2) had significantly lower flows than other streams. However, Lincoln Creek (U9), in a urban area with clayey surficial deposits, had slightly higher flow than streams in basins with similar poorly permeable deposits. Flow in Lincoln Creek was not significantly different from that of the Fixed Sites in most high- and low-permeability areas.

During the Applicability Study, base-flow conditions were similar throughout the Study Unit. Flow-duration values were approximately 85 percent. Streamflows at the Fixed Sites during this time (indicated by triangles) were among the lowest sampled at each of the sites (fig. 6A). Streamflows at the Fixed Sites during this study, although consistently lower than their median base flows, demonstrated a similar pattern to that found using all of the base-flow data (that being, lower flows in streams in areas with less permeable deposits than in streams in areas with more permeable deposits). Therefore, the variation in streamflow during the Applicability Study is representative of the Fixed Sites.

Streamflow at all of the sites sampled during the Applicability Study in the RHU's with Fixed Sites are shown in figure 6B. This figure depicts the variability in flow throughout each RHU and the average flow measured in the RHU (indicated by a triangle) and identifies which sample was from the Fixed Site (indicated by a + through the box). Streamflow varies considerably in the RHU's; however, the streamflows at the Fixed Sites are generally representative of typical sites in the RHU's. Flow at the East River Fixed Site, in Ag23, appears to be unusually low for its RHU; however, all but one of the sites in this RHU had no flow during this period. Several of the RHU's had a wide range in flows, especially F16. The differences in streamflow among RHU's is similar whether only data from the Fixed Sites or the average streamflow in the RHU's is examined; therefore, data collected only at the Fixed Sites provide similar information to data collected throughout these RHU's.

Streamflows measured at all of the sites sampled during the Applicability Study are shown in figure 7. Streamflow is strongly related to the surficial deposits in the basins of the respective sites (fig. 3). Highest streamflows were measured in the west side of the

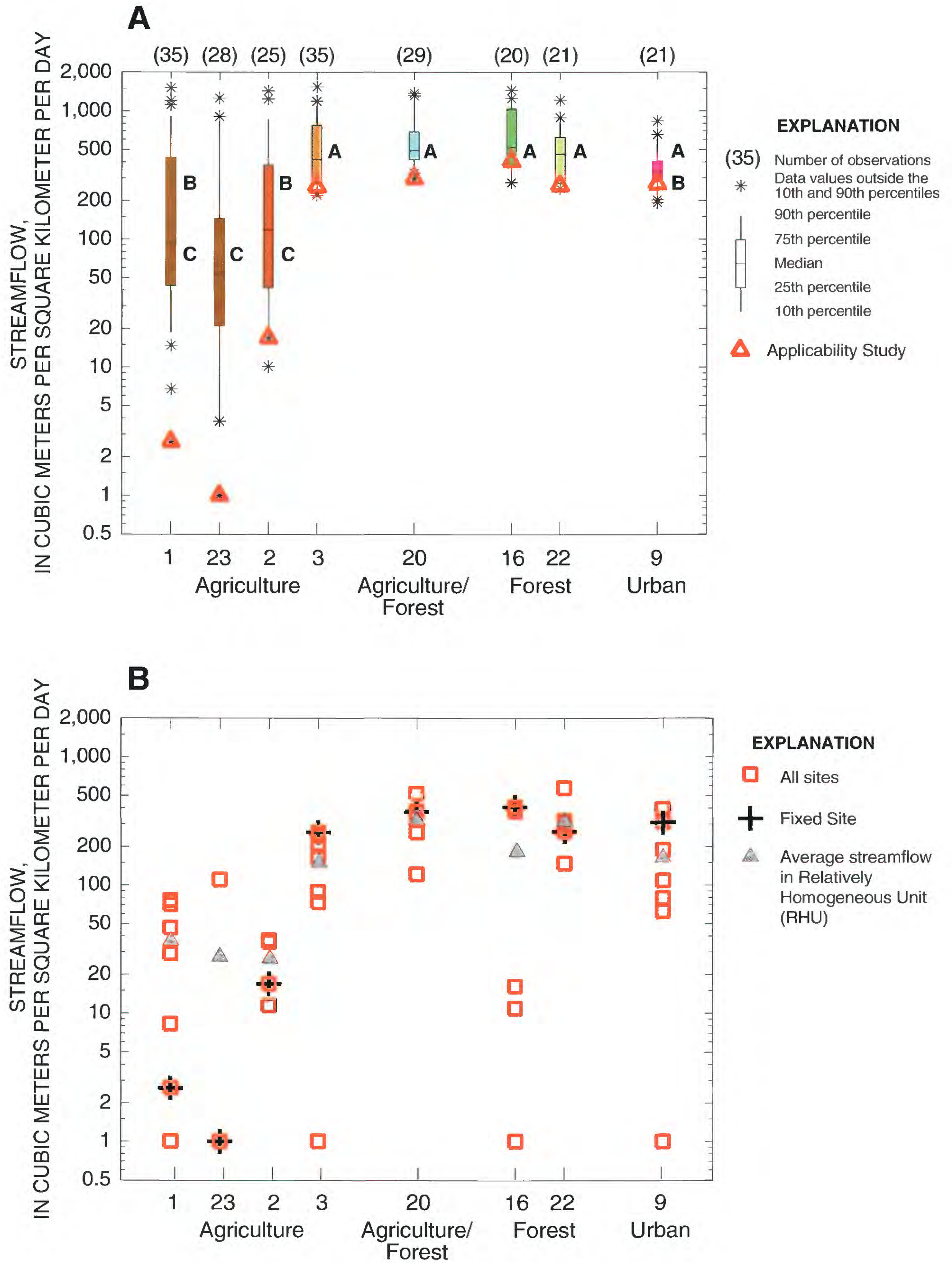

Figure 6. Streamflows measured in the Western Lake Michigan Drainages at (A) Fixed Sites during base flow and (B) sites within the Relatively Homogeneous Units with Fixed Sites. (The measurements collected at the Fixed Sites during the Applicability Study are identified in both graphs. Letters placed on the boxplots demonstrate which groupings were or were not statistically different ($p < 0.05$). Boxes with the same letter are not significantly different.)

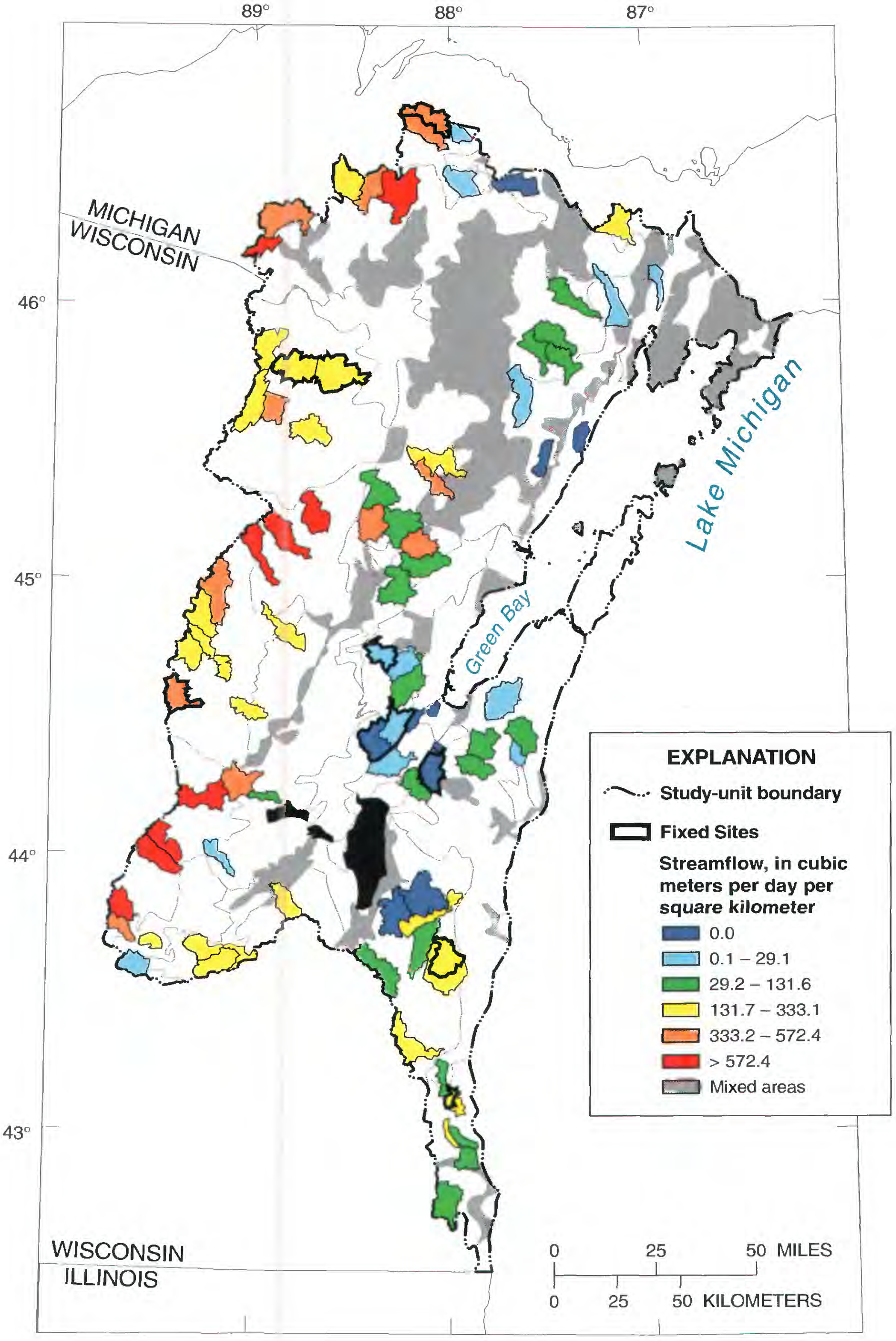

Figure 7. Streamflows measured at each site sampled during the Applicability Study.

Table 4. Stepwise regression models to explain variability in water-quality characteristics, Western Lake Michigan Drainages

[Environmental factors included in analysis: land use—percentage of agricultural and urban areas; surficial deposits—erodibility, permeability, and percentage of clay area; bedrock—percentage of sandstone and shale areas and bedrock permeability; general characteristics—drainage area and gradient. All regresssions were on transformed data (table 2). Abbreviations: r—correlation coefficient with independent variable; Step R^2—coefficient of determination for one- and two-variable models; R^2—coefficient of determination for overall model]

Water-quality characteristic	Independent variables: Variable entered at first step	Variable entered at second step	Variable entered at third step
Streamflow	Bedrock permeability r = -0.45 Step R^2 = 0.21	Percent shale r = -0.25 R^2 = 0.35	No additional significant variables
Total phosphorus	Percent agriculture r = 0.72 Step R^2 = 0.51	Permeability r = -0.46 Step R^2 = 0.60	Percent shale r = 0.45 R^2 = 0.64
Nitrite plus nitrate	Percent agriculture r = 0.52 Step R^2 = 0.27	Percent shale r = -0.17 Step R^2 = 0.39	Bedrock permeability r = 0.11 R^2 = 0.43
Kjeldahl nitrogen	Percent agriculture r = 0.48 Step R^2 = 0.23	Permeability r = -0.44 Step R^2 = 0.35	Percent urban r = -0.10 R^2 = 0.39
Suspended sediment	Percent agriculture r = -0.48 Step R^2 = 0.21	Percent shale r = -0.41 R^2 = 0.29	No additional significant variables

Study Unit, where permeable sandy and sand and gravel deposits are present. The lowest flows (no apparent flow) were measured in streams around Lake Winnebago, where areas of extensive clayey deposits are present. Streams in areas with loamy deposits had intermediate flows. Streamflows measured at the Fixed Sites cover almost the entire range in flows that occurred throughout the Study Unit.

Streamflow was most strongly correlated with factors describing the surficial deposits and bedrock. The two factors most strongly related to streamflow (negative correlation) were the percentage of carbonate bedrock and bedrock permeability (table 3). Both factors were negatively correlated with various factors describing the permeability of the surficial deposits; therefore, separating the influence of the differences in bedrock from the differences in the surficial deposits is difficult. However, it seems more likely that increased streamflow is related to increased permeability of the surficial deposits than to reduced bedrock permeability. The regression model that best explained the variation in streamflow was a function of bedrock characteristics (bedrock permeability and percentage of shale bedrock) (table 4). This model explained 35 percent of the variability in the streamflows in the Study Unit. If the factors describing the bedrock of the basin were omitted, then factors describing the surficial deposits (erodibility and permeability) became most important.

The only statistical difference in streams in different land-use categories was that flow in agricultural areas was significantly lower than in forested and mixed agriculture/forested areas (table 5). This difference may be the result of more of the streams in agricultural areas having basins with less permeable surficial deposits than the basins of streams in areas of other land uses.

If just the streams in forested areas are considered, the effects of the percentage of wetlands in the basin can be evaluated. During base-flow conditions, the dry-forest sites had significantly higher flow than the wet-forest sites (table 6). This difference is similar to that measured at the two forested Fixed Sites, F16 (dry forest) > F22 (wet forest), although this was a nonsignificant difference. This difference in base flow is the opposite of what may be expected if wetlands buffered the peaks in flow and extended the recession.

If just the streams in agricultural areas are examined, the influence of the surficial deposits can be seen. Streamflows in areas with more permeable deposits (sand, and sand and gravel) were significantly higher than in areas with less permeable deposits (clay) (table 7). Streamflows in areas with loamy surficial deposits

Table 5. Comparison of water quality among land-use categories, Western Lake Michigan Drainages
[Land-use categories with the same letter are not significantly different at $p < 0.05$. Agric/Forest, mixed agriculture/forested land use]

Water-quality characteristic	Land-use category			
	Highest values	⟶	⟶	Lowest values
Streamflow	Agric/Forest A	Forest A	Urban A, B	Agriculture B
Total phosphorus	Agriculture A	Urban A, B	Agric/Forest B, C	Forest C
Nitrite plus nitrate	Agric/Forest A	Agriculture A	Urban A, B	Forest B
Kjeldahl nitrogen	Agriculture A	Forest B	Urban A, B	Agric/Forest B
Suspended sediment	Agriculture A	Agric/Forest A, B	Urban A, B	Forest B

Table 6. Comparison of water quality between forest types, Western Lake Michigan Drainages
[Forest types with the same letter are not significantly different at $p < 0.05$]

Water-quality characteristic	Forest type	
	Highest values	Lowest values
Streamflow	Dry forest A	Wet forest B
Total phosphorus	Dry forest A	Wet forest A
Nitrite plus nitrate	Dry forest A	Wet forest B
Kjeldahl nitrogen	Wet forest A	Dry forest B
Suspended sediment	Dry forest A	Wet forest A

were not significantly different from those in areas of other surficial deposits.

Because of the variability in surficial deposits in each ecoregion, streamflows within each ecoregion were also quite variable. Streams in the Northern Lakes and Forest ecoregion had high flows on the western side and lower flows on the eastern side, and higher flows in areas with a lower percentage of wetlands than in areas with a higher percentage of wetlands. Streams in the North Central Hardwood Forests ecoregion had relatively high flows except in the southern corner. Streams in the Southeastern Wisconsin Till Plains ecoregion had moderate flows except for those around Lake Winnebago which had very low flows. The only conclusion that can be made by comparing streams in these ecoregions is that flows in the Southeastern Wisconsin Till Plains ecoregion were significantly less than those in the other two ecoregions (table 8).

In summary, base flow appears to be affected primarily by the permeability of the deposits in the basin, with higher flows occurring in areas of permeable deposits than in areas of less permeable deposits. However, relatively high flows occur in streams in urban areas regardless of the type of surficial deposits. These conclusions are consistent with those based on data collected at the Fixed Sites.

Total Phosphorus

Differences in concentrations of total phosphorus measured at the Fixed Sites during base-flow conditions appear to be related primarily to the differences in the land use in their basins (fig. 8A). Concentrations at Fixed Sites in agricultural areas were significantly higher than those in urban and mixed agricultural/forested areas, which in turn were significantly higher than

Table 7. Comparison of water quality among surficial-deposit categories for agricultural basins, Western Lake Michigan Drainages

[Surficial-deposit categories with the same letter are not significantly different at $p < 0.05$. Sand/S&G, sand and sand and gravel deposits]

Water-quality characteristic	Surficial-deposit category		
	Highest values	→	Lowest values
Streamflow	Sand/S&G A	Loam A, B	Clay B
Total phosphorus	Clay A	Loam A	Sand/S&G A
Nitrite plus nitrate	Sand/S&G A	Clay A	Loam A
Kjeldahl nitrogen	Clay A	Loam A	Sand/S&G A
Suspended sediment	Clay A	Sand/S&G A	Loam A

those in forested areas. Concentrations measured at the mixed agricultural/forested site were not significantly different from those measured at the forested sites. If concentrations just at the agricultural Fixed Sites are examined, streams in areas with clayey surficial deposits (Ag1 and Ag23) appear to have slightly higher concentrations of total phosphorus than those in non-clayey areas, although not significantly higher concentrations.

