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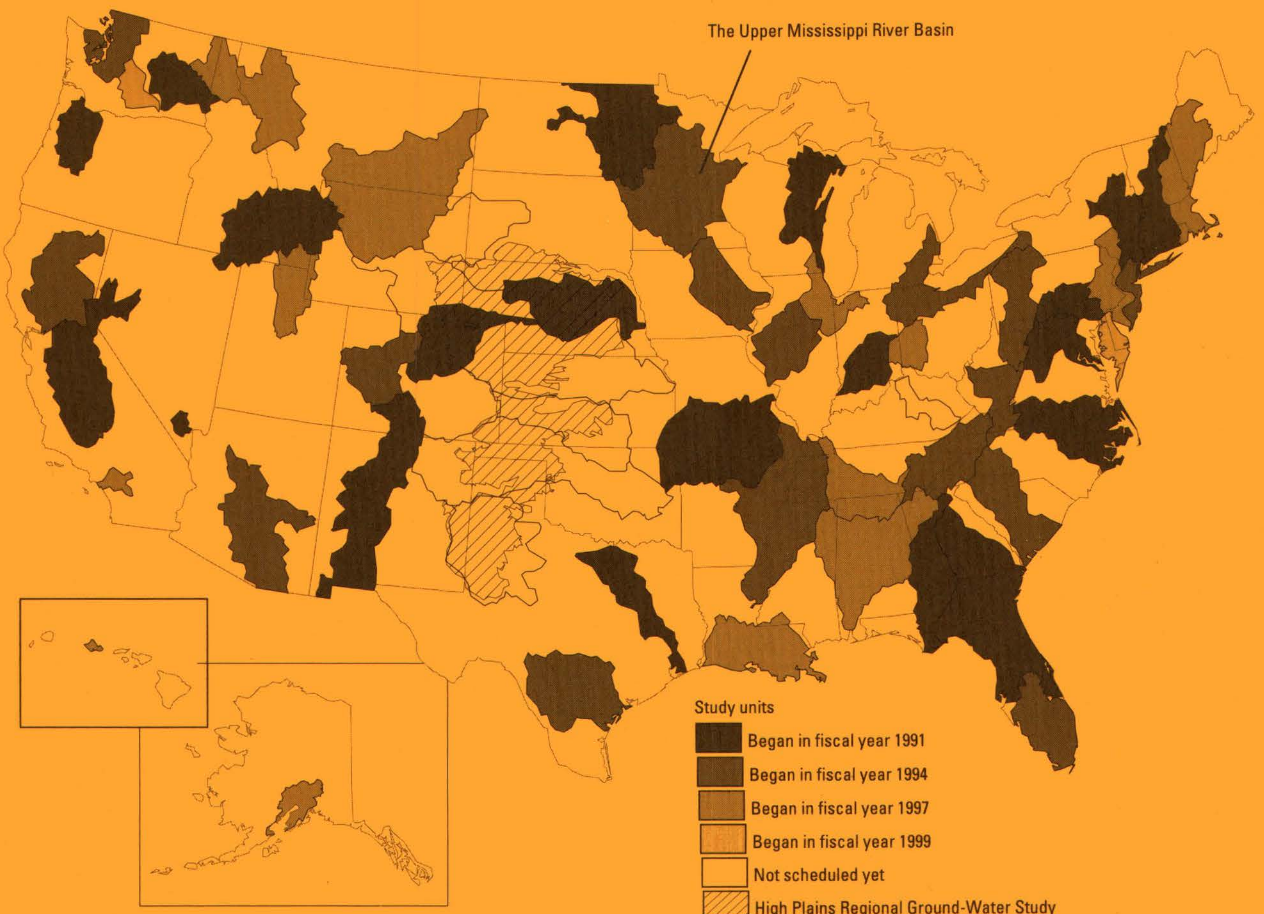
Relation of Periphyton and Benthic Invertebrate Communities to Environmental Factors and Land Use at Selected Sites in Part of the Upper Mississippi River Basin, 1996-98

Water-Resources Investigations Report 03–4121



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Relation of Periphyton and Benthic Invertebrate Communities to Environmental Factors and Land Use at Selected Sites in Part of the Upper Mississippi River Basin, 1996-98

By Jeremy R. ZumBerge[1], Kathy E. Lee[2], and Robert M. Goldstein[2]

Water-Resources Investigations Report 03-4121

National Water-Quality Assessment Program

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Forward

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

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

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

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

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

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 42 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 42 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

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

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

Robert M. Hirsch
Chief Hydrologist

Contents

Page

Abstract.. 1

Introduction 2

Purpose and scope... 3

Environmental setting.. 3

Methods 4

Site selection and characterization... 4

Biological community sampling... 7

Biological community characterization and analysis 8

Comparison among small stream sites 8

Basin characteristics 8

Segment characteristics 8

Reach characteristics 9

Water chemistry... 9

Periphyton communities 10

Benthic-invertebrate communities... 12

Comparison among large river sites 14

Periphyton communities 15

Benthic-invertebrate communities... 15

Relation of benthic invertebrate and periphyton communities to environmental and land use factors 17

Summary.. 19

References 19

Appendix 22

Illustrations

Figures 1-2. Maps showing:

1. Location of the Upper Mississippi River Basin study unit, hydrology, selected towns and cities, and sampling sites 2

2. Population change from 1970 to 1990, by county, in the Upper Mississippi River Basin study unit 3

Figure 3. Boxplots showing generalized water quality at selected sites in the Upper Mississippi River Basin Study unit, 1977-94 5

Figure 4. Map showing land use, land cover, and small stream and large river sites in the Upper Mississippi River Basin study unit ... 6

Figures 5-12. Graphs showing:.

5. Stream stages for small stream indicator sites of the Upper Mississippi River Basin study unit during June-August 1997 9

6. Periphyton density in the small stream indicator sites of the Upper Mississippi River Basin study unit during 1996......... 12

7. Periphyton biovolume in the small stream indicator sites of the Upper Mississippi River Basin study unit during 1996 ... 12

8. Benthic-invertebrate taxa richness in the small stream indicator sites of the Upper Mississippi River Basin study unit during 1996 13

9. Ephemeroptera, Plecoptera, and Trichoptera taxa richness and Diptera and non-insect taxa richness in the small stream indicator sites of the Upper Mississippi River Basin study unit during 1996 13

Figures 5-12. Graphs showing--Continued:

10. Periphyton density in the large river integrator sites of the Upper Mississippi River Basin study unit during 1996 17

11. Periphyton biovolume in the large river integrator sites of the Upper Mississippi River Basin study unit during 1996 17

12. Benthic-invertebrate taxa richness and diversity in the large river integrator sites of the Upper Mississippi River Basin study unit during 1996 18

Tables

1. Stratification of Upper Mississippi River Basin study unit small-stream indicator sites according to land use, glacial deposit composition, and surficial geology 7

2. General characteristics of small streams studied in the Upper Mississippi River Basin study unit 8

3. Reach level physical habitat of selected small streams in different land use settings in the Upper Mississippi River Basin study unit 10

4. Seasonal median physical and mean chemical parameters of selected small streams in the Upper Mississippi River Basin study unit, 1996-98 11

5. General characteristics of the large river integrator sites in the Upper Mississippi River Basin study unit 14

6. Reach level physical characteristics of large river integrator sites in the Upper Mississippi River Basin study unit 15

7. Seasonal median physical and mean chemical parameters of large river integrator sites in the Upper Mississippi River Basin study unit, 1996-98 16

Appendix A. Periphyton taxa densities for Upper Mississippi River Basin study unit small stream indicator sites, 1996 23

Appendix B. Benthic-invertebrate taxa abundances for Upper Mississippi River Basin study unit small stream indicator sites, 1996 27

Appendix C. Periphyton taxa densities for Upper Mississippi River Basin study unit large river integrator sites, 1996 31

Appendix D. Benthic-invertebrate taxa abundances for Upper Mississippi River Basin study unit large river integrator sites, 1996 36

Conversion Factors, Datums, and Abbreviated Water-Quality Units

Multiply	By	To obtain
micrometer (µm)	0.000003937	inch
centimeter (cm)	0.3937	inch
meter (m)	3.281	foot
square centimeter (cm^2)	0.1550	square inches
square kilometer (km^2)	0.3861	square mile
cubic centimeter (cm^3)	0.06102	cubic inches
cubic meter per second (m^3/s)	35.31	cubic foot per second
degrees Celsius (°C)	(temp°F–32)/1.8	degrees Fahrenheit

Chemical concentrations of substances in water are given in metric units of milligrams per liter (mg/L) and micrograms per liter (µg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as mass (milligrams) of solute per unit volume (liter) of water. One milligram per liter is equivalent to one thousand micrograms per liter.

Sea level: Vertical cordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD of 1929). Horizontal coordinate information is referenced to the NGVD of 1929.

Relation of Periphyton and Benthic Invertebrate Communities to Environmental Factors and Land Use at Selected Sites in Part of the Upper Mississippi River Basin, 1996–98

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ABSTRACT

The Upper Mississippi River Basin is one of the hydrologic systems selected for study by the National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey. NAWQA utilizes a multi-disciplinary approach to explain factors that affect water quality. Part of the NAWQA design addresses the relation of land use and environmental factors to periphyton and benthic invertebrate communities in streams.

