In cooperation with the Wisconsin Department of Natural Resources

Nutrient Concentrations and Their Relations to the Biotic Integrity of Wadeable Streams in Wisconsin

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

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By Dale M. Robertson, David J. Graczyk, Paul J. Garrison, Lizhu Wang,
Gina LaLiberte, and Roger Bannerman

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Conversion Factors

Multiply	By	To obtain
	Length	
micrometer (µm)	0.00003927	inch (in.)
millimeter (mm)	0.03937	inch (in.)
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square meter (m^2)	0.0002471	acre
square centimeter (cm^2)	0.001076	square foot (ft^2)
square meter (m^2)	10.76	square foot (ft^2)
square centimeter (cm^2)	0.1550	square inch (in^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
liter (L)	0.2642	gallon (gal)
cubic centimeter (cm^3)	0.06102	cubic inch (in^3)
cubic meter (m^3)	35.31	cubic foot (ft^3)
	Flow rate	
cubic meter per second (m^3/s)	70.07	acre-foot per day (acre-ft/d)
cubic meter per second per square kilometer [(m^3/s)/km^2]	91.49	cubic foot per second per square mile [(ft^3/s)/mi^2]
meter per second (m/s)	3.281	feet per second (ft/s)
millimeter per hour (mm/hr)	0.03937	inch per hour (in/hr)
millimeter per year (mm/yr)	0.03937	inch per year (in/yr)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound, avoirdupois (lb)
kilogram per square kilometer (kg/km^2)	5.70992	pound per square mile (lb/mi^2)
milligram (mg)	0.00003527	ounce, avoirdupois (oz)
milligram per square meter (mg/m^2)	0.000003277	ounce, avoirdupois, per square foot (oz/ft^2)
	Hydraulic gradient	
meter per kilometer (m/km)	5.27983	foot per mile (ft/mi)

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

°F=(1.8×°C)+32

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Abbreviations

Ag	Agricultural land
BCHL	Benthic chlorophyll *a*
BIN	Biotic Index of total Nitrogen
BIP	Biotic Index of total Phosphorus
CARN%	Percentage of fish that are top carnivores
DBI	Diatom Biotic Index
DEM	Digital Elevation Model
DFA	Driftless Area level III ecoregion
DNI	Diatom Nutrient Index
DP	Dissolved phosphorus
DSI	Diatom Siltation Index
EPT	Ephemeroptera, Plecoptera, or Trichoptera
EPTN%	Percentage of macroinvertebrate individuals that were EPT
EPTTX%	Percentage of macroinvertebrate taxa that were EPT
EPZ	Environmental phosphorus zone
EV	Explained Variance
FISHN	Number of fish caught
FISHSPEC	Number of fish species caught
GIS	Geographic Information System
HBI	Hilsenhoff Biotic Index
High Sites	Sites with nutrient concentration above the upper 95-percent confidence limits for reference nutrient concentrations
IBI	Fish Index of Biotic Integrity
INSECT%	Percentage of fish that are insectivores
INTOL%	Percentage of fish that are pollution intolerant
Log	Logarithmic transformation to base 10
n	number
N	Nitrogen
NCHF	North Central Hardwood Forest level III ecoregion
NLF	Northern Lakes and Forests level III ecoregion
NH_4-N	Dissolved ammonia
NO_3-N	Dissolved nitrite plus nitrate
NWIS	National Water Information System
OEPA	Ohio Environmental Protection Agency
OMNI%	Percentage of fish that are omnivorous
p	Probability
P	Phosphorus
PtS	Point-source loadings of phosphorus
r	Pearson correlation coefficient
r_s	Spearman correlation coefficient
R^2	Coefficient of determination
Ref Sites	Sites with nutrient concentration below median reference concentrations
Res	Residualized
RDA	Redundancy analysis
SCHL	Suspended chlorophyll *a*

SCRAP%	Percentage of macroinvertebrates that are scrapers
SD	Secchi tube depth
SHRED%	Percentage of macroinvertebrates that are shredders
SPARTA	Spatial regression-tree analysis
SWTP	Southeastern Wisconsin Till Plains level III ecoregion
t	tolerance-index value
TAXAN	Number of macoinvertebrate taxa
TKN	Total Kjeldahl nitrogen
TOL%	Percentage of fish that are pollution tolerant
Urb	Urban land
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WDNR	Wisconsin Department of Natural Resources
<	Less than
%	Percentage of
#	Number

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Nutrient Concentrations and Their Relations to the Biotic Integrity of Wadeable Streams in Wisconsin

Dale M. Robertson[1], David J. Graczyk[1], Paul J. Garrison[2], Lizhu Wang[3], Gina LaLiberte[2], and Roger Bannerman[4]

Abstract

Excessive nutrient (phosphorus and nitrogen) loss from watersheds is frequently associated with degraded water quality in streams. To reduce this loss, agricultural performance standards and regulations for croplands and livestock operations are being proposed by various States. In addition, the U.S. Environmental Protection Agency is establishing regionally based nutrient criteria that can be refined by each State to determine whether actions are needed to improve a stream's water quality. More confidence in the environmental benefits of the proposed performance standards and nutrient criteria will be possible with a better understanding of the biotic responses to a range of nutrient concentrations in different environmental settings.

The U.S. Geological Survey and the Wisconsin Department of Natural Resources collected data from 240 wadeable streams throughout Wisconsin to: 1) describe how nutrient concentrations and biotic-community structure vary throughout the State; 2) determine which environmental characteristics are most strongly related to the distribution of nutrient concentrations; 3) determine reference water-quality and biotic conditions for different areas of the State; 4) determine how the biotic community of streams in different areas of the State respond to changes in nutrient concentrations; 5) determine the best regionalization scheme to describe the patterns in reference conditions and the responses in water quality and the biotic community; and 6) develop new indices to estimate nutrient concentrations in streams from a combination of biotic indices. The ultimate goal of this study is to provide the information needed to guide the development of regionally based nutrient criteria for Wisconsin streams.

For total nitrogen (N) and suspended chlorophyll (SCHL) concentrations and water clarity, regional variability in reference conditions and in the responses in water quality to changes in land use are best described by subdividing wadeable streams into two categories: streams in areas with high clay-content soils (Environmental Phosphorus Zone 3, EPZ 3) and streams throughout the rest of the State. The regional variability in the response in total phosphorus (P) concentrations is also best described by subdividing the streams into these two categories; however, little consistent variability was found in reference P concentrations in streams throughout the State.

Reference P concentrations are similar throughout the State (0.03–0.04 mg/L). Reference N concentrations are divided into two categories: 0.6–0.7 mg/L in all streams except those in areas with high clay-content soils, where 0.4 mg/L is more appropriate. Reference SCHL concentrations are divided into two categories: 1.2–1.7 µg/L in all streams except those in areas with high clay-content soils, where 1.0 µg/L may be more appropriate. Reference water clarity is divided into two categories: streams in areas with high clay-content soils with a lower reference water clarity (Secchi tube depth, SD, of about 110 cm) and streams throughout the rest of the State (SD greater than or equal to about 115 cm). For each category of the biotic community (SCHL and benthic chlorophyll *a* concentrations (BCHL), periphytic diatoms, macroinvertebrates, and fish), a few biotic indices were more related to differences in nutrient concentrations than were others. For each of the indices more strongly related to nutrient concentrations, reference conditions were obtained by determining values corresponding to the worst 75th percentile value from a subset of minimally impacted streams (streams having reference nutrient concentrations).

By examining the biotic community in streams having either reference P or N concentrations but not both, the relative importance of these two nutrients was determined. For SCHL, P was the more important limiting nutrient;

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[1] U.S. Geological Survey, Wisconsin Water Science Center, Middleton, Wisconsin

[2] Wisconsin Department of Natural Resources, Monona, Wisconsin

[3] Michigan Department of Natural Resources, Ann Arbor, Michigan

[4] Wisconsin Department of Natural Resources, Madison, Wisconsin

however, for BCHL and all macroinvertebrate indices, it appears that N was the more important nutrient when concentrations were near reference concentrations. For other diatom indices and all fish indices, small additions of P or N appear to have little effect on these communities when nutrient concentrations are near reference conditions.

Concentrations of P and N in streams increase as the percentage of agricultural land increases. Concentrations of P increase more quickly and concentrations of N increase more slowly in response to increasing percentages of agriculture in areas with high clay-content soils than do streams in the rest of the State. The response in water clarity is similar in streams throughout the State; however, the streams in areas with high clay-content soils have poorer reference water clarity, and, therefore, as the percentage of agriculture increases, their clarity remains lower than in streams in areas with other soil types.

As nutrient concentrations increase, many biotic indices change. This result indicates that these nutrients have direct or indirect effects on the composition of the biotic community. Thresholds were identified at which a small change in nutrient concentrations results in a relatively large change in the biotic communities. The thresholds in the response to changes in P concentrations range from about 0.04 mg/L for BCHL, to 0.06–0.07 mg/L for diatom and fish indices, to about 0.09 mg/L for macroinvertebrate indices. The thresholds in the response to changes in N concentrations range from 0.5 mg/L for the fish indices and one macroinvertebrate index to about 0.9–1.2 mg/L for the diatom and other macroinvertebrate indices. Most of the biotic indices had a wedge-shaped response to increases in nutrient concentrations. At relatively low nutrient concentrations, the biotic indices ranged widely, but at relatively high concentrations, the indices generally were poor. The wedge-shaped distribution indicates that at low nutrient concentrations, factors other than nutrients often limit the health of biotic communities, whereas, at high nutrient concentrations, nutrients and factors correlated with high nutrient concentrations are the predominant factors.

The biotic communities that are present in a stream reflect the overall ecological integrity; therefore, they integrate the effects of many different stressors and thus provide a broad measure of their aggregate effect. Nutrient concentrations by themselves explained from about 6 to 13 percent of the total variance in the components of the biotic communities or from about 14 to 23 percent of the explained variance. Nutrient concentrations were most important in affecting SCHL concentrations and macroinvertebrate communities, and least important in affecting BCHL, periphytic diatoms, and fish-community structure. For each component of the biotic community, nutrients by themselves only explained a small part of the overall variance; about half of the variance could not be explained by the variables examined in this study and about one-third of the explained variance could not be assigned to single categories of environmental characteristics.

By use of a combination of four biotic indices, two new multiparameter indices (Biotic Index of total Phosphorus, BIP, and Biotic Index of total Nitrogen, BIN) were developed to estimate P and N concentrations in streams from biotic data collected in streams. These multiparameter models estimated high and low nutrient concentrations equally well. The BIP predicted P concentrations better than the BIN predicted N concentrations. The difference in the accuracy of these indices was consistent with biotic indices being more correlated with P concentrations than with N concentrations. This result suggests that P is more important than N in affecting most biotic communities as nutrient concentrations increase above reference concentrations.

Although specific mechanisms of how nutrients affect the biota in wadeable streams were not examined in this study, the results indicate that nutrients are important in controlling the biotic health of streams. Although the biotic-community structure represents the overall ecological integrity of the stream, nutrients alone explained only a small part of the variance in the biotic community. Therefore, it is difficult to predict the exact result of reducing nutrient concentrations without also modifying the factors typically associated with high nutrient concentrations. Nutrient concentrations in many streams, especially those in agricultural areas, are well above the concentrations where thresholds in the response were found to occur; therefore, small reductions in nutrient concentrations in these streams are not expected to have large effects on the biotic community. Even with these limitations, however, it is expected that reducing nutrient concentrations will improve the biotic community, further the beneficial ecological functioning of most streams, and improve the quality of downstream nutrient-limited receiving waters.

Introduction

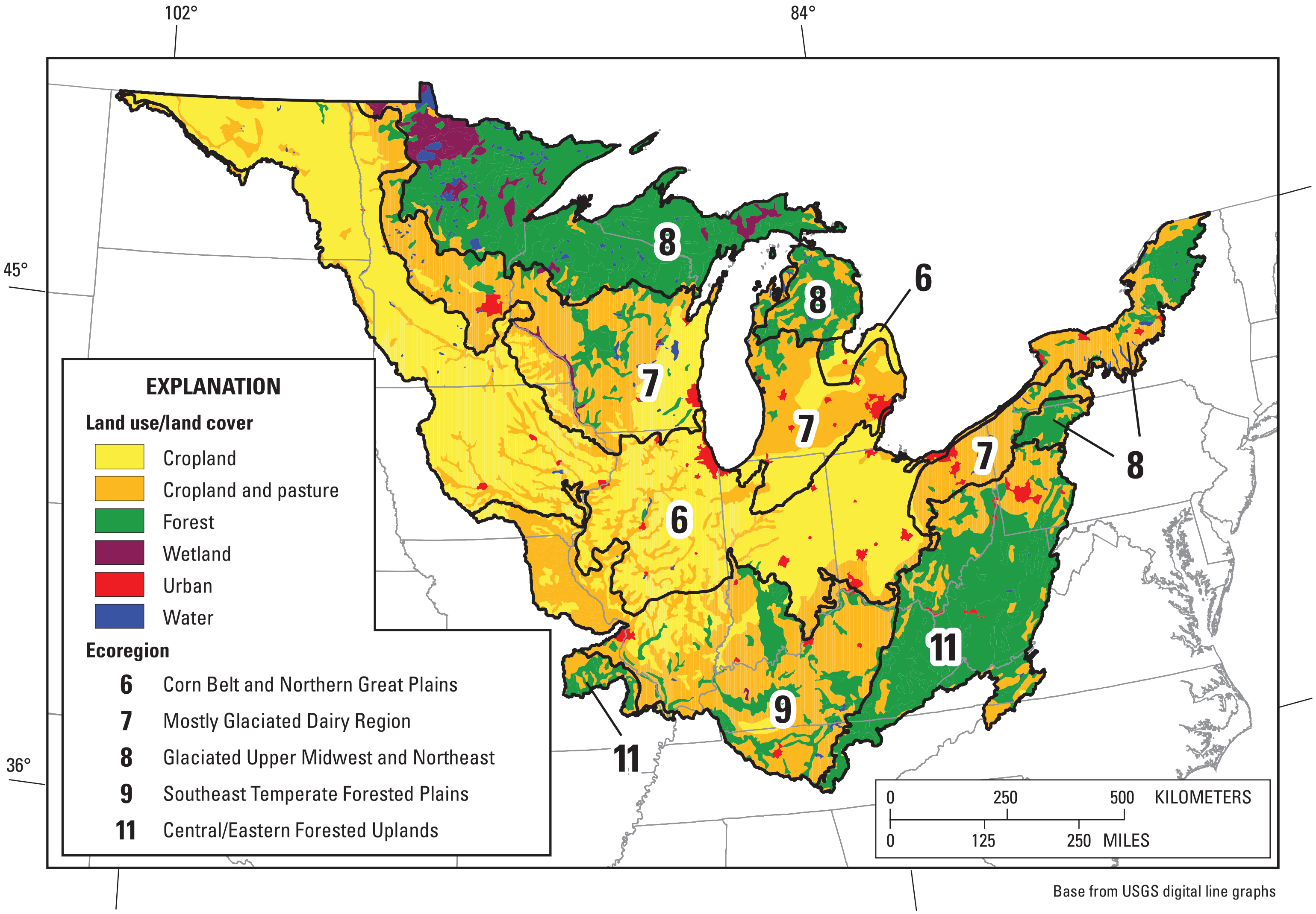
Elevated nutrient concentrations above background conditions are one of the most common stressors (contaminants) affecting streams throughout the United States.

Problems associated with elevated nutrient concentrations in surface water are not new, but they are among the most persistent. According to the National Water Quality Inventory: 1996 Report to Congress by the U.S. Environmental Protection Agency (USEPA), 50 States, Tribes, and other jurisdictions surveyed water-quality conditions in 19 percent of the Nation's 3.6 million miles of rivers and streams and found overenrichment of nutrients to be the second most common reason for impairment following the combined effects of suspended sediment and siltation (U.S. Environmental Protection Agency, 1996). Excessive nutrients in rivers and streams can result in the overgrowth of benthic algae in shallow areas and in areas with fast current and an overabundance of phytoplankton and macrophytes in deep areas with slow current. High algal and macrophyte biomass can cause severe diurnal fluctuations in dissolved oxygen and pH because of biotic production and respiration, and can generate harmful organic materials when part of the population dies (Welch and others, 1992). These conditions can lead to an increase in the availability of toxic substances, reduction in available aquatic habitat, modifications to the composition of the biotic communities, and a decrease in the overall usefulness of the stream (Miltner and Rankin, 1998; Dodds and Welch, 2000). Excessive transport of nutrients has also been linked to eutrophication of downstream lakes and impoundments, outbreaks of *Pfiesteria* in bays and estuaries in various Gulf and Mid-Atlantic States, and hypoxia in the Gulf of Mexico (U.S. Environmental Protection Agency, 2000a).

Under recommendations of the Clean Water Action Plan released in 1998, the USEPA has developed a National strategy to develop waterbody-specific nutrient criteria for lakes and reservoirs, rivers and streams, wetlands, and estuaries (U.S. Environmental Protection Agency, 1998); this study is concerned with those for rivers and streams. The intent of this strategy is to get all States and tribes to establish nutrient standards, that, if enforced, will reduce nutrient concentrations and improve the beneficial ecological uses of surface waters. The best way to control nutrient concentrations is to reduce that part contributed by humans, not that part contributed naturally. It has been recognized that various environmental characteristics, such as land use, geology, soils, climate, and hydrology (including human modifications and hydrologic structures) are important in determining water quality (Monteith and Sonzogni, 1981; Clesceri and others, 1986; and Robertson, 1997). Because these characteristics vary greatly across the United States, the establishment of regional nutrient criteria makes scientific sense.

Various frameworks have been used to divide large areas into smaller areas of relatively similar environmental characteristics to minimize the natural variation in water quality within the areas and maximize the differences among the areas. One such framework is the ecoregion delineation developed and refined by Omernik (1987; 1995) and Omernik and others (2000). Ecoregions are a mapped-classification system of regions with assumed relative homogeneity in ecological characteristics. These regions were said to be defined on the basis of relative differences in a suite of environmental characteristics, such as land use/land cover, land-surface form, geology, physiography, climate, soils, potential natural vegetation, and other environmental characteristics (Omernik, 1987 and 1995). The USEPA has taken the initial step in developing regional nutrient criteria based on combining Omernik's 84 level III ecoregions into 14 national nutrient ecoregions for the conterminous United States (U.S. Environmental Protection Agency, 1998; fig. 1). On a subregional basis, such as a specific State, each of these 14 nutrient ecoregions can be further subdivided into the original level III ecoregions. Wisconsin is subdivided into two national nutrient ecoregions (ecoregions 7 and 8; fig. 1), which are further subdivided into four primary level III ecoregions: Northern Lakes and Forests (NLF), North Central Hardwood Forests (NCHF), Southeastern Wisconsin Till Plains (SWTP), and the Driftless Area (DFA)(Omernik and others, 2000; fig. 2A). In addition, there are small pieces of the Western Cornbelt Plains and the Central Cornbelt Plains ecoregions. Because the Cornbelt Plains ecoregions represent only a small part of the State, they will not be discussed in this report. The nutrient ecoregions provide an initial classification scheme for developing nutrient criteria; however, the USEPA expects individual States and tribes to evaluate and possibly develop alternative regionalization schemes (U.S. Environmental Protection Agency, 2000b).

The nutrient ecoregions proposed by the U.S. Environmental Protection Agency (1998) may define spatial patterns in water quality; however, this regionalization scheme has some inherent problems. Although the boundaries between ecoregions are supposed to represent the differences in a suite of related environmental characteristics (Omernik, 1995), specific boundary lines are often based on differences in a single environmental characteristic and that characteristic may not be the primary one affecting a specific water-quality characteristic. Therefore, greater variations in water quality may occur within an ecoregion than among ecoregions. Second, in defining most



Base from USGS digital line graphs

Figure 1. National nutrient ecoregions (U.S. Environmental Protection Agency, 1998) and major land uses in the upper Midwest (U.S. Geological Survey, 2000 and 2004).

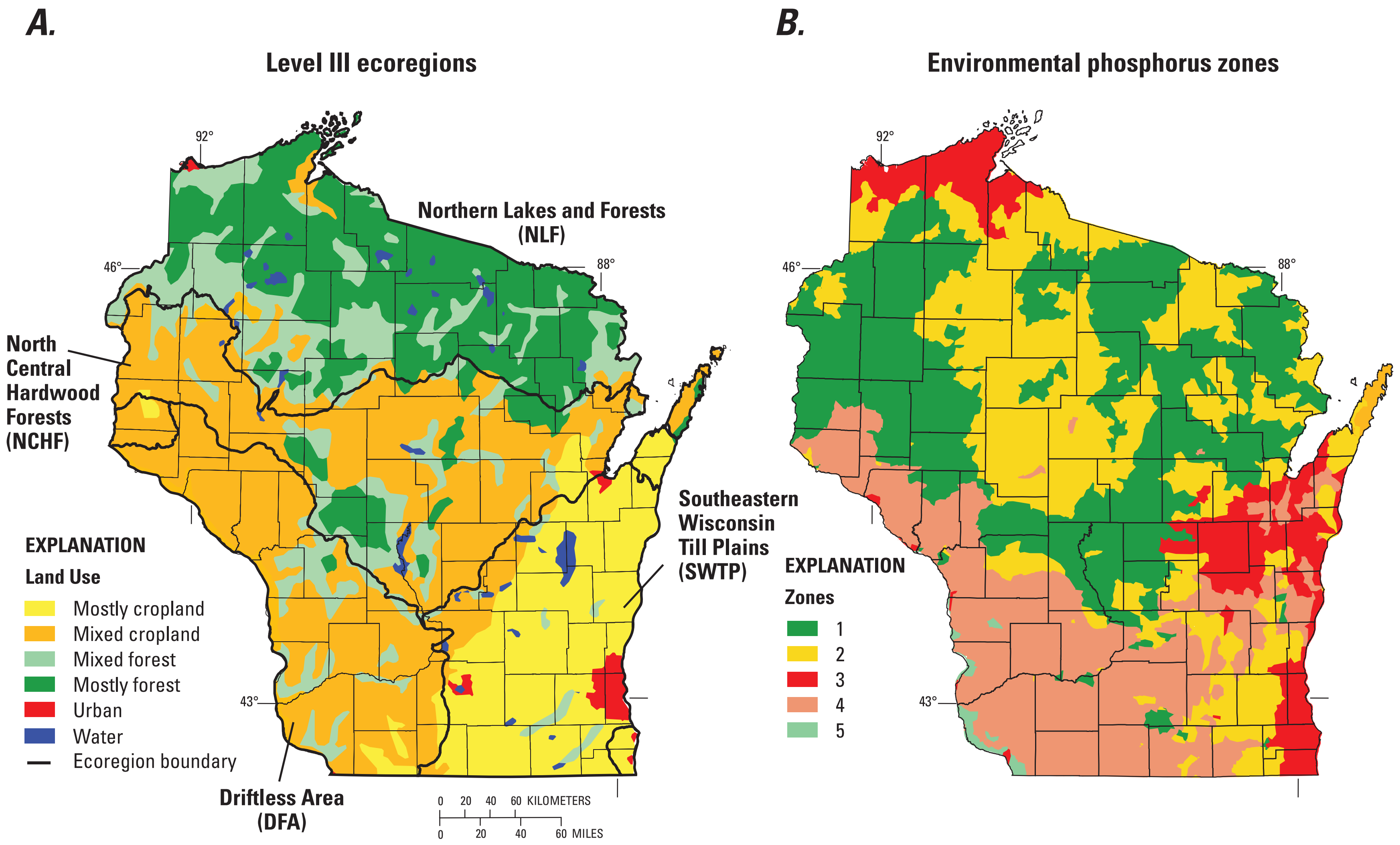


Figure 2. Two regionalization schemes considered for wadeable streams in Wisconsin: ***A***, level III ecoregions (Omernik and others, 2000) with major land-use/land-cover categories (Lillesand and others, 1998) and ***B***, environmental phosphorus zones (Robertson and others, 2006; described on page 6).

ecoregions, the relative importance of each environmental characteristic is often unknown and can vary from one area of the country to another in an unknown way. Therefore, the differences in water quality among ecoregions can be difficult to attribute to any specific environmental characteristic. Finally, for many applications, such as establishing reference conditions for nutrient criteria, the environmental characteristics used to delineate regions of similar water quality should be restricted, as much as possible, to characteristics that are intrinsic, or natural, and are not the result of human activities (U.S. Environmental Protection Agency, 2000a). Here, "reference" water quality refers to background concentrations or the potential water quality that could be achieved in the absence of human activities. By comparing the lines delineating the ecoregions with the land-use patterns in figure 1, it is apparent, however, that land use was the most important characteristic in defining the ecoregions in the upper Midwest. Although the ecoregion delineation is supposed to represent differences in a full suite of environmental characteristics, nutrient ecoregions primarily subdivide the upper Midwest (and Wisconsin) into areas of forest, cropland and pasture, and cropland.

To overcome the problems just described with the USEPA's nutrient ecoregions, SPARTA (SPAtial Regression-Tree Analysis) was developed to define characteristic-specific zones with similar reference water quality for the upper Midwest (Robertson and Saad, 2003) and refined to remove both the direct and indirect effects of land use (Robertson and others, 2006). There are two steps in the SPARTA process to delineate water-quality zones. The first step is to use regression-tree analysis (Breiman and others, 1984) to describe the relations between a single dependent variable (for example, phosphorus (P) concentrations) and various independent variables (for example, clay content of the soil and basin slope) thought to affect the distribution of the dependent variable. The second step of SPARTA is to use the regression-tree results (specific characteristics and breakpoints) to divide the entire study area into zones representing each of the final branches of the analysis.

To refine the SPARTA approach, land-use-adjusted (residualized) water-quality and environmental characteristics were computed and used to remove the direct and indirect effects of land use from the data for each site. Although SPARTA can be applied with only intrinsic or natural characteristics to remove the direct effects of land use as done by Robertson and Saad (2003), these natural characteristics themselves may be strongly correlated with land use. Thus, even if natural characteristics are the only factors included in the analysis, land use can be indirectly incorporated into the results. SPARTA was applied to the land-use-adjusted nutrient data and land-use-adjusted environmental-characteristic data for sites throughout the upper Midwest to develop environmental water-quality zones (Robertson and others, 2006). Because the biota in streams were assumed to be more influenced by P than by total nitrogen (N) concentrations, environmental P zones (EPZs) were examined as an alternative regionalization scheme for the wadeable streams of Wisconsin (fig. 3). The upper Midwest is divided into five EPZs based primarily on the clay content of the soil and secondarily on the slope of the terrain. Wisconsin consists of four major EPZs and one minor EPZ (fig. 2B). Streams in EPZ 1 have basins with the lowest clay content, streams in EPZ 2 have soils with moderate clay content and low-gradient terrain, streams in EPZ 3 have basins with high clay content and low-gradient terrain, and streams in EPZ 4 have basins with moderate clay content and steep terrain. Only a small part of EPZ 5 (basins with high clay content, steep terrain, and high soil erodibility) is in Wisconsin and, therefore, is not examined in detail in this study. Each of these zones contain streams with relatively similar reference P concentrations and with P concentrations that should respond similarly to changes in land use.

After relatively homogenous geographic areas are chosen, several approaches have been used to define quantitative nutrient criteria. The approach suggested by the USEPA to define possible criteria is based on the reference or potential water quality of each area. In other words, the criteria should be based on the conditions that are attainable in the geographic location of each stream (U.S. Environmental Protection Agency, 2000a). Reference concentrations for P, N, suspended chlorophyll *a* (SCHL, also referred to as sestonic chlorophyll), and turbidity have been defined from the frequency distribution of all available data (from USEPA's Storage and Retrieval, STORET, database) for each area. It has been suggested that the lower 25th percentile of all concentration data for an area may represent this reference condition (U.S. Environmental Protection Agency, 2000b). In other words, 25 percent of all the sites have water quality at least as good as this reference condition. It has also been suggested that the upper (highest or worst) 75th percentile of the concentration data for a subset of streams thought to be minimally impacted for a defined area may represent this reference condition. In other words, 75 percent of the minimally impacted sites have water quality at least as good as this reference condition. The final criterion should be between

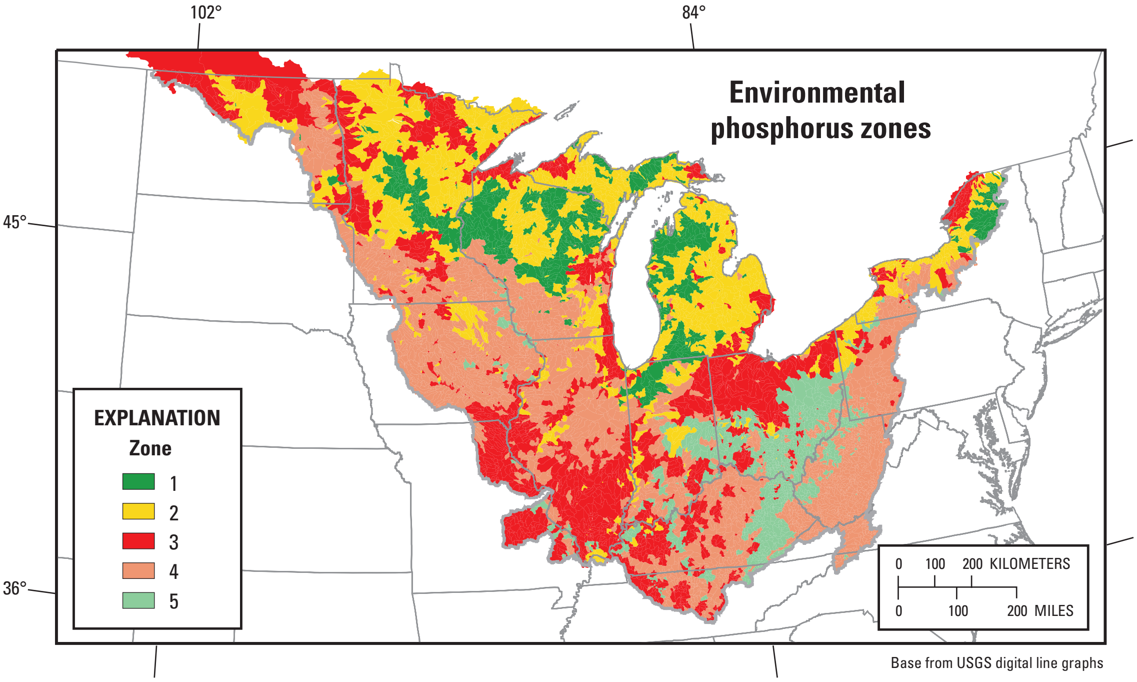


Figure 3. Environmental phosphorus zones (EPZs) in the upper Midwest from Robertson and others (2006).

these two concentrations. Another approach to estimate reference concentrations for each relatively homogeneous area is to develop a multiple linear-regression model that relates water quality to various anthropogenic factors or characteristics such as the percentages of agriculture and urban area in the watershed (Dodds and Oakes, 2004). With this approach, the estimated concentration of a constituent occurring in the absence of human activities (in other words, with 0-percent agricultural and 0-percent urban areas) represents the reference concentration. These relations or equations can also be used to place confidence intervals on the reference concentrations.

An alternative approach to defining the nutrient criteria is based on thresholds in the response between nutrient concentrations and biotic indices such as algal productivity (chlorophyll *a* concentration), water clarity, or diatom or fish biotic indices (U.S. Environmental Protection Agency, 2000a). The biotic community that is present in a stream, however, reflects more than just the nutrient concentrations that are or were present in the stream. The biotic community represents the overall ecological integrity of the stream (in other words, physical, chemical, and biological integrity), and thus provides a broad measure of the aggregate effect of all stressors (Barbour and others, 1999). Biotic communities are controlled by many physical, chemical, and biological factors, though they may be directly affected by only a subset of variables. Watershed characteristics (such as geomorphology, geochemistry, and land use/land cover) control the physical/chemical habitat of the stream where the biota live (Frissell and others, 1986; Poff, 1997). Nutrients have been shown to directly affect the productivity and species composition of primary producers, such as macrophytes and benthic and suspended algae, and indirectly affect the primary and secondary consumers in controlled nutrient-enrichment experiments (for example, Mundie and others, 1991; Peterson and others, 1993; Perrin and Richardson, 1997); however, only limited studies have shown observational linkages between nutrients and the health of the biotic communities in natural streams. Among the limited studies in natural environments, Miltner and Rankin (1998) reported that macroinvertebrate- and fish-community indices were negatively correlated with N and P concentrations in wadeable streams in Ohio. Zorn (2003) reported that P was one of the important variables for predicting the presence or absence of specific fish species in Michigan streams. Heiskary and Markus (2003) also reported significant negative correlations between macroinvertebrate- and fish-community characteristics and P and N concentrations in nonwadeable rivers in Minnesota.

If relations between nutrient concentrations and biotic integrity are used to define criteria, the final nutrient criteria should be chosen to minimize degradation in the biotic integrity of the streams. In other words, the criteria should be the concentrations that would not result in high algal concentrations or degradation of other biotic indices. One of the difficulties in defining nutrient criteria is determining the chlorophyll *a* concentration or other biotic index values for which a stream is considered degraded or impaired. The assumption made with this biotic-response approach is that each of the subregions in a regional framework also delineates an area with streams whose biotic indices respond in a similar manner to changes in nutrients. Whichever approach is used, the final criteria must be stringent enough to protect the specific site and cause no adverse effects in downstream waters.

Reference nutrient concentrations, the responses in nutrient concentrations to changes in land use, and the biotic responses to changes in nutrients may differ in streams throughout Wisconsin. There would be more confidence in the potential environmental benefits of enforcing nutrient criteria and standards for the State, if the criteria and standards were based on the most appropriate regionalization scheme (such as nutrient ecoregions or EPZs), and if the criteria and standards were based on the appropriate regionally defined thresholds to biotic response. Defined nutrient criteria and thresholds for responsive biotic indices would enable the use of monitoring data to identify streams affected by excessive nutrients and to direct rehabilitation efforts.

The two regionalization schemes being considered for the establishment of nutrient criteria for Wisconsin, level III ecoregions and EPZs, are shown in figure 2. The USEPA developed the preliminary criteria based on median concentrations of all the data measured at each site rather than mean concentrations, because a median value represents the concentration most frequently occurring in the stream, and a statistical summary based on median values reduces the effects of outliers and values reported as less than their respective detection limits. The USEPA has provided preliminary criteria for P, N, SCHL, and turbidity for the national nutrient ecoregions and most level III ecoregions (table 1). The proposed criteria by the USEPA for P, based on the 25th-percentile approach, are 0.033 mg/L for national nutrient ecoregion 7 and 0.010 mg/L for national nutrient ecoregion 8 (same as the NLF ecoregion). The USEPA has refined the P criteria for level III ecoregions in national nutrient ecoregion 7: 0.029 mg/L for NCHF, 0.070 mg/L for DFA, and 0.080 for SWTP (U.S. Environmental Protection Agency, 2000b and 2001).

Robertson and others (2006) estimated median reference P concentrations for the two major national ecoregions and four major EPZs in Wisconsin (fig. 2) by use of the multiple linear-regression approach (previously described). They found that median reference P concentrations for the two national nutrient ecoregions were similar, approximately 0.015–0.016 mg/L. They also found that the four major EPZs could be combined into two zones based on estimated reference P concentrations of 0.012 mg/L for EPZ 1 and approximately 0.021–0.023 mg/L for EPZ 2, EPZ 3, and EPZ 4, and the four major EPZs could be combined into three zones based on the response of P concentrations to changes in land use: EPZ 1 was least responsive, EPZ 2 and EPZ 4 were moderately responsive, and EPZ 3 was most responsive. Streams in EPZ 3, with the highest clay content, had high reference P concentrations (similar to EPZs 2 and 4), but were the most responsive to changes in land use.

Purpose and Scope

In 2001, the U.S. Geological Survey (USGS) and the Wisconsin Department of Natural Resources (WDNR), began a collaborative study to: 1) describe how the nutrient concentrations and biotic-community structure in streams differ throughout Wisconsin; 2) determine which environmental characteristics of watersheds are most strongly related to the distribution of nutrient concentrations in streams; 3) determine reference water-quality and biotic conditions for different areas of the State; 4) determine how the biotic community of streams in different areas of the State respond to changes in nutrient concentrations; 5) evaluate existing regionalization schemes in terms of describing patterns in reference water-quality conditions and patterns in biotic response to changes in nutrient concentrations; and 6) develop new multiparameter biotic indices to predict nutrient concentrations in streams. The ultimate goal of this study is to provide the information needed to guide the development of regionally based nutrient criteria for streams in Wisconsin.

Because the biotic response in streams was expected to vary as a function of stream size, and wadeable streams are sampled with different techniques than nonwadeable streams, the study was divided into two parts. The first part involved sampling 240 wadeable streams in 2001–03, and the second part involved sampling approximately 40 nonwadeable streams in 2003. In this report, the results of the first part of this study are presented: nutrient concentrations and their relations to the biotic integrity of wadeable streams in Wisconsin. The second part of the study will be presented in a separate report.

Table 1. Reference concentrations for total phosphorus, total nitrogen, and suspended chlorophyll *a*, and turbidity in selected national nutrient and level III ecoregions (U.S. Environmental Protection Agency, 2000b and 2001) and environmental phosphorus zones (EPZs) from Robertson and others (2006).

[USEPA, U.S. Environmental Protection Agency; NCHF, North Central Hardwood Forests; DFA, Driftless Area; SWTP, Southeastern Wisconsin Till Plains; --, no data; NTU, nephelometric turbidity units; FTU, formazin turbidity units; mg/L, milligram per liter; µg/L, microgram per liter]

Region	USEPA criteria	Reference concentration based on Robertson and others (2006)			
		Median	Standard error	Upper 95-percent confidence limit	25th percentile of all sites
		Total phosphorus (mg/L)			
Ecoregion 7	0.033	0.016	0.003	0.024	0.040
NCHF-51[a]	.029	--	--	--	--
DFA-52[a]	.070	--	--	--	--
SWTP-53[a]	.080	--	--	--	--
Ecoregion 8	.010	.015	.002	.019	.010
EPZ 1	--	.012	.002	.017	.020
EPZ 2	--	.021	.003	.026	.030
EPZ 3	--	.021	.004	.030	.060
EPZ 4	--	.023	.003	.030	.050
		Total nitrogen (mg/L, calculated/reported)			
Ecoregion 7	0.54/0.54	--	--	--	--
NCHF-51[a]	.46/.71	--	--	--	--
DFA-52[a]	1.88/1.51	--	--	--	--
SWTP-53[a]	1.59/1.30	--	--	--	--
Ecoregion 8	.20/.38	--	--	--	--
		Turbidity (NTU/FTU)			
Ecoregion 7	1.7/2.32	--	--	--	--
NCHF-51[a]	.84/2.14	--	--	--	--
DFA-52[a]	3.38/2.4	--	--	--	--
SWTP-53[a]	--/2.74	--	--	--	--
Ecoregion 8	.81/1.3	--	--	--	--
		Chlorophyll *a* (µg/L, fluorometric/spectrophotometric/trichromatic methods)			
Ecoregion 7	1.54/3.50/5.8	--	--	--	--
NCHF-51[a]	1.03/8.76/--	--	--	--	--
DFA-52[a]	1.00/2.32/--	--	--	--	--
SWTP-53[a]	.55/3.52/--	--	--	--	--
Ecoregion 8	.60/2.60/4.3	--	--	--	--

[a] USEPA level III ecoregion identification numbers

Approach

Because simultaneously collected hydrological, water-quality, and biological data were not available to determine how the biotic integrity of Wisconsin streams is related to changes in nutrient concentrations, a network of streams was selected to represent the wadeable and nonwadeable streams in the level III ecoregions and EPZs in the State. Although some level III ecoregions were combined into larger-scale national nutrient ecoregions and some of the EPZs were combined because there were no statistical differences in reference concentrations or in the responses to changes in land use among some zones in the upper Midwest study (Robertson and others, 2006), each of the level III ecoregions and EPZs were examined separately in this study. The locations of the 240 wadeable streams are shown in figure 4 and listed in appendix 1. To try to obtain streams that represent the range in environmental conditions in Wisconsin, approximately the same number of sites was chosen in each of the level III ecoregions. To try to obtain streams with a wide range in nutrient concentrations, sites in each ecoregion were chosen to try to represent a full range in the percentage of agricultural land, although this was not always possible. Discharge and water quality of each stream were sampled monthly over a 6-month period (May through October). Benthic (attached) algae and diatoms were sampled once during the period. During 2001, 157 streams with the smallest watersheds were sampled (2.2 to 222 km^2, but generally less than 90 km^2). During 2002, 78 larger streams were sampled (40 to 1,947 km^2). In 2003, 42 nonwadeable streams (not discussed in this report) and five additional wadeable streams were sampled (11 to 106 km^2). Data on macroinvertebrate and fish populations were not collected as part of this study, but were available from past surveys. A prerequisite for site selection was that the macroinvertebrate and fish populations in the stream had been sampled during the past 5 years.

For each site, the drainage basin was digitized and a geographic information system (GIS) was used to describe the environmental characteristics of the watershed. Various multivariate statistical approaches were then used to determine how the environmental characteristics of the watershed were related to water quality and biotic-community structure. The data were used to determine which stratification scheme (level III ecoregions or EPZs) best describes the distributions in reference nutrient concentrations and the responses in nutrient concentrations to changes in land use. Reference concentrations of P, N, and SCHL, and water clarity were estimated by use of the multiple linear-regression approach and the 25th-percentile approach for the best regionalization scheme. Reference values for the biotic indices were estimated by use of the 75th-percentile approach by examining the values of the biotic indices at minimally impacted sites (sites with nutrient concentrations at or below the estimated reference concentrations). Water-quality data were statistically compared with biotic indices describing the suspended and benthic algae, diatoms, macroinvertebrates, and fish to determine how the biotic integrity of streams is related to changes in nutrient concentrations, and whether or not thresholds in P and (or) N concentrations can be defined above which the biology is adversely affected. Two new multiparameter indices were then developed to estimate P and N concentrations in streams on the basis of the biotic-community structure.

Methods of Data Collection and Analysis

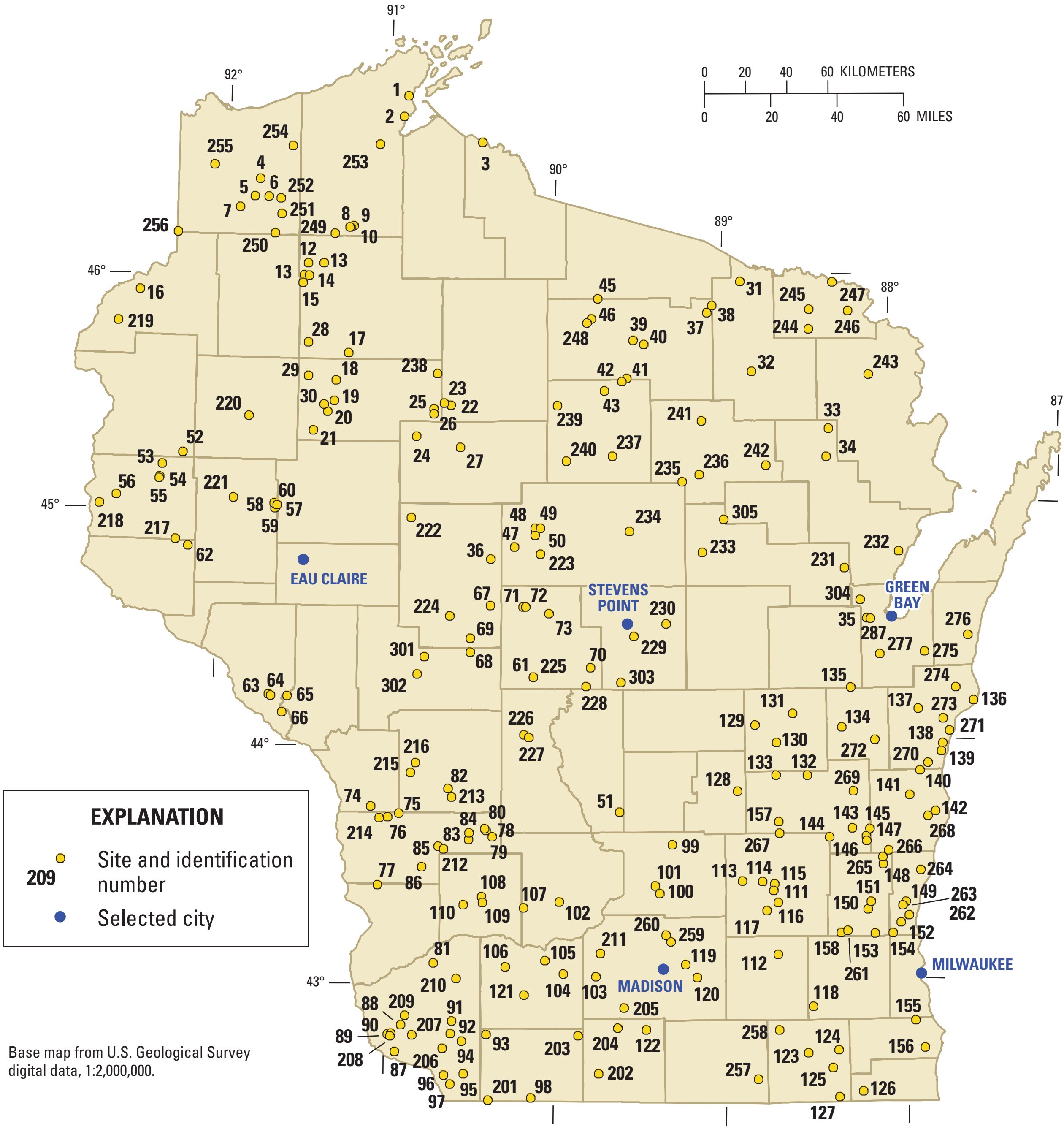
Field Methods

Discharge, Water Chemistry, and Suspended Chlorophyll *a* Concentrations

Streamflow and water quality in each stream were sampled monthly over a 6-month period (May through October). Each site was sampled near the middle of the month regardless of flow conditions. During each visit, discharge and field parameters (specific conductance, water temperature, dissolved oxygen, and pH) were either measured or estimated and a water-quality sample was collected.

Discharge was determined at each site with a current meter (Rantz and others, 1982), with a stage/discharge relation for a continuous-recording gaging station at the site, or estimated from a nearby site. If the site was not wadeable because of high flow and did not have a continuous-recording gage, the discharge was estimated from a nearby streamflow-gaging station by use of relations between previous discharge measurements at the site and at the nearby station.

Specific conductance, water temperature, dissolved oxygen, pH, and, at some sites, turbidity were measured in the field at the time of sampling by use of a multiparameter meter. The meters were calibrated each day before use. Water clarity was measured by use of a 120-cm



Base map from U.S. Geological Survey digital data, 1:2,000,000.

Figure 4. Sites on wadeable streams in Wisconsin included in this study. Water-quality and biotic data for each site are given by site identification number in the appendixes.

Secchi tube (also referred to as a transparency tube, U.S. Environmental Protection Agency, 2004). The Secchi tube was held into the flowing stream and filled. The tube was then held perpendicular to the ground and drained until the Secchi disk at the bottom of the tube became visible. The water level in the tube was read to the nearest centimeter and defined as the Secchi tube depth (SD). If the disk was visible when the tube was full, the value was reported as greater than 120 cm.

All water samples were collected by use of the equal-width-increment (EWI) method with a hand-held DH-59 depth-integrating sampler (Edwards and Glysson, 1999), except when stream conditions were not appropriate (stream velocity less than approximately 0.45 m/s, maximum depth less than 0.15 m, or the stream was nonwadeable); in this case, a grab sample was collected with an open bottle at the center of the flow. Samples were then split into appropriate bottles for lab analysis. Samples to be analyzed for dissolved constituents were filtered in the field through 0.45-µm membrane filters. Samples to be analyzed for SCHL were obtained by filtering a known volume of water through a 5-µm membrane filter. The filter was then placed in a labeled petri dish and wrapped in aluminum foil. All samples were chilled until they were delivered to the Wisconsin State Laboratory of Hygiene for analysis, except samples to be analyzed for SCHL, which were frozen, kept in the dark, and delivered to the WDNR Research Laboratory. All samples were analyzed for P, dissolved phosphorus (DP), total Kjeldahl nitrogen (TKN), dissolved nitrite plus nitrate nitrogen (NO_3-N), dissolved ammonia nitrogen (NH_4-N), and SCHL. In July of 2002, samples were also collected for analysis of suspended sediment. All chemical analyses of water samples (except SCHL) were done by the Wisconsin State Laboratory of Hygiene in accordance with standard analytical procedures described in the “Manual of Analytical Methods, Inorganic Chemistry Unit” (Wisconsin State Laboratory of Hygiene, 1993). At the WDNR Research Laboratory, the filters for SCHL analysis were placed in tubes containing 90 percent acetone, stored at least 24 hours, sonicated for 15 minutes, and stored an additional 24 hours in a freezer. The trichromatic chlorophyll *a* content of the samples was determined by means of a USEPA-approved method (Greenberg and others, 1992). Throughout this report, the water-chemistry, water-clarity, and SCHL data are collectively referred to as “water-quality data.” All water-quality data were input into the USGS National Water Information System (NWIS) (U.S. Geological Survey, 1998).

Benthic Chlorophyll *a* and Diatoms

Samples for benthic chlorophyll *a* (BCHL) and periphytic-diatom analyses were collected once during August or September. Care was taken to avoid collecting samples within 2 weeks of appreciable rainfall to minimize the potential effect of scouring. Samples were collected by brushing a known area of three to five rocks with a toothbrush. Following collection, the samples were placed on ice and kept in the dark. Within 12 hours of sampling, the sample was diluted to a known volume with distilled water, homogenized in a blender, and a portion was filtered through two 3–5 µm glass-fiber filters. One filter was placed in 90 percent acetone and was analyzed for its acid-corrected chlorophyll a content (BCHL) by means of a USEPA-approved monochromatic method (Greenburg and others, 1992). The other filter was used for the determination of ash-free dry weight. This sample was dried overnight at 105ºC and ashed at 550ºC for 1 hour. The sample was weighed before and after ashing. Because of either lack of suitable substrate or lack of water at the time of collection, BCHL samples were collected from only 199 sites.

The sample for microscopic analysis of the diatom assemblage was obtained from a portion of the homogenized sample used for BCHL analysis; however, if rocks were not available, samples were collected from sticks. The sample was preserved with Lugols solution and cleaned with hydrogen peroxide and potassium dichromate (van der Werff, 1955). A portion of the diatom suspension was dried on a cover slip and mounted in Naphrax. Specimen were identified and counted under an oil-immersion objective (1,400 or 1,750X). At least 300 diatoms were counted from two slides in each sample. The keys used to identify the species included Patrick and Reimer (1966, 1975), Camburn and others (1984–86), Dodd (1987), and Krammer and Lange-Bertalot (1986, 1988, 1991a,b). Because of either lack of coarse substrate or lack of water at the time of collection, samples were collected from only 214 sites.

Physical Habitat and Fish

Physical-habitat and fish data were collected by the WDNR once at each site between 1997 and 2002. The physical habitat was determined for a stream length equal to 35 times the mean stream width, or a minimum of 100 m. This length is generally sufficient to encompass about three meander sequences (Simonson and others, 1994; Wang and others, 1996). The physical habitat and fish were quantified between late May and late August when low flows facilitated effective sampling and large-scale seasonal fish movement was unlikely to occur (Lyons and Kanehl, 1993). At each site, 30 physical-habitat characteristics, including channel morphology, bottom substrates, cover, bank conditions, riparian vegetation, and land cover were measured or visually estimated along 12 transects by use of standard procedures (Simonson and others, 1994). The entire length of each site was electrofished with either two backpack units in tandem or a single tow-barge unit with three anodes (Lyons and Kanehl, 1993; Simonson and Lyons, 1995). Efforts were made to collect all of the fish greater than or equal to 25 cm in length. All captured fish were identified to species, counted, and weighed in aggregate by species.

Macroinvertebrates

Macroinvertebrate samples were collected by the WDNR once at each site between 1999 and 2002. Two types of macroinvertebrate samples were collected according to procedures described by Hilsenhoff (1988). Samples were generally collected from each site during low flow in early October by use of a 600-µm mesh D-frame kick net. The first sample was collected from riffles or rocky substrates. If rocky substrates were not present, then vegetative snags (areas with overhanging grasses, logs, woody debris, and leaf packs) were sampled to ensure that the sample was from the most representative habitat at each site. The second sample was collected only from snags to ensure that these data were comparable between all sites because rocky substrates were not always present.

Samples from riffle or rocky substrates were collected by placing the net on the stream bottom and kicking an area immediately upstream of the net to dislodge the macroinvertebrates and wash them into the net. In addition, individual rocks were picked up and the attached macroinvertebrates were removed and added to the sample. This process was repeated in at least three locations within the same riffle or different riffles until at least 200–300 organisms were collected. Samples were collected in snags by placing a net in the water column downstream of the snag, where it would collect most of the dislodged debris. The snags were then disturbed by scraping or shaking them with a net, hands, or feet. At each site, all available snag types at multiple locations were sampled, with first consideration given to larger snags in higher water-velocity habitats.

Samples were sorted and identified at the laboratory of Dr. Stanley Szczytko at the University of Wisconsin, Stevens Point. The samples were placed in a glass pan positioned over a 6.5-cm^2 grid. All of the organisms from randomly chosen grid squares were selected until a minimum of 125 organisms having tolerance values cited in the literature (such as the values in Hilsenhoff, 1988) were picked, or, until the entire sample was sorted. All of the picked organisms were counted and identified to the species or the lowest taxonomic level possible.

Watershed Boundaries and Environmental Characteristics

Watershed boundaries for the sampled streams were manually digitized from 1:24,000-scale USGS topographic quadrangle maps. The environmental characteristics thought to affect the water quality and biology in the streams were compiled for each watershed used in this study: land use/land cover (Lillesand and others, 1998); soil characteristics (from the USSOILS digital coverage of the State Soil Geographic, STATSGO, data base; Schwarz and Alexander, 1995); types of surficial deposits (Fullerton and others, 2003); annual air temperature and precipitation (National Climatic Data Center, 2002); mean land-surface slope (based on 30-m DEM data resampled to 100 m; U.S. Geological Survey, 1999); and average annual runoff (Gebert and others, 1987).

Point-source loadings of phosphorus upstream of each sampling site (PtS) were estimated from monthly mean P concentrations and monthly mean discharge volumes as reported by the dischargers (for example, wastewater-treatment plants and cheese factories) in their Discharge Monitoring Report with the WDNR (James Baumann, Wisconsin Department of Natural Resources, written commun., 2004). The number of concentrations and discharge volumes reported in a month varied with the size and type of discharger and ranged from one sample per month to daily samples. For sites where P concentrations were not required to be measured and, therefore not reported, the P concentrations were estimated based on the size and type of discharger.

All basin characteristics were compiled in digital form by use of a GIS. A digital coverage of each watershed was used to compute the average or percentage value for each environmental characteristic, including the PtS for each of the 240 watersheds. A summary of the environmental characteristics (with the specific metric describing each environmental characteristic) for all of the watersheds used in this study is given in table 2.

Data Summaries

All of the water-quality data collected in this study were input into the USGS NWIS database (U.S. Geological Survey, 1998) and are summarized in appendix 1. In computing summary statistics, all of the data were used regardless of whether or not flow could be detected. During some samplings, the water in the streams was found to have dried up, and no water-quality data were collected. All data reported as less than the detection limit were set to one-half of the detection limit, and all SD data greater than 120 cm were set to 120 cm prior to any statistical and graphical analyses.

Physical-habitat data were summarized into: mean wetted width, depth, thalweg depth, and stream gradient; the percentage of the stream reach with riffles, runs, or pools; the mean depth of sediment; the percentage of the bottom of the stream reach composed of different substrates, embedded rocky substrate, and covered by algae or macrophytes; the percentage of the stream reach that contains fish cover, is shaded, and that has streambank erosion; and buffer width (Simonson and others, 1994). The physical-habitat data for each site are summarized in appendix 2.

Three metrics were used to summarize the diatom-community data: the Diatom Nutrient Index (DNI), the Diatom Siltation Index (DSI; Bahls, 1992), and the Diatom Biotic Index (DBI). The DNI computations are based on tolerance values assigned to individual taxa. DNI values range from 1 to 6, with 1 representing species typically found with the lowest nutrient concentrations (oligotrophic, good water quality) and 6 typically representing species found with the highest nutrient concentrations (hypereutrophic, poor water quality). The values for Wisconsin diatoms (appendix 3) were generated largely from Van Dam and others (1994), but values were also assigned based upon experience with the diatom communities in Wisconsin. If no autecological data were known, the taxa were not assigned a value and were not included in the DNI calculation. Because the index is based upon relative abundance, rare species have little effect on the final index value. The formula used to calculate DNI value is

$$\mathrm{DNI} = \frac{\sum_{i=1}^{j} n_i \cdot t_i}{N} \qquad (1),$$

where

n_i = number of individuals of species i;
t_i = tolerance-index value for species i;
j = total number of species in the sample with tolerance-index values; and
N = total number of individuals in the sample having tolerance-index values.

The second metric for the diatom community is the Diatom Siltation Index (DSI). This index is based on the sum of all individuals in the *Navicula* (including *Cavinula, Chamaepinnularia, Craticula, Diadesmis, Fallacia*, *Fistulifera, Geissleria, Hippodonta, Kobayasiella, Luticola, Mayamaia, Placoneis*, and *Sellaphora*), *Nitzschia* (including *Psammodictyon* and *Tryblionella*), and *Surirella* taxa. These taxa were chosen because they have good motility; therefore, this metric reflects the degree of siltation in a reach (Bahls, 1992). The scale for the index is 0–100 with lower values indicating less silt and thus better water quality.

To assess stream biotic integrity, a multimetric index called the Diatom Biotic Index (DBI) was created. The DBI is based on both diatom indices, DNI and DSI. For computing the DBI, each metric was standardized to the 95th percentile for a number of reference sites and then the two metrics were averaged. For sites with an individual metric exceeding its 95th percentile, the metric was set to 100. The scale of the DBI is 0 to 100, with higher values indicating better biotic integrity. The DBI is intrinsically designed to be sensitive to nutrient enrichment and the effects of sedimentation. The reference sites used to standardize the metric were chosen by combining the northern ecoregions (NLF, NCHF) and the southern ecoregions (DFA, SWTP). Reference sites for the southern ecoregions were those where P concentrations for August were less than or equal to 0.050 mg/L. For the southern ecoregions, there were 13 reference sites and 105 sites with P concentrations exceeding 0.050 mg/L. Reference sites for the northern ecoregions were sites with less than or equal to 10-percent agriculture in the watershed. For the northern ecoregions, there were 42 reference sites and 55 sites with more than 10-percent agriculture.

Six common measures were used to summarize the macroinvertebrate data: the Hilsenhoff Biotic Index (HBI; Hilsenhoff, 1988) and five other macroinvertebrate indices based on the percentage or total number of individuals of various groups or species that were counted in the samples (for example, Ohio Environmental Protection Agency,

Table 2. Summary statistics for median monthly water-quality and environmental (anthropogenic/land-use, basin, soil, and surficial-deposit) characteristics of the watersheds of the sites in the studied wadeable streams in Wisconsin.

[mg/L, milligram per liter; log, logarithm to base 10 transformation; µg/L, microgram per liter; C, Celsius; µS/cm, microSiemen per centimeter; cm, centimeter; (m^3/s)/km^2, cubic meter per second per square kilometer; km^2, square kilometer; mm, millimeter; mm/year, millimeter per year; --, unitless; %, percent; mm/hr, millimeter per hour; kg/km^2, kilogram per square kilometer; >, greater than; no PtS, only sites with less than 12 kg/km^2 of point-source loading of phosphorus are included in this part of the analysis; summary statistics based on monthly values]

Characteristic	Unit	Transformation	Count	Median	Mean	Standard deviation	Minimum	Maximum
Water-quality characteristics								
Total phosphorus	mg/L	log	240	0.085	0.116	0.144	0.012	1.641
Total phosphorus (no PtS)	mg/L	log	234	.082	.105	.097	.012	.741
Dissolved phosphorus	mg/L	log	240	.050	.079	.122	.004	1.495
Dissolved phosphorus (no PtS)	mg/L	log	234	.050	.069	.074	.004	.553
Total nitrogen	mg/L	log	240	1.695	2.807	2.860	.131	21.260
Dissolved nitrite plus nitrate	mg/L	log	240	1.048	2.086	2.865	.005	20.550
Dissolved ammonia	mg/L	log	240	.029	.039	.044	.007	.040
Total Kjeldahl nitrogen	mg/L	log	240	.563	.675	.414	.070	2.350
Suspended chlorophyll *a*	µg/L	log	240	2.27	3.23	4.06	.40	38.01
Water temperature	C	none	240	15.7	15.5	2.0	9.3	21.6
Specific conductance	µS/cm	none	240	478	455	284	27	1,405
Secchi tube depth[a]	cm	none	240	112.0	97.3[a]	28.9	23.5	>120
Flow per unit area	(m^3/s)/km^2	log	240	.007	.009	.011	.001	.122
Anthropogenic/land-use characteristics								
Urban	%	none	240	.00	.01	.01	.00	.14
Agriculture (row crops)	%	none	240	.20	.24	.21	.00	.78
Agriculture (other)	%	none	240	.20	.19	.15	.00	.57
Total agriculture	%	none	240	.46	.42	.31	.00	.94
Grassland	%	none	240	.09	.10	.08	.00	.39
Wetland (open)	%	none	240	.02	.04	.06	.00	.48
Wetland (forested)	%	none	240	.03	.07	.10	.00	.85
Barren	%	none	240	.01	.02	.02	.00	.21
Forest (all)	%	none	240	.31	.40	.31	.01	.99
Point-source loading of phosphorus	kg/km^2	log	240	.00	1.47	6.44	.00	73.62
Basin characteristics								
Watershed area	km^2	log	240	26.4	121.9	261.8	2.2	1947.1
Air temperature	C	none	240	6.9	6.5	1.4	3.7	9.2
Precipitation	mm	none	240	837	836	37	743	926
Runoff	mm/yr	none	240	229	246	50	152	366
Basin slope	degrees	none	240	5.92	6.85	3.49	1.35	16.04
Soil characteristics								
Clay content	%	none	240	18.10	19.07	10.58	3.43	41.80
Erodibility	--	none	240	.28	.26	.07	.11	.40
Organic-matter content	%	none	240	3.83	5.19	5.06	.30	31.02
Permeability	mm/hr	none	240	58.32	84.57	66.41	16.00	307.71
Soil slope	%	none	240	6.03	7.49	4.59	1.02	23.03
Surficial-deposit characteristics								
Nonglacial deposits	%	none	240	.00	.23	.41	.00	1.00
Clay	%	none	240	.00	.12	.30	.00	1.00
Loam	%	none	240	.00	.08	.26	.00	1.00
Peat	%	none	240	.00	.01	.04	.00	.42
Sand	%	none	240	.26	.37	.40	.00	1.00
Sand and gravel	%	none	240	.01	.19	.28	.00	1.00

[a] All values greater than 120 cm were set to 120 cm for computation of summary statistics, which result in the mean values being biased low.