The pattern in concentrations of total phosphorus measured at the Fixed Sites during the Applicability Study was similar to that found using all of the data collected during base-flow conditions (highest concentrations in agricultural areas, moderate in urban areas, and lowest in forested and mixed agricultural/forested areas) (fig. 8A). Therefore, the variation in concentrations of total phosphorus during the Applicability Study should be representative of what typically occurs among the Fixed Sites during base-flow conditions. The concentrations in agricultural areas were among some of the highest measured during base-flow conditions of the 3-year period of study and coincided with the very low streamflows. This indicates that as flow becomes very low in these agricultural areas with different surficial deposits, concentrations of total phosphorus consistently increase.

Concentrations of total phosphorus in all of the streams in the RHU's with a Fixed Site are shown in figure 8B. Variability in concentrations of total phosphorus was found within RHU's; however, the variability within the RHU's is generally much less than among the RHU's. Concentrations measured at the Fixed Sites were generally representative of a typical site in the RHU except at the Pensaukee River, Ag2. During summer 1995, beavers constructed a dam just below the sampling site on the Pensaukee River; as a result data collected during this study represented a small pond rather than a stream in Ag2. Concentrations in the Pensaukee River were normally lower than those at the other agricultural Fixed Sites (fig. 8A) and similar to those measured at other sites in Ag2 (fig. 8B). The differences in concentrations of phosphorus among RHU's is similar whether only the data from the Fixed Sites or the average concentration in the RHU's is examined, except in Ag2, where the concentration at the Fixed Site was unusually high. Therefore, data collected only at the Fixed Sites provide similar information to data collected throughout these RHU's.

Table 8. Comparison of water quality among ecoregions, Western Lake Michigan Drainages

[Ecoregions with the same letter are not significantly different at $p < 0.05$. NLF, Northern Lakes and Forest; NHF, Northern Hardwood Forest; SWTP, Southeastern Wisconsin Till Plains]

Water-quality characteristic	Ecoregion		
	Highest values	→	Lowest values
Streamflow	NHF A	NLF A	SWTP B
Total phosphorus	SWTP A	NHF B	NLF C
Nitrite plus nitrate	NHF A	SWTP B	NLF C
Kjeldahl nitrogen	SWTP A	NLF B	NHF B
Suspended sediment	SWTP A	NHF A	NLF B

Concentrations of total phosphorus at all of the sites sampled during the Applicability Study are shown in figure 9A. Concentrations at these sites are strongly related to the land use in their basins (fig. 2). The lowest concentrations were measured in northern and western areas of the Study Unit, which are forested and not intensively agricultural. The highest concentrations were measured north of Lake Winnebago, where agriculture is extensive, and includes farms on poorly permeable, clayey deposits. Streams in areas with agriculture on more permeable deposits had intermediate concentrations. To discourage excessive biotic growth in flowing water, the U.S. Environmental Protection Agency (USEPA) has recommended that con-

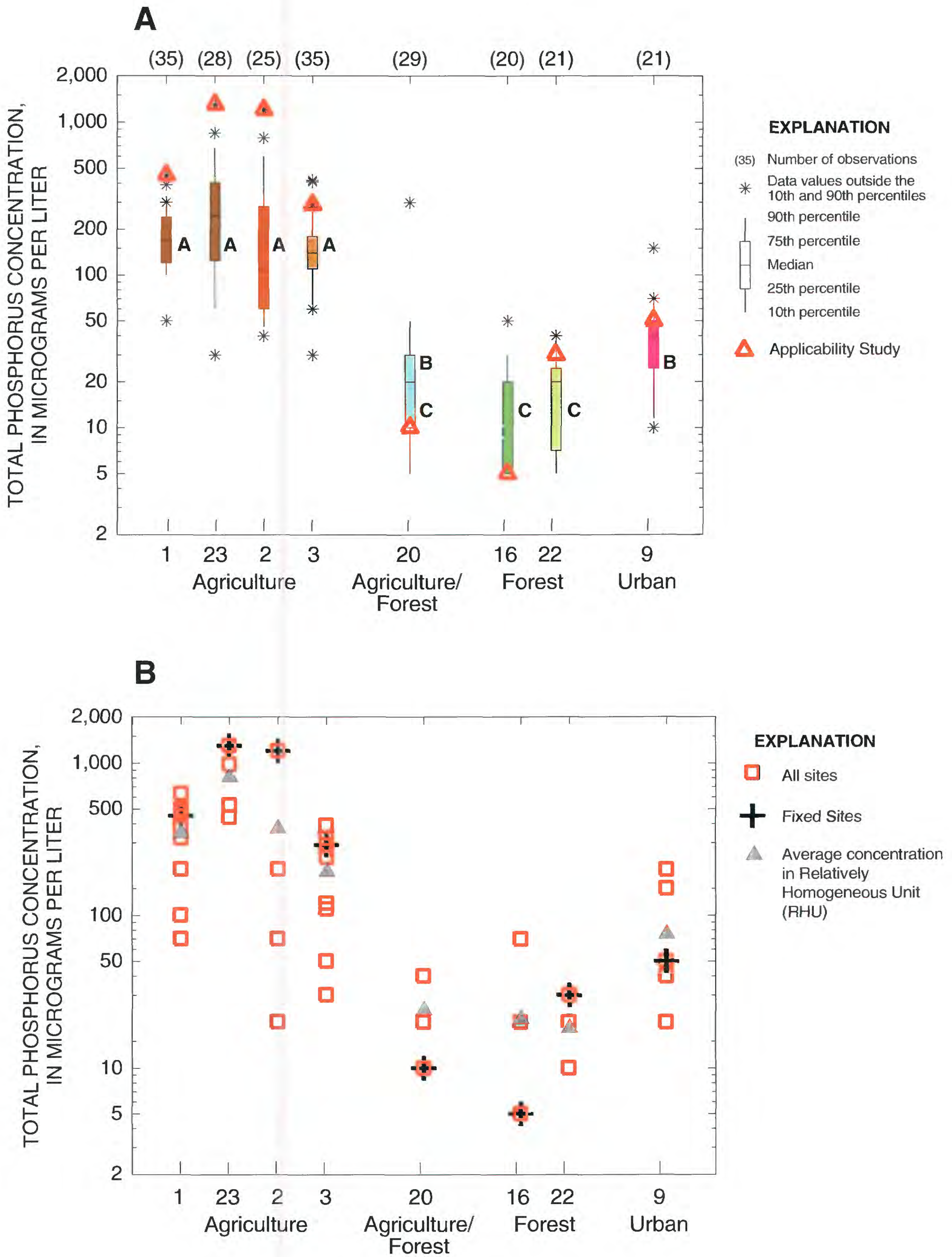

Figure 8. Total phosphorus concentrations measured at (A) Fixed Sites during base flow and (B) sites within the Relatively Homogeneous Units with Fixed Sites. (The measurements collected at the Fixed Sites during the Applicability Study are identified in both graphs. Letters placed on the boxplots demonstrate which groupings were or were not statistically different ($p < 0.05$). Boxes with the same letter are not significantly different.)

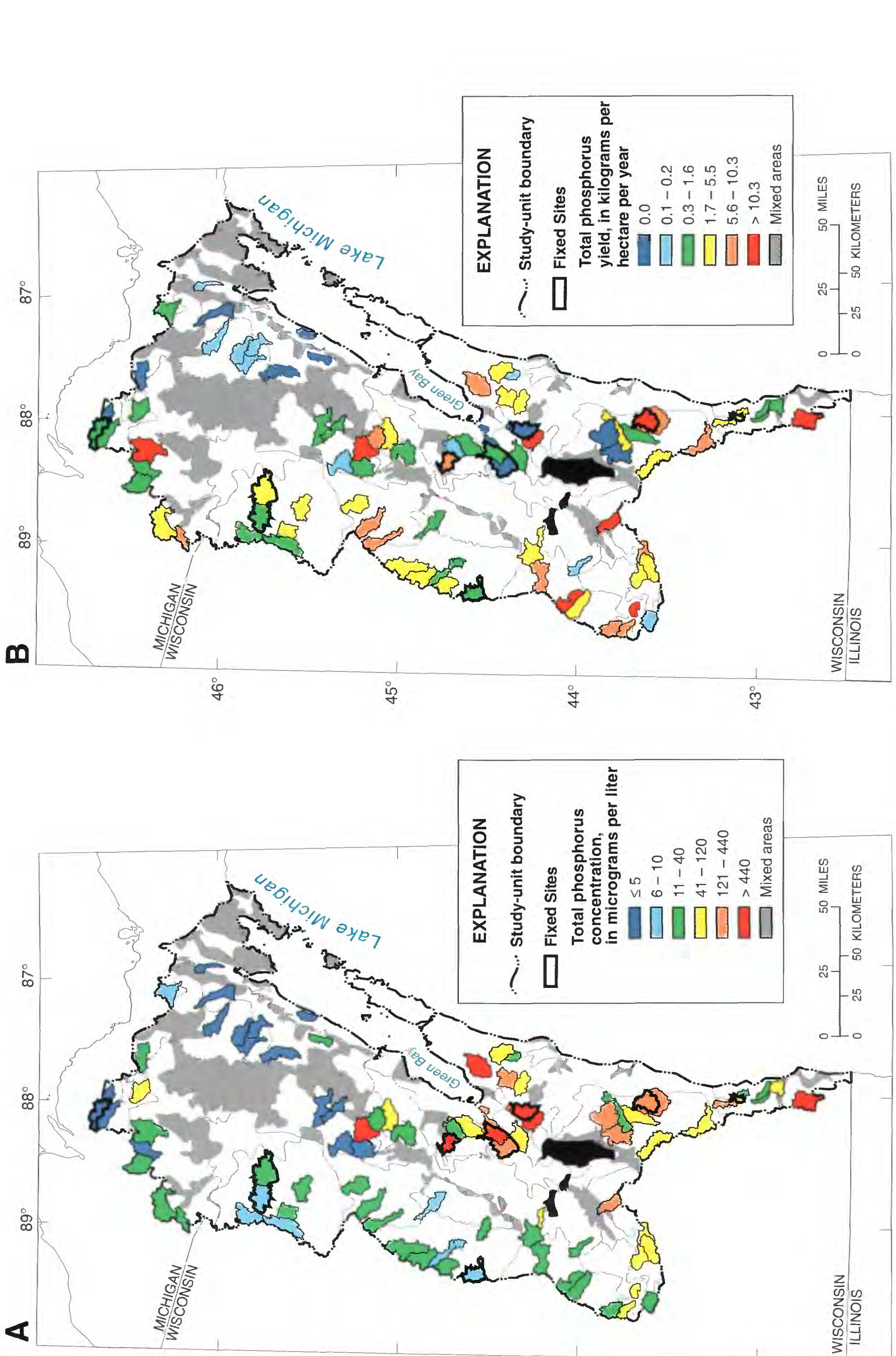

Figure 9. Total phosphorus (A) concentrations and (B) yields measured at each site sampled during the Applicability Study.

centrations of total phosphorus should not exceed 100 µg/L (U.S. Environmental Protection Agency, 1986). Concentrations above this value were routinely observed only in the agricultural streams. The concentrations of total phosphorus measured at the Fixed Sites cover the entire range in concentrations measured during the Applicability Study.

Concentrations of total phosphorus were most strongly correlated with factors describing land use and secondarily with factors describing surficial deposits. Concentrations of total phosphorus were most strongly correlated (positive) with the percentage of agricultural land (table 3). Concentrations also increased with increases in the erodibility and the percentage of clayey surficial deposits, and decreased with increases in the permeability of the surficial deposits. Concentrations of total phosphorus also were higher in areas with shale bedrock (primarily in Ag23). The area with shale bedrock also had high percentages of agricultural land and clayey surficial deposits that are highly erodible and have low permeability; therefore, it is difficult to separate the effects of the shale bedrock from the other factors. The regression model that best explained the variation in total phosphorus (64 percent) was a function of the type of land use (percentage of agricultural land), the permeability of the surficial deposits, and the percentage of shale bedrock (table 4).

The differences in concentrations in the different land-use categories was similar to that measured at the Fixed Sites (agriculture > urban > mixed agriculture/forest > forest, although concentrations in urban areas were not significantly different from those in agricultural and mixed agricultural/forested areas, and concentrations in mixed agricultural/forested areas were not significantly different from those in urban and forested areas; see table 5). The percentage of wetlands in the basin had no significant effect on the distribution of the concentrations of total phosphorus (table 6). Examination of just the agricultural sites demonstrated the influence of the surficial deposits; specifically, highest concentrations were in areas of poorly permeable deposits (clay > loam > sand/sand and gravel, although none of the differences were significant; see table 7).

Because land use was the primary factor influencing the distribution of the concentrations of total phosphorus and because land use is relatively uniform in each ecoregion, concentrations also were quite uniform in each ecoregion. Within the Southeastern Wisconsin Till Plains and North Central Hardwood Forests ecoregions, however, concentrations were highest in areas with intensive agriculture on poorly permeable surficial deposits. The only conclusion that can be made by comparing concentrations among ecoregions is that concentrations in streams in the Northern Lakes and Forests ecoregion were significantly less than those in the North Central Hardwood Forests ecoregion, which in turn were significantly less than those in the Southeastern Wisconsin Till Plains ecoregion (table 8).

The combination of higher concentrations of total phosphorus and lower streamflows in areas with poorly permeable surficial deposits than in areas with fairly permeable deposits and higher streamflows results in little or no pattern in the yields of total phosphorus (kilograms per unit area) across the Study Unit (fig. 9B). Moderate to high yields of phosphorus during base-flow conditions were found in both forested and agricultural areas. The only area with relatively consistent high yields was in the southwest corner of the Study Unit, where extensive agricultural areas coincide with very permeable surficial deposits; even in this area, however, there were areas with clayey surficial deposits, low flows, and low yields.

In summary, variability in concentrations of total phosphorus is primarily related to differences in land use and secondarily to differences in surficial deposits. The highest concentrations of total phosphorus occurred in agricultural areas with poorly permeable surficial deposits, especially in areas with clayey surficial deposits. This conclusion is consistent with that found from data collected at the Fixed Sites and consistent with that found by Monteith and Sonzogni (1981), who state that the two most important physical factors affecting the chemical concentrations in rivers near the Great Lakes are the texture of the soil material and the land use on that soil.

Dissolved Nitrite Plus Nitrate

Differences in concentrations of dissolved nitrite plus nitrate measured at the Fixed Sites during base-flow conditions appear to be primarily related to the differences in the land use and the surficial deposits in their basins (fig. 10A). The highest concentrations were measured in agricultural and mixed agricultural areas with permeable surficial deposits (Ag3 and AF20). Moderate concentrations were measured in agricultural areas with less permeable surficial deposits and in urban areas. Lowest concentrations were measured in forested areas. All of the streams in agricultural and urban areas, regardless of the type of surficial deposits, had signifi-

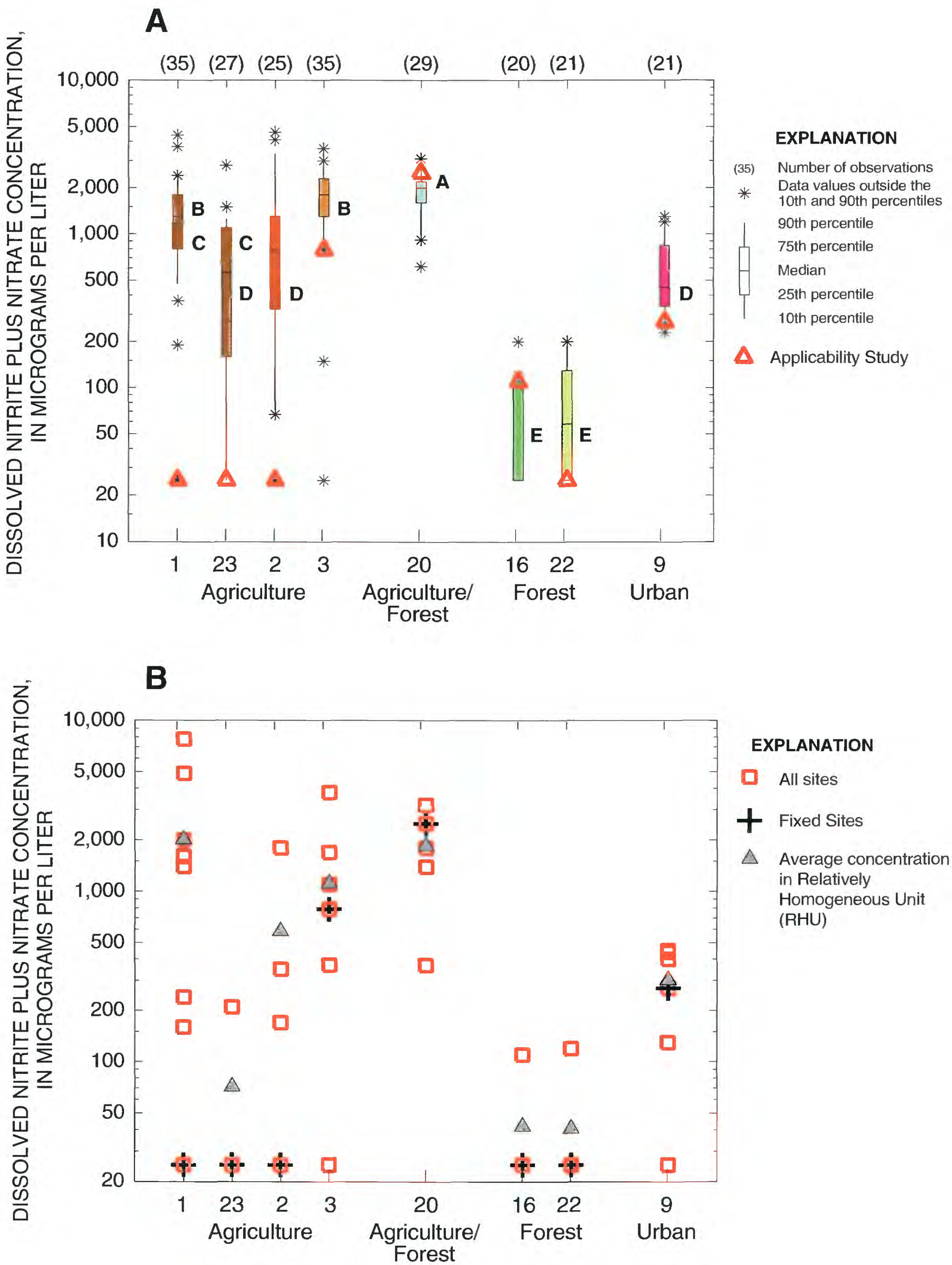

Figure 10. Dissolved nitrite plus nitrate concentrations measured at (A) Fixed Sites during base flow and (B) sites within the Relatively Homogeneous Units with Fixed Sites. (The measurements collected at the Fixed Sites during the Applicability Study are identified in both graphs. Letters placed on the boxplots demonstrate which groupings were or were not statistically different ($p < 0.05$). Boxes with the same letter are not significantly different.)

cantly higher concentrations than those in forested areas.