This report focuses on a 122,000 square kilometer area of the Mississippi River Basin, including the Twin Cities metropolitan area (TCMA). The northeastern part of the study area is forested, the southwestern part is agricultural, and the central part is transitional between forest and agriculture. Sampling sites were selected based on a process that identified small streams in predominantly forested, agricultural, and urban settings, and large river sites on the Mississippi River and major tributaries. Periphyton and benthic invertebrate communities were evaluated at each site. Compared to the forested site, periphyton density and biovolume in small streams generally increased as nutrient concentrations associated with urban and agricultural land use increased. Periphyton communities varied within agricultural and urban streams, indicating that physical and chemical factors other than land use also affect periphyton communities.

Benthic invertebrate communities also are affected by land use and associated stream habitat. There were few intolerant taxa (Ephemeroptera and Plecoptera) in urban streams, potentially due to high streamflow variability and contaminants from runoff. Ephemeroptera taxa richness was greatest in the agricultural streams. The most abundant Ephemeroptera taxa were those tolerant to high concentrations of suspended sediment. Richness of Plecoptera and Trichoptera taxa were greatest in the forested stream.

Biological communities in the St. Croix and Minnesota River generally reflected relatively homogeneous land uses. Biological communities in the Mississippi River reflected changes in water quality and physical habitat as the Minnesota and St. Croix Rivers join the Mississippi River. Periphyton density and biovolume, and the relative abundance of blue-green algae density increased in the Mississippi River at the confluence compared to the Minnesota and St. Croix Rivers. Relative abundance of benthic invertebrate taxa richness and diversity generally decreased downstream in the large rivers as urban and agricultural land use become more prevalent. Impoundments and dredging of the Mississippi River in and downstream from the TCMA exacerbate effects of increasing river size to produce a more lake-like system.

INTRODUCTION

The U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program was initiated to define the current status and trends in the quality of the nation's surface- and ground-water resources. Because the geographic distribution of these resources are so vast, the major activities of NAWQA occur within 42 hydrologic systems across the country accounting for about 70 percent of the nation's water use and population served by public water supply. The implementation plan (Leahy and others, 1990) specified that one-third of the study units were to be operational during each of three cycles. Each cycle includes 3 years of intensive study followed by 6 years of low-intensity monitoring. Intensive studies are initiated at 3-year intervals. In 1994, the USGS implemented the Upper Mississippi River Basin (UMIS) study unit (fig. 1).

The influence of land use on water quality is an integral part of the NAWQA study design. Changes in land use may contribute to degradation of water quality (Omernik, 1976; Fuhrer and others, 1999). Changes in natural land cover to agricultural and urban areas are factors that have affected water quality in the UMIS and across the country. The UMIS was selected as a study unit because it represents an important hydrologic region where water quality can have a direct affect on water resources of the entire Mississippi River, and because the study unit represents major agricultural and urban areas.

NAWQA uses a multidisciplinary approach to assess water quality. Evaluation of aquatic biological communities is one of the multiple lines of evidence used to assess water quality

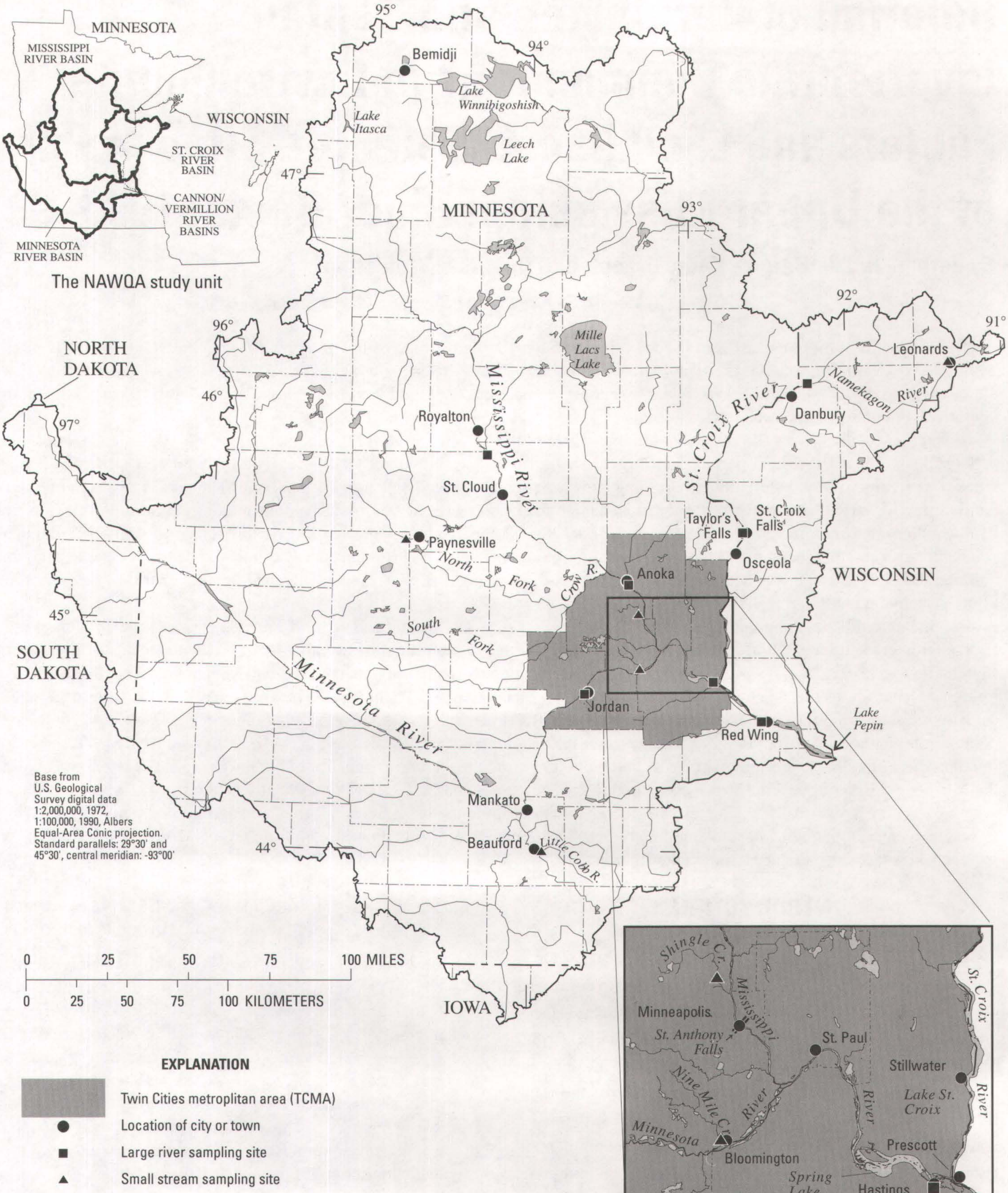

Figure 1. Location of the Upper Mississippi River Basin study unit, hydrology, selected towns and cities, and sampling sites.

(Gurtz, 1994). Aquatic biological communities provide measures of water quality because they are sensitive to changes in environmental conditions occurring at different spatial and temporal scales (Cuffney and others, 1993; Meador and others, 1993a). Periphyton integrate physical and chemical characteristics over shorter time periods (hours to days). Benthic invertebrate communities integrate physical and chemical characteristics of streams over periods of months to years. The composition of these communities (taxonomic richness and pollution tolerance measures) is useful for water-quality assessment because it has expected responses to variations in water-quality conditions at a site or between sites (Barbour and others, 1997).

PURPOSE AND SCOPE

The purposes of this report are to (1) characterize periphyton and benthic invertebrate communities at selected sites in the UMIS, and (2) relate periphyton and benthic invertebrate community composition to land use and associated physical and chemical factors, including hydrology, habitat, and water quality. Results of other UMIS studies are referenced to supplement data collected in 1996–98 provided in this report. Together these studies are part of the multiple lines of evidence used to assess aquatic-resource quality in part of the UMIS.

ENVIRONMENTAL SETTING

The UMIS study unit (hereinafter referred to as study unit) includes the 122,000 square kilometer (km^2) drainage basin of the Mississippi River upstream from Lake Pepin (fig.1). The population of the study unit was about 3.7 million in 1990 (based on data from U.S. Bureau of Census, 1991), of which approximately 75 percent live in the Twin Cities metropolitan area (TCMA). Between 1970 and 1990, the population of the TCMA increased about 20 percent (Stark and others, 1996). While the populations of the Mississippi and St. Croix River Basins have increased, the population in the rural Minnesota River Basin has decreased (fig. 2).