1988; Kerans and Karr, 1994; Barbour and others, 1999; and Weigel, 2003). The HBI is an abundance-weighted tolerance index based on the tolerance of each macroinvertebrate taxon to organic pollution and dissolved oxygen depletion. HBI values range from 0 to 10, with higher values indicating more degraded water quality. The five other macroinvertebrate indices included the percentage of individuals that were either Ephemeroptera, Plecoptera, or Trichoptera (EPTN%), the percentage of taxa that were Ephemeroptera, Plecoptera, or Trichoptera (EPTTX%), the percentage of individuals that were scrapers (SCRAP%), the percentage of individuals that were shredders (SHRED%), and the total number of taxa (TAXAN). For each site, each of these indices was computed for the riffle and snag samples separately, and then an average value was computed. The macroinvertebrate indices for each site are summarized in appendix 4.

Eight community measures were computed to summarize the fish data. Two measures described the quantity of fish caught: total number of fish caught (FISHN) and total number of species caught (FISHSPEC). Five indices described feeding and tolerant classifications: the percentages of top carnivores (CARN%), insectivores (INSECT%), and omnivores (OMNI%), and the percentages of pollution-tolerant (TOL%) and pollution-intolerant (INTOL%) fish (based on Lyons, 1992; and Lyons and others, 1996). In addition, the fish Index of Biotic Integrity (IBI) score was computed by use of both the cold-water (Lyons and others, 1996) and warm-water (Lyons, 1992) versions. Because all of the sites were not classified as a warm-water, cool-water, or cold-water fishery and a cool-water version of the IBI is not available for Wisconsin, the higher of the two IBI scores was used as the site's fish IBI value. The use of different versions of the IBI compensates for different fish assemblages in different thermal regimes. Differences in the other fish indices represent broad feeding and pollution-tolerance classifications; therefore, the metrics in streams with very different species are comparable. The fish metrics for each site are summarized in appendix 4.

Statistical Methods

The SAS statistical software package (SAS Institute, Inc., 1989) was used for all statistical analyses except for the redundancy analyses, which were done with the CANOCO statistical software package (ter Braak and Smilauer, 2002), and the regression-tree analyses, which were done with the SPLUS statistical software package (Lam, 2001).

Normalization

Before statistical analyses, all water-quality data except the SD data were logarithmically transformed (base 10) to improve the normality of the data. This transformation improved the normality of the data although not always to the 5-percent-significance level (Shapiro-Wilk normality test). In addition, all chlorophyll *a* data, point-source data, and watershed areas were logarithmically transformed prior to statistical analyses.

Correlations and Regressions

Spearman correlation analyses were used to determine the relation between each water-quality characteristic and biotic index and each environmental characteristic. This nonparametric procedure was chosen to reduce the influence of the assumption of normal-data distributions. Sequential Bonferroni tests were used to determine the statistical significance of the correlations to eliminate the effects of the number of tests on the significant level (Rice, 1989). Pearson correlation analyses were also used to determine the relation between each water-quality characteristic and each environmental characteristic prior to the use of multiple regressions and forward stepwise-regression analysis (with $p < 0.05$ as the critical level for entry). This procedure was used to determine the magnitude of the interaction between environmental characteristics and water-quality characteristics, as well as to determine the best multivariate relation to estimate concentrations at a specific site as a function of the environmental characteristics in its watershed.

Simultaneous Partial Residualization

Many studies (such as Robertson and others, 2006, and this study), have shown that land use not only directly affects water quality, but it is often strongly correlated with the environmental characteristics used to define regions of similar water quality (indirect effects of land use). Therefore, in order to determine the relation between water quality and the nonanthropogenic or natural characteristics, a simultaneous partial-residualization approach, related to partial correlation, was used to remove the agricultural and urban effects from the concentrations of P and N and from the measures of each of the environmental characteristics.

In simple regression, the relation between the dependent variable Y (for example, P) and a predictor variable X_1 (for example, the clay content of the soil in the basin) can be measured by the sample correlation r_{YX1}. If the variable X_1 is regressed on the variable X_2 (for example, the percentage of agricultural area), the estimated regression equation $X_{1,2} = \beta_0 + \beta_1 X_2$ would be obtained. To adjust X_1 for the effects of X_2, a "residualized X_1", X_1^*, can be obtained by computing $X_1^* = X_1 - X_{1,2}$. In a manner similar to simple correlation, the strength of the relation between Y and X_1 adjusted for X_2 (in this case, land use) can be obtained by the correlation between the residuals for Y on X_2 (Y^*) and the residuals for X_1 on X_2 (X_1^*). The resulting correlation is the partial correlation of Y and X_1 adjusted for X_2; the strength of the relation between Y and X_1 has been adjusted for the effects of X_2. This approach, described by Weisberg (1980), is easily extended to control for more than one variable; X_2 can be replaced by an arbitrary set of variables. In this study, the residualization approach was used to remove the effects of the percentages of agriculture and urban areas and PtS (logarithmically transformed point-source loading in the basin) to enable the relations between the dependent variables P, N, SCHL, and SD and all of the nonanthropogenic environmental characteristics to be further examined. This approach was not used to examine relations between environmental characteristics and the biotic indices. Spearman correlations and forward stepwise regressions were done with raw data and with residualized data to determine which environmental characteristics best described the distribution of each water-quality characteristic.

Regression-Tree Analysis

In traditional linear-regression analysis, a continuous dependent variable is assumed to be a linear function of a set of independent variables. This is often an unrealistic assumption, and departures from linearity can result in underestimating, or completely discounting, important independent variables. Although departures from linearity can be addressed to some extent by trial-and-error data transformations, this approach becomes problematic when independent variables interact in multiple dimensions. The method of regression-tree analysis (Breiman and others, 1984) prevents these problems by not incorporating the assumptions about the shapes of the relations between a dependent variable and one or more independent variables. Regression-tree analysis sequentially partitions the values of each independent variable into two groups, computes mean values of the dependent variable for each group, and then computes square errors for each partition. At each step, all of the independent variables are scanned, and the independent variable and its breakpoint that minimize the least-square-error criterion are chosen. In a manner similar to the F-statistic in an analysis of variance, the least-square-error criterion is used to identify breakpoints that maximize the variance of the interpartition means relative to the intrapartition variance. This process partitions the independent-variable space into increasingly homogeneous regions (branches on a tree). The end result of this sequential process is a branching diagram. If only one independent variable is used (for example, the concentration of P or N) at each step in the analysis, the best breakpoint for the independent variable is defined as the value which subdivides values of the dependent variable (for example, IBI) into the two groups with the maximum difference in their mean values. This breakpoint represents the threshold in the response of the dependent variable.

Regression-tree analyses were done with various dependent variables (SCHL, SD, and various biotic indices) and the corresponding independent variables (nutrient concentrations) to determine breakpoints or thresholds in the responses of the dependent variables to changes in specific nutrient concentrations. In the analysis, the minimum number of sites used to define a subgroup was set to 25 to avoid creating small outlier groups. Regression-tree analysis was also used to determine the value (threshold) below which PtS had minimal effect on P concentrations.

Redundancy Analysis

Redundancy analysis (RDA) is a form of direct-gradient analysis that describes the variation between two multivariate data sets (for example, water-quality and environmental characteristics; ter Braak and Prentice, 1988). In RDA, the site scores from a principal-component analysis are regressed on a specified set of environmental characteristics, and the fitted values of the regression become new site scores for the following iteration; therefore, the principal component analysis is constrained by the environmental variables (Jongman and others, 1987). RDA was used in this study to quantify the variance in the dependent variables (for example, water-quality characteristics) explained by the independent variables (for example, environmental characteristics) and to determine which environmental characteristics best explained the variance in water quality.

In addition, partial RDA (Richards and others, 1996) was used to determine the fraction of the variance in the water-quality characteristics explained by specified categories of the environmental characteristics (such as land-use, basin, and soil/surficial-deposit characteristics), and to determine the fraction of the variance in populations of specified groups of the biotic community (such as benthic chlorophyll *a* concentrations and populations of diatoms, macroinvertebrates, and fish) explained by specified categories of environmental characteristics (such as nutrient characteristics and environmental characteristics). 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 permutating the assignment of the independent (environmental) data to the dependent (water-quality or biological) data randomly and repeating the ordinations (Richards and others, 1996; Johnson and others, 1997).

Statistical Differences among Groups

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

Water Quality and Its Relations with Environmental Characteristics in the Watershed

U.S. Geological Survey personnel collecting streamflow measurements.

Median monthly concentrations of total P ranged from 0.012 to 1.641 mg/L (table 2 on page 15). The overall median and mean were 0.085 and 0.116 mg/L, respectively. Highest concentrations were measured in the central part of the State, especially south of Green Bay (fig. 5). High concentrations were also measured in the southwestern part of the State. The lowest P concentrations were measured in the northern one-third of the State. The highest P concentrations were measured in June and July, and the lowest concentrations were measured in October (table 3).

Median monthly concentrations of DP ranged from 0.004 mg/L (less than the 0.005 mg/L detection limit) to 1.495 mg/L (table 2). The overall median and mean were 0.050 and 0.079 mg/L, respectively. The distribution and seasonality in DP concentrations were similar to total P concentrations (table 3). DP concentrations were strongly correlated to total P concentrations. Pearson correlation coefficients (r values) between DP and P ranged from 0.90 in June to 0.98 in September. DP represented about 53 to 62 percent of the phosphorus during May through July and about 70 percent during August through October.

Median monthly concentrations of N ranged from 0.131 to 21.260 mg/L (table 2). The overall median and mean were 1.695 and 2.807 mg/L, respectively. The highest median N concentrations were measured in the southern quarter of the State and the eastern half of the State (fig. 5). The lowest N concentrations were found in the northern quarter of the State. The highest N concentrations were measured in June, but no consistent seasonal patterns were measured (table 3).

Median monthly concentrations of NO_3-N ranged from 0.005 mg/L (less than the 0.010 mg/L detection limit) to 20.550 mg/L (table 2). The overall median and mean were 1.048 and 2.086 mg/L, respectively. Median monthly concentrations of NH_4-N ranged from 0.007 mg/L (less than the 0.013 mg/L detection limit) to 0.040 mg/L. The overall median and mean were 0.029 and 0.039 mg/L, respectively. Median monthly concentrations of TKN ranged from 0.070 mg/L (less the 0.140 mg/L detection limit) to 2.350 mg/L. The overall median and mean were 0.563 and 0.675 mg/L, respectively. Most of the nitrogen was in the form of NO_3-N (ranging from 63 percent in June to 73–79 percent in other months). Highest NO_3-N

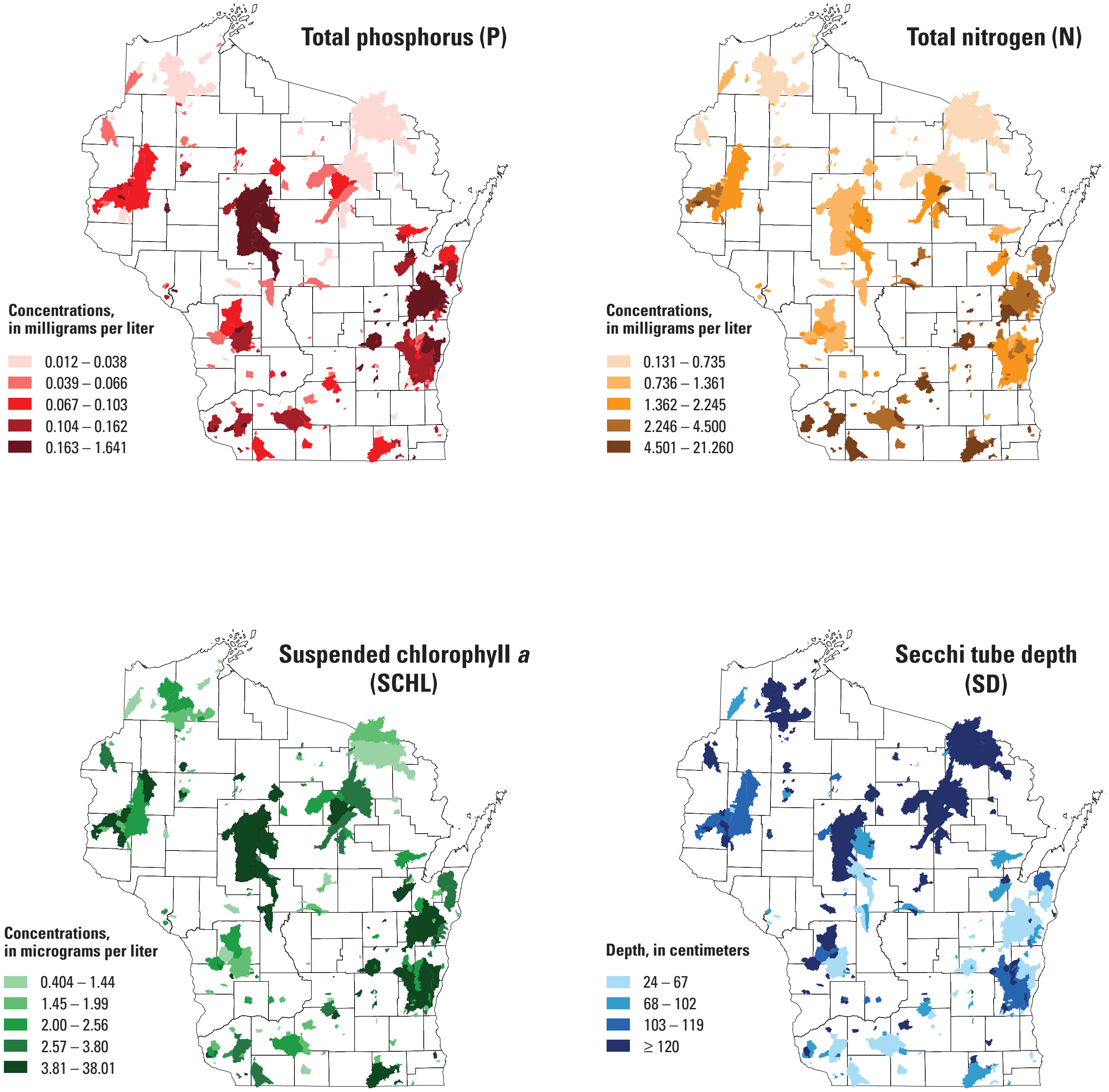


Figure 5. Distributions (quintiles) of median monthly total phosphorus (P), total nitrogen (N), and suspended chlorophyll *a* concentrations (SCHL), and Secchi tube depth (SD) for the studied wadeable streams in Wisconsin. (Note: the upper 40 percent of SDs were all greater than or equal to 120 centimeters.)

and TKN concentrations were measured in June, but no consistent seasonal patterns were measured in any form of nitrogen.

Median monthly concentrations of SCHL ranged from 0.40 to 38.01 µg/L (table 2). The overall median and mean were 2.27 and 3.23 µg/L, respectively. Highest SCHL concentrations were measured in the central and eastern parts of the State, especially south of Green Bay and north of Milwaukee (fig. 5). Lowest SCHL concentrations were measured in the northern one-third of the State and in the southwestern part of the State. Highest SCHL concentrations were measured in July, and lowest concentrations were measured in September and October (table 3).

Median monthly SDs ranged from 23.5 cm to greater than 120 cm (table 2). Many sites consistently had clarities greater than the length of the Secchi tube. The overall median and mean were 112 and 97.3 cm, respectively. Highest SDs (the best clarities) were measured in the northern half of the State (fig. 5). Lowest SDs (the worst clarities) were measured in the southwestern and central parts of the State and south of Green Bay. Lowest SDs were measured during May through July, and the highest SDs were measured during August through October (table 3).

Relations between Water Quality and Environmental Characteristics in the Watershed

Correlations between Individual Characteristics

Spearman correlation coefficients (r_s values) between median water-quality characteristics are shown in table 4. P and DP were significantly correlated with N, NO_3-N, NH_4-N, and TKN (r_s values ranged from 0.36 to 0.61). Correlations between P and the nitrogen species were slightly stronger than between DP and the nitrogen species. Concentrations of N were strongly correlated ($r_s = 0.91$) to NO_3-N because NO_3-N was the major form of nitrogen. Concentrations of NH_4-N and TKN were more strongly correlated to one another ($r_s = 0.66$) and to P ($r_s \sim 0.6$) than they were to total N and NO_3-N ($r_s \sim$ 0.1–0.3). NH_4-N is part of TKN; therefore, a correlation between these two forms of nitrogen was expected. Total organic nitrogen was computed by subtracting the NH_4-N concentration from the TKN concentration. Total organic nitrogen and NH_4-N were still strongly correlated with one

Table 3. Median and average monthly concentrations for total and dissolved phosphorus, suspended chlorophyll *a*, total nitrogen, nitrite plus nitrate, ammonia, and Kjeldahl nitrogen, and Secchi tube depths in the studied wadeable streams in Wisconsin.

[mg/L, milligram per liter; µg/L, microgram per liter; cm, centimeter; >, greater than; all concentrations are in mg/L, except chlorophyll *a*, which is in µg/L, and Secchi tube depth, which is in cm]

	Total phosphorus		Dissolved phosphorus		Chlorophyll *a*		Secchi tube depth	
Month	Median	Average	Median	Average	Median	Average	Median	Average
May	0.070	0.115	0.037	0.071	2.890	4.420	105.0	89.8
June	.107	.164	.058	.101	2.120	3.120	88.5	79.6
July	.092	.143	.052	.089	3.042	7.885	90.0	82.9
August	.088	.138	.059	.096	2.168	5.096	> 120	92.9
September	.075	.120	.049	.085	1.773	3.336	> 120	101.1
October	.049	.101	.035	.070	1.546	2.922	> 120	107.9

	Total nitrogen		Nitrite plus nitrate		Ammonia		Kjeldahl nitrogen	
Month	Median	Average	Median	Average	Median	Average	Median	Average
May	1.589	2.919	0.911	2.120	0.030	0.061	0.700	0.800
June	2.110	3.949	1.120	2.500	.033	.049	.790	.949
July	1.740	2.851	.903	2.083	.032	.067	.560	.768
August	1.573	2.634	.788	1.919	.031	.062	.525	.715
September	1.622	2.750	.987	2.115	.031	.060	.510	.650
October	1.657	2.834	1.080	2.229	.027	.046	.470	.606

Table 4. Spearman correlation coefficients (r_s) between median concentrations of total phosphorus, dissolved phosphorus, total nitrogen, nitrite plus nitrate, ammonia, total Kjeldahl nitrogen, median Secchi tube depths, suspended chlorophyll *a* concentrations, percentages of urban and agricultural areas, point-source loadings of phosphorus, and specific environmental (anthropogenic/land-use, basin, soil and surficial-deposit) characteristics for the studied wadeable streams in Wisconsin.

[P, total phosphorus; DP, dissolved phosphorus; N; total nitrogen; NO_3-N, nitrite plus nitrate; NH_4-N, ammonia; TKN, total Kjeldahl nitrogen; SD, Secchi tube depth; SCHL, suspended chlorophyll *a* concentration; % Urb, percentage of urban area; % Ag, percentage of agricultural area; PtS, point-source loading of phosphorus in kilograms per square kilometer; <, less than; no PtS, only sites with less than 12 kilograms per square kilometer of point-source loading of phosphorus are included in analysis; all values with an absolute value greater than 0.22 are statistically significant at $p < 0.05$; all values with an absolute value greater than 0.4 are in **bold**]

Characteristic	P	P (no PtS)	DP	DP (no PtS)	N	NO_3-N	NH_4-N	TKN	SD	SCHL	% Urb	% Ag	PtS
Water-quality characteristics													
Total phosphorus	**1.00**	**1.00**	**0.95**	**0.95**	**0.54**	0.38	**0.61**	**0.56**	**-0.57**	**0.44**	0.14	**0.67**	.29
Dissolved phosphorus	**0.95**	**0.95**	**1.00**	**1.00**	**.51**	.36	**.55**	**.52**	**-.48**	.35	.11	**.63**	.27
Total nitrogen	**.54**	**.52**	**.51**	**.50**	**1.00**	**.91**	.29	.19	**-.55**	.31	.28	**.81**	.19
Dissolved nitrite plus nitrate	.38	.37	.36	.35	**.91**	**1.00**	.11	-.12	**-.42**	.18	.29	**.77**	.18
Dissolved ammonia	**.61**	**.61**	**.55**	**.56**	.29	.11	**1.00**	**.66**	**-.48**	.35	-.02	.34	-.02
Total Kjeldahl nitrogen	**.56**	**.55**	**.52**	**.52**	.19	-.12	**.66**	**1.00**	-.38	**.45**	.04	.25	.08
Suspended chlorophyll *a*	**.44**	**.43**	.35	.34	.31	.18	.35	**.45**	**-.40**	**1.00**	.25	**.45**	.29
Secchi tube depth	**-.56**	**-.55**	**-.48**	**-.46**	**-.55**	**-.42**	**-.47**	-.38	**1.00**	**-.40**	-.26	**-.55**	-.23
Anthropogenic/land-use characteristics													
Urban	.14	.08	.11	.05	.28	.29	-.02	.04	-.26	.25	**1.00**	.20	**.49**
Agriculture (row crops)	**.65**	**.65**	**.60**	**.59**	**.81**	**.73**	.37	.33	**-.55**	**.46**	.23	**.94**	.20
Agriculture (other)	**.56**	**.56**	**.56**	**.56**	**.61**	**.63**	.22	.04	-.37	.31	.16	**.80**	.22
Total agriculture	**.67**	**.67**	**.63**	**.63**	**.81**	**.76**	.34	.25	**-.55**	**.45**	.20	**1.00**	.21
Grassland	.02	.03	.03	.04	.17	.25	-.02	-.19	.07	-.07	.21	.00	.08
Wetland (open)	.07	.06	.03	.02	-.10	-.23	.18	**.48**	-.04	.21	.18	-.10	.18
Wetland (forested)	-.22	-.21	-.21	-.20	**-.52**	**-.66**	.08	**.47**	.27	-.04	-.10	**-.52**	-.08
Barren	.34	.32	.29	.27	.37	.33	.14	.22	-.23	**.40**	.33	**.46**	.17
Forest (all)	**-.64**	**-.63**	**-.58**	**-.58**	**-.83**	**-.75**	-.38	-.30	**.57**	**-.47**	-.27	**-.94**	-.21
Point-source loading of phosphorus	.29	.22	.27	.19	.19	.18	-.02	.08	-.23	.29	**.49**	.21	**1.00**

Table 4. Spearman correlation coefficients (r_s) between median concentrations of total phosphorus, dissolved phosphorus, total nitrogen, nitrite plus nitrate, ammonia, total Kjeldahl nitrogen, median Secchi tube depths, suspended chlorophyll *a* concentrations, percentages of urban and agricultural areas, point-source loadings of phosphorus, and specific environmental (anthropogenic/land-use, basin, soil and surficial-deposit) characteristics for the studied wadeable streams in Wisconsin—Continued.

[P, total phosphorus; DP, dissolved phosphorus; N; total nitrogen; NO_3-N, nitrite plus nitrate; NH_4-N, ammonia; TKN, total Kjeldahl nitrogen; SD, Secchi tube depth; SCHL, suspended chlorophyll *a* concentration; % Urb, percentage of urban area; % Ag, percentage of agricultural area; PtS, point-source loading of phosphorus in kilograms per square kilometer; <, less than; no PtS, only sites with less than 12 kilograms per square kilometer of point-source loading of phosphorus are included in analysis; all values with an absolute value greater than 0.22 are statistically significant at $p < 0.05$; all values with an absolute value greater than 0.4 are in **bold**]

Characteristic	P	P (no PtS)	DP	DP (no PtS)	N	NO_3-N	NH_4-N	TKN	SD	SCHL	% Urb	% Ag	PtS
Basin characteristics													
Watershed area	-0.07	-0.07	-0.08	-0.09	-0.06	-0.02	-0.23	-0.04	0.03	0.21	0.28	-0.04	**0.51**
Air temperature	**.50**	**.47**	**.44**	**.42**	**.76**	**.74**	.29	.09	**-.55**	.30	0.25	**0.76**	0.15
Precipitation	.07	.04	.05	.02	.27	.36	-.07	-.32	-.17	.03	0.20	0.14	0.02
Runoff	**-.48**	**-.48**	**-.43**	**-.43**	**-.60**	**-.59**	-.36	-.19	**.41**	-.25	-0.24	**-0.62**	-0.16
Basin slope	.19	.20	.22	.23	.17	.31	.00	-.39	-.14	-.15	-0.05	0.23	0.03
Flow per unit area	-.21	-.20	-.17	-.16	-.17	-.13	-.13	-.18	.15	-.16	-0.04	-0.25	-0.18
Soil characteristics													
Clay content	**.52**	**.53**	**.52**	**.52**	**.58**	**.58**	.24	.04	**-.54**	.22	0.14	**0.73**	0.15
Erodibility	**.54**	**.55**	**.55**	**.55**	**.57**	**.55**	.21	.15	**-.47**	.35	0.11	**0.76**	0.12
Organic matter content	-.34	-.36	-.35	-.36	-.38	**-.51**	-.05	.33	.17	.01	0.02	-0.40	-0.05
Permeability	**-.53**	**-.54**	**-.54**	**-.56**	**-.46**	**-.44**	-.21	-.09	**.48**	-.21	-0.05	**-0.63**	-0.09
Soil slope	-.31	-.32	-.30	-.30	-.21	.01	-.35	**-.68**	.28	-.34	-0.06	-0.30	-0.04
Surficial-deposit characteristics													
Nonglacial deposits	.03	.02	.03	.02	.26	.36	-.11	**-.45**	-.17	-.01	0.05	0.22	0.09
Clay	.26	.28	.24	.25	.09	.04	.21	.31	-.29	.20	0.06	0.31	0.16
Loam	.23	.26	.22	.25	-.04	-.07	.07	.18	.04	-.01	-0.02	0.06	0.15
Peat	-.06	-.06	-.08	-.07	-.14	-.20	.09	.17	-.08	.07	-0.05	-0.20	0.05
Sand	-.13	-.14	-.14	-.15	-.16	-.24	-.04	.20	.12	.08	0.05	-0.22	-0.05
Sand and gravel	**-.42**	**-.44**	**-.43**	**-.45**	-.34	-.33	-.13	.07	.23	-.08	0.13	**-0.42**	0.05

another ($r_s = 0.62$). Concentrations of P and DP were also significantly correlated with the PtS in the basin ($r_s \sim 0.3$). The six streams with PtS values higher than 12 kg/km^2 had some of the highest measured P (ranging from 0.17 to 1.64 mg/L) and DP concentrations (ranging from 0.098 to 1.49 mg/L). Annual PtS below 12 kg/km^2 had little effect on the concentrations of P and DP in the streams (on the basis of results from regression-tree analyses and graphical examination of the data). Omitting the six streams with PtS greater than 12 kg/km^2 from the analyses, however, had little effect on the correlations with the other characteristics (table 4).

Spearman correlation coefficients between the water-quality characteristics and each environmental characteristic (anthropogenic/land-use, basin, soil, and surficial-deposit characteristics) are also shown in table 4. All water-quality characteristics were significantly correlated with many environmental characteristics; however, they were most strongly correlated with characteristics describing land use (presence of agriculture or absence of forest), basin characteristics describing air temperature and runoff from the watershed, and the soil characteristics (clay content, erodibility, and permeability). In general, N (and NO_3-N) and P (and DP) were correlated with the same environmental characteristics; however, the correlations with N concentrations were generally stronger than with P concentrations. Concentrations of NH_4-N and TKN were less strongly correlated with the nonanthropogenic or natural environmental characteristics than the other water-quality characteristics. Concentrations of NH_4-N were most strongly correlated with runoff and soil slope ($r_s \sim -0.35$) and concentrations of TKN were most strongly correlated with soil slope ($r_s = -0.68$).

Concentrations of SCHL were significantly correlated with all but one of the nutrient constituents (the exception is NO_3-N with $r_s = 0.18$). Concentrations of SCHL were most strongly correlated with TKN and P ($r_s \sim .45$), less strongly correlated with NH_4-N, DP, and N ($r_s = 0.31$ to $r_s = 0.35$), and insignificantly correlated with NO_3-N ($r_s = 0.18$). Concentrations of SCHL were significantly correlated with most environmental characteristics; however, they were most strongly correlated with land-use characteristics (positively correlated with the percentage of total agriculture and negatively correlated with the percentage of forest), basin characteristics describing the air temperature and runoff from the watershed, and soil properties in the watershed (erodibility and soil slope). SDs were most strongly correlated with many of the same characteristics as SCHL; however, SDs were more strongly correlated with most characteristics, especially more correlated with N, NO_3-N, clay content, and runoff. Similar results were obtained if only sites with SDs less than 120 cm were included in the analysis; however, the correlation coefficients were slightly smaller.

Correlations with Individual Characteristics after Removing Relations with Anthropogenic Characteristics

Many of the environmental characteristics were strongly correlated with the anthropogenic characteristics (characteristics describing the land use and PtS in the basin), primarily the percentage of agriculture in the basin, and less strongly with the percentage of urban area and the PtS in the basin (table 4). Many of the nonanthropogenic or natural characteristics were also strongly correlated with the anthropogenic characteristics. For example, air temperature and runoff were correlated with the percentage of agriculture (r_s values of 0.76 and -0.62, respectively). Therefore, even if the anthropogenic characteristics were not included in further statistical analyses, their effects could be incorporated into the final results by use of characteristics such as air temperature.

To examine the relations between the nonanthropogenic characteristics and the water-quality characteristics further, the relations between the anthropogenic characteristics (percentages of agriculture, Ag %, and urban, Urb %, areas in the basin and the PtS in the basin) and P, N, SCHL, and SD were removed by use of simultaneous partial-residualization. Residualized P, N, and SCHL concentrations and SDs were computed with equations 2–9:

$$\mathbf{Log\ P_{Res} = Log\ P_{Measured} - Log\ P_{Predicted}}\ , \tag{2}$$

where

$$\text{Log P}_{\text{Predicted}} = -1.448 + 0.744\ \text{Ag}\ \% - 1.101\ \text{Urb}\ \% + 0.267\ \text{Log(PtS)} \tag{3}$$

$R^2 = 0.49$;

$$\mathbf{Log\ N_{Res} = Log\ N_{Measured} - Log\ N_{Predicted}}\ , \tag{4}$$

where

$$\text{Log N}_{\text{Predicted}} = -0.247 + 1.112\ \text{Ag}\ \% + 3.830\ \text{Urb}\ \% + 0.045\ \text{Log(PtS)} \tag{5}$$

$R^2 = 0.68$;

$$\mathbf{Log\ SCHL_{Res} = Log\ SCHL_{Measured} - Log\ SCHL_{Predicted}}\ , \tag{6}$$

where

$$\text{Log SCHL}_{\text{Predicted}} = 0.182 + 0.383\ \text{Ag}\ \% - 0.860\ \text{Urb}\ \% + 0.260\ \text{Log(PtS)} \tag{7}$$

$R^2 = 0.26$;

$$\mathbf{SD_{Res} = SD_{Measured} - SD_{Predicted}}, \quad (8)$$

where

$$SD_{Predicted} = 119.6 - 47.371 \text{ Ag } \% - 227.5 \text{ Urb } \% + 8.039 \text{ Log(PtS)} \quad (9)$$

$R^2 = 0.30$.

Residual transformations were also applied to all of the other water-quality and environmental characteristics.

Spearman correlation coefficients between the residualized values for the water-quality characteristics and the residualized values for the environmental characteristics are shown in table 5. Residualized concentrations and SDs were still significantly correlated with many residualized environmental characteristics; however, they were not as strongly correlated. P_{Res} and DP_{Res} concentrations were most strongly correlated with residualized permeability of the soil, residualized soil slope, and residualized sand-and-gravel surficial deposits. Basins with more permeable soils had lower P_{Res} concentrations. N_{Res} concentrations were most strongly correlated with various basin characteristics (residualized air temperature, precipitation, and runoff) and residualized clay content of the surficial deposits. Highest N_{Res} concentrations occurred in areas with warmer air temperatures, more precipitation, lower runoff, and lower clay content in the surficial deposits. Highest $NO_3\text{-}N_{Res}$ concentrations also occurred in these areas, especially if the areas had steep slopes. Highest TKN_{Res} concentrations occurred where $NO_3\text{-}N_{Res}$ concentrations were the lowest. Residualized SCHL concentrations were most strongly correlated with the slopes of the terrain and the soils, organic-matter content, and some surficial-deposit characteristics. Lowest $SCHL_{Res}$ concentrations occurred in areas with steep terrain and high organic-matter content. Residualized SDs were most strongly correlated with the clay content of the soil and surficial deposits; the best water clarity occurred in areas with low clay content.

Thresholds in Water-Quality Responses

Concentrations of P and N were significantly correlated with the percentage of agriculture in the watershed. To define these relations better, logarithmically transformed P and N concentrations were plotted against the percentage of agriculture in the watershed (fig. 6), and regression-tree analyses were done to determine the percentages of agriculture that were the best breakpoints or thresholds in the responses. Regression-tree results indicate that the best statistically significant ($p < 0.001$) breakpoints in the responses of P and N to percentages of total agriculture were at 14.1 and 21.3 percent, respectively. In both cases, however, the relations between P and N concentrations and the percentage of agriculture appear linear and the line determined with linear regression better defined the response than a step change in values (on the basis of a mean-square-error criterion).

Concentrations of SCHL were significantly correlated with P and N concentrations (tables 4 and 5). To better define these relations, logarithmically transformed SCHL concentrations were plotted against logarithmically transformed P and N concentrations (fig. 7) and regression-tree analyses were done. Regression-tree results indicate that the best breakpoint in the response of SCHL to changes in P concentration was at 0.070 mg/L (log P = -1.16) and to changes in N concentrations occurred at 1.169 mg/L (log N = 0.07); both breakpoints were statistically significant at $p < 0.001$. The relations between SCHL and P and N concentrations appear linear and the regression line defines the response better than a step change in median P concentrations; however, the step-change response better defines the relation with N (on the basis of a mean-square-error criterion). A similar response was found between P and SCHL in temperate streams, with the greatest increase in SCHL occurring at P concentrations less than 0.1 mg/L (Van Nieuwenhuyse and Jones, 1996).

To define the relations between SDs and P and N concentrations better, SDs were plotted against logarithmically transformed P and N concentrations (fig. 7) and regression-tree analyses were done. There was little apparent relation between SDs and P and between SDs and N at lower nutrient concentrations because of the limited length of the Secchi tube; however, with higher nutrient concentrations, SDs gradually decreased. Regression-tree results indicate that the best breakpoint in the response of SDs to changes in P concentrations was at 0.106 mg/L (log P = -0.97) and to changes in N concentrations was at 3.305 mg/L (log N = 0.52); both breakpoints were statistically significant at $p < 0.001$. A regression line defines the response better than a step change for P and N (on the basis of a mean-square-error criterion). The reduction in SDs with increasing nutrient concentrations may have been caused by other factors that are correlated to P and N concentrations, such as the clay content of the soils and surficial deposits (table 4).

Table 5. Spearman correlation coefficients (r_s) between residualized logarithmically transformed median concentrations of total phosphorus, dissolved phosphorus, nitrogen, nitrite plus nitrate, total Kjeldahl nitrogen, ammonia and suspended chlorophyll *a*, median Secchi tube depths, and specific residualized environmental (basin, soil, and surficial-deposit) characteristics for the studied wadeable streams in Wisconsin.

[P_{Res}, residualized total phosphorus; DP_{Res}, residualized dissolved phosphorus; N_{Res} residualized nitrogen; NO_3-N_{Res}, residualized nitrite plus nitrate; NH_4-N_{Res}. residualized ammonia; TKN_{Res}, residualized total Kjeldahl nitrogen; SD_{Res}, residualized Secchi tube depth; $SCHL_{Res}$, residualized suspended chlorophyll *a* concentration; all values with an absolute value greater than 0.18 are statistically significant at $p < 0.05$; all statistically significant values (not including relations between nutrients) are in **bold**]

Residualized characteristic	P_{Res}	DP_{Res}	N_{Res}	NO_3-N_{Res}	NH_4-N_{Res}	TKN_{Res}	SD_{Res}	$SCHL_{Res}$
Residualized water-quality characteristics								
Total phosphorus	1.00	0.91	-0.02	-0.29	0.58	0.55	**-0.26**	0.22
Dissolved phosphorus	.91	1.00	.00	-.22	.50	.48	-.15	.07
Total nitrogen	-.02	.00	1.00	.55	.09	.01	-.15	-.11
Dissolved nitrite plus nitrate	-.29	-.22	.55	1.00	-.22	-.56	.14	-.30
Dissolved ammonia	.58	.50	.09	-.22	1.00	.63	**-.31**	.28
Total Kjeldahl nitrogen	.55	.48	.01	-.56	.63	1.00	**-.25**	**.40**
Suspended chlorophyll *a*	.22	.07	-.11	-.30	.28	.40	-.18	1.00
Secchi tube depth	-.26	-.15	-.15	.14	-.31	-.25	1.00	-.18
Residualized basin characteristics								
Watershed area	-.18	**-.19**	-.06	.03	**-.22**	-.05	.09	.14
Air temperature	-.08	-.09	**.24**	**.43**	.00	**-.27**	-.06	-.10
Precipitation	-.07	-.06	**.22**	**.36**	-.12	**-.37**	-.05	-.03
Runoff	-.10	-.08	-.18	**-.41**	-.18	.04	-.07	.03
Basin slope	.01	.07	.01	**.33**	-.09	**-.48**	.01	**-.32**
Flow per unit area	-.05	-.01	.09	.13	-.06	-.16	.06	-.08
Residualized soil characteristics								
Clay content	.08	.15	-.11	.02	-.04	**-.19**	**-.28**	-.13
Erodibility	.13	**.19**	-.09	-.02	-.08	-.12	-.02	.00
Organic-matter content	-.11	-.16	-.09	**-.44**	.08	**.41**	-.13	**.23**
Permeability	**-.28**	**-.34**	.06	.01	-.02	.06	.14	.07
Soil slope	**-.20**	**-.19**	.06	**.39**	**-.23**	**-.61**	.09	**-.24**
Residualized surficial-deposit characteristics								
Nonglacial deposits	-.18	-.13	.16	**.28**	**-.19**	**-.50**	-.02	**-.19**
Clay	.12	.12	**-.27**	**-.34**	.10	**.27**	**-.22**	.06
Loam	.12	.11	-.09	-.13	.03	.11	.05	-.06
Peat	.06	.03	.07	-.03	.08	.09	-.04	.04
Sand	.05	-.01	.03	**-.21**	.04	**.28**	.02	**.25**
Sand and gravel	**-.31**	**-.33**	-.01	-.02	-.03	.14	.04	.07

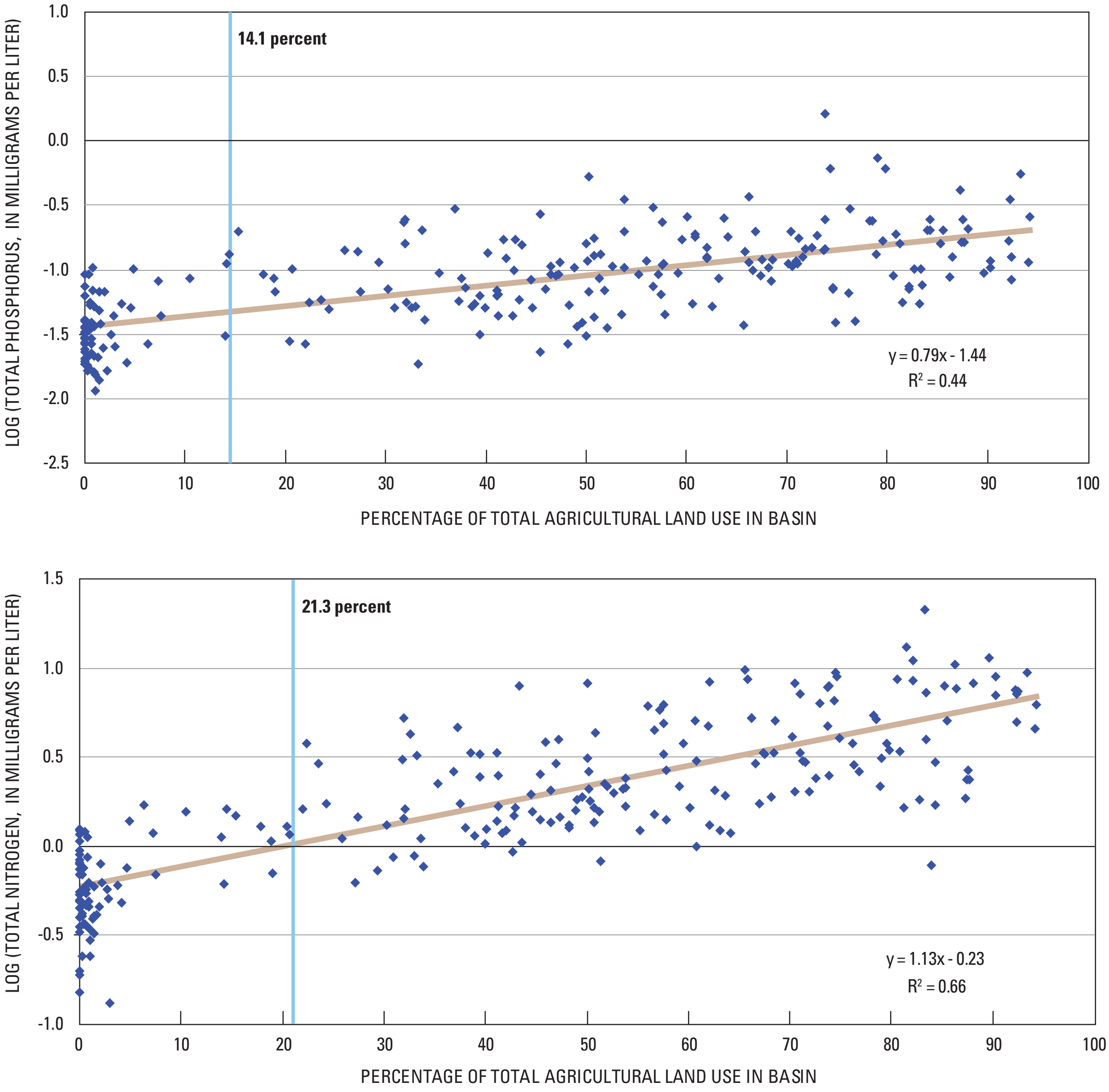


Figure 6. Total phosphorus and total nitrogen concentrations as a function of the percentage of total agriculture in the watersheds of the studied wadeable streams in Wisconsin. Computed thresholds in the response are identified by vertical lines. Linear-regression lines and coefficients of determination (R^2) are given on each graph.

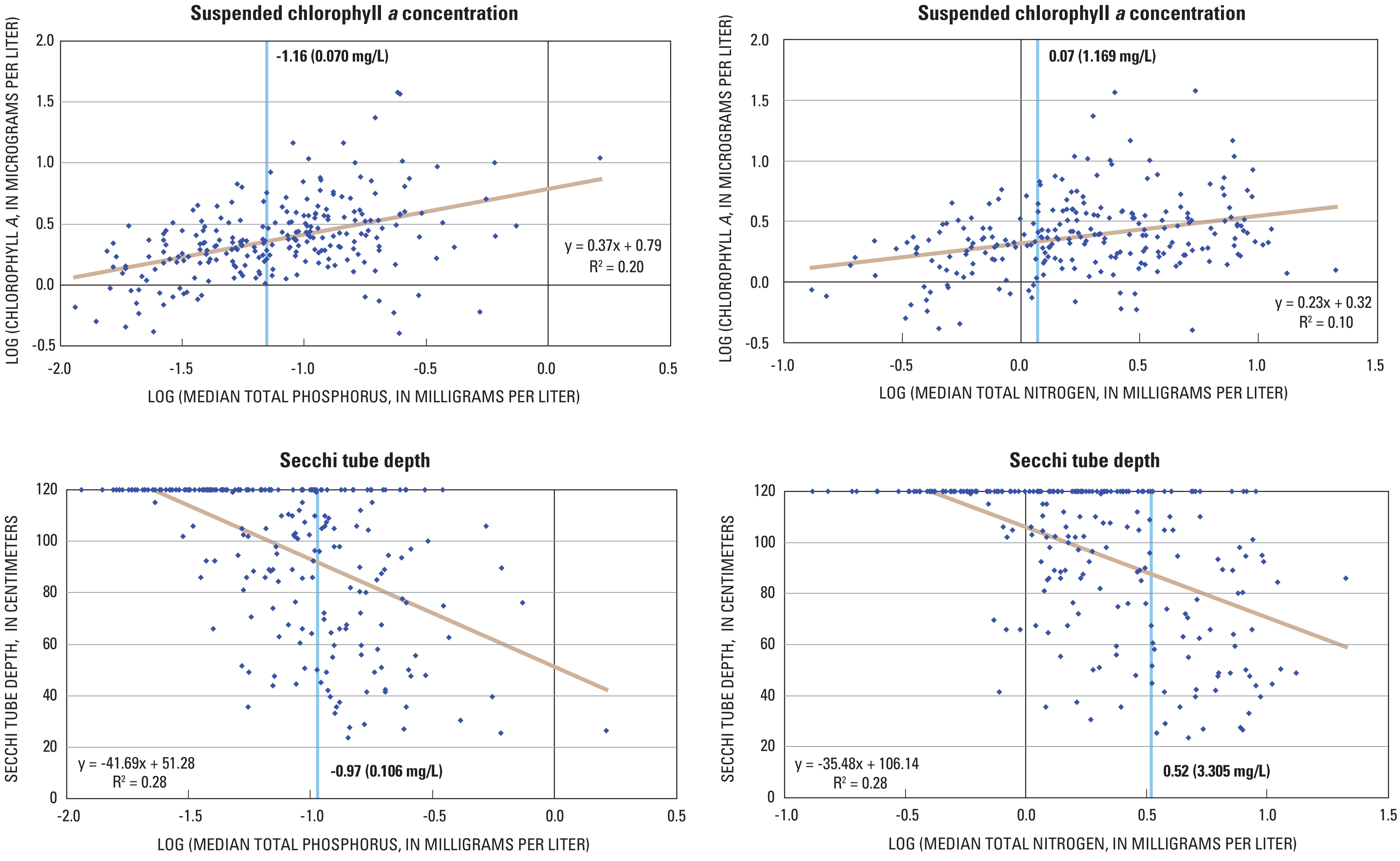


Figure 7. Suspended chlorophyll *a* (SCHL) concentrations and Secchi tube depths (SDs) as a function of median total phosphorus and total nitrogen concentrations (logarithm to base 10 transformation) for the studied wadeable streams in Wisconsin. Linear-regression lines and coefficients of determination (R^2) are given on each graph.

Effects of Multiple Environmental Characteristics on Water Quality

Stepwise Regression

Forward stepwise regressions were done with all of the environmental characteristics to determine which three environmental characteristics best described the variance in P, N, and SCHL concentrations and SDs, done with only the nonanthropogenic (natural) characteristics to determine which of these characteristics best described the variance, and done with residualized characteristics (whose correlations with anthropogenic characteristics had been removed) best described the variance in the water-quality characteristics. Models with more than three variables did not significantly increase the amount of variance explained (accumulative R^2 values).

The percentage of total agriculture was the first variable incorporated into the model explaining variability in P concentrations; the second and third variables were log PtS and the percentage of loam deposits in the basin, respectively (table 6). Collectively, this model explained 56 percent of the variance in P concentrations. If the anthropogenic characteristics were omitted from the analysis, the erodibility of the soil was the first variable incorporated into the model, runoff was second, and the percentage of loam deposits was third. This model explained 44 percent of the variance. After the characteristics were adjusted to remove the anthropogenic effects, residualized loam deposits became the first variable incorporated into the model, residualized sand-and-gravel deposits was second, and residualized nonglacial deposits was third. This model collectively explained 19 percent of the variance in P_{Res}. The difference in the amount of variance explained by the first two regression models was caused by the removal of the effects of the anthropogenic characteristics that were not correlated with other environmental characteristics in the second model. The large difference in the amount of variance explained by the last two regressions was caused by the removal of all of the effects of the anthropogenic characteristics, including the independent (direct) effects and correlated (indirect) effects on the other variables.

The percentage of total forest in the basin was the first variable incorporated into the model explaining variability in N concentrations, precipitation was the second, and the percentage of row crops in the basin was the third. Collectively, this model explained 72 percent of the variance in N concentrations. If the anthropogenic characteristics were omitted from the analysis, air temperature was the first variable, soil slope was the second, and the clay content of the soil was the third. After the characteristics were adjusted to remove the anthropogenic effects, residualized clay deposits was the first variable included in the model, residualized air temperature was the second, and residualized peat deposits was the third. This model collectively explained 20 percent of the variance in N concentrations.

For both of these constituents, removing the anthropogenic effects greatly reduced the predictability of the regression models. When the direct and indirect effects of the anthropogenic characteristics were included in the models, 56 to 72 percent of the variance could be explained with three variables; however, when all of the anthropogenic effects were removed, the models only explained about 20 percent of the variance.

To develop regression models to predict SCHL and SD, all of the water-quality characteristics and environmental characteristics (including the physical-habitat characteristics, such as shading, streambank erosion, and so on) were included. The percentage of total forest in the basin was the first variable incorporated into the model to predict SCHL, TKN was the second, and watershed area was the third. Collectively, this model explained 42 percent of the variance in SCHL concentrations. If the anthropogenic characteristics were simply omitted from the analysis, TKN was the first variable selected, watershed area was the second, and soil erodibility was the third. After the environmental characteristics were adjusted to remove the anthropogenic effects, TKN was the first variable incorporated in the model, watershed area was the second, and P was the third. This model explained 36 percent of the total variance.

The percentage of row-crop agriculture in the basin was the first variable incorporated into the model to predict SDs, percentage of clay deposits was the second, and TKN was the third. Collectively, this model explained 43 percent of the variance in SDs. When the anthropogenic characteristics were omitted, total P was the first variable incorporated into the model, the percentage of clay deposits was the second, and DP was the third. After the environmental characteristics were adjusted to remove the anthropogenic effects, total P was the first variable included in the model, total N was the second, and DP was the third. This model explained 42 percent of the total variance.

Removing the anthropogenic effects on the environmental characteristics had little effect on the predictability of the SCHL and SD models when nutrients were included in the models (second and third models). The anthropogenic characteristics were strongly correlated with nutrient concentrations, and therefore, similar predictability was obtained by including either the anthropogenic characteristics or the nutrient concentrations. The SD models

Table 6. Results of forward stepwise-regression analyses used to explain the variance in raw and residualized water-quality concentrations in the studied wadeable streams in Wisconsin.

[all regressions were on log-transformed concentrations; r, Pearson correlation coefficient; R^2, coefficient of determination for the one, two, and three variable models; Res, residualized]

Dependent variable	First variable	Second variable	Third variable
	Total phosphorus (P)		
All environmental characteristics			
P	Total agriculture	Point-source loading	Loam deposits
r	0.66	0.34	0.24
Accumulative R^2	.44	.51	.56
No anthropogenic characteristics			
P	Erodibility	Runoff	Loam deposits
r	.54	-.54	.24
Accumulative R^2	.29	.38	.44
Residualized characteristics			
P_{Res}	Loam_{Res} deposits	$\text{Sand-and-gravel}_{\text{Res}}$ deposits	$\text{Nonglacial}_{\text{Res}}$ deposits
r	.30	-.29	-.16
Accumulative R^2	.09	.15	.19
	Total nitrogen (N)		
All environmental characteristics			
N	Total forest	Precipitation	Agriculture (row)
r	-.82	.29	.77
Accumulative R^2	.67	.69	.72
No anthropogenic characteristics			
N	Air temperature	Soil slope	Clay content of soil
r	.75	-.19	.51
Accumulative R^2	.56	.59	.61
Residualized characteristics			
N_{Res}	Clay_{Res} deposits	$\text{Air temperature}_{\text{Res}}$	Peat_{Res} deposits
r	-.35	.25	.16
Accumulative R^2	.12	.17	.20
	Suspended chlorophyll *a* (SCHL)		
All environmental characteristics			
SCHL	Total forest	Kjeldahl nitrogen	Watershed area
r	-.47	.46	.28
Accumulative R^2	.22	.33	.42
No anthropogenic characteristics			
SCHL	Kjeldahl nitrogen	Watershed area	Erodibility
r	.46	.28	.33
Accumulative R^2	.21	.30	.41
Residualized characteristics			
SCHL_{Res}	Kjeldahl nitrogen	$\text{Watershed area}_{\text{Res}}$	Total phosphorus
r	.46	.28	.44
Accumulative R^2	.21	.30	.36
	Secchi tube depth (SD)		
All environmental characteristics			
SD	Agriculture (row)	Clay deposits	Kjeldahl nitrogen
r	-.55	-.32	-.37
Accumulative R^2	.30	.37	.43
No anthropogenic characteristics			
SD	Total phosphorus	Clay deposits	Dissolved phosphorus
r	-.53	-.32	-.44
Accumulative R_2	.28	.36	.44
Residualized characteristics			
SD_{Res}	Total phosphorus	Total nitrogen	Dissolved phosphorus
r	-.53	-.53	-.44
Accumulative R^2	.28	.36	.42

that included both P concentration and percentage of clay deposits were significantly better than models that only included P concentrations.

Redundancy Analysis

Each of the four primary water-quality characteristics (P, N, SCHL, and SD) has been shown to be influenced by the anthropogenic characteristics and other characteristics in the watershed upstream from the assessment site. The relative importance of these factors differs for each characteristic. The relative importance of each of the general types of environmental characteristics thought to influence the distribution of overall water quality, as defined by these four water-quality characteristics, was determined by partial RDA.

In the partial RDA, the environmental characteristics were divided into three main categories: anthropogenic/land-use characteristics, soil and surficial-deposit characteristics, and basin characteristics (table 2). A two-step process was used to select four characteristics to describe each category. The characteristics initially chosen were those significantly correlated with the individual water-quality characteristics. The final characteristics within a specific category were chosen to have minimal correlations among themselves. For example, the percentage of agriculture and the percentage of forest, although both strongly correlated with water quality, were not both chosen for the anthropogenic/land-use category because they were strongly correlated to one another. The anthropogenic/land-use category was described by the percentages of total agriculture, urban, and open wetland, and the log PtS in the basin. Soils/surficial deposits were described by the clay content and organic-matter content of the soils, permeability, and erodibility. The basin characteristics were described by log (watershed area), precipitation, runoff, and basin slope. The anthropogenic/land-use characteristics category reflects the extent of human intervention—characteristics that may be altered. The soil and surficial-deposit characteristics and basin characteristics categories reflect the geological and topographical effects—characteristics that cannot be altered.

The total variance in the four water-quality characteristics was separated into five categories: 1) variance explained by the anthropogenic/land-use characteristics alone, 2) variance explained by soil and surficial-deposit characteristics alone, 3) variance explained by the basin characteristics alone, 4) variance explained by the interactions of anthropogenic/land-use, soil and surficial-deposit, and basin characteristics (joint variation that could not be assigned to a single category), and 5) variance not explained by these characteristics. Results from the partial RDA indicated that these 12 characteristics collectively explained 43 percent of the variance in water quality (P, N, SCHL, and SD; $p < 0.001$). Independently, the anthropogenic/land-use characteristics explained 12 percent of the explained variance (5 percent of the total variance; $p < 0.001$; fig. 8), the soil and surficial-deposit characteristics explained 17 percent of the explained variance (7 percent of the total variance; $p < 0.001$), and the basin characteristics explained 4 percent of the explained variance (2 percent of the total variance; $p < 0.15$). The shared contribution or interactions of all three general categories of environmental characteristics explained about 67 of the explained variance or 30 percent of the total variance. Therefore, much of the variance in water quality could not be explained by a single category of environmental characteristics.

RDA was also used to determine which environmental characteristics explained the most variance in overall water quality (P, N, SCHL, and SD). In RDA, as in principal-component analysis, the explained variance is separated into a series of ordination (canonical) axes. Almost all of the variance in this analysis was explained on the first canonical axis. Therefore, examination of the scores on the first axis (table 7) enables the determination of the importance of individual environmental characteristics and water-quality characteristics that have the most explained variance. Total N and SD had the highest scores (absolute values) on the first canonical axis, which indicates that more of their variance was explained by the environmental characteristics than were the variances in P and SCHL. The most important characteristics explaining the variance in these four water-quality characteristics in descending order of axis score were the percentage of agriculture in the basin, the clay content of the soil, soil erodibility, runoff, and permeability. The relations between the environmental characteristics and water-quality characteristics can be determined by comparing their respective axis scores. Areas with high percentages of agriculture, high clay-content soils, highly erodible soils, low runoff, and low soil permeability had the highest nutrient and SCHL concentrations and worst water clarity. These results agree with the findings of the correlation and regression analyses.

A multiple-regression approach (similar to partial RDA) was performed to determine how the total variance in SDs and SCHL, independently, could be separated into four categories: 1) variance explained by the 5 nutrients alone (P, DP, N, NO_3-N, and TKN), 2) variance explained by environmental characteristics alone (the same 12 environmental characteristics used in the partial RDA for water quality), 3) variance explained by the interactions between nutrients and environmental characteristics, and 4) variance not explained by these characteristics. In this approach, three regressions were performed for SD and for SCHL; multiple regressions with all 17 variables, with only the 5 nutrients, and with only the 12 environmental characteristics. The first regression with all 17 variables was used to determine the total variance explained by all of the variables. The other two regressions were used to partition the variance between the three categories. The amount of variance explained by the interaction of the two categories was determined by equation 10:

$$EV_{Interactions} = (EV_{Nutrients} + EV_{Environmental} - EV_{All\ Variables}), \quad (10)$$

where

EV is the explained variance by the specified group of variables.

The variance explained by each subset of variables alone was then determined by subtracting the variance explained by the interactions between the variables from the total variance explained by a subset of variables. For example, the variance explained by the nutrients alone is equal to the coefficient of determination for the nutrient regression minus the variance explained by the interactions. Results from this analysis indicated that these characteristics collectively explained about 55 percent of the variance in both SDs and SCHL concentrations. Nutrients alone explained 22–23 percent of the explained variance in each of these characteristics (fig. 9). The environmental characteristics alone explained more of the variance in SCHL concentrations than in the SDs, whereas the interactions between the nutrients and environmental characteristics explained more of the variance in SDs than in SCHL concentrations. Again, much of the total variability in these two parameters could not be explained by the nutrients alone.

Environmental Characteristics Most Strongly Related to Water Quality

Correlations, stepwise regressions, and regression-tree analyses all indicated that the anthropogenic/land-use characteristics (primarily the amount of forest and agriculture in the basin) were the characteristics most strongly related to water quality. Simply omitting the anthropogenic characteristics and reanalyzing the data, however, may not provide a true indication of what factors affect water quality because some of the remaining factors may be correlated with the anthropogenic characteristics of the basins. For example, air temperature and clay content of the soil were both strongly correlated with many water-quality characteristics and with the percentage of agriculture in the basin (table 4). Therefore, it is difficult to determine whether it was these factors or the indirect effects of agriculture that affected water quality. The clay content of the soil has been demonstrated to have a strong effect on the water quality of Midwestern streams (Robertson, 1997; Robertson and others, 2006); however, the effects of air temperature seem questionable and may be indirectly related to the anthropogenic characteristics.

Various approaches were used to determine which other environmental characteristics were most strongly related to water quality. The results of partial RDA indicated that soil characteristics were important; however, much of the variance explained by soil characteristics was also explained by the anthropogenic/land-use characteristics.

Table 7. Results from redundancy analysis between water-quality and environmental (anthropogenic/land-use, basin, and soil and surficial-deposit) characteristics for the studied wadeable streams in Wisconsin.