The pattern in concentrations of dissolved nitrite plus nitrate measured at the Fixed Sites during the Applicability Study differed substantially from that found using all of the data collected during base-flow conditions (fig. 10A). Concentrations at three of the four agricultural Fixed Sites were below the 50-µg/L MDL and were among the lowest concentrations measured during the 3-year period of study at these sites. These very low concentrations coincided with the very low streamflows. Therefore, the variation in concentrations of dissolved nitrite plus nitrate during the Applicability Study, at least in the agricultural sites, may not represent the typical differences among Fixed Sites during base-flow conditions.

Concentrations of dissolved nitrite plus nitrate in the RHU's with Fixed Sites are shown in figure 10B. Concentrations were extremely variable in the agricultural RHU's; however, concentrations at the other Fixed Sites were representative of typical sites within their respective RHU's. It appears that as streamflow becomes very low in agricultural areas, the concentration of dissolved nitrite plus nitrate may drop below the present MDL.

Concentrations of dissolved nitrite plus nitrate measured at all of the sites are shown in figure 11A. Concentrations at these sites were strongly related to the land use in their basins (fig. 2). Low concentrations were measured throughout the northern half of the Study Unit, where forested areas predominate. Moderate to high concentrations were measured in agricultural and urban areas, regardless of the types of surficial deposits or bedrock. Very low concentrations also were usually measured in agricultural areas when there was no apparent flow, but a few streams with no apparent flow also had moderate concentrations. No concentrations of dissolved nitrite plus nitrate were found above the 10,000-µg/L maximum contaminant level (U.S. Environmental Protection Agency, 1986) during the Applicability Study or during base-flow conditions at any of the Fixed Sites. The concentrations of dissolved nitrite plus nitrate measured at the Fixed Sites covered the entire range in concentrations that occurred throughout the Study Unit during the Applicability Study.

Concentrations of dissolved nitrite plus nitrate were most strongly correlated with land-use factors. The factor most strongly related (positively) to concentrations of dissolved nitrite plus nitrate was the percentage of agricultural land (table 3). The regression model that best explained the variation in concentrations of dissolved nitrite plus nitrate was a function of the type of land use (percentage of agriculture in the basin), the percentage of shale bedrock, and the bedrock permeability (table 4). This model explained 43 percent of the variability in the concentrations in the Study Unit. The high percentage of shale bedrock and low bedrock permeability helped explain the very low concentrations in the streams north of Lake Winnebago with very low streamflow.

The differences in concentrations in different land-use categories were similar to those measured at the Fixed Sites (agriculture/forest > agriculture > urban > forest, although only concentrations in forested areas were significantly less than those in agricultural and mixed agricultural areas; see table 5). During base-flow conditions, the dry-forest sites had significantly higher concentrations of dissolved nitrite plus nitrate than the wet-forest sites (table 6). This difference was observed during the Applicability Study, but not between the two forested Fixed Sites when all the base-flow data were examined (fig. 10A). The influence of the surficial deposits was examined by analyzing data from the agricultural sites only. Concentrations were highest in areas with sandy or sand and gravel deposits, moderate in areas with clayey deposits, and lowest in areas with loamy deposits, but none of these differences were statistically significant (table 7).

Because land use was the primary factor influencing the distribution of the concentrations of dissolved nitrite plus nitrate, the concentrations were also quite uniform in each ecoregion, except for the very low concentrations measured around Lake Winnebago in the Southeastern Wisconsin Till Plains ecoregion. Some of the lowest and highest concentrations were measured within the Southeastern Wisconsin Till Plains ecoregion. Because of the low concentrations in the Southeastern Wisconsin Till Plains ecoregion, the overall concentrations in this ecoregion were significantly less than those in the North Central Hardwood Forests ecoregion (table 8). Concentrations in the Northern Lakes and Forests ecoregion were significantly less than those in the other two ecoregions.

The high concentrations of dissolved nitrite plus nitrate measured throughout the agricultural and mixed agricultural/forested areas resulted in relatively high yields in all agricultural areas with highly permeable surficial deposits (high flows), especially in the southwestern part of the Study Unit (fig. 11B). Moderate yields were found in forested areas with permeable surf-

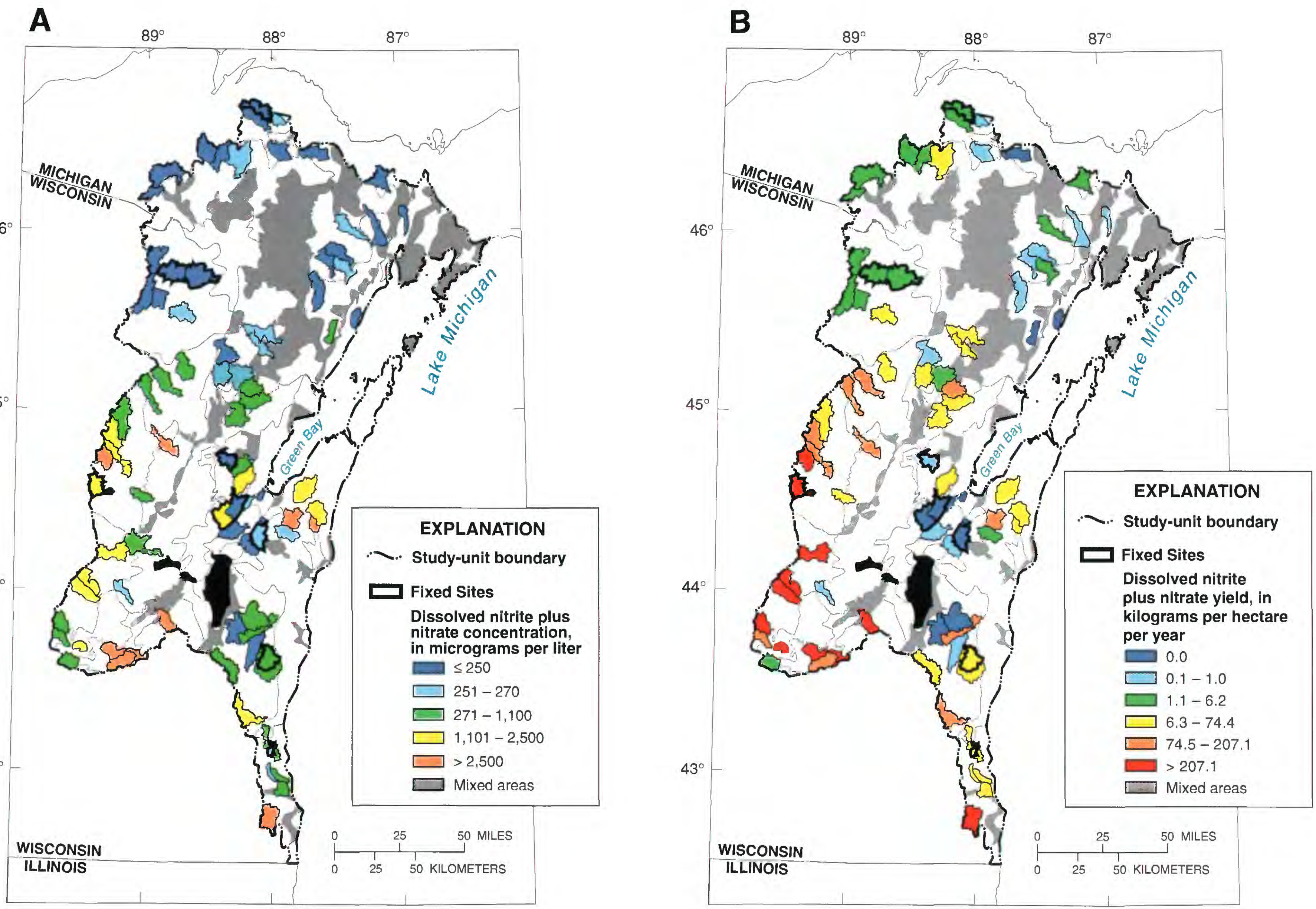

Figure 11. Dissolved nitrite plus nitrate (A) concentrations and (B) yields measured at each site sampled during the Applicability Study.

icial deposits, agricultural areas with less permeable surficial deposits, and urban areas. Relatively low yields were found in forested areas with low or moderately permeable surficial deposits and in agricultural areas with poorly permeable surficial deposits.

In summary, concentrations of dissolved nitrite plus nitrate were lowest in forested areas and some streams in other land-use areas with very low flow. Concentrations were high in agricultural areas and areas with a relatively small percentage of agriculture if streamflow was moderate. No consistent influence of surficial deposit and bedrock was found for concentrations of dissolved nitrate plus nitrate; however, yields were relatively high in areas of permeable surficial deposits and high base flow. These conclusions are consistent with those found when all of the data collected during base-flow conditions at the Fixed Sites were examined, although three of the four agricultural Fixed Sites sampled during the Applicability Study had concentrations as low as those measured in forested areas.

Total Kjeldahl Nitrogen

Differences in concentrations of total Kjeldahl nitrogen measured at the Fixed Sites during base-flow conditions appear to be primarily related to differences in land use and secondarily related to the differences in the surficial deposits (fig. 12A). All of the streams in agricultural areas had significantly higher concentrations than those in any other type of land use. Concentrations in the mixed agricultural/forested, forested, and urban areas were not significantly different. If data from only the agricultural Fixed Sites are examined, areas with less permeable surficial deposits (Agl and Ag23) appear to have higher concentrations than areas with more permeable deposits (Ag3).

The pattern in concentrations of total Kjeldahl nitrogen measured at the Fixed Sites during the Applicability Study was similar to that found using all of the data collected during base-flow conditions; in other words, highest concentrations were measured in agricultural areas, and relatively similar concentrations were measured in all other areas. Therefore, the variation in concentrations measured during the Applicability Study should be representative of the Fixed Sites. The concentrations measured in all agricultural areas, except Agl, were among the highest measured during the 3-year period of study, and the concentration at the mixed agricultural/forested site was one of the lowest.

Concentrations of total Kjeldahl nitrogen measured in all of the streams in the RHU's with Fixed Sites are shown in figure 12B. Concentrations vary within the RHU's; however, the mean concentration for each RHU was similar to that measured at the Fixed Site, and the measurements at the Fixed Sites were generally representative of typical streams in the RHU's. Therefore, data collected only at the Fixed Sites should provide similar information to data collected throughout these RHU's.

Concentrations of total Kjeldahl nitrogen at all of the sites are shown in figure 13A. Concentrations varied by slightly more than an order of magnitude. Differences in concentrations appear to be strongly related to differences in land use (fig. 2) and surficial deposits (fig. 3). The lowest concentrations were measured on the western side of the Study Unit, where surficial deposits are permeable and agriculture is neither extensive nor intensive. The highest concentrations were measured near Lake Winnebago, where agricultural areas coincide with poorly permeable clayey deposits. Areas of moderately permeable deposits coinciding with agriculture or forest had intermediate concentrations. Concentrations measured at the Fixed Sites cover the entire range in concentrations throughout the Study Unit during the Applicability Study.

Concentrations of total Kjeldahl nitrogen were most strongly correlated with land-use factors and slightly less strongly correlated with factors describing the surficial deposits. The percentage of agricultural land was the factor most strongly related (positively) to concentrations of total Kjeldahl nitrogen (table 3). All factors describing the surficial deposits were also correlated with concentrations of total Kjeldahl nitrogen; concentrations increased with increases in the erodibility and the percentage of clayey surficial deposits, and concentrations decreased with increased permeability of the surficial deposits. The regression model that best explained the variation in total Kjeldahl nitrogen was a function of the type of land use (percentage of agricultural and urban areas) and the permeability of the surficial deposits (table 4). This model explained 39 percent of the variability in concentrations of total Kjeldahl nitrogen.

The differences in concentrations of total Kjeldahl nitrogen in different land-use categories was similar to that measured at the Fixed Sites (agriculture > forest, urban, mixed agriculture/forest; although concentrations in urban areas were not significantly different from those in agricultural areas; see table 5). During

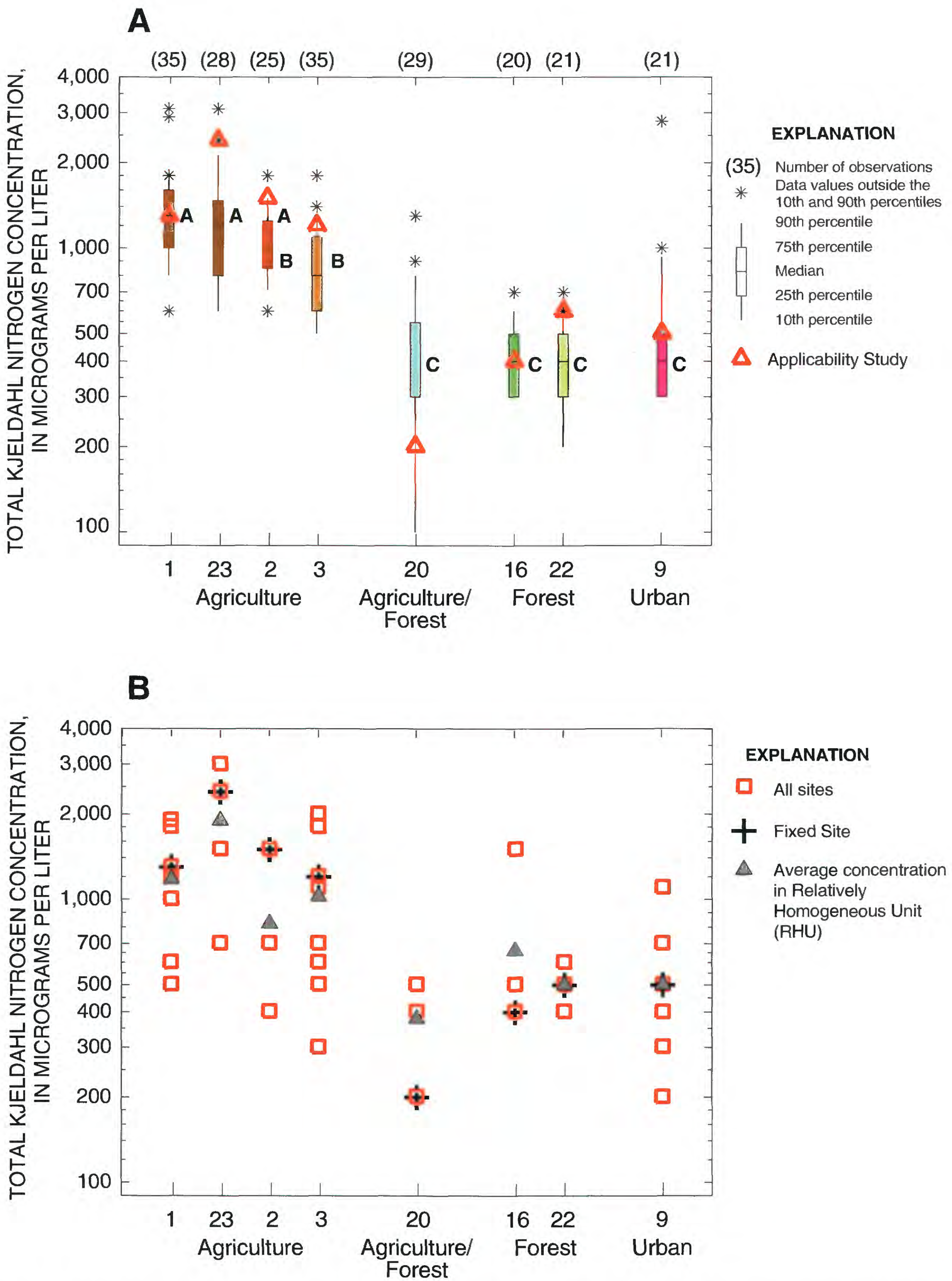

Figure 12. Total Kjeldahl nitrogen concentrations measured at (A) Fixed Sites during base flow and (B) sites within the Relatively Homogeneous Units with Fixed Sites. (The measurements collected at the Fixed Sites during the Applicability Study are identified in both graphs. Letters placed on the boxplots demonstrate which groupings were or were not statistically different ($p < 0.05$). Boxes with the same letter are not significantly different.)