The topography in the study unit is generally rolling and altitudes range from a high of 640 m above NGVD of 1929 to about 200 m above NGVD of 1929 at Lake Pepin. Generally, river gradients are greater upstream from the TCMA than downstream. Minneapolis and St. Paul are the northern most deep-water ports on the Mississippi River. A series of locks and dams have been constructed on the main stem of the Mississippi River in and downstream from the TCMA for commercial navigation. Periodically, the channel is dredged to maintain depth for shipping. The environmental setting of the UMIS is

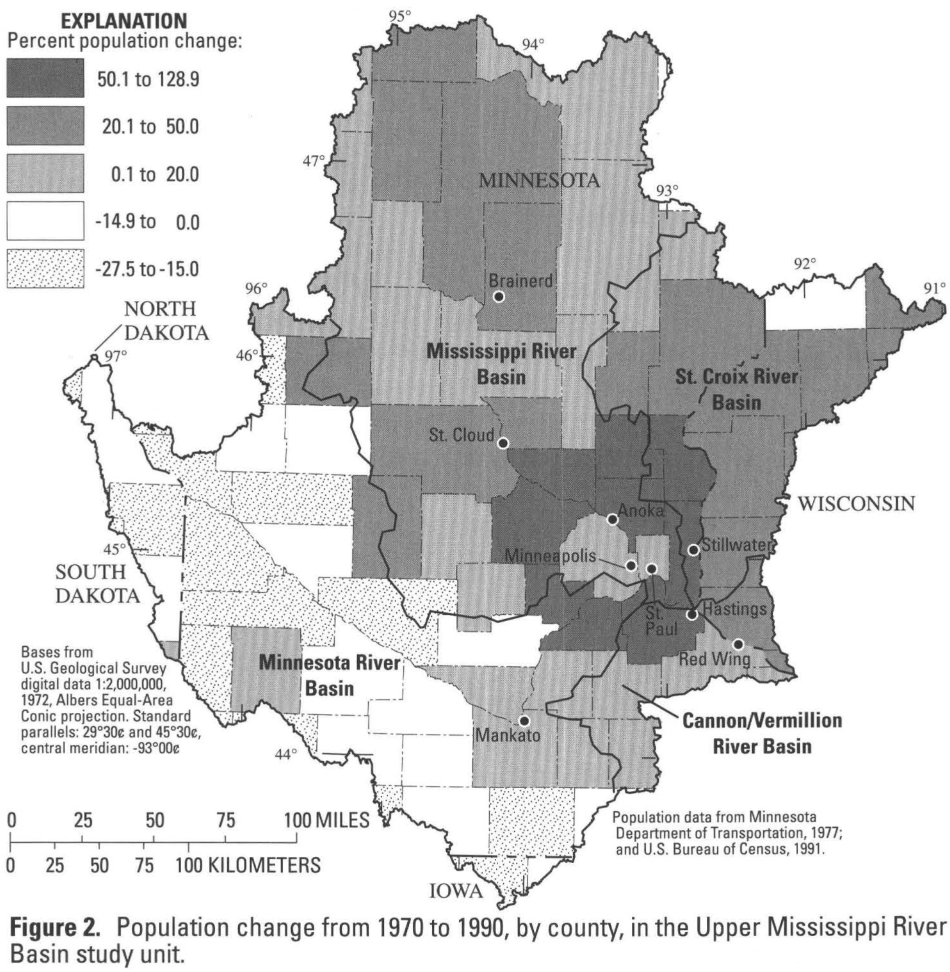

Figure 2. Population change from 1970 to 1990, by county, in the Upper Mississippi River Basin study unit.

described in detail by Stark and others (1996).

Most of the study unit is contained in two physiographic provinces (Fenneman and Johnson, 1946). The Superior Upland physiographic province includes much of the eastern portion of the basin. This province is characterized by flat to hilly moraines and outwash plains. The western and central portion is characterized by the flat lying to rolling ground moraines and outwash plains of the Central Lowland Province. The area from the TCMA to Lake Pepin is bisected by the hilly terrain of the Wisconsin Driftless Section of the Central Lowlands to the north and the Dissected Till Plains Section to the south (Stark and others, 1996).

The geologic characteristics of the study unit are due to the composition of the underlying rock and glaciation. The western portion of the study unit is underlain by a combination of Precambrian-age crystalline and Cretaceous-age rocks; whereas the eastern portion is underlain by mostly Precambrian-age and Paleozoic-age sedimentary rock (Sims and Morey, 1972). The glacial period of the study unit ended about 10,000 years ago when the remaining lobes of the Wisconsin-aged glaciers retreated (Wright, 1972). The Des Moines Lobe, which covered the central and western portion of the study unit, left calcareous deposits, and the Superior Lobe, which covered the northeastern portion of the study unit, left silicious deposits (Hobbs and Goebel, 1982; Olcott, 1992). These glacial deposits were either unstratified or stratified (Woodward, 1986). The unstratified deposits are primarily of till (unsorted clay, silt, sand, and gravel), and the stratified deposits are mostly outwash (water-deposited sand and gravel).

The Mississippi, Minnesota, and St. Croix Rivers form the dominant drainage features of the study unit. The Minnesota River flows into the Mississippi River just upstream from St. Paul, Minnesota (fig. 1). The St. Croix River flows from the north to join the Mississippi River at Prescott, Wisconsin. The Minnesota River at Jordan, Minnesota, has a mean annual flow of approximately 120 m^3/s, and the St. Croix River at St. Croix Falls, Wisconsin, has a mean annual flow of about 123 m^3/s (Mitton and others, 1997). The flow from these two tributaries almost doubles the flow of the Mississippi River. Downstream from the confluences with these two rivers, the Mississippi River has a mean annual flow at Prescott, Wisconsin of 507 m^3/s (Mitton and others, 1997). Lakes, ponds, and wetlands are abundant throughout the UMIS, although most of the wetlands in the Minnesota River Basin have been drained to increase agricultural production (Leach and Magner, 1992).

Surficial geology can greatly affect surface-water quality (Stark and others, 1996). Water-quality characteristics such as alkalinity, specific conductance, and concentrations of dissolved solids, nutrients, and suspended sediment generally follow a consistent pattern in the main tributaries to the Mississippi River (fig. 3). Water-quality measures of the Minnesota River (alkalinity, dissolved solids, and suspended sediment) have greater concentrations than the other rivers partly because the basin is developed on calcareous glacial till. Concentrations of general water-quality measures are lowest in the St. Croix River, which flows through silicious outwash deposits, and intermediate in the Mississippi River, below the confluence with its two main tributaries. Concentrations of these chemical constituents generally increase in a downstream direction (Stark and others, 1996).

METHODS

The study unit was stratified (subdivided) into areas with relatively homogeneous natural and anthropogenic features. The stratification reflects various land uses, glacial deposit compositions, and surficial geology. Further information on the stratification process can be found in Stark and others (1996).

SITE SELECTION AND CHARACTERIZATION

Sites were selected on small streams and large rivers (fig. 1). The small streams were selected to reflect unique combinations of land use (fig. 4), glacial deposits, and surficial geology (table 1). The Namekagon River (Namekagon) drains a forested basin with silicious glacial deposits. Each stream will hereinafter be referenced by the abbreviated name indicated in parentheses. The North Fork Crow River (North Fork Crow) and the Little Cobb River (Little Cobb) drain agricultural basins that also have calcareous glacial deposits. Shingle Creek (Shingle) and Nine Mile Creek (Nine Mile) drain urban basins with calcareous glacial deposits in the TCMA.

Large river sampling sites on the Mississippi, Minnesota and St. Croix Rivers were selected to reflect the major basin land uses; forested in the St. Croix, agricultural in the Minnesota, forested and agriculture above the TCMA, and urban in the Mississippi in and downstream from the TCMA (fig. 4). Two sites were selected on the Mississippi River main stem upstream from the TCMA. The Mississippi River at Royalton site is located at the transition between predominantly forested land use and a mixture of forest and agricultural land use. The Mississippi River at Anoka site is within the TCMA. There is one site on the Minnesota River near Jordan, Minnesota. The Mississippi River site at Hastings, Minnesota is downstream from the confluence of the Minnesota and Mississippi Rivers. Two sites were selected on the St. Croix River: St. Croix River at Danbury, Wisconsin; and St. Croix River at St. Croix Falls, Wisconsin. The Mississippi River site at Red Wing, Minnesota is downstream from all the major tributary confluences in the study unit. These sites will hereinafter be referenced as Royalton, Anoka, Jordan, Hastings, Danbury,