[log, logarithm to base 10 transformation]

	First canonical axis score
Water-quality characteristics	
Total phosphorus – log	0.54
Total nitrogen – log	.67
Suspended chlorophyll *a* – log	.48
Secchi tube depth	-.65
Anthropogenic/land-use characteristics	
Total agriculture	.81
Urban	.25
Open wetland	.19
Point-source loading of phosphorus – log	.31
Basin characteristics	
Watershed area – log	.00
Precipitation	.23
Runoff	-.61
Basin slope	.11
Soil and surficial-deposit characteristics	
Clay content of the soil	.78
Erodibility	.63
Organic-matter content	-.24
Permeability	-.58

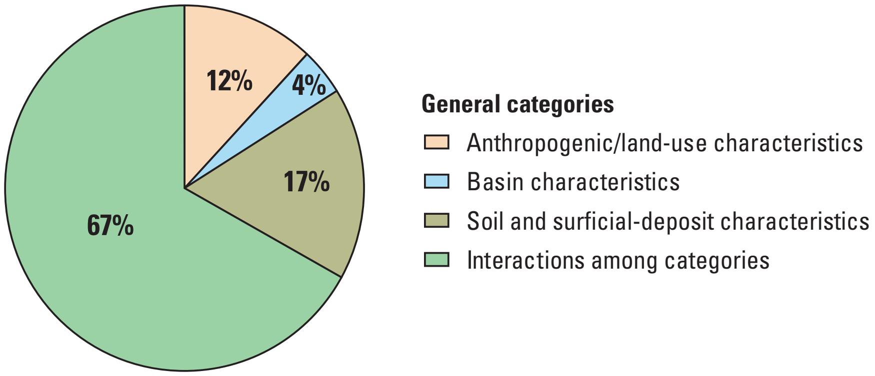


Figure 8. Percentages of explained variance in water quality (total phosphorus, total nitrogen, and suspended chlorophyll *a* concentrations and Secchi tube depth) described by anthropogenic/land-use, basin, soil and surficial-deposit characteristics, and interactions among categories (variance that can not be explained by a single category) for the studied wadeable streams in Wisconsin. [%, percentage of explained variance]

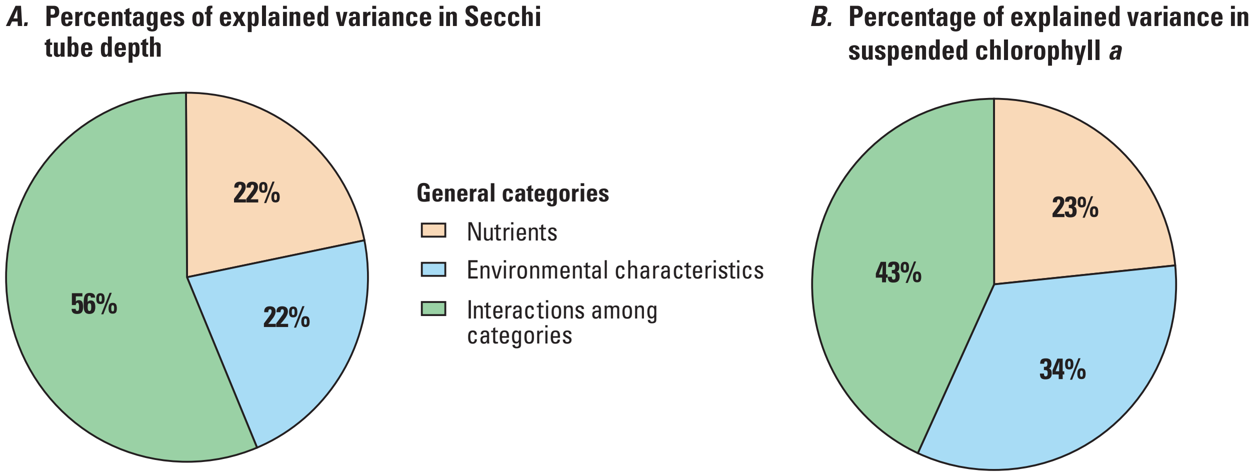


Figure 9. Percentages of explained variance in ***A***, Secchi tube depths and ***B***, suspended chlorophyll *a* concentrations described by nutrients, environmental characteristics (anthropogenic/land-use, soil, and surficial-deposit characteristics), and interactions among categories (variance that can not be explained by a single category) for the studied wadeable streams in Wisconsin. [%, percentage of explained variance]

Results of RDA indicated that the most important soil characteristics were the clay content of the soils, soil erodibility, and soil permeability. The results also indicated that the amount of runoff was also strongly related to water quality.

The results of the residualization analyses indicated that the natural (nonanthropogenic) environmental characteristics most strongly related to the distribution of P were soil permeability, the soil slope, and the percentage of sand-and-gravel deposits. The natural environmental characteristics most strongly related to the distribution of N were the percentage of clay deposits and other basin characteristics. A few of the natural characteristics, however, such as clay content of the soil and soil erodibility, were so strongly correlated with the percentage of agriculture in the basin that their relation to water quality may have been removed by the residualization approach. Stepwise regressions with residualized environmental characteristics only explained about 20 percent of the variance in P and N concentrations.

In addition to anthropogenic/land-use characteristics, residualization analyses indicated that the distribution of SCHL concentrations and SDs were related to concentrations of P and various forms of nitrogen. Other important natural characteristics related to SCHL concentrations were the slope of the basin and the soils, the organic-matter content of the soil, and some surficial-deposit characteristics. Other important natural characteristics related to SDs were the clay content of the soil and surficial deposits.

Regionalization Schemes for Reference Water Quality and the Response in Water Quality to Changes in Land Use

The two primary regionalization schemes considered in choosing the sites for this study and for developing nutrient criteria for Wisconsin were the level III ecoregions of Omernik and others (2000) and the environmental phosphorus zones of Robertson and others (2006) (fig. 2). In addition, a third regionalization scheme was considered after the sites were chosen and sampled. In this third scheme, the EPZs were refined based on the water-quality and environmental characteristics of only the 240 sites in this study rather than from information from sites throughout the entire upper Midwest. To refine the EPZs in figure 2B, the SPARTA approach (Robertson and others, 2006) was used with land-use-adjusted (residualized) water-quality and environmental characteristics computed for each site to remove the direct and indirect effects of land use (and PtS). P concentrations and many of the natural environmental characteristics related to P (such as the clay content of the soil and soil erodibility) were so strongly correlated with land use (and PtS) that the residualization process almost completely removed their relations with residualized P concentrations. These correlations resulted in a regionalization scheme that explained very little variance in P concentrations and which did not demonstrate clear regional patterns. Therefore, the revised EPZ regionalization scheme based on data from only the 240 sites in this study was discarded.

The primary purpose of most regionalization schemes is to minimize the variability in water quality within regions and maximize the variability among regions. This purpose was the reasoning behind the use of Omernik's ecoregions as the building block for USEPA's nutrient ecoregions. The distribution of agriculture differs among the four level III ecoregions in Wisconsin (fig. 10A). Almost 90 percent of the sites in the NLF had less than 8 percent agriculture in their basins; whereas, over 75 percent of the sites in the SWTP had over 50 percent agriculture in their basins. The use of land-use information to delineate specific regions may minimize the variability in water quality within the ecoregions across the upper Midwest and in Wisconsin because land use is the most important factor influencing the geographic distribution of most water-quality characteristics. The USEPA, however, has stated that the environmental characteristics used to delineate regions of similar reference or potential water quality should be restricted, as much as possible, to those that are intrinsic, or natural, and not the result of human activities (U.S. Environmental Protection Agency, 2000a). Therefore, the most appropriate stratification scheme for developing nutrient criteria for Wisconsin should be one that delineates areas with different reference or potential nutrient concentrations (not necessarily actual water quality), different responses in nutrient concentrations to changes in land use, and different biotic responses to changes in nutrients.

Reference Water-Quality Conditions

Various approaches have been used to define reference water quality for specific areas. Reference water quality is also referred to as background or potential water quality in other publications. In defining reference conditions for national nutrient criteria, the USEPA has suggested that a value based on the frequency distribution of the data available for a specific area could be used to define a reference condition. The USEPA has suggested that the value indicative of reference conditions be defined as the lower 25th percentile of all the data for that area or the upper (or worst) 75th percentile of the data for a subset of streams thought to be minimally impacted (U.S. Environmental Protection Agency, 2000a). Because it is often difficult to determine which sites are minimally impacted, the lower 25th percentile is the more common approach and the one that has been used by the USEPA to define their proposed water-quality criteria (table 1; U.S. Environmental Protection Agency, 2004).

One of the problems with the percentile approach (25th percentile) is that differences in land use within the ecoregions and zones can strongly affect the results for characteristics correlated with land use, such as the water-quality characteristics examined in this study. The reference P and N concentrations based on the percentile approach were directly related to the percentage of the sites within each ecoregion or zone dominated by agriculture. In the ecoregions examined in this study, the percentages of sites dominated by agriculture decrease from the SWTP to DFA to NCHF to NLF (fig. 10A). These differences in land use result in a gradient of conditions affecting water quality, and result in P, N, and SCHL concentrations and SDs at the 25th percentile that follow the same gradient (25th percentiles in table 8). For the EPZs,

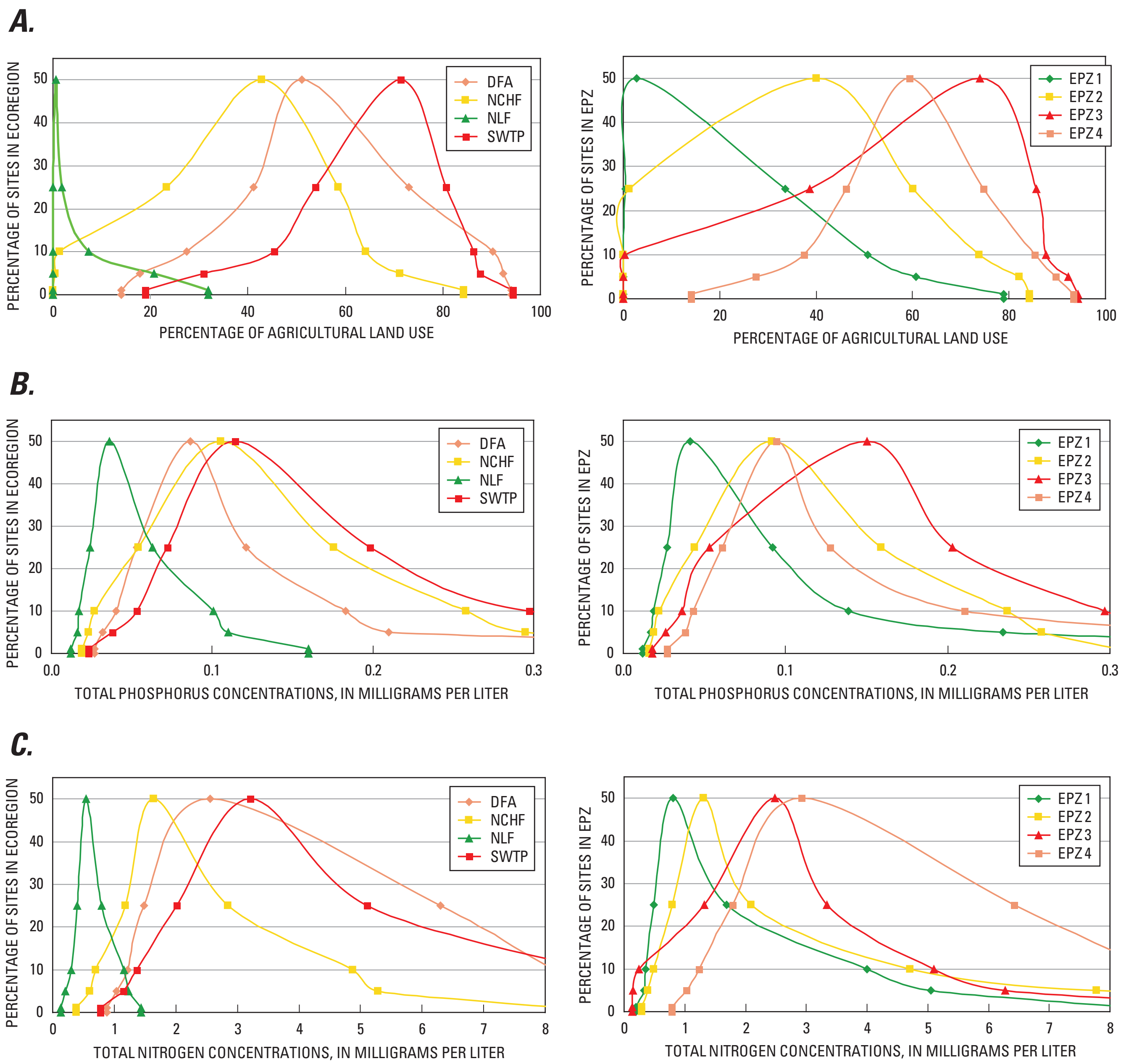


Figure 10. Percentiles of ***A***, total agriculture in the watersheds, ***B***, total phosphorus, and ***C***, total nitrogen in streams in the level III ecoregions and environmental phosphorus zones (EPZs) for the studied wadeable streams in Wisconsin. [DFA, Driftless Area; NCHF, North Central Hardwood Forests; NLF, Northern Lakes and Forests; and SWTP, Southeastern Wisconsin Till Plains]

Table 8. Reference conditions for total phosphorus, total nitrogen, and suspended chlorophyll *a* concentrations, and Secchi tube depths in the environmental phosphorus zones and level III ecoregions for wadeable streams in Wisconsin. Median reference values, standard errors, and upper 95-percent confidence limits were estimated with the multiple linear-regression approach.

[USEPA, U.S. Environmental Protection Agency; EPZ, environmental phosphorus zone; DFA, driftless area; NCHF, North Central Hardwood Forests; NLF, Northern Lakes and Forests; SWTP, Southeastern Wisconsin Till Plains; --, no data; mg/L, milligram per liter; µg/L, microgram per liter; cm, centimeter; >, greater than; --, not available]

Zone/ ecoregion	Number of sites	Multiple linear-regression approach			USEPA criteria	Percentiles						
		Median reference	Standard error	Upper 95-percent confidence limit		0	10	25	50	75	90	100
						Total phosphorus (mg/L)						
EPZ 1	69	0.032	0.003	0.039	--	0.012	0.019	0.027	0.041	0.092	0.139	0.527
EPZ 2	58	.042	.006	.054	--	.016	.022	.044	.092	.159	.237	.304
EPZ 3	25	.029	.006	.043	--	.018	.036	.053	.150	.203	.297	.741
EPZ 4	84	.035	.009	.055	--	.027	.043	.061	.095	.128	.210	1.641
DFA	58	.040	.008	.057	.070	.027	.040	.053	.087	.121	.183	.611
NCHF	48	.041	.009	.060	.029	.019	.027	.054	.106	.176	.258	.527
NLF	62	.032	.002	.036	.010	.012	.017	.024	.036	.063	.101	.160
SWTP	72	.025	.008	.044	.080	.023	.053	.072	.114	.199	.297	1.641
						Total nitrogen (mg/L)						
EPZ 1	69	.557	.057	.676	--	.191	.353	.486	.808	1.690	4.005	8.240
EPZ 2	58	.632	.066	.771	--	.298	.492	.793	1.303	2.095	4.710	21.260
EPZ 3	25	.367	.103	.601	--	.131	.244	1.318	2.481	3.340	5.095	10.465
EPZ 4	84	.690	.161	1.050	--	.780	1.240	1.780	2.920	6.420	8.720	13.205
DFA	58	.643	.118	.901	1.880	.882	1.223	1.489	2.563	6.300	8.145	11.385
NCHF	48	1.132	.229	1.637	.460	.391	.698	1.188	1.646	2.843	4.870	8.240
NLF	62	.509	.038	.587	.200	.131	.298	.403	.548	.793	1.158	1.435
SWTP	72	.811	.258	1.409	1.590	.777	1.361	2.020	3.204	5.110	8.720	21.260

Table 8. Reference conditions for total phosphorus, total nitrogen, and suspended chlorophyll *a* concentrations, and Secchi tube depths in the environmental phosphorus zones and level III ecoregions for wadeable streams in Wisconsin—Continued. Median reference values, standard errors, and upper 95-percent confidence limits were estimated with the multiple linear-regression approach.

[USEPA, U.S. Environmental Protection Agency; EPZ, environmental phosphorus zone; DFA, driftless area; NCHF, North Central Hardwood Forests; NLF, Northern Lakes and Forests; SWTP, Southeastern Wisconsin Till Plains; --, no data; mg/L, milligram per liter; µg/L, microgram per liter; cm, centimeter; >, greater than; --, not available]

Zone/ ecoregion	Number of sites	Multiple linear-regression approach			USEPA criteria	Percentiles						
		Median reference	Standard error	Upper 95-percent confidence limit		0	10	25	50	75	90	100
Suspended chlorophyll *a* (µg/L, trichromatic method)												
EPZ 1	69	1.56	0.17	1.93	--	0.40	0.65	1.37	1.95	2.63	3.97	14.64
EPZ 2	58	1.71	.24	2.23	--	.45	1.03	1.56	2.34	3.86	5.60	38.01
EPZ 3	25	1.03	.24	1.55	--	.77	1.14	1.62	2.48	3.80	7.11	36.63
EPZ 4	84	1.17	.25	1.72	--	.94	1.35	1.86	2.44	3.48	5.94	23.51
DFA	58	1.48	.25	2.02	--	.94	1.35	1.75	2.16	2.90	4.12	14.64
NCHF	48	1.73	.41	2.65	--	.40	.74	1.49	2.43	3.84	5.78	7.46
NLF	62	1.49	.12	1.74	--	.41	.77	1.08	1.71	2.34	3.06	4.82
SWTP	72	1.44	.54	2.71	--	1.19	1.62	2.02	3.07	5.22	10.10	38.01
Secchi tube depth (cm)												
EPZ 1	69	115.0	2.5	>120.0	--	35.5	98.0	>120.0	>120.0	>120.0	>120.0	>120.0
EPZ 2	58	117.7	4.9	>120.0	--	27.0	47.5	88.5	117.5	>120.0	>120.0	>120.0
EPZ 3	25	109.5	10.6	>120.0	--	23.5	42.5	51.5	76.0	102.5	>120.0	>120.0
EPZ 4	84	>120.0	10.2	>120.0	--	25.5	41.5	65.3	95.5	>120.0	>120.0	>120.0
DFA	58	118.6	9.2	>120.0	--	35.5	50.0	67.5	98.0	>120.0	>120.0	>120.0
NCHF	48	104.4	6.2	116.9	--	35.5	81.0	102.3	>120.0	>120.0	>120.0	>120.0
NLF	62	116.5	1.7	119.8	--	66.0	102.0	>120.0	>120.0	>120.0	>120.0	>120.0
SWTP	72	>120.0	13.4	>120.0	--	23.5	33.0	47.8	84.0	108.3	>120.0	>120.0

the percentages of agriculture in the basins decreased from EPZ 3 to EPZ 4 to EPZ 2 to EPZ 1, and results for the nutrient concentrations and SDs at the 25th percentile followed the same gradient except for EPZ 3 and EPZ 4, which were sometimes reversed (table 8). Therefore, the values of the water-quality characteristics at the 25th percentile do not appear to represent the true, or even relative, reference conditions for these different ecoregions and zones. The differences in the values at the 25th percentile represent the differences in the types of land uses among the different ecoregions and zones.

Another approach to estimate reference concentrations is a multiple linear-regression model that relates water quality to anthropogenic characteristics (Dodds and Oakes, 2004). After calibrating the model with data from a specific area, an estimate of reference conditions in the absence of anthropogenic activities can be obtained by setting the variables describing anthropogenic characteristics to 0 (in this study, setting percentage of agricultural area to 0, percentage of urban area to 0, and PtS to 0). These relations can also be used to place confidence intervals on the reference concentrations. Reference conditions were computed for each level III ecoregion and EPZ (fig. 2) based on all of the data available for each area with the general multiple linear-regression model:

$$\text{Log}\ \text{P}_{\text{Predicted}} = a + b\,\text{Ag\%} + c\,\text{Urb\%} + d\,\text{Log(PtS)}, \qquad (11)$$

where

a, b, c and d are empirical coefficients determined for each area.

The general form of this model is similar to that used to estimate residualized concentrations in equations 3, 5, 7, and 9 (pages 24 and 25). Because this type of model estimates the logarithm of the reference concentration, the median reference concentration for each area was estimated as 10^a. For each level III ecoregion and EPZ, the median reference condition, the standard error of the reference condition, and the upper bound of the 95-percent confidence interval of the reference condition were estimated (table 8). A bias correction is typically applied to results for mean values obtained by logarithmic regression; however, the bias correction was not used here because of the choice of median rather than mean reference conditions.

Total Phosphorus

Reference concentrations for P ranged from 0.029 mg/L in EPZ 3 to 0.042 mg/L in EPZ 2, with the upper 95-percent confidence intervals ranging from 0.039 mg/L in EPZ 1 to 0.055 mg/L in EPZ 4 (table 8). No statistical differences are present among the reference concentrations for these zones. The regression approach was also used to estimate reference concentrations for each level III ecoregion. Reference concentrations ranged from 0.025 mg/L in the SWTP to 0.041 mg/L in the NCHF. The upper 95-percent confidence intervals ranged from 0.036 mg/L in the NLF to 0.060 mg/L in the NCHF. Again, no statistical differences are present among these concentrations. The standard errors for the reference concentrations of the EPZs were similar in magnitude to those of the ecoregions (from 0.002 to 0.009 mg/L); therefore, neither regionalization scheme was better in estimating reference P concentrations. Both regionalization schemes indicate that one reference P concentration would be appropriate for wadeable Wisconsin streams: 0.03–0.04 mg/L with an upper 95-percent confidence limit of 0.04–0.06 mg/L.

Total Nitrogen

Reference concentrations for N ranged from 0.367 mg/L in EPZ 3 to 0.690 mg/L in EPZ 4, with the upper 95-percent confidence intervals ranging from 0.601 mg/L in EPZ 3 to 1.050 mg/L in EPZ 4 (table 8). Reference concentrations for EPZ 3 were lower than those for the other EPZs; however, the differences were not significant at $p < 0.05$. Reference concentrations ranged from 0.509 mg/L in the NLF to 1.132 mg/L in the NCHF. The upper 95-percent confidence intervals ranged from 0.587 mg/L in the NLF to 1.637 mg/L in the NCHF. Reference concentrations for the NCHF were slightly higher than those for the other ecoregions; however, no statistical differences were present between these concentrations. The standard errors of the reference concentrations of the EPZs ranged from 0.066 to 0.161 mg/L, compared to 0.038 to 0.258 mg/L for the level III ecoregions; the 95-percent confidence limits for the EPZs were generally smaller than those of the ecoregions. Therefore, the EPZs provided more precise estimates of reference N concentrations, although the differences were not significant at $p < 0.05$. On the basis of the EPZ regionalization scheme, two reference N concentrations may be appropriate for wadeable Wisconsin streams: 0.6–0.7 mg/L in all streams except those in EPZ 3, where 0.4 mg/L may be more appropriate.

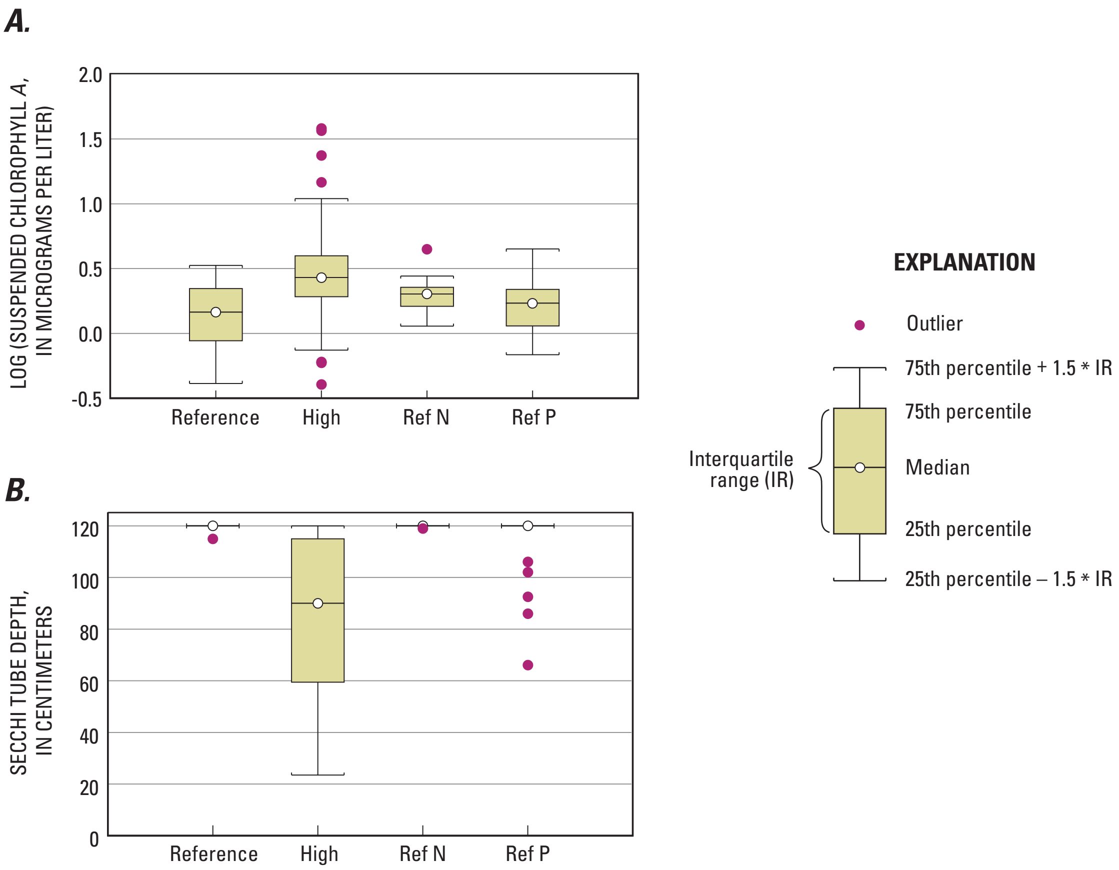


Figure 11. ***A***, suspended chlorophyll *a* (SCHL) concentrations and ***B***, Secchi tube depths (SDs) in Reference sites, High (nonreference) sites, and sites with only reference total nitrogen (Ref N sites) or reference total phosphorus (Ref P sites) concentrations in the studied wadeable streams in Wisconsin.

Suspended Chlorophyll *a*

Reference concentrations for SCHL ranged from 1.03 µg/L in EPZ 3 to 1.71 µg/L in EPZ 2, with the upper 95-percent confidence intervals ranging from 1.55 µg/L in EPZ 3 to 2.28 µg/L in EPZ 2 (table 8). Reference concentrations for EPZ 3 were lower than those for the other EPZs; however, the differences were not significant at $p < 0.05$. Reference concentrations ranged from 1.44 to 1.73 µg/L in the four level III ecoregions, with the upper 95-percent confidence intervals ranging from 1.74 µg/L in the NLF to 2.71 µg/L in the SWTP. Again, the differences were not significant at $p < 0.05$. The standard errors for the reference concentrations of the EPZs ranged from about 0.17 to 0.25 µg/L compared to 0.12 to 0.54 µg/L for the ecoregions; the 95-percent confidence limits for the EPZs were generally smaller than those of the ecoregions. Therefore, the EPZs provided more precise estimates of reference SCHL concentrations, although the differences were not significant at $p < 0.05$. On the basis of the EPZ regionalization scheme, two reference SCHL concentrations may be appropriate for wadeable Wisconsin streams: 1.2–1.7 µg/L in all streams except those in EPZ 3, where 1.0 µg/L may be more appropriate.

Reference SCHL concentrations and the relative importance of P and N in controlling or limiting SCHL at low nutrient concentrations was also estimated by examining the SCHL concentrations in sites with either or both reference P and reference N concentrations. For this analysis, the 240 sites were divided into five categories: reference sites (Reference, fig. 11)—36 sites with both P concentrations at or below the 0.04-mg/L reference concentration and N concentrations at or below the 0.70-mg/L reference concentration; reference P sites (Ref P)—22 sites with P concentrations at or below the reference concentration, but with N concentrations above the reference concentration; reference N sites (Ref N)—10 sites with N concentrations at or below the reference concentration, but with P concentrations above the reference concentration; high nutrient-concentration sites (High)—135 sites with both P and N concentrations above their respective upper 95-percent confidence limits for reference concentrations

(P concentrations above 0.06 mg/L and N concentrations above 1.0 mg/L); and nonclassified sites—37 sites with P and N concentrations above their respective reference concentrations but below their upper 95-percent confidence limits (these sites were not included in this analysis and not included in figure 11). Comparison of the SCHL concentrations for the Reference sites with those of the Ref P and Ref N sites is similar to the comparison of SCHL concentrations for nutrient-addition experiments. SCHL concentrations for Ref P sites are similar to SCHL concentrations for experiments with N additions, and the SCHL concentrations for the Ref N sites are similar to those for experiments with P additions.

The approach described above was used to estimate the reference SCHL concentration for the entire State because nutrient concentrations at or below reference concentrations were primarily measured only in the northern part of the State. The median SCHL concentration of the Reference sites was 1.46 µg/L ($\log(1.46) = 0.16$), with the upper 75th percentile being 2.22 µg/L ($\log(2.22) = 0.35$), which was significantly less than the median concentration of 2.75 µg/L ($\log(2.75) = 0.44$) measured in the High sites (fig. 11A). It has been suggested by the USEPA that the upper 75th percentile of a subset of streams thought to be minimally impacted (Reference sites) may represent the reference condition; therefore, an alternative reference SCHL concentration for the entire State would be 2.22 µg/L. The reference values estimated with both approaches are less than those defined by the USEPA for nutrient ecoregions 7 and 8 when the trichromatic method of analysis is used (5.8 and 4.3 µg/L, respectively; table 1).

Comparing the median concentration for the Reference sites with the median concentrations for the Ref N and Ref P sites may provide an indication of whether P or N is more important in limiting the concentrations of SCHL in streams with nutrient concentrations near reference conditions (fig. 11A). The median SCHL concentrations for Ref P and Ref N sites were both higher than that for the Reference sites, although the median concentrations for these categories were not statistically different from one another at $p < 0.05$. The Ref N sites had a median SCHL concentration most different from that of the Reference sites; therefore, it appears that it may be more important to have low P concentrations than low N concentrations to limit SCHL concentrations (in other words, potential P limitation for sites near reference conditions).

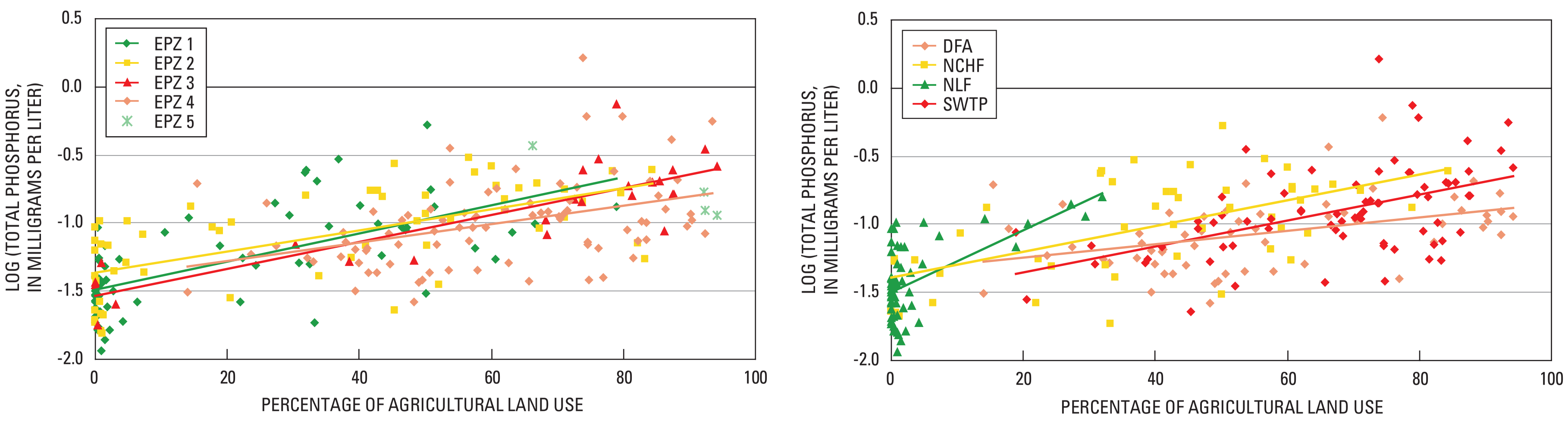
Secchi Tube Depth

Reference SDs ranged from about 110 cm in EPZ 3 to greater than 120 cm in EPZ 4, with all upper 95-percent confidence intervals greater than 120 cm (table 8). These differences were not statistically different from one another at $p < 0.05$. Reference SDs ranged from 104.4 cm in the NCHF to greater than 120 cm in the SWTP. The upper 95-percent confidence intervals ranged from 116.9 cm in the NCHF to greater than 120 cm in the DFA and the SWTP. These differences were not statistically different from one another at $p < 0.05$. The standard errors of the EPZs ranged from 2.5 to 10.6 cm, compared to 1.7 to 13.4 cm for the ecoregions. Therefore, the EPZs provided slightly more precise estimates of reference clarity than the level III ecoregions, although the differences were not statistically different from one another at $p < 0.05$. On the basis of the EPZ regionalization scheme, two reference SDs may be appropriate for wadeable Wisconsin streams: greater than 115 cm for all streams except those in EPZ 3, where greater than 110 cm may be more appropriate.

A reference SD was also determined by examining the sites at which both P and N concentrations were at or below their respective reference concentrations. The median SD measured at the Reference sites was greater than 120 cm, which was significantly greater than the median SD measured in the High sites (90 cm; fig. 11B). The lower 25th percentile of SDs at the Reference sites (equivalent to the worst 75th percentile of the minimally impacted sites) was greater than 120 cm; therefore, an alternative reference SD for the entire State would be greater than 120 cm. The median SDs for Ref P and Ref N sites were similar to that for the Reference sites (fig. 11B); therefore, a 120-cm Secchi tube was not long enough to determine whether small increases in P or N concentrations were more important in reducing water clarity.

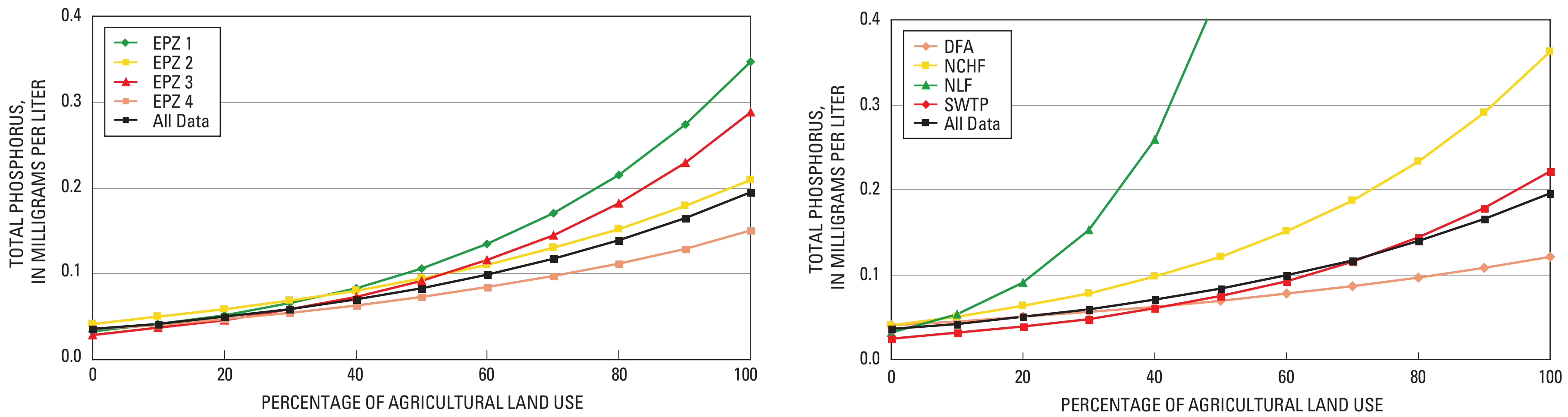
Responses of Nutrient Concentrations to Changes in Land Use

The responses of specific nutrients to changes in land use or other anthropogenic characteristics, such as PtS, can be estimated for each EPZ and ecoregion by the ways in which concentrations in each area change as a function of a specific anthropogenic characteristic. Overall, concentrations of P and N increase as the percentage of agricultural land increases (figs. 12A, B and 13A, B); however, variation in these responses may be associated with other



***A.* Total phosphorus by environmental phosphorus zone**

***B.* Total phosphorus by ecoregion**



***C.* Response as a function of the percentage of total agriculture**

***D.* Response as a function of the percentage of total agriculture**

Figure 12. Total phosphorus concentrations as a function of the percentage of agricultural land use in ***A***, environmental phosphorus zones (EPZs) and ***B***, level III ecoregions, and response curves for phosphorus concentrations as a function of the percentage of agriculture in the watershed, in ***C***, EPZs, and ***D***, level III ecoregions for wadeable streams in Wisconsin. [DFA, Driftless Area; NCHF, North Central Hardwood Forests; NLF, Northern Lakes and Forests; and SWTP, Southeastern Wisconsin Till Plains]

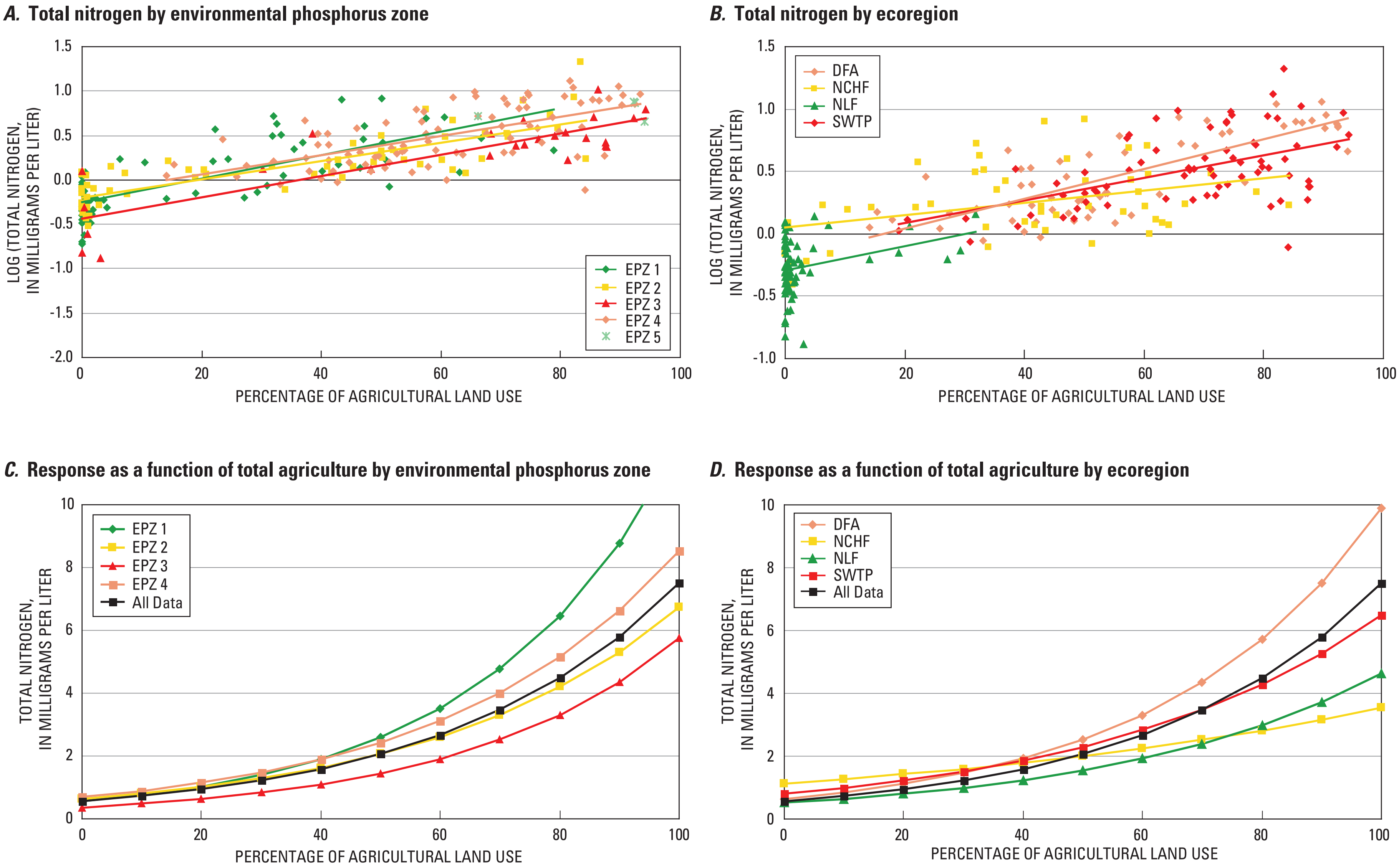


Figure 13. Total nitrogen concentrations as a function of the percentage of agricultural land use in ***A***, environmental phosphorus zones (EPZs) and ***B***, level III ecoregions, and response curves for nitrogen concentrations as a function of the percentage of agriculture in the watershed, in ***C***, EPZs, and ***D***, level III ecoregions for wadeable streams in Wisconsin. [DFA, Driftless Area; NCHF, North Central Hardwood Forests; NLF, Northern Lakes and Forests; and SWTP, Southeastern Wisconsin Till Plains]

anthropogenic characteristics such as differences in PtS or the percentage of urban area in the watershed. The four sites in EPZ 5 are plotted in figures 12 and 13 (and in the figures for other water-quality characteristics and biotic indices); however, these sites were not used to obtain regression lines or used in the multiple-regression analyses for P or any of the other water-quality characteristics.

A better approach to estimate the response of specific water-quality characteristics to changes in specific anthropogenic characteristics is the use of multiple-regression equations, such as those used to estimate reference concentrations. The response of a specific water-quality characteristic (for example, P) can be estimated for each EPZ and level III ecoregion shown in figure 2 by first determining values for the coefficients *a, b, c,* and *d*, in equation 11 on page 38 on the basis of all of the available data for each zone or ecoregion. Concentrations can then be predicted as a function of specific anthropogenic characteristics by varying the characteristic of interest while holding the other characteristics constant; in this case, at 0 percent or 0 PtS (figs. 12C, D and 13C, D). This approach removes the complicating effects of the other characteristics. Because this equation estimates the logarithm of the concentration, the final concentrations were computed as 10^{a}. A bias correction is typically applied to the results for mean values obtained by logarithmic regression; however, a bias correction was not used here because of the choice of median rather than mean concentrations.

Plots of the regression lines show that concentrations of P increase as the percentage of agricultural land increases in all of the EPZs and ecoregions (figs. 12A, B); however, a more detailed evaluation of the responses of P concentrations in the EPZs and ecoregions can be made with multiple-regression analysis. The response of P concentrations to changes in only the percentage of agricultural land was largest in EPZ 1, followed by EPZ3, EPZ 2, and EPZ 4 (fig. 12C). To determine if these responses were statistically significant from one another, the standard errors in the estimates of coefficient *b* were used to place 95-percent confidence limits on the estimated values (table 9). The responses in P concentrations in EPZ 1 and EPZ 3 were larger than the responses in the other EPZs, although their 95-percent confidence intervals for coefficient *b* slightly overlapped those of the other EPZs. Because most of the sites in EPZ 1 were in areas with limited agriculture, this difference may not reflect changes that would occur at higher percentages of agriculture. Changes in P concentrations as a function of only the percentage of agricultural land were largest in the NLF ecoregion, followed by NCHF, SWTP, and DFA (fig. 12D). The response in concentrations in the NLF was significantly larger than in any other ecoregion; however, similar to EPZ 1, the ranges in the percentage of agriculture and measured P concentrations were limited, and, therefore, this difference may simply reflect the distribution of the original data. The standard errors in the estimates of coefficient *b* for the EPZs ranged from 0.12 to 0.15 compared to 0.13 to 0.40 for the ecoregions. Therefore, the EPZs provided better estimates of the response to changes in the amount of agriculture than the level III ecoregions. Based on the EPZ regionalization scheme, subdividing wadeable streams in Wisconsin into two categories seems appropriate: streams in areas with high clay-content soils (EPZ 3), which respond more dramatically to changes in the amount of agriculture, and streams in the rest of the State.

Concentrations of N also increase as the percentage of agricultural land increases in all of the EPZs and ecoregions (fig. 13). The responses in concentrations in EPZ 1 and EPZ 4 were larger than the responses in the other EPZs, and the response in concentrations in EPZ 3 was smaller than those in the other EPZs; however, these differences were not statistically significant at $p < 0.05$. The changes in N concentrations were largest in the DFA, followed by SWTP, NLF, and NCHF. The response in concentrations in the DFA was significantly larger than in the NCHF, but not significantly larger than in the other ecoregions at $p < 0.05$. The response in concentrations in EPZ 1 was larger than in any other EPZ and the response in NLF was smaller than in any other ecoregion; however, this difference may simply reflect the distribution of the original data. The standard errors in the estimates of coefficient *b* for the EPZs ranged from 0.10 to 0.16 compared to 0.12 to 0.40 for the ecoregions (table 9). Therefore, the EPZs provided better estimates of the response to changes in the percentage of agricultural land use than the level III ecoregions. Based on the EPZ regionalization scheme, subdividing wadeable streams in Wisconsin into two categories seems appropriate: streams in areas with clay soils (EPZ 3), which respond less dramatically to changes in the amount of agriculture, and streams in the rest of the State.

Table 9. Responses to changes in the percentage of agricultural land use in the watershed. Estimated values for coefficient *b* for total phosphorus, total nitrogen, and suspended chlorophyll *a* concentrations, and Secchi tube depths in environmental phosphorus zones and level III ecoregions for wadeable streams in Wisconsin.

[*b*, factor associated with the percentage of agriculture in the watershed (eq. 11 in the text on page 38); mg/L, milligram per liter; µg/L, microgram per liter; cm, centimeter, EPZ, environmental phosphorus zone; DFA, Driftless Area; NCHF, North Central Hardwood Forests; NLF, Northern Lakes and Forests; SWTP, Southeastern Wisconsin Till Plains]

Zone/ecoregion	Estimated value for *b*	Standard error for *b*	Upper 95-percent confidence value for *b*
Total phosphorus			
EPZ 1	1.03	0.15	1.33
EPZ 2	0.70	.13	0.96
EPZ 3	.99	.12	1.23
EPZ 4	.63	.15	.93
DFA	.48	.13	.74
NCHF	.95	.19	1.33
NLF	2.28	.40	3.08
SWTP	.95	.18	1.31
Total nitrogen			
EPZ 1	1.33	.14	1.61
EPZ 2	1.03	.10	1.23
EPZ 3	1.19	.16	1.51
EPZ 4	1.09	.14	1.37
DFA	1.19	.12	1.43
NCHF	.49	.18	.85
NLF	.96	.40	1.76
SWTP	.90	.17	1.24
Suspended chlorophyll *a*			
EPZ 1	.22	.16	.55
EPZ 2	.36	.14	.63
EPZ 3	.60	.13	.87
EPZ 4	.54	.13	.80
DFA	.35	.35	1.05
NCHF	.16	.20	.55
NLF	.93	.44	1.80
SWTP	.47	.20	.86
Secchi tube depth			
EPZ 1	-7.1	8.7	10.3
EPZ 2	-49.8	11.0	-27.8
EPZ 3	-53.0	15.4	-22.1
EPZ 4	-48.5	16.1	-16.2
DFA	-42.1	15.2	-11.8
NCHF	8.8	13.7	36.2
NLF	-33.8	21.5	9.3
SWTP	-89.0	19.2	-50.5

Responses of Chlorophyll *a* Concentrations and Secchi Tube Depth to Changes in Nutrient Concentrations and Land Use

Concentrations of SCHL increased as P and N concentrations increased; however, there was much variation in these relations (fig. 14). For any nutrient concentration, there was about an order of magnitude of variation in SCHL concentrations. Although nutrient concentrations were lower or higher in some areas (especially lower in EPZ 1 and the NLF ecoregion), there was a relatively similar response in SCHL concentrations to changes in nutrient concentrations in all EPZs and level III ecoregions. Five sites, however, had SCHL concentrations that were lower than might be expected for the measured P and N concentrations at the site. These sites were in EPZ 1 and the NCHF, and were generally small sites (5.8–55.6 km^2) with extensive sedimentation and embedded rocky substrate (94–100 percent).

The best breakpoints or thresholds in the response of SCHL to changes in P and N concentrations were at 0.070 mg/L (log(P) = -1.16) and 1.169 mg/L (log(N) = 0.07), respectively. This P concentration is expected to occur at approximately 30- to 50-percent agriculture in all areas (fig. 12). This N concentration is expected to occur at approximately 30-percent agriculture in all areas except EPZ 3, where it occurs at about 50-percent agriculture (fig. 13).

Water clarity (SDs) decreased as P and N concentrations increased (fig. 15). At low nutrient concentrations, water clarity often exceeded the 120-cm length of the Secchi tube. Then, as nutrient concentrations increased, water clarity decreased; however, there was much variation in this relation. For most nutrient concentrations, other than very low concentrations, SDs ranged from 20 cm to greater than 120 cm. In general, the SD responses were similar in most EPZs and ecoregions. The best breakpoints or thresholds in the response of SDs to changes in P and N concentrations were at 0.106 mg/L (log(P) = -0.97) and 3.305 mg/L (log(N) = 0.52), respectively. This P concentration is expected to occur at approximately 50- to 70-percent agriculture in all areas (fig. 12). This N concentration is expected to occur at approximately 55- to 70-percent agriculture in all areas except EPZ 3, where it occurs at about 80-percent agriculture (fig. 13).

The multiple-regression approach was again used to estimate changes in SCHL concentrations and SDs in response to changes in the percentage of agricultural land in the watershed. Concentrations of SCHL increased as the percentage of agricultural land increased in all of the EPZs (fig. 16A) and ecoregions (not shown), and the response was similar in all areas except EPZ 1. The response in concentrations in EPZ 1 was less than in any other EPZ; however, this difference may simply reflect the limited distribution of the original data in EPZ 1. The standard errors in the estimates of coefficient *b* for the EPZs ranged from 0.13 to 0.16 compared to 0.20 to 0.44 for the level III ecoregions (table 9). As are result, the 95-percent confidence intervals for the EPZs were smaller than those for the ecoregions. Therefore, the EPZs provided better estimates of the response in SCHL concentrations to changes in the amount of agricultural land in the watershed than the level III ecoregions. Based on the similarity in the distribution of concentrations (fig. 15) and insignificant differences in values for coefficient *b* among EPZs, it is not appropriate to subdivide the wadeable streams of Wisconsin based on the response in SCHL concentrations to changes in nutrient concentrations and land use.

Water clarity decreased as the percentage of agriculture land increased in all of the EPZs and level III ecoregions, and the response was similar in all areas except EPZ 1 (fig. 16B, shown for EPZs only). The water clarity decreased more slowly in EPZ 1 than in the other zones; however, there were only a few sites in EPZ 1 with extensive agriculture to support this conclusion. The response in water clarity in EPZ 3 was similar to the other areas; the difference in the water clarity in this area was caused by the lower reference clarity. The standard errors in the estimates of coefficient *b* for the EPZs ranged from 8.7 to 16.1 compared to 13.7 to 21.5 cm for the ecoregions (table 9). Therefore, the EPZs provided better estimates of the response in SDs to changes in the amount of agricultural land in the watershed than the level III ecoregions. Based on the results for the EPZ regionalization scheme, subdividing wadeable streams into two categories seems appropriate: streams in areas with high clay-content soils (EPZ 3), which have a lower reference water clarity and clarity that decreases and remains lower than sites in the other areas as the percentage of agricultural land in the watershed increases, and streams in the rest of the State.

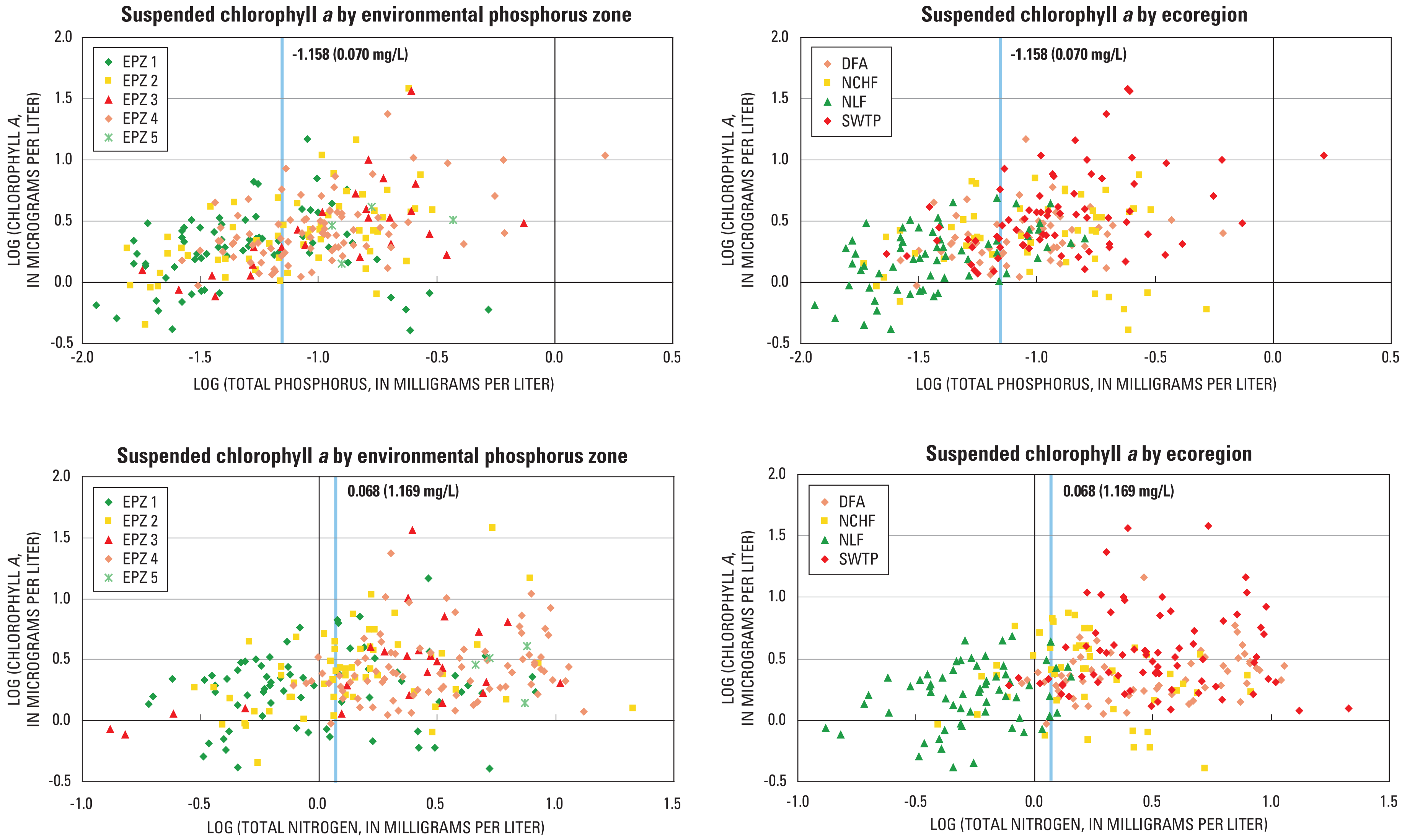


Figure 14. Suspended chlorophyll *a* concentrations as a function of total phosphorus and total nitrogen concentration (logarithm to base 10 transformation), by environmental phosphorus zones (EPZs) and by level III ecoregions for the studied wadeable streams in Wisconsin. Computed thresholds in the response are identified by vertical lines. [DFA, Driftless Area; NCHF, North Central Hardwood Forests; NLF, Northern Lakes and Forests; and SWTP, Southeastern Wisconsin Till Plains]

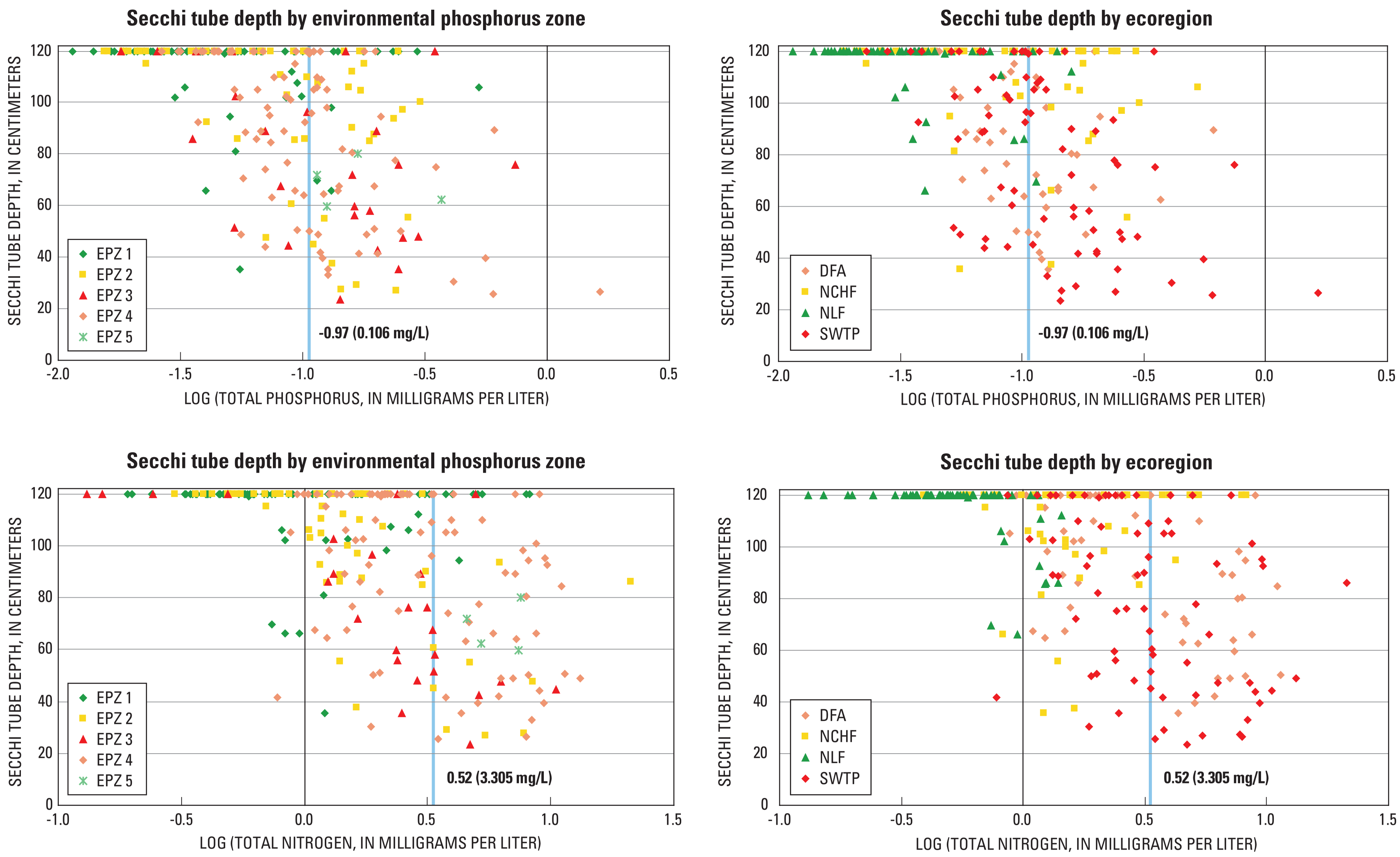
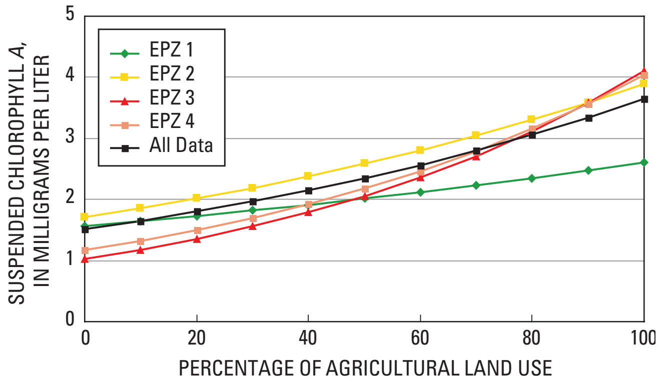


Figure 15. Secchi tube depth as a function of total phosphorus and total nitrogen concentration (logarithm to base 10 transformation), by environmental phosphorus zones (EPZs) and by level III ecoregions for the studied wadeable streams in Wisconsin. Computed thresholds in the response are identified by vertical lines. [DFA, Driftless Area; NCHF, North Central Hardwood Forests; NLF, Northern Lakes and Forests; and SWTP, Southeastern Wisconsin Till Plains]

A.* Response in suspended chlorophyll *a



***B.* Response in secchi tube depth**

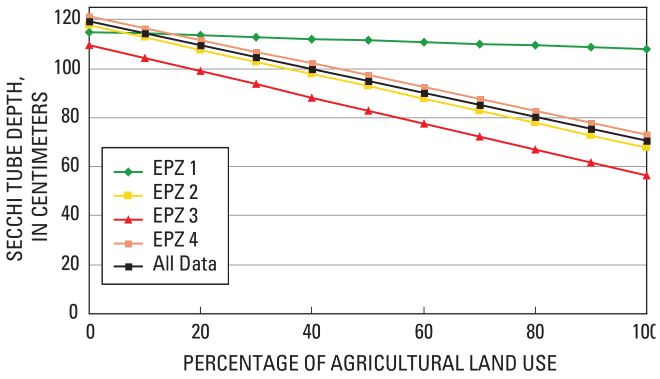


Figure 16. Response curves for ***A***, suspended chlorophyll *a* concentrations and ***B***, Secchi tube depths in the environmental phosphorus zones (EPZs) as a function of the percentage of agriculture in the watershed for wadeable streams in Wisconsin.