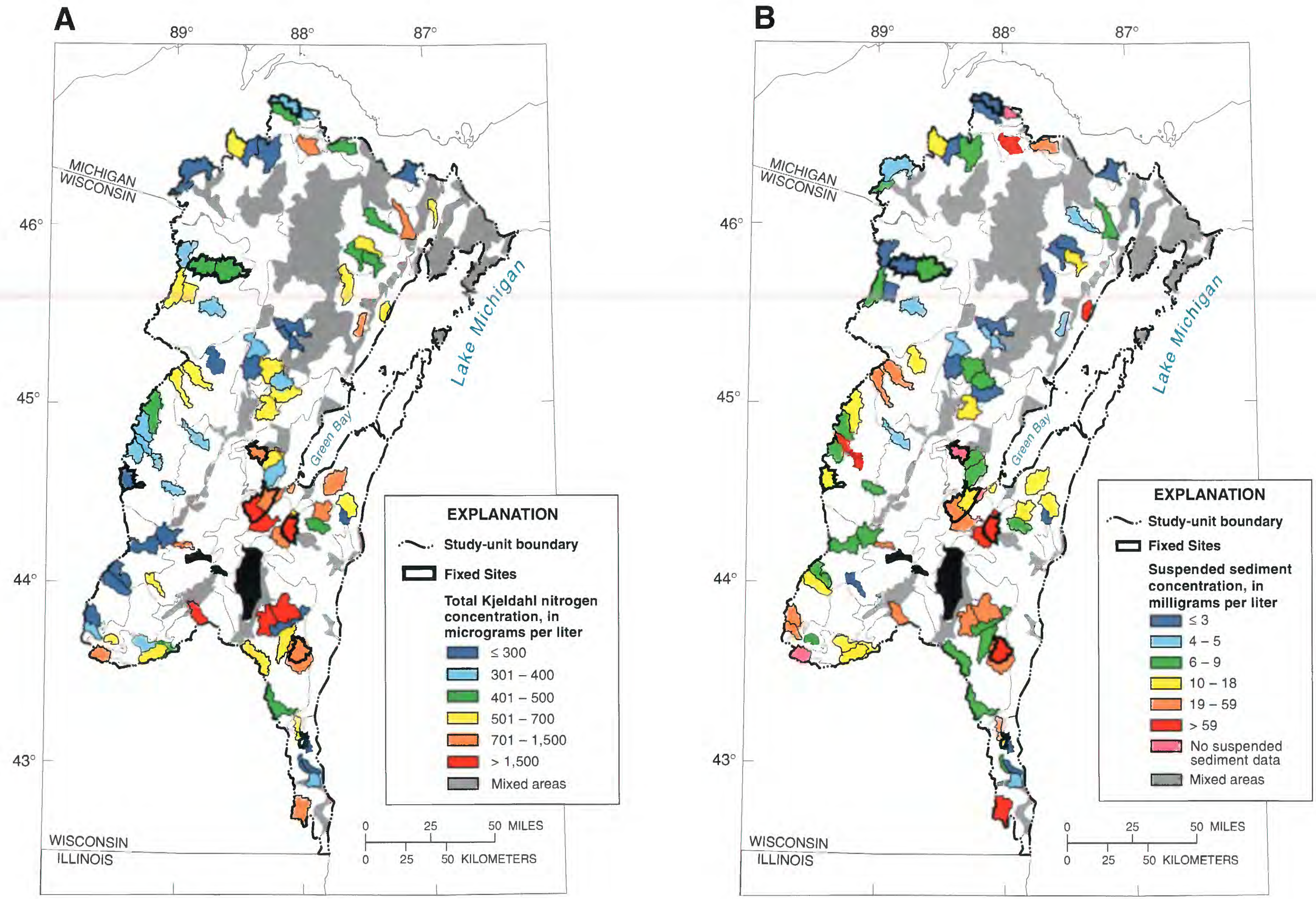

Figure 13. Concentrations of (A) total Kjeldahl nitrogen and (B) suspended sediment measured at each site sampled during the Applicability Study.

base-flow conditions, the wet-forest sites had significantly higher concentrations than the dry-forest sites (table 6). This difference was observed during the Applicability Study but not between the two forested Fixed Sites (fig. 12A). If data from only the agricultural sites are examined, the influence of the surficial deposits is seen (clay > loam > sand/sand and gravel; in other words, concentrations decrease with increasing permeability of surficial deposits, although these differences were not statistically significant; see table 7).

The distribution of concentrations of total Kjeldahl nitrogen was influenced by both land use and surficial deposits, higher concentrations being found in areas with more intense agriculture and less permeable surficial deposits than in areas with less intense agriculture and more permeable surficial deposits. Therefore, because the surficial deposits varied across the ecoregions, concentrations also varied across the ecoregions. Within the Southeastern Wisconsin Till Plains ecoregion, concentrations decreased with the distance from the poorly permeable, clayey deposits around Lake Winnebago; concentrations were also low in urban areas. Within the Northern Lakes and Forests ecoregion, concentrations decreased from west to east with decreasing permeabilities in the surficial deposits. By comparing concentrations among ecoregions, the only conclusion that can be made is that concentrations in the Southeastern Wisconsin Till Plains were significantly higher than those in the other two ecoregions (table 8).

Similar to the findings for total phosphorus, the combination of higher concentrations of total Kjeldahl nitrogen in areas with lower permeabilities of the surficial deposits (and lower streamflows) than in areas with higher permeabilities (and higher streamflows) resulted little pattern in yields of total Kjeldahl nitrogen across the Study Unit. The highest yields during base-flow conditions were found in areas with permeable surficial deposits (with high flows) and only low to moderate concentrations.

In summary, concentrations of total Kjeldahl nitrogen were highest in areas with a combination of intensive agriculture and poorly permeable surficial deposits. This conclusion is consistent with that found by examining data collected only at the Fixed Sites. This pattern is similar to that found for total phosphorus; however, the effect of the surficial deposits appears to be more influential on the distribution of the concentrations of total Kjeldahl nitrogen.

Suspended Sediment

Differences in concentrations of suspended sediment measured at the Fixed Sites during base-flow conditions appear to be primarily related to differences in land use (fig. 14A). Concentrations were significantly higher at all agricultural Fixed Sites than at mixed agricultural/forested and forested Fixed Sites. Concentrations at the urban Fixed Site were not significantly different from those at two of the agricultural Fixed Sites or at the mixed agricultural/forest Fixed Site. Therefore, concentrations of suspended sediment appear, in general, to be directly related to the amount of agriculture, with streams in urban areas being similar to those in low-intensity agricultural areas. No consistent differences were observed among agricultural areas with different surficial deposits.

The pattern in concentrations of suspended sediment measured at the Fixed Sites during the Applicability Study was fairly similar to that found using all of the base-flow data (in other words, highest concentrations in agricultural areas, moderate concentrations in mixed agriculture/forested and urban areas, and lowest concentrations in forested areas). Therefore, the variation in concentrations during the Applicability Study should be representative of the Fixed Sites. However, two of the Fixed Sites with no apparent flow were not sampled for suspended sediment (Ag23 and Ag2). The concentrations measured at the mixed agricultural/forested Fixed Site and one forested Fixed Site were among the highest concentrations measured at these sites during the 3-year period of study.

Concentrations of suspended sediment at all of the streams in the RHU's with a Fixed Site are shown in figure 14B. Concentrations were highly variable within the RHU's, with concentrations from one site in almost every RHU overlapping that from every other RHU. The highest concentrations were found in the agricultural areas with clayey surficial deposits, and the lowest concentrations were found in remote forested areas and urban areas with cement channels. Therefore, data collected only at the Fixed Sites provide very sketchy information about concentrations of suspended sediment throughout the RHU's during base-flow conditions.

Concentrations of suspended sediment in all of the streams sampled during the Applicability Study are shown in figure 13B. Differences in concentration were most strongly related to the differences in land use (fig. 2). In general, the lowest concentrations were in the

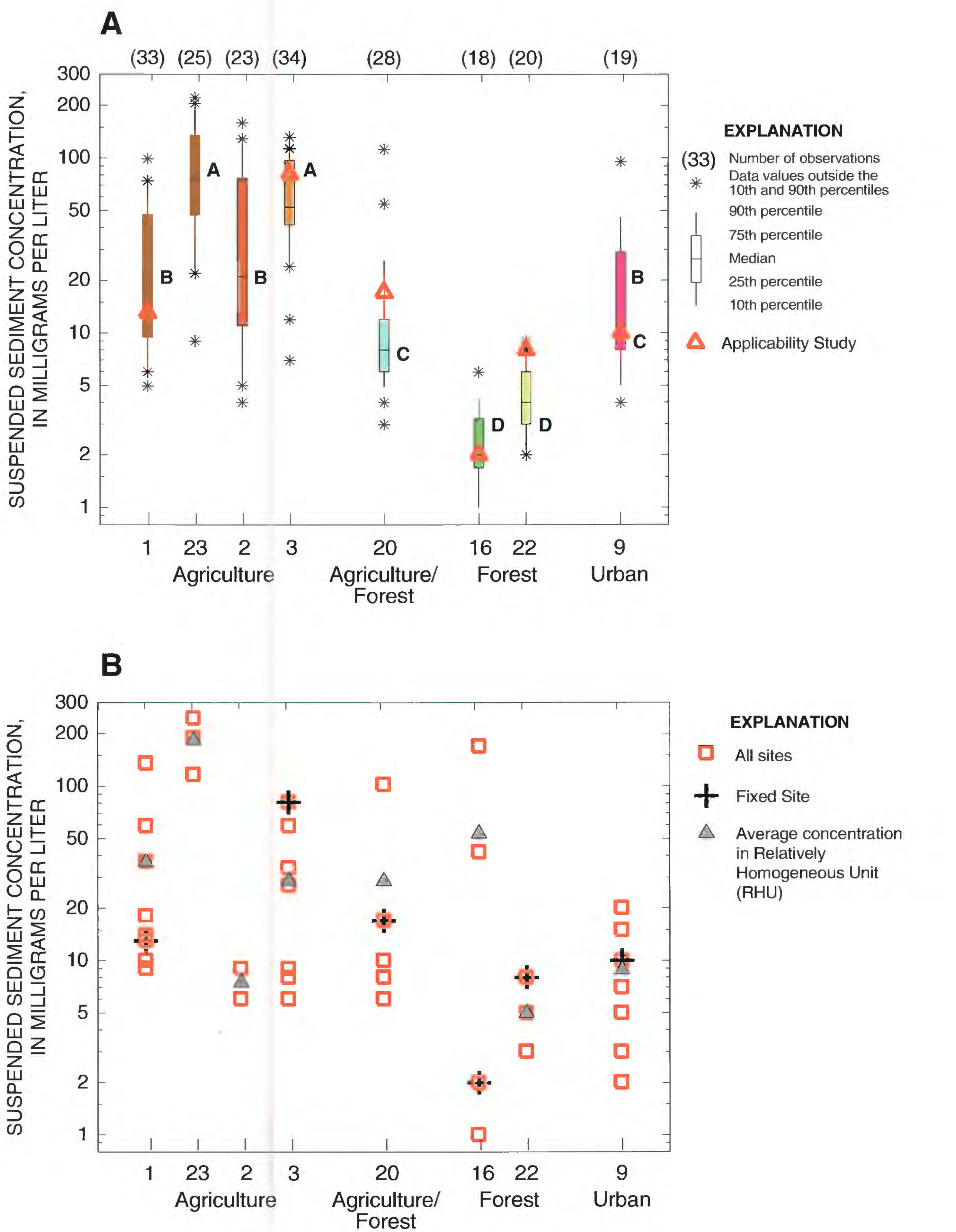

Figure 14. Suspended sediment concentrations measured at (A) Fixed Sites during base flow and (B) sites within the Relatively Homogeneous Units with Fixed Sites. (The measurements collected at the Fixed Sites during the Applicability Study are identified in both graphs. Letters placed on the boxplots demonstrate which groupings were or were not statistically different ($p < 0.05$). Boxes with the same letter are not significantly different.)

northern areas of the Study Unit where forests predominate; however, a few high concentrations were measured even in these areas (such as two streams in the far north-central part). In general, concentrations in agricultural areas were above the overall median concentration. The concentrations measured at the Fixed Sites cover the entire range in the Study Unit during the Applicability Study.

Concentrations of suspended sediment were most strongly correlated with land-use factors and slightly less strongly correlated with factors describing the amount of clayey deposits in the basin (table 3). In the normalization process, concentrations of suspended sediment were raised to the -0.2 power; therefore, a negative correlation is actually a positive correlation with the non-normalized data. The factor most strongly correlated with concentrations of suspended sediment was the percentage of agricultural land; concentrations increased with increases in the percentage of agricultural land. All of the factors describing the amount of clayey surficial deposits were also correlated with concentrations of suspended sediment; concentrations increased with increases in the percentage of clayey deposits, the erodibility of the surficial deposits, and the percentage of shale bedrock (primarily found in Ag23). The high concentrations in areas with clayey surficial deposits may be caused by the tendency for clay particles to remain in suspension much longer than other larger particles. The regression model that best explained the variation in concentrations was a function of the type of land use (percentage of agriculture) and the percentage of shale bedrock (table 4). This model explained 29 percent of the variability in concentrations of suspended sediment.

The differences in concentrations in different land-use categories was similar to that measured at the Fixed Sites (agriculture > mixed agriculture/forest > urban > forest, although only concentrations in agriculture and forest areas were significantly different; see table 5). The percentage of wetlands in the basin did not significantly affect the distribution of the concentrations of suspended sediment (table 6). If data from only agricultural areas are examined, the influence of the clayey surficial deposits is observed (clay > sand/sand and gravel > loam, although none of the differences were statistically significant; see table 7).

Because land use was the primary factor influencing the distribution of the concentrations of suspended sediment and because land use is relatively uniform in each ecoregion, concentrations were also quite uniform in each ecoregion. Within the Southeastern Wisconsin Till Plains and North Central Hardwood Forests ecoregions, concentrations were slightly higher in areas with intensive agriculture on less permeable surficial deposits than areas with less intensive agriculture on more permeable deposits. However, by comparing ecoregions, the only conclusion that can be made is that concentrations in the Northern Lakes and Forests ecoregion were significantly less than those in the North Central Hardwood Forests and Southeastern Wisconsin Till Plains ecoregions (table 8).

Similar to the findings for total phosphorus and total Kjeldahl nitrogen, the combination of higher concentrations of suspended sediment and lower streamflow in areas with poorly permeable clayey surficial deposits than in areas with more permeable deposits and higher streamflows resulted in almost no pattern in yields across the Study Unit. The only consistent pattern was in the area around Lake Winnebago with no apparent flows and no estimated yields. The highest yields were in areas with permeable surficial deposits (with high flows) and only low to moderate concentrations.

In summary, concentrations of suspended sediment were highest in agricultural areas, especially areas with clayey surficial deposits. This conclusion is consistent with the findings from data collected at the Fixed Sites.

Effects on Overall Water Quality

Each of the five water-quality characteristics measured during base-flow conditions has been shown to be influenced by various environmental factors, primarily those factors describing the land use and the surficial deposits in the basin upstream from the site. The relative importance of these factors differs with each characteristic. In this section, the relative importance of each of the general types of environmental factors thought to influence the distribution of overall water quality (general water quality on the basis of all five water-quality characteristics) is examined by use of redundancy analysis (RDA) and cluster analysis. RDA also was used to determine which environmental variables had the most influence in explaining the variability in overall water quality.