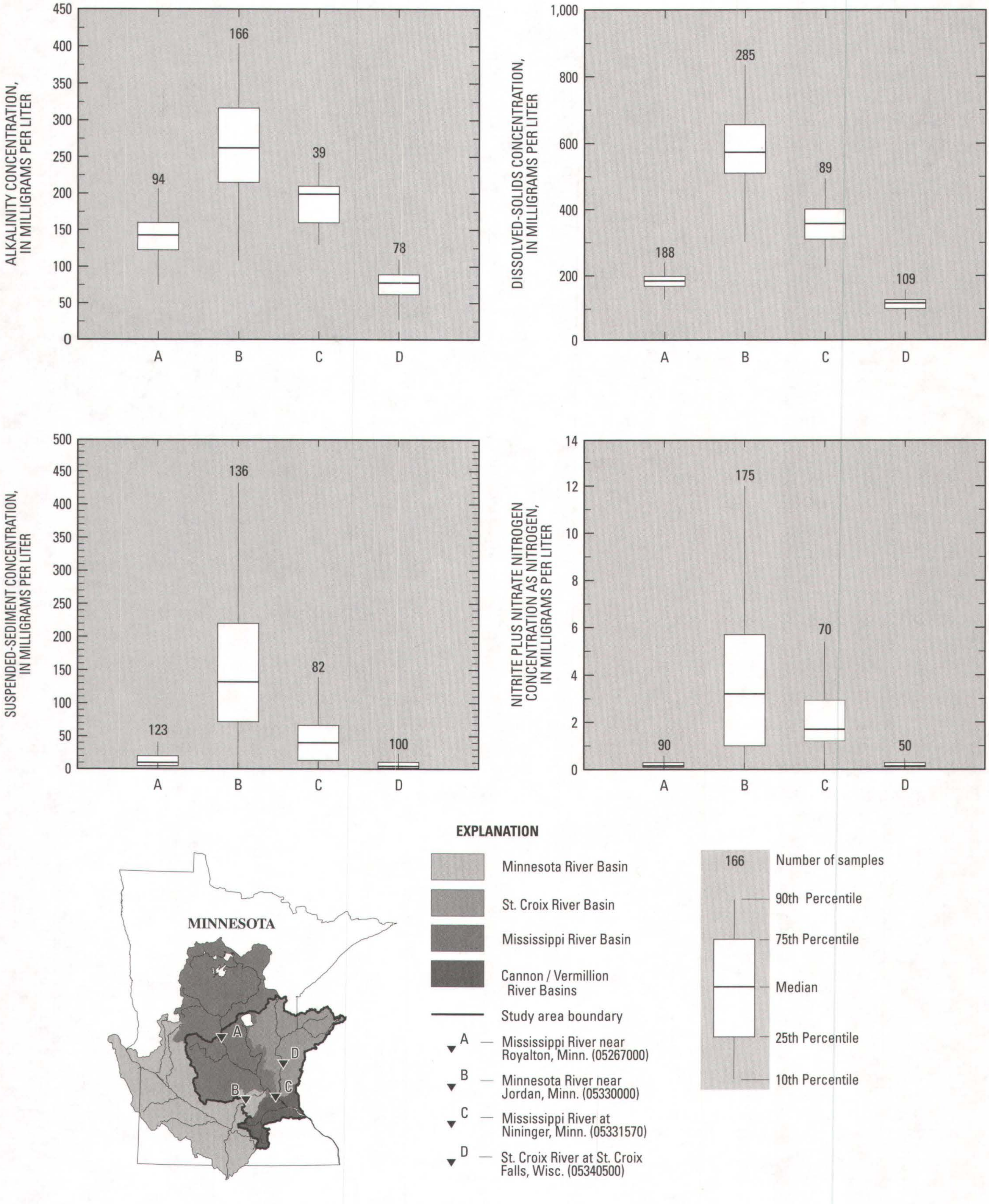

Figure 3. Generalized water quality at selected sites in the Upper Mississippi River Basin study unit, 1977-94.

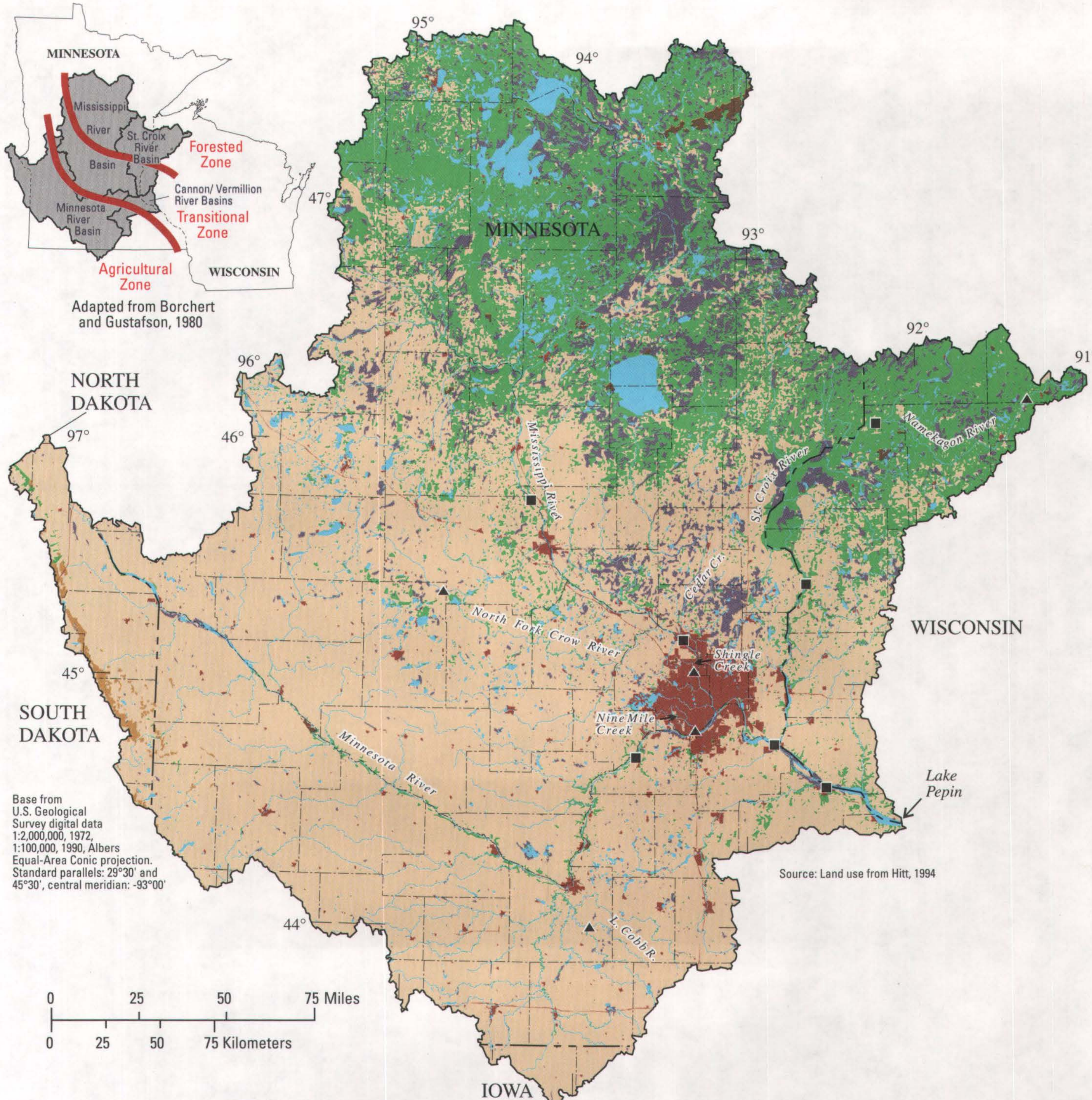

Figure 4. Land use, land cover, and small stream and large river sites in the Upper Mississippi River Basin study unit.

Table 1. Stratification of Upper Mississippi River Basin study unit small-stream indicator sites according to land use, glacial deposit composition, and surficial geology

Stream	Land Use	Glacial Deposit Composition	Surficial Geology
Namekagon River	Forested	Silicious	Outwash plains, Alluvium
North Fork Crow River	Agricultural	Calcareous	Outwash plains, Alluvium
Shingle Creek	Urban	Calcareous	Outwash plains, Alluvium
Nine Mile Creek	Urban	Calcareous	Till plains, moraines
Little Cobb River	Agricultural	Calcareous	Till plains, moraines

St. Croix Falls, and Red Wing, respectively.

Periphyton, benthic invertebrates, and stream physical characteristics were sampled or measured at all sites during 1996. Water chemistry parameters were measured at all sites during 1996–98.

Physical characterization of the streams followed a hierarchical system of habitat classification (Frissell and others, 1986), and was conducted in accordance with Meador and others (1993b). Physical characterization included basin level (100's of square kilometers), segment level (thousands of square meters), and reach level (100's of square meters) components.

Basin-level characterization was used to determine gross differences among the streams. Basin-level characteristics measured included basin area, land use (percent urban, agricultural, forested, wetland), population density, physiography, and streamflow variability. Land-use percentages were determined using 1970's land-use data, adjusted with 1990 population data in urban areas (Hitt, 1994). Population density was calculated by dividing the population by the drainage area. Streamflow variability was assessed for the five small streams using stage data from USGS stream gages. Streams that reached high peak flows quickly as a result of precipitation and returned to stable flow after a short duration were classified as highly variable. Streams that responded to precipitation runoff with moderate peak flows and extended time durations before returning to stable flow were classified as moderately variable.

Segment-level characterization included sinuosity and channel gradient. Sinuosity is the length of the stream in the segment divided by the straight line distance from the upstream boundary of the segment to the downstream boundary. Gradient is the rate of altitude change along the segment. These measurements were determined from USGS digital raster graphics (1:24,000 scale).

Reach-level characterization included measuring or defining features of the streambed (substrate, woody debris, aquatic vegetation), channel (width, depth, velocity), and riparian canopy that shade the stream (sun angle), according to Meador and others (1993b). A reach was determined in one of three ways: (1) two replications of two geomorphological units, (2) one meander wavelength, or (3) a minimum distance not less than 150 m. Stream order (Strahler, 1957) was used to provide an additional measure of stream size for comparison. All three levels of physical characterization were used for the small streams, but not the large rivers.

Collection and analysis of water-quality samples followed NAWQA procedures (Shelton, 1994). Sampling for all sites included monthly water samples and storm runoff at selected sites. Water-quality parameters included specific conductance, temperature, alkalinity, chloride, nutrients (ammonia nitrogen, nitrite+nitrate as nitrogen, and dissolved orthophosphorus), and suspended sediment.

BIOLOGICAL COMMUNITY SAMPLING

Periphyton samples were collected from woody debris (snags) submerged in the euphotic zone at a minimum of five locations in each stream reach using standard NAWQA protocols (Porter and others, 1993). Branches from each snag were removed from the water to minimize disturbance to the periphyton community. An 8- to 10-cm long section was cut from each branch; and retained in a plastic bag prior to processing. Periphyton were removed from each branch section and processed according to Porter and others (1993). All samples were preserved in a 4 percent formalin solution and sent to the USGS National Water-Quality Laboratory, Colorado for identification and enumeration.

The surface area of each piece of wood was measured for quantification of periphyton density and biovolume. Density is defined as the number of algal cells per square centimeter (cm^2) of surface area. Biovolume is defined as the volume of algae (cm^3) per square meter (m^2) of surface area.