Physical Habitat

The streams examined in this study exhibit considerable variation in their physical habitats, particularly with respect to mean stream widths and depths. Mean widths ranged from 1.1 m to over 55 m, with an overall mean width of 7.6 m (table 10). Mean depths ranged from 0.1 m to 1.0 m, with an overall mean depth of 0.3 m. Mean thalweg depths (deepest part of the cross section) ranged from 0.1 m to 1.3 m, with an overall mean depth of 0.4 m. The gradients of the streams at the sampling sites ranged from nearly flat (0.0 m/km) to quite steep (up to 20.7 m/km) and their sinuosity (not in table 10) ranged from highly meandered to straight channels. About half of the streams contained well-developed runs. On average, 75 percent of the stream's reach was classified as runs. Most streams had less than 10 percent of the reach classified as pools and riffles. Stream bottoms ranged from being almost completely silt to being dominated by sand or gravel. The percentage of the stream's reach that was shaded ranged from 0 to 93.7 percent.

Table 10. Summary statistics for the physical-habitat characteristics and biotic indices for the studied wadeable streams in Wisconsin.

[EPT, Ephemeroptera, Plecoptera, and Trichoptera; #, number; m, meter; m/km, meter per kilometer; mg/m^2, milligram per square meter; log, logarithm to base 10 transformation; --, values are not indicative of water quality]

Characteristic/index	Abbreviation	Units	Transformation	Count	Median	Mean	Best 25th percentile of all sites	Standard deviation	Minimum	Maximum
Physical-habitat characteristics										
Stream width	WIDTH	m	none	235	4.5	7.6	--	8.3	1.1	56.3
Stream mean depth	DEPTH	m	none	235	.3	.3	--	.2	.1	1.0
Mean thalweg depth	THALD	m	none	235	.4	.4	--	.2	.1	1.3
Stream gradient	GRAD	m/km	none	231	2.5	3.2	--	3.0	.0	20.7
Percentage of pools	POOL%	%	none	234	5.0	10.5	--	13.9	.0	100.0
Percentage of riffle	RIFF%	%	none	234	8.5	13.9	--	17.2	.0	100.0
Percentage of run	RUN%	%	none	234	49.7	75.3	--	22.9	.0	100.0
Depth of sediment on stream bottom	SEDEP	m	none	235	.1	.1	--	.1	.0	0.9
Percentage of silt in bottom sediments	SILT%	%	none	235	10.6	17.2	--	18.3	.0	95.6
Percentage of sand in bottom sediments	SAND%	%	none	235	27.3	34.3	--	25.3	.0	99.6
Percentage of gravel in bottom sediments	GRAV%	%	none	235	18.8	19.6	--	14.5	.0	66.2
Percentage of rocky-substrate embeddedness	EMB%	%	none	235	64.2	59.8	--	29.5	6.2	100.0
Percentage of stream bottom covered by algae	ALGAE%	%	none	235	.4	4.8	--	9.1	.0	53.8
Percentage of stream bottom covered by macrophytes	MACR%	%	none	235	1.3	6.3	--	10.9	.0	54.8
Percentage of stream with fish cover	COVER%	%	none	235	7.2	9.3	--	9.2	.0	65.5
Percentage of stream shaded	SHADE%	%	none	235	28.9	33.9	--	27.8	.0	93.7
Percentage of stream bank with erosion	EROSION%	%	none	235	12.5	17.7	--	15.9	.0	76.5
Buffer width	BUFFER	m	none	235	10.5	12.6	--	6.5	.0	30.0
Benthic chlorophyll *a* / diatoms										
Benthic chlorophyll *a*	BCHL	mg/m^2	log	199	1,919	12,879	552	80,884	7	1,068,000
Diatom Nutrient Index	DNI	#	none	214	4.1	3.9	3.5	0.8	1.7	5.4
Diatom Siltation Index	DSI	#	none	214	38.2	39.9	16.7	24.9	2.6	95.3
Diatom Biotic Index	DBI	#	none	214	42.1	46.4	51.3	15.7	22.8	100.0

Table 10. Summary statistics for the physical-habitat characteristics and biotic indices for the studied wadeable streams in Wisconsin—Continued.

[EPT, Ephemeroptera, Plecoptera, and Trichoptera; #, number; m, meter; m/km, meter per kilometer; mg/m^2, milligram per square meter; log, logarithm to base 10 transformation; --, values are not indicative of water quality]

Characteristic/index	Abbreviation	Units	Transformation	Count	Median	Mean	Best 25th percentile of all sites	Standard deviation	Minimum	Maximum
Macroinvertebrates										
Hilsenhoff Biotic Index	HBI	#	none	227	4.7	4.9	4.0	1.6	0.8	9.4
Percentage of EPT individuals	EPTN%	%	none	227	42.3	41.0	61.8	26.1	.0	99.2
Percentage of EPT taxa	EPTTX%	%	none	227	35.7	33.9	45.7	16.8	.0	74.3
Percentage of scrapers	SCRAP%	%	none	227	14.7	19.0	29.5	18.0	.0	85.4
Percentage of shredders	SHRED%	%	none	227	0.0	1.0	--	3.1	.0	24.7
Number of taxa	TAXAN	#	none	232	29	29.2	35.0	10.4	4	67
Fish										
Fish Index of Biotic Integrity	IBI	#	none	235	40.0	40.2	52.0	20.8	.0	100.0
Percentage of carnivores	CARN%	%	none	234	1.6	11.4	9.8	21.3	.0	100.0
Percentage of insectivores	INSECT%	%	none	234	48.9	49.8	29.1	24.2	.0	100.0
Percentage of omnivores	OMNI%	%	none	234	10.5	15.4	3.8	16.0	.0	81.1
Percentage of intolerant species	TOL%	%	none	234	3.3	14.6	15.8	23.3	.0	97.9
Percentage of tolerant species	INTOL%	%	none	234	42.8	41.5	19.5	25.6	.0	100.0
Number of fish	FISHN	#	log	234	130	199.6	--	247.8	7	2,147
Number of fish species	FISHSPEC	#	none	235	11	11.5	--	5.4	1	33

Benthic Chlorophyll *a* and Periphytic-Diatom Communities and Their Relations with Water-Quality, Environmental, and Physical-Habitat Characteristics

Wisconsin Department of Natural Resources personnel collecting diatom samples. Microscopic diatom pictures provided by Paul Garrison (Wisconsin Department of Natural Resources).

Four indices were used to describe the benthic chlorophyll *a* and periphytic-diatom communities found in the streams in this study (table 10). Benthic chlorophyll *a* (BCHL) concentrations ranged from 7 mg/m^2 to over 1,000,000 mg/m^2 (median = 1,919 mg/m^2), the Diatom Nutrient Index (DNI) values ranged from 1.7 to 5.4 (median = 4.1), the Diatom Siltation Index (DSI) values ranged from 2.6 to 95.3 (median = 38.2), and Diatom Biotic Index (DBI) values ranged from 22.8 to 100 (median = 42.1). In general, streams in the northern part of the State had lower BCHL concentrations and better quality diatom communities, lower DNI and DSI values, and higher DBI values than streams in the rest of the State (fig. 17).

Relations with Individual Characteristics

Correlations

Spearman rank correlation coefficients (r_s values) between the four indices describing BCHL and diatom communities and the water-quality, environmental, and physical-habitat characteristics are given in table 11. All four indices were significantly correlated with P and DP concentrations; however, only BCHL, DNI, and DSI were significantly correlated with N and NO_3-N concentrations. Only DNI and DSI were correlated with NH_4-N, and only DNI was significantly correlated with TKN. The relations found for N were primarily the result of variability in NO_3-N concentrations, because N was computed as the sum of NO_3-N and TKN, and TKN was only weakly correlated with most indices. DSI values were more strongly correlated with nutrient concentrations than were the

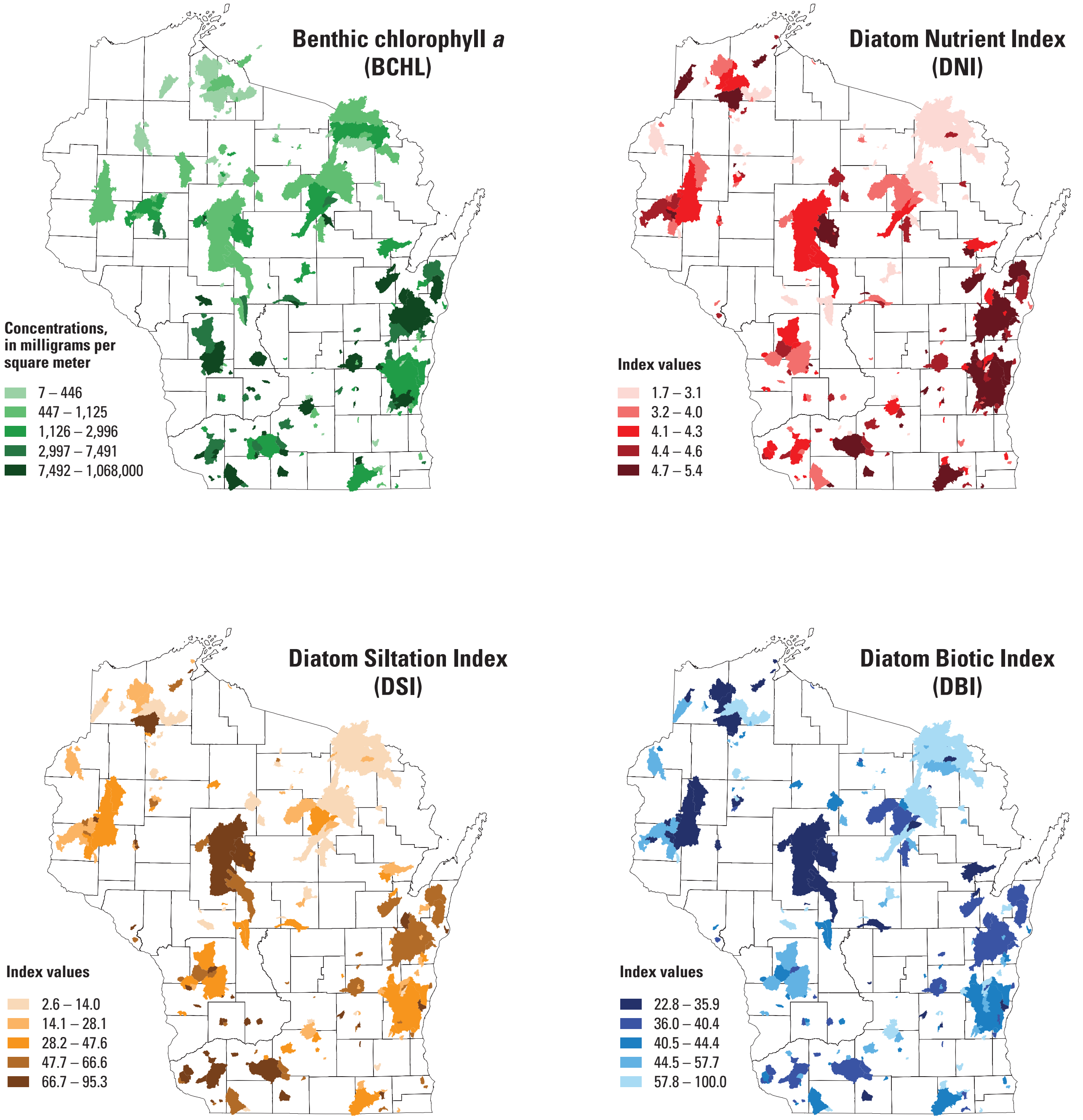


Figure 17. Distributions (quintiles) of benthic chlorophyll *a* (BCHL) concentrations, Diatom Nutrient Index (DNI) values, Diatom Siltation Index (DSI) values, and Diatom Biotic Index (DBI) values for the studied wadeable streams in Wisconsin.

Table 11. Spearman rank correlation coefficients (r_s) between benthic chlorophyll *a* concentrations (BCHL) and diatom community indices, and median water-quality, environmental (anthropogenic/land-use, basin, soil and surficial-deposit), and physical-habitat characteristics for the studied wadeable streams in Wisconsin.

[all **bold** values were significant at $p < 0.05$, after being adjusted for the Bonferroni correction (Zar, 1999); see table 10 on page 49 for definitions of abbreviations and units for each characteristic]

Characteristic	Benthic chlorophyll *a* (BCHL)	Diatoms		
		Diatom Nutrient Index (DNI)	Diatom Siltation Index (DSI)	Diatom Biotic Index (DBI)
Water-quality characteristics				
Total phosphorus	**0.33**	**0.47**	**0.60**	**-0.46**
Dissolved phosphorus	**.33**	**.47**	**.59**	**-.46**
Total nitrogen	**.49**	**.36**	**.43**	-.10
Dissolved nitrite plus nitrate	**.53**	**.31**	**.40**	-.05
Dissolved ammonia	.12	**.21**	**.30**	-.13
Total Kjeldahl nitrogen	-.07	**.24**	.09	-.17
Suspended chlorophyll *a*	**.21**	**.24**	**.29**	-.17
Secchi tube depth	**-.22**	**-.39**	**-.41**	.17
Anthropogenic/land-use characteristics				
Urban	**.25**	**.26**	.10	.03
Agriculture (row crops)	**.44**	**.42**	**.42**	-.13
Agriculture (all)	**.50**	**.44**	**.51**	-.14
Grassland	.10	.12	.20	-.14
Wetland (open)	-.12	.18	**-.22**	-.02
Wetland (forested)	**-.44**	-.18	**-.51**	.10
Forest (all)	**-.44**	**-.45**	**-.48**	.17
Point-source loading of phosphorus	**.27**	**.26**	.18	-.17
Basin characteristics				
Watershed area	.10	.12	-.07	-.07
Air temperature	**.48**	**.42**	**.51**	.00
Precipitation	**.21**	.05	**.28**	.08
Runoff	**-.42**	**-.41**	**-.35**	.00
Basin slope	**.28**	.08	**.48**	-.15
Flow per unit area	-.16	-.17	-.18	.15
Soil and surficial-deposit characteristics				
Clay content	**.46**	**.44**	**.63**	-.15
Erodibility	**.37**	**.37**	**.52**	-.12
Organic-matter content	**-.41**	-.14	**-.55**	.17
Permeability	**-.35**	**-.36**	**-.60**	**.25**
Soil slope	.06	**-.25**	.11	.08
Nonglacial deposits	**.42**	-.01	**.45**	.03
Clay deposits	.10	**.30**	.13	-.17
Loam deposits	-.06	.02	.04	**-.25**
Peat deposits	-.09	-.10	-.05	-.02
Sand deposits	**-.35**	.00	**-.34**	.12
Sand-and-gravel deposits	**-.26**	-.20	**-.52**	**.24**

Table 11. Spearman rank correlation coefficients (r_s) between benthic chlorophyll *a* concentrations (BCHL) and diatom community indices, and median water-quality, environmental (anthropogenic/land-use, basin, soil and surficial-deposit), and physical-habitat characteristics for the studied wadeable streams in Wisconsin—Continued.

[all **bold** values were significant at $p < 0.05$, after being adjusted for the Bonferroni correction (Zar, 1999); see table 10 on page 49 for definitions of abbreviations and units for each characteristic]

Characteristic	Benthic chlorophyll *a* (BCHL)	Diatoms		
		Diatom Nutrient Index (DNI)	Diatom Siltation Index (DSI)	Diatom Biotic Index (DBI)
Physical-habitat characteristics				
WIDTH	-0.03	-0.01	-0.17	-0.04
DEPTH	.11	.00	.03	-.03
THALD	.07	-.03	.01	-.03
GRAD	.02	-.05	.13	.01
POOL%	.00	-.04	.13	-.02
RIFF%	.13	.13	.11	-.01
RUN%	-.07	-.04	-.15	.05
SEDEP	-.04	-.10	-.05	.01
SILT%	.17	.05	.18	.06
SAND%	**-.29**	-.18	**-.22**	-.02
GRAV%	.00	**.22**	-.02	-.04
EMB%	-.08	-.18	-.06	.04
ALGAE%	**.28**	**.21**	**.24**	.02
MACR%	.01	-.12	-.06	.12
COVER%	-.12	-.10	-.19	.06
SHADE%	-.07	.07	-.11	.00
EROSION%	.18	.20	**.32**	-.15
BUFFER	-.03	.09	-.07	.04

DNI values except for TKN, and both indices were more strongly correlated with nutrient concentrations than were DBI values. BCHL concentrations were more strongly correlated with the different forms of N, whereas the diatom indices were more strongly correlated with the different forms of P. Other studies have found the P-chlorophyll relation to be stronger than the N-chlorophyll relation (for example, Van Nieuwenhuyse and Jones, 1996).

BCHL, DNI, and DSI were strongly correlated with SCHL, SD, and many of the anthropogenic/land-use characteristics, especially the percentages of total agriculture, row-crop agriculture, and forested areas. In addition, BCHL and the DNI were significantly correlated with the amount of urban land and PtS in the basin. Better index values (lower values for BCHL, DNI, and DSI) generally occurred in streams with lower SCHL and higher clarity, in areas with lower percentages of agriculture, less PtS, and higher percentages of forest. In general, these indices were also strongly correlated with several basin (air temperature and runoff) and soil (clay content, erodibility, organic-matter content, and permeability) characteristics. Lower BCHL concentrations and better diatom indices generally occurred in areas with cooler air temperatures, higher runoff, less erodible soils with lower clay content and higher permeability, and sand-and-gravel surficial deposits. These areas with lower BCHL concentrations and better diatom indices are the mixed and mostly forested areas of Wisconsin (fig. 2A).

In general, the BCHL and diatom indices were only weakly correlated with any physical-habitat characteristics except the percentage of the bottom covered in algae and the amount of sandy sediment. Better benthic diatom communities occurred in streams with lower percentages of algal cover. BCHL and the diatom indices were unrelated to the size or depth of the streams.

Table 12. Thresholds or breakpoints in the responses of benthic chlorophyll *a* (BCHL) concentrations and diatom indices to changes in nutrient concentrations for wadeable streams in Wisconsin.

[all nutrient concentrations are in milligrams per liter; log, logarithm to base 10 transformation]

Biological Indices	Total phosphorus	Dissolved phosphorus	Total nitrogen	Dissolved nitrite plus nitrate	Dissolved ammonia	Total Kjeldahl nitrogen
Benthic chlorophyll *a* (BCHL) - log	0.039	0.020	0.918	0.187	0.040	0.310
Diatom Nutrient Index (DNI)	.057	.026	1.216	.381	.021	.745
Diatom Siltation Index (DSI)	.074	.046	.872	.089	.022	1.080
Diatom Biotic Index (DBI)	.072	.039	1.169	.381	.022	.388

Responses to Changes in Nutrient Concentrations

Responses in BCHL, DNI, and DSI to changes in nutrient concentrations are shown in figures 18 and 19 (DBI values, which were computed on the basis of DNI and DSI values, were less strongly correlated with nutrient concentrations and therefore are not shown). In general, all three indices increased as nutrient concentrations increased, although the responses to changes in N concentrations ranged more widely than changes in P. At low nutrient concentrations, the values of the indices ranged widely; however, at high nutrient concentrations, the values were generally limited to high BCHL and poor diatom indices. High BCHL concentrations and poor diatom indices were measured even at low nutrient concentrations. The lower bounds of the BCHL and DNI plots may provide an indication of the extent to which nutrients are capable of limiting BCHL and the diatom community. The variation above these bounds may indicate the effects caused by factors other than nutrients.

Although nutrient concentrations were lower or higher in some EPZs and level III ecoregions (especially lower in EPZ 1 and the NLF ecoregion), BCHL concentrations and diatom indices responded similarly to changes in nutrient concentrations in all areas (fig. 18). In all EPZs and ecoregions, there was a broad response at low nutrient concentrations and poor (higher) indices at high nutrient concentrations. Differences in the responses among areas could not be distinguished because of the range in the data and because the gradient in nutrient concentrations within many areas was small.

Regression-tree analyses were done to define specific thresholds or breakpoints in the responses of BCHL concentrations and the diatom indices (table 12). The best statistical thresholds or breakpoints in the responses to changes in total P concentrations ranged from 0.039 mg/L for BCHL concentrations to 0.057–0.074 mg/L for the diatom indices. Thresholds in the response to changes in DP concentrations ranged from 0.020 mg/L for BCHL to 0.046 mg/L for DSI. Thresholds in the responses to changes in the different forms of N are also listed in table 12; however, the data in figures 18 and 19 do not show any consistent response except the DNI as a function of N. Thresholds in the responses to changes in N concentrations ranged from 0.872 to 1.216 mg/L. In general, sites with concentrations below the defined thresholds had a broad range in index values and sites above the defined threshold had poor index values, although the data do not indicate well-defined thresholds.

To examine further the thresholds or breakpoints in the responses of BCHL and the diatom indices to changes in nutrient concentrations, a categorical approach developed by the Ohio Environmental Protection Agency (OEPA; Miltner and Rankin, 1998) was used to examine the BCHL and DNI responses. With this approach, not only was the response to a single nutrient constituent examined but also the interaction of P and N. For this analysis, each of the sites having BCHL and diatom index data was placed into one of five categories based upon their percentile rankings for P and N concentrations (25th, 50th, 75th, and 90th percentiles; table 13). The five categories in increasing nutrient concentrations are: category 1, sites that have both P and N concentrations less than their

Table 13. Percentiles of total phosphorus and total nitrogen concentration for the studied wadeable streams in Wisconsin having both benthic chlorophyll *a* and diatom index data.

[all concentrations in milligrams per liter]

Percentile	Total phosphorus	Total nitrogen
25th	0.039	0.797
50th	.071	1.724
75th	.125	3.771
90th	.203	7.447

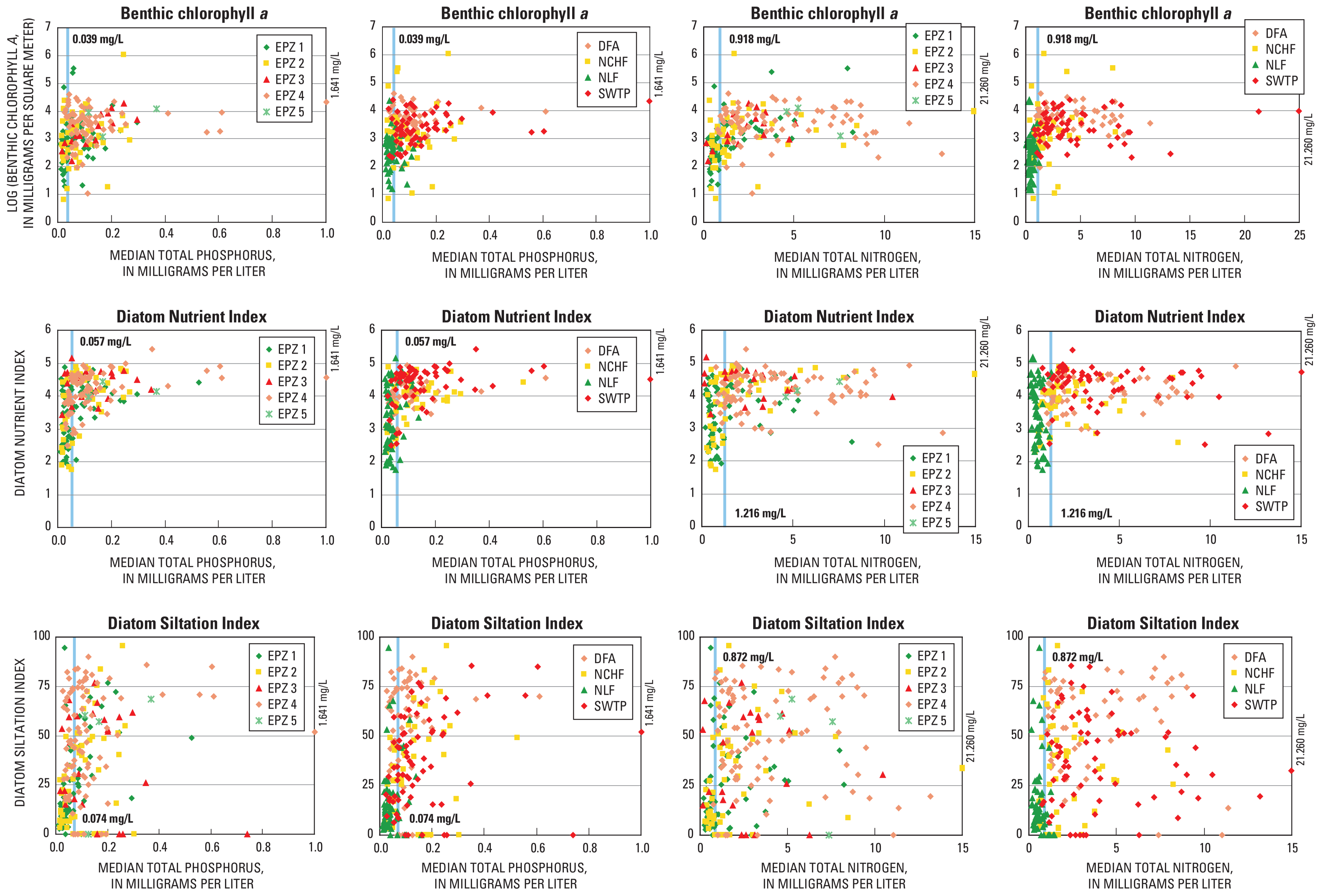


Figure 18. Benthic chlorophyll *a* concentrations (logarithm to base 10 transformation), Diatom Nutrient Index values, and Diatom Siltation Index values as a function of total phosphorus and total nitrogen concentration in the environmental phosphorus zones (EPZs) and level III ecoregions for the studied wadeable streams in Wisconsin. Computed thresholds in the response are identified by vertical lines. [DFA, Driftless Area; NCHF, North Central Hardwood Forests; NLF, Northern Lakes and Forests; and SWTP, Southeastern Wisconsin Till Plains]

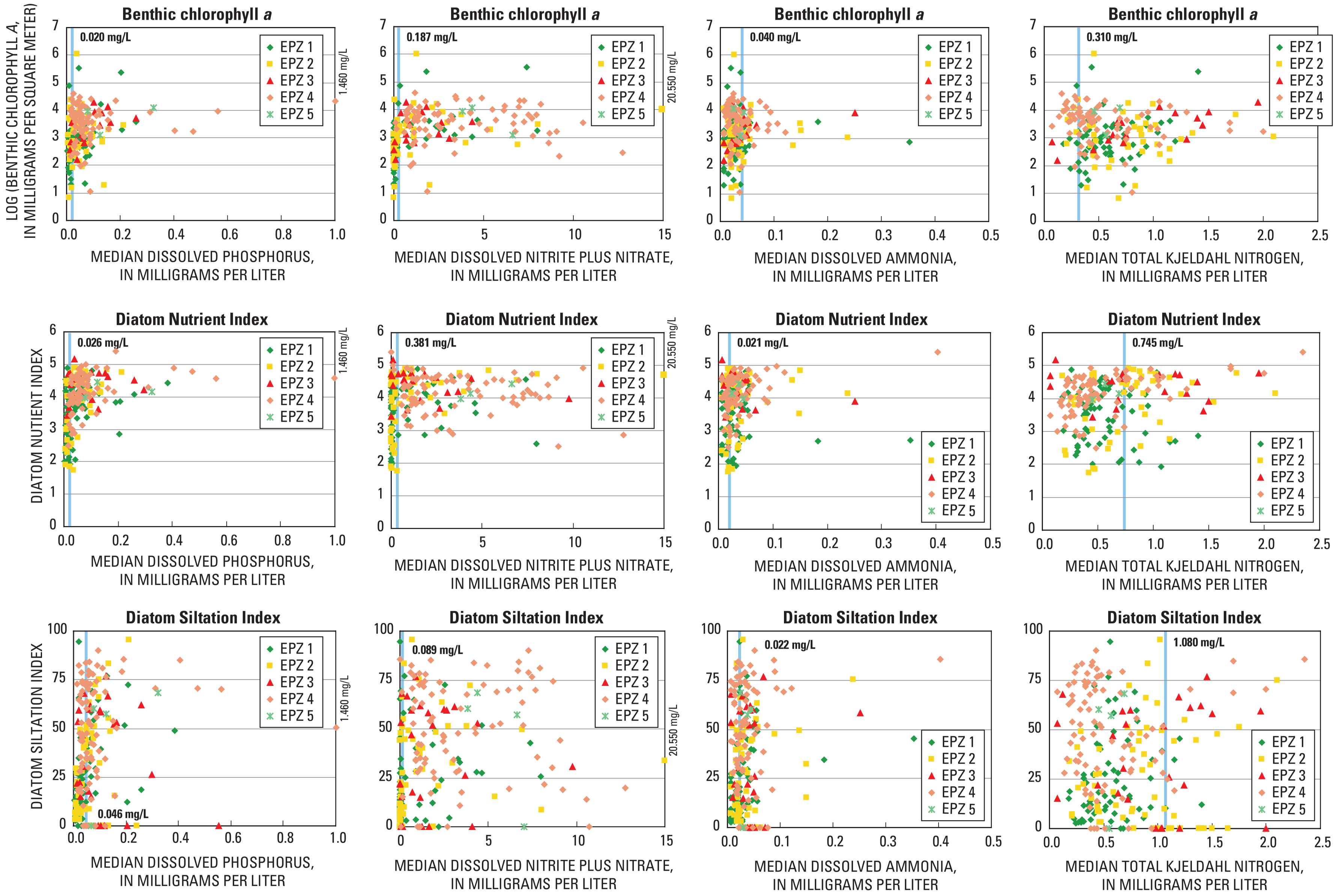


Figure 19. Benthic chlorophyll *a* concentrations (logarithm to base 10 transformation), Diatom Nutrient Index values, and Diatom Siltation Index values as a function of dissolved phosphorus, dissolved nitrite plus nitrate, dissolved ammonia, and total Kjeldahl nitrogen concentrations in the environmental phosphorus zones (EPZs) for the studied wadeable streams in Wisconsin. Computed thresholds in the response are identified by vertical lines.

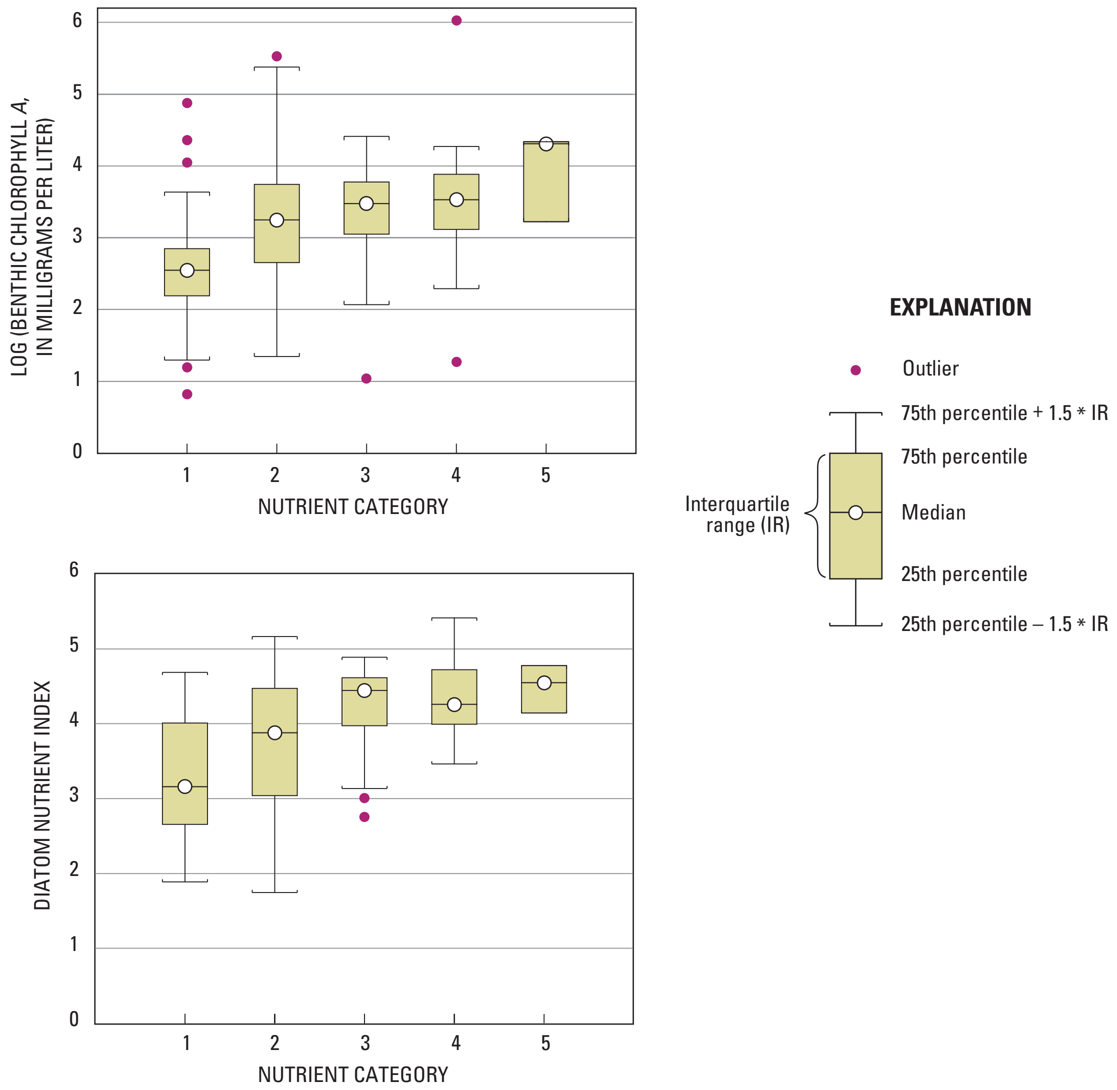


Figure 20. Benthic chlorophyll *a* concentrations and Diatom Nutrient Index values for five nutrient categories for the studied wadeable streams in Wisconsin (each nutrient category is defined in the text on pages 55 and 58).

25th percentiles; category 2, sites that are not in category 1 and have either P or N concentrations less than their 50th percentiles; category 3, sites that are not in categories 1 or 2 and have P concentrations less than its 75th percentile and N concentrations less than its 90th percentile; category 4, sites that are not in categories 1, 2, or 3 and have P concentrations between and including its 75th and 90th percentiles (N concentrations do not matter); and category 5, sites that have both P and N concentrations greater than their 90th percentiles (OEPA also includes a sixth category for sites that have NH_4-N concentrations greater than 1.0 mg/L but there were no such sites in this study.)

Sites in category 1 (P concentrations less than 0.039 mg/L and N concentrations less than 0.797 mg/L) had BCHL concentrations significantly less than those in categories 2 through 5 (fig. 20). BCHL concentrations increased slightly from category 2 to category 5; however, the differences were not statistically significant at $p < 0.05$. Sites in categories 1 and 2 (P concentrations less than 0.071 mg/L and N concentrations less than 1.724 mg/L) had significantly lower (better) DNI values than those in categories 3 through 5. Therefore, the threshold in the response of the BCHL concentrations was at P concentrations less than about 0.04 mg/L and N less than about 0.8 mg/L, whereas the threshold in the response in DNI values was at higher concentrations of P (less than about 0.07 mg/L) and N (less than about 1.7 mg/L). These thresholds are similar to those found from the regression-tree approach, except for the N threshold for the diatom community, which was less (about 1.2 mg/L; table 12) than the value found with this approach.

The multimetric diatom index DBI was also tested as a means to define thresholds in the response of the diatom community to changes in nutrient concentrations. The DNI and DSI, however, provided more defined thresholds in the response of the diatom community to changes in nutrient concentrations, and, therefore, the DBI was not examined in further detail for this purpose.

Effects of Multiple Characteristics on Benthic Chlorophyll *a* Concentrations and Diatom Indices

Stepwise Regressions

Forward stepwise regressions were done with the water-quality (median values), environmental, and physical-habitat characteristics to determine which four characteristics best described the variance in BCHL concentrations and the diatom indices (table 14). Models with more than four variables did not significantly increase the amount of variance explained (accumulative R^2 values). For BCHL, NO_3-N concentration was the first variable incorporated in the model, whereas DP concentration was the first variable incorporated in the DNI and DBI models. The clay content of the soil was the first variable incorporated in the DSI model, followed by P concentration. The clay content of the soil indicates the potential for siltation and, therefore, was expected to be an important variable in the DSI model. With four variables, the models explained between 31 and 60 percent of the total variance in the indices; therefore, 40 to 70 percent of the variance was not explained by the characteristics examined in this study.

Redundancy Analysis

Partial RDA was used to determine the relative importance of nutrients, other water-quality characteristics (pH, specific conductance, water clarity, and flow), and environmental and physical-habitat characteristics (tables 2 and 10) in influencing the distribution of BCHL and the three diatom indices. In this analysis, individual monthly (July and August) and median values were included for each nutrient. A forward variable-selection procedure, which correlated the BCHL and the three diatom indices to the other factors, was used to select a subset of variables for each general type of characteristic. This procedure retained 7 nutrient variables, 5 other water-quality characteristics, and 11 environmental and physical-habitat characteristics. These final 23 characteristics explained 54 percent of the variance in BCHL and the diatom indices. Of the explained variance, 13 percent was explained by the nutrients alone, 4 percent by the other water-quality characteristics alone, 46 percent by the environmental and physical-habitat characteristics alone, and 37 percent by the interactions among all the characteristics (fig. 21). Therefore, nutrient concentrations by themselves explained only a small part (about 7 percent) of the total variance in BCHL and the diatom communities. About 46 percent of the total variance could not be explained with the characteristics examined in this study.

Table 14. Results of forward stepwise-regression analysis to explain the variance in benthic chlorophyll *a* concentrations and the three diatom indices in the studied wadeable streams in Wisconsin.

[R^2, coefficient of determination for the one-, two-, three-, and four-variable models; all regressions were on log-transformed values of the dependant variable]

Dependent variable	First variable	Second variable	Third variable	Fourth variable
Benthic chlorophyll *a* (BCHL)	Nitrite plus nitrate	Nonglacial deposits	Loam deposits	Runoff
Accumulative R^2	0.32	0.37	0.40	0.43
Diatom Nutrient Index (DNI)	Dissolved phosphorus	Wetland (forested)	Percentage of pools	Soil slope
Accumulative R^2	.25	.31	.33	.34
Diatom Siltation Index (DSI)	Clay content of soil	Total phosphorus	Nonglacial deposits	Grassland
Accumulative R^2	.42	.49	.59	.60
Diatom Biotic Index (DBI)	Dissolved phosphorus	Agriculture (row crops)	Wetland (forested)	Percentage of sand bottom
Accumulative R^2	.19	.25	.29	.31

Reference Values for Benthic Chlorophyll *a* Concentrations and Diatom Indices

A reference BCHL concentration and reference values for the three diatom indices were determined by examining the concentrations and index values at only the sites having both P and N concentrations at or below their respective reference concentrations (35 Reference sites). The median BCHL concentration for the Reference sites was 331 mg/m^2 (log (331) = 2.52; the 75th percentile was 673 mg/m^2), which was significantly less than the median concentration measured at the High (nonreference) sites (3,020 mg/m^2; log (3,020) = 3.48; fig. 22). The median DNI and DSI values for the Reference sites were 3.38 and 11.80, respectively (with 75th percentiles of 4.05 and 22.50, respectively), which were significantly less than the median values measured at the High sites (4.39 and 52.00, respectively). The median DBI value for the Reference sites was 47.5 (with a 25th percentile of 37.4; a lower percentile is given because a larger DBI represents a better diatom community), which was significantly greater than the median value measured at the High sites (39.9). If 75 percent of the minimally impacted sites (the Reference sites) have water-quality conditions or index values at least as good as the reference condition, then the reference concentration for BCHL is 673 mg/m^2, and the reference index values for DNI, DSI, and DBI are 4.05, 22.5, and 37.4, respectively.

Comparing the median concentration and index values for the Reference sites with those for the Ref N and Ref P sites may provide an indication of whether P or N is more important in limiting the concentrations of BCHL and the degradation of the diatom community in streams with nutrient concentrations near reference conditions (fig. 22). For BCHL, it appears that N is the more important limiting nutrient because the median value for the Ref P sites was significantly higher than the median value for the Reference sites, and there was no statistical difference between median values for Reference sites and the Ref N sites. In other words, small additions of N (Ref P) had more of an effect on BCHL concentrations than small additions of P (Ref N). Small additions of N also may have had a small effect on DSI values, although the median values for the categories were not significantly different. Small additions of P and N had little effect on DNI and DBI values in streams with nutrient concentrations near reference conditions.

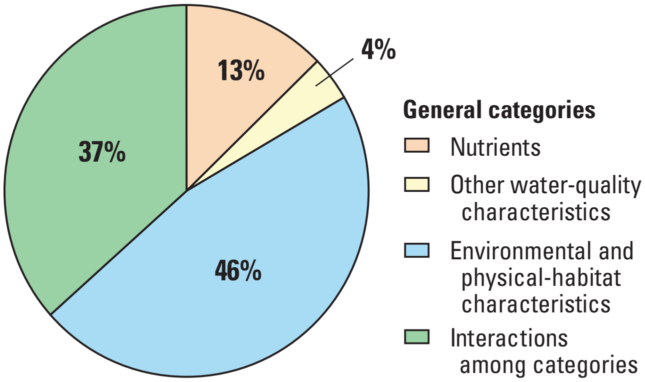


Figure 21. Percentage of explained variance in benthic chlorophyll *a* concentrations and diatom index values described by nutrients, other water-quality characteristics, environmental (anthropogenic/land-use, soil, and surficial-deposit characteristics) and physical-habitat characteristics, and interactions among categories (variance that can not be explained by a single category) for the studied wadeable streams in Wisconsin. [%, percentage of explained variance]

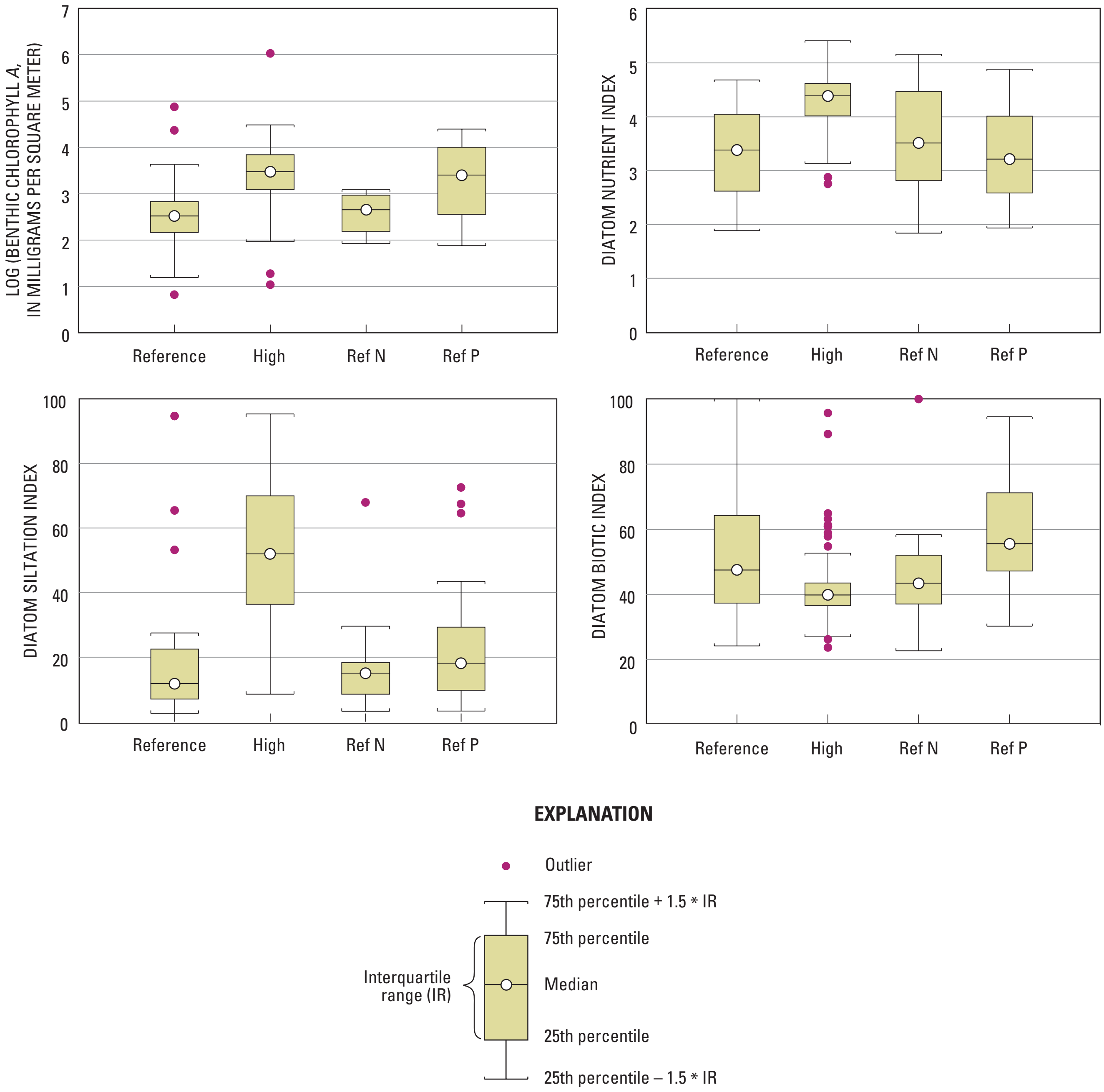


Figure 22. Benthic chlorophyll *a* concentrations, Diatom Nutrient Index, Diatom Siltation Index, and Diatom Biotic Index values in Reference sites, High (nonreference) sites, and sites with only reference total nitrogen (Ref N sites) or reference total phosphorus (Ref P sites) concentrations in the studied wadeable streams in Wisconsin. [log, logarithm to base 10 transformation]

Macroinvertebrate Communities and Their Relations with Water-Quality, Environmental, and Physical-Habitat Characteristics

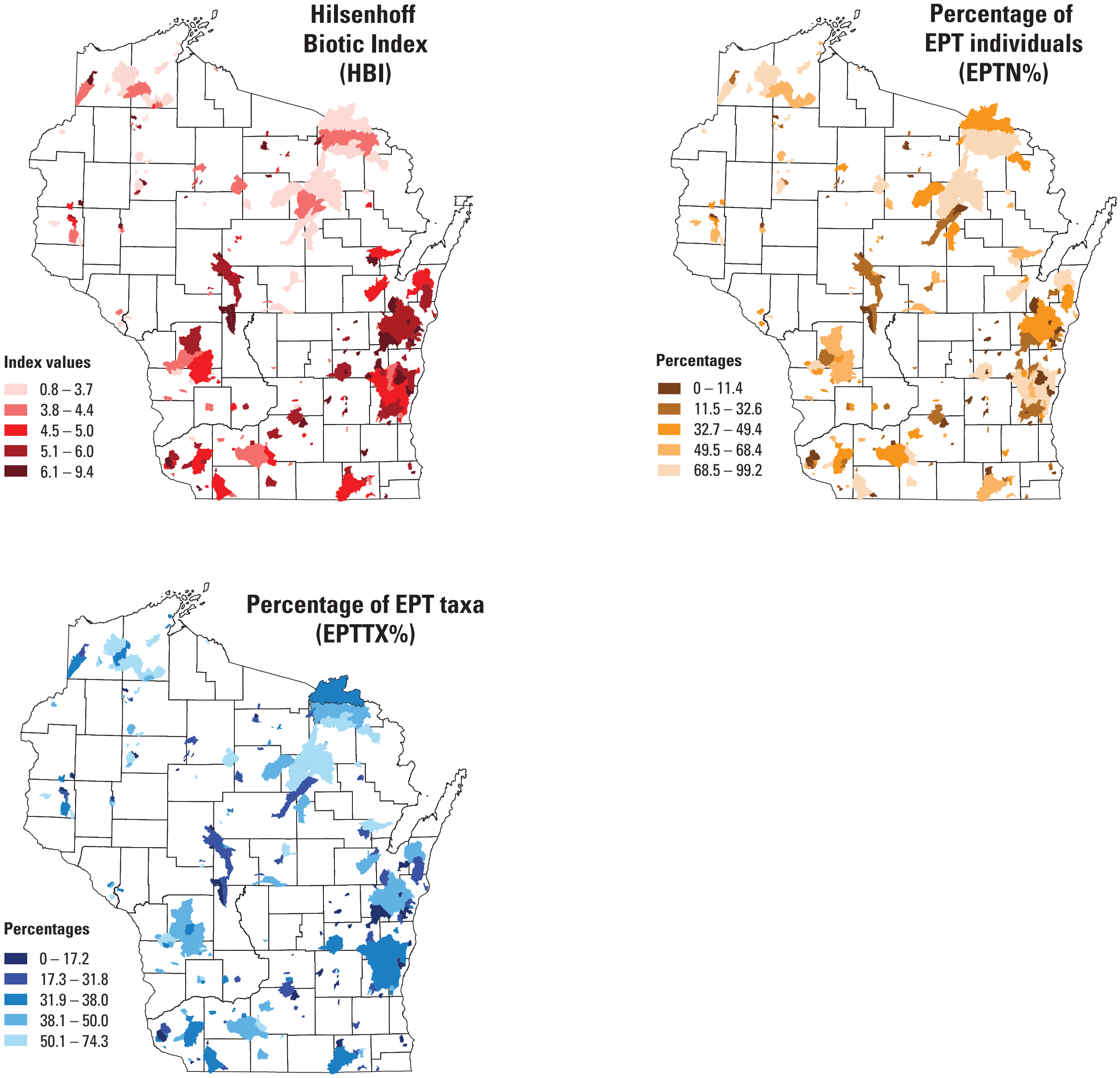
Wisconsin Department of Natural Resources personnel collecting macroinvertebrate samples. Macroinvertebrate pictures provided by Stanley Szczytko (University of Wisconsin–Stevens Point).

Six indices were used to describe the macroinvertebrate communities in the studied wadeable streams in Wisconsin (table 10 on page 50). Hilsenhoff Biotic Index (HBI) values ranged from 0.8 to 9.4 (median = 4.7); the percentage of individuals that were either Ephemeroptera, Plecoptera, or Trichoptera (EPTN%) varied from 0.0 to 99.2 percent (median = 42.3 percent); the percentage of taxa that were Ephemeroptera, Plecoptera, or Trichoptera (EPTTX%) varied from 0.0 to 74.3 percent (median = 35.7 percent); the percentage of the individuals that were scrapers (SCRAP%) varied from 0.0 to 85.4 percent (median = 14.7 percent); the percentage of individuals that were shredders (SHRED%) varied from 0.0 to 24.7 percent (median = 0.0 percent), and the total numbers of taxa (TAXAN) varied from 4 to 67 (median = 29). In general, streams in the northern part of the State had macroinvertebrate communities that would normally be considered representative of better water quality, with lower HBI values, higher EPTN% and EPTTX% (fig. 23), and higher TAXAN than the streams in the southeastern part of the State. The SCRAP% and SHRED% did not exhibit strong regional patterns.

Relations with Individual Characteristics

Correlations

Spearman rank correlation coefficients (r_s values) between the six macroinvertebrate indices and median water-quality, environmental, and physical-habitat characteristics are given in table 15. All six indices were significantly correlated with at least two nutrient constituents. Of the six macroinvertebrate indices, HBI, EPTN%, and EPTTX% were most strongly correlated with the nutrients. HBI and EPTN% were significantly correlated with all of the nutrients except NO_3-N. SCRAP% and TAXAN were negatively correlated with most nutrients, although many of the correlations were not statistically significant. Concentrations of P and N were positively correlated with HBI values and negatively correlated with EPTN%, EPTTX%, and TAXAN. Better macroinvertebrate indices (lower HBI values, higher EPT indices, and more taxa) occurred with lower nutrient concentrations. The SCRAP%, SHRED%, and TAXAN were less strongly correlated with most nutrient concentrations. Individual monthly nutrient



Hilsenhoff Biotic Index (HBI)

Percentage of EPT individuals (EPTN%)

Percentage of EPT taxa (EPTTX%)

Figure 23. Distributions (quintiles) of macroinvertebrate Hilsenhoff Biotic Index (HBI) values, the percentages of individuals that were Ephemeroptera, Plecoptera, or Trichoptera (EPTN%), and the percentages of taxa that were Ephemeroptera, Plecoptera, or Trichoptera (EPTTX%) for the studied wadeable streams in Wisconsin.

Table 15. Spearman rank correlation coefficients (r_s) between macroinvertebrate-community indices and median water-quality, environmental (anthropogenic/land-use, basin, soil and surficial-deposit), and physical-habitat characteristics for the studied wadeable streams in Wisconsin.

[EPT, Ephemeroptera, Plecoptera, and Trichoptera; %, percent; all **bold** values were significant at $p < 0.05$, after being adjusted for the Bonferroni correction (Zar, 1999); see table 10 on page 49 for definitions of abbreviations and units for each parameter]

Characteristic	Hilsenhoff Biotic Index	Percentage of EPT individuals	Percentage of EPT taxa	Percentage of scrapers	Percentage of shredders	Number of taxa
Water-quality characteristics						
Total phosphorus	**0.55**	**-0.35**	**-0.46**	**-0.21**	0.09	-0.19
Dissolved phosphorus	**.50**	**-.33**	**-.43**	-.18	.06	-.18
Total nitrogen	**.37**	**-.37**	**-.39**	-.10	-.06	**-.30**
Dissolved nitrite plus nitrate	.16	**-.24**	-.20	.03	**-.21**	**-.28**
Dissolved ammonia	**.53**	**-.39**	**-.54**	**-.21**	.12	**-.27**
Total Kjeldahl nitrogen	**.54**	**-.28**	**-.44**	**-.28**	**.30**	-.10
Suspended chlorophyll *a*	**.42**	**-.27**	**-.33**	-.04	.18	.04
Secchi tube depth	**-.41**	**.29**	**.34**	.17	-.11	**.23**
Anthropogenic/land-use characteristics						
Urban	.16	-.10	-.03	.00	.06	-.08
Agriculture (row crops)	**.45**	**-.42**	**-.45**	-.07	-.04	**-.33**
Agriculture (all)	**.43**	**-.38**	**-.42**	-.02	-.06	**-.31**
Grassland	-.12	-.02	.08	.18	**-.22**	-.15
Wetland (open)	.17	-.07	-.11	-.08	**.22**	.04
Wetland (forested)	.04	.11	.04	-.14	**.25**	.16
Forest (all)	**-.48**	**.42**	**.48**	.08	.01	**.30**
Point-source loading of phosphorus	.14	.05	.05	-.05	.11	.03
Basin characteristics						
Watershed area	-.13	.24	.17	.05	.09	**.23**
Air temperature	**.36**	**-.33**	**-.33**	.01	-.13	**-.30**
Precipitation	-.08	-.03	.11	**.25**	**-.21**	-.09
Runoff	**-.32**	**.27**	**.26**	-.01	.14	**.27**
Basin Slope	-.15	.11	.15	.18	**-.26**	-.11
Flow per unit area	**-.30**	**.22**	**.27**	.17	-.09	.08
Soil and surficial-deposit characteristics						
Clay content	**.24**	**-.26**	**-.24**	.07	-.10	**-.31**
Erodibility	**.29**	**-.24**	**-.28**	.07	-.07	**-.21**
Organic-matter content	.05	.02	-.02	**-.21**	**.31**	.13
Permeability	-.20	.20	**.22**	-.05	.06	**.21**
Soil slope	**-.39**	**.28**	**.42**	**.23**	**-.23**	.13
Nonglacial deposits	-.10	.05	.09	.18	-.18	-.03
Clay deposits	**.24**	-.19	**-.22**	-.16	.10	-.09
Loam deposits	.04	.09	.04	.03	-.03	.00
Peat deposits	.09	-.06	-.13	-.19	**.24**	.01
Sand deposits	.02	-.03	-.01	-.08	.17	.09
Sand-and-gravel deposits	-.14	.13	.15	-.07	.07	.11

Table 15. Spearman rank correlation coefficients (r_s) between macroinvertebrate-community indices and median water-quality, environmental (anthropogenic/land-use, basin, soil and surficial-deposit), and physical-habitat characteristics for the studied wadeable streams in Wisconsin—Continued.

[EPT, Ephemeroptera, Plecoptera, and Trichoptera; %, percent; all **bold** values were significant at $p < 0.05$, after being adjusted for the Bonferroni correction (Zar, 1999); see table 10 on page 49 for definitions of abbreviations and units for each parameter]

Characteristic	Hilsenhoff Biotic Index	Percentage of EPT individuals	Percentage of EPT taxa	Percentage of scrapers	Percentage of shredders	Number of taxa
Physical-habitat characteristics						
WIDTH	-0.20	**0.35**	**0.25**	0.09	0.11	0.31
DEPTH	.00	.13	.04	.00	.12	.10
THALD	-.04	.17	.07	.00	.13	.14
GRAD	-.16	.01	.11	.19	**-.26**	-.08
POOL%	-.16	.07	.10	.19	-.17	.03
RIFF%	**-.26**	**.23**	**.28**	**.28**	**-.28**	.01
RUN%	**.25**	-.19	**-.25**	**-.28**	**.26**	-.04
SEDEP	.20	-.20	**-.26**	**-.27**	.15	-.08
SILT%	**.41**	**-.32**	**-.43**	-.15	.09	-.11
SAND%	-.18	.06	.16	-.05	-.03	.12
GRAV%	**-.25**	**.24**	**.28**	**.30**	**-.22**	.04
EMB%	**.26**	**-.26**	**-.30**	**-.31**	.15	-.05
ALGAE%	**.25**	-.15	**-.23**	.04	-.05	-.13
MACR%	.16	-.08	-.15	-.14	.13	.15
COVER%	.06	.01	-.07	-.12	**.21**	.16
SHADE%	-.09	.04	.05	.00	-.19	-.15
EROSION%	.02	-.03	.00	.06	**-.21**	-.18
BUFFER	.05	-.07	-.05	-.04	.08	-.14

concentrations were examined, but in all cases the monthly values explained less variance than the median values.

In general, HBI, EPTN%, and EPTTX% were also the indices most strongly correlated with SCHL, SD, and the anthropogenic/land-use characteristics, especially the percentages of total agriculture, row-crop agriculture, and forested areas. Better macroinvertebrate indices (lower HBIs and higher EPT indices) generally occurred in streams with lower SCHL and higher clarity, in areas with lower percentages of agriculture and higher percentages of forest. SCRAP%, SHRED%, and TAXAN were less strongly correlated with the anthropogenic/land-use characteristics. HBI, EPTN%, and EPTTX% were also more strongly correlated with the basin characteristics (air temperature, runoff, and flow per unit area) and the soil and surficial-deposit characteristics (clay content of the soil, erodibility, soil slope, and clay deposits) than were the other three macroinvertebrate indices. In general, better macroinvertebrate communities were found in areas with cooler air temperatures, higher runoff, soils with lower clay content, and higher soil slope. These areas with better macroinvertebrate indices are generally the mixed and mostly forested areas of Wisconsin (fig. 2A).

In general, the macroinvertebrate indices were only moderately correlated with the physical-habitat characteristics. The physical-habitat characteristics that were most strongly correlated with macroinvertebrate indices were the percentages of rocky-substrate embeddedness, percentages of riffles and runs, and percentages of silt and gravel sediment. Better macroinvertebrate communities were found in wider streams with lower percentages of runs, rocky-substrate embeddedness, and silt sediment, and higher percentages of riffles and gravel substrate. Many macroinvertebrate samples were collected in areas of the stream with physical-habitat characteristics that were substantially different from the average characteristics for the entire stream reach. Improved correlations between the physical-habitat characteristics and the macroinvertebrate indices would have probably occurred if the habitat characteristics were estimated for only the area near the macroinvertebrate-sampling location.

Response to Changes in Nutrient Concentrations

Responses in the three macroinvertebrate community indices most strongly correlated with nutrients (HBI, EPTN%, and EPTTX%) are shown in figures 24 and 25. In general, HBI values increased as nutrient concentrations increased, whereas EPTN% and EPTTX% values decreased or showed no clear trend with increases in nutrient concentrations. At low nutrient concentrations, the values of these macroinvertebrate measures ranged widely; however, at high nutrient concentrations, the values were generally poor (high HBI values and low EPT indices). The best relations were found between HBI values and P, DP, and TKN concentrations, and between both EPT indices and P, DP, and NH_4-N concentrations. The other relations with nutrient concentrations ranged more widely; little relation was found between both EPT indices and N, TKN, and NO_3-N concentrations. The lower bounds of HBI plots and the upper bounds of the EPT plots may provide an indication of how nutrients are capable of affecting the macroinvertebrate community. The variation below the HBI bounds and above the EPT bounds may indicate the effects caused by factors other than nutrients.

Although nutrient concentrations were lower or higher in some EPZs and ecoregions (especially lower in EPZ 1 and the NLF ecoregion), macroinvertebrate indices responded similarly to changes in nutrient concentrations in all areas of the State (fig. 24). In all areas, there was a broad response at low nutrient concentrations and poor indices at high nutrient concentrations. Differences in the responses among areas could not be distinguished because of the range of the data and because the gradient in nutrient concentrations within some areas was small.