Results of Redundancy Analysis

In the RDA, the environmental factors were divided into the three main categories originally used to

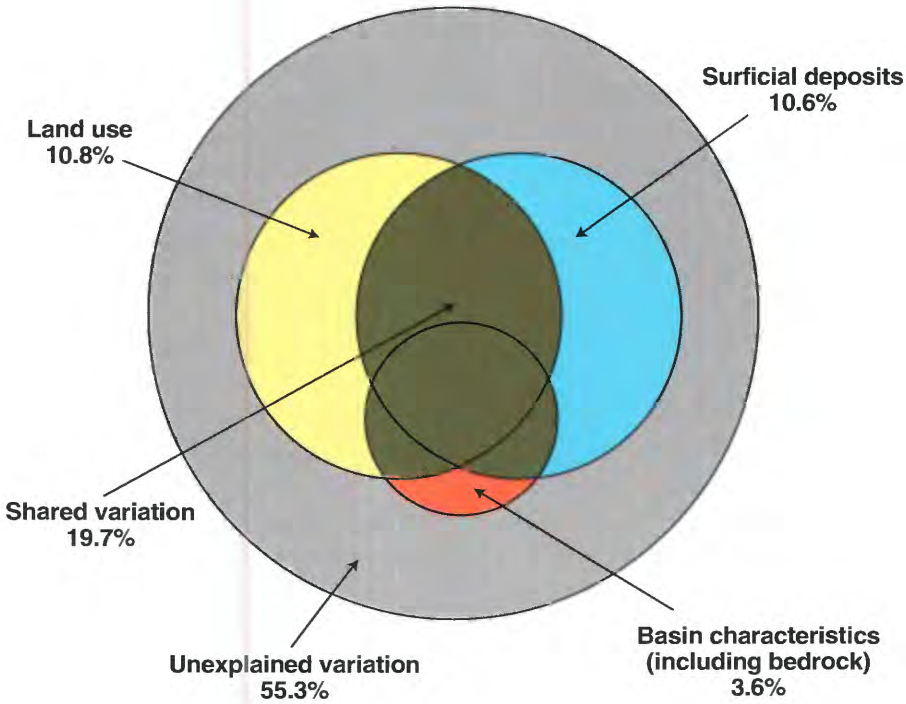

Figure 15. Distribution of water-quality variation explained by general categories of environmental factors, based on partial redundancy analysis, for selected streams in the Western Lake Michigan Drainages.

subdivide the Study Unit and define the RHU's: land use, surficial deposits, and general basin characteristics (including bedrock type). Two variables were included in the land-use category: the percentages of agriculture and urban areas in the basin. Three variables were included in the surficial-deposit category: permeability, erodibility, and percentage of clayey deposits. Three variables were included in the general-basin-characteristics category: bedrock permeability, drainage area, and topographic gradient. In this analysis, the variabilities of all five water-quality characteristics were equally weighted by the standardization process. The land-use category reflects the extent of human intervention—a factor that can be altered. The surficial-deposits and general-basin-characteristics categories reflect the geological and topographical influences—factors that cannot be altered.

In the RDA, the total variation in water quality was separated into five categories: (1) variation explained by land use alone, (2) variation explained by surficial deposits alone, (3) variation explained by the general basin characteristics alone, (4) variation explained by the overlap of land use, surficial deposits, and general basin characteristics (joint variation that cannot be assigned to a single category), and (5) variation not explained by these factors. Results from the RDA demonstrated that these landscape factors collectively explained 45 percent of the variation in water quality observed during the Applicability Study ($p < 0.01$) (fig. 15). The land-use factors and the surficial-deposit factors each independently explained about 11 percent of the variation ($p < 0.01$); the general basin characteristics (including bedrock) alone explained about 4 percent of the variation ($p < 0.03$); and the shared contribution of all three factors explained about 20 percent of the variation. Therefore, land use and surficial deposits again are the most influential factors in describing the distribution of these water-quality characteristics during base-flow conditions.

RDA also was used to determine which environmental variables explained the most variability in overall water quality (including streamflow). In RDA, as in principal component analyses, the explained variability is separated into a series of ordination (canonical) axes.

Of the 45 percent of the variation explained in the four canonical axis, the first two canonical axes explained more than 41 percent. Therefore, examination of just these first two axes enables the importance of individual environmental factors to be determined. It also enables one to determine which water-quality characteristics had the most explained variability.

The first two axes for the eight environmental factors and five water-quality characteristics are shown in the biplots in figure 16. In these biplots, the scores for each factor and each characteristic are weighted by the overall amount of variability explained by the axis; therefore, the range of scores along the first axis, which explained 32 percent of the variation, is wider than that for the second axis, which explained 9 percent of the variation. In each biplot, the distance of a point from the origin is proportional to the amount of variability that an environmental factor explains or the amount of variability in the characteristic that is explained. Therefore, the most important factors explaining the variability in the water-quality characteristics are the percentage of agriculture in the basin, followed by three factors describing the surficial deposits (permeability, erodibility, and percentage of clay in the basin) (fig. 16A). Other environmental factors that are strongly correlated with these factors could be equally important. For example, the percentage of forested land may give similar results to that found using the percentage of agricultural land. All of the general basin characteristics plot near the origin, an indication that they were not very important in influencing the distribution in the water-quality characteristics during base-flow conditions.

By comparing the location of the scores in the two biplots in figure 16, one can determine which environmental factors are most influential in driving the variability in various water-quality characteristics. Permeability in the surficial deposits and streamflow both plot in the upper left side of the graphs, an indication of a strong relation. Concentrations of total phosphorus and total Kjeldahl nitrogen, percentages of agriculture and clayey deposits, and soil erodibility all plot near the x-axis on the right side of the graphs, an indication of a strong relation between these characteristics and environmental factors. These results agree with the findings of the correlation and regression analyses.

Results of Cluster Analysis—Types of Streams

A cluster analysis was used to determine what types of streams were present in the Study Unit and how well the chosen Fixed Sites represent these general types of streams. Data for the five water-quality characteristics measured during the Applicability Study were used to divide the streams into different types (fig. 17). In figure 17, the specific types or groups of streams are determined by the relative distance between the various sites. The relative distance is a unitless measure of site similarity, in this case based on a complete linkage algorithm (SAS Institute, Inc., 1989). Streams that are connected at a value of "1" are more similar than streams that are connected at a value of "2." In figure 17, the relative distance starts with a value of "1"; subdivisions beyond this point appear to have little meaning.

It is simplest to start at the top of figure 17 and proceed downward to explain the results of the cluster analysis. The streams seem to cluster into two general types: the streams to the left side of the figure have generally good water quality (comparatively low concentrations of suspended sediment, total phosphorus, and total Kjeldahl nitrogen and high streamflow), whereas streams to the right have generally poor quality (comparatively high concentrations of suspended sediment, total phosphorus, and total Kjeldahl nitrogen and low streamflow). The subdivision process then continues until 10 types or groups of streams are identified in the WMIC Study Unit. The average for each water-quality characteristic for each group is given in table 9, and the streams in each group are listed in table 10. In table 10, the RHU's from which the streams were chosen are color coded on the basis of their land use and type of surficial deposits; a "W" or "D" was added to the RHU description to demonstrate whether it was a wet-forest area (FW) or a dry-forest area (FD) upstream from the site.

Groups A, B and C consist of streams having the best water quality (low concentrations of nutrients and suspended sediment and high streamflow). Of these three groups, group A generally has the lowest concentrations of nutrients and suspended sediment and consists of streams from forested areas (both wet and dry forests). The Fixed Site at the Peshekee River, FD16, was in group A. Groups B and C were generally streams from forested areas; however, a few streams were from mixed agricultural/forested areas, a few were cement-lined urban streams, and one was a stream from an agri-

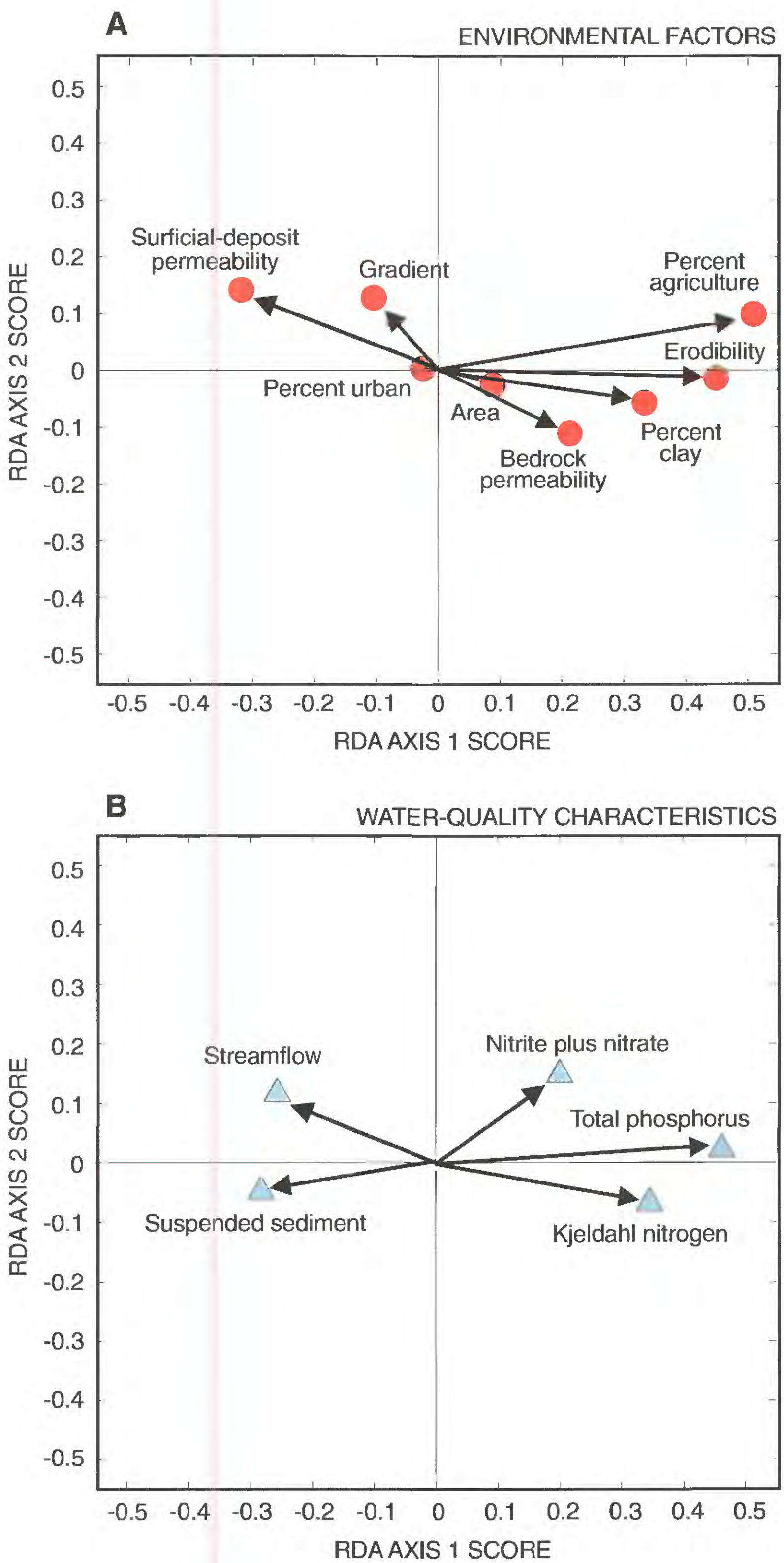

Figure 16. Ordination diagrams based on redundancy analysis of water-quality data from the Western Lake Michigan Drainages Applicability Study with the environmental factors of each basin: (A) environmental factors and (B) water-quality characteristics. (The arrows in (A) refer to the direction and relative influence of the environmental variables in the ordination. The arrows in (B) refer to the relative amount of variability in each water-quality characteristic explained by the environmental variables.)

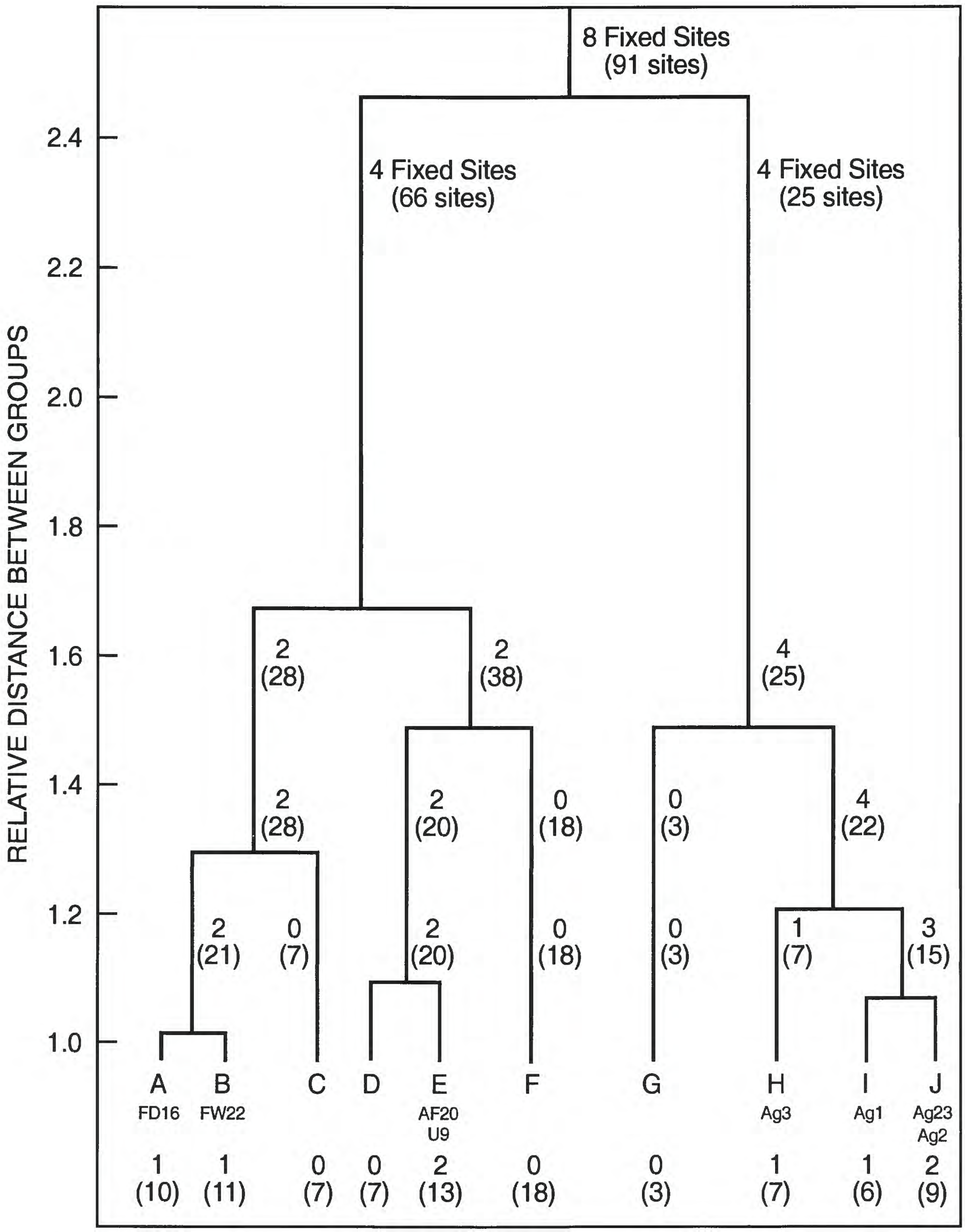

Figure 17. Types of streams in the Western Lake Michigan Drainages Study Unit based on data collected during the Applicability Study, as shown by cluster analysis of water-quality data. (At each subdivision the number of Fixed Sites and total number of sites sampled during the Applicability Study, in parentheses, are identified. The final 10 groups (types) of streams are designated by letters A through J; Fixed Sites are identified by their Relatively Homogeneous Unit. The average for each water-quality characteristic for each final group is given in table 9; sites in each group are listed in table 10.)

Table 9. Average water-quality characteristics for groupings of streams in the Western Lake Michigan Drainages

[Streams in each group are listed in table 10. Abbreviations: $m^3/km^2/d$, cubic meters per square kilometer per day; mg/L, milligrams per liter; µg/L, micrograms per liter]

Group	Number of sites	Fixed Sites in group	Streamflow ($m^3/km^2/d$)	Suspended sediment (mg/L)	Total phosphorus (µg/L)	Dissolved nitrite plus nitrate (µg/L)	Total Kjeldahl nitrogen (µg/L)
A	10	F16	274	2.8	8	35	440
B	11	F22	92	5.5	15	47	600
C	7	None	295	3.9	17	201	230
D	7	None	908	10.0	26	806	200
E	13	AF20, U9	422	21.4	32	1,108	420
F	18	None	102	7.3	66	1,609	560
G	32	None	4	94.3	31	25	890
H	7	Ag3	127	55.7	300	3,000	1,200
I	6	Ag1	31	13.0	308	148	970
J	9	Ag23, Ag2	15	86.0	638	260	1,830

cultural area. These groups had slightly higher concentrations of suspended sediment or dissolved nitrite plus nitrate than those in Group A. The Fixed Site at the Popple River, FW22, was in group B. The one stream in group B that is in an agricultural RHU, the East Branch of the Milwaukee River, has part of its drainage within the Kettle Moraine State Park and has only 56 percent of its basin in agriculture, most of which is pasture.