Benthic invertebrates also were collected in accordance with standard NAWQA protocols (Cuffney and others, 1993). Samples were collected from complex woody debris (snags with leaf packs) at a minimum of five locations in each stream reach. The snag was disturbed for 30–60 seconds to dislodge benthic invertebrates into a 425-µm mesh Slack sampler placed immediately downstream. Several pieces of wood were cut and collected in the net for further examination. Benthic invertebrates were hand-picked or brushed from each piece. All samples were preserved in 10 percent buffered formalin and sent to the USGS National Water-Quality Laboratory, Colorado for identification and enumeration.

BIOLOGICAL COMMUNITY CHARACTERIZATION AND ANALYSIS

In the small streams, periphyton communities were characterized by quantifying total periphyton cell density and biovolume, as well as density and biovolume of select algal divisions. Diatom communities were characterized by the Shannon Diversity Index (Brower and others, 1990) and the Pollution Index (Bahls, 1992). The Pollution Index is based on the fraction of diatoms in each of the three tolerance groups of Lange-Bertalot (1979): most tolerant, less tolerant, and sensitive. The pollution index value will range from 1.00 (all most-tolerant diatoms) to 3.00 (all sensitive diatoms). Species not designated tolerance values were assigned a default tolerance value based on the genus to which it belongs (Bahls, 1992). Benthic invertebrate communities were characterized by richness of total taxa, Ephemeroptera-Plecoptera-Trichoptera (EPT) (generally considered intolerant taxa), and Dipteran/non-insect taxa (generally considered tolerant taxa). The taxonomic level of identification varied by invertebrate order. Insects could be identified to the family level and many to genus and species. Within the non-insect orders, the level of identification was less precise. Abundance of individuals representing each taxa was used as an additional measure for comparison.

In the large rivers, periphyton communities were characterized by quantifying total cell density and biovolume, and cell density and biovolume of select algal divisions. Diatom communities were characterized by the Shannon Diversity Index. Benthic invertebrate communities were characterized by taxa richness and the Shannon Diversity Index.

Characteristics of periphyton and benthic invertebrate communities in small streams were compared among three land use settings—forested, agricultural, and urban—to determine relations between land use, physical and chemical characteristics, and biological communities. Large river biological communities were then compared in a stepwise manner moving downstream to evaluate the effects of a major urban area on communities in part of the Upper Mississippi River and to determine the effects of inflow from two major tributaries from different environmental settings, agriculture (Minnesota River) and forest (St. Croix River).

COMPARISONS AMONG SMALL STREAM SITES

BASIN CHARACTERISTICS

Drainage area and stream order differed among the small streams (table 2). The agricultural streams (Little Cobb and North Fork Crow) had higher stream order and drained larger basins than either the forest (Namekagon) or urban streams (Shingle and Nine Mile). The urban basins contained at least 70 percent urban land use. Between 23 and 28 percent of the land surface of the urban basins was covered with impervious materials (asphalt, concrete, roofs). The agricultural basins had greater than 90 percent agricultural land use; whereas the basin of the Namekagon contained almost 80 percent forested land. Secondary land uses among the small stream basins generally were no greater than 20 percent. Population density was about 200 times greater in the urban basins than the agricultural basins and about 300 times greater than in the forested basin (table 2).

Streams with different basin land uses had different hydrologic characteristics (fig. 5). The forest stream was most stable. The urban streams were more variable than the agricultural streams. The "flashy" nature of the urban streams is due to areas of impervious surfaces (Riley, 1998) and small basin areas.

SEGMENT CHARACTERISTICS

Sinuosity and gradient did not correspond with land use. Sinuosity (value approaches 1 when a stream is channelized) was lowest at Shingle and greatest at Little Cobb (table 3). Shingle also had the lowest stream gradient, while Nine Mile had the steepest gradient. The portion of Nine Mile with the steepest gradient was upstream from the sampling site, but was included in gradient determination; therefore, the actual gradient

Table 2. General characteristics of small streams studied in the Upper Mississippi River Basin study unit

[km^2, square kilometer; people/km^2, people per square kilometer]

Stream	Upstream drainage area (km^2)	Stream order	Land use, 1990 (percent)					Population density, 1990 (people/km^2)
			Urban	Agriculture	Forest	Wetland	Other	
Namekagon River	312	3	0.7	1.6	77.6	6.0	14.1	3
North Fork Crow River	601	4	0.3	90.2	2.1	6.0	1.4	5
Shingle Creek	73.0	2	70.6	20.3	0.9	0.7	7.5	1,006
Nine Mile Creek	116	2	86.7	5.7	2.2	2.0	3.4	853
Little Cobb River	336	4	0.2	94.7	0.5	4.0	0.6	5

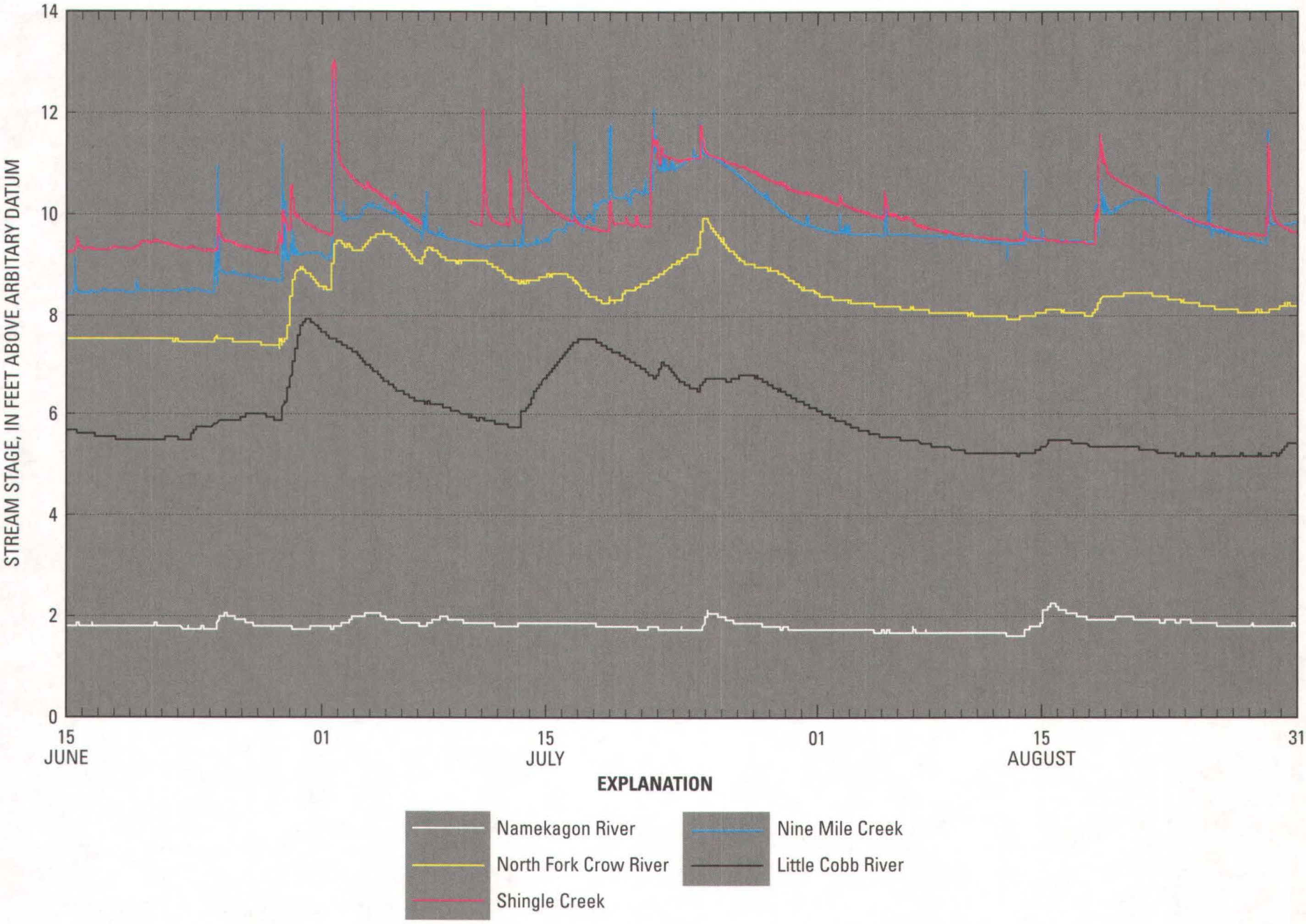

Figure 5. Stream stages for small stream indicator sites of the Upper Mississippi River Basin study unit during June-August 1997.

at the sampling site was probably much lower. Namekagon had the second steepest gradient of the small streams.

REACH CHARACTERISTICS

The mean channel widths (measured at low flow from edge of water to edge of water) at the small streams ranged from about 7 to 20 m. Mean depths ranged from about 25 to about 55 cm. The forested stream had the greatest mean width, depth, and velocity (table 3).

Little Cobb had the narrowest sun angle, indicating a thick overhead canopy shading the stream, and also had the greatest amount of woody debris habitat (table 3). The most open or unshaded stream (widest sun angle) was Namekagon due to the width of the stream and not a lack of riparian trees.

Streambed substrate composition is related to geology, water velocity, depth, gradient, and other factors that cause erosion and affect particle movement in water. Namekagon has the greatest amount of cobbles, whereas the urban and agricultural streams generally contain more gravel, sand, and silt (table 3). The percentage of fine substrate (silt and sand) was greatest at Shingle. The percentage of silt substrate was greatest at Little Cobb, followed by Shingle and North Fork Crow.