Regression-tree analyses were performed to define specific thresholds or breakpoints in the responses of the three macroinvertebrate community indices most strongly correlated with nutrients (table 16). The thresholds or breakpoints in the responses to changes in most nutrient concentrations were consistent among these three indices, although the data do not indicate well-defined thresholds. The thresholds in the responses to changes in total P concentrations were at about 0.09 mg/L, to changes in DP concentrations were at about 0.06–0.08 mg/L, to changes in total N concentrations were from 0.609 to 1.106 mg/L (the lowest threshold value occurred for HBI), to changes in NH_4-N concentrations were at about 0.03 mg/L, and to changes in TKN concentrations were at about 1.0 mg/L. The range in the thresholds to changes in NO_3-N concentrations was broader (from 1.157 to 3.585 mg/L). In general, the macroinvertebrate indices ranged widely below the thresholds; however, macroinvertebrate indices were poor above the thresholds.

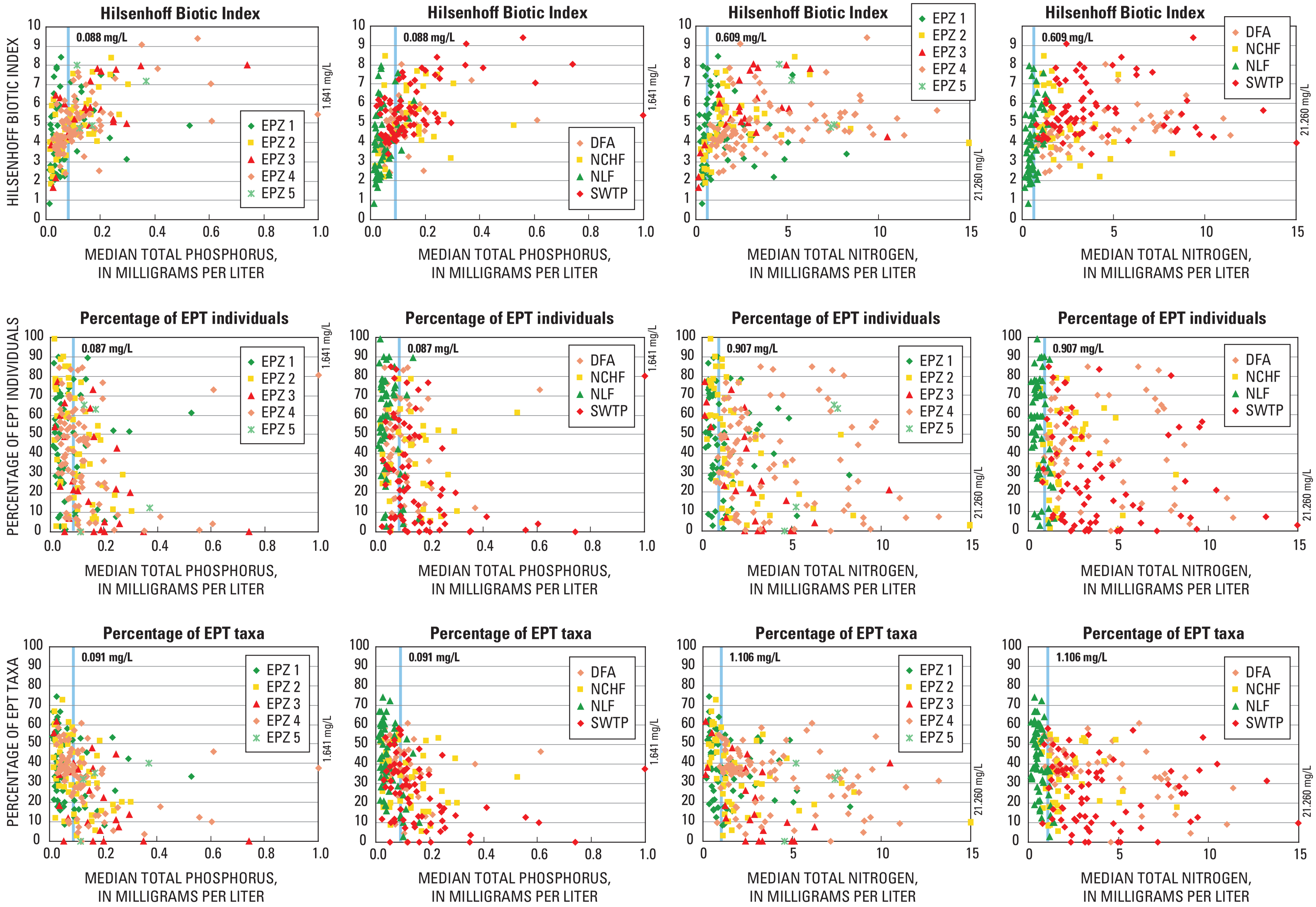


Figure 24. Hilsenhoff Biotic Index values, the percentages of individuals that were Ephemeroptera, Plecoptera, or Trichoptera, and the percentages of taxa that were Ephemeroptera, Plecoptera, or Trichoptera as a function of total phosphorus and total nitrogen concentration in the environmental phosphorus zones (EPZs) and level III ecoregions for the studied wadeable streams in Wisconsin. Computed thresholds in the response are identified by vertical lines. [DFA, Driftless Area; NCHF, North Central Hardwood Forests; NLF, Northern Lakes and Forests; and SWTP, Southeastern Wisconsin Till Plains]

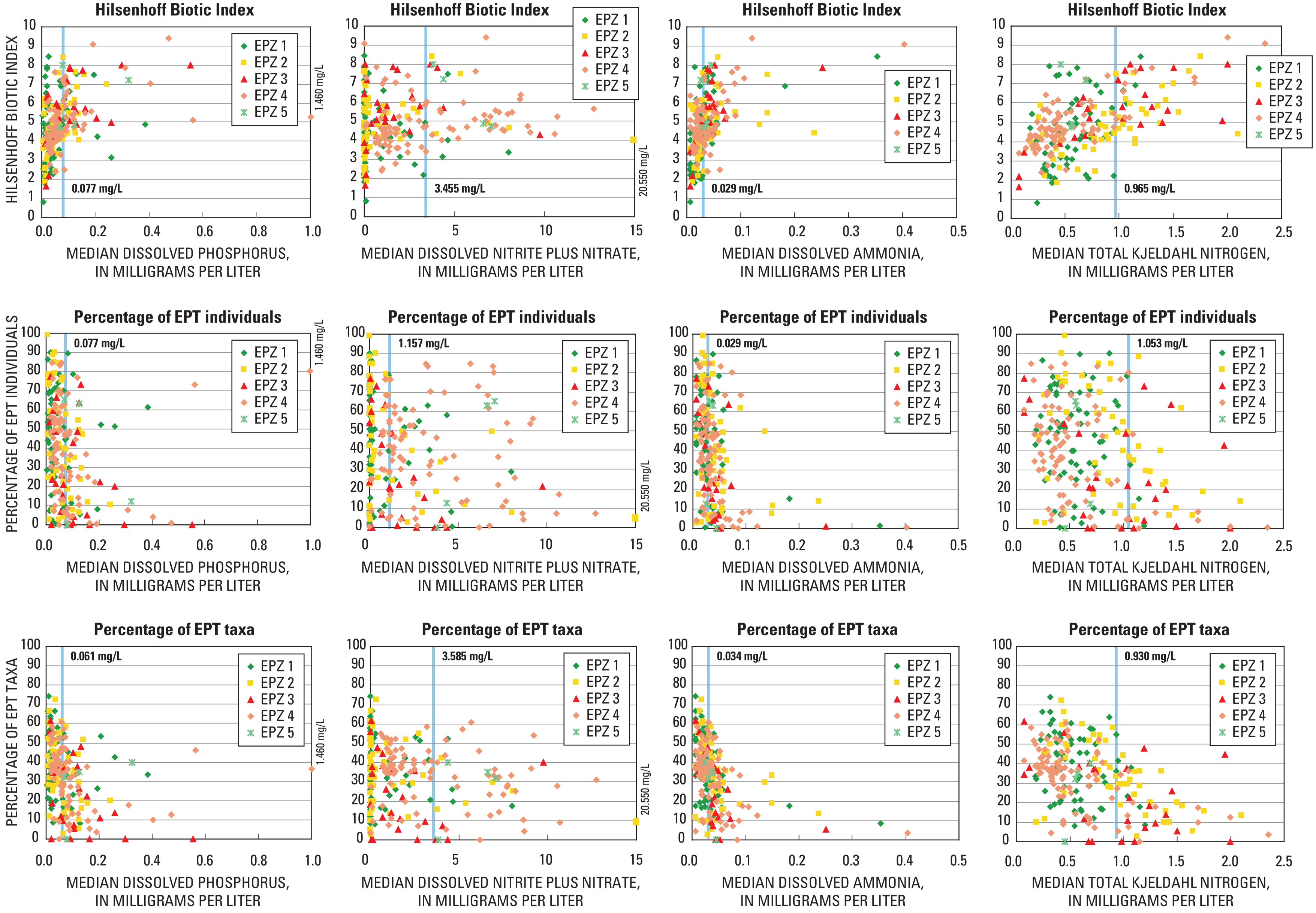


Figure 25. Hilsenhoff Biotic Index values, the percentages of individuals that were Ephemeroptera, Plecoptera, or Trichoptera, and the percentages of taxa that were Ephemeroptera, Plecoptera, or Trichoptera as a function of dissolved phosphorus, dissolved nitrite plus nitrate, dissolved ammonia, and total Kjeldahl nitrogen concentrations in the environmental phosphorus zones (EPZs) for the studied wadeable streams in Wisconsin. Computed thresholds in the response are identified by vertical lines.

Effects of Multiple Characteristics on Macroinvertebrate Indices

Stepwise Regressions

Forward stepwise regressions were done with the median water-quality, environmental, and physical-habitat characteristics to determine which four characteristics best described the variance in the macroinvertebrate indices (table 17). Models with more than four variables did not significantly increase the amount of variance explained (accumulative R^2 value). For most indices, either a nutrient or the percentage of forest/agriculture was the first variable incorporated in the models, except for the SCRAP% and SHRED% that were found to be weakly correlated with nutrient concentrations. Even with four variables, the models explained only 19 to 47 percent of the variance in the indices. The stepwise regressions explained the most variance in the same three macroinvertebrate indices (HBI, EPTN%, and EPTTX%) that were most related to the nutrients and environmental characteristics. The SHRED% model appears to have better predictability than the percent variance explained indicates because most of the values for SHRED% were 0.

Table 16. Thresholds or breakpoints in the responses in macroinvertebrate indices to changes in nutrient concentrations for wadeable streams in Wisconsin.

[EPT, Ephemeroptera, Plecoptera, and Trichoptera; all concentrations are in milligrams per liter]

Biological indices	Total phosphorus	Dissolved phosphorus	Total nitrogen	Dissolved nitrite plus nitrate	Dissolved ammonia	Total Kjeldahl nitrogen
Hilsenhoff Biotic Index (HBI)	0.088	0.077	0.609	3.455	0.029	0.965
Percentage of EPT individuals (EPTN%)	.087	.077	.970	1.157	.029	1.053
Percentage of EPT taxa (EPTTX%)	.091	.061	1.106	3.585	.034	.938

Table 17. Results of forward stepwise-regression analyses to explain variance in macroinvertebrate indices for the studied wadeable streams in Wisconsin.

[EPT, Ephemeroptera, Plecoptera, and Trichoptera; R^2, coefficient of determination for the one-, two-, three-, and four-variable models]

Dependent variable	First variable	Second variable	Third variable	Fourth variable
Hilsenhoff Biotic Index (HBI)	Dissolved ammonia	Flow per unit area	Percentage of macrophyte cover	Total phosphorus
Accumulative R^2	0.31	0.38	0.43	0.47
Percentage of EPT individuals (EPTN%)	Forest (all)	Percentage of rocky-substrate embeddedness	Stream depth	Organic-matter content
Accumulative R^2	.19	.28	.32	.35
Percentage of EPT taxa (EPTTX%)	Dissolved ammonia	Agriculture (row crops)	Percentage of rocky-substrate embeddedness	Flow per unit area
Accumulative R^2	.26	.35	.42	.45
Percentage of scrapers (SCRAP%)	Precipitation	Sediment depth	Total phosphorus	Percentage of macrophyte cover
Accumulative R^2	.07	.12	.16	.19
Percentage of shredders (SHRED%)	Peat deposits	Kjeldahl nitrogen	Percentage of streambank with erosion	Percentage of silt
Accumulative R^2	.30	.35	.38	.41
Number of taxa (TAXAN)	Total nitrogen	Watershed area	Clay deposits	Buffer width
Accumulative R^2	.14	.17	.20	.22

Redundancy Analysis

Partial RDA was used to determine the relative importance of the nutrients, other water-quality characteristics, and environmental and physical-habitat characteristics (tables 2 and 10) in affecting the distribution of the macroinvertebrate communities (the six macroinvertebrate-community indices). In this analysis, individual monthly (July and August) and median values were included for each nutrient. A forward variable-selection procedure, which correlated the macroinvertebrate indices with the other factors, was used to select a subset of variables for each general type of characteristic. This procedure retained 9 nutrient variables, 3 other water-quality characteristics, and 17 environmental and physical-habitat characteristics. These 29 characteristics explained 43 percent of the variance in the six macroinvertebrate-community indices. Of the explained variance, 22 percent was described by the nutrients alone, 5 percent by the other water-quality characteristics alone, 41 percent by the environmental and physical-habitat characteristics alone, and 32 percent by the interactions among all the characteristics (fig. 26). Therefore, nutrient concentrations by themselves explained only a small part (about 10 percent) of the total variance in the macroinvertebrate communities. About 57 percent of the total variance could not be explained by the characteristics examined in this study, and 14 percent of the total variance could not be separated into a single category of characteristics.

Reference Values for the Macroinvertebrate Indices

Reference values for the three macroinvertebrate indices most related to nutrient concentrations (HBI, EPTN%, and EPTTX%) were determined by examining the index values at only the sites having both P and N concentrations at or below their respective reference concentrations. The median HBI value for the Reference sites was 3.1 (with a 75th-percentile value of 4.4), which was significantly less than the median value at the High (nonreference) sites (5.1; fig. 27). The median reference EPTN% and EPTTX% values were 60 and 50 percent, respectively (with 25th-percentile values of 51 and 38 percent, respectively; lower percentiles are given for these indices because larger values represent better macroinvertebrate communities), which were significantly more than the median values measured at the High sites (33 and 31 percent, respectively). If 75 percent of the minimally impacted sites (the Reference sites) have index values at least as good as the reference condition, then the reference index values for HBI, EPTN%, and EPTTX% are 4.4, 51 percent, and 38 percent, respectively.

Comparing the median index values for the Reference sites with those for the Ref N and Ref P sites may provide an indication of whether P or N is more important in the degradation of the macroinvertebrate community in streams with nutrient concentrations near reference conditions (fig. 27). For all three indices, it appears that N is the more important limiting nutrient because the median values for the Ref P sites were significantly higher (HBI) or lower (EPTN% and EPTTX%) than the median values for the Reference sites. There were no differences between median values for Reference sites and the Ref N sites. Small additions of N (Ref P) had more of an effect on the macroinvertebrate communities than small additions of P (Ref N) for sites with nutrient concentrations near reference conditions.

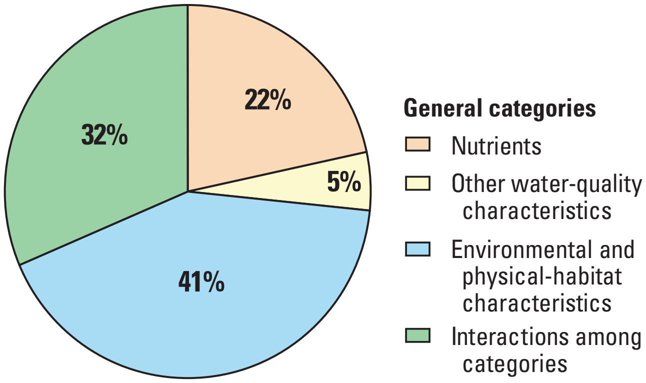


Figure 26. Percentages of explained variance in six macroinvertebrate index values described by nutrients, other water-quality characteristics, environmental (anthropogenic/land-use, soil, and surficial-deposit characteristics) and physical-habitat characteristics, and interactions among categories (variance that can not be explained by a single category) for the studied wadeable streams in Wisconsin. [%, percentage of explained variance]

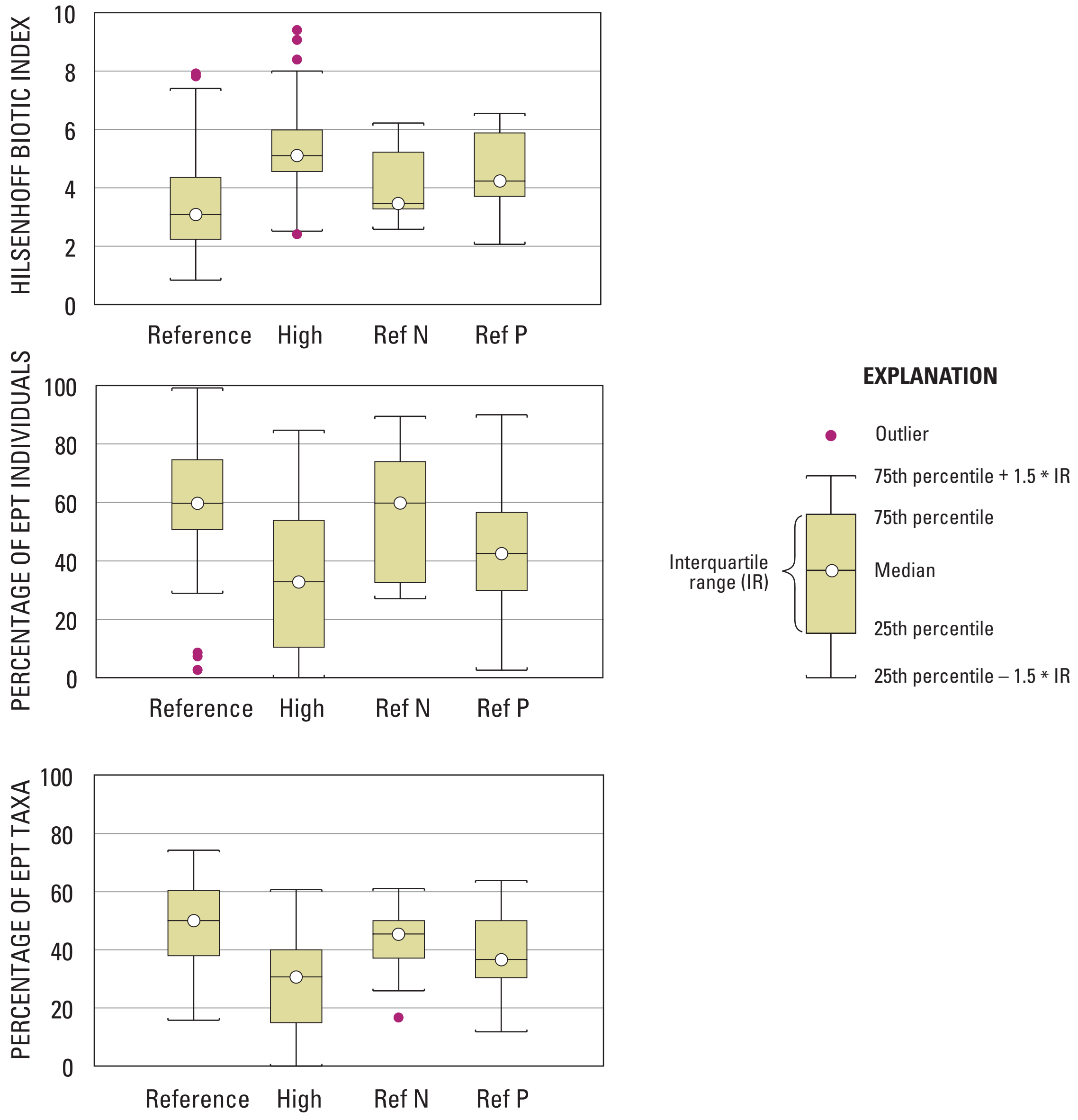


Figure 27. Hilsenhoff Biotic Index values, the percentages of individuals that were Ephemeroptera, Plecoptera, or Trichoptera, and the percentages of taxa that were Ephemeroptera, Plecoptera, or Trichoptera in Reference sites, High (nonreference) sites, and sites with only reference total nitrogen (Ref N sites) or reference total phosphorus (Ref P sites) concentrations in the studied wadeable streams in Wisconsin.

Fish Communities and Their Relations with Water-Quality, Environmental, and Physical-Habitat Characteristics

Wisconsin Department of Natural Resources personnel collecting fish with electrofishing gear. Fish pictures provided by Michael Miller and John Lyons (Wisconsin Department of Natural Resources).

The streams examined had a wide range in fish communities. Eight indices were used to describe the fish communities (table 10 on page 50). Fish Index of Biotic Integrity (IBI) values ranged from 0.0 to 100.0 (median = 40.0). The percentages of fish considered carnivores (CARN%) and insectivores (INSECT%) ranged from 0.0 to 100.0 percent (median = 1.6 and 48.9 percent, respectively). The percentages of fish considered omnivores (OMNI%) ranged from 0.0 to 81.1 percent (median = 10.5 percent). The percentages of fish considered pollution intolerant (INTOL%) ranged from 0.0 to 97.9 percent (median = 3.3 percent), and the percentage of fish considered pollution tolerant (TOL%) ranged from 0.0 to 100.0 percent (median = 42.8 percent). The number of fish caught (FISHN) ranged from 7 to 2,147 fish (median = 130). The number of species of fish caught (FISHSPEC) ranged from 1 to 33 species (median = 11). Streams in the northern and central parts of the State generally had higher IBI, INTOL%, and CARN% than streams in other parts of the State (fig. 28). The INSECT%, OMNI%, TOL%, FISHN, and FISHSPEC did not exhibit strong regional patterns.

Relations with Individual Characteristics

Correlations

Spearman rank correlation coefficients between the eight fish indices and median water-quality, environmental, and physical-habitat characteristics are shown in table 18. All eight indices were significantly correlated with at least one nutrient constituent. IBI, CARN%, and INTOL% values were most strongly correlated with most nutrients. OMNI% and TOL% values were also significantly correlated with some nutrients, but less strongly correlated than these three indices. The other three indices (INSECT%, FISHSPEC, and FISHN) were significantly correlated with only NH_4-N, TKN, or DP. In general, the fish indices indicative of better conditions (higher IBI, CARN%, INTOL% values) occurred with lower nutrient concentrations. Concentrations of NO_3-N were significantly correlated with the smallest number of fish indices. Individual monthly nutrient concentrations were also examined, but in all cases explained less variance than the median values.

In general, IBI, CARN%, INTOL%, OMNI%, and FISHAB were the indices most strongly correlated with

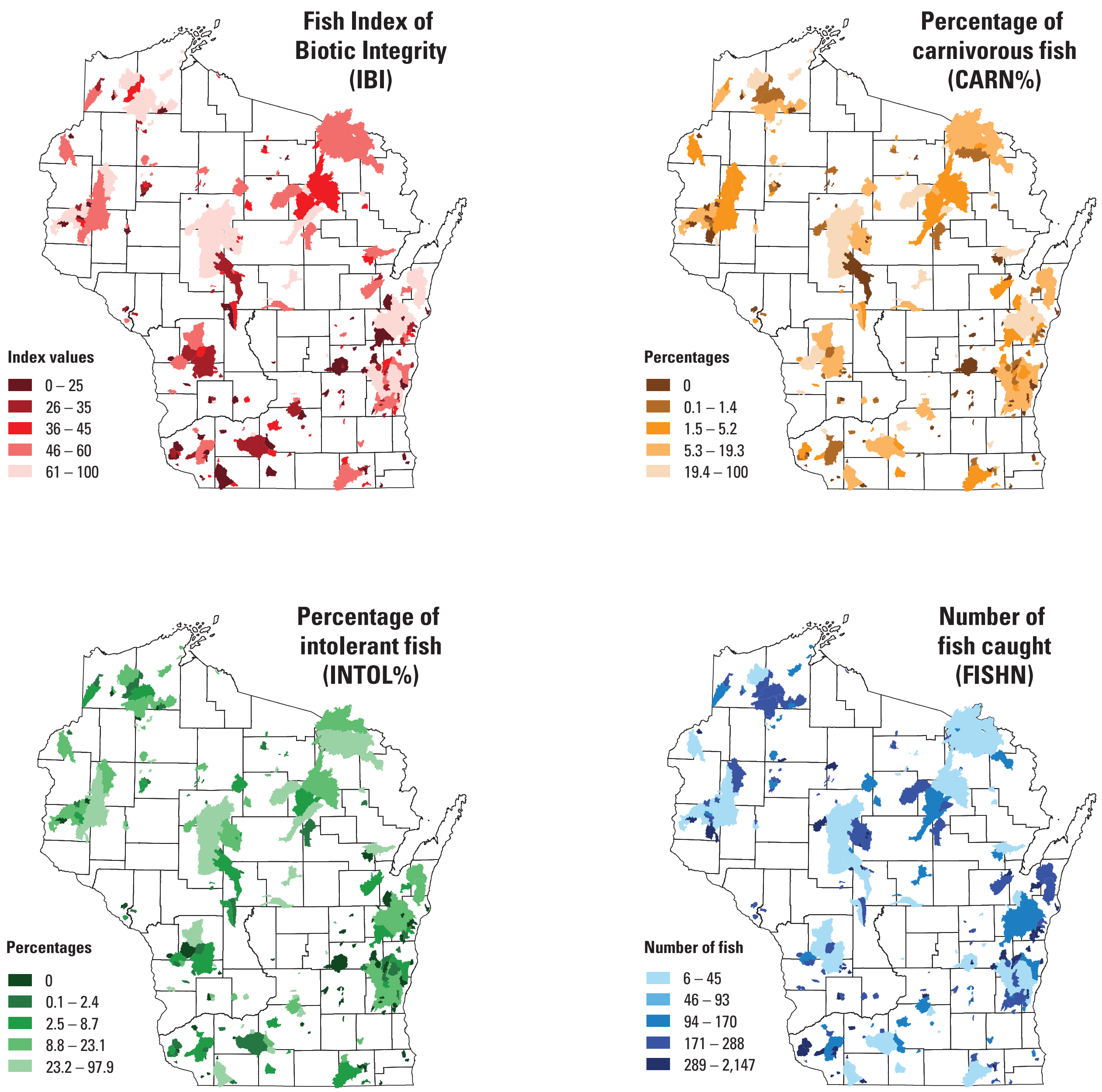


Figure 28. Distributions (quintiles) of fish Index of Biotic Integrity (IBI) values, the percentages of the fish that are carnivorous (CARN%), the percentages of fish considered pollution intolerant (INTOL%), and the number of fish caught (FISHN) for the studied wadeable streams in Wisconsin.

Table 18. Spearman rank correlation coefficients (r_s) between fish-community indices and median water-quality, environmental (anthropogenic/land-use, basin, soil, and surficial-deposit), and physical-habitat characteristics for the studied wadeable streams in Wisconsin.

[all **bold** values were significant at $p < 0.05$, after being adjusted for the Bonferroni correction (Zar, 1999); see table 10 on page 49 for definitions of abbreviations and units for each parameter]

Characteristic	Fish Index of Biotic Integrity	Percentage of carnivores	Percentage of insectivores	Percentage of omnivores	Percentage of intolerant species	Percentage of tolerant species	Number of fish species	Number of fish
Water-quality characteristics								
Total phosphorus	**-0.33**	**-0.42**	0.13	**0.23**	**-0.36**	**0.24**	0.12	0.18
Dissolved phosphorus	**-.29**	**-.41**	.09	**.21**	**-.36**	**.22**	.12	**.23**
Total nitrogen	**-.31**	**-.29**	.09	**.26**	**-.31**	.08	-.07	.14
Dissolved nitrate plus nitrite	-.20	-.14	-.04	**.27**	-.17	-.04	-.10	.12
Dissolved ammonia	**-.27**	**-.46**	**.23**	.16	**-.39**	**.29**	.04	.16
Total Kjeldahl nitrogen	**-.25**	**-.43**	**.29**	.11	**-.40**	**.36**	**.24**	.08
Suspended chlorophyll *a*	-.04	**-.28**	.18	**.26**	-.20	.03	**.33**	.15
Secchi tube depth	**.32**	**.36**	-.11	**-.29**	**.38**	-.17	-.05	.01
Anthropogenic/land-use characteristics								
Urban	.03	.10	.13	.15	.04	-.05	.12	-.17
Agriculture (row crops)	**-.25**	**-.37**	.13	**.26**	**-.41**	.13	.03	**.22**
Agriculture (all)	**-.26**	**-.36**	.09	**.29**	**-.37**	.09	.04	**.27**
Grassland	.06	.00	-.02	.07	.09	-.03	-.07	-.01
Wetland (open)	.14	-.09	**.30**	.05	.00	.06	**.34**	-.08
Wetland (forested)	.13	.04	.19	**-.22**	.05	.12	.16	**-.21**
Forest (all)	**.28**	**.39**	-.11	**-.31**	**.40**	-.13	-.05	**-.24**
Point-source loading of phosphorus	.09	.16	.05	.21	.11	-.11	**.30**	**-.23**
Basin characteristics								
Watershed area	**.26**	**.34**	.08	**.24**	**.25**	**-.25**	**.47**	-.20
Air temperature	**-.32**	**-.30**	.04	**.35**	**-.42**	.15	-.05	**.25**
Precipitation	-.15	-.06	-.17	.20	-.12	.02	-.05	.14
Runoff	**.26**	**.26**	-.11	**-.28**	**.37**	-.16	.04	-.17
Basin slope	-.12	.05	**-.22**	.10	-.01	-.04	-.18	.12
Unit area flow	.07	.08	-.06	-.09	.20	.03	-.02	.02

Table 18. Spearman rank correlation coefficients (r_s) between fish-community indices and median water-quality, environmental (anthropogenic/land-use, basin, soil, and surficial-deposit), and physical-habitat characteristics for the studied wadeable streams in Wisconsin—Continued.

[all **bold** values were significant at $p < 0.05$, after being adjusted for the Bonferroni correction (Zar, 1999); see table 10 on page 49 for definitions of abbreviations and units for each parameter]

Characteristic	Fish Index of Biotic Integrity	Percentage of carnivores	Percentage of insectivores	Percentage of omnivores	Percentage of intolerant species	Percentage of tolerant species	Number of fish species	Number of fish
Soil and surficial-deposit characteristics								
Clay content	**-.27**	**-.25**	-.02	**.26**	**-.33**	.09	-.05	**.23**
Erodibility	**-.28**	**-.35**	-.05	**.28**	**-.35**	.10	.07	**.38**
Organic-matter content	.16	.12	.18	-.18	.04	.05	.10	**-.25**
Permeability	**.26**	**.27**	.11	-.20	**.26**	-.10	.01	**-.29**
Soil slope	.05	**.30**	**-.22**	-.02	**.24**	-.16	-.16	-.03
Nonglacial deposits	-.13	.04	-.16	.20	.00	-.12	-.07	.13
Clay deposits	-.02	.01	.12	.05	-.14	-.02	.09	-.07
Loam deposits	.09	.02	.12	-.14	.18	-.07	.13	-.18
Peat deposits	.05	.03	.18	.00	.06	-.11	.15	-.12
Sand deposits	.12	-.04	.05	-.14	.04	.02	.03	-.02
Sand-and-gravel deposits	.21	.19	.09	-.03	.11	-.01	.11	**-.26**
Physical-habitat characteristics								
WIDTH	**0.31**	**0.35**	0.02	0.17	**0.31**	**-0.28**	**0.54**	-0.17
DEPTH	.04	.15	.12	**.32**	.13	-.10	**.25**	**-.21**
THALD	.08	**.22**	.12	**.29**	.18	-.15	**.26**	**-.24**
GRAD	-.11	-.19	-.18	-.10	-.15	.04	-.16	**.36**
POOL%	-.03	-.01	-.20	.03	-.05	.01	.07	**.29**
RIFF%	.14	.00	-.17	-.07	-.01	-.11	**.21**	**.26**
RUN%	-.03	.03	**.24**	.01	.07	.08	-.13	**-.31**
SEDEP	-.13	.03	.12	-.01	.01	.07	**-.30**	**-.29**
SILT%	**-.40**	**-.32**	.09	.18	**-.39**	**.25**	**-.25**	.20
SAND%	.15	.27	-.05	-.15	**.27**	-.05	-.11	**-.31**
GRAV%	.15	-.01	-.18	.03	.03	-.03	**.39**	**.23**
EMB%	-.19	-.01	.11	-.04	-.03	.11	**-.40**	**-.23**
ALGAE%	-.11	**-.25**	.00	.18	**-.22**	.05	.14	**.33**
MACR%	-.07	.02	.08	-.04	-.03	-.02	-.10	.13
COVER%	.11	.08	.12	.05	.07	.01	.02	-.10
SHADE%	.01	.03	-.13	-.08	.02	.03	-.06	-.10
EROSION%	-.11	-.06	-.16	.12	-.04	.03	.10	.01
BUFFER	.07	.07	.12	-.08	.03	-.06	.07	**-.23**

SCHL, SD, and the anthropogenic/land-use characteristics than were the other indices. These fish indices were most strongly correlated with the percentage of total agriculture, row-crop agriculture, and forested areas. Better fish indices (high IBI, CARN%, and INTOL% values) occurred with lower percentages of agriculture and higher percentages of forest. INSECT%, TOL%, and FISHSPEC were less strongly correlated with most of the anthropogenic/land-use characteristics than were IBI, CARN%, and INTOL%. IBI, CARN%, OMNI%, and INTOL% were more strongly correlated with several basin characteristics (watershed area, air temperature, and runoff) and soil characteristics (clay content, erodibility, permeability, and soil slope) than were INSECT%, TOL%, and FISHSPEC. In general, streams with better fish indices have larger drainage areas, cooler air temperatures, higher runoff, and soils with lower clay content, lower erodibility, and higher permeability. These areas with better fish indices, again, are generally the mixed and mostly forested areas of Wisconsin (fig. 2A).

In general, most fish indices were significantly correlated with only a few physical-habitat characteristics except for FISHSPEC and FISHN, which were significantly correlated with many of the characteristics. The physical-habitat characteristics most strongly correlated with fish indices were stream width and the percentage of silt in the bottom sediments. Better fish communities occurred in wider streams with lower percentages of silt in the sediments. More fish and more fish species were caught in streams with higher percentages of pools and riffles, gravel bottoms having less accumulated sediment (shallower sediment depths), lower percentages of rocky-substrate embeddedness, and a higher percentage of algal cover. More fish but fewer fish species were caught in narrower, shallower streams with steeper gradients.

Responses to Changes in Nutrient Concentrations

Responses of the three fish-community indices most strongly correlated with nutrient concentrations (IBI, CARN%, and INTOL%) are shown in figures 29 and 30. In general, IBI, CARN%, and INTOL% values decrease with increases in P and DP concentrations; however, no consistent pattern is apparent in the relations of these indices to changes in concentrations of the N constituents, except for NH_4-N. At low total P, DP, and NH_4-N concentrations, the values of these fish indices ranged widely; however, at high nutrient concentrations, the values were generally indicative of poor water quality (low values). The upper bounds of the IBI, CARN%, and INTOL% plots may provide an indication of how P, DP, and NH_4-N are capable of affecting the fish community. As was true for the other biotic indices, the variability below these bounds may be indicative of the effects of factors other than nutrients.

Relations between selected fish indices and nutrient concentrations appear to be similar in the various EPZs and ecoregions (fig. 29). In all areas, there was a broad response at low nutrient concentrations and lower indices (generally indicative of poor water quality) at high nutrient (P, DP, and NH_4-N) concentrations. As for the other biotic indices, no significant differences in the responses were found among areas because of the range in the data, and because the gradient in nutrient concentrations within some areas was small.

Regression-tree analyses were done to define specific thresholds or breakpoints in the responses of the three fish-community indices that were most strongly correlated with the nutrient concentrations (table 19). The thresholds or breakpoints in the responses to changes in nutrient concentrations were consistent among these three indices. The thresholds in the responses to changes in P concentrations were about 0.06 mg/L, to changes in DP concentrations were from about 0.04 to 0.07 mg/L, and to changes in NH_4-N concentrations thresholds were about 0.02–0.03 mg/L. In general, below these thresholds the fish indices ranged widely, but were consistently poor above these thresholds. The regression-tree analyses defined specific thresholds for N, TKN, and NO_3-N; however, the data in figures 29 and 30 do not indicate any change in the indices with changes in the concentrations of these constituents.

Effects of Multiple Characteristics on Fish Indices

Stepwise Regressions

Forward stepwise regressions were done with the median water-quality, environmental, and physical-habitat characteristics to determine which four characteristics best described the variance in the fish indices (table 20). Models with more than four variables did not significantly increase the amount of variance explained. For most indices, either P or TKN concentration was the first variable incorporated in these models. If TKN concentrations were not included in these models, then P concentrations became the first variable in the models. Other important variables included the width and depth of the streams and characteristics describing the substrate of the stream bottom. As was

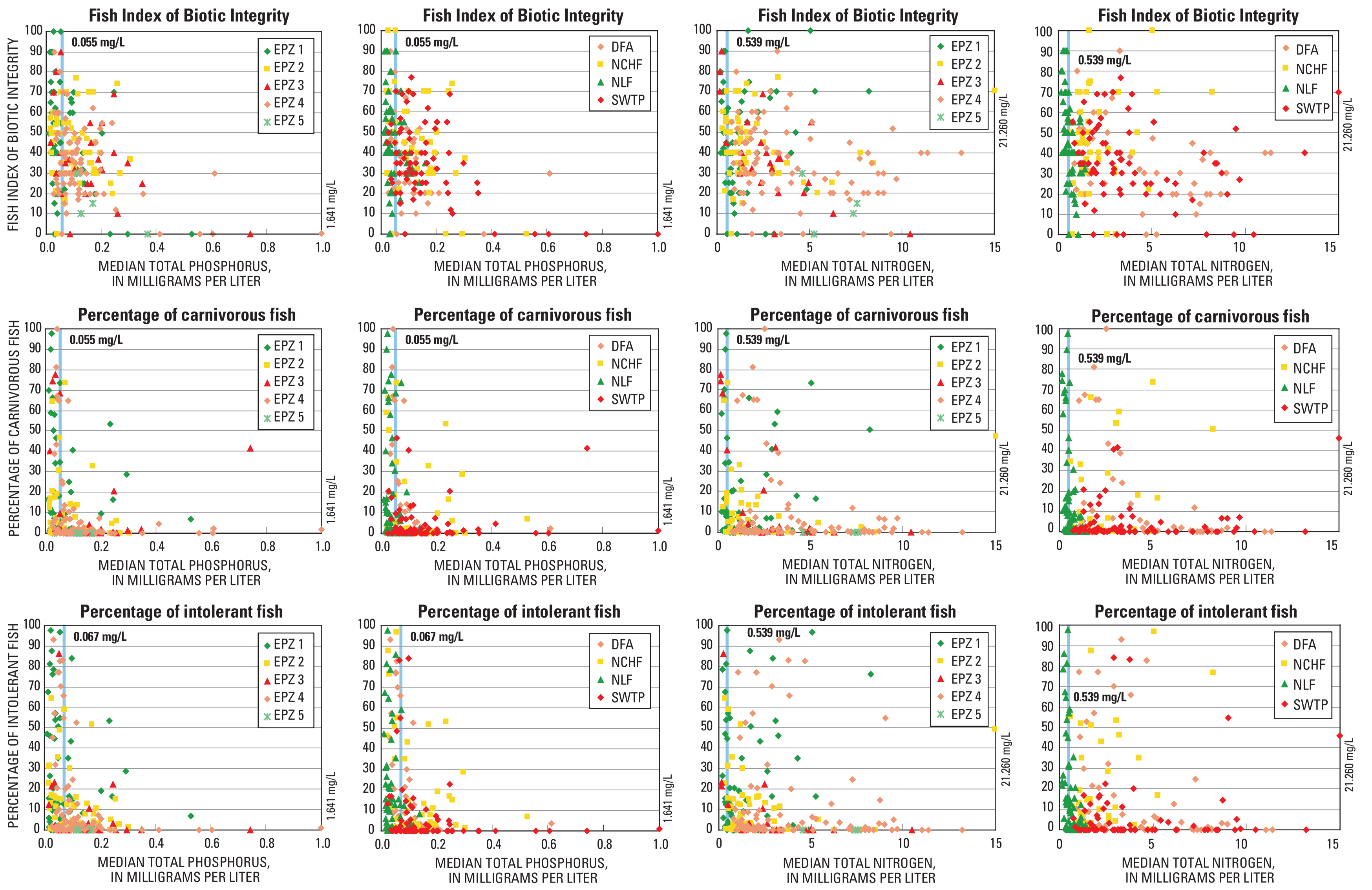


Figure 29. Fish Index of Biotic Integrity values, the percentages of fish considered pollution intolerant, and the percentages of the fish that are carnivorous as a function of total phosphorus and total nitrogen concentration in the environmental phosphorus zones (EPZs) and level III ecoregions for the studied wadeable streams in Wisconsin. Computed thresholds in the response are identified by vertical lines. [DFA, Driftless Area; NCHF, North Central Hardwood Forests; NLF, Northern Lakes and Forests; and SWTP, Southeastern Wisconsin Till Plains]

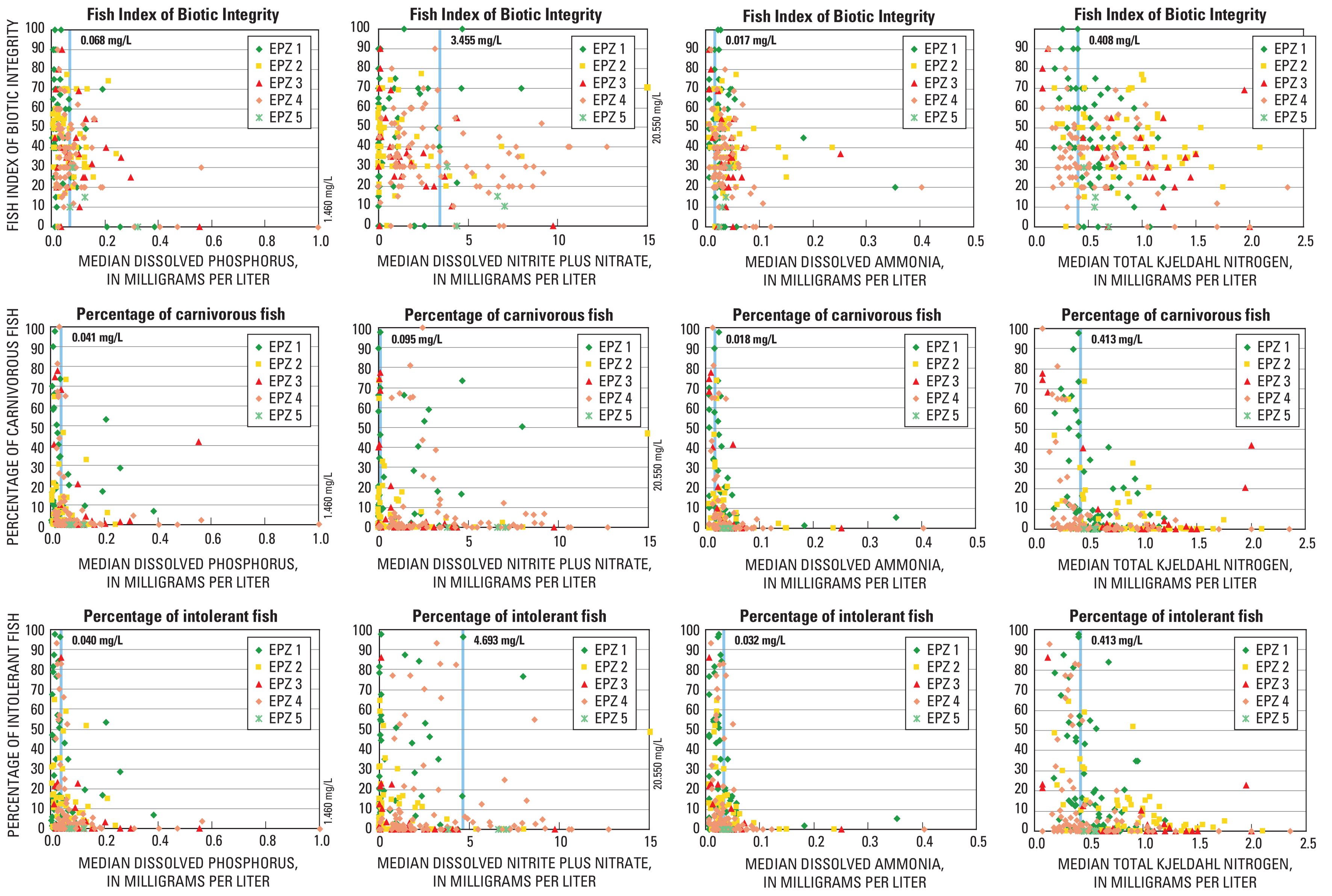


Figure 30. Fish Index of Biotic Integrity values, the percentages of fish considered pollution intolerant, and the percentages of the fish that are carnivorous as a function of dissolved phosphorus, dissolved nitrite plus nitrate, dissolved ammonia, and total Kjeldahl nitrogen concentrations in the environmental phosphorus zones (EPZs) for the studied wadeable streams in Wisconsin. Computed thresholds in the response are identified by vertical lines.

Table 19. Thresholds or breakpoints in the responses in fish indices to changes in nutrient concentrations for wadeable streams in Wisconsin.

[all concentrations are in milligrams per liter]

Biological Indices	Total Phosphorus	Dissolved phosphorus	Total nitrogen	Dissolved nitrite plus nitrate	Dissolved ammonia	Total Kjeldahl nitrogen
Fish Index of Biotic Integrity (IBI)	0.055	0.068	0.539	3.455	0.017	0.408
Percentage of carnivorous fish (CARN%)	.055	.041	.539	.095	.018	.413
Percentage of intolerant fish (INTOL%)	.067	.040	.539	4.693	.032	.413

Table 20. Results of forward stepwise-regression analyses to explain variance in fish indices for the studied wadeable streams in Wisconsin.

[R^2, coefficient of determination for the one-, two-, three-, and four-variable models; log, logarithm to base 10 transformation]

Dependent variable	First variable	Second variable	Third variable	Fourth variable
Fish Index of Biotic Integrity (IBI)	Total phosphorus	Stream width	Percentage of silt	Wetland (forested)
Accumulative R^2	0.14	0.21	0.25	0.27
Percentage of carnivorous fish (CARN%)	Kjeldahl nitrogen	Nonglacial deposits	Buffer width	Runoff
Accumulative R^2	.23	.29	.31	.32
Percentage of insectivorous fish (INSECT%)	Kjeldahl nitrogen	Percentage of pools	Percentage of gravel	Stream width
Accumulative R^2	.10	.16	.18	.22
Percentage of omnivorous fish (OMNI%)	Air temperature	Stream depth	Buffer width	Point-source loading of phosphorus
Accumulative R^2	.15	.22	.27	.29
Percentage of tolerant fish (TOL%)	Kjeldahl nitrogen	Stream width	Flow per unit area	Soil slope
Accumulative R^2	.15	.21	.23	.24
Percentage of intolerant fish (INTOL%)	Kjeldahl nitrogen	Stream width	Flow per unit area	Soil slope
Accumulative R^2	.15	.26	.27	.29
Number of fish species (FISHSPEC)	Watershed area	Percentage of gravel	Kjeldahl nitrogen	Buffer width
Accumulative R^2	.27	.35	.41	.42
Number of fish caught - log (FISHN)	Erodibility	Thalweg depth	Percentage of stream shaded	Percentage of gravel
Accumulative R^2	.15	.23	.26	.30

true for many other biotic-index models, even with four variables included, the relations only explained a small part of the total variance in these indices (in this case, from 22 to 42 percent). The model that explained the most variance was for FISHSPEC, which had watershed area and bottom substrate as the first two variables incorporated in the model.

Redundancy Analysis

Partial RDA was used to determine the relative importance of the nutrients, other water-quality characteristics, and environmental and physical-habitat characteristics (tables 2 and 10) in affecting the distribution of the fish communities (the eight fish indices). In this analysis, individual monthly (July and August) and median values were included for each nutrient constituent. A forward variable-selection procedure, which correlated fish indices with the other factors, was used to select a subset of variables for each general type of characteristic. This procedure retained 8 nutrient variables, 3 other water-quality characteristics, and 20 environmental and physical-habitat characteristics. These 31 characteristics explained 44 percent of the variance in the 8 fish-community indices. Of the explained variance, 15 percent was described by the nutrients alone, 3 percent by the other water-quality characteristics alone, 46 percent by the environmental and physical-habitat characteristics alone, and 36 percent by the interactions among all characteristics (fig. 31). About 56 percent of the total variance could not be explained with the characteristics examined in this study, and 16 percent of the total variance could not be separated into a single category of characteristics.

Reference Values for the Fish Indices

Reference values for the three fish indices that were most related to nutrient concentrations (IBI, CARN%, and INTOL%) were determined by examining the index values at only the sites having both P and N concentrations at or below their respective reference concentrations. The median IBI value for the Reference sites was 50 (with a 25th percentile of 40), the median reference CARN% value was 9.9 percent (with a 25th percentile of 1.5 percent), and the median reference INTOL% value was 14.7 percent (with a 25th percentile of 2.0 percent). Lower percentiles are given because larger values represent better fish communities. These median values were significantly higher than the median values measured at the High sites (35, 0.3 percent, and 2.0 percent respectively; fig. 32). If 75 percent of the minimally impacted sites (the Reference sites) had index values at least as good as the reference condition, then the reference index values for IBI, CARN%, and INTOL% are 40, 9.9 percent, and 2.0 percent, respectively.

Comparing the median index values for the Reference sites with those for the Ref N and Ref P sites may provide an indication of whether P or N is more important in the degradation of the fish communities in streams with nutrient concentrations near reference conditions (fig. 32). For all three indices, there was no difference between median values for Reference sites and median values of the Ref N sites and Ref P sites. Therefore, small additions of P or N appear to have little effect on the fish communities in streams with nutrient concentrations near reference conditions.

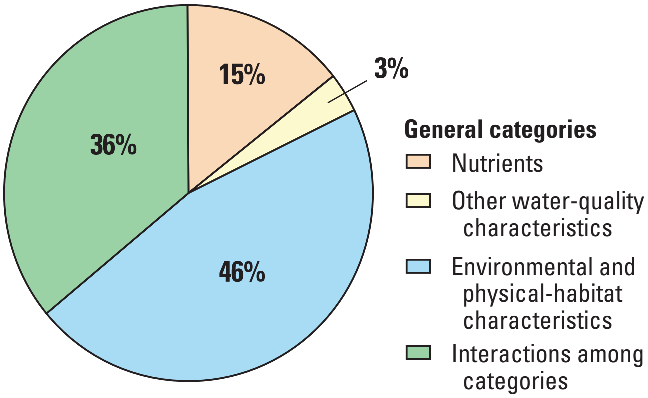


Figure 31. Percentages of explained variance in eight fish index values described by nutrients, other water-quality characteristics, environmental (anthropogenic/land-use, soil, and surficial-deposit characteristics) and physical-habitat characteristics, and interactions among categories (variance that can not be explained by a single category) for the studied wadeable streams in Wisconsin. [%, percentage of explained variance]

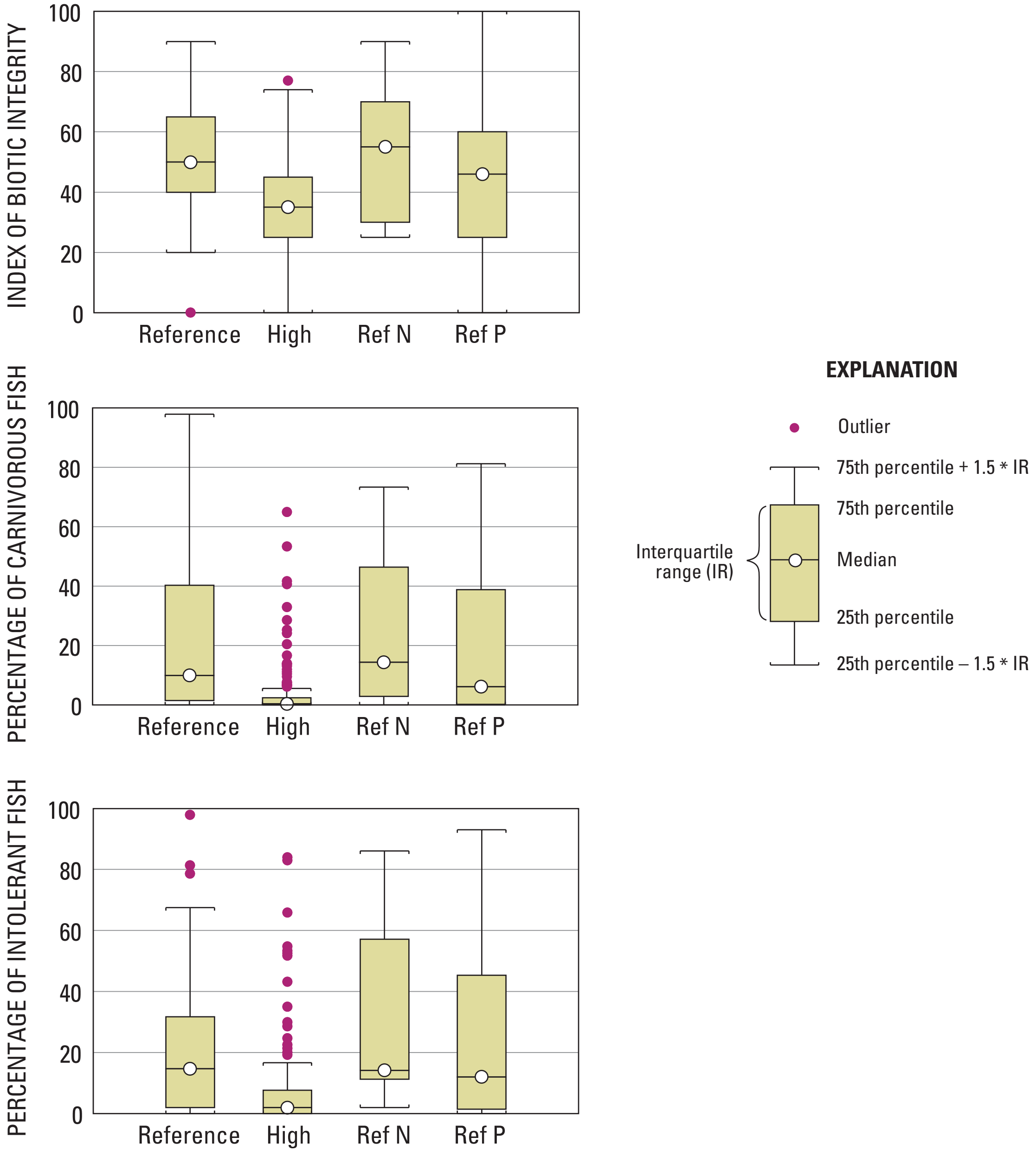


Figure 32. Fish Index of Biotic Integrity values, the percentages of the fish that are carnivorous, and the percentages of fish that are considered pollution intolerant in Reference sites, High (nonreference) sites, and sites with only reference total nitrogen (Ref N sites) or reference total phosphorus (Ref P sites) concentrations in the studied wadeable streams in Wisconsin.

Multiparameter Biotic Indices to Estimate Nutrient Concentrations in Wadeable Streams

One goal of this study was to estimate nutrient concentrations in streams from the biotic data. Most of the biotic indices, however, had a wedge-shaped response to increases in nutrient concentrations. In other words, there was a broad response in almost all index values at low nutrient concentrations; however, at high nutrient concentrations, the indices had a narrow range of values normally indicative of poor conditions. This wedge-shaped response of the biotic indices to increases in nutrient concentrations is common in describing relations between biotic indices and human disturbance levels, such as the percentage of urban land use in an area (Wang and others, 2001; 2003). The wedge-shaped response implies that at low nutrient concentrations, factors other than nutrients are predominant factors limiting the health of biotic communities, whereas at high nutrient concentrations, nutrients may be the predominant factors affecting biotic communities (Cade and others, 1999). Although these relations between nutrient concentrations and biotic indices have rarely been reported for wadeable streams in the literature, relations similar to those found in this study have been reported between P concentrations and percentages of gastropods and predator macroinvertebrates in P-addition experiments in Everglades sloughs (King and Richardson, 2004).

The wedge-shaped distribution makes predictions of low nutrient concentrations difficult with any single index. A combination of various biotic indices was used to assess whether this wedge-shaped response could be eliminated or at least reduced. To develop multiparameter indices to estimate P and N concentrations in wadeable streams, each of the indices found to be strongly related to changes in the nutrient concentrations was input into forward stepwise-regression analyses. Eleven biotic indices were included in this analysis: two describing chlorophyll *a* concentrations in the streams (log SCHL and log BCHL), three describing the periphytic-diatom community (DNI, DPTI, and DSI), three describing the macroinvertebrate community (HBI, EPTN%, and EPTTX%), and three describing the fish community (IBI, INTOL%, and CARN%).

The four-parameter model to estimate P concentrations in wadeable streams included indices describing the diatom community (DSI and DNI), suspended chlorophyll *a* (SCHL), and the fish community (IBI), and explained 54 percent of the variance in P concentrations (table 21). Models with more than four variables did not significantly increase the amount of variance explained (accumulative R^2 value). Measured and estimated log P concentrations are shown in figure 33A. This multiparameter model estimated high and low P concentrations equally well.

The four-parameter model to estimate N concentrations included indices describing benthic chlorophyll *a* (BCHL), the diatom community (DNI), the macroinvertebrate community (EPTTX%), and the fish community

Table 21. Results of forward stepwise-regression analyses to explain variance in total phosphorus and total nitrogen concentrations with biotic indices in the studied wadeable streams in Wisconsin.

[log, logarithm to base 10 transformation; r_s, Spearman correlation coefficient; R^2, coefficient of determination for the one-, two-, three-, and four-variable models; SCHL, suspended chlorophyll *a* concentration; na, not applicable; all regressions were on log-transformed concentrations; see table 10 on page 49 for definitions of abbreviations and units for each parameter]

Statistical parameter	Constant	First variable	Second variable	Third variable	Fourth variable
Total phosphorus (P)					
		Diatom DSI	Log (SCHL)	Diatom DNI	Fish IBI
Coefficient in equation	-1.797	0.005	0.300	0.140	-0.004
r_s	na	.60	.44	.47	-.33
Accumulative R^2	na	.32	.41	.48	.54
Total nitrogen (N)					
		Log (BCHL)	EPTTX%	Fish IBI	Diatom DNI
Coefficient in equation	-0.373	.200	-.007	-.005	.108
r_s	na	.49	-.39	-.31	.36
Accumulative R^2	na	.23	.33	.37	.41

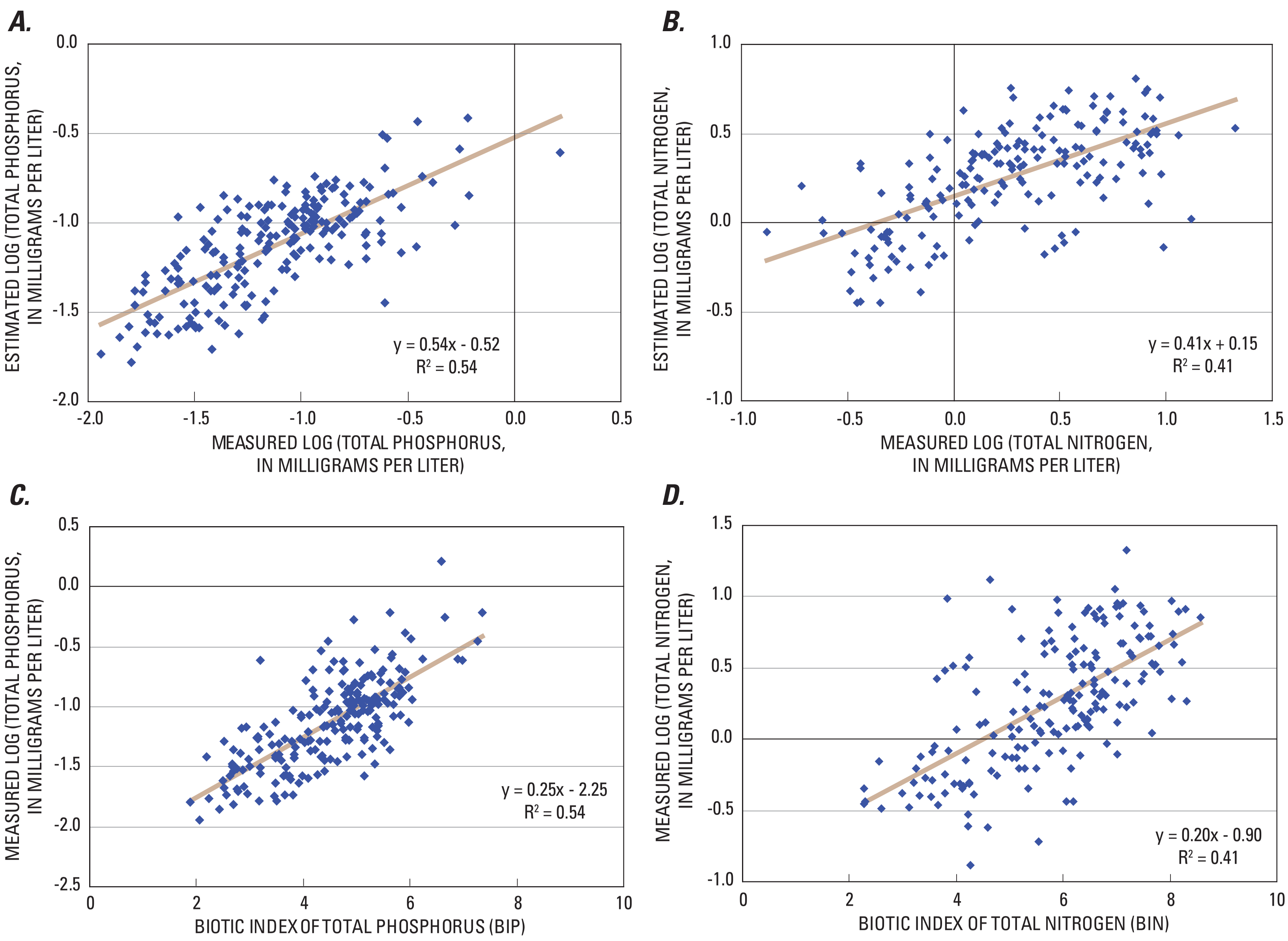


Figure 33. Measured and estimated ***A***, total phosphorus and ***B***, total nitrogen concentrations (logarithm to base 10 transformation) for the four-parameter regression models, ***C***, measured phosphorus concentrations as a function of Biotic Index of total Phosphorus (BIP) values, and ***D***, measured nitrogen concentrations as a function of Biotic Index of total Nitrogen (BIN) values, with the regression equations and coefficients of determination (R^2) for the studied wadeable streams in Wisconsin.