Groups D, E, and F consist of streams having a wide range in water-quality conditions; but, in general, they have relatively high flow and high concentrations of dissolved nitrite plus nitrate. Most of the streams in these groups are in mixed land-use areas and agricultural areas with permeable surficial deposits. The Fixed Sites at the Tomorrow River (AF20) and Lincoln Creek (U9) were in group E.

Groups G, H, I, and J consist of streams having the worst water quality (high concentrations of nutrients and suspended sediment and low streamflow, except for group H, which had moderate streamflow). Group G consisted of three streams in forested areas with very low nutrient concentrations, very low flows, and high concentrations of suspended sediment. There was a great deal of logging activity in these areas, which may have influenced the concentrations of suspended sediment. Further study is needed to clarify the relations between land use and water quality for the streams in group G. Streams in groups H, I, and J had generally the worst water quality and were subdivided primarily on the basis of flow. Group H consisted primarily of streams in agricultural areas with high base flow. The Fixed Site at the North Branch of the Milwaukee River, Ag3, was in group H. Streams in group I had slightly lower flows than the streams in group H. The Fixed Site at Duck Creek, Ag1, was in group I. Duck Creek is in an area with extensive clayey deposits, but the stream flows over areas of exposed bedrock. Two streams in urban areas and one in a forested area were also in group I. The stream in the forested area, Peshtigo Brook, was the only stream sampled that was in a forested area on clayey deposits, but just upstream from the sampling site is an area of intensive cash cropping; therefore, this stream may not represent a forested area with clayey deposits. Group J consisted of streams with the overall worst water quality (high concentrations of suspended sediment, total phosphorus, and total Kjeldahl nitrogen and very low streamflow). The streams in group J were primarily in agricultural areas with poorly permeable deposits. The Fixed Sites at the East River, Ag23, and the Pensaukee River, Ag2, were in group J. The relatively low concentrations of dissolved nitrite plus nitrate measured in streams in this group may not be very indicative of what is present most of the time. At both the East River and Pensaukee River, these low concentrations were quite unusual and only occur with very low flows. The Pensaukee River seems to be out of place in group J, and its water quality measured during the Applicability Study appears to be greatly affected by the beaver dam and the resultant ponding. Most of the other sites in Ag2 were in group F; if the more typical water quality at the Pensaukee site had been used in

Table 10. Composition of groups of streams in the Western Lake Michigan Drainages

[Each stream is listed by its abbreviation (full stream names are given in Appendix 1) and by the Relatively Homogenous Unit from which it was chosen. Abbreviations of Fixed Sites are colored]

Groups A, B, C

Group A	
W. Br. White	FD6
Peshekee	FD16
W. Br. Pesh	FD16
Thunder	FD17
Waupee	FD17
Cedar	FW7
Hunters	FW7
Pine	FW22
Popple (Long)	FW22
S. Br. Pesh.	FW22
Group B	
Dishno	FD16
W. B. Net	FD18
47 Mile	FW7
10 Mile	FW7
Chippeny	FW14
Popple	FW22
Wolf	FW22
Days	AF12
Little Cedar	AF12
Sucker	AF28
E. Br. Milw.	Ag3
Group C	
Middle Inlet	FD17
Wausaukee	FD17
E. Br. Net	FD18
Rat	FW22
Honey	[illegible]
Kinnickinnic	U9
Lincoln	U9

Groups D, E, F

Group D	
Fence	FD18
S. Br. Paint	FD18
N. Br. Paint	FD
Chaffee	AF26
Mecan	AF26
Neenan	AF26
Pine(Sax.)	AF26
Group E	
Evergreen	FD19
L. W. Br. Wolf	FD19
S. Br. Oconto	FD19
Comet	AF20
M. Br. Embarrass	AF20
S. Br. Embarrass	AF20
Tomorrow	AF20
Widow	AF27
Walla Walla	AF28
[illegible]	[illegible]
Mullet	Ag3
Belle Fountain	[illegible]
S. Br. Beaver	Ag24
Group F	
Big Brook	AF12
Little Wolf	AF20
Big Slough	AF27
Good Earth	AF27
Oak Creek	U9
Cedar Creek	[illegible]
W. Br. Milw.	[illegible]
Tisch Mills	[illegible]
Fox	[illegible]
Grand	[illegible]
L. Suam. (C)	Ag2
Suamico	Ag2
Blake Creek	Ag15
Mill Creek	Ag15
Kelly Brook	Ag24
Little Peshtigo	Ag24
Devils	Ag1
E. Br. Twin	Ag1

Groups G, H, I, J

Group G	
Black	FD16
E. Br. Escanaba	FD16
Deer	FW13
Group H	
Alder Creek	AF28
N. Br. Milw.	Ag3
N. Br. Milw. (8)	Ag3
Silver Creek	Ag3
Kewaunee	Ag1
Neshota	Ag1
Root	Ag1
Group I	
Peshtigo Br.	FW21
Beaver Dam	U9
L. Menomonee	U9
L. Suamico	Ag2
Duck (H)	Ag1
Duck	Ag1
Group J	
Sheboygan (5)	AF5
Sheboygan	Ag3
Pensaukee	Ag2
Apple	Ag1
Duck (S)	Ag1
East (32)	Ag23
East	Ag23
East (ZZ)	Ag23
Plum Creek	Ag23

this analysis, the Fixed Site may have been placed in group F.

Relation of Water Quality During Base Flow to That During Higher Flow

The Applicability Study was designed to examine the variability in water-quality characteristics in streams within and among RHU's during one hydrologic condition—base-flow conditions during summer. This condition was chosen to minimize hydrological differences that may occur throughout the Study Unit and to maximize compatibility of data with those from other water-quality studies. This study was not designed to examine the variability that occurs during runoff, when most of the nutrient and sediment transport occurs. An applicability study during high flow would be very difficult to conduct because of the difficulty in finding similar hydrologic conditions at all sites.

The results found in this study agree with those from many previous studies. For example, Monteith and Sonzogni (1981) state that the two most important factors affecting the chemical concentrations in rivers near the Great Lakes are the texture of the soil material and the land use on that soil. Other factors may affect these water-quality characteristics during high runoff. Robertson (1996) found that the topographic gradient of the basin was the primary factor influencing the transport of suspended sediment during high runoff (and an important factor influencing the transport of phosphorus) and that the texture of the surficial sediments was the second most important factor.

EVALUATION OF SAMPLING DESIGN

Representativeness of Data Collected at the Fixed Sites

The primary goal of the surface-water sampling design was to establish a network of sites (Fixed Sites) to describe the variability in the flow characteristics, the concentrations and loads of nutrients, major ions, and suspended sediment, and the biological communities that exist in the WMIC Study Unit. For practical application, however, only eight Fixed Sites on small streams could be chosen. Therefore, this study was designed to determine (1) how adequate the data collected at the eight Fixed Sites are to describe the variability in the water-quality characteristics in the specific RHU's from which they were chosen to represent and throughout the Study Unit during base-flow conditions, and (2) how applicable the interpretive results made from the data collected at the eight Fixed Sites are to streams throughout the Study Unit.

For each water-quality characteristic examined during this study, the data collected at the eight Fixed Sites represented the range that was measured throughout the entire Study Unit and generally represented that in the RHU's from which they were chosen. There were, however, two exceptions: First, concentrations of dissolved nitrite plus nitrate measured during the Applicability Study at three Fixed Sites were below the MDL, whereas concentrations at these Fixed Sites were usually quite high (fig. 10A). These low concentrations were associated with very low flows and may also occur as very low flows are reached at other sites. The low concentrations of nitrite plus nitrate may be due to the reduction of the nitrates during times of low concentrations of dissolved oxygen or due to denitrified ground water being the main source of water during base-flow conditions. Cluster-analysis results indicate several sites where this may have occurred, specifically, sites in groups I and J (tables 9 and 10). Therefore, the difference between groups I and J and group H may be due to the extent of base flow and the extent of nitrate reduction. The second exception is that the data collected at the Pensaukee River (Fixed Site in Ag2) were quite different from those that were previously collected at that site and quite different from the data collected throughout the RHU from which it was chosen. The unrepresentativeness of this Fixed Site appears to be due to the damming of the river by beavers. Most data previously collected at the Pensaukee River were similar to what were collected throughout Ag2 during this Applicability Study; therefore, the data collected as part of the NAWQA program (until just prior to the Applicability Study) may be representative of other streams in this RHU.

On the basis of the results of the cluster analysis, streams in the WMIC Study Unit may be divided into various types or groups depending on the value of the relative distance chosen (fig. 17). To demonstrate how many Fixed Sites were in each of these various types or groups of streams, the number of Fixed Sites is indicated at each subdivision along with the total number of streams in each group (in parentheses). At the most general subdivision (relative distance of 1.7 or greater), four Fixed Sites were included in the streams to the left side of the figure with generally good water quality (66 total sites) and four Fixed Sites were included in the streams to the right with generally poor water quality (25 total sites). At a relative distance of "1," there were 10 different groups of streams. One Fixed Site was in group A (10 sites) and one was in group B (11 total sites), groups that represent streams from the most pristine areas of the Study Unit. These Fixed Sites were specifically chosen to represent minimally affected streams and therefore were appropriate representatives. Four Fixed Sites were in groups H, I, and J, representing streams that were most influenced by agricultural activities (22 total sites). At first glance, these types of streams appear to be overrepresented; however, one of the initial thrusts of the NAWQA program was to determine water quality in agricultural areas. Therefore, these sites do appear to represent the range in water quality in agricultural areas. One type of agricultural stream appears not to be represented, that being a stream in a mostly agricultural area with mostly loamy surficial deposits (group F, with a total of 18 sites). The data collected at the Pensaukee River, Ag2, before the construction of the beaver dam may, however, represent this area. The two other Fixed Sites were on streams with moderate water quality. These types of streams had a Fixed Site in a mixed agricultural/forested area and a Fixed Site in an urban area. The water-quality characteristics during base-flow conditions in urban areas is quite variable. Streams in urban areas were grouped along with those in forested areas (group C), mixed areas (groups E and F), and intensive agricultural areas (group I). It is difficult to choose a single stream in an urban area that will describe the variability that occurs in urban streams during base-flow conditions. Therefore, these eight Fixed Sites represent the different types of streams in the WMIC Study Unit very well.

Implications for Study-Unit Stratification Design

To improve the general understanding of how environmental factors affect water quality, the WMIC Study Unit was divided into RHU's, areas each dominated by one unique combination of three specific environmental factors thought to be important in affecting water quality: land use, surficial deposits, and bedrock type. On the basis of the results of the Applicability Study, land use and surficial deposits are crucial factors in any stratification design; however, bedrock type added very little information. Therefore, to describe the variability in streamflow and concentrations of total phosphorus, dissolved nitrite plus nitrate, total Kjeldahl nitrogen, and suspended sediment in the WMIC Study Unit, differences in bedrock types do not appear to be very important and RHU's that differ only by bedrock type can be combined. For example, the mixed agricultural/forested RHU's, AF20 and AF26, can be combined into one RHU.

Differences in bedrock types were included in the stratification design not only for examining the distribution of nutrients and suspended sediment but also for major ions and for examining the distribution of ground-water quality. The chemical character of ground water entering streams may be affected by the bedrock with which it was in contact. For example, higher concentrations of calcium were found at Fixed Sites with carbonate bedrock than at Fixed Sites on other types of bedrock (Richards and others, 1998). Therefore, although bedrock was not required to be considered for the characteristics examined in this study, it may be important for other properties and constituents sampled for at the Fixed Sites.

Water-quality characteristics in streams in a few of the RHU's were found to be quite variable; for example, streams in U9 (urban areas with clayey surficial deposits) and Ag3 (agricultural areas with relatively permeable surficial deposits). The variability in water-quality characteristics in these areas may have been caused by variations in the physical structure of the stream or variability in an environmental factor used in the stratification design. One factor not included in the stratification design was the bottom type of the streams. During base-flow conditions, streams flowing over extensive areas of cement or bedrock appear to have better water quality (lower concentrations of suspended sediment) than streams flowing over unconsolidated material. This may in part explain the variability in urban areas and also the better quality measured in a few of the streams in Ag1 that commonly flow over extensive bedrock outcrops. Part of the variability in the water-quality characteristics in Ag3 may be due to the position of the transition from clayey surficial deposits to the north to sandy surficial deposits to the south. On the basis of water-quality characteristics in the northern areas of Ag3, the clayey surficial deposits would seem to extend further south on the eastern side of Lake Winnebago than depicted in figure 3.

Two general approaches have been used to design schemes for defining boundaries to subdivide various environmental factors. One is the explicit, rule-based approach that partitions the landscape into RHU's on the basis of differences in the factors thought to control the characteristics being examined; each factor is equally weighted in defining the RHU's (Bailey, 1996). This approach was used to subdivide the WMIC Study Unit and select the Fixed Sites. The other is the more commonly used qualitative, ecoregion approach, in which expert judgment is used to integrate the various factors thought to be important in influencing various response variables and used to partition the landscape; each factor is not equally weighted or used independently in defining the ecoregions (Omernik, 1995). Differences in each water-quality characteristic were measured among ecoregions; therefore, patterns can be described using the ecoregion approach. However, the differences measured among ecoregions could not be attributed to differences in specific environmental factors because each environmental factor was not equally weighted or used independently in defining the ecoregions. In addition, because each environmental factor was not equally weighted, each ecoregion contained areas with quite different environmental and water-quality characteristics. For example, water-quality characteristics in the clayey regions of the Southeastern Wisconsin Till Plains ecoregion around Lake Winnebago were quite different from those in other more permeable areas of the ecoregion. If just ecoregions are considered, water-quality characteristics in these two quite different areas are averaged together, obscuring the patterns observed by use of the RHU approach. Therefore, dividing the WMIC Study Unit into RHU's and selecting Fixed Sites within specific RHU's enabled differences in water-quality characteristics to be measured and related to the differences in specific environmental characteristics.

SUMMARY AND CONCLUSIONS

Water quality in streams throughout the Western Lake Michigan Drainages Study Unit during base-flow conditions was primarily influenced by the land use and the types of surficial deposits in their drainage basins. These two factors explained approximately 40 percent of the total variability observed during this Applicability Study. Each of these two general types of environmental factors appears to be of similar importance, each independently explaining about 11 percent of the total variation. General basin characteristics, including bedrock information, independently explained only about 4 percent of the total variation. Therefore, factors that cannot be altered (surficial deposits and other basin characteristics) appear to be as important in influencing water-quality characteristics as factors that can be altered (land use).

In general, streams in agricultural areas had the poorest water quality, exhibiting the highest concentrations of total phosphorus, total Kjeldahl nitrogen, and suspended sediment. Streams in forested areas had the best water quality, exhibiting the lowest concentrations of total phosphorus, dissolved nitrite plus nitrate, and suspended sediment. Streams in urban and mixed agricultural/forested areas had moderate water quality and were usually not significantly different from one another. Within a specific land-use type, streams in areas with poorly permeable clayey deposits had the poorest water quality, exhibiting the highest concentrations of total phosphorus, total Kjeldahl nitrogen, and suspended sediment and lowest flow. In general, water-quality characteristics in areas with sand/sand and gravel deposits had the best water quality, exhibiting the lowest concentrations of total phosphorus, total Kjeldahl nitrogen, and suspended sediment and the highest streamflow.