WATER CHEMISTRY

Water chemistry, particularly the concentrations of dissolved and suspended constituents, varies with land use, glacial deposits, surficial geology, streamflow, and other factors. The median concentrations of major ions, specific conductance, and alkalinity generally were greatest during winter due to contributing baseflow. The forest stream, in a basin in silicious glacial deposits, exhibited lower mean values of specific conductance, alkalinity, chloride, and suspended sediment than the urban and agricultural streams in basins in calcareous glacial deposits (table 4). Median water temperature during the non-winter seasons was consistently lower in the forested stream. Median nutrient concentrations (nitrogen compounds and phosphorus) were generally greatest in the agricultural streams and least in the forest stream (table 4). Chloride concentrations were greatest in the

Table 3. Reach level physical habitat of selected small streams in different land use settings in the Upper Mississippi River Basin study unit

[m, meters; cm, centimeters; cm/s, centimeters per second; m/km, meters per kilometer; <, less than; substrate frequency is the frequency of occurrence as the dominant substrate, in percent]

Characteristic	Stream				
	Namekagon River (forest)	North Fork of the Crow River (agriculture)	Shingle Creek (urban)	Nine Mile Creek (urban)	Little Cobb River (agriculture)
Mean channel width (m)	19.8	12.2	7.6	6.7	13.7
Mean depth (cm)	54.8	42.7	27.4	24.4	36.5
Mean velocity (cm/s)	42.7	39.6	<0.3	18.3	30.5
Sun angle (degrees)	105	87	26	63	16
Gradient (m/km)	.95	.83	.33	4.41	.38
Sinuosity	1.4	1.4	1.1	2.1	2.3
	Substrate frequency (percent)				
Silt	0	5	47	0	64
Sand	31	44	43	32	11
Gravel	28	33	5	43	22
Cobble	39	14	8	20	3
Boulders	3	0	0	5	0
	Instream habitat (percent of reach area)				
Boulders	1.7	0.6	0.2	3.8	0
Woody debris	5.0	5.6	4.6	8.2	27.5
Overhanging vegetation	3.1	3.1	7.3	2.3	0
Rubbish	0	0	1.7	0	0
Undercut banks	0	0.6	0.2	2.0	1.7
Aquatic plants	12.6	6.6	1.8	0.1	0
Total habitat	22.4	18.3	15.6	16.8	30.0

urban streams, possibly owing to application of road de-icing materials (table 4).

PERIPHYTON COMMUNITIES

A total of 173 algal taxa from 48 genera and 5 divisions were collected while sampling the small stream sites (Appendix A). Total periphyton density was least at Namekagon and greatest at North Fork Crow (fig. 6). Total density was similar at Little Cobb and Nine Mile, but greater at Shingle. By density, diatoms were the dominant algal division at Namekagon, North Fork Crow, and Nine Mile, while blue-green algae were the dominant algal division at Little Cobb and Shingle (fig. 6).

Periphyton biovolume was not directly related to land use. The abundance or composition of periphyton communities may be influenced by nutrient concentrations; however, responses to nutrients may not be observed or may be secondary to habitat-related factors (Richards and others, 1993). The greatest biovolume occurred at North Fork Crow and was lowest at Namekagon, but Little Cobb had periphyton biovolume similar to Namekagon (fig. 7). Diatoms dominated the total biovolume in all streams (fig. 7), ranging from 84 percent at Little Cobb to 98 percent at North Fork Crow.

Seasonal median concentrations of nutrients (nitrite plus nitrate nitrogen and dissolved orthophosphorus) were greatest at Little Cobb, but only Namekagon had less periphyton density and biovolume. Generally periphyton density and biovolume are related to nutrient concentrations. Other factors such as suspended sediment can affect primary production.

Primary production of many midwestern agricultural streams is limited by light, often caused by turbidity from suspended sediment (Munn and others, 1989). Lloyd and others (1987) found that even low levels of turbidity can cause major reductions in primary productivity. Little Cobb had the greatest suspended-sediment concentrations (table 4) and was most shaded (sun angle) (table 3). Algal communities at Little Cobb were dominated by planktonic blue-green algae that probably settled out of the water column onto the surface of the woody debris. These algae (*Oscillatoria formosa, O. limnetica, and Merisomopedia tenuissima*) have the ability to regulate buoyancy and are efficient producers under low light conditions (Horne and Goldman, 1994). Reductions in ambient light may allow blue-green algae to out compete other algae and dominate the algal community (Porter, 1999).

Diatoms are considered useful indicators of environmental changes because they are sensitive to many environmental variables, including light, temperature, current velocity, oxygen, and nutrients (Van Dam and others, 1994). Shingle had the greatest diatom Shannon Diversity Index value (4.04), followed by Little Cobb (3.81), North

Table 4. Seasonal median physical and mean chemical parameters of selected small streams in the Upper Mississippi River Basin study unit, 1996-98

[m^3/s, cubic meters per second; N, number of samples; °C, degrees Celsius; µS/cm, microseimens per centimeter at 25° Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; na, no data available; spring=March-May; summer=June-August; fall=September-November; winter=December-February]

Stream	Season	N	Discharge (ft^3/s)	Specific conductivity (µS/cm)	Water temperature (°C)	Alkalinity (mg/L)	Chloride (mg/L)	Nitrite + nitrate as nitrogen (mg/L)	Ammonia nitrogen (mg/L)	Dissolved ortho-phosphorus (mg/L)	Suspended sediment (mg/L)
Namekagon River (forest)	Spring	9	6,850	113	7.9	41	3.2	0.10	0.03	<0.01	4.3
	Summer	10	4,910	130	17.5	62	2.4	0.15	<0.02	<0.01	3.5
	Fall	6	4,590	126	9.0	54	4.8	0.11	<0.02	0.01	3.2
	Winter	5	4,200	129	1.3	51	3.8	0.16	<0.02	<0.01	5.6
North Fork Crow River (agriculture)	Spring	6	9,390	602	8.0	255	16	1.2	0.02	0.02	57
	Summer	5	3,100	599	21.2	255	14	0.61	0.03	0.04	81
	Fall	5	1,230	649	10.5	280	18	1.2	0.05	0.01	81
	Winter	7	1,270	712	0.1	304	33	1.5	0.12	0.02	68
Shingle Creek (urban)	Spring	14	2,780	1,024	10.5	198	150	0.40	0.10	<0.01	50
	Summer	12	713	808	21.6	186	99	0.29	0.15	0.02	40
	Fall	8	463	1,230	11.2	253	200	0.37	0.25	0.01	115
	Winter	8	219	1,933	1.9	268	400	0.46	0.38	0.01	98
Nine Mile Creek (urban)	Spring	17	953	806	13.2	172	130	0.36	0.06	0.02	18
	Summer	8	1,540	542	20.6	142	70	0.22	0.03	0.04	27
	Fall	9	766	688	9.9	185	98	0.51	0.09	0.02	35
	Winter	6	381	1,347	1.0	245	260	0.64	0.42	0.02	45
Little Cobb River (agriculture)	Spring	14	5,510	631	9.5	250	15	8.4	<0.02	0.02	139
	Summer	9	2,610	564	21.5	227	16	3.5	<0.02	0.06	92
	Fall	5	816	684	9.6	295	22	5.9	0.02	0.04	76
	Winter	5	953	772	0	337	25	6.7	0.39	0.12	99

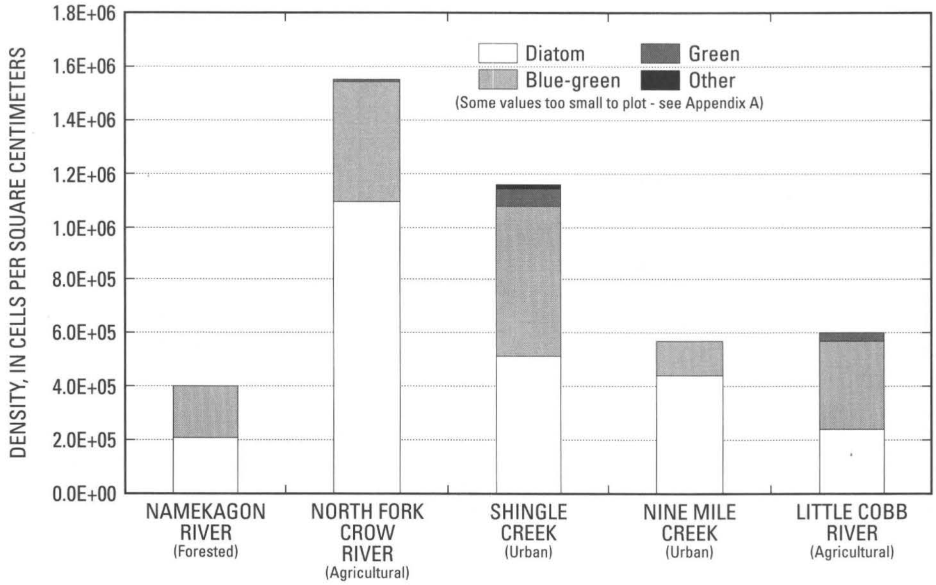

Figure 6. Periphyton density in the small stream indicator sites of the Upper Mississippi River Basin study unit during 1996.

Fork Crow (3.65), Nine Mile (3.59), and Namekagon (3.56). The pollution index followed an inverse pattern. Shingle had the lowest pollution index (2.15), followed by Little Cobb (2.22), North Fork Crow (2.45), Nine Mile (2.47), and Namekagon (2.82).