(IBI). This model explained 41 percent of the variance in N concentrations (table 21). Models with more than four variables did not significantly increase the amount of variance explained. Measured and estimated log N concentrations are shown in figure 33B. This multiparameter model estimated high and low N concentrations equally well, but did not estimate N concentrations as well as the P model estimated P concentrations.

The regression equations described in table 21 were then used to develop multiparameter biotic indices to estimate P and N concentrations in wadeable streams. The indices were developed to provide values ranging from 1 to 10, with 1 representing the lowest P and N concentrations and 10 representing the highest concentrations.

The Biotic Index of total P (BIP) is computed as:

$$\mathrm{BIP} = 4.0(-1.797 + 0.005\,\mathrm{DSI} + 0.300\,\mathrm{Log\ SCHL} + 0.140\,\mathrm{DNI} - 0.004\,\mathrm{IBI}) + 9.0 \qquad (12)$$

The Biotic Index of total N (BIN) is computed as:

$$\mathrm{BIN} = 5.0(-0.373 + 0.200\,\mathrm{Log\,BCHL} - 0.007\,\mathrm{EPTTX\%} - 0.005\,\mathrm{IBI} + 0.108\,\mathrm{DNI}) + 4.5 \qquad (13)$$

The BIP and BIN values are plotted against their respective measured P and N concentrations in figures 33C and D. Both BIP and BIN estimate median P and N concentrations equally well over the range of concentrations measured in this study. The BIP predicted P concentrations better than the BIN predicted N concentrations (54 percent of the variance in P concentrations compared to 41 percent of the variance in N concentrations). The difference in the predictability of these indices was consistent with most of the biotic indices being more strongly correlated with P concentrations than with N concentrations. This difference in predictability suggests that P concentrations are more important than N concentrations in affecting the biotic communities over the range in nutrient concentrations measured in this study.

Summary and Conclusions

Excessive nutrient loss from watersheds is frequently associated with degraded water quality in streams. To reduce this loss from agricultural areas, performance standards and regulations for croplands and livestock operations are being proposed by various States. In addition, the USEPA is establishing regionally based nutrient criteria that can be refined by each State to determine whether actions are needed to improve a stream's water quality. More confidence in the environmental benefits of the proposed standards and nutrient criteria are possible with a better understanding of the biotic responses to a range of nutrient concentrations in different environmental settings.

To provide the information needed to guide the development of regionally based nutrient criteria for Wisconsin streams, the USGS and WDNR collected water-quality and biotic data in 240 wadeable streams throughout Wisconsin to: 1) describe how nutrient concentrations and biotic-community structure vary throughout the State; 2) determine which environmental characteristics are most strongly related to the distribution of nutrient concentrations; 3) determine reference water-quality and biotic conditions for different areas of the State; 4) determine how the biotic community of streams in different areas of the State respond to changes in nutrient concentrations; 5) determine the best regionalization scheme to describe the patterns in reference conditions and the responses in water quality and the biotic community; and 6) develop new indices to estimate nutrient concentrations in streams from a combination of biotic indices.

Final Regionalization Scheme for Wisconsin Streams

Two regionalization schemes were proposed for defining nutrient criteria for Wisconsin's wadeable streams: level III ecoregions and environmental phosphorus zones (EPZs). On the basis of the results of this study, the EPZ regionalization scheme was better than the level III ecoregion scheme at defining differences in reference water quality and differences in the responses in water quality to changes in land use for constituents that varied regionally. For some water-quality characteristics, however, the results indicated that little consistent variability was present and no regionalization was warranted. For total nitrogen (N) concentrations, suspended chlorophyll *a* (SCHL) and Secchi tube depth (SD), the regional variabilities in reference conditions and in the water-quality responses are best described by subdividing wadeable streams into two categories: streams in areas with high clay-content soils (EPZ 3) and streams throughout the rest of the State (fig. 34). The regional variability in the response in total phosphorus (P) concentrations to changes in land use was also best described by subdividing the streams into these two categories; however, little consistent variability was found in reference P concentrations in streams throughout the State.

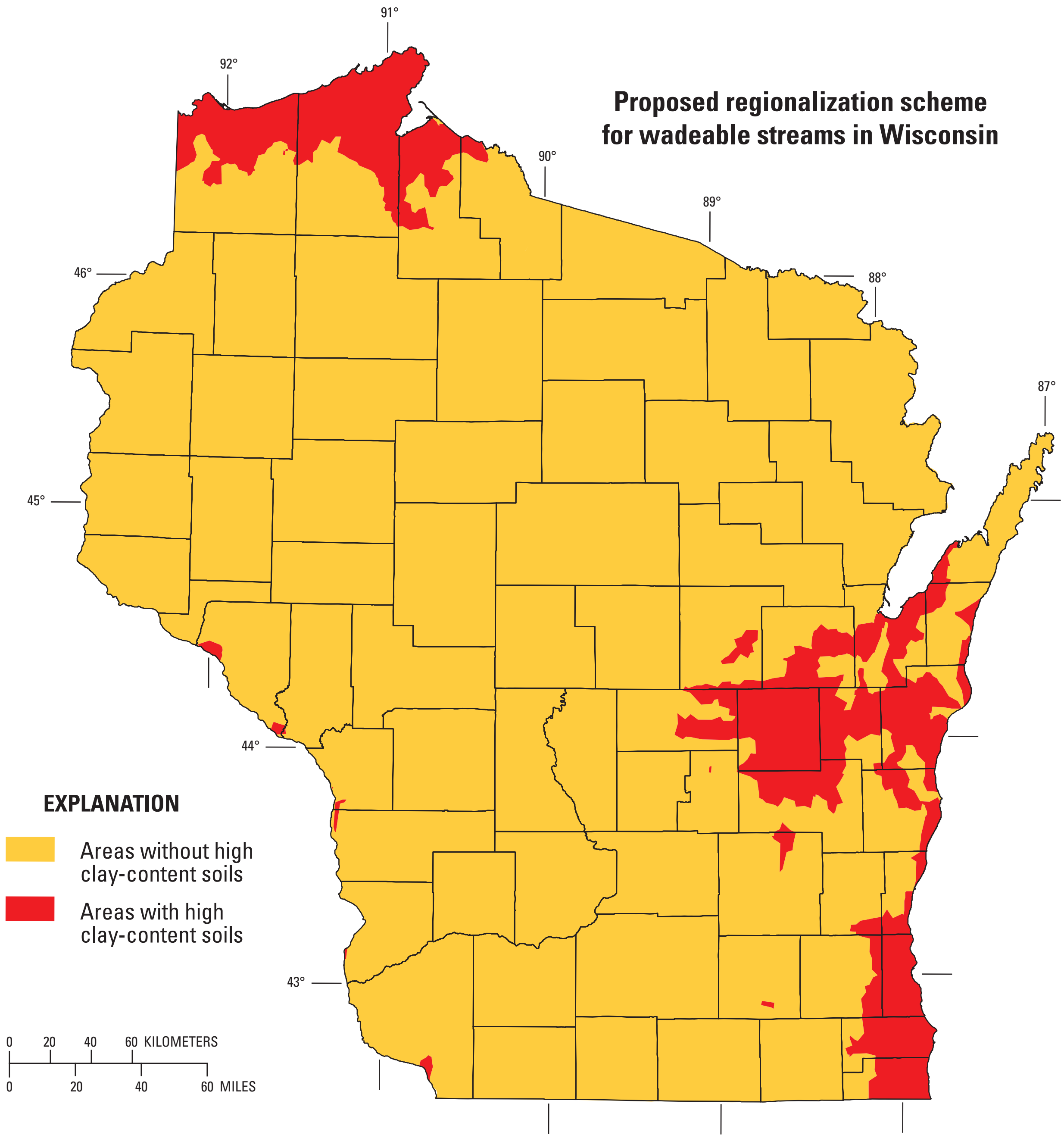


Figure 34. Proposed regionalization scheme for defining nutrient criteria for wadeable streams in Wisconsin.

Despite variation in nutrient concentrations among EPZs and level III ecoregions (especially lower nutrient concentrations in the northern part of the State), the responses of all of the biotic indices to changes in nutrient concentrations were similar throughout the State. In all areas, there was a broad response in the indices at low nutrient concentrations and a narrower range in values, indicative of poor water quality, at high nutrient concentrations. No regional differences were found in the biotic responses among areas; therefore, there is no reason to subdivide the streams based on the biotic response to changes in nutrient concentrations.

Reference Conditions

Results of this study indicate that reference P concentrations for wadeable streams are similar throughout the State: 0.03–0.04 mg/L with an upper 95-percent confidence limit of 0.04–0.06 mg/L (table 22). These values are higher than those estimated by Robertson and others (2006), who estimated that reference P concentrations for Wisconsin streams and larger rivers were between 0.012 and 0.023 mg/L. Values from this study are similar to those defined by the USEPA for nutrient ecoregion 7, but higher than those defined for nutrient ecoregion 8. The USEPA defined reference P concentrations for the DFA and SWTP ecoregions at 0.070 and 0.080 mg/L, respectively, which are higher than those estimated in this study. The higher values defined for the DFA and SWTP ecoregions were probably because most of the watersheds of streams in those areas are dominated by agriculture, and more than 25 percent of the streams are affected by anthropogenic factors.

Reference N concentrations can be subdivided into two categories: 0.6–0.7 mg/L with the upper 95-percent confidence limit of 0.7–1.0 mg/L in all streams except those in areas with high clay-content soils, where 0.4 mg/L and an upper 95-percent confidence limit of 0.6 mg/L are more appropriate (table 22). These values are also similar to those defined by the USEPA for nutrient ecoregion 7 (0.54 mg/L), but higher than those defined for nutrient ecoregion 8 (0.20–0.38 mg/L). The USEPA defined reference N concentrations for the DFA and SWTP ecoregions to be 1.30–1.88 mg/L, which are higher than those estimated in this study, probably because most of the streams in these areas are dominated by agriculture.

Reference SCHL concentrations can be subdivided into two categories: 1.2–1.7 µg/L with the upper 95-percent confidence limit of 1.7–2.2 µg/L in all streams except those in areas with high clay-content soils, where 1.0 µg/L and upper 95-percent confidence limit of 1.6 µg/L are more appropriate (table 22). These values are less than those defined by the USEPA for nutrient ecoregions 7 and 8 when the trichromatic method of analysis is used (5.8 and 4.3 µg/L, respectively).

Reference water clarity can be subdivided into two categories: streams in areas with high clay-content soils (EPZ 3) with poorer reference water clarity (a SD of about 110 cm), and streams throughout the rest of the State with better water clarity (SD greater than 115 cm; table 22). In all areas of the State, the upper 95-percent confidence limit for reference water clarity was better than could be measured with the 120-cm Secchi tube used in this study. It is likely that the poorer clarity in the streams in areas with high clay-content soils is caused by colloidal clay particles, which often remain in suspension. Reference SDs are not directly comparable with values defined by the USEPA for turbidity.

For each category of the biotic community (SCHL, BCHL, periphytic diatoms, macroinvertebrates, and fish), the indices most related to changes in nutrient concentrations are listed in table 22. The three diatom indices (Diatom Nutrient Index (DNI), Diatom Siltation Index (DSI), and Diatom Biotic Index (DBI)) displayed the strongest responses to changes in nutrient concentrations. The three macroinvertebrate indices that displayed the strongest responses to changes in nutrient concentrations were the Hilsenhoff Biotic Index (HBI), the percentage of individuals that were Ephemeroptera, Plecoptera, or Trichoptera (EPTN%), and the percentage of taxa that were Ephemeroptera, Plecoptera, or Trichoptera (EPTTX%). The three fish indices that displayed the strongest responses to changes in nutrient concentrations were the fish Index of Biotic Integrity (IBI), the percentage of carnivorous fish (CARN%), and the percentage of fish that are considered pollution intolerant (INTOL%). Values of each of these indices ranged widely when nutrient concentrations were at or below the reference concentrations, but were significantly different from the respective values for streams with nutrient concentrations significantly higher than reference conditions. The median values of the biotic indices at the Reference sites (sites with nutrient concentrations at or below reference concentrations) are given in table 22. It has been suggested that the upper 75th percentile for the concentration data for a subset of streams thought to be minimally impacted for a defined area may represent the reference conditions. This upper 75th percentile assumes that high values are indicative of poor conditions. For some biotic indices, however, lower values are indicative of poor conditions; therefore, the values for each biotic index at the worst 75th percentile of the subset of streams

Table 22. Reference conditions for water quality, chlorophyll *a*, diatoms, macroinvertebrates, and fish indices for wadeable streams in Wisconsin.

[EPT, Ephemeroptera, Plecoptera, and Trichoptera; %, percent; mg/L, milligram per liter; µg/L, microgram per liter; cm, centimeter; >, greater than; mg/m^2, milligram per square meter]

	Median reference	Upper 95-percent confidence limits
Total phosphorus (P) (mg/L)		
Entire State	0.03–0.04	0.04–0.06
Total nitrogen (N) (mg/L)		
High-clay content areas (EPZ 3)	0.4	0.6
Rest of State	0.6–0.7	0.7–1.0
Suspended chlorophyll *a* (SCHL)(µg/L)		
High-clay content areas (EPZ 3)	1.0	1.6
Rest of State	1.2–1.7	1.7–2.2
Secchi tube depth (SD)(cm)		
High-clay content areas (EPZ 3)	110	> 120
Rest of State	>115	> 120

	Median reference	[1] Worst 75th percentile of sites with reference nutrient concentrations
Benthic Chlorophyll *a* (BCHL)(mg/m^2)	331	673
Diatoms		
Diatom nutrient index (DNI)	3.4	4.1
Diatom siltation index (DSI)	11.8	22.5
Diaton biotic index (DBI)	47.5	37.4
Macroinvertebrates		
Hilsenhoff Biotic Index (HBI)	3.1	4.4
Percentage of EPT individuals (EPTN%)	59.7	50.7
Percentage of EPT taxa (EPTTX%)	50.0	38.0
Fish		
Fish Index of Biotic Integrity (IBI)	50.0	40.0
Percentage of carnivorous fish (CARN%)	9.9	1.5
Percentage of intolerant fish (INTOL%)	14.7	2.0

[1] Lower values of the indices are not always indicative of better biotic conditions; therefore, the values at the worst (or poorer) 75th percentiles of a subset of minimally impacted streams are given.

thought to be minimally impacted would represent the reference condition. The values of each of the biotic indices at the worst 75th percentile for the minimally impacted streams are given in table 22.

Responses of Water Quality to Changes in Land Use

Concentrations of P and N in streams throughout the State increase at different rates as the percentage of agricultural land increases. Concentrations of P increase more quickly and concentrations of N increase more slowly in response to increasing percentages of agriculture in areas with high clay-content soils than do P and N concentrations in streams in the rest of the State. The response of water clarity to changes in nutrient concentrations is similar in streams throughout the State. The streams in areas with high clay-content soils, however, have a lower reference water clarity, and their clarity remains lower than that in streams from other areas with similar nutrient concentrations as the percentage of agriculture increases.

Responses of Biotic Indices to Changes in Nutrient Concentrations

The responses of biotic indices to changes in nutrient concentrations were examined when nutrient concentrations were at or near reference concentrations and thus had potential to limit biotic growth, and as nutrient concentrations increase. Comparison of the median index values for Reference sites with those for sites with P concentrations at or below reference conditions, but with N concentrations above reference conditions and with those of sites with N concentrations at or below the reference conditions, but with P concentrations above reference conditions provided an indication of whether P or N was more important in affecting the biota. For SCHL, P was the more important limiting nutrient, whereas for BCHL and all of the macroinvertebrate indices, N was the more important limiting nutrient. For other diatom indices and all fish indices, there were no differences between the median values for Reference sites and those of the other two categories of sites; therefore, small additions of P or N appear to have little effect on these communities in streams with nutrient concentrations near reference conditions. At the start of this study, it was thought that the biota in streams were more affected by P than N concentrations; however, these results suggest that in streams with low nutrient concentrations, N may be at least as important as P in affecting BCHL concentrations and the macroinvertebrate communities.

Changes in the biotic indices as nutrient concentrations increase indicate that nutrients have direct or indirect effects on the composition of the biotic community in Wisconsin's wadeable streams. Visual inspection of scatterplots and results of Spearman correlations and multiple linear regressions indicate that as nutrient concentrations increase above reference conditions, changes in the biotic community are more strongly related to changes in P concentrations than to changes in N concentrations. The relations between nutrient concentrations and most biotic indices were found to be nonlinear. The biotic integrity of wadeable streams was negatively correlated with increasing nutrient concentrations, and the effects on the biotic community were largest at relatively low nutrient concentrations. From the data collected in this study, nutrient-concentration thresholds were identified where a small change in nutrient concentrations corresponds to a relatively large change in the biotic communities. A summary of the nutrient thresholds is given in table 23. The thresholds in the responses to changes in P concentrations ranged from 0.039 mg/L for BCHL, to about 0.06–0.07 mg/L for SCHL, diatom indices, and fish indices, to about 0.09–0.10 mg/L for macroinvertebrate indices and SD. The thresholds in the responses to changes in N constituents were more variable than for P concentrations. The thresholds in the responses to changes in N concentrations ranged from about 0.5–0.6 mg/L for the fish indices and one macroinvertebrate index, to about 0.9–1.2 for SCHL, the diatom indices, and the other macroinvertebrate indices, to about 3.3 mg/L for SD. The thresholds for most of the biotic responses were not much above the reference concentrations estimated for P and N throughout the State.

Most of the biotic indices had a wedge-shaped response to increases in nutrient concentrations. In other words, there was a broad response in almost all index values at low nutrient concentrations; however, at high nutrient concentrations, the indices had a narrow range of values normally indicative of poor water-quality conditions. This wedge-shaped response of the biotic indices to increases in nutrient concentrations is common in describing relations between biotic indices and human disturbance levels. The wedge-shaped response implies that at low nutrient concentrations, factors other than nutrients are predominant factors limiting the health of biotic communities, whereas at high nutrient concentrations, nutrients may be the predominant factors affecting biotic communities.

Table 23. Summary of thresholds or breakpoints in the responses of suspended chlorophyll *a* concentrations, Secchi tube depth, and various biotic indices to changes in nutrient concentrations for wadeable streams in Wisconsin.

[EPT, Ephemeroptera, Plecoptera, and Trichoptera; all concentrations are in milligrams per liter]

Indices	Total phosphorus	Dissolved phosphorus	Total nitrogen	Dissolved nitrite plus nitrate	Dissolved ammonia	Total Kjeldahl nitrogen
Water quality						
Suspended chlorophyll *a* (SCHL)	0.070	0.028	1.169	0.095	0.057	0.563
Secchi tube depth (SD)	.106	.047	3.305	2.583	.039	.920
Benthic chlorophyll *a* and diatom indices						
Benthic chlorophyll *a* (BCHL)	.039	.020	.918	.187	.040	.310
Diatom Nutrient Index (DNI)	.057	.026	1.216	.381	.021	.745
Diatom Siltation Index (DSI)	.074	.046	.872	.089	.022	1.080
Diatom Biotic Index (DBI)	.072	.039	1.169	.381	.022	.388
Macroinvertebrate indices						
Hilsenhoff Biotic Index (HBI)	.088	.077	.609	3.455	.029	.965
Percentage of EPT individuals (EPTN%)	.087	.077	.970	1.157	.029	1.053
Percentage of EPT taxa (EPTTX%)	.091	.061	1.106	3.585	.034	.938
Fish indices						
Fish Index of Biotic Integrity (IBI)	.055	.068	.539	3.455	.017	.408
Percentage of carnivorous fish (CARN%)	.055	.041	.539	.095	.018	.413
Percentage of intolerant fish (INTOL%)	.067	.040	.539	4.693	.032	.413

Although there were significant correlations and visual relations between the nutrient concentrations and the characteristics of biotic communities, this may or may not be an indication of cause-and-effect relations. The biotic communities that are present in a stream reflect the overall ecological integrity (in other words, physical, chemical, and biological integrity); therefore, they integrate the effects of many different stressors (such as hydrology, sedimentation, pesticides, and nutrients) over the time-span of days to years and thus provide a broad measure of their aggregate impact. In addition, the geomorphology, geochemistry, land use, and land cover in the watershed control the physical/chemical habitat of the stream where the biota live. The characteristics of biotic communities are controlled by many environmental factors, though they may be directly affected by only a subset of variables. Results of redundancy analyses indicate that nutrients alone explained only a small part of the variance in the biotic indices for wadeable streams, and about a third of the variance could not be resolved into single categories of environmental characteristics. Nutrient concentrations by themselves explained from about 6 to 13 percent of the total variance in the biotic indices or about 13 to 23 percent of the explained variance. Nutrient concentrations were most important in affecting SCHL concentrations and macroinvertebrate communities, and least important in affecting BCHL concentrations, periphytic diatoms, and fish communities.

Multiparameter Biotic Indices to Estimate Nutrient Concentrations in Wadeable Streams

One goal of this study was to develop an index based on biotic indices to estimate nutrient concentrations in streams. Most of the biotic indices had wedge-shaped responses to increases in nutrient concentrations; thus, estimations of low nutrient concentrations would be difficult with any single index. Through the use of a combination of the biotic indices that were significantly correlated to nutrient concentrations, two new multiparameter indices were developed which eliminated this nonlinear response (Biotic Index of total Phosphorus, BIP, and Biotic Index of total Nitrogen, BIN). These multiparameter models estimated high and low nutrient concentrations equally well. The BIP estimated P concentrations better than the BIN estimated N concentrations (54 percent of the variance in P concentrations compared to 41 percent of the variance in N concentrations). The difference in the predictability of these indices was consistent with the biotic indices being more strongly correlated to P concentrations than to N concentrations. This difference again suggests that P concentrations are more important than N concentrations in affecting the biotic communities as nutrient concentrations increase above reference conditions.

Nutrient Concentrations Controlling the Biotic Integrity of Streams

Rather than examining causal relations between nutrients and the biotic community structure, this study focused on demonstrating that nutrient concentrations are correlated with the health of wadeable streams, that specific responses exist and in some cases differ geographically, and that specific nutrients are more related to changes in stream health than other nutrients. With the results of this study, management activities can be better directed to reduce the controllable nutrient sources. Although the specific mechanisms of how nutrients affect the biota in wadeable streams were not examined, the results of this study indicate that nutrients are important in controlling the biotic health of streams. The biotic-community structure represents the overall ecological integrity of the stream; however, results of this study demonstrated that nutrients alone explained only a small part of the variability in the structure. Therefore, it is difficult to predict the exact result of reducing nutrient concentrations without also modifying the factors typically associated with high nutrient concentrations. Nutrient concentrations in many streams, especially those in agricultural areas, are well above the response thresholds for the biotic indices; therefore, small reductions in concentrations in these streams are not expected to have large effects on the biotic community. Even with these limitations, however, it is expected that reducing nutrient concentrations will improve the biotic community, further the beneficial ecological uses of most streams, and improve the quality of downstream nutrient-limited receiving waters.

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Appendixes

Appendix 1. Stream identification (ID) information, location information, and summary statistics for flow and water-quality data collected for each of the 240 studied wadeable streams in Wisconsin.

[Cr, Creek; Trib, Tributary; Br, Brook; ID, identification number; USGS, U.S. Geological Survey; km^2, square kilometer; m^3/s/km^2, cubic meter per second per square kilometer; mg/L, milligram per liter; µg/L, microgram per liter; C; degrees centigrade; µS/cm; microSiemen per centimeter; m, meter; --, no data collected at site; all water-quality data are median values unless otherwise noted]

ID (see fig. 4)	Stream name	USGS site number	Ecoregion ID	Phosphorus zone	Longitude	Latitude	Collection year	Watershed area (km^2)	Flow per unit area (m^3/s/km^2)
1	Onion	04026232	NLF-18	3	90.8903	46.7547	2001	15.4	0.0171
2	Thompson	040263165	NLF-15	3	90.9161	46.6686	2001	13.3	.0055
3	Parker	04027788	NLF-12	3	90.4358	46.5608	2001	8.4	.0027
4	Catlin	053315805	NLF-03	1	91.7911	46.3975	2001	5.2	.0111
5	Leo	05331581	NLF-14	1	91.8214	46.3222	2001	15.3	.0078
6	Lower Ox	05331590	NLF-10	1	91.7381	46.3222	2001	221.7	.0026
7	Lord	05331615	NLF-29	1	91.9089	46.2756	2001	26.5	.0068
8	Fivemile	05331811	NLF-01	1	91.2158	46.2042	2001	3.2	.0206
9	Cap	05331813	NLF-33	1	91.2344	46.1975	2001	39.7	.0032
10	Spring Cr	05331814	NLF-22	1	91.2417	46.1986	2001	13.8	.0055
11	Mosquito Br	05331856	NLF-35	1	91.3947	46.0458	2001	24.3	.0032
12	Smith Lake	053318635	NLF-24	1	91.4883	46.0450	2001	19.6	.0033
13	Fiddler	05331872	NLF-02	1	91.5139	45.9936	2001	8.2	.0098
14	Spring Lake	05331873	NLF-23	1	91.4831	45.9911	2001	16.6	.0066
15	Rainbow	05331877	NLF-19	1	91.5192	45.9608	2001	2.9	.0180
16	Dody Brook	05335530	NLF-20	2	92.5036	45.9186	2001	23.9	.0019
17	Swan	05356324	NLF-04	2	91.2369	45.6678	2001	25.1	.0104
18	Becky	05356368	NLF-06	1	91.3108	45.5522	2001	9.5	.0127
19	Hay	053563725	NLF-30	1	91.3178	45.4647	2001	24.8	.0162
20	Soft Maple	05356700	NLF-09	1	91.3507	45.4178	2001	82.7	.0180
21	Mcdermott	05356729	NLF-28	1	91.4408	45.3386	2001	21.0	.0138
22	Meadow Cr	05361730	NLF-41	2	90.6183	45.4500	2001	5.4	.0157
23	Gilbert Cr	05361833	NLF-40	2	90.6583	45.4586	2001	10.3	.0162
24	Trib 1 Shoulder Cr	05362010	NLF-44	2	90.8222	45.3186	2001	7.3	.0057
25	Crazy Horse Cr	05362325	NLF-39	2	90.7192	45.4336	2001	5.8	.0007
26	Alder Cr	05362409	NLF-38	2	90.7197	45.4133	2001	4.5	.0299
27	Sailor Cr	05363619	NLF-43	2	90.5586	45.2725	2001	9.4	.0069
28	Knuteson	05367087	NLF-34	2	91.4814	45.7094	2001	71.4	.0153
29	South Fork Hemlock	05367182	NLF-08	2	91.4756	45.5678	2001	9.0	.0267
30	Little Soft Maple	05376697	NLF-27	1	91.3789	45.4486	2001	21.9	.0161
31	Alvin	04059789	NLF-16	2	88.8739	45.9689	2001	14.4	.0075
32	North Otter	04067725	NLF-07	2	88.8094	45.5889	2001	7.4	.0070
33	North Fork Thunder	04068090	NLF-36	1	88.3550	45.3431	2001	35.2	.0053
34	Waupee	04070175	NLF-25	1	88.3711	45.2242	2001	31.7	.0050
35	Trout	04072167	NCHF-19	2	88.1517	44.5383	2001	35.7	.0055
36	South Fork Popple	053808864	NCHF-17	2	90.3753	44.8000	2001	23.3	.0023

Total phos-phorus (mg/L)	Dissolved phos-phorus (mg/L)	Total nitrogen (mg/L)	Dissolved nitrite plus nitrate (mg/L)	Dissolved ammonia (mg/L)	Total Kjeldahl nitrogen (mg/L)	Suspended chlorophyll *a* (µg/L)	Average temperature (degrees C)	Specific conduc-tance (µS/cm)	Secchi depth (m)	August pH (standard units)	Average color (standard units)
0.037	0.028	0.151	0.081	0.010	0.070	0.768	9.3	139.0	>120.0	7.8	10.0
.052	.040	.244	.092	.007	.120	1.138	11.1	246.0	>120.0	8.2	15.0
.018	.013	.486	.018	.013	.450	1.255	15.7	320.5	>120.0	8.0	50.0
.024	.016	.452	.081	.025	.405	.412	15.0	161.5	>120.0	7.6	80.0
.021	.010	.398	.017	.014	.375	.708	16.2	89.0	>120.0	7.2	110.0
.027	.011	.330	.005	.007	.320	2.135	20.1	116.5	>120.0	8.1	40.0
.033	.019	.808	.005	.028	.715	.870	16.8	106.0	106.0	7.4	141.0
.029	.015	.900	.022	.019	.870	.798	15.9	136.5	>120.0	7.1	141.0
.039	.018	.689	.027	.021	.660	2.241	16.0	105.5	>120.0	6.9	141.0
.025	.010	.455	.011	.007	.440	1.340	17.3	135.5	>120.0	7.2	90.0
.021	.011	.403	.018	.017	.360	.580	16.5	129.5	>120.0	7.4	45.0
.092	.069	.759	.012	.039	.725	2.373	19.1	121.5	>120.0	6.8	60.0
.036	.017	.454	.074	.026	.380	2.568	16.3	194.0	>120.0	7.7	50.0
.048	.022	.592	.021	.057	.560	1.811	16.9	144.5	119.0	7.0	80.0
.032	.010	.200	.005	.017	.190	1.585	13.1	200.5	>120.0	7.6	15.0
.038	.020	.422	.032	.021	.390	1.507	14.0	161.0	>120.0	7.2	110.0
.051	.035	.758	.357	.019	.420	1.555	15.7	133.0	>120.0	7.2	80.0
.038	.032	.416	.091	.015	.320	.822	13.9	50.0	>120.0	7.7	90.0
.111	.085	.620	.020	.018	.600	1.951	15.5	89.5	>120.0	6.5	110.0
.114	.066	.735	.181	.027	.595	4.418	15.7	148.0	69.6	7.7	90.0
.139	.084	.626	.025	.038	.595	2.080	15.7	207.5	>120.0	7.4	110.0
.160	.124	1.435	.014	.029	1.430	2.260	15.6	142.0	112.0	7.0	140.0
.103	.064	1.127	.012	.042	1.100	3.060	14.8	120.0	>120.0	7.0	140.0
.101	.065	1.158	.028	.030	1.130	1.560	14.7	117.5	>120.0	6.5	130.0
.102	.065	1.390	.017	.047	1.380	2.705	14.3	65.0	86.0	6.8	141.0
.093	.069	1.230	.016	.040	1.210	2.689	14.3	73.5	85.5	6.8	120.0
.069	.052	.868	.032	.033	.780	1.027	14.7	86.5	>120.0	7.3	140.0
.044	.023	.511	.053	.026	.475	4.460	17.3	113.5	>120.0	7.9	4.3
.074	.060	.536	.041	.021	.465	1.184	14.1	100.5	>120.0	7.5	80.0
.068	.041	.709	.015	.024	.690	1.753	14.2	55.5	>120.0	7.4	100.0
.020	.012	.492	.027	.015	.450	.903	12.9	142.0	>120.0	7.5	141.0
.027	.016	.363	.034	.021	.315	1.875	16.1	247.0	>120.0	7.9	141.0
.014	.008	.326	.075	.007	.245	.504	10.7	238.0	>120.0	8.0	80.0
.017	.008	.625	.025	.026	.600	1.410	17.1	220.0	>120.0	8.0	65.0
.178	.125	3.020	1.885	.058	.955	.797	15.2	802.0	>120.0	8.1	120.0
.172	.125	1.655	0.005	.038	1.650	2.626	16.3	156.5	>120.0	6.8	141.0

Appendix 1. Stream identification (ID) information, location information, and summary statistics for flow and water-quality data collected for each of the 240 studied wadeable streams in Wisconsin—Continued.

[Cr, Creek; Trib, Tributary; Br, Brook; ID, identification number; USGS, U.S. Geological Survey; km^2, square kilometer; m^3/s/km^2, cubic meter per second per square kilometer; mg/L, milligram per liter; µg/L, microgram per liter; C; degrees centigrade; µS/cm; microSiemen per centimeter; m, meter; --, no data collected at site; all water-quality data are median values unless otherwise noted]

ID (see fig. 4)	Stream name	USGS site number	Ecoregion ID	Phosphorus zone	Longitude	Latitude	Collection year	Watershed area (km^2)	Flow per unit area (m^3/s/km^2)
37	Mosquito Cr	05390240	NLF-26	1	89.0758	45.8378	2001	26.7	.0066
38	Hay Meadow	05390248	NLF-17	1	89.0458	45.8683	2001	16.8	.0077
39	Cedar Springs	05391045	NLF-37	1	89.5231	45.7247	2001	2.2	.0548
40	Skunk Cr	05391068	NLF-21	1	89.4589	45.7075	2001	15.0	.0112
41	Jennie	05392002	NLF-05	1	89.5614	45.5631	2001	4.4	.0289
42	Trout	05392006	NLF-11	1	89.5925	45.5497	2001	13.6	.0018
43	Muskellunge – Heafford Junction	05392030	NLF-42	1	89.6972	45.5108	2001	16.3	.0125
45	Johnson	05392109	NLF-31	1	89.7358	45.8997	2001	27.8	.0053
46	Threemile	05392227	NLF-13	1	89.7728	45.8158	2001	13.1	.0005
47	Raeder Cr	05399348	NCHF-13	2	90.2350	44.8511	2001	8.3	.0182
48	Hamann Cr	05399415	NCHF-09	4	90.1119	44.9308	2001	11.9	.0119
49	East Fork Hamann	05399420	NCHF-04	4	90.0786	44.9317	2001	7.9	.0063
50	Hamann Trib	05399434	NCHF-22	4	90.1117	44.9019	2001	6.3	.0061
51	Widow Green	04072670	NCHF-24	2	89.6175	43.7308	2001	8.7	.0055
52	North Fork Willow	05341629	NCHF-11	1	92.2189	45.2344	2001	26.4	.0019
53	Black Brook	05341676	NCHF-02	1	92.3417	45.1833	2001	37.6	.0028
54	South Fork Willow	053416925	NCHF-16	1	92.3531	45.1275	2001	26.1	.0059
55	Hutton Cr	053416927	NCHF-10	1	92.3561	45.1217	2001	51.3	.0021
56	Tenmile Cr	05341732	NCHF-18	1	92.6094	45.0500	2001	47.2	.0091
57	Cr 12–13	05366709	NCHF-06	1	91.6611	45.0067	2001	12.5	.0131
58	Running Valley	05367506	NCHF-14	1	91.6614	45.0267	2001	13.4	.0076
59	Cr 1–8	05367507	NCHF-08	1	91.6686	45.0261	2001	5.8	.0013
60	Cr 1–12	05367508	NCHF-05	1	91.6503	45.0189	2001	6.4	.0066
61	18-mile	05367515	NCHF-07	1	90.1219	44.3022	2001	55.6	.0098
62	Cady	05370509	DFA-08	4	92.1761	44.8414	2001	31.9	.0038
63	Eagle	05378181	DFA-12	4	91.6789	44.2197	2001	17.7	.0077
64	Joos	05378183	DFA-11	4	91.6647	44.2147	2001	15.5	.0074
65	Trout Run	05379430	DFA-13	4	91.5683	44.2136	2001	19.6	.0068
66	Bohris	05379472	DFA-14	4	91.5972	44.1456	2001	24.5	.0061
67	South Branch Oneill Cr	05380984	NCHF-15	2	90.3761	44.6031	2001	15.3	.0110
68	Unnamed Trib 1 East Fork Black	053811665	NCHF-21	2	90.4928	44.4075	2001	13.9	.0064
69	Unnamed Trib 1 Rock Cr	05381168	NCHF-23	2	90.4942	44.4661	2001	9.0	.0069
70	Bloody Run	05400881	NCHF-03	1	89.7853	44.3425	2001	17.7	.0043
71	Beaver Cr	05401764	NCHF-01	2	90.1814	44.5983	2001	11.1	.1215

Total phos-phorus (mg/L)	Dissolved phos-phorus (mg/L)	Total nitrogen (mg/L)	Dissolved nitrite plus nitrate (mg/L)	Dissolved ammonia (mg/L)	Total Kjeldahl nitrogen (mg/L)	Suspended chlorophyll *a* (µg/L)	Average temperature (degrees C)	Specific conduc-tance (µS/cm)	Secchi depth (m)	August pH (standard units)	Average color (standard units)
0.030	0.016	0.837	0.019	0.036	0.825	1.545	14.6	53.0	102.0	6.9	141.0
.027	.013	.741	.005	.020	.735	2.775	17.3	67.0	>120.0	7.1	141.0
.032	.022	1.075	.018	.033	1.070	.848	14.6	65.0	>120.0	7.2	--
.040	.019	.950	.009	.036	.930	1.935	16.0	44.0	66.0	6.8	141.0
.039	.019	.467	.036	.047	.375	2.990	15.2	120.0	>120.0	7.0	80.0
.041	.026	.500	.076	.025	.410	1.623	11.5	88.0	>120.0	6.8	141.0
.029	.013	.542	.102	.037	.415	3.216	14.8	112.0	>120.0	7.5	141.0
.019	.004	.486	.031	.026	.450	3.045	18.2	159.0	>120.0	8.5	15.0
.038	.021	.619	.011	.034	.610	3.353	17.7	82.0	>120.0	7.2	100.0
.188	.140	3.010	2.020	.030	.840	3.383	15.2	271.5	85.0	7.0	141.0
.094	.068	2.165	1.056	.020	.740	1.212	14.5	300.0	>120.0	7.0	120.0
.178	.121	.990	.052	.035	.945	3.333	15.8	329.0	>120.0	7.7	110.0
.112	.087	2.675	1.845	.036	.805	3.887	15.2	340.5	>120.0	7.2	110.0
.041	.026	.773	.508	.018	.295	1.536	13.8	385.5	>120.0	8.1	30.0
.132	.071	.831	.046	.024	.785	5.780	18.2	152.5	66.0	7.6	110.0
.134	.077	1.246	.164	.054	.810	1.437	17.5	218.5	>120.0	7.7	140.0
.177	.095	1.644	.819	.035	.545	1.535	15.7	342.5	>120.0	7.7	55.0
.092	.064	4.005	3.400	.030	.540	1.725	14.8	399.5	>120.0	8.0	110.0
.065	.043	4.870	4.355	.025	.515	1.674	14.3	427.0	>120.0	7.9	55.0
.234	.208	3.080	2.550	.023	.410	.594	11.7	129.5	>120.0	6.7	15.0
.203	.129	1.114	.226	.037	.540	.744	13.4	160.0	>120.0	6.7	110.0
.246	.193	5.280	4.610	.049	.440	.404	12.0	176.5	>120.0	6.6	25.0
.527	.385	2.640	1.995	.057	.590	.602	12.6	188.0	106.0	7.0	30.0
.295	.259	2.620	1.975	.023	.455	.816	12.6	138.0	>120.0	7.0	30.0
.032	.025	3.290	3.170	.010	.135	1.811	11.6	483.0	>120.0	7.9	5.0
.056	.047	1.605	1.335	.041	.330	2.097	15.4	540.5	102.0	8.3	10.0
.068	.038	1.458	1.105	.049	.410	2.992	17.0	538.0	89.0	8.3	10.0
.196	.083	1.489	1.005	.061	.510	1.297	13.7	579.0	67.5	8.0	15.0
.141	.072	1.100	.730	.044	.365	2.028	13.7	534.0	67.5	8.1	5.0
.196	.133	1.724	.121	.059	1.400	5.595	17.4	185.0	87.5	8.7	141.0
.023	.011	.698	.013	.021	.685	2.324	16.7	27.0	115.0	7.0	141.0
.132	.069	1.629	.059	.090	1.550	5.520	17.2	63.5	37.5	6.8	141.0
.027	.013	1.690	1.430	.028	.265	.685	13.2	174.0	>120.0	7.4	140.0
.149	.109	1.304	.129	.064	1.100	2.640	15.2	418.0	>120.0	7.4	141.0

Appendix 1. Stream identification (ID) information, location information, and summary statistics for flow and water-quality data collected for each of the 240 studied wadeable streams in Wisconsin—Continued.

[Cr, Creek; Trib, Tributary; Br, Brook; ID, identification number; USGS, U.S. Geological Survey; km^2, square kilometer; m^3/s/km^2, cubic meter per second per square kilometer; mg/L, milligram per liter; µg/L, microgram per liter; C; degrees centigrade; µS/cm; microSiemen per centimeter; m, meter; --, no data collected at site; all water-quality data are median values unless otherwise noted]

ID (see fig. 4)	Stream name	USGS site number	Ecoregion ID	Phosphorus zone	Longitude	Latitude	Collection year	Watershed area (km^2)	Flow per unit area (m^3/s/km^2)
72	Trib To Beaver Cr	054017645	NCHF-20	2	90.1675	44.5981	2001	12.4	0.1017
73	North Fork Hemlock Cr	05402040	NCHF-12	2	90.0281	44.5697	2001	12.5	.0056
74	Mormon	05386295	DFA-46	4	91.0697	43.7531	2001	28.2	.0048
75	Timber Coulee	05386479	DFA-07	4	90.9039	43.7233	2001	31.2	.0083
76	Spring Coulee	05386493	DFA-43	4	90.9700	43.7078	2001	29.4	.0089
77	Rush-02	05388368	DFA-36	4	91.0231	43.4197	2001	34.2	.0049
78	Beaver	054040135	DFA-03	4	90.3594	43.6261	2001	12.6	.0041
79	Dilly	05404112	DFA-05	4	90.3958	43.6531	2001	12.1	.0076
80	Trib West Branch Baraboo	054041125	DFA-01	4	90.4025	43.6603	2001	10.5	.0119
81	Crooked	05407190	DFA-40	4	90.6964	43.0919	2001	28.9	.0110
82	Moore	05407410	DFA-09	4	90.6181	43.8303	2001	47.0	.0056
83	Warner Br	05407740	DFA-02	4	90.4967	43.6147	2001	4.9	.0070
84	Warner	05407775	DFA-04	4	90.4942	43.6433	2001	10.2	.0388
85	Otter Cr – Lafarge	05408149	DFA-38	4	90.6725	43.5853	2001	21.8	.0103
86	Harrison	05409090	DFA-41	4	90.7689	43.4978	2001	18.0	.0085
87	Mccartney Br	05412709	DFA-21	5	90.9161	42.7164	2001	6.2	.0040
88	Hackett Br	05413268	DFA-19	4	90.8822	42.8311	2001	12.4	.0076
89	Kuenster	054134435	DFA-27	5	90.9572	42.7908	2001	23.6	.0130
90	Muskellunge Cr – Beetown	05413447	DFA-25	4	90.9358	42.7939	2001	18.1	.0060
91	Bull	05413885	DFA-28	4	90.5889	42.8467	2001	29.2	.0071
92	Willow	05413959	DFA-10	4	90.5964	42.7942	2001	17.5	.0096
93	Mounds Br	05414129	DFA-18	4	90.3889	42.7914	2001	7.3	.0099
94	Young Br	05414205	DFA-20	4	90.5322	42.7619	2001	6.1	.0019
95	Mcadam Br	05414259	DFA-22	4	90.5189	42.6247	2001	9.5	.0075
96	Indian Cr – Dickeyville	05414278	DFA-16	5	90.6322	42.6183	2001	9.4	.0052
97	Kieler Cr	05414753	DFA-23	5	90.5967	42.5814	2001	8.4	.0031
98	Apple	05418731	DFA-26	4	90.1339	42.5228	2001	24.2	.0187
99	Trib 1 French Spring Cr	040727260	SWTP-09	1	89.3103	43.5917	2001	2.9	.0100
100	Rowan	05405598	SWTP-48	4	89.3861	43.3864	2001	27.4	.0087
101	Hinkson	05405648	SWTP-47	1	89.4111	43.4172	2001	13.0	.0066
102	North Branch Honey	05406210	DFA-44	4	89.9692	43.3514	2001	34.0	.0050
103	Moen	05406370	DFA-29	4	89.7578	43.0347	2001	6.1	.0118
104	Trout Cr – Barneveld	05406573	DFA-06	4	89.9467	43.0478	2001	21.7	.0096
105	Lowery	05406602	DFA-30	4	90.0525	43.1036	2001	10.0	.0045

Total phos-phorus (mg/L)	Dissolved phos-phorus (mg/L)	Total nitrogen (mg/L)	Dissolved nitrite plus nitrate (mg/L)	Dissolved ammonia (mg/L)	Total Kjeldahl nitrogen (mg/L)	Suspended chlorophyll *a* (µg/L)	Average temperature (degrees C)	Specific conduc-tance (µS/cm)	Secchi depth (m)	August pH (standard units)	Average color (standard units)
0.179	0.122	1.178	0.163	0.052	1.000	2.560	15.3	241.0	115.0	7.2	120.0
.304	.243	1.505	.038	.055	1.500	3.860	15.9	222.0	100.0	7.3	110.0
.045	.032	1.415	1.255	.014	.175	2.318	12.4	520.5	>120.0	8.4	10.0
.046	.029	2.105	1.890	.012	.255	3.518	13.1	470.5	>120.0	8.5	10.0
.039	.027	1.885	1.770	.016	.210	2.191	12.9	483.0	>120.0	8.4	5.0
.040	.035	2.615	2.435	.011	.195	1.780	13.5	464.0	>120.0	8.2	5.0
.106	.074	1.975	1.440	.027	.480	2.731	14.7	414.0	>120.0	8.1	15.0
.087	.044	1.565	1.150	.032	.380	3.248	13.6	425.0	76.5	8.1	15.0
.052	.029	2.055	1.720	.020	.335	1.451	12.5	516.0	>120.0	8.0	15.0
.044	.033	2.510	2.435	.014	.075	1.605	11.4	559.0	>120.0	7.4	5.0
.093	.056	1.223	.798	.023	.455	2.333	15.6	416.0	115.0	7.8	20.0
.065	.035	1.685	1.175	.035	.410	1.290	14.3	436.0	86.0	8.0	15.0
.072	.051	1.260	.944	.040	.285	1.749	14.1	471.5	98.0	8.1	--
.051	.032	1.555	1.340	.017	.225	4.756	14.1	496.0	>120.0	8.0	10.0
.027	.015	1.265	1.110	.014	.175	1.505	13.7	493.5	>120.0	7.9	5.0
.125	.068	7.385	7.040	.031	.555	1.405	13.6	638.5	59.5	7.7	15.0
.126	.094	7.705	7.265	.051	.430	3.447	14.6	718.0	98.0	8.3	10.0
.169	.124	7.570	6.625	.038	.565	4.118	15.1	735.5	80.0	8.2	30.0
.210	.185	8.145	7.260	.033	.555	2.900	14.6	767.0	94.5	8.0	15.0
.183	.122	6.300	5.475	.056	.655	2.800	14.1	706.5	49.0	8.2	10.0
.115	.091	5.270	4.910	.043	.390	1.834	16.5	659.0	110.0	8.3	10.0
.074	.049	11.040	10.695	.022	.440	2.124	15.5	627.5	84.5	8.2	5.0
.116	.056	7.050	6.670	.090	.675	5.935	17.9	749.5	49.0	8.4	15.0
.084	.060	7.185	6.730	.020	.395	5.185	15.1	798.5	89.0	8.0	40.0
.370	.324	5.235	4.370	.025	.690	3.240	16.8	770.0	62.5	8.5	30.0
.114	.078	4.585	3.815	.045	.455	2.902	16.2	747.5	72.0	8.0	110.0
.095	.066	11.385	10.550	.041	.435	2.746	14.3	661.0	50.5	7.5	55.0
.093	.066	1.361	.590	.055	.805	3.907	15.9	546.5	>120.0	8.1	80.0
.066	.038	3.765	3.405	.032	.370	1.220	12.2	545.5	105.0	7.6	15.0
.100	.031	2.930	2.210	.030	.680	3.720	14.4	486.0	>120.0	7.5	45.0
.115	.063	1.465	1.110	.050	.350	1.503	12.3	356.0	106.0	7.5	10.0
.057	.025	4.675	4.270	.026	.405	1.438	14.4	670.0	70.5	8.0	10.0
.059	.034	2.890	2.515	.021	.305	1.725	13.4	534.0	88.5	7.5	10.0
.031	.020	1.127	.852	.035	.210	.939	15.9	496.5	>120.0	8.1	5.0

Appendix 1. Stream identification (ID) information, location information, and summary statistics for flow and water-quality data collected for each of the 240 studied wadeable streams in Wisconsin—Continued.

[Cr, Creek; Trib, Tributary; Br, Brook; ID, identification number; USGS, U.S. Geological Survey; km^2, square kilometer; m^3/s/km^2, cubic meter per second per square kilometer; mg/L, milligram per liter; µg/L, microgram per liter; C; degrees centigrade; µS/cm; microSiemen per centimeter; m, meter; --, no data collected at site; all water-quality data are median values unless otherwise noted]

ID (see fig. 4)	Stream name	USGS site number	Ecoregion ID	Phosphorus zone	Longitude	Latitude	Collection year	Watershed area (km^2)	Flow per unit area (m^3/s/km^2)
106	Trib Otter Cr	054066478	DFA-39	4	90.2806	43.0767	2001	26.5	0.0046
107	Bear	05406670	DFA-42	4	90.1756	43.3272	2001	43.8	.0101
108	Horse	05406783	DFA-35	4	90.4200	43.3725	2001	19.1	.0103
109	Brush	05406788	DFA-32	4	90.4147	43.3483	2001	14.0	.0107
110	East Mill	05407010	DFA-37	4	90.5258	43.3397	2001	26.3	.0092
111	Trib 1 Dead Cr	05424071	SWTP-10	4	88.7000	43.3428	2001	13.7	.0071
112	Johnson Cr – Farmington	05425534	SWTP-11	2	88.7047	43.1228	2001	8.0	.0061
113	Calamus Cr	05425913	SWTP-13	4	88.9044	43.4347	2001	35.2	.0110
114	Schultz Cr	05425919	SWTP-31	2	88.7894	43.4325	2001	12.9	.0105
115	Pratt Cr	05425928	SWTP-25	4	88.7189	43.4228	2001	9.2	.0126
116	Trib Pratt Cr	05425929	SWTP-12	4	88.7258	43.3939	2001	4.6	.0114
117	Casper Cr	05425935	SWTP-26	4	88.7647	43.3094	2001	10.5	.0025
118	Scuppernong	05426390	SWTP-41	2	88.5061	42.9022	2001	35.7	.0068
119	Door Cr	05429560	SWTP-15	4	89.2392	43.0839	2001	15.7	.0048
120	Little Door Cr	05429590	SWTP-30	4	89.1725	43.0289	2001	6.0	.0050
121	Branch Mineral Point	05432140	DFA-17	4	90.1722	42.9589	2001	8.3	.0077
122	Gill	05436204	SWTP-49	4	89.4678	42.8103	2001	12.3	.0081
123	Baker	05545102	SWTP-20	4	88.5392	42.7061	2001	21.0	.0044
124	Spring Brook	05545118	SWTP-14	4	88.3639	42.7169	2001	12.7	.0099
125	Ore	05545187	SWTP-43	2	88.3994	42.6400	2001	28.4	.0055
126	Bassett Cr	05545955	SWTP-05	2	88.2278	42.5406	2001	11.8	.0090
127	West Branch Nippersink	05548159	SWTP-42	2	88.3636	42.5181	2001	26.2	.0082
128	White Cr	04073462	SWTP-50	2	88.9283	43.8161	2001	9.1	.0198
129	Pumpkinseed Cr	04081480	SWTP-32	3	88.8197	44.0936	2001	5.8	.0034
130	Spring Bk	04081605	SWTP-33	3	88.6958	44.0189	2001	26.4	.0059
131	Daggets Cr	04081775	SWTP-39	3	88.5994	44.1414	2001	10.4	.0030
132	Van Dyne Cr	04082580	SWTP-29	3	88.5194	43.8792	2001	14.3	.0007
133	Trib 1 West Branch Fond Du Lac	04082831	SWTP-28	3	88.7006	43.8800	2001	11.8	.0067
134	Mill Cr	040842515	SWTP-34	3	88.3111	44.0792	2001	8.7	.0035
135	Kankapot Cr	04084479	SWTP-38	4	88.2542	44.2472	2001	11.7	.0007
136	Molash	040852095	SWTP-23	3	87.5342	44.1811	2001	21.2	.0086
137	Grimms	040854193	SWTP-37	3	87.8619	44.1517	2001	13.8	.0022
138	Pine Cr – Newton	0408543802	SWTP-36	3	87.7219	44.0039	2001	16.2	.0035
139	Point Cr	04085439	SWTP-35	3	87.7314	43.9692	2001	45.5	.0028

Total phos-phorus (mg/L)	Dissolved phos-phorus (mg/L)	Total nitrogen (mg/L)	Dissolved nitrite plus nitrate (mg/L)	Dissolved ammonia (mg/L)	Total Kjeldahl nitrogen (mg/L)	Suspended chlorophyll *a* (µg/L)	Average temperature (degrees C)	Specific conduc-tance (µS/cm)	Secchi depth (m)	August pH (standard units)	Average color (standard units)
0.064	0.050	2.455	2.240	0.025	0.230	1.148	15.7	533.0	>120.0	8.1	10.0
.086	.034	1.740	1.390	.033	.355	2.535	12.4	488.5	102.5	7.9	10.0
.053	.031	.882	.604	.033	.235	2.015	14.0	393.0	105.0	8.0	40.0
.051	.029	1.034	.724	.037	.285	2.448	14.2	484.5	>120.0	8.1	20.0
.044	.021	.936	.669	.026	.255	2.112	16.1	477.5	>120.0	8.2	35.0
.352	.190	2.407	.013	.404	2.350	9.401	17.9	711.5	75.0	7.1	140.0
.159	.097	3.132	1.115	.238	2.100	1.293	16.4	743.0	90.0	8.1	141.0
.253	.082	1.906	.090	.107	1.700	10.411	17.3	576.0	50.0	7.2	110.0
.071	.027	8.485	8.035	.054	.450	2.923	13.2	826.0	47.5	7.5	20.0
.039	.021	4.015	3.485	.017	.385	2.786	14.4	756.0	>120.0	7.5	25.0
.109	.081	3.265	2.710	.076	.730	2.435	16.7	991.5	96.0	7.7	50.0
.239	.163	5.125	4.260	.056	.950	3.109	16.3	740.5	77.5	7.5	50.0
.028	.014	1.301	.228	.042	1.060	1.626	19.0	579.5	>120.0	8.0	130.0
.127	.066	8.385	7.760	.039	.670	1.640	13.3	819.0	33.0	8.1	10.0
.056	.029	13.205	12.750	.021	.330	1.185	13.2	736.5	49.0	8.0	15.0
.107	.056	8.145	7.690	.050	.495	3.017	16.5	830.5	50.0	8.0	5.0
.093	.066	5.820	5.220	.027	.480	1.879	14.9	597.0	66.0	8.2	40.0
.112	.088	4.082	3.359	.029	.750	3.820	18.2	762.5	105.0	8.0	25.0
.038	.016	9.685	9.215	.018	.485	2.168	16.5	693.0	92.5	8.3	15.0
.123	.085	4.710	4.005	.039	.740	4.152	16.6	718.5	55.0	8.0	15.0
.237	.159	6.240	5.370	.151	.975	1.477	17.4	1405.0	93.5	7.9	25.0
.145	.050	7.780	6.905	.136	1.040	14.605	18.4	743.5	27.5	8.0	25.0
.055	.051	21.260	20.550	.017	.185	1.260	11.4	803.0	86.0	8.0	25.0
.162	.093	2.382	.147	.047	.985	10.096	15.6	797.5	56.0	8.0	25.0
.203	.163	5.095	4.385	.052	.710	2.068	17.5	737.0	42.5	8.2	50.0
.258	.106	6.270	4.075	.039	1.200	6.393	15.9	920.0	47.5	7.2	40.0
.741	.553	3.143	.043	.051	2.000	3.038	21.6	824.0	76.0	9.2	80.0
.189	.104	3.400	1.590	.252	1.500	7.112	18.8	744.0	58.0	8.1	80.0
.088	.038	10.465	9.760	.022	.680	2.028	14.7	815.5	44.5	8.1	15.0
.557	.473	9.382	6.760	.122	2.000	5.048	15.7	1023.5	39.5	7.7	55.0
.150	.126	2.395	.891	.068	1.450	1.615	15.5	529.0	>120.0	7.6	110.0
.349	.297	4.945	3.685	.052	1.100	1.665	15.1	912.0	>120.0	7.7	55.0
.162	.119	2.365	1.265	.043	1.030	3.390	16.9	948.5	59.5	8.1	80.0
.247	.204	2.651	1.651	.072	1.040	3.796	17.0	739.0	76.0	8.3	70.0

Appendix 1. Stream identification (ID) information, location information, and summary statistics for flow and water-quality data collected for each of the 240 studied wadeable streams in Wisconsin—Continued.