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APPENDIXES 1–3

Appendix 1. Description of sites used in the Applicability Study, Western Lake Michigan Drainages

[USGS, U.S. Geological Survey; RHU, Relatively Homogeneous Unit; km^2, square kilometer]

Site abbreviation	Site name	USGS site number	RHU	Drainage area (km^2)	Percentage of land use in basin					
					Agriculture	Forest	Forested wetland	Open wetland	Urban	Water
Duck (S)	Duck Creek at Co. Trunk Highway S near Freedom, Wis.	4072028	Ag1	127	88.8	2.5	7.3	0	0.6	0
Duck	Duck Creek at Seminary Road near Oneida, Wis.	4072050	Ag1	247	89.3	4.6	4.8	0	.6	0
Duck (H)	Duck Creek near Howard, Wis.	4072150	Ag1	281	88.4	5.6	4.3	0	.9	0
Apple	Apple Creek near Wrightstown, Wis.	4085051	Ag1	123	90.7	2.2	0	0	6.6	0
E. Br. Twin	East Twin River near Tisch Mills, Wis.	4085240	Ag1	122	81.4	6.2	12.2	0	.1	0
Neshota	Neshota River near Denmark, Wis.	4085310	Ag1	111	91.1	6	.1	0	2.5	.2
Devils	Devils River near Denmark, Wis.	4085323	Ag1	95	90	6	2.5	0	1.4	.1
Kewaunee	Kewaunee River near Casco, Wis.	40851958	Ag1	165	93.9	3.8	.8	0	1.3	0
Root	Root River Canal near Raymond, Wis.	40872325	Ag1	142	94.5	1.6	0	0	3.4	.2
Pensaukee	Pensaukee River near Krakow, Wis.	4071795	Ag2	87	86.1	4.4	9.3	0	.2	0
L. Suam. (C)	Little Suamico River near Co. Trunk C near Sobieski, Wis.	4071902	Ag2	97	90.4	3.4	3.3	.2	2.2	.2
L. Suamico	Little Suamico River near Sobieski, Wis.	4071903	Ag2	103	88.7	5.5	3	2	2	.1
Suamico	Suamico River at Flintville, Wis.	4071990	Ag2	137	89	8.1	2.2	.1	.3	.2
Mullet	Mullet River near Plymouth, Wis.	4085760	Ag3	115	73.3	15.1	4.9	2.8	2.4	.8
W. Br. Milw.	West Branch Milwaukee River near Kewaskum, Wis.	4086139	Ag3	148	91.2	2.4	4.2	.9	.9	.1
E. Br. Milw.	East Branch Milwaukee River at New Fane, Wis.	4086200	Ag3	139	56.3	31.4	7.1	.6	2.3	2.3
N. Br. Milw. (8)	North Br. Milwaukee R. at Highway 84 near Random Lake, Wis.	4086326	Ag3	268	78.7	5.3	4.9	.4	9.7	.6
Cedar Creek	Cedar Creek near Jackson, Wis.	4086460	Ag3	140	82.7	6	.5	.1	6.4	3.3
Silver Creek	Silver Creek at South Koro Road near Ripon, Wis.	40734644	Ag3	93	85.2	1.1	1.6	4.2	7.5	.2
Sheboygan	Sheboygan River near St. Cloud, Wis.	40854805	Ag3	148	87.6	7.5	1.9	1.3	1.5	0
N. Br. Milw.	North Branch Milwaukee River near Random Lake, Wis.	40863075	Ag3	133	88	6.4	3.9	.2	1.1	.3
Tisch Mills	Tisch Mills Creek at Tisch Mills, Wis.	40852508	Ag4	43	81.4	7.6	10.8	0	0	0
Mill Creek	Mill Creek near Pella, Wis.	4078490	Ag15	105	47.4	30.9	21.5	0	.2	.1
Blake Creek	Blake Creek at Symco, Wis.	4079840	Ag15	77	60.1	35.2	3.4	0	.6	.7
Plum Creek	Plum Creek near Co. Highway ZZ near Wrightstown, Wis.	4084940	Ag23	91	93.7	5.5	0	0	.6	0
East (ZZ)	East River at Co. Highway ZZ near Greenleaf, Wis.	4085108	Ag23	117	91.9	4.7	2.4	0	.8	0
East	East River at Midway Road near De Pere, Wis.	4085109	Ag23	122	91.5	5	2.3	.2	.8	0
East (32)	East River at Highway 32 in Brown County, Wis.	4085110	Ag23	134	91.8	5.1	2.1	.2	.7	0
S. Br. Beaver	South Branch Beaver Creek near Pound, Wis.	4069343	Ag24	116	56.2	25.8	11.4	.6	1.3	4.6
Little Peshtigo	Little Peshtigo River near Coleman, Wis.	4069390	Ag24	133	63.4	13	19.8	1.4	.5	1.7

Appendix 1. Description of sites used in the Applicability Study, Western Lake Michigan Drainages—Continued

[USGS, U.S. Geological Survey; RHU, Relatively Homogeneous Unit; km^2, square kilometer]

Site abbreviation	Site name	USGS site number	RHU	Drainage area (km^2)	Percentage of land use in basin					
					Agriculture	Forest	Forested wetland	Open wetland	Urban	Water
Kelly Brook	Kelly Brook near Oconto Falls, Wis.	4071720	Ag24	150	61.1	21.3	15.1	.4	.1	1.9
Fox	Fox River near Pardeeville, Wis.	4072410	Ag24	122	83.4	10.7	0	5.9	0	0
Grand	Grand River Tributary near Kingston, Wis.	4073069	Ag25	49	90.7	4.4	0	2.4	0	2.4
Belle Fountain	Belle Fountain Creek near Kingston, Wis.	4073100	Ag25	92	76.1	15.8	1.4	6.3	.3	.1
Sheboygan (5)	Sheboygan River near Elkhart Lake, Wis.	40854945	AF5	348	75.7	4.9	13.7	3.1	1.4	1.1
Days	Days River near Brampton, Mich.	4057658	AF12	128	7.7	51.1	40.4	.2	0	0
Big Brook	Big Brook near Palestine, Mich.	4059758	AF12	63	46.5	14.4	38.4	0	0	.7
Little Cedar	Little Cedar River near Bagley, Mich.	4067080	AF12	144	20.6	42.1	35.9	.2	.7	.4
M. Br. Embarrass	Middle Branch Embarrass River near Eland, Wis.	4078092	AF20	191	39.7	34.6	24.4	1	.1	.1
S. Br. Embarrass	South Br. Embarrass R. at Co. M near Wittenberg, Wis.	4078109	AF20	131	46.5	38.5	10.4	2.4	.7	1.4
Little Wolf	Little Wolf River near St. Highway 49 near Galloway, Wis.	4079608	AF20	103	38.7	31.4	25.2	3.7	.1	1
Comet	Comet Creek near Big Falls, Wis.	4079657	AF20	111	30.2	50.1	18.6	.6	.1	.3
Tomorrow	Tomorrow River near Nelsonville, Wis.	4080798	AF20	114	58.3	31.5	6.5	2.3	.2	1.2
Neenah	Neenah Creek near Co. Trunk Highway A near Oxford, Wis.	4072665	AF26	91	60.5	32.5	.1	2.8	1.7	2.4
Mecan	Mecan River at 14th Avenue near Richford, Wis.	4073230	AF26	108	52.3	41.6	2.9	2.5	.1	.7
Chaffee	Chaffee Creek near Budsin, Wis.	4073302	AF26	124	42.2	50.7	3.1	2.4	.7	.4
Pine (Sax.)	Pine River near Saxeville, Wis.	4081412	AF26	147	44.9	50.1	2	0	.2	2.7
Widow	Widow Green Creek near Briggsville, Wis.	4072690	AF27	62	67.6	25.2	0	4.5	1.5	1.2
Big Slough	Big Slough near Briggsville, Wis.	4072711	AF27	87	62	20.6	11.9	5.4	0	0
Good Earth	Good Earth Creek near Endeavor, Wis.	4072732	AF27	43	68.4	19.7	8.6	3.3	0	0
Sucker	Sucker Creek near Princeton, Wis.	4073452	AF28	63	65.2	25.5	.6	6.5	.5	1.6
Walla Walla	Walla Walla Creek near Weyauwega, Wis.	4081100	AF28	135	70.2	20.9	5.1	2.6	.2	.9
Alder Creek	Alder Creek near Fremont, Wis.	4081402	AF28	37	62.3	12.2	18.7	6.8	0	0
W. Br. White	West Branch Whitefish River near Diffin, Mich.	4057529	FD6	116	3.5	71.1	25.3	0	0	0
Black	Black River near Republic, Mich.	4057950	FD16	113	0	92.9	2.8	0	0	1.6
E. Br. Escanaba	East Branch Escanaba River near Palmer, Mich.	4058305	FD16	109	.1	82.8	.4	0	2.5	4.4
Peshekee	Peshekee River near Martins Landing, Mich.	4062085	FD16	114	0	87.7	10	0	0	2.3
Dishno	Dishno Creek near Champion, Mich.	4062095	FD16	45	0	95.3	1.3	0	0	1
W. Br. Pesh.	West Branch Peshekee River near Champion, Mich.	4062190	FD16	110	0	83.9	13.1	.3	0	2.7
Wausaukee	Wausaukee River near Wausaukee, Wis.	4066690	FD17	138	12.8	66.9	18.3	0	.6	1.3
Thunder	Thunder River near Lakewood, Wis.	4068200	FD17	138	2.9	85.3	10.4	0	0	.6

Appendix 1. Description of sites used in the Applicability Study, Western Lake Michigan Drainages—Continued

[USGS, U.S. Geological Survey; RHU, Relatively Homogeneous Unit; km^2, square kilometer]

Site abbreviation	Site name	USGS site number	RHU	Drainage area (km^2)	Percentage of land use in basin					
					Agriculture	Forest	Forested wetland	Open wetland	Urban	Water
Middle Inlet	Middle Inlet at Camp Road near Middle Inlet, Wis.	4069200	FD17	76	7	72.1	10.3	.4	.2	10.1
Waupee	Waupee Creek near Mountain, Wis.	4070300	FD17	133	3.4	70.5	23.2	.3	.8	1.8
S. Br. Paint	South Branch Paint River near Gibbs City, Mich.	4061050	FD18	66	0	86.2	11.3	.5	0	2
W. Br. Net	West Branch Net River near Park Siding, Mich.	4061200	FD18	144	.8	69.3	28.1	.8	0	1.1
E. Br. Net	East Branch Net River near Park Siding, Mich.	4061245	FD18	113	0	68.2	27.9	2.4	0	1.5
Fence	Fence River near Michigamme, Mich.	4062462	FD18	220	0	82.1	14.6	.7	0	2.6
S. Br. Oconto	South Branch Oconto River near Boulder Lake, Wis.	4070606	FD19	131	5.9	86.3	6.6	0	0	1.2
Evergreen	Evergreen River at Co. WW near Langlade, Wis.	4075350	FD19	140	11.7	80.5	7.7	0	0	.1
L. W. Br. Wolf	Little W. Br. Wolf R. at Mill Pond at Neopit, Wis.	4075860	FD19	120	27.2	67.2	4.9	0	.1	.6
N. Br. Paint	North Branch Paint near Gibbs City, Mich.	4061025	FD	203	0	84	10.7	0	0	3.3
Hunters	Hunters Brook near Cornell, Mich.	4058980	FW7	121	4.8	45.1	49.6	0	0	0
10 Mile	Tenmile Creek at Perronville, Mich.	4059400	FW7	113	5.3	40.3	54.2	0	0	.1
Cedar	Cedar River near Spalding, Mich.	4059685	FW7	89	0	63.8	35.7	.5	0	0
47 Mile	Forty Seven Mile Creek near Houle, Mich.	4059715	FW7	103	10.9	57.8	31.2	0	0	0
Deer Creek	Deer Creek near Fox, Mich.	4059620	FW13	55	0	72.4	25.7	1.8	0	0
Chippeny	Chippeny Creek near Rapid River, Mich.	4057577	FW14	53	9.1	60.5	30.4	0	0	0
Peshtigo Br.	Peshtigo Brook near Suring, Wis.	4070850	FW21	157	2	52.5	41.3	3.3	.2	.8
Pine	Pine River near Windsor Dam near Alvin, Wis.	4063631	FW22	131	0	44.2	54.5	1.3	0	0
Popple (Long)	Popple River near Long Lake, Wis.	4063674	FW22	156	1.6	55.5	41.9	.6	.2	.1
Popple	Popple River near Fence, Wis.	4063700	FW22	362	3	61.1	33.6	1.4	.1	.6
S. Br. Pesh.	South Branch Peshtigo River near Argonne, Wis.	4067690	FW22	93	23.5	48.3	25.3	.8	1.1	.9
Rat	Rat River at Co. Trunk Highway H at Blackwell, Wis.	4067892	FW22	124	7	69.3	17.1	0	1.6	5
Wolf	Wolf River near Nashville, Wis.	4074350	FW22	157	2.2	61	27.2	3.3	.2	6.2
Beaver Dam	Beaver Dam Creek near Howard, Wis.	4072225	U9	19	15.1	5.1	0	2.1	77.5	0
Lincoln	Lincoln Creek at Milwaukee, Wis.	4086950	U9	56	1.5	0	0	0	98.4	.1
L. Menomonee	Little Menomonee River at Milwaukee, Wis.	4087070	U9	51	25.4	3.3	0	0	70	0
Honey Creek	Honey Creek at Wauwatosa, Wis.	4087119	U9	27	5.6	0	0	0	94.1	0
Kinnickinnic	Kinnickinnic River at S. 27th St. at Milwaukee, Wis.	4087150	U9	45	5.4	0	0	0	94.5	0
Oak Creek	Oak Creek at South Milwaukee, Wis.	4087204	U9	65	62.6	0	0	0	37.4	0
Lincoln (47)	Lincoln Creek at 47th Street at Milwaukee, Wis.	40869415	U9	25	3.2	0	0	0	96.8	0

Appendix 2. Description of surficial-deposit and bedrock characteristics of sites used in the Applicability Study, Western Lake Michigan Drainages
[RHU, Relatively Homogeneous Unit; S and G, sand and gravel; carb/sand, carbonate and sandstone; cm/h, centimeters per hour; m/km, meters per kilometer]

Site abbreviation[1]	RHU	Percentage of surficial deposit type in the basin				Permeability (cm/h)	Erodibility (K factor)	Gradient (m/km)	Dominant bedrock type	Relative bedrock permeability
		S and G	Sand	Loam	Clay					
Duck (S)	Ag1	0	0	17.7	82.3	3.62	0.27	2.38	Carbonate	9.63
Duck	Ag1	0	0	23.9	76.1	4.25	.27	1.69	Carbonate	9.75
Duck (H)	Ag1	0	0	21.1	78.9	4.85	.27	1.53	Carbonate	9.78
Apple	Ag1	0	0	0	100	4.78	.29	3.44	Carbonate	10
E. Br. Twin	Ag1	40.6	0	0	59.4	14.44	.24	5.15	Carbonate	10
Neshota	Ag1	12	0	0	88	5.40	.29	4.68	Carbonate	10
Devils	Ag1	.4	0	0	99.6	4.55	.29	4.86	Carbonate	10
Kewaunee	Ag1	8.7	0	0	91.3	5.13	.29	5.34	Carbonate	10
Root	Ag1	12.1	0	0	87.9	2.17	.32	3.03	Carbonate	9.51
Pensaukee	Ag2	.8	0	99.2	0	8.09	.26	5.8	Carbonate	9.84
L. Suam. (C)	Ag2	0	0	98.3	1.7	8.47	.25	3.36	Carbonate	9.18
L. Suamico	Ag2	1.7	0	95.6	2.7	9.06	.25	3.64	Carbonate	9.36
Suamico	Ag2	0	0	74.7	25.3	8.60	.26	2.88	Carbonate	9.99
Mullet	Ag3	26.9	73.1	0	0	14.88	.23	3.92	Carbonate	10
W. Br. Milw.	Ag3	2.7	97.3	0	0	8.37	.27	3.89	Carbonate	10
E. Br. Milw.	Ag3	39	61	0	0	21.15	.2	2.78	Carbonate	10
N. Br. Milw. (8)	Ag3	20	78.7	0	1.3	9.36	.27	4.48	Carbonate	10
Cedar Creek	Ag3	2.7	78.9	0	.3	6.47	.29	5.7	Carbonate	8.72
Silver Creek	Ag3	5.8	94.2	0	0	3.91	.32	4.45	Carbonate	9.57
Sheboygan	Ag3	15.6	84.4	0	0	6.89	.28	5.6	Carbonate	10
N. Br. Milw.	Ag3	9.9	89	0	1.1	7.90	.28	5.68	Carbonate	10
Tisch Mills	Ag4	23	0	0	77	14.24	.25	4.71	Carbonate	10
Mill Creek	Ag15	59.6	4.5	35.8	.1	19.37	.19	4.27	Ig/Met	5
Blake Creek	Ag15	58.3	14.1	27.6	0	14.23	.2	4.33	Ig/Met	5
Plum Creek	Ag23	0	0	0	100	5.17	.29	5.21	Shale	4.89
East (ZZ)	Ag23	3.8	1	0	95.3	5.13	.29	6.12	Shale	4.17
East	Ag23	3.6	.9	0	95.4	5.24	.29	5.67	Shale	4.08
East (32)	Ag23	4.6	.8	0	94.6	5.52	.29	5.21	Shale	3.9
S. Br. Beaver	Ag24	10.4	0	86.7	2.8	14.97	.21	4.85	Sandstone	5.61
Little Peshtigo	Ag24	4.8	0	95.2	0	8.65	.25	4.53	Sandstone	6.82

Appendix 2. Description of surficial-deposit and bedrock characteristics of sites used in the Applicability Study, Western Lake Michigan Drainages—Continued