Bahls (1992) found that diatom community diversity decreased with increasing physical and chemical disturbance. As a result, Namekagon could be expected to have the greatest diatom diversity, and urban streams could be expected to have the lowest diatom diversity. Although the range of diversity values was narrow and may not be statistically significant, the observed pattern was contrary to what was expected. The lower Shannon Diversity Index of the Namekagon diatom community compared to other communities in other streams may be a result of oligotrophic conditions such as low nutrient concentrations, cool water temperatures, and high average velocity.

The Pollution Index scores followed a pattern similar to what was expected. Based on the autecological criteria for assignment of diatom tolerance, a Pollution Index of about 2.00 (Shingle) indicates moderately tolerant diatom communities, tolerant to moderate temperatures and nutrient enrichment (mesotrophic), and moderately tolerant to salts, organic contaminants, and suspended sediment. A Pollution Index of about 3.00 (Namekagon) indicates sensitive diatom communities with low tolerance to salts, organic contaminants, and suspended sediment and oligotrophic conditions, with generally cool water temperatures.

Although the amount of urban land use in the basin of Nine Mile exceeded that of Shingle, the diversity and pollution tolerance of the diatom community was greater. This may be the result of interrelated factors including channel gradient, substrate, and riparian characteristics. For example, the sampled reach of Nine Mile is located in the valley of the Minnesota River. As a result, channel gradient is steeper than any of the other sampled streams. The stream is shallow and flows over sand, gravel, and cobble substrate at a relatively high velocity. In addition, a portion of the sampled reach has undergone some bank and riparian restoration. Therefore, Nine Mile may be more physically similar to Namekagon than the other urban stream, Shingle Creek.

BENTHIC INVERTEBRATE COMMUNITIES

The benthic invertebrate fauna of the small streams contained 100 taxa in 35 families in 8 orders of insects and 22 taxa of non-insects (Appendix B). Taxa richness was greatest at North Fork Crow (fig. 8). EPT taxa richness was greatest at Namekagon and North Fork Crow, and least at Shingle (fig. 9). Specifically, Ephemeroptera taxa (mayflies) richness was greatest at North Fork Crow and Little Cobb, and least at Shingle. Plecoptera taxa (stoneflies) richness was greatest at Namekagon, and least at Shingle and Nine Mile (fig. 8). Trichoptera tax (caddisflies) richness also was greatest at Namekagon, and least at Little Cobb. Diptera and non-insect taxa

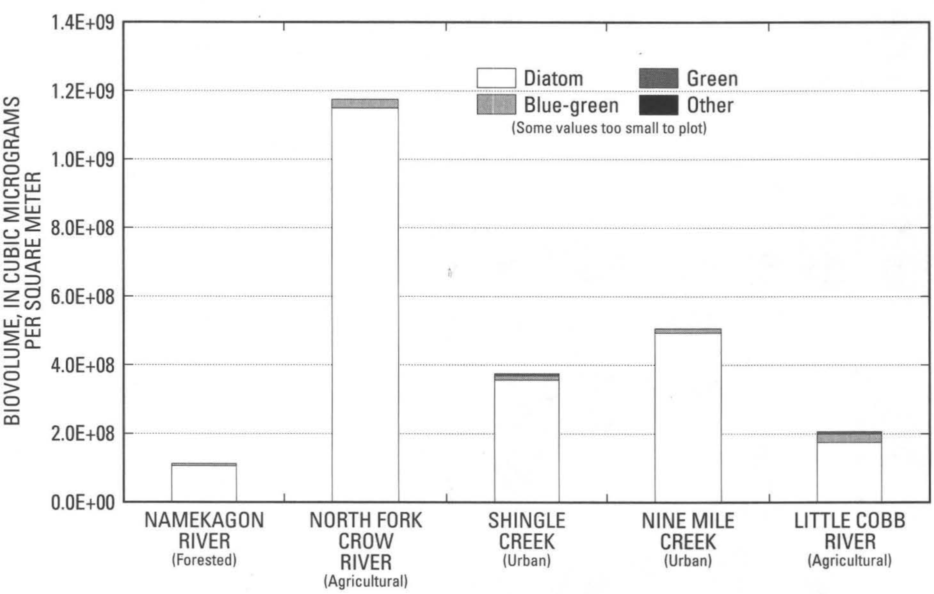

Figure 7. Periphyton biovolume in the small stream indicator sites of the Upper Mississippi River Basin study unit during 1996.

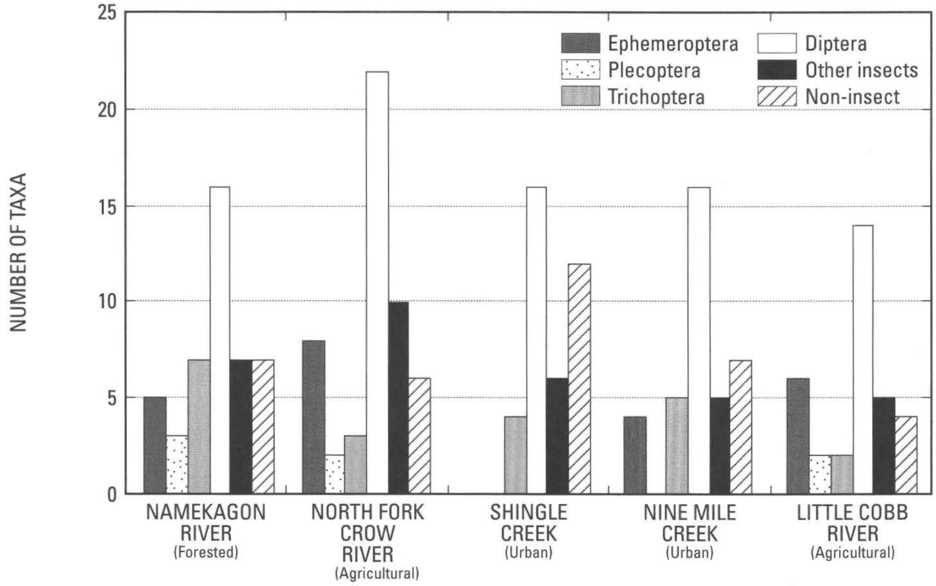

Figure 8. Benthic-invertebrate taxa richness in the small stream indicator sites of the Upper Mississippi River Basin study unit during 1996. [Insect taxa are either genus or species, non-insects are lowest level identified.]

richness was greatest at Shingle and North Fork Crow (fig. 9).

Richness of benthic invertebrate taxa is dependent upon many physical and chemical factors such as instream habitat, food sources, hydrology, and water quality. In general, benthic invertebrate taxa richness is expected to decrease with increasing physical and chemical disturbance factors (Merritt and Cummins, 1996). The taxonomically richest benthic-invertebrate communities were expected to be found at the forest stream, and the least-rich benthic-invertebrate communities at urban streams. Results varied somewhat from expectations. The agricultural North Fork Crow had the greatest benthic invertebrate taxa richness. A large proportion of the taxa sampled in this stream were dipteran and non-insect taxa (fig. 9). Many dipteran and non-insect taxa (some Chironomidae, Oligochaeta) are considered tolerant to various disturbance factors such as agricultural nutrient enrichment. Tolerant taxa are often found in environments of varying levels of degradation. The presence of intolerant taxa often reflects minimally degraded conditions. Comparison of total tolerant and intolerant taxa richness in these streams (fig. 9) suggests that intolerant taxa richness (EPT taxa) may give a better indication of overall physical and chemical conditions in a stream than richness of total taxa or tolerant taxa.

Ephemeroptera taxa richness was greatest in the agricultural streams and least in the urban streams (fig. 8). The Ephemeroptera taxa found in the greatest abundance in the agricultural streams (*Paraleptophlebia* sp., *Caenis* sp., *Stenonema* sp., and *Tricorythodes* sp.) generally exist by clinging to hard, coarse substrates such as woody debris, and coarse substrates (gravel, cobble, and boulders). While North Fork Crow had the greatest periphyton density and biovolume, Little Cobb had considerably less of each. Both urban sites had greater periphyton biovolume than Little Cobb. Given the differences in food availability and the abundance of habitat (figs. 6 and 7; table 3) it is unlikely either factor is causing the differences in Ephemeroptera taxa richness between agricultural and urban streams.