[Cr, Creek; Trib, Tributary; Br, Brook; ID, identification number; USGS, U.S. Geological Survey; km², square kilometer; m³/s/km², cubic meter per second per square kilometer; mg/L, milligram per liter; µg/L, microgram per liter; C; degrees centigrade; µS/cm; microSiemen per centimeter; m, meter; --, no data collected at site; all water-quality data are median values unless otherwise noted]

ID (see fig. 4)	Stream name	USGS site number	Ecoregion ID	Phosphorus zone	Longitude	Latitude	Collection year	Watershed area (km²)	Flow per unit area (m³/s/km²)
140	Pigeon	040854496	SWTP-22	4	87.8583	43.8917	2001	40.7	0.0037
141	Otter Cr – Plymouth	040857005	SWTP-19	3	87.9222	43.7889	2001	24.7	.0118
142	Weedens	04085995	SWTP-24	3	87.7733	43.7175	2001	19.6	.0146
143	Kettle Moraine	04086096	SWTP-07	2	88.2600	43.6517	2001	39.0	.0110
144	West Branch Milwaukee	04086125	SWTP-21	4	88.3936	43.6161	2001	36.0	.0075
145	Parnell	04086175	SWTP-01	2	88.1600	43.6478	2001	17.1	.0042
146	East Branch Milwaukee	04086177	SWTP-46	1	88.1811	43.6161	2001	93.4	.0051
147	Crooked	04086190	SWTP-03	2	88.1797	43.5978	2001	30.4	.0041
148	Wallace	04086335	SWTP-04	4	88.0864	43.4983	2001	39.3	.0063
149	Hanneman	04086408	SWTP-08	2	87.9589	43.3378	2001	21.7	.0066
150	Mayfield Cr	04086443	SWTP-27	2	88.1814	43.3078	2001	8.8	.0082
151	Friedens	04086465	SWTP-17	2	88.1614	43.3400	2001	10.5	.0052
152	Pigeon Cr – Theinsville	04086696	SWTP-06	3	87.9903	43.2508	2001	23.7	.0050
153	Willow Cr – Germantown	040870195	SWTP-02	3	88.1428	43.2067	2001	16.4	.0089
154	Little Menomonee	04087050	SWTP-44	3	88.0383	43.2067	2001	18.9	.0067
155	Husher	040872347	SWTP-40	3	87.9200	42.8364	2001	27.0	.0068
156	North Branch Pike	04087243	SWTP-18	3	87.8683	42.7194	2001	11.6	.0052
157	Willow Cr – Waupun	05422990	SWTP-16	4	88.6892	43.6836	2001	12.7	.0081
158	Flynn	05424450	SWTP-45	2	88.3375	43.2106	2001	13.4	.0058
201	Galena	05415000	2-DFA-01	4	90.3778	42.5136	2002	322.9	.0094
202	Skinner Cr – Klondyke	05434240	2-DFA-02	4	89.7444	42.6253	2002	90.6	.0068
203	East Branch Pecatonica	05433000	2-DFA-03	4	89.8611	42.7856	2002	571.4	.0062
204	Little Sugar	05436280	2-DFA-04	4	89.6319	42.8172	2002	57.6	.0060
205	West Branch Sugar – #1	05436010	2-DFA-05	4	89.5972	42.9031	2002	84.9	.0084
206	Platte – Rockville	05414000	2-DFA-06	4	90.6403	42.7319	2002	367.2	.0068
207	Pigeon	05413415	2-DFA-07	4	90.8161	42.7864	2002	54.4	.0066
208	Rattlesnake	05413449	2-DFA-08	4	90.9411	42.7817	2002	109.7	.0058
209	Blake	05413245	2-DFA-10	4	90.8583	42.8692	2002	85.8	.0056
210	Fennimore	05407039	2-DFA-11	4	90.5631	43.0278	2002	39.6	.0030
211	Black Earth 1	05406500	2-DFA-12	4	89.7322	43.1342	2002	112.1	.0217
212	Kickapoo	05408000	2-DFA-13	4	90.6431	43.5750	2002	689.7	.0062
213	Moore	05407428	2-DFA-15	4	90.5967	43.7933	2002	94.1	.0047
214	Coon Cr	05386500	2-DFA-16	4	91.0183	43.7047	2002	201.1	.0076
215	Little La Crosse – Sparta	05382500	2-DFA-18	4	90.8403	43.8958	2002	200.2	.0062

Total phos-phorus (mg/L)	Dissolved phos-phorus (mg/L)	Total nitrogen (mg/L)	Dissolved nitrite plus nitrate (mg/L)	Dissolved ammonia (mg/L)	Total Kjeldahl nitrogen (mg/L)	Suspended chlorophyll *a* (µg/L)	Average temperature (degrees C)	Specific conduc-tance (µS/cm)	Secchi depth (m)	August pH (standard units)	Average color (standard units)
0.125	0.090	2.950	1.950	0.046	1.090	3.630	16.2	657.5	105.0	7.6	60.0
.104	.066	1.889	1.134	.030	.721	3.700	17.3	672.0	96.5	7.6	40.0
.297	.260	2.859	1.159	.044	1.400	2.475	17.4	789.0	48.0	7.6	110.0
.103	.077	1.593	.297	.049	1.355	2.250	16.9	500.0	>120.0	7.3	120.0
.118	.050	7.160	6.165	.085	1.150	7.276	14.2	832.0	>120.0	7.3	70.0
.087	.077	1.060	.135	.037	.900	2.004	17.2	482.0	103.0	7.9	120.0
.051	.031	.861	.084	.020	.735	2.230	17.3	493.0	>120.0	7.3	110.0
.055	.030	1.144	.209	.038	.885	2.168	16.5	488.5	>120.0	7.8	60.0
.106	.057	2.050	1.125	.028	.755	2.470	15.9	645.0	119.0	7.9	50.0
.068	.043	1.780	.772	.027	.825	2.361	16.4	759.0	>120.0	8.0	55.0
.166	.102	3.790	2.970	.150	.930	1.778	14.8	818.0	29.0	8.2	40.0
.091	.050	3.365	2.750	.011	.725	2.413	14.3	833.0	60.5	8.0	25.0
.053	.035	1.318	.663	.021	.585	1.947	15.8	752.0	102.5	7.8	40.0
.070	.057	1.316	.705	.050	.630	1.927	15.9	935.0	89.0	8.0	60.0
.082	.059	3.320	2.485	.049	.750	2.693	14.6	819.0	67.5	7.5	110.0
.143	.063	4.715	3.085	.036	1.300	5.335	17.2	679.0	23.5	--	60.0
.053	.021	3.340	2.645	.044	.670	1.400	17.0	895.0	51.5	7.5	30.0
.146	.087	2.025	1.011	.063	1.050	3.579	15.0	756.5	82.0	7.3	110.0
.069	0.034	1.396	.931	.038	.465	1.562	15.0	703.0	88.5	8.0	40.0
.102	.052	7.260	6.940	.014	.325	3.181	17.1	841.2	64.0	8.0	--
.075	.048	4.500	4.200	.024	.300	1.349	15.4	649.0	63.0	7.8	--
.128	.074	4.345	3.775	.037	.375	2.117	16.3	596.3	35.5	7.2	--
.070	.050	3.825	3.425	.024	.285	1.625	13.6	622.0	74.0	7.2	--
.118	.060	6.125	5.680	.032	.460	1.918	12.9	654.0	42.0	7.2	--
.121	.063	5.055	4.735	.017	.330	3.712	15.0	650.3	39.5	7.2	--
.611	.563	6.540	6.110	.007	.425	2.511	16.3	793.7	89.5	7.6	--
.104	.088	8.990	8.680	.007	.325	2.537	16.3	742.3	>120.0	7.7	--
.159	.124	7.925	7.495	.019	.435	1.990	18.1	725.3	80.5	7.8	--
.140	.112	8.690	7.940	.016	.440	2.673	18.5	748.5	66.0	8.1	--
.063	.051	3.350	3.055	.016	.240	1.905	12.4	637.0	>120.0	7.0	--
.122	.069	1.235	.920	.018	.265	1.916	15.9	470.3	64.5	7.8	--
.198	.153	2.125	1.695	.029	.415	2.456	18.3	478.2	>120.0	7.4	--
.043	.028	1.355	1.155	.025	.160	2.071	14.4	301.8	>120.0	7.1	--
.084	.058	1.945	1.750	.017	.215	1.115	15.0	464.7	110.0	7.2	--

Appendix 1. Stream identification (ID) information, location information, and summary statistics for flow and water-quality data collected for each of the 240 studied wadeable streams in Wisconsin—Continued.

[Cr, Creek; Trib, Tributary; Br, Brook; ID, identification number; USGS, U.S. Geological Survey; km², square kilometer; m³/s/km², cubic meter per second per square kilometer; mg/L, milligram per liter; µg/L, microgram per liter; C; degrees centigrade; µS/cm; microSiemen per centimeter; m, meter; --, no data collected at site; all water-quality data are median values unless otherwise noted]

ID (see fig. 4)	Stream name	USGS site number	Ecoregion ID	Phosphorus zone	Longitude	Latitude	Collection year	Watershed area (km^2)	Flow per unit area ($m^3/s/km^2$)
216	Lacrosse	05382325	2-DFA-19	2	90.8106	43.9375	2002	434.1	0.0090
217	Eau Galle 2	05369945	2-DFA-20	4	92.2519	44.8672	2002	124.2	.0100
218	Willow	05341752	2-DFA-21	1	92.7083	45.0117	2002	751.0	.0070
219	Wood	05338955	2-NCHF-01	2	92.6311	45.7853	2002	348.1	.0061
220	Yellow – Barron	053674464	2-NCHF-02	1	91.8300	45.3953	2002	396.1	.0111
221	Hay River	05368000	2-NCHF-03	1	91.9108	45.0478	2002	1083.2	.0111
222	North Fork Eau Claire	05365707	2-NCHF-04	2	90.8492	44.9736	2002	131.8	.0075
223	Big Eau Pleine	05399500	2-NCHF-05	2	90.0794	44.8219	2002	578.6	.0034
224	Black	05381000	2-NCHF-06	2	90.6150	44.5597	2002	1947.1	.0061
225	Yellow – Babcock	05402000	2-NCHF-07	2	90.1219	44.3022	2002	561.3	.0047
226	Little Yellow	05403043	2-NCHF-08	1	90.1764	44.0575	2002	144.5	.0057
227	South Branch Yellow	05403044	2-NCHF-09	1	90.1478	44.0469	2002	144.5	.0025
228	Ten Mile Cr	05401050	2-NCHF-10	1	89.8103	44.2625	2002	173.3	.0108
229	Little Plover	05400650	2-NCHF-11	1	89.5281	44.4736	2002	49.3	.0059
230	Tomorrow	04080798	2-NCHF-12	1	89.3378	44.5244	2002	113.9	.0058
231	Pensaukee – Krakow	04071795	2-NCHF-13	1	88.2764	44.7525	2002	86.7	.0016
232	Pensaukee – Pensaukee	04071858	2-NCHF-14	1	87.9533	44.8189	2002	343.1	.0027
233	Middle Branch Embarrass	0407809265	2-NCHF-15	1	89.1181	44.8253	2002	254.7	.0046
234	Eau Claire – Kelly	05397500	2-NCHF-16	1	89.5500	44.9181	2002	923.8	.0046
235	Eau Claire – Antigo	05397110	2-NCHF-17	1	89.2339	45.1258	2002	471.0	.0069
236	Spring Brook 2	05397180	2-NCHF-18	1	89.1331	45.1547	2002	93.6	.0011
237	Prairie	05394500	2-NCHF-19	1	89.6497	45.2358	2002	477.2	.0092
238	Skinner	05359698	2-NLF-01	2	90.6994	45.5833	2002	74.8	.0086
239	Spirit	05393500	2-NLF-02	2	89.9797	45.4494	2002	211.3	.0120
240	North Fork Copper	05394079	2-NLF-03	2	89.9247	45.2150	2002	70.3	.0084
241	Hunting	04074720	2-NLF-04	1	89.1142	45.3814	2002	67.9	.0084
242	Wolf River	04074950	2-NLF-05	1	88.7333	45.1900	2002	1182.5	.0107
243	North Branch Pike	04066350	2-NLF-06	1	88.1089	45.5675	2002	238.0	.0102
244	Popple	04063700	2-NLF-07	2	88.4631	45.7636	2002	362.4	.0096
245	Woods	04063774	2-NLF-08	2	88.4600	45.8461	2002	59.9	.0096
246	Pine	04064500	2-NLF-09	2	88.2253	45.8378	2002	1377.9	.0094
247	Brule	04060993	2-NLF-10	2	88.3158	45.9608	2002	990.2	.0096
248	Kaubashine	05392233	2-NLF-11	1	89.8008	45.7994	2002	47.7	.0058
249	Namekagon	05331833	2-NLF-12	1	91.3292	46.1714	2002	326.2	.0129

Total phosphorus (mg/L)	Dissolved phosphorus (mg/L)	Total nitrogen (mg/L)	Dissolved nitrite plus nitrate (mg/L)	Dissolved ammonia (mg/L)	Total Kjeldahl nitrogen (mg/L)	Suspended chlorophyll *a* (µg/L)	Average temperature (degrees C)	Specific conductance (µS/cm)	Secchi depth (m)	August pH (standard units)	Average color (standard units)
0.092	0.047	1.295	1.040	0.034	0.260	2.321	16.7	185.0	>120.0	7.5	--
.037	.033	1.837	1.415	.019	.330	4.480	14.5	356.7	>120.0	7.3	--
.090	.033	2.890	2.335	.044	.615	14.644	17.3	337.7	112.0	7.9	--
.044	.022	.694	.098	.036	.595	2.770	18.1	191.3	>120.0	6.9	--
.099	.050	1.495	.890	.046	.470	7.079	16.7	178.5	102.5	7.0	--
.095	.053	2.245	1.820	.019	.465	2.110	14.6	320.3	107.5	7.4	--
.155	.097	1.051	.145	.025	.895	5.172	16.8	147.3	106.0	6.9	--
.258	.213	1.648	.692	.031	1.020	3.985	18.6	228.8	97.0	7.6	--
.173	.135	1.178	.255	.019	.910	3.814	19.4	137.0	104.5	8.0	--
.271	.136	1.397	.221	.055	1.250	7.457	17.2	142.5	55.5	7.3	--
.056	.026	1.211	.011	.353	1.200	6.347	14.4	115.8	35.5	6.6	--
.053	.019	1.197	.047	.183	1.150	6.683	16.6	71.2	81.0	6.9	--
.051	.019	4.250	3.280	.029	.950	1.956	14.9	372.8	94.5	7.8	--
.031	.023	8.240	7.985	.007	.315	1.702	13.2	497.0	>120.0	8.0	--
.019	.012	3.215	2.775	.007	.385	1.429	10.9	514.8	>120.0	8.0	--
.132	.103	2.155	1.055	.050	1.035	2.496	15.4	716.0	98.0	7.0	--
.086	.067	1.220	.306	.041	.930	2.368	16.5	552.7	102.0	7.7	--
.027	.020	1.616	1.085	.021	.520	2.631	15.0	450.3	>120.0	8.4	--
.049	.032	1.724	.914	.024	.565	3.239	16.1	244.0	>120.0	8.3	--
.085	.048	1.561	.911	.021	.635	3.971	15.4	195.0	>120.0	7.5	--
.055	.038	5.055	4.650	.024	.405	3.399	11.4	376.2	>120.0	7.2	--
.055	.037	0.600	.072	.015	.515	2.270	16.4	141.3	>120.0	8.1	--
.082	.051	1.177	.012	.045	1.150	4.392	17.5	65.5	110.5	6.5	--
.068	.045	.801	.031	.022	.770	4.823	16.7	77.7	>120.0	7.8	--
.063	.043	.793	.019	.025	.760	2.042	13.8	72.5	>120.0	7.1	--
.068	.046	.408	.013	.021	.385	2.204	17.5	184.8	>120.0	8.1	--
.032	.014	.571	.048	.018	.515	2.801	15.8	186.5	>120.0	7.6	--
.012	.006	.344	.043	.007	.300	.653	15.4	233.5	>120.0	8.2	--
.022	.012	.623	.011	.020	.615	1.180	15.6	149.2	>120.0	7.8	--
.019	.015	.554	.149	.011	.430	.452	12.4	231.3	>120.0	7.9	--
.016	.008	.490	.018	.019	.460	.941	16.1	178.2	>120.0	8.2	--
.016	.006	.298	.088	.007	.210	1.881	14.1	274.2	>120.0	7.8	--
.038	.020	.366	.011	.015	.355	1.939	16.9	111.2	>120.0	7.3	--
.017	.011	.363	.033	.007	.315	1.714	14.8	118.8	>120.0	8.0	--

Appendix 1. Stream identification (ID) information, location information, and summary statistics for flow and water-quality data collected for each of the 240 studied wadeable streams in Wisconsin—Continued.

[Cr, Creek; Trib, Tributary; Br, Brook; ID, identification number; USGS, U.S. Geological Survey; km², square kilometer; m³/s/km², cubic meter per second per square kilometer; mg/L, milligram per liter; µg/L, microgram per liter; C; degrees centigrade; µS/cm; microSiemen per centimeter; m, meter; --, no data collected at site; all water-quality data are median values unless otherwise noted]

ID (see fig. 4)	Stream name	USGS site number	Ecoregion ID	Phosphorus zone	Longitude	Latitude	Collection year	Watershed area (km²)	Flow per unit area (m³/s/km²)
250	Totagatic	05333067	2-NLF-13	1	91.6947	46.1672	2002	389.6	0.0053
251	Eau Claire	05331597	2-NLF-14	1	91.6550	46.2506	2002	312.6	.0068
252	Upper Ox	05331585	2-NLF-15	1	91.6625	46.3161	2002	180.3	.0017
253	North Fish Cr	040263491	2-NLF-16	3	91.0619	46.5489	2002	99.3	.0258
254	Bois Brule	04025500	2-NLF-17	1	91.5953	46.5378	2002	343.5	.0141
255	Amnicon	04024570	2-NLF-18	3	92.0706	46.4531	2002	67.7	.0141
256	Upper Tamarack	05335574	2-NLF-19	2	92.2839	46.1644	2002	223.1	.0099
257	Turtle Cr 2	05431486	2-SWTP-01	4	88.8292	42.5972	2002	483.9	.0056
258	Whitewater Cr	05426900	2-SWTP-02	2	88.7025	42.8039	2002	53.3	.0081
259	Token Cr	05427800	2-SWTP-03	4	89.3244	43.1811	2002	63.0	.0114
260	Yahara	05427718	2-SWTP-04	4	89.3525	43.2089	2002	192.4	.0025
261	Oconomowoc	05424440	2-SWTP-05	2	88.3006	43.2192	2002	54.0	.0036
262	Milwaukee	04086600	2-SWTP-06	2	87.9428	43.2803	2002	1571.6	.0033
263	Cedar Cr	04086500	2-SWTP-07	2	87.9786	43.3231	2002	290.7	.0031
264	Sauk	04086017	2-SWTP-08	4	87.8692	43.4703	2002	55.2	.0011
265	Stoney	040863313	2-SWTP-09	4	88.0889	43.5275	2002	53.5	.0022
266	North Branch Milwaukee	040863075	2-SWTP-10	4	88.0528	43.5569	2002	132.7	.0055
267	West Branch Rock	05423510	2-SWTP-11	4	88.6856	43.6344	2002	292.2	.0024
268	Onion	04085845	2-SWTP-13	4	87.8200	43.6967	2002	243.5	.0025
269	South Branch Sheboygan	04085480	2-SWTP-14	4	88.2511	43.8092	2002	71.3	.0021
270	Meeme	04085454	2-SWTP-15	4	87.8125	43.9222	2002	49.7	.0024
271	Silver Cr	04085435	2-SWTP-16	3	87.6806	44.0547	2002	54.6	.0031
272	South Branch Manitowoc	04085395	2-SWTP-17	2	88.1181	44.0247	2002	283.1	.0013
273	Manitowoc	04085427	2-SWTP-18	3	87.7142	44.1072	2002	1359.0	.0029
274	East Twin	04085281	2-SWTP-19	2	87.6364	44.2378	2002	285.8	.0043
275	Neshota	04085305	2-SWTP-20	4	87.8142	44.3928	2002	71.8	.0019
276	Kewaunee	04085200	2-SWTP-21	4	87.5564	44.4583	2002	328.6	.0035
277	East	04085109	2-SWTP-22	4	88.0797	44.3867	2002	122.2	.0021
278	Duck Cr	04072150	2-SWTP-23	3	88.1297	44.5358	2002	280.7	.0230
301	Vismal Cr	05381195	3-NCHF-06	2	90.7647	44.3869	2003	10.5	.0061
302	Levis Cr	05381350	3-NCHF-07	1	90.8064	44.3117	2003	106.1	.0051
303	Ditch #6 South Branch Ten Mile Cr	05401035	3-NCHF-11	1	89.6064	44.2783	2003	39.2	.0048
304	South Branch Suamico	040719496	3-NCHF-15	2	88.1867	44.6175	2003	38.8	.0017
305	West Branch Red	04077601	3-NCHF-17	1	88.9882	44.9644	2003	84.0	.0100

Total phos-phorus (mg/L)	Dissolved phos-phorus (mg/L)	Total nitrogen (mg/L)	Dissolved nitrite plus nitrate (mg/L)	Dissolved ammonia (mg/L)	Total Kjeldahl nitrogen (mg/L)	Suspended chlorophyll *a* (µg/L)	Average temperature (degrees C)	Specific conduc-tance (µS/cm)	Secchi depth (m)	August pH (standard units)	Average color (standard units)
0.034	0.022	0.586	0.015	0.024	0.560	1.706	16.9	84.2	>120.0	7.2	--
.017	.008	.241	.011	.007	.230	2.197	18.1	130.2	>120.0	7.7	--
.019	.012	.191	.008	.007	.180	1.367	14.2	127.5	>120.0	7.4	--
.026	.018	.131	.030	.007	.070	.857	9.5	331.0	>120.0	7.7	--
.027	.017	.353	.012	.007	.340	2.342	13.1	260.3	>120.0	7.2	--
.036	.022	1.248	.008	.038	1.240	1.142	16.5	115.0	86.0	5.5	--
.041	.027	1.161	.011	.024	1.150	1.081	17.3	118.8	92.5	6.4	--
.073	.028	9.505	9.090	.007	.575	8.421	18.4	768.8	95.0	7.3	--
.023	.014	2.545	2.170	.007	.270	1.717	15.5	661.0	>120.0	7.1	--
.070	.030	9.020	8.620	.020	.435	5.690	14.6	741.3	44.0	7.1	--
.089	.060	8.720	8.190	.018	.510	3.298	16.1	738.3	101.0	6.7	--
.035	.010	2.170	1.305	.036	.860	4.128	19.7	643.7	>120.0	8.2	--
.116	.064	2.095	1.150	.028	.880	7.619	18.1	808.3	107.5	8.6	--
.104	.041	1.677	1.105	.017	.775	10.850	18.6	761.5	110.0	8.3	--
.605	.405	3.476	1.748	.089	1.700	10.075	17.6	883.8	25.5	8.9	--
.069	.050	2.250	1.445	.029	.775	2.286	18.6	647.3	>120.0	8.1	--
.170	.098	3.750	2.615	.069	1.035	7.707	18.3	708.5	41.5	8.1	--
1.641	1.460	7.935	6.995	.075	1.050	10.947	15.9	1205.2	26.5	7.5	--
.196	.120	2.014	.895	.029	.975	23.512	17.4	688.8	51.0	7.8	--
.119	.086	3.265	2.430	.032	.890	2.422	18.2	763.8	109.0	8.0	--
.103	.078	1.825	1.180	.034	.690	5.100	17.7	590.2	92.5	7.4	--
.201	.153	2.955	1.825	.042	1.055	3.378	18.1	709.5	89.0	8.0	--
.242	.081	5.430	3.780	.058	1.750	38.007	19.8	927.7	27.0	8.3	--
.247	.102	2.481	.665	.023	1.950	36.629	19.1	672.5	35.5	8.5	--
.111	.060	3.340	2.400	.057	1.000	3.517	17.8	668.0	45.0	8.0	--
.203	.158	.777	.153	.055	.670	1.926	15.0	695.2	41.5	7.6	--
.076	.051	3.945	3.285	.052	.755	3.243	17.9	691.0	110.0	8.0	--
.412	.311	1.858	.680	.094	1.300	2.054	16.0	816.8	30.5	7.3	--
.160	.130	1.653	.396	.029	1.195	3.996	16.9	775.2	72.0	8.5	--
.021	.015	.391	.194	.014	.215	.917	14.1	62.5	>120.0	7.5	--
.023	.011	.575	.365	.014	.295	1.094	14.9	96.5	>120.0	7.6	--
.058	.046	7.960	7.395	.019	.435	2.285	15.8	430.0	>120.0	8.5	--
.247	.040	1.700	1.285	.026	.460	3.763	17.5	835.0	>120.0	8.0	--
.056	.204	3.755	1.825	.039	1.405	2.340	15.3	394.5	>120.0	8.1	--

Appendix 2. Physical-habitat characteristics of each of the 240 studied wadeable streams in Wisconsin. All data collected by the Wisconsin Department of Natural Resources.

[CR, Creek; TRIB, Tributary; BR, Brook; ID, identification number; m/km, meter per kilometer; m, meter; --, no data collected at site]

ID (see fig. 4)	Stream name	Stream width (m)	Stream mean depth (m)	Mean thalweg depth (m)	Stream gradient (m/km)	Percent pools	Percent riffle	Percent run	Depth of sediment on stream bottom (m)
1	Onion	4.35	0.27	0.36	2.03	0.00	0.00	100.00	0.30
2	Thompson	4.29	.22	.35	4.04	11.81	10.42	77.78	.17
3	Parker	4.95	.09	.17	19.70	5.48	67.14	27.38	.00
4	Catlin	2.89	.18	.22	12.40	7.62	35.24	57.14	.02
5	Leo	3.12	.23	.32	3.42	12.96	1.85	85.19	.11
6	Lower Ox	14.18	.27	.37	2.80	1.16	42.82	56.02	.03
7	Lord	4.51	.22	.31	4.35	18.07	28.31	53.61	.01
8	Fivemile	4.38	.12	.16	3.50	19.31	14.48	66.21	.06
9	Cap	5.05	.38	.48	2.50	4.73	.00	95.27	.07
10	Spring Cr	5.52	.17	.24	2.31	2.65	12.39	84.96	.14
11	Mosquito Br	3.67	.17	.25	9.90	14.02	44.86	41.12	.02
12	Smith Lake	3.07	.27	.36	4.85	4.55	.00	95.45	.10
13	Fiddler	4.09	.10	.13	2.10	.00	.00	100.00	.05
14	Spring Lake	8.92	.23	.33	.82	.00	.00	100.00	.12
15	Rainbow	6.96	.16	.23	1.54	.00	.00	100.00	.06
16	Dody Brook	4.80	.40	.54	8.08	73.00	.00	27.00	.14
17	Swan	4.46	.27	.36	2.58	46.62	18.92	34.46	.00
18	Becky	3.00	.20	.27	--	.00	61.86	38.14	.01
19	Hay	5.30	.43	.61	.52	.00	.00	100.00	.20
20	Soft Maple	7.59	.46	.56	.91	19.93	14.59	65.48	.04
21	Mcdermott	4.57	.40	.48	3.30	6.49	.00	93.51	.14
22	Meadow Cr	1.37	.20	.24	2.40	.00	3.26	96.74	.10
23	Gilbert Cr	2.47	.18	.22	6.63	29.00	17.00	54.00	.02
24	Trib 1 Shoulder Cr	4.74	.35	.41	1.82	.00	.00	100.00	.37
25	Crazy Horse Cr	3.20	.39	.48	4.48	13.00	.00	87.00	.12
26	Alder Cr	2.27	.19	.24	2.18	9.00	.00	91.00	.19
27	Sailor Cr	4.27	.19	.27	4.00	12.00	15.00	73.00	.06
28	Knuteson	9.37	.40	.52	3.60	28.37	12.77	58.87	.02
29	South Fork Hemlock	3.57	.11	.18	5.40	4.20	23.08	72.73	.02
30	Little Soft Maple	4.45	.26	.31	4.50	52.00	26.00	22.00	.01
31	Alvin	3.05	.28	.36	2.40	.00	.00	100.00	.09
32	North Otter	4.12	.18	.24	4.10	.00	37.59	62.41	.02
33	North Fork Thunder	4.24	.33	.45	.82	14.38	.00	85.63	.22
34	Waupee	5.13	.36	.52	2.25	19.38	.00	80.63	.36
35	Trout	5.50	.26	.32	2.80	31.20	15.38	53.42	.01
36	South Fork Popple	4.47	.65	.74	.98	.00	.00	100.00	.25
37	Mosquito Cr	4.51	.34	.48	1.16	16.20	.00	83.80	.30
38	Hay Meadow	3.34	.22	.32	2.54	14.55	.00	85.45	.06

Percent silt	Percent sand	Percent gravel	Percent rocky-substrate embeddedness	Percent stream bottom covered by algae	Percent macro-phytes	Percent cover	Percent stream shaded	Percent streambank with erosion	Buffer width (m)
2.40	85.21	5.42	87.29	0.00	0.00	16.53	78.23	18.13	8.90
3.02	71.35	23.02	77.50	.00	.00	7.60	42.71	34.58	9.46
.77	.67	25.29	6.15	.00	.00	.71	56.15	.58	10.00
.00	36.35	24.27	47.92	.00	.00	6.83	86.77	7.29	10.00
5.83	65.10	11.35	83.33	.00	3.13	4.29	60.31	39.58	10.00
7.92	47.19	22.92	39.48	.00	9.69	3.04	.10	.42	10.00
1.48	28.07	28.41	26.70	.00	.00	4.24	61.14	20.23	10.00
41.77	22.81	25.21	68.44	.21	5.73	.00	51.88	6.46	10.00
33.65	41.88	16.46	80.52	.00	.83	14.07	60.21	6.46	10.00
43.85	40.94	3.23	93.33	.00	31.25	.54	22.50	1.46	9.67
.00	42.71	31.88	50.21	.00	.00	9.13	89.48	6.25	10.00
24.69	67.08	5.83	94.06	.00	36.88	18.50	20.52	7.08	.63
1.56	64.06	33.02	67.50	.00	.00	.00	70.00	1.25	10.00
8.96	68.85	6.98	88.96	.00	9.58	1.92	46.98	1.04	10.00
34.69	52.81	.00	100.00	.00	13.75	4.33	17.81	2.50	10.00
32.12	41.25	2.88	94.81	.00	1.54	29.43	58.17	7.12	9.23
.63	33.96	33.02	25.83	20.00	.00	14.21	28.75	9.79	8.58
.63	7.08	10.42	18.13	13.96	.00	7.52	13.65	10.00	.00
22.29	37.60	.21	100.00	.00	20.42	1.34	13.33	6.67	10.00
7.29	26.35	30.52	42.60	.00	.00	11.44	82.40	5.21	10.00
21.88	32.50	26.46	74.38	.00	51.15	38.53	.00	5.21	10.00
29.97	26.69	11.09	76.09	.47	2.84	11.93	27.37	11.15	20.00
6.04	29.09	29.19	32.94	5.29	4.35	11.48	19.64	8.44	20.00
61.20	23.10	.39	99.19	16.67	30.05	16.18	2.50	5.26	12.21
31.46	11.15	2.76	91.25	.00	.60	22.99	57.11	4.06	19.31
30.13	23.65	.83	98.83	.00	4.66	6.19	69.45	5.94	18.74
4.69	40.68	40.42	43.72	.36	2.86	6.22	74.64	13.07	19.48
5.63	33.44	36.04	50.83	.00	.00	7.59	49.79	12.29	7.92
1.04	54.90	25.00	73.85	.00	.00	8.87	86.77	21.67	10.00
1.59	22.84	14.20	29.20	.00	.57	6.91	56.93	22.27	10.00
6.04	63.54	16.67	76.15	.00	11.46	13.34	9.48	13.54	9.92
1.98	34.79	39.48	36.25	.00	2.71	14.70	84.06	5.42	10.00
.00	90.38	1.15	99.04	.00	2.60	26.03	69.33	10.77	10.00
24.62	55.67	.00	100.00	.00	5.10	9.55	33.46	.38	10.00
10.31	35.31	34.27	35.83	9.79	.00	1.32	69.48	72.50	10.00
45.73	8.33	.42	99.11	.10	8.39	45.74	.00	.00	20.00
9.27	87.19	.00	100.00	.00	1.56	15.72	11.15	7.50	10.00
5.83	77.60	9.38	79.58	.00	21.15	16.36	25.10	2.08	10.00

Appendix 2. Physical-habitat characteristics of each of the 240 studied wadeable streams in Wisconsin—Continued. All data collected by the Wisconsin Department of Natural Resources.

[Cr, Creek; Trib, Tributary; Br, Brook; ID, identification number; m/km, meter per kilometer; m, meter; --, no data collected at site]

ID (see fig. 4)	Stream name	Stream width (m)	Stream mean depth (m)	Mean thalweg depth (m)	Stream gradient (m/km)	Percent pools	Percent riffle	Percent run	Depth of sediment on stream bottom (m)
39	Cedar Springs	2.42	0.22	0.30	1.97	14.00	0.00	86.00	0.07
40	Skunk Cr	4.02	.48	.61	1.58	.00	3.85	96.15	.12
41	Jennie	5.31	.15	.23	5.44	.00	9.44	90.56	.08
42	Trout	2.62	.13	.19	2.77	.00	.00	100.00	.08
43	Muskellunge – Heafford Junction	6.20	.28	.37	.79	1.38	.00	98.62	.10
45	Johnson	6.77	.20	.34	1.60	.00	.00	100.00	.09
46	Threemile	3.23	.17	.24	1.16	.00	.00	100.00	.10
47	Raeder Cr	3.74	.15	.20	6.49	11.00	35.00	54.00	.01
48	Hamann Cr	4.95	.20	.26	4.22	16.00	14.00	70.00	.01
49	East Fork Hamann	1.78	.21	.25	3.39	11.00	23.00	66.00	.02
50	Hamann Trib	2.07	.17	.21	6.22	6.00	38.00	56.00	.01
51	Widow Green	2.62	.26	.32	1.90	.00	.00	0.00	.16
52	North Fork Willow	6.42	.78	.89	1.76	100.00	.00	0.00	.05
53	Black Brook	4.57	.23	.30	4.47	4.55	2.27	93.18	.04
54	South Fork Willow	3.72	.19	.29	2.41	27.14	.00	72.86	.19
55	Hutton Cr	6.79	.31	.42	2.60	55.00	8.75	36.25	.06
56	Tenmile Cr	6.26	.29	.37	2.80	22.43	2.76	74.81	.02
57	Cr 12–13	1.15	.18	.23	6.57	2.78	.00	97.22	.17
58	Running Valley	4.59	.52	.72	2.24	17.92	4.17	77.92	.11
59	Cr 1–8	1.07	.17	.20	3.33	5.93	.00	94.07	.23
60	Cr 1–12	2.13	.20	.26	2.80	.00	.00	100.00	.75
61	18-mile	1.68	.31	.37	4.40	.00	.00	100.00	.11
62	Cady	4.63	.21	.27	8.24	10.27	31.35	58.38	.00
63	Eagle	2.88	.28	.34	5.10	2.79	12.40	84.80	.17
64	Joos	3.57	.75	.86	5.80	6.61	.00	93.39	.20
65	Trout Run	2.72	.19	.25	4.10	1.94	9.71	88.35	.10
66	Bohris	4.07	.19	.27	4.10	6.11	18.32	75.57	.15
67	South Branch Oneill Cr	3.42	.20	.25	2.67	28.00	7.00	65.00	.03
68	Unnamed Trib 1 East Fork Black	3.50	.22	.28	3.67	31.00	31.00	38.00	.02
69	Unnamed Trib 1 Rock Cr	2.11	.16	.23	2.16	2.06	.00	97.94	.16
70	Bloody Run	3.23	.11	.16	2.30	.00	.00	100.00	.18
71	Beaver Cr	3.27	.26	.31	2.34	29.00	3.00	68.00	.06
72	Tributary To Beaver Cr	3.10	.22	.27	.38	15.00	15.00	70.00	.04
73	North Fork Hemlock Cr	5.17	.17	.22	3.43	28.87	18.56	52.58	.01
74	Mormon	6.58	.22	.34	4.43	7.72	17.83	74.45	.02
75	Timber Coulee	4.32	.27	.37	4.97	18.33	5.00	76.67	.01

Percent silt	Percent sand	Percent gravel	Percent rocky-substrate embeddedness	Percent stream bottom covered by algae	Percent macro-phytes	Percent cover	Percent stream shaded	Percent streambank with erosion	Buffer width (m)
11.02	64.66	1.02	98.30	0.00	22.95	17.09	13.64	1.82	10.00
5.00	65.00	10.96	87.12	.00	5.29	8.82	3.65	.00	9.50
26.67	54.27	17.29	85.73	.00	4.69	2.27	.21	1.46	10.00
.77	76.63	13.17	79.71	3.27	.77	6.80	26.44	15.96	10.00
26.77	64.69	1.67	98.33	.00	.00	1.81	34.90	5.00	10.00
5.21	81.67	9.48	87.19	.00	.00	14.91	71.67	8.13	10.00
15.00	69.90	.00	100.00	1.04	22.92	7.96	31.25	3.75	10.00
.99	20.18	32.08	20.36	2.06	.18	6.15	69.43	15.10	20.00
2.03	14.71	44.40	14.87	20.08	3.07	6.69	70.31	9.43	19.70
10.21	18.02	21.85	33.91	3.49	.23	12.81	58.59	6.77	17.81
4.11	13.13	18.85	18.98	12.40	2.27	10.40	24.14	3.75	15.60
22.50	75.42	.00	100.00	.00	6.56	.56	.00	6.25	.00
31.54	23.46	17.12	64.90	2.21	8.37	21.11	7.12	1.15	10.00
10.58	53.08	27.60	68.46	.00	.00	3.41	63.94	35.00	9.65
26.06	47.02	16.83	84.04	.10	.19	1.42	67.12	56.54	9.23
26.25	31.44	14.23	67.69	2.69	.00	1.59	37.21	70.19	8.62
6.73	38.08	39.52	47.69	.00	.00	3.20	64.04	11.15	9.08
24.81	46.44	.38	99.81	.00	12.40	1.40	30.77	76.54	10.00
14.23	72.50	1.54	94.23	.96	2.02	7.20	16.15	9.81	10.00
34.90	41.04	.00	100.00	.00	3.75	6.48	19.38	63.33	10.00
66.92	.38	.00	100.00	.00	5.00	.00	73.17	67.12	9.92
5.52	89.69	.00	100.00	.00	.00	10.14	.00	8.33	10.00
10.10	2.29	18.33	20.63	6.04	21.46	6.64	29.17	17.29	10.00
31.46	9.90	11.15	79.38	.21	.00	2.33	.00	4.58	8.83
64.13	25.48	.38	98.27	.00	1.73	28.27	9.52	22.69	10.00
10.52	62.08	6.35	76.56	4.17	.83	.00	.00	43.75	.00
15.52	67.60	5.94	87.71	.31	1.04	.00	31.88	23.96	9.38
14.40	21.46	28.13	40.16	13.59	17.50	9.12	5.81	24.27	.21
.76	25.70	29.61	26.54	8.18	3.20	11.55	20.73	21.25	19.86
3.44	89.38	.78	98.31	.00	.00	5.33	76.61	18.49	18.45
13.54	66.98	3.54	97.71	.00	9.17	.64	84.38	28.33	12.38
3.46	25.89	40.29	34.53	3.39	.00	10.73	62.66	20.68	10.78
7.76	33.20	37.19	48.15	2.42	2.84	8.18	52.19	20.47	20.00
3.23	13.07	30.36	16.20	19.35	.31	1.99	90.60	17.34	20.00
26.25	14.90	17.81	51.56	1.04	45.63	.42	33.23	.00	14.88
13.33	11.46	29.17	41.56	14.06	18.44	7.84	51.25	5.83	5.17

Appendix 2. Physical-habitat characteristics of each of the 240 studied wadeable streams in Wisconsin—Continued. All data collected by the Wisconsin Department of Natural Resources.

[Cr, Creek; Trib, Tributary; Br, Brook; ID, identification number; m/km, meter per kilometer; m, meter; --, no data collected at site]

ID (see fig. 4)	Stream name	Stream width (m)	Stream mean depth (m)	Mean thalweg depth (m)	Stream gradient (m/km)	Percent pools	Percent riffle	Percent run	Depth of sediment on stream bottom (m)
76	Spring Coulee	7.32	0.27	0.43	4.30	24.80	26.42	48.78	0.07
77	Rush-02	3.53	.19	.24	--	10.10	63.64	26.26	.01
78	Beaver	2.63	.29	.37	3.40	35.14	24.32	40.54	.01
79	Dilly	2.13	.28	.31	5.51	.00	33.62	66.38	.00
80	Trib West Branch Baraboo	2.96	.26	.31	--	26.67	14.29	59.05	.04
81	Crooked	4.76	.38	.54	1.42	28.81	.00	71.19	.14
82	Moore	6.43	.33	.41	5.23	6.57	32.86	60.56	.00
83	Warner Br	2.34	.21	.24	5.28	6.09	22.61	71.30	.02
84	Warner	6.99	.41	.57	2.81	12.85	11.17	75.98	.12
85	Otter Cr – Lafarge	4.50	.30	.43	2.31	28.82	32.53	38.65	.04
86	Harrison	2.35	.41	.49	2.46	39.04	3.59	57.37	.08
87	Mccartney Br	2.04	.20	.25	5.23	18.00	30.00	52.00	.04
88	Hackett Br	3.41	.16	.20	10.00	.00	55.00	45.00	.00
89	Kuenster	6.11	.23	.33	5.24	.00	34.07	65.93	.05
90	Muskellunge Cr – Beetown	4.55	.33	.45	4.40	28.74	9.58	61.68	.06
91	Bull	5.32	.32	.41	4.50	29.03	25.35	45.62	.11
92	Willow	4.44	.23	.30	5.00	.00	20.14	79.86	.02
93	Mounds Br	1.93	.22	.28	4.76	4.81	43.27	51.92	.01
94	Young Br	3.09	.22	.28	15.86	19.80	36.63	43.56	.01
95	Mcadam Br	2.45	.22	.28	10.97	14.14	29.29	56.57	.02
96	Indian Cr – Dickeyville	1.36	.07	.10	12.01	.00	85.00	15.00	.00
97	Kieler Cr	1.89	.16	.20	7.35	6.67	28.57	64.76	.01
98	Apple	4.87	.43	.53	4.50	17.81	15.07	67.12	.03
99	Trib 1 French Spring Cr	1.39	.18	.23	3.95	21.43	6.12	72.45	.10
100	Rowan	3.72	.52	.70	2.30	39.23	.00	60.77	.10
101	Hinkson	3.47	.18	.24	1.30	5.13	.00	94.87	.11
102	North Branch Honey	2.61	.32	.38	7.30	.00	.00	100.00	.14
103	Moen	1.87	.16	.22	8.33	13.15	34.74	52.11	.04
104	Trout Cr – Barneveld	4.47	.46	.66	6.02	25.81	16.77	57.42	.12
105	Lowery	2.65	.17	.28	5.39	28.46	8.13	63.41	.17
106	Trib Otter Cr	5.73	.28	.38	4.60	29.93	19.20	50.87	.06
107	Bear	3.49	.37	.53	2.70	23.49	.00	76.51	.07
108	Horse	2.67	.25	.35	2.80	3.57	.00	96.43	.16
109	Brush	2.47	.29	.36	1.70	28.64	17.27	54.09	.08
110	East Mill	3.34	.33	.38	3.36	20.00	27.08	52.92	.01
111	Trib 1 Dead Cr	1.63	.38	.46	.56	.00	.00	100.00	.31
112	Johnson Cr – Farmington	2.32	.26	.33	.74	.00	.00	100.00	.50
113	Calamus Cr	3.43	.35	.39	1.95	.00	.00	100.00	.13

Percent silt	Percent sand	Percent gravel	Percent rocky-substrate embeddedness	Percent stream bottom covered by algae	Percent macro-phytes	Percent cover	Percent stream shaded	Percent streambank with erosion	Buffer width (m)
24.48	44.58	10.00	64.48	0.10	32.29	1.53	69.90	17.50	18.83
5.42	11.46	40.42	21.25	.21	.10	.89	67.19	13.33	16.38
7.19	10.10	46.25	18.54	5.83	.00	7.30	5.73	8.13	20.00
6.98	12.50	27.81	18.75	3.33	.00	5.21	2.29	2.71	.00
9.58	24.17	38.33	36.25	.00	.00	11.00	41.98	12.50	18.92
59.61	25.39	6.41	88.28	.39	47.66	3.91	.00	.47	17.72
3.33	11.88	17.50	17.19	.63	.00	3.43	56.67	19.58	6.71
1.98	34.38	29.79	35.10	10.00	.00	4.33	.00	32.92	.00
5.42	60.94	23.96	68.65	3.75	.00	3.00	53.02	28.33	20.00
10.63	29.61	24.14	42.58	.00	.00	1.32	76.64	29.22	23.44
14.46	28.48	20.54	65.18	.00	15.45	19.88	.00	4.46	.00
32.47	4.92	26.90	46.48	2.84	1.90	11.18	.00	21.41	.00
9.48	3.46	15.36	21.02	45.91	2.21	2.40	1.43	21.46	.00
41.46	3.65	18.75	61.35	22.81	6.25	.00	39.17	22.92	.00
48.46	2.60	15.87	69.52	10.67	28.85	8.13	15.48	26.35	.00
46.25	6.52	17.68	64.55	15.98	17.32	3.21	37.95	38.57	.00
16.46	16.04	15.00	49.38	14.48	19.90	.49	42.71	31.46	.00
15.41	5.79	44.28	29.13	3.99	2.88	8.41	.00	24.13	.00
18.05	1.85	14.95	33.75	19.51	.96	4.39	50.99	28.33	19.78
23.95	5.18	18.88	42.47	19.84	14.87	6.08	5.83	25.83	.00
7.55	6.80	29.92	21.95	6.98	.00	.00	69.51	28.96	17.71
25.28	2.33	15.90	49.75	13.73	1.00	6.46	6.98	9.50	11.03
8.54	9.06	38.75	24.38	14.17	2.81	1.11	.00	38.75	10.00
24.17	50.18	1.61	96.41	.00	.18	20.52	8.98	3.85	16.83
51.44	2.02	10.48	77.60	.00	18.75	9.13	.77	7.50	10.00
13.94	50.87	.48	98.27	.00	.00	1.40	71.73	15.77	10.00
42.40	52.40	2.08	95.42	.10	10.10	4.14	.10	60.63	.00
.54	59.73	20.71	61.52	.54	7.32	7.95	.00	7.86	20.57
15.52	44.79	17.50	68.13	.00	27.29	5.85	.00	33.13	20.00
80.39	4.77	5.39	82.89	.00	54.77	1.12	.00	19.06	.00
39.06	19.90	29.06	67.92	.00	.52	.00	73.33	34.38	.00
22.50	34.23	16.15	76.54	.00	7.40	.79	44.90	28.46	30.00
5.77	88.08	3.17	97.12	.00	.77	1.25	.00	40.00	.00
3.96	40.73	46.56	43.02	.21	.00	11.29	.00	19.79	18.13
3.84	36.52	34.46	32.41	.36	1.70	7.62	.00	8.04	10.00
42.19	.78	1.35	98.88	.00	5.42	30.51	.00	.16	16.61
12.92	81.95	.00	100.00	.00	.00	13.54	6.59	1.25	18.88
60.73	13.26	2.66	96.33	.42	47.71	43.37	.00	1.56	17.85

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[Cr, Creek; Trib, Tributary; Br, Brook; ID, identification number; m/km, meter per kilometer; m, meter; --, no data collected at site]

ID (see fig. 4)	Stream name	Stream width (m)	Stream mean depth (m)	Mean thalweg depth (m)	Stream gradient (m/km)	Percent pools	Percent riffle	Percent run	Depth of sediment on stream bottom (m)
114	Schultz Cr	2.12	0.25	0.32	4.62	0.00	0.00	100.00	0.07
115	Pratt Cr	2.80	.29	.34	1.60	.00	.00	100.00	.22
116	Trib Pratt Cr	1.95	.21	.26	1.33	.00	.00	100.00	.26
117	Casper Cr	1.46	.15	.19	5.04	4.08	12.24	83.67	.07
118	Scuppernong	3.11	.47	.54	.70	.00	.00	100.00	.08
119	Door Cr	2.25	.32	.40	1.37	.00	.00	100.00	.14
120	Little Door Cr	3.10	.17	.22	3.89	.00	13.00	87.00	.08
121	Branch Mineral Point	2.28	.19	.24	4.32	21.00	41.00	38.00	.01
122	Gill	2.56	.22	.26	2.82	.00	.00	100.00	.07
123	Baker	2.60	.18	.24	7.60	18.69	26.17	55.14	.02
124	Spring Brook	4.07	.25	.31	7.20	16.67	26.39	56.94	.02
125	Ore	4.75	.31	.39	2.61	36.80	11.20	52.00	.02
126	Bassett Cr	2.60	.17	.21	3.86	.00	25.00	75.00	.04
127	West Branch Nippersink	5.41	.27	.40	2.23	9.71	.00	90.29	.11
128	White Cr	3.35	.24	.31	4.67	9.03	22.22	68.75	.10
129	Pumpkinseed Cr	2.17	.40	.48	1.71	.00	.00	100.00	.09
130	Spring Bk	2.58	.08	.11	20.73	.00	100.00	0.00	.00
131	Daggets Cr	1.97	.27	.33	1.70	.00	.00	100.00	.20
132	Van Dyne Cr	2.22	.21	.26	8.70	44.00	17.00	39.00	.05
133	Trib 1 West Branch Fond Du Lac	2.43	.26	.32	.87	.00	.00	100.00	.18
134	Mill Cr	2.33	.15	.18	4.32	.00	54.17	45.83	.03
135	Kankapot Cr	2.18	.17	.23	2.57	37.00	17.00	46.00	.04
136	Molash	4.02	.72	.87	.92	.00	.00	100.00	.14
137	Grimms	1.39	.27	.32	2.00	1.94	.00	98.06	.06
138	Pine Cr – Newton	2.90	.33	.40	3.41	4.50	.00	95.50	.07
139	Point Cr	6.24	.30	.36	2.59	8.97	11.03	80.00	.03
140	Pigeon	3.21	.26	.31	1.50	3.73	2.24	94.03	.06
141	Otter Cr – Plymouth	4.80	.20	.25	2.50	.00	6.31	93.69	.01
142	Weedens	3.63	.27	.35	6.80	13.08	16.82	70.09	.01
143	Kettle Moraine	3.58	.26	.29	4.60	18.54	13.25	68.21	.02
144	West Branch Milwaukee	3.17	.48	.63	6.89	.00	.00	100.00	.46
145	Parnell	3.21	.17	.21	5.70	6.03	38.79	55.17	.01
146	East Branch Milwaukee	7.06	.34	.45	.93	13.15	.00	86.85	.11
147	Crooked	5.07	.27	.37	1.09	.00	.00	100.00	.22
148	Wallace	4.22	.39	.47	3.01	29.79	9.93	60.28	.07
149	Hanneman	3.98	.23	.29	3.35	.00	2.88	97.12	.02
150	Mayfield Cr	3.77	.30	.35	6.80	14.29	19.05	66.67	.02
151	Friedens	3.75	.22	.28	9.83	17.14	50.00	32.86	.01

Percent silt	Percent sand	Percent gravel	Percent rocky-substrate embeddedness	Percent stream bottom covered by algae	Percent macro-phytes	Percent cover	Percent stream shaded	Percent streambank with erosion	Buffer width (m)
30.99	4.11	2.63	86.09	4.82	4.35	19.38	62.79	8.59	20.00
61.09	2.58	2.55	99.87	4.64	16.04	19.66	13.85	4.53	10.17
64.79	3.33	.57	97.89	1.30	1.07	16.43	38.67	9.84	9.42
27.86	23.28	13.13	66.56	3.46	.26	5.47	35.16	15.52	12.21
32.08	52.08	.42	100.00	.42	14.38	3.35	.00	27.92	20.00
32.97	32.21	1.69	90.78	.00	3.07	26.95	28.41	3.07	.11
37.42	31.15	8.52	80.49	.00	.00	1.50	78.85	17.34	11.79
12.92	6.95	31.12	25.00	15.03	.03	8.95	17.40	20.89	6.08
7.60	70.00	6.92	82.12	.00	.00	.00	67.02	39.42	6.27
4.58	31.25	48.54	33.75	7.29	7.08	.00	66.77	28.75	17.21
11.67	23.75	17.08	41.98	.00	.00	17.00	93.65	39.79	5.04
11.82	25.80	46.70	36.59	.00	.00	.56	71.48	33.86	20.00
7.45	35.57	34.51	42.58	1.46	.00	1.66	88.91	22.34	6.40
28.44	29.69	25.10	66.56	.63	15.73	6.61	6.04	10.00	20.00
21.98	25.83	13.54	54.38	3.33	1.35	3.13	87.29	11.04	15.79
12.08	.05	.05	99.82	.83	.00	36.82	24.24	2.81	5.84
5.83	5.60	24.74	9.79	3.15	.78	.00	72.76	13.23	17.65
51.49	7.95	1.91	96.67	.00	1.15	4.81	71.53	13.26	15.75
25.97	16.32	18.75	63.65	32.74	1.91	10.05	29.51	17.15	17.96
49.35	7.86	1.85	94.74	11.69	7.06	9.97	39.35	10.78	7.44
8.39	31.41	29.77	34.11	1.09	.00	.42	70.00	26.15	19.55
3.91	23.49	24.24	44.01	6.67	.00	3.20	81.67	45.10	19.32
17.50	58.13	.00	100.00	.00	3.85	14.41	18.96	5.00	20.00
23.13	37.92	10.42	80.21	.42	.00	37.26	22.71	6.04	17.58
42.71	21.98	18.75	70.31	12.71	.00	9.96	8.23	11.04	19.54
20.63	27.29	17.92	62.19	34.38	.00	4.46	22.29	9.58	18.33
51.07	15.63	15.80	76.61	10.98	37.86	19.46	.00	5.00	4.75
17.12	28.85	35.77	43.56	5.38	34.13	1.97	.00	1.92	7.23
6.35	28.13	34.38	28.96	53.75	.00	1.67	32.40	36.25	20.00
13.33	37.29	21.25	50.42	22.50	19.27	7.63	2.92	8.96	19.67
95.63	.21	.00	100.00	30.21	23.75	14.17	.00	4.79	20.00
8.85	18.13	24.17	24.90	16.15	2.50	.00	10.83	41.04	6.56
35.94	34.06	9.90	83.23	.00	.00	2.86	61.35	51.67	10.00
59.09	7.95	9.55	89.09	.00	3.98	1.59	70.91	12.50	19.41
22.81	34.58	18.85	63.65	.83	.00	19.30	66.56	29.58	19.50
17.92	39.38	27.81	51.98	10.00	2.71	1.30	36.35	17.08	17.63
15.00	22.40	26.56	44.38	30.42	.00	9.59	75.00	41.25	19.79
1.77	6.35	27.71	15.10	1.46	.00	6.74	90.52	14.38	9.58

Appendix 2. Physical-habitat characteristics of each of the 240 studied wadeable streams in Wisconsin—Continued. All data collected by the Wisconsin Department of Natural Resources.

[Cr, Creek; Trib, Tributary; Br, Brook; ID, identification number; m/km, meter per kilometer; m, meter; --, no data collected at site]

ID (see fig. 4)	Stream name	Stream width (m)	Stream mean depth (m)	Mean thalweg depth (m)	Stream gradient (m/km)	Percent pools	Percent riffle	Percent run	Depth of sediment on stream bottom (m)
152	Pigeon Cr – Theinsville	3.30	0.18	0.23	1.38	19.61	29.41	50.98	0.01
153	Willow Cr – Germantown	2.75	.21	.29	5.09	.00	.00	100.00	.15
154	Little Menomonee	4.12	.32	.40	.51	.00	.00	100.00	.02
155	Husher	4.54	.35	.42	2.51	.00	.00	100.00	.05
156	North Branch Pike	2.96	.45	.51	.82	.00	.00	100.00	.10
157	Willow Cr – Waupun	2.60	.42	.51	.87	.00	.00	100.00	.29
158	Flynn	4.25	.16	.23	6.22	17.69	60.77	21.54	.01
201	Galena	17.76	.43	.54	1.25	.00	31.88	68.13	.00
202	Skinner Cr – Klondyke	7.00	.51	.71	.70	.00	6.49	93.51	.13
203	East Branch Pecatonica	16.30	1.00	1.27	.52	.00	.00	100.00	.33
204	Little Sugar	6.60	.56	.70	1.32	.00	20.35	79.65	.05
205	West Branch Sugar – #1	5.25	.76	.85	.34	.00	.00	100.00	.23
206	Platte – Rockville	16.84	.66	.92	3.30	17.02	25.96	57.02	.03
207	Pigeon	5.95	.42	.58	3.05	14.47	16.23	69.30	.05
208	Rattlesnake	11.81	.41	.49	3.36	1.63	15.12	83.26	.01
209	Blake	7.86	.42	.60	2.20	10.25	8.13	81.63	.06
210	Fennimore	5.23	.44	.54	11.30	16.30	12.77	70.92	.07
211	Black Earth 1	13.02	.60	.69	.95	1.58	4.75	93.67	.07
212	Kickapoo	13.97	.62	.89	.61	.00	.00	100.00	.21
213	Moore	8.00	.29	.42	1.87	3.85	18.38	77.78	.04
214	Coon Cr	12.19	.58	.76	.98	.00	6.46	93.54	.46
215	Little La Crosse – Sparta	8.47	.47	.65	.94	.00	.00	100.00	.15
216	Lacrosse	14.45	.92	1.15	.71	.00	2.79	97.21	.14
217	Eau Galle 2	8.92	.33	.44	2.32	15.10	63.27	21.63	.02
218	Willow	18.51	.70	1.01	2.84	.00	11.08	88.92	.01
219	Wood	11.09	.62	.94	.49	.00	.00	100.00	.74
220	Yellow – Barron	20.74	.52	.66	1.65	9.88	28.50	61.63	.02
221	Hay River	27.03	.67	1.02	.67	.00	.00	100.00	.13
222	North Fork Eau Claire	12.07	.36	.51	1.96	12.42	10.00	77.58	.01
223	Big Eau Pleine	28.08	.70	.86	.96	6.88	9.00	84.13	.02
224	Black	56.27	.62	.78	1.55	1.15	5.13	93.72	.01
225	Yellow – Babcock	18.04	.85	1.21	.19	.00	.00	100.00	.17
226	Little Yellow	9.94	.60	.91	.31	.00	.00	100.00	.89
227	South Branch Yellow	8.68	.24	.37	.31	4.01	.00	95.99	.27
228	Ten Mile Cr	10.44	.61	.97	2.67	.85	.00	99.15	.21
229	Little Plover	5.74	.30	.40	2.55	.00	1.63	98.37	.09
230	Tomorrow	9.08	.54	.69	1.07	.00	5.13	94.87	.07
231	Pensaukee – Krakow	10.56	.35	.43	--	.00	3.13	96.88	.03

Percent silt	Percent sand	Percent gravel	Percent rocky-substrate embeddedness	Percent stream bottom covered by algae	Percent macro-phytes	Percent cover	Percent stream shaded	Percent streambank with erosion	Buffer width (m)
3.65	15.63	49.58	23.54	4.17	0.00	8.42	84.90	13.96	20.00
40.63	23.65	7.60	91.15	.00	.00	4.40	60.21	30.42	18.33
22.40	25.58	19.13	61.06	5.19	3.46	1.59	67.31	15.38	10.00
22.92	23.13	18.75	70.83	.00	.00	6.56	82.08	40.42	20.00
17.89	14.41	17.43	70.00	1.64	1.23	6.86	50.93	22.45	13.55
76.90	.00	.00	100.00	.00	5.36	25.62	.00	2.03	19.13
3.98	12.84	41.93	14.20	5.00	.23	.00	60.80	10.00	20.00
3.63	6.63	30.81	16.31	48.38	.00	2.55	21.44	16.00	10.53
25.52	1.35	14.58	82.50	.63	.00	7.37	61.77	44.58	13.83
19.25	53.25	11.50	80.67	.00	.00	7.23	21.67	36.83	20.00
11.04	15.94	23.33	33.02	9.58	.00	3.98	68.44	23.96	14.21
76.88	11.67	.00	98.54	.00	.00	7.87	29.90	17.71	2.63
19.87	13.62	35.53	35.13	1.18	6.51	5.84	15.26	11.32	15.55
29.42	21.54	13.65	59.81	13.94	21.35	1.87	.58	34.23	.00
23.57	6.34	23.75	38.48	16.88	14.91	2.66	26.43	12.50	.71
28.54	30.21	19.58	69.90	19.38	16.67	.57	.21	38.54	.00
64.50	4.00	21.50	78.17	1.67	4.42	1.15	.00	24.00	.00
17.88	13.56	50.63	37.75	3.88	16.69	21.65	35.56	17.38	10.80
.97	81.16	11.59	84.19	.00	2.72	6.21	23.88	29.63	16.00
1.54	55.87	28.94	61.83	.96	.19	1.76	65.77	65.38	10.27
8.69	68.00	3.13	87.06	.00	.00	4.83	33.69	25.88	12.75
.63	88.23	10.94	77.50	.00	1.25	12.64	.83	17.71	16.63
.13	65.44	19.13	64.94	.00	2.13	14.11	49.88	21.38	11.35
2.08	17.08	33.85	16.88	11.46	4.79	7.23	22.81	8.33	19.00
.00	19.13	28.00	15.81	9.13	1.75	7.65	18.19	11.78	20.00
.31	99.56	.00	100.00	.50	.88	15.25	5.69	13.88	20.00
.38	6.56	32.19	19.00	8.75	14.63	21.73	21.88	11.38	15.63
.00	90.37	8.90	82.65	.44	.00	2.70	14.63	38.97	20.00
.00	25.52	40.52	12.50	.00	.00	3.02	11.46	15.63	.00
.19	18.19	35.06	19.25	.00	.00	13.75	8.00	12.00	19.05
.94	21.88	20.75	34.75	10.50	.00	21.30	4.94	23.50	18.58
.63	83.33	3.96	89.79	.00	.00	25.89	58.33	37.71	20.00
1.88	97.50	.00	100.00	.00	.00	13.32	63.44	65.00	20.00
1.88	92.29	.00	100.00	.00	.00	11.23	47.29	52.29	19.83
.10	93.02	.73	98.96	.00	.00	19.75	38.02	11.04	15.71
.83	85.73	.00	96.04	1.88	6.35	11.88	53.23	.00	20.00
10.19	54.25	12.94	70.31	.31	7.06	24.68	42.69	2.25	19.55
11.98	27.81	42.29	38.23	21.04	1.98	.96	45.63	16.88	17.94

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[Cr, Creek; Trib, Tributary; Br, Brook; ID, identification number; m/km, meter per kilometer; m, meter; --, no data collected at site]

ID (see fig. 4)	Stream name	Stream width (m)	Stream mean depth (m)	Mean thalweg depth (m)	Stream gradient (m/km)	Percent pools	Percent riffle	Percent run	Depth of sediment on stream bottom (m)
232	Pensaukee – Pensaukee	13.40	0.73	0.97	0.97	19.33	0.00	80.67	0.13
233	Middle Branch Embarrass	16.24	.39	.48	.99	.00	14.41	85.59	.04
234	Eau Claire – Kelly	27.24	.60	.88	1.00	24.70	47.12	28.18	.02
235	Eau Claire – Antigo	19.16	.58	.72	.86	.00	11.62	88.38	.03
236	Spring Brook 2	6.07	.19	.26	1.49	13.86	5.94	80.20	.06
237	Prairie	22.86	.41	.54	1.35	.00	.00	100.00	.03
238	Skinner	9.72	.56	.66	2.19	30.25	.00	69.75	.04
239	Spirit	18.06	.51	.63	1.46	.00	10.94	89.06	.03
240	North Fork Copper	9.18	.45	.56	.87	22.50	.00	77.50	.04
241	Hunting	18.80	.27	.42	1.96	.00	27.78	72.22	.03
242	Wolf River	55.12	.61	.82	1.17	.00	11.52	88.48	.02
243	North Branch Pike	11.35	.83	.97	.50	6.77	.00	93.23	.10
244	Popple	22.97	.85	1.01	1.26	22.88	.00	77.13	.04
245	Woods	9.82	.22	.28	3.03	.00	11.27	88.73	.02
246	Pine	35.80	.51	.68	1.05	3.75	6.50	89.75	.01
247	Brule	31.58	.55	.81	1.77	2.75	20.38	76.88	.00
248	Kaubashine	7.71	.17	.23	.44	.00	20.18	79.82	.21
249	Namekagon	27.91	.38	.59	2.52	1.88	31.88	66.25	.02
250	Totagatic	10.89	.32	.54	.92	8.33	3.66	88.01	.20
251	Eau Claire	17.12	.41	.57	1.32	6.60	28.47	64.93	.05
252	Upper Ox	7.70	.35	.59	.89	23.97	.00	76.03	.19
253	North Fish Cr	11.48	.47	.72	.86	4.43	15.44	80.13	.11
254	Bois Brule	19.85	.57	.74	2.67	.00	43.66	56.34	.02
255	Amnicon	8.31	.35	.58	.29	16.27	.00	83.73	.13
256	Upper Tamarack	17.31	.48	.59	1.11	4.76	13.69	81.55	.02
257	Turtle Cr 2	28.63	.38	.52	1.21	.00	17.38	82.63	.03
258	Whitewater Cr	12.49	.43	.49	.98	.00	.00	100.00	.04
259	Token Cr	9.25	.44	.63	.61	.00	.00	100.00	.26
260	Yahara	5.86	.39	.47	1.06	.00	.00	100.00	.06
261	Oconomowoc	10.59	.35	.50	1.30	7.53	.00	92.47	.16
262	Milwaukee	51.87	.42	.60	1.75	.00	40.00	60.00	.01
263	Cedar Cr	21.64	.36	.47	.56	2.72	8.31	88.97	.03
264	Sauk	2.72	.26	.30	.77	--	--	--	.02
265	Stoney	4.64	.28	.35	9.24	5.56	9.44	85.00	.08
266	North Branch Milwaukee	12.01	.39	.51	.18	.00	8.30	91.70	.12
267	West Branch Rock	17.39	.48	.65	.03	16.94	21.67	61.39	.03
268	Onion	16.09	.22	.34	4.45	.00	56.96	43.04	.01
269	South Branch Sheboygan	4.91	.26	.32	5.39	20.41	40.31	39.29	.00

Percent silt	Percent sand	Percent gravel	Percent rocky-substrate embeddedness	Percent stream bottom covered by algae	Percent macro-phytes	Percent cover	Percent stream shaded	Percent streambank with erosion	Buffer width (m)
12.06	56.88	8.06	80.19	0.00	0.00	7.90	39.50	33.25	20.00
2.11	40.39	41.05	45.72	.00	.00	15.35	19.01	3.55	10.26
.00	21.72	30.94	28.44	.63	.00	11.13	24.38	22.34	12.66
.00	28.38	36.56	13.94	4.06	.31	1.63	27.81	9.13	18.25
4.90	52.71	25.10	72.71	.00	1.04	3.99	49.79	2.29	19.71
2.31	25.50	44.56	17.56	.13	10.19	13.00	17.50	12.63	19.63
28.54	16.67	18.75	48.56	.00	.83	16.79	32.02	4.42	10.00
3.88	23.38	29.63	25.06	1.13	15.38	22.58	14.44	8.75	19.78
17.88	32.50	27.88	56.35	.00	1.25	5.67	32.12	28.85	10.00
11.15	20.19	35.58	37.69	.00	3.27	20.73	34.13	2.69	10.00
1.69	22.50	33.31	25.00	.25	6.50	12.77	1.81	7.25	16.50
5.58	73.56	12.98	72.02	.00	1.54	28.23	33.37	4.23	9.62
12.94	45.50	24.75	55.81	.00	.06	11.51	.00	6.00	19.38
4.04	10.77	66.15	11.06	.00	4.71	9.84	30.77	10.38	10.00
2.00	11.63	58.00	7.88	.13	.06	3.86	2.69	11.13	20.00
.00	5.75	37.31	10.44	2.63	.00	15.04	4.19	5.88	19.25
27.19	27.92	16.88	72.92	.00	12.81	2.78	24.38	6.88	10.00
4.81	25.06	25.00	24.25	.75	1.31	6.50	12.44	.75	19.63
3.65	84.42	7.50	87.12	.00	3.37	10.75	32.46	35.38	9.65
5.52	44.90	27.40	53.85	.00	6.35	.55	9.17	.42	8.79
14.20	85.11	.68	97.73	.00	31.70	4.19	.34	.00	10.00
.13	71.00	15.75	64.31	1.00	.00	8.47	11.81	25.00	20.00
1.50	27.19	38.81	33.31	.00	1.19	20.45	23.44	3.88	20.00
35.00	46.63	4.52	87.31	.77	34.33	18.47	2.02	13.27	10.00
2.79	24.71	42.31	22.88	1.54	6.63	16.89	11.63	12.12	9.85
1.81	51.88	26.75	28.91	18.19	8.69	10.54	7.44	23.38	20.00
12.50	55.38	20.63	63.00	21.13	50.63	65.52	10.75	6.63	20.00
33.64	51.48	8.30	85.11	.91	7.61	4.89	39.55	2.73	20.00
2.83	75.00	12.50	64.17	4.50	18.75	13.78	16.58	11.50	1.30
47.19	28.23	5.42	87.19	.10	1.56	1.83	11.98	.63	9.63
.38	11.25	27.69	8.63	2.19	31.44	12.17	4.00	3.00	15.48
6.18	26.91	38.09	31.71	.00	.86	4.34	52.43	20.79	12.82
7.98	31.83	34.90	41.92	19.23	.19	.77	.00	37.31	13.04
13.75	55.42	18.02	62.50	.00	.00	.00	40.94	21.25	20.00
42.13	24.81	18.94	70.50	.00	3.06	9.62	19.88	5.88	20.00
15.92	6.33	19.00	28.42	5.00	.00	16.27	45.33	18.00	9.53
2.50	9.69	19.94	18.25	24.00	.25	10.08	36.88	10.63	11.10
.21	12.40	20.21	11.25	40.83	.00	14.84	13.96	3.75	20.00

Appendix 2. Physical-habitat characteristics of each of the 240 studied wadeable streams in Wisconsin—Continued. All data collected by the Wisconsin Department of Natural Resources.