Site abbreviation[1]	RHU	Percentage of surficial deposit type in the basin				Permeability (cm/h)	Erodibility (K factor)	Gradient (m/km)	Dominant bedrock type	Relative bedrock permeability
		S and G	Sand	Loam	Clay					
Kelly Brook	Ag24	9	0	88.4	2.6	9.93	.25	3.09	Sandstone	6.08
Fox	Ag24	16.2	83.8	0	0	8.54	.26	4.61	Sandstone	6.82
Grand	Ag25	20.6	79.4	0	0	4.19	.32	3.92	Carb/Sand	7.97
Belle Fountain	Ag25	27.8	65.5	0	6.7	13.37	.21	9.86	Sandstone	6.09
Sheboygan (5)	AF5	26.2	73.8	0	0	7.43	.26	2.87	Carbonate	10
Days	AF12	0	0	93.2	0	9.81	.2	2.67	Carbonate	10
Big Brook	AF12	0	0	100	0	8.24	.21	3.37	Carbonate	10
Little Cedar	AF12	0	0	97.2	0	8.24	.21	4.01	Carbonate	9.97
M. Br. Embarrass	AF20	65.2	34.8	0	0	15.33	.16	3.98	Ig/Met	5
S. Br. Embarrass	AF20	51.4	48.6	0	0	15.43	.16	3.18	Ig/Met	5
Little Wolf	AF20	52.6	47.4	0	0	16.24	.16	4.32	Ig/Met	5
Comet	AF20	67.2	32.8	0	0	15.35	.16	3.6	Ig/Met	5
Tomorrow	AF20	50.6	49.4	0	0	16.34	.16	3.99	Ig/Met	5
Neenah	AF26	73.6	23.9	0	2.4	24.40	.16	6.19	Sandstone	6
Mecan	AF26	73.9	25.9	0	.2	26.14	.16	5.74	Sandstone	6
Chaffee	AF26	73.4	26.2	0	.4	25.41	.17	5.73	Sandstone	6
Pine (Sax.)	AF26	64.9	35.1	0	0	24.39	.16	6.34	Sandstone	6
Widow	AF27	28.2	45.4	0	26.4	18.33	.21	6.27	Sandstone	6
Big Slough	AF27	0	29.2	0	70.9	19.75	.18	7.51	Sandstone	6
Good Earth	AF27	0	40.7	0	59.3	15.81	.2	4.98	Sandstone	6
Sucker	AF28	32.9	6.9	0	60.2	20.99	.16	3.85	Sandstone	5.83
Walla Walla	AF28	36.2	5.4	0	58.4	14.13	.21	4.36	Sandstone	5.97
Alder Creek	AF28	0	0	0	100	11.36	.2	3.14	Sandstone	5.98
W. Br. White	FD6	0	0	100	0	9.01	.21	5.01	Carbonate	10
Black	FD16	0	7.5	92.5	0	9.81	.12	4.48	Ig/Met	5
E. Br. Escanaba	FD16	.4	13.5	86.2	0	8.90	.13	9.77	Ig/Met	5
Peshekee	FD16	0	0	100	0	7.99	.13	3.95	Ig/Met	5
Dishno	FD16	0	21.1	78.9	0	7.39	.13	6.48	Ig/Met	5
W. Br. Pesh.	FD16	0	0	100	0	7.99	.13	3.79	Ig/Met	5
Wausaukee	FD17	60.2	0	39.8	0	29.20	.14	6.35	Ig/Met	5
Thunder	FD17	53	6.5	40.5	0	21.88	.14	11.58	Ig/Met	5

Appendix 2. Description of surficial-deposit and bedrock characteristics of sites used in the Applicability Study, Western Lake Michigan Drainages—Continued

Site abbreviation[1]	RHU	Percentage of surficial deposit type in the basin				Permeability (cm/h)	Erodibility (K factor)	Gradient (m/km)	Dominant bedrock type	Relative bedrock permeability
		S and G	Sand	Loam	Clay					
Middle Inlet	FD17	52.9	0	47.1	0	27.33	.15	5.26	Ig/Met	5.01
Waupee	FD17	62.2	0	37.8	0	27.41	.15	6.74	Ig/Met	5
S. Br. Paint	FD18	12.5	87.5	0	0	4.66	.2	3.79	Ig/Met	5
W. Br. Net	FD18	0	94.8	5.2	0	7.52	.12	3.17	Ig/Met	5
E. Br. Net	FD18	9.7	90.3	0	0	8.11	.12	6.67	Ig/Met	5
Fence	FD18	7.6	88	0	0	7.98	.13	4.38	Ig/Met	5.02
S. Br. Oconto	FD19	66.2	33.8	0	0	16.70	.15	9.69	Ig/Met	5
Evergreen	FD19	57	43	0	0	15.21	.16	8.67	Ig/Met	5
L. W. Br. Wolf	FD19	59.8	40.2	0	0	15.38	.16	7	Ig/Met	5
N. Br. Paint	FD	16.7	83.2	0.1	0	8.03	.16	2.9	Ig/Met	5
Hunters	FW7	0	0	100	0	9.11	.19	4.34	Carbonate	10
10 Mile	FW7	98.9	0	1.1	0	10.16	.21	3.23	Carbonate	10
Cedar	FW7	0	0	82.3	0	13.63	.19	4.63	Carbonate	10
47 Mile	FW7	7.5	0	92.5	0	8.37	.21	3.84	Carbonate	10
Deer Creek	FW13	0	92.6	7.4	0	16.29	.16	2.87	Carbonate	10
Chippeny	FW14	52.3	0	47.7	0	15.60	.17	4.62	Carbonate	10
Peshtigo Br.	FW21	57.7	0	7.8	34.5	23.29	.16	3.55	Ig/Met	5
Pine	FW22	48.5	51.5	0	0	11.51	.17	2.99	Ig/Met	5
Popple (Long)	FW22	49.4	50.6	0	0	10.14	.17	4.18	Ig/Met	5
Popple	FW22	76.3	23.7	0	0	14.58	.16	3.11	Ig/Met	5
S. Br. Pesh.	FW22	40.8	59.2	0	0	14.22	.16	5.52	Ig/Met	5
Rat	FW22	94.9	5.1	0	0	16.58	.15	6.31	Ig/Met	5
Wolf	FW22	53.5	46.5	0	0	13.44	.17	3.17	Ig/Met	5
Beaver Dam	U9	0	0	0	100	2.60	.28	5.02	Carbonate	10
Lincoln	U9	.2	0	0	99.8	2.60	.33	3.22	Carbonate	10
L. Menomonee	U9	0	0	0	100	2.60	.33	3.92	Carbonate	10
Honey Creek	U9	0	0	0	100	2.60	.33	3.92	Carbonate	10
Kinnickinnic	U9	0	0	0	100	2.60	.33	4.86	Carbonate	10
Oak Creek	U9	0	0	0	100	2.83	.32	3.78	Carbonate	10
Lincoln (47)	U9	0	0	0	100	2.60	.33	3.85	Carbonate	10

[1]Full site names are listed in Appendix 1.

Appendix 3. Water-quality characteristics measured at sites in the Applicability Study, Western Lake Michigan Drainages

[RHU, Relatively Homogeneous Unit; $m^3/km^2/d$, cubic meters per kilometer squared per day; µg/L, micrograms per liter; kg/ha/yr, kilograms per hectare per year; mg/L, milligrams per liter]

Site abbreviation[1]	RHU	Streamflow ($m^3/km^2/d$)	Total phosphorus (µg/L)	Total phosphorus yield (kg/ha/yr)	Dissolved nitrite plus nitrate (µg/L)	Dissolved nitrite plus nitrate yield (kg/ha/yr)	Total Kjeldahl nitrogen (µg/L)	Total Kjeldahl nitrogen yield (kg/ha/yr)	Suspended sediment (mg/L)	Suspended sediment yield (kg/ha/yr)
Duck (S)	Ag1	0	200	0	1,400	0	1,900	0	37	0
Duck	Ag1	3	450	.43	<50	0	1,300	1.2	13	12.5
Duck (H)	Ag1	0	390	0	160	0	1,300	0	NA	0
Apple	Ag1	8	500	1.51	<50	.1	1,800	5.4	59	178.3
E. Br. Twin	Ag1	76	100	2.78	1,600	44.5	600	16.7	10	278
Neshota	Ag1	46	320	5.41	4,900	82.8	1,000	16.9	18	304.3
Devils	Ag1	70	70	1.8	240	6.2	500	12.9	9	231.3
Kewaunee	Ag1	29	630	6.68	2,000	21.2	1,000	10.6	14	148.5
Root	Ag1	76	480	13.29	7,800	215.9	1,200	33.2	135	3,737.2
Pensaukee	Ag2	17	1,200	7.41	<50	.2	1,500	9.3	NA	NA
L. Suam. (C)	Ag2	12	20	.08	350	1.5	700	2.9	9	37.8
L. Suamico	Ag2	36	200	2.61	170	2.2	700	9.1	NA	NA
Suamico	Ag2	37	70	.95	1,800	24.5	400	5.4	6	81.6
Mullet	Ag3	203	30	2.22	1,100	81.5	300	22.2	8	592.5
W. Br. Milw.	Ag3	74	120	3.23	370	10	700	18.8	6	161.4
E. Br. Milw.	Ag3	89	50	1.62	<50	.8	600	19.4	6	194.4
N. Br. Milw. (8)	Ag3	169	240	14.79	1,100	67.8	1,100	67.8	59	3,636.7
Cedar Creek	Ag3	162	110	6.49	1,700	100.4	500	29.5	9	531.4
Silver Creek	Ag3	242	320	28.24	3,800	335.4	2,000	176.5	34	3,000.9
Sheboygan	Ag3	0	390	0	<50	0	1,800	0	27	0
N. Br. Milw.	Ag3	258	290	27.33	790	74.4	1,200	113.1	81	7,632.7
Tisch Mills	Ag4	21	30	.23	2,700	20.8	300	2.3	3	23.1
Mill Creek	Ag15	152	10	.56	3,300	183.3	400	22.2	4	222.2
Blake Creek	Ag15	227	40	3.32	510	42.3	400	33.2	6	497.3
Plum Creek	Ag23	110	980	39.3	<50	1	1,500	60.2	245	9,826.1
East (ZZ)	Ag23	0	530	0	210	0	3,000	0	189	0
East	Ag23	0	1,300	0	<50	0	2,400	0	NA	0
East (32)	Ag23	0	440	0	<50	0	700	0	116	0
S. Br. Beaver	Ag24	419	40	6.11	700	107	400	61.1	8	1,222.4
Little Peshtigo	Ag24	95	120	4.18	970	33.8	700	24.4	3	104.6

Appendix 3. Water-quality characteristics measured at sites in the Applicability Study, Western Lake Michigan Drainages—Continued

[RHU, Relatively Homogeneous Unit; $m^3/km^2/d$, cubic meters per kilometer squared per day; µg/L, micrograms per liter; kg/ha/yr, kilograms per hectare per year; mg/L, milligrams per liter]

Site abbreviation[1]	RHU	Streamflow ($m^3/km^2/d$)	Total phosphorus (µg/L)	Total phosphorus yield (kg/ha/yr)	Dissolved nitrite plus nitrate (µg/L)	Dissolved nitrite plus nitrate yield (kg/ha/yr)	Total Kjeldahl nitrogen (µg/L)	Total Kjeldahl nitrogen yield (kg/ha/yr)	Suspended sediment (mg/L)	Suspended sediment yield (kg/ha/yr)
Kelly Brook	Ag24	92	40	1.34	770	25.8	700	23.5	10	335
Fox	Ag24	149	100	5.44	3,100	168.6	700	38.1	12	652.5
Grand	Ag25	173	120	7.6	4,100	259.6	500	31.7	10	633.3
Belle Fountain	Ag25	302	50	5.51	2,800	308.8	400	44.1	14	1,544
Sheboygan (5)	AF5	0	200	0	580	0	1,900	0	36	0
Days	AF12	9	<10	.02	<50	.1	900	3	6	20.2
Big Brook	AF12	0	20	0	850	0	800	0	5	0
Little Cedar	AF12	19	<10	.03	<50	.2	700	4.8	3	20.5
M. Br. Embarrass	AF20	518	20	3.78	370	70	500	94.6	10	1,892.3
S. Br. Embarrass	AF20	257	40	3.76	1,800	169.1	400	37.6	8	751.3
Little Wolf	AF20	122	40	1.77	3,200	141.9	400	17.7	6	266.2
Comet	AF20	333	10	1.22	1,400	170.3	400	48.6	102	12,404.6
Tomorrow	AF20	376	10	1.37	2,500	342.8	200	27.4	17	2,331.3
Neenah	AF26	1,320	20	9.64	740	356.6	300	144.6	21	10,119.4
Mecan	AF26	1,231	30	13.48	1,700	764	200	89.9	9	4,044.5
Chaffee	AF26	734	20	5.36	1,800	482.5	200	53.6	15	4,021.2
Pine (Sax.)	AF26	819	20	5.98	1,300	388.7	200	59.8	7	2,093
Widow	AF27	442	50	8.06	860	138.6	400	64.5	24	3,868.2
Big Slough	AF27	14	30	.15	960.	4.9	800	4.1	NA	NA
Good Earth	AF27	287	100	10.46	2,000	209.2	600	62.8	8	836.8
Sucker	AF28	19	30	.21	50	.4	600	4.3	2	14.2
Walla Walla	AF28	382	20	2.79	820	114.5	300	41.9	9	1,256.3
Alder Creek	AF28	69	100	2.53	770	19.5	900	22.8	49	1,239.1
W. Br. White	FD6	221	10	.81	<50	2	300	24.2	3	242
Black	FD16	11	70	.28	<50	.1	1,500	6	169	673
E. Br. Escanaba	FD16	0	20	0	<50	0	500	0	42	0
Peshekee	FD16	406	<10	.74	<50	3.7	400	59.4	2	296.8
Dishno	FD16	16	<10	.03	110	.6	400	2.4	NA	NA
W. Br. Pesh.	FD16	376	<10	.69	<50	3.4	500	68.5	1	137.1
Wausaukee	FD17	220	<10	.4	220	17.7	200	16.1	3	241.4
Thunder	FD17	104	<10	.19	<50	1	400	15.2	4	152.1

Appendix 3. Water-quality characteristics measured at sites in the Applicability Study, Western Lake Michigan Drainages—Continued

[RHU, Relatively Homogeneous Unit; $m^3/km^2/d$, cubic meters per kilometer squared per day; µg/L, micrograms per liter; kg/ha/yr, kilograms per hectare per year; mg/L, milligrams per liter]

Site abbreviation[1]	RHU	Streamflow ($m^3/km^2/d$)	Total phosphorus (µg/L)	Total phosphorus yield (kg/ha/yr)	Dissolved nitrite plus nitrate (µg/L)	Dissolved nitrite plus nitrate yield (kg/ha/yr)	Total Kjeldahl nitrogen (µg/L)	Total Kjeldahl nitrogen yield (kg/ha/yr)	Suspended sediment (mg/L)	Suspended sediment yield (kg/ha/yr)
Middle Inlet	FD17	513	<10	.94	110	20.6	<200	18.7	5	936.6
Waupee	FD17	344	<10	.63	100	12.5	300	37.6	3	376.4
S. Br. Paint	FD18	636	30	6.97	<50	5.8	300	69.7	7	1,625.2
W. Br. Net	FD18	160	20	1.17	<50	1.5	700	40.8	10	582.7
E. Br. Net	FD18	347	<10	.63	<50	3.2	<200	12.7	2	253.3
Fence	FD18	976	40	14.25	50	17.8	300	106.9	6	2,137.5
S. Br. Oconto	FD19	572	20	4.18	350	73.1	300	62.7	15	3,134.4
Evergreen	FD19	702	40	10.25	600	153.7	700	179.3	29	7,428.3
L. W. Br. Wolf	FD19	675	40	9.86	840	207.1	700	172.6	24	5,916
N. Br. Paint	FD	643	20	4.69	<50	5.9	300	70.4	5	1,172.8
Hunters	FW7	126	<10	.23	50	2.3	500	23	4	183.7
10 Mile	FW7	41	<10	.07	<50	.4	600	9	2	30
Cedar	FW7	132	<10	.24	<50	1.2	500	24	2	96.1
47 Mile	FW7	61	<10	.11	160	3.6	500	11.1	11	244.3
Deer Creek	FW13	0	<10	0	<50	0	600	0	72	0
Chippeny	FW14	33	<10	.06	<50	.3	600	7.2	3	36.1
Peshtigo Br.	FW21	87	460	14.69	70	2.2	700	22.3	8	255.4
Pine	FW22	318	10	1.16	<50	2.9	400	46.4	3	348.1
Popple (Long)	FW22	148	10	.54	<50	1.3	500	27	3	161.8
Popple	FW22	263	30	2.88	<50	2.4	500	48	8	768.8
S. Br. Pesh.	FW22	572	20	4.18	<50	5.2	600	125.3	3	626.7
Rat	FW22	291	30	3.18	120	12.7	400	42.4	5	530.6
Wolf	FW22	297	10	1.08	<50	2.7	600	65	8	866.7
Beaver Dam	U9	0	200	0	<50	0	1,100	0	15	0
Lincoln	U9	394	20	2.88	400	57.5	300	43.1	3	431.4
L. Menomonee	U9	63	150	3.43	440	10.1	700	16	20	457.2
Honey Creek	U9	188	20	1.38	130	8.9	200	13.8	7	481.6
Kinnickinnic	U9	109	40	1.59	400	15.9	300	11.9	2	79.3
Oak Creek	U9	79	50	1.45	450	13.1	400	11.6	5	145
Lincoln (47)	U9	309	50	5.64	270	30.5	500	56.4	10	1,128

[1]Full site names are listed in Appendix 1.