[Cr, Creek; Trib, Tributary; Br, Brook; ID, identification number; m/km, meter per kilometer; m, meter; --, no data collected at site]

ID (see fig. 4)	Stream name	Stream width (m)	Stream mean depth (m)	Mean thalweg depth (m)	Stream gradient (m/km)	Percent pools	Percent riffle	Percent run	Depth of sediment on stream bottom (m)
270	Meeme	4.25	.21	.27	2.80	0.00	37.86	62.14	0.01
271	Silver Cr	4.41	.51	.59	3.08	24.14	.00	75.86	.02
272	South Branch Manitowoc	18.47	.38	.46	.51	.00	7.86	92.14	.02
273	Manitowoc	27.93	.44	.64	1.12	16.42	28.64	54.94	.01
274	East Twin	12.96	.36	.45	1.30	6.74	20.43	72.83	.02
275	Neshota	5.03	.13	.17	1.11	18.30	12.50	69.20	.04
276	Kewaunee	16.44	.36	.47	.86	.00	30.44	69.56	.01
277	East	6.35	.44	.55	.68	53.36	.00	46.64	.16
278	Duck Cr	10.80	.27	.35	2.19	13.51	25.33	61.16	.01
301	Vismal Cr	--	--	--	--	--	--	--	--
302	Levis Cr	--	--	--	--	--	--	--	--
303	Ditch #6 South Branch Ten Mile Cr	--	--	--	--	--	--	--	--
304	South Branch Suamico	--	--	--	--	--	--	--	--
305	West Branch Red	--	--	--	--	--	--	--	--

Percent silt	Percent sand	Percent gravel	Percent rocky-substrate embeddedness	Percent stream bottom covered by algae	Percent macrophytes	Percent cover	Percent stream shaded	Percent streambank with erosion	Buffer width (m)
5.94	22.29	53.44	26.04	5.00	1.56	8.57	24.06	12.29	8.92
4.42	22.88	37.50	26.54	37.40	4.04	5.88	.38	1.54	6.92
6.50	16.19	42.06	26.75	.00	.00	14.72	26.88	12.25	13.88
1.00	11.06	35.19	12.06	.38	.00	11.71	8.94	14.13	20.00
7.38	21.56	45.63	24.50	.00	.00	1.85	61.00	7.88	9.85
11.70	26.07	40.98	41.88	1.79	.00	.00	65.18	56.61	10.00
5.31	11.80	27.19	21.72	10.16	.00	5.88	9.06	1.41	14.97
16.50	45.00	5.75	91.00	.00	.00	7.18	77.00	59.50	15.97
.25	12.81	28.88	15.94	.13	.00	8.71	26.50	8.00	16.83
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Appendix 3. Diatom nutrient-tolerance ranking for individual diatom taxa. Taxa without nutrient-tolerance values are not included in the table.

[nutrient-tolerance ranking: 1, oligotrophic; 2, oligo-mesotrophic; 3, mesotrophic; 4, meso-eutrophic; 5, eutrophic; 6, hypereutrophic; var, variety]

Diatom taxa	Nutrient-tolerance ranking
Achnanthidium exiguum	2
Achnanthidium hungaricum	6
Achnanthidium minutissimum	2
Amphipleura pellucida	2
Amphora ovalis	5
Amphora ovalis var. *affinis*	5
Amphora ovalis var. *pediculus*	5
Amphora perpusilla	5
Amphora veneta	5
Aulacoseira granulata	5
Aulacoseira italica	3
Brachysira brachysira	1
Caloneis bacillum	4
Cocconeis pediculus	5
Cocconeis placentula var. *euglypta*	5
Cocconeis placentula var. *lineata*	5
Cocconeis placentula var. *placentula*	5
Craticula accomoda	1
Craticula buderi	3
Craticula cuspidata	3
Cyclostephanodiscus species	5
Cyclotella atomus	1
Cyclotella radiosa	1
Cymbella affinis	5
Cymbella naviculiformis	2
Cymbella tumida	2
Cymbella tumidula	3
Diatoma vulgare	1
Discotella stelligera	1
Encyonema minutum	5
Encyonema silesiacum	3
Eolimna minima	3
Eolimna subminuscula	5
Epithemia adnata	3
Epithemia sorex	5
Epithemia species	5
Epithemia turgida	5
Eunotia formica	5
Eunotia incisa	5
Eunotia naegelii	4
Eunotia pectinalis var. *undulata*	5
Eunotia sudetica	2
Fallacia pygmaea	5
Fistulifera pelliculosa	2
Fragilaria capucina (several var.)	3
Fragilaria crotonensis	2
Fragilaria vaucheriae	3
Frustulia rhomboides	4
Frustulia saxonica	1
Frustulia vulgaris	4
Geissleria decussis	4
Gomphoneis minutum	1
Gomphoneis olivacea	2
Gomphonema acuminatum	2
Gomphonema acuminatum var. *pusilla*	2
Gomphonema affine	3
Gomphonema apuncto	1
Gomphonema gracile	1
Gomphonema parvulum	2
Gomphonema truncatum	4
Gyrosigma attenuatum	5
Gyrosigma spencerii	5
Hippodonta capitata	1
Melosira varians	1
Meridion circulare	3
Navicula angusta	2
Navicula antonii	5
Navicula arvensis	4
Navicula capitatoradiata	5
Navicula gottlandica	5
Navicula gregaria	5
Navicula lanceolata	5
Navicula minuscula	4
Navicula radiosa	4
Navicula rostellata	5
Navicula tenelloides	5
Navicula tripunctata	5
Navicula trivialis	5

Appendix 3. Diatom nutrient-tolerance ranking for individual diatom taxa. Taxa without nutrient-tolerance values are not included in the table—Continued.

[nutrient ranking: 1, oligotrophic; 2, oligo-mesotrophic; 3, mesotrophic; 4, meso-eutrophic; 5, eutrophic; 6, hypereutrophic; var, variety]

Diatom taxa	Nutrient-tolerance ranking
Navicula veneta	5
Navicula viridula	5
Nitzschia acicularis	5
Nitzschia amphibia	5
Nitzschia capitellata	6
Nitzschia dissipata	4
Nitzschia fonticola	4
Nitzschia frustulum	5
Nitzschia gracilis	3
Nitzschia inconspicua	5
Nitzschia linearis	4
Nitzschia nana	3
Nitzschia palea	6
Nitzschia paleacea	5
Nitzschia pusilla	4
Parlibellus protracta	5
Placoneis exigua var. *capitata*	4
Planothidium dubium	5
Planothidium lanceolatum	5
Psammothidium subatomoides	2
Reimeria sinuata	3
Rhoicosphenia curvata	5
Rhopalodia gibba	5
Rossithidium linearis	1
Sellaphora pupula	4
Sellaphora rectangularis	4
Sellaphora seminulum	5
Stauroneis anceps	4
Staurosira construens	4
Staurosira construens var. *binodis*	6
Staurosira construens var. *venter*	4
Staurosira elliptica	5
Staurosirella leptostauron	4
Staurosirella leptostauron var. *dubia*	4
Staurosirella pinnata	4
Staurosirella pinnata var. *intercedens*	5
Stenopterobia delicatissima	1
Stephanocyclus meneghiana	4
Surirella angusta	5
Surirella linearis	2
Synedra delicatissima	3
Synedra filiformis var. *exilis*	2
Synedra parasitica	4
Synedra rumpens	2
Synedra rumpens var. *familiaris*	2
Synedra ulna var. *amphirhynchus*	5
Synedra ulna var. *contracta*	3
Tabellaria fenestrata	2
Tabellaria flocculosa	3
Tabellaria flocculosa strain IV	3
Tabularia fasciculata	5
Thalassiosira weissflogii	6

Appendix 4. Biological data for each of the 240 studied wadeable streams in Wisconsin. All data collected by the Wisconsin Department of Natural Resources.

[CR, Creek; TRIB, Tributary; BR, Brook; ID, identification number EPT, Ephemeroptera, Plecoptera, or Trichoptera; mg/m^2, milligram per square meter; --, no data collected at site]

ID (see fig. 4)	Stream name	Benthic chlorophyll *a* (mg/m^2)	Diatom Nutrient Index	Diatom Siltation Index	Diatom Biotic Index	Hilsenhoff Biotic Index	Percent EPT number	Percent EPT taxa	Percent scrapers
1	Onion	--	4.38	15.10	35.86	2.19	59.69	34.29	1.53
2	Thompson	155	5.16	67.93	22.76	3.46	66.40	37.93	.00
3	Parker	355	3.43	21.80	38.66	3.87	53.85	55.88	23.08
4	Catlin	31	3.98	27.50	32.68	2.07	75.37	55.56	14.18
5	Leo	54	3.47	14.00	43.02	1.84	68.61	38.46	6.73
6	Lower Ox	64	4.10	27.25	32.00	2.47	73.13	74.29	41.85
7	Lord	165	2.14	4.20	92.25	2.07	77.56	57.58	25.64
8	Fivemile	256	2.07	5.25	85.20	4.26	90.00	63.89	5.91
9	Cap	--	--	--	--	4.36	59.20	45.45	16.42
10	Spring Cr	654	3.69	9.20	48.09	4.42	53.79	44.00	35.61
11	Mosquito Br	227	4.34	9.04	44.29	2.18	74.32	56.25	9.29
12	Smith Lake	22	3.76	44.83	31.67	7.15	10.22	12.12	6.57
13	Fiddler	189	3.54	10.10	47.52	4.24	49.37	44.83	34.81
14	Spring Lake	--	2.82	13.40	50.54	5.95	32.61	25.93	1.45
15	Rainbow	--	3.01	18.80	44.15	5.42	50.72	32.20	6.52
16	Dody Brook	16	3.38	15.20	42.74	3.08	77.47	40.00	37.36
17	Swan	2,544	1.75	21.31	58.66	3.63	90.09	72.41	7.76
18	Becky	569	2.38	11.80	59.21	2.36	71.15	66.67	13.46
19	Hay	228	4.47	16.67	34.22	6.22	29.37	16.67	3.97
20	Soft Maple	446	4.29	58.33	27.27	3.57	70.18	52.83	15.54
21	Mcdermott	929	3.36	29.60	37.07	5.22	89.50	45.45	4.50
22	Meadow Cr	--	--	--	--	6.16	6.58	10.00	2.63
23	Gilbert Cr	--	--	--	--	4.64	11.24	24.14	62.13
24	Trib 1 Shoulder Cr	--	--	--	--	7.57	4.27	2.78	5.49
25	Crazy Horse Cr	--	--	--	--	4.93	22.29	10.00	2.29
26	Alder Cr	--	--	--	--	5.67	29.80	13.51	1.32
27	Sailor Cr	--	--	--	--	2.44	70.11	54.55	21.26
28	Knuteson	737	1.84	3.25	100.00	3.28	59.75	48.65	55.08
29	South Fork Hemlock	87	4.78	8.50	43.39	3.32	75.36	61.11	8.70
30	Little Soft Maple	2,197	2.07	20.60	58.96	2.28	71.23	58.00	20.89
31	Alvin	239	3.05	11.05	50.67	2.62	75.91	66.67	27.74
32	North Otter	23,122	4.01	22.50	34.00	2.21	59.24	50.00	32.35
33	North Fork Thunder	80	4.53	2.60	72.84	.84	86.59	66.67	11.59
34	Waupee	318	3.14	7.47	57.72	4.92	53.59	21.43	.00
35	Trout	--	--	--	--	4.42	49.37	29.63	23.63
36	South Fork Popple	--	--	--	--	7.64	6.54	5.26	14.95
37	Mosquito Cr	76	2.43	9.70	61.55	6.55	36.56	30.43	.54
38	Hay Meadow	977	3.14	15.32	45.00	5.46	47.92	36.96	3.65

Percent shredders	Number of taxa	Fish index of biotic integrity	Percent carnivores	Percent insectivores	Percent omnivores	Percent intolerant species	Percent tolerant species	Number of fish	Number of fish species
0.51	35.00	80.00	77.61	22.39	0.00	23.13	0.00	89	9
.00	29.00	90.00	68.35	29.11	.00	86.08	2.53	55	6
1.40	34.00	45.00	40.30	21.39	6.47	12.44	38.81	96	16
.00	27.00	90.00	97.87	2.13	.00	97.87	2.13	45	2
.00	26.00	60.00	11.24	48.31	5.62	12.36	20.22	82	11
.00	35.00	42.00	1.43	67.91	6.24	1.96	30.48	130	15
.00	33.00	20.00	.00	39.87	21.52	.00	51.27	95	9
.91	36.00	15.00	1.67	20.00	1.67	.83	85.00	83	10
.00	44.00	20.00	.00	37.18	7.69	1.28	66.67	53	8
.00	25.00	25.00	1.67	83.33	.00	.00	77.50	106	6
.00	32.00	90.00	89.83	10.17	.00	81.36	.00	55	4
.73	33.00	30.00	20.00	71.43	8.57	.00	80.00	95	4
.00	29.00	50.00	7.89	81.58	2.63	44.74	23.68	34	8
4.35	27.00	30.00	2.88	58.27	17.99	12.95	48.20	93	10
3.14	59.00	80.00	58.04	28.57	2.68	78.57	9.82	75	8
.00	25.00	21.00	.00	46.94	19.97	.58	50.73	457	10
.00	29.00	50.00	30.63	21.35	17.63	35.50	50.81	291	16
.00	36.00	60.00	34.07	24.73	7.14	53.85	32.97	182	9
.79	24.00	30.00	.00	43.00	7.00	2.00	48.00	97	10
.00	53.00	32.00	1.08	31.89	18.38	2.70	65.41	66	12
.00	22.00	25.00	2.31	31.02	10.42	8.33	61.34	281	10
4.61	30.00	35.00	.00	66.19	1.64	.00	48.16	128	8
.00	29.00	40.00	.00	55.01	1.16	4.67	45.31	237	13
18.90	36.00	30.00	.00	80.24	3.12	3.43	52.92	214	13
14.86	30.00	32.00	.00	60.58	3.01	2.15	12.67	233	10
.00	37.00	35.00	.00	46.07	8.86	1.30	30.09	192	13
.00	33.00	17.00	.00	22.65	1.91	.96	70.55	157	13
.00	37.00	55.00	19.32	47.16	18.18	15.34	34.66	62	16
.00	36.00	70.00	73.38	4.32	3.60	58.99	22.30	97	12
.68	50.00	40.00	7.01	10.83	5.73	7.01	76.43	157	11
1.46	33.00	50.00	17.07	18.29	.00	31.71	65.85	78	7
.00	36.00	60.00	64.48	1.64	.00	64.48	33.33	130	5
.00	33.00	90.00	70.00	27.50	.00	67.50	2.50	25	7
.00	42.00	40.00	1.39	75.00	6.94	1.39	37.50	45	9
.00	27.00	32.00	.00	49.17	5.48	4.24	52.38	414	14
4.05	38.00	30.00	.00	56.65	7.98	1.60	42.29	63	12
2.69	46.00	40.00	20.69	75.86	.00	20.69	13.79	20	9
1.56	46.00	40.00	1.59	82.17	3.82	10.83	21.34	285	12

Appendix 4. Biological data for each of the 240 studied wadeable streams in Wisconsin—Continued. All data collected by the Wisconsin Department of Natural Resources.

[Cr, Creek; Trib, Tributary; Br, Brook; ID, identification number EPT, Ephemeroptera, Plecoptera, or Trichoptera; mg/m², milligram per square meter; --, no data collected at site]

ID (see fig. 4)	Stream name	Benthic chlorophyll *a* (mg/m²)	Diatom Nutrient Index	Diatom Siltation Index	Diatom Biotic Index	Hilsenhoff Biotic Index	Percent EPT number	Percent EPT taxa	Percent scrapers
39	Cedar Springs	3,419	1.94	10.46	67.65	5.98	32.62	37.93	0.53
40	Skunk Cr	505	2.96	10.61	52.41	5.76	65.54	36.00	7.43
41	Jennie	315	2.78	14.02	50.41	3.90	69.73	45.65	24.04
42	Trout	449	3.01	7.71	58.39	4.90	27.03	37.14	17.57
43	Muskellunge – Heafford Junction	--	2.61	27.37	46.45	7.41	7.35	20.83	.74
45	Johnson	347	2.01	12.94	64.27	5.35	28.83	28.26	9.82
46	Threemile	293	2.99	65.46	37.37	7.82	2.63	15.79	.00
47	Raeder Cr	19	4.37	48.21	27.48	4.06	47.26	51.61	23.29
48	Hamann Cr	117	3.13	42.39	37.37	4.45	62.94	34.29	26.40
49	East Fork Hamann	--	--	--	--	4.75	24.83	27.27	46.21
50	Hamann Trib	11	4.31	55.66	27.35	4.61	47.37	40.48	30.70
51	Widow Green	1,629	3.81	49.17	30.93	4.33	25.50	45.83	61.92
52	North Fork Willow	196	4.11	69.21	27.85	6.91	44.33	17.14	.99
53	Black Brook	553	3.63	54.42	31.92	4.88	44.98	33.33	14.83
54	South Fork Willow	470	4.28	64.88	27.04	5.67	11.43	15.63	1.14
55	Hutton Cr	1,222	4.63	33.10	27.94	4.91	40.00	20.83	5.45
56	Tenmile Cr	1,029	4.52	27.89	29.52	3.13	58.27	52.17	33.09
57	Cr 12–13	2,000	3.85	72.33	29.41	4.26	52.17	53.33	2.54
58	Running Valley	16,672	4.09	76.94	27.71	7.53	5.33	8.00	.59
59	Cr 1–8	--	3.84	51.60	30.52	7.47	7.97	26.09	.00
60	Cr 1–12	--	4.42	48.90	27.18	4.88	61.19	33.33	.00
61	18-mile	3,915	4.07	18.35	35.50	3.15	51.59	42.55	35.69
62	Cady	5,970	3.01	28.01	63.68	3.67	84.65	58.33	14.11
63	Eagle	8,368	3.82	71.79	42.88	4.34	39.95	34.38	34.80
64	Joos	--	--	--	--	4.28	42.52	41.94	36.92
65	Trout Run	--	--	--	--	2.51	68.63	36.36	.65
66	Bohris	3,924	4.40	60.19	39.54	3.27	47.92	52.94	50.52
67	South Branch Oneill Cr	--	--	--	--	6.87	23.67	15.63	10.06
68	Unnamed Trib 1 East Fork Black	7	2.98	5.54	68.10	3.71	73.19	52.00	30.43
69	Unnamed Trib 1 Rock Cr	--	3.88	47.60	30.56	5.52	61.83	18.52	10.22
70	Bloody Run	--	4.88	3.30	71.19	4.16	24.82	25.93	5.67
71	Beaver Cr	--	--	--	--	5.97	34.78	35.71	27.33
72	Tributary To Beaver Cr	--	--	--	--	4.66	54.55	44.00	42.42
73	North Fork Hemlock Cr	--	--	--	--	7.01	10.30	20.00	1.82
74	Mormon	--	3.97	62.88	42.50	4.35	34.73	38.71	37.25
75	Timber Coulee	--	3.46	28.13	57.65	3.62	34.75	43.75	24.82

Percent shredders	Number of taxa	Fish index of biotic integrity	Percent carnivores	Percent insectivores	Percent omnivores	Percent intolerant species	Percent tolerant species	Number of fish	Number of fish species
2.67	29.00	0.00	7.14	71.43	7.14	0.00	92.86	14	4
.00	25.00	10.00	.00	85.37	4.88	2.44	92.68	26	5
.00	46.00	40.00	1.00	23.38	1.49	15.92	55.22	112	14
.68	35.00	60.00	46.43	14.29	10.71	57.14	42.86	25	5
.00	24.00	.00	9.52	47.62	28.57	9.52	47.62	10	7
1.23	46.00	45.00	2.47	74.38	5.56	4.01	24.07	145	11
.66	19.00	30.00	1.49	24.25	3.73	1.49	64.18	211	8
.00	31.00	30.00	.00	37.37	4.39	10.70	62.02	325	14
.00	35.00	37.00	.00	43.02	9.04	9.72	48.62	332	19
.00	22.00	45.00	.88	47.05	15.61	3.53	69.29	113	13
.44	42.00	42.00	.00	24.61	12.98	5.09	55.73	290	17
.00	24.00	.00	.00	22.22	29.63	.00	51.85	40	4
.00	35.00	25.00	.00	17.77	17.77	.00	18.18	224	7
.00	42.00	32.00	.00	42.17	3.21	1.61	58.63	189	13
.00	32.00	20.00	.00	38.46	5.77	2.88	59.62	87	12
1.21	48.00	40.00	.72	11.69	21.36	2.45	49.78	289	15
.00	23.00	22.00	.00	20.63	17.62	.00	57.23	342	13
.36	30.00	.00	53.33	46.67	.00	53.33	46.67	14	2
.00	25.00	50.00	9.63	52.75	7.80	19.27	37.16	182	10
.00	23.00	70.00	16.67	80.56	2.78	16.67	5.56	33	4
.00	24.00	.00	6.67	93.33	.00	6.67	.00	14	2
.00	47.00	.00	28.57	71.43	.00	28.57	28.57	13	4
.00	24.00	90.00	38.78	58.68	.00	93.03	2.53	426	6
.00	32.00	30.00	.00	52.56	38.46	.00	47.44	174	6
.00	31.00	15.00	.00	7.57	54.98	.00	81.67	234	9
.00	22.00	32.00	.86	57.76	39.66	1.72	45.69	113	9
.00	17.00	52.00	2.59	81.61	9.20	2.87	15.23	266	16
.00	32.00	40.00	.00	43.75	30.21	3.29	58.39	738	19
.00	25.00	30.00	1.96	26.96	28.92	.98	76.47	101	12
.00	27.00	50.00	.00	56.28	4.21	3.16	75.07	96	11
.00	27.00	100.00	66.07	28.57	1.79	87.50	3.57	51	7
.00	14.00	47.00	.00	44.26	19.78	7.65	62.92	333	20
.00	25.00	45.00	.00	46.86	13.51	7.89	64.20	224	17
8.48	30.00	37.00	.00	78.55	4.39	1.46	68.87	208	12
.00	31.00	20.00	1.63	33.70	54.08	.00	62.77	135	9
.00	32.00	60.00	65.23	28.30	6.47	20.49	6.47	206	5

Appendix 4. Biological data for each of the 240 studied wadeable streams in Wisconsin—Continued. All data collected by the Wisconsin Department of Natural Resources.

[Cr, Creek; Trib, Tributary; Br, Brook; ID, identification number EPT, Ephemeroptera, Plecoptera, or Trichoptera; mg/m^2, milligram per square meter; --, no data collected at site]

ID (see fig. 4)	Stream name	Benthic chlorophyll *a* (mg/m^2)	Diatom Nutrient Index	Diatom Siltation Index	Diatom Biotic Index	Hilsenhoff Biotic Index	Percent EPT number	Percent EPT taxa	Percent scrapers
76	Spring Coulee	19,863	3.42	67.49	47.54	3.62	45.43	37.50	19.29
77	Rush-02	16,047	4.13	43.51	44.80	3.81	52.82	39.29	30.26
78	Beaver	12,290	4.16	77.78	39.45	4.42	47.00	46.43	37.60
79	Dilly	--	--	--	--	4.55	53.91	39.39	32.35
80	Trib West Branch Baraboo	500	4.65	17.21	59.15	2.77	55.83	38.10	38.65
81	Crooked	2,690	3.47	69.41	46.70	3.40	60.89	41.67	9.68
82	Moore	7,423	4.07	77.19	40.22	4.05	49.74	37.93	56.92
83	Warner Br	730	3.97	73.25	41.36	3.78	17.00	37.84	59.65
84	Warner	93	4.35	37.62	45.00	2.42	68.46	52.63	36.91
85	Otter Cr – Lafarge	3,832	4.55	47.25	40.83	3.41	38.43	42.86	56.33
86	Harrison	9,024	3.78	72.64	43.18	4.20	48.57	50.00	36.00
87	Mccartney Br	--	--	--	--	4.76	65.36	32.14	22.88
88	Hackett Br	3,771	4.00	90.03	39.87	4.80	36.47	32.35	24.71
89	Kuenster	1,239	4.44	57.28	39.71	4.90	63.22	35.00	27.59
90	Muskellunge Cr – Beetown	21,785	4.14	79.05	39.43	5.56	22.22	14.29	9.66
91	Bull	10,157	3.46	68.83	46.87	5.97	14.12	13.04	20.00
92	Willow	25,755	4.07	82.41	39.80	4.59	25.39	27.27	26.94
93	Mounds Br	--	--	--	--	5.23	17.19	9.09	5.63
94	Young Br	3,094	3.88	79.57	41.68	5.37	68.51	33.33	18.78
95	Mcadam Br	5,905	4.02	84.19	40.01	5.02	61.79	23.26	12.62
96	Indian Cr – Dickeyville	12,262	4.14	68.52	40.44	7.21	12.43	40.00	.56
97	Kieler Cr	9,107	3.97	60.16	42.91	8.01	.00	.00	.00
98	Apple	3,446	4.93	13.79	64.88	4.34	7.03	27.78	85.41
99	Trib 1 French Spring Cr	3,537	4.28	59.74	40.48	5.01	8.44	16.67	53.90
100	Rowan	264	2.88	10.61	95.68	3.41	32.16	35.29	44.31
101	Hinkson	--	--	--	--	4.42	33.55	28.57	.66
102	North Branch Honey	3,915	3.97	78.58	40.92	5.54	28.88	29.41	1.07
103	Moen	7,491	4.43	47.68	41.58	4.01	35.37	51.85	30.61
104	Trout Cr – Barneveld	7,706	2.99	45.73	56.91	5.12	9.78	36.36	8.00
105	Lowery	11,216	3.16	64.61	51.15	3.81	29.91	35.00	14.53
106	Trib Otter Cr	6,954	4.59	73.90	36.66	4.29	52.60	35.29	30.96
107	Bear	5,507	4.60	74.31	36.59	4.71	41.35	36.11	3.76
108	Horse	1,517	3.80	78.88	42.47	3.87	38.27	55.00	52.35
109	Brush	4,598	3.47	52.79	49.03	4.14	49.45	37.50	39.34
110	East Mill	6,620	4.06	82.35	39.87	4.19	30.34	38.46	17.24
111	Trib 1 Dead Cr	--	5.41	85.67	31.20	9.08	.54	3.57	1.63
112	Johnson Cr – Farmington	1,077	4.15	75.16	39.69	4.41	13.83	13.33	.00
113	Calamus Cr	3,455	4.99	68.88	34.81	7.31	8.56	17.24	1.60

Percent shredders	Number of taxa	Fish index of biotic integrity	Percent carnivores	Percent insectivores	Percent omnivores	Percent intolerant species	Percent tolerant species	Number of fish	Number of fish species
0.00	32.00	60.00	81.20	10.20	7.40	1.40	7.40	203	6
.00	28.00	50.00	43.59	31.41	.00	32.05	25.00	158	6
.00	28.00	30.00	.14	41.64	23.37	.00	41.78	636	12
.00	33.00	45.00	.00	75.58	8.43	8.72	22.97	297	11
.00	21.00	35.00	.57	85.63	2.30	77.01	13.79	166	8
.00	24.00	60.00	100.00	.00	.00	.00	.00	93	2
.00	29.00	40.00	1.26	51.13	24.69	.76	42.82	186	14
.00	37.00	30.00	.00	40.72	1.70	1.14	56.63	459	8
.00	19.00	30.00	.74	52.96	15.19	5.19	44.44	151	12
.00	28.00	30.00	1.07	57.22	13.37	2.14	37.70	163	11
.00	24.00	20.00	5.17	35.63	31.61	1.72	57.47	139	8
.00	28.00	10.00	.00	8.56	60.48	.00	63.12	228	9
.39	34.00	37.00	.00	72.88	.00	.00	13.87	476	9
.00	20.00	15.00	.11	32.17	50.88	.11	51.97	1004	14
.00	42.00	20.00	.32	42.07	42.03	.32	43.12	1483	14
.00	23.00	20.00	.07	26.33	48.94	.20	53.79	693	15
.00	33.00	30.00	.63	53.13	23.44	5.31	30.31	691	15
.00	33.00	40.00	.00	50.94	3.77	.00	32.48	294	11
.00	27.00	20.00	.34	21.13	15.35	.34	26.44	292	13
.33	43.00	45.00	.00	70.71	3.21	.00	4.58	391	13
.00	20.00	.00	--	--	--	--	--	--	1
.00	8.00	30.00	.00	6.83	29.93	.00	31.51	432	9
.00	18.00	40.00	.00	25.10	14.82	.05	17.21	1336	15
1.30	30.00	65.00	.56	43.33	38.57	9.24	69.92	269	10
.00	17.00	50.00	11.25	83.25	5.50	83.00	5.50	308	4
.00	28.00	70.00	40.64	58.90	.00	84.02	14.61	187	5
.00	34.00	45.00	.40	64.94	6.37	52.59	22.71	246	11
.00	27.00	.00	4.35	78.26	.00	82.61	4.35	22	5
.00	22.00	70.00	25.79	69.68	4.52	70.14	4.52	143	5
.00	20.00	60.00	2.67	81.33	.00	45.33	16.00	60	4
.00	34.00	25.00	.37	36.48	38.21	1.74	58.44	405	13
.00	36.00	25.00	10.43	15.95	26.38	21.47	65.64	98	9
.00	20.00	35.00	.00	31.25	11.72	10.16	72.66	115	10
.00	24.00	80.00	64.75	22.13	8.20	77.05	15.57	111	9
.00	26.00	22.00	.64	11.92	19.65	.00	85.19	518	7
3.80	28.00	20.00	.00	96.83	3.17	.00	100.00	95	3
.00	15.00	40.00	.00	94.38	2.76	.00	89.47	263	8
2.14	29.00	12.00	.00	29.13	70.87	.00	98.70	193	9

Appendix 4. Biological data for each of the 240 studied wadeable streams in Wisconsin—Continued. All data collected by the Wisconsin Department of Natural Resources.

[Cr, Creek; Trib, Tributary; Br, Brook; ID, identification number EPT, Ephemeroptera, Plecoptera, or Trichoptera; mg/m^2, milligram per square meter; --, no data collected at site]

ID (see fig. 4)	Stream name	Benthic chlorophyll *a* (mg/m^2)	Diatom Nutrient Index	Diatom Siltation Index	Diatom Biotic Index	Hilsenhoff Biotic Index	Percent EPT number	Percent EPT taxa	Percent scrapers
114	Schultz Cr	2,907	4.72	8.50	89.24	4.68	7.60	25.00	43.27
115	Pratt Cr	24,862	3.76	17.43	65.69	6.01	34.36	36.36	18.40
116	Trib Pratt Cr	--	--	--	--	6.13	1.01	7.14	5.05
117	Casper Cr	8,196	4.26	50.33	42.22	5.50	.79	5.56	16.67
118	Scuppernong	252	3.27	9.71	94.51	6.20	36.97	31.82	1.82
119	Door Cr	1,115	4.74	35.42	43.28	4.52	53.88	28.57	19.40
120	Little Door Cr	279	2.86	19.67	73.77	5.66	7.14	31.25	1.95
121	Branch Mineral Point	4,924	4.12	69.95	40.45	4.57	13.38	27.59	61.20
122	Gill	1,909	4.47	51.45	40.51	4.10	13.08	57.14	38.46
123	Baker	855	4.54	28.79	47.86	5.85	27.67	31.82	32.08
124	Spring Brook	212	2.50	18.76	77.32	4.42	56.52	53.85	27.72
125	Ore	615	4.18	72.21	39.75	4.36	33.82	42.31	57.88
126	Bassett Cr	1,954	4.83	15.45	61.42	7.49	11.61	18.75	.65
127	West Branch Nippersink	559	4.55	49.51	40.36	4.87	49.68	29.63	2.55
128	White Cr	8,993	4.68	34.11	44.18	3.99	2.92	10.00	1.46
129	Pumpkinseed Cr	--	--	--	--	7.18	.00	.00	2.96
130	Spring Bk	3,613	4.61	52.81	39.36	5.71	.00	.00	4.14
131	Daggets Cr	--	--	--	--	7.81	4.14	7.14	.00
132	Van Dyne Cr	--	--	--	--	8.01	.00	.00	.00
133	Trib 1 West Branch Fond Du Lac	8,427	3.91	58.18	43.77	7.85	1.04	5.41	1.04
134	Mill Cr		3.97	30.46	51.21	4.28	21.29	40.00	17.42
135	Kankapot Cr	1,680	4.78	70.67	35.84	9.41	.74	12.50	.00
136	Molash	2,850	3.62	76.80	44.39	5.60	63.64	26.09	5.84
137	Grimms	--	4.20	26.07	52.16	7.99	.00	.00	.00
138	Pine Cr – Newton	--	--	--	--	5.81	48.67	37.50	16.67
139	Point Cr	--	--	--	--	5.22	22.11	10.81	47.52
140	Pigeon	1,125	4.65	24.92	49.94	5.24	48.61	20.00	28.70
141	Otter Cr – Plymouth	653	4.75	14.85	63.25	5.22	20.83	36.96	31.25
142	Weedens	5,128	4.51	61.84	38.59	4.98	19.87	13.79	26.94
143	Kettle Moraine	1,518	4.47	44.82	41.95	5.82	39.76	36.36	11.81
144	West Branch Milwaukee	13,871	3.99	19.19	60.92	7.63	.00	.00	.29
145	Parnell	311	4.66	50.94	39.34	4.12	57.59	58.33	27.85
146	East Branch Milwaukee	1,376	4.20	16.67	63.27	4.20	32.24	50.00	68.31
147	Crooked	2,051	2.54	6.49	100.00	4.34	84.81	27.78	12.03
148	Wallace	1,528	4.86	29.70	45.37	4.60	55.49	45.16	29.48
149	Hanneman	2,478	4.89	44.39	39.48	4.84	60.83	40.00	34.10
150	Mayfield Cr	3,377	3.51	32.27	54.73	5.46	7.65	33.33	7.65
151	Friedens	8,416	4.47	51.36	40.53	5.67	17.28	55.00	14.73

Percent shredders	Number of taxa	Fish index of biotic integrity	Percent carnivores	Percent insectivores	Percent omnivores	Percent intolerant species	Percent tolerant species	Number of fish	Number of fish species
0.00	12.00	35.00	0.00	95.00	5.00	0.00	6.11	91	4
.00	11.00	25.00	.00	93.87	6.13	.00	77.02	114	4
.00	28.00	40.00	.00	70.68	26.95	.00	68.11	84	9
.00	18.00	55.00	.00	88.52	7.25	.00	35.65	84	10
.00	22.00	50.00	20.75	64.15	11.32	16.98	56.60	50	10
.00	14.00	35.00	.00	65.84	28.30	.00	56.82	74	8
.00	16.00	40.00	.00	100.00	.00	.00	.00	36	1
.00	29.00	40.00	.00	43.20	1.45	.00	18.77	206	9
.00	14.00	27.00	.00	48.15	11.11	3.70	50.00	52	6
.00	22.00	30.00	.00	25.43	3.47	.00	59.54	162	10
.00	26.00	27.00	6.96	16.16	8.08	.28	72.98	249	18
.00	26.00	25.00	.09	14.89	11.89	.00	53.30	908	13
.00	16.00	25.00	.00	36.45	36.61	.00	87.82	213	9
1.91	27.00	40.00	2.22	48.56	29.93	.22	42.35	258	22
.00	10.00	70.00	46.51	51.16	.00	48.84	2.33	30	4
8.37	16.00	45.00	.00	77.16	11.06	10.42	61.54	104	11
2.76	18.00	55.00	.00	90.47	6.86	.00	26.11	131	13
5.33	14.00	10.00	.00	73.03	20.22	.00	49.44	30	6
.00	4.00	.00	41.67	50.00	8.33	.00	50.00	12	5
11.40	37.00	37.00	.00	73.06	1.46	.00	50.36	206	8
.00	15.00	.00	.00	30.41	6.08	.00	69.59	50	6
.00	8.00	.00	.00	44.64	18.75	.00	63.39	38	5
.00	23.00	25.00	.00	96.91	3.00	.00	94.29	733	6
.38	9.00	25.00	1.92	78.85	9.62	.00	92.31	50	6
.00	16.00	25.00	.00	75.63	14.21	.00	52.28	177	8
.00	37.00	40.00	.29	51.70	5.92	3.30	22.21	711	14
.00	30.00	30.00	1.47	52.11	17.77	.00	46.42	865	11
.42	46.00	32.00	1.14	42.24	22.37	1.14	51.83	395	16
.00	29.00	35.00	1.40	20.30	14.59	.00	80.28	626	17
.00	22.00	35.00	.41	69.67	16.60	.00	83.61	271	14
3.79	17.00	17.00	.00	76.88	19.17	1.98	69.96	469	7
.00	24.00	40.00	.00	39.54	2.29	.00	36.60	222	12
.00	26.00	45.00	1.27	66.76	24.73	1.27	32.06	354	17
.00	18.00	35.00	1.67	55.00	.00	.00	45.00	43	10
.00	31.00	35.00	1.67	43.75	13.33	5.42	56.67	170	14
.00	25.00	30.00	.00	37.27	18.03	2.27	64.09	475	13
.00	9.00	35.00	.00	77.55	15.65	.00	86.39	140	9
.00	20.00	30.00	.00	42.42	13.13	.00	61.62	71	10

Appendix 4. Biological data for each of the 240 studied wadeable streams in Wisconsin—Continued. All data collected by the Wisconsin Department of Natural Resources.

[Cr, Creek; Trib, Tributary; Br, Brook; ID, identification number EPT, Ephemeroptera, Plecoptera, or Trichoptera; mg/m^2, milligram per square meter; --, no data collected at site]

ID (see fig. 4)	Stream name	Benthic chlorophyll *a* (mg/m^2)	Diatom Nutrient Index	Diatom Siltation Index	Diatom Biotic Index	Hilsenhoff Biotic Index	Percent EPT number	Percent EPT taxa	Percent scrapers
152	Pigeon Cr – Theinsville	800	4.53	46.71	41.10	4.23	48.78	38.46	24.39
153	Willow Cr – Germantown	1,303	4.54	17.78	58.93	5.99	6.90	11.76	6.21
154	Little Menomonee	1,305	4.62	59.87	38.14	4.49	25.81	35.71	40.65
155	Husher	912	4.15	61.37	41.22	5.79	15.38	9.52	10.77
156	North Branch Pike	3,424	3.66	59.48	45.88	6.30	.00	.00	1.19
157	Willow Cr – Waupun	550	4.39	28.13	49.36	7.01	4.71	7.69	.52
158	Flynn	221	4.61	27.84	48.01	4.16	79.20	50.00	28.76
201	Galena	12,363	3.79	63.67	44.08	4.58	83.13	33.33	11.08
202	Skinner Cr – Klondyke	23,008	4.67	83.67	35.37	5.64	70.00	43.75	52.14
203	East Branch Pecatonica	2,162	4.68	67.67	36.72	4.27	46.28	40.00	9.57
204	Little Sugar	30,670	4.51	60.33	38.77	4.75	70.06	40.91	18.64
205	West Branch Sugar – #1	4,137	4.56	52.67	39.70	4.71	84.66	60.71	23.93
206	Platte – Rockville	3,114	4.21	72.67	39.51	4.67	36.76	32.56	18.38
207	Pigeon	9,212	4.55	70.00	37.32	5.14	73.06	46.15	16.06
208	Rattlesnake	1,369	4.01	74.33	40.91	6.41	3.87	4.55	2.21
209	Blake	6,691	4.26	76.67	38.77	5.49	10.65	23.33	2.37
210	Fennimore	6,408	4.11	81.00	39.56	5.41	44.53	33.33	4.86
211	Black Earth 1	3,942	4.51	34.33	45.21	5.02	48.89	40.00	25.93
212	Kickapoo	12,823	3.63	34.00	52.73	4.67	62.58	47.22	11.04
213	Moore	4,259	3.87	54.00	44.76	4.60	36.69	37.50	44.60
214	Coon Cr	40,143	3.88	35.33	49.71	4.08	76.42	51.61	24.12
215	Little La Crosse – Sparta	--	4.40	54.00	40.55	4.32	30.14	47.37	11.42
216	Lacrosse	5,539	3.98	41.00	46.83	5.27	68.42	45.45	23.44
217	Eau Galle 2	5,996	3.86	32.33	51.27	3.71	62.79	35.71	20.93
218	Willow	2,517	4.42	24.00	52.24	--	--	--	--
219	Wood	84	2.46	18.33	52.07	--	--	--	--
220	Yellow – Barron	457	3.69	40.00	32.66	--	--	--	--
221	Hay River	903	4.15	42.00	29.30	--	--	--	--
222	North Fork Eau Claire	1,303	3.71	66.00	30.66	--	--	--	--
223	Big Eau Pleine	2,856	4.74	95.33	23.75	--	--	--	--
224	Black	722	4.16	83.33	27.10	--	--	--	--
225	Yellow – Babcock	902	4.12	55.00	28.48	5.42	29.33	20.00	2.00
226	Little Yellow	752	2.72	45.33	42.17	8.43	1.49	8.70	.00
227	South Branch Yellow	4,043	2.68	34.67	43.97	6.91	15.45	17.65	2.08
228	Ten Mile Cr	5,562	3.77	34.67	32.80	2.20	63.22	41.38	14.94
229	Little Plover	1,711	2.58	25.67	47.24	3.39	28.68	17.65	.78
230	Tomorrow	1,853	3.07	4.67	73.24	2.74	54.93	51.52	19.01
231	Pensaukee – Krakow	1,621	4.80	39.33	26.23	6.63	78.62	23.08	22.64

Percent shredders	Number of taxa	Fish index of biotic integrity	Percent carnivores	Percent insectivores	Percent omnivores	Percent intolerant species	Percent tolerant species	Number of fish	Number of fish species
0.00	13.00	40.00	9.78	56.00	8.44	0.00	48.44	221	12
1.38	17.00	35.00	.76	51.52	30.30	.00	65.91	132	11
.65	14.00	37.00	.00	85.87	9.78	.00	20.65	60	7
.00	21.00	20.00	.00	65.26	27.37	.00	82.11	68	9
.00	15.00	20.00	2.66	23.32	66.62	.00	87.03	248	15
1.05	39.00	30.00	.00	49.14	23.80	.00	54.33	396	14
.00	26.00	15.00	2.36	23.62	5.51	.00	74.02	98	6
.24	24.00	25.00	11.97	41.88	43.59	24.79	46.15	15	12
.00	16.00	10.00	1.85	14.81	51.85	3.70	72.22	23	12
4.79	25.00	32.00	5.58	28.43	46.19	1.52	50.25	34	24
.00	22.00	38.00	13.87	66.47	19.65	65.90	20.23	77	4
.00	28.00	20.00	2.44	15.85	81.10	12.80	81.71	83	11
.00	43.00	47.00	1.19	68.77	7.11	6.52	7.31	89	17
.00	26.00	30.00	2.08	58.31	28.00	3.67	28.36	359	14
.00	44.00	30.00	2.11	64.43	25.51	2.81	26.13	298	15
.59	30.00	20.00	1.54	37.43	52.99	1.60	53.87	598	13
.81	36.00	20.00	.30	6.53	64.09	3.26	80.42	183	11
.00	30.00	40.00	24.20	10.50	65.30	7.31	66.21	50	8
1.23	36.00	35.00	5.22	26.10	25.70	2.81	65.06	39	24
.00	32.00	40.00	.98	33.66	21.38	2.21	62.90	174	20
.00	31.00	50.00	67.31	7.31	25.38	8.46	26.92	54	7
.46	19.00	30.00	65.04	4.88	22.76	.00	30.08	38	5
.00	33.00	52.00	14.00	56.00	6.00	30.00	6.00	9	12
.00	42.00	47.00	.00	77.78	15.07	57.21	19.47	371	13
--	--	67.00	6.73	75.78	16.59	16.59	16.59	27	15
--	--	50.00	5.08	83.62	7.91	11.30	11.30	45	18
--	--	70.00	1.92	49.27	6.34	14.40	7.73	189	33
--	--	60.00	2.27	47.73	2.27	43.18	20.45	7	14
--	--	70.00	.67	66.64	12.16	12.99	16.19	406	23
--	--	74.00	6.10	68.92	.32	15.02	.80	156	21
--	--	70.00	32.94	55.29	11.76	51.76	11.76	11	11
2.00	30.00	30.00	.00	82.89	10.53	2.63	13.16	18	15
.00	23.00	20.00	5.32	54.26	39.36	5.32	53.19	35	13
9.55	51.00	45.00	1.55	95.36	1.55	1.86	10.84	100	13
.00	29.00	50.00	18.07	46.99	34.94	34.94	36.14	24	9
.00	17.00	70.00	50.42	32.77	16.81	76.47	18.49	49	5
.00	33.00	70.00	59.06	26.17	13.42	46.31	13.42	48	6
.00	13.00	40.00	.00	66.36	9.81	.00	47.20	74	14

Appendix 4. Biological data for each of the 240 studied wadeable streams in Wisconsin—Continued. All data collected by the Wisconsin Department of Natural Resources.

[Cr, Creek; Trib, Tributary; Br, Brook; ID, identification number EPT, Ephemeroptera, Plecoptera, or Trichoptera; mg/m^2, milligram per square meter; --, no data collected at site]

ID (see fig. 4)	Stream name	Benthic chlorophyll *a* (mg/m^2)	Diatom Nutrient Index	Diatom Siltation Index	Diatom Biotic Index	Hilsenhoff Biotic Index	Percent EPT number	Percent EPT taxa	Percent scrapers
232	Pensaukee – Pensaukee	2,768	4.12	25.37	32.41	4.44	51.01	54.84	64.93
233	Middle Branch Embarrass	1,015	4.36	11.33	40.05	3.70	39.71	41.18	.74
234	Eau Claire – Kelly	2,661	4.28	3.67	74.18	3.08	25.00	31.82	69.74
235	Eau Claire – Antigo	2,997	3.33	28.33	37.61	4.11	78.74	52.17	6.90
236	Spring Brook 2	4,389	3.55	27.33	35.93	4.00	.49	20.00	.00
237	Prairie	1,010	3.71	16.67	38.95	2.58	34.08	50.00	56.95
238	Skinner	139	2.75	44.00	41.77	4.10	42.33	28.57	.00
239	Spirit	447	4.53	9.67	41.94	4.16	84.72	51.52	4.63
240	North Fork Copper	531	4.41	8.33	45.63	3.58	59.02	31.82	23.77
241	Hunting	1,230	3.67	12.00	43.59	3.15	73.95	50.98	43.14
242	Wolf River	705	2.62	9.33	59.30	2.81	69.68	60.53	25.81
243	North Branch Pike	650	2.29	4.67	84.79	2.58	44.19	54.00	30.23
244	Popple	156	2.66	11.67	54.78	2.55	78.42	60.47	29.50
245	Woods	536	4.40	27.33	30.27	1.86	74.60	59.70	26.70
246	Pine	1,280	1.89	3.00	100.00	4.00	99.17	42.86	.00
247	Brule	627	2.40	7.00	69.50	3.62	47.10	38.00	23.87
248	Kaubashine	1,074	3.86	11.67	42.62	7.92	8.59	19.23	4.91
249	Namekagon	137	2.51	3.67	91.15	2.82	51.35	60.47	41.62
250	Totagatic	281	4.63	94.67	24.29	--	--	--	--
251	Eau Claire	982	4.18	5.00	61.71	4.05	58.05	52.27	11.49
252	Upper Ox	620	4.05	15.33	37.61	4.72	42.93	33.33	14.13
253	North Fish Cr	694	4.69	53.30	25.54	1.64	77.12	61.54	32.68
254	Bois Brule	20	3.94	23.00	34.28	2.24	78.16	62.50	14.37
255	Amnicon	--	4.72	22.00	30.31	6.44	23.45	18.42	3.54
256	Upper Tamarack	391	4.63	6.33	51.51	3.90	88.46	36.36	1.65
257	Turtle Cr 2	1,628	4.63	44.00	41.15	4.75	53.72	36.96	23.62
258	Whitewater Cr	11,991	4.01	20.67	58.83	5.88	2.58	11.76	5.73
259	Token Cr	625	4.41	30.33	47.86	6.16	7.05	10.53	1.28
260	Yahara	15,612	3.99	21.67	57.86	5.47	25.87	25.00	13.93
261	Oconomowoc	5,280	4.47	29.33	48.03	5.45	24.35	28.13	43.04
262	Milwaukee	1,936	4.82	37.33	42.06	4.76	76.63	37.93	.54
263	Cedar Cr	17,460	4.89	39.67	40.85	5.78	28.25	36.59	27.14
264	Sauk	1,873	4.90	85.00	33.90	7.04	4.07	10.00	.00
265	Stoney	2,082	4.60	34.67	44.49	3.97	58.85	52.17	66.51
266	North Branch Milwaukee	2,132	4.69	38.67	42.35	6.62	4.59	13.33	2.14
267	West Branch Rock	20,485	4.55	52.00	39.88	5.26	80.05	36.36	13.21
268	Onion	2,458	4.91	34.33	42.74	5.15	76.69	34.48	4.21
269	South Branch Sheboygan	6,796	4.61	46.67	40.58	7.40	23.02	22.22	24.40

Percent shredders	Number of taxa	Fish index of biotic integrity	Percent carnivores	Percent insectivores	Percent omnivores	Percent intolerant species	Percent tolerant species	Number of fish	Number of fish species
0.00	31.00	60.00	25.30	48.19	16.87	34.94	16.87	14	14
.00	17.00	55.00	.16	62.30	16.88	1.85	30.87	179	22
.00	22.00	75.00	4.94	86.29	.90	50.79	1.80	67	22
.00	23.00	45.00	1.84	50.41	7.55	3.06	48.16	84	15
.00	5.00	100.00	73.46	25.31	.00	96.60	3.09	154	5
.00	32.00	55.00	34.60	33.68	24.64	54.91	29.10	130	19
24.72	21.00	55.00	.08	66.05	9.80	12.25	32.69	365	20
2.31	33.00	55.00	5.93	71.51	14.24	2.97	25.52	48	17
.00	44.00	40.00	9.16	46.56	27.48	15.27	52.67	55	14
.00	51.00	70.00	9.36	63.69	9.22	12.82	26.96	501	18
.00	38.00	44.00	4.92	84.43	1.64	13.93	11.48	15	13
.58	50.00	50.00	16.30	43.17	6.61	47.14	40.53	59	9
.72	43.00	40.00	.36	77.86	11.79	.36	21.43	35	15
.00	67.00	40.00	5.03	29.54	20.57	10.28	64.77	224	16
.17	7.00	57.00	14.88	82.14	.00	30.95	2.98	21	10
3.87	50.00	52.00	12.27	38.99	10.47	22.74	49.82	35	17
.61	26.00	40.00	.48	24.16	3.68	.80	71.68	287	13
.54	43.00	75.00	12.14	78.60	2.00	15.39	5.63	100	18
--	--	62.00	5.71	59.93	23.57	20.35	29.53	164	23
.00	44.00	65.00	1.05	81.18	5.26	5.79	13.29	132	17
.54	54.00	40.00	10.26	41.03	11.54	26.50	46.58	80	11
.00	26.00	70.00	74.54	21.47	3.68	21.47	3.68	54	6
.00	40.00	70.00	66.22	19.06	4.68	13.71	14.38	39	15
21.24	38.00	30.00	2.26	65.66	26.79	1.89	59.62	105	13
2.20	22.00	57.00	7.41	74.07	3.13	5.98	23.65	70	18
.97	46.00	52.00	1.78	74.56	9.76	5.03	10.06	42	21
.00	34.00	45.00	.16	87.73	11.70	13.10	12.85	276	12
.64	38.00	20.00	6.45	58.06	35.48	54.84	38.71	15	4
.00	36.00	30.00	6.81	46.81	38.72	14.47	53.19	86	18
.43	32.00	54.00	17.36	60.88	19.32	16.63	25.92	147	21
.00	29.00	69.00	13.51	70.72	10.81	15.77	10.81	28	20
.37	41.00	47.00	13.10	75.95	10.95	12.44	25.79	173	17
3.52	40.00	.00	.00	33.33	4.17	.00	68.75	44	7
.00	23.00	57.00	.67	34.83	19.33	.45	64.94	247	19
.61	45.00	62.00	2.43	80.10	15.05	2.43	19.42	41	21
.54	22.00	.00	.00	27.66	72.34	.00	82.98	13	6
.28	29.00	52.00	7.37	68.84	23.80	7.08	23.80	65	15
1.37	36.00	22.00	1.81	30.02	30.10	.00	65.54	620	15

Appendix 4. Biological data for each of the 240 studied wadeable streams in Wisconsin—Continued. All data collected by the Wisconsin Department of Natural Resources.

[Cr, Creek; Trib, Tributary; Br, Brook; ID, identification number EPT, Ephemeroptera, Plecoptera, or Trichoptera; mg/m^2, milligram per square meter; --, no data collected at site]

ID (see fig. 4)	Stream name	Benthic chlorophyll *a* (mg/m^2)	Diatom Nutrient Index	Diatom Siltation Index	Diatom Biotic Index	Hilsenhoff Biotic Index	Percent EPT number	Percent EPT taxa	Percent scrapers
270	Meeme	5,249	4.58	41.67	42.11	7.23	5.91	11.43	0.39
271	Silver Cr	13,180	4.72	52.00	38.80	7.70	5.15	22.22	.74
272	South Branch Manitowoc	6,716	4.77	51.33	38.64	8.40	18.64	15.63	.45
273	Manitowoc	18,736	4.76	59.33	37.35	5.06	42.78	44.74	8.33
274	East Twin	16,379	4.52	63.33	38.29	5.23	39.80	29.41	27.55
275	Neshota	2,077	4.88	15.33	61.42	4.90	25.00	9.52	8.93
276	Kewaunee	4,428	4.67	47.67	39.97	4.72	83.44	45.83	24.50
277	East	8,536	4.29	70.67	39.06	7.85	7.85	17.65	3.66
278	Duck Cr	7,653	4.74	66.67	36.51	4.89	73.04	47.83	16.67
301	Vismal Cr	4,333	2.29	6.33	74.40	--	--	--	--
302	Levis Cr	75,030	2.87	3.00	97.60	--	--	--	--
303	Ditch #6 South Branch Ten Mile Cr	337,121	4.56	42.67	27.03	--	--	--	--
304	South Branch Suamico	1,068,000	3.93	40.30	30.89	--	--	--	--
305	West Branch Red	239,188	2.85	12.00	51.66	--	--	--	--

Percent shredders	Number of taxa	Fish index of biotic integrity	Percent carnivores	Percent insectivores	Percent omnivores	Percent intolerant species	Percent tolerant species	Number of fish	Number of fish species
0.00	35.00	50.00	0.67	62.97	26.01	0.47	37.43	2147	15
7.35	27.00	32.00	1.70	58.52	28.98	.00	39.77	152	11
7.05	32.00	20.00	4.55	23.94	70.91	4.85	74.24	47	22
.83	38.00	69.00	20.51	59.68	12.67	22.58	12.90	54	23
.00	34.00	77.00	7.74	81.98	7.36	11.29	14.59	171	25
.00	21.00	55.00	.61	37.40	14.42	5.53	40.30	663	19
.00	24.00	69.00	7.53	66.97	18.99	20.00	19.55	179	23
.52	34.00	.00	4.55	59.09	31.82	.00	40.91	8	10
.00	23.00	55.00	3.96	69.23	3.30	3.41	28.68	171	14
--	33.00	--	--	--	--	--	--	--	--
--	29.00	--	--	--	--	--	--	--	--
--	50.00	--	--	--	--	--	--	--	--
--	32.00	--	--	--	--	--	--	--	--
--	36.00	--	--	--	--	--	--	--	--

Robertson, D.M., Graczyk, D.J., Garrison, P.J., Wang, L., LaLiberte, G., and Bannerman, R.—
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