While Plecoptera taxa richness was low compared to other insect orders in all streams, the greatest richness and abundance of Plecoptera taxa are found at Namekagon (fig. 8; Appendix B). Plecoptera are associated with clean, cool running waters, and have microhabitat requirements including boulder surfaces, cobble and gravel interstices, and debris accumulations (Merritt and Cummins, 1996). Relative to the other small streams, Namekagon has a steep gradient, cool water temperatures, and the greatest total amount of coarse substrate. Plecoptera were absent from both urban streams. Nine Mile is similar to Namekagon in gradient and substrate composition so it is unlikely that these

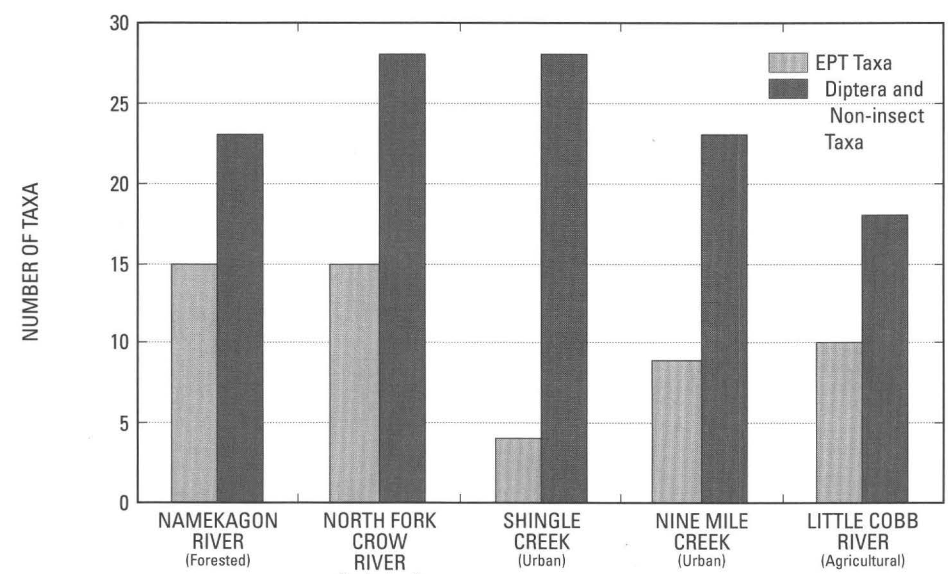

Figure 9. Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa richness and Diptera and non-insect taxa richness in the small stream indicator sites of the Upper Mississippi River Basin study unit during 1996. [Insect taxa are either genus or species, non-insects are lowest level identified.]

characteristics preclude Plecoptera from this stream. Plecoptera were found in the agricultural streams despite fewer coarse substrates, warmer water temperatures during the summer, and greater total nitrogen and suspended sediment concentrations relative to urban streams. Factors limiting Plecoptera taxa in urban streams may be related to water-quality factors and not gradient, temperature, substrate, nutrients, and suspended sediment.

Some benthic invertebrate taxa were associated with one environmental setting as a result of physical and chemical conditions specific to that environmental setting. The forested stream was unique including the ephemeropteran family Ephemerellidae, the trichopterans *Brachycentrus* sp., three odonate taxa (*Gomphus* sp., *Ophiogomphus* sp., and *Boyeria vinosa* (Say), the megalopteran *Nigronia serricornis* (Say), the coleopterans *Macronychus glabratus* (Say) and *Optioservus* sp., several dipteran taxa (*Antocha* sp., *Corynoneura* sp., and *Eukiefferiella* sp.), and the amphipod *Gammarus* sp. These taxa vary with respect to functional feeding group and habitat preference (Merritt and Cummins, 1996). With the exception of *Eukiefferiella* sp. and *Gomphus* sp., all are considered to be relatively intolerant to organic contamination and low dissolved-oxygen concentrations (Hilsenhoff, 1987; Illinois Environmental Protection Agency, 1986).

Several benthic invertebrate taxa were found only in the agricultural streams: the ephemeropterans *Caenis* sp., *Paraleptophelia* sp., and *Tricorythodes* sp., the coleopteran *Stenelmis* sp., and the dipteran *Nanocladius* sp. Some factors associated with the agricultural streams include relatively low stream gradients, warm water, and high productivity. Consequently these sites have more fine particulate organic matter and more types of slow water, marginal habitats preferred by *Tricorythodes* sp. (T.F. Cuffney, U.S. Geological Survey, 1999, written commun.). *Tricorythodes* sp. and *Caenis* sp. are characterized by enlarged anterior gill pairs, presumably to shield posterior pairs from fine sediment (Merritt and Cummins, 1996). Both *Caenis* sp. and *Stenelmis* sp. feed by scraping periphyton from hard surfaces such as rocks and woody debris, whereas *Tricorythodes* sp. feeds by collecting fine particulate organic matter from hard surfaces such as woody debris, or in interstices of mosses or other plant growth commonly in stream margins. Cuffney and others (1996) found *Tricorythodes* sp. to be associated with agricultural land use.

COMPARISONS AMONG LARGE RIVER SITES

Water quality and aquatic biological communities in sites on the three large rivers are the result of a combination of physical and chemical characteristics in the smaller tributary streams, and discharges directly into the rivers and habitat conditions in the main stem. The large rivers integrate inflow from tributary streams. Land use in the Minnesota River Basin is mostly agricultural and in the St. Croix River Basin is primarily forested. The Mississippi River Basin, upstream from the TCMA (Anoka), is a mixture of forest and agriculture (table 5). Downstream from the confluence of the Mississippi River with the Minnesota and St. Croix Rivers, the Mississippi River represents the combined influences of the two main tributaries and the influences of the TCMA.

The physical characteristics of the Mississippi River upstream from the TCMA are very different from downstream. Upstream from the TCMA, the Mississippi River contains diverse habitats that includes riffles, runs, and pools. Downstream the channel becomes wider and deeper, water velocity slows and the substrate becomes more fine grained (table 6). Within and downstream from the TCMA, the river is primarily a series of impoundments that are managed and used for navigation. Channels are routinely dredged to maintain sufficient depth. The change in the physical habitat from a lotic (flowing) to a lentic (lake-like) system may have significant influence on periphyton and benthic invertebrate community composition.

Water quality in the Mississippi River also changes as the river flows downstream and in response to the confluences with the Minnesota and St. Croix Rivers (table 7). Alkalinity and concentrations of chloride, nitrite plus nitrate, orthophosphorus, and suspended sediment were least at Royalton and increased downstream. The greatest increases in concentrations of chloride,

Table 5. General characteristics of the large river integrator sites studied in the Upper Mississippi River Basin study unit

[km^2, square kilometer]

Stream	Upstream drainage area (km^2)	Land use, 1990 (percent)				
		Urban	Agriculture	Forest	Wetland	Other
Mississippi River at Royalton	30,040	0.6	25	49	16	9.5
Mississippi River near Anoka	49,700	1.1	45	34	12	8.3
Mississippi River at Hastings	95,800	2.5	66	18	7.1	5.6
Mississippi River at Red Wing	121,000	2.3	62	23	7.8	5.2
Minnesota River at Jordan	42,000	0.9	94	1.7	1.1	2.4
St. Croix River at Danbury	3,910	0.3	4.9	79	12	4.3
St. Croix River at St. Croix Falls	15,500	0.4	26	56	14	3.0

Table 6. Reach level physical characteristics of large river integrator sites in the Upper Mississippi River Basin study unit

[m, meter; m^3/s, cubic meters per second; Substrate frequency is the frequency of occurrence as the dominant substrate, in percent; n/a, data not available]

	Mississippi River at Royalton	Mississippi River at Anoka	Mississippi River at Hastings	Mississippi River at Red Wing	Minnesota River at Jordan	St. Croix River at Danbury	St. Croix River at St. Croix Falls
			Channel Characteristics				
Median depth (m)	3.9	n/a	22.8	15.2	7.3	2.6	4.4
Median velocity (m^3/s)	918	n/a	39	64	71	777	64
Median width (m)	494	n/a	687	668	323	231	174
			Substrate frequency				
Silt	0	n/a	24	0	n/a	0	0
Sand	17	n/a	47	76	n/a	39	83
Gravel	11	n/a	24	0	n/a	6	17
Cobble	72	n/a	0	0	n/a	33	0
Boulder	0	n/a	6	12	n/a	22	0

nutrients (nitrite plus nitrate and orthophosphorus), and suspended sediment were observed between Anoka and Hastings, reflecting the influence of the TCMA and the agricultural influence of the Minnesota River. Water-quality values decrease slightly or do not appreciably change from Hastings to Red Wing after the contribution of flow from the St. Croix River, even though there is a substantial increase in the size of the Mississippi River Basin.

PERIPHYTON COMMUNITIES

A total of 192 algal taxa from 4 algal divisions were collected by sampling the large rivers (Appendix C). Diatoms constituted the major portion of total taxa (151). Green algae were represented by 18 taxa, blue-green algae by 19 taxa, and euglenoids by 4 taxa. One red algal taxa was found in the large rivers.

Total periphyton density and biovolume was greatest at Red Wing (figs. 10 and 11), the most downstream site. By density, diatoms were dominant at all sites, except for Jordan, where blue-green algae were dominant (fig. 10). Although diatoms dominated periphyton biovolume in all streams (fig. 11), diatom relative abundance decreased downstream along the Mississippi and St. Croix Rivers. At the Mississippi River sites, the proportion of total periphyton density from diatoms was greatest at Royalton and least at Hastings. Overall, the proportion of diatoms to total periphyton density was greatest at Danbury and least at Jordan. Blue-green algae followed a pattern inverse to diatoms.

Diatom community diversity paralleled the pattern observed for diatom relative abundance. Royalton had the greatest diatom community diversity, based on the Shannon Diversity Index, of Mississippi River sites (3.91). Diversity decreased downstream at Anoka (3.84), and again at Hastings (3.60). The Minnesota River had the lowest diatom community diversity (3.36). Diversity increased downstream at Red Wing (3.90), below the confluence of the Mississippi and St. Croix Rivers. Diatom diversity increased downstream from Danbury (3.55) to St. Croix Falls (4.24)

Periphyton community abundance and composition in the large rivers are influenced by many physical and chemical factors. While nutrients are often the primary limiting factor for periphyton growth, factors such as turbidity, temperature, and water velocity also are important. Although Jordan is the most nutrient enriched site, it has the least periphyton density and biovolume. High suspended-sediment concentrations are probably causing light to be a limiting factor for periphyton growth. When water clarity is low and nutrients are not limited, planktonic taxa, such as blue-green algae can out compete benthic taxa, resulting in low periphyton density and biovolume.

BENTHIC-INVERTEBRATE COMMUNITIES

A total of 106 taxa from 40 families in 9 orders of insects and 15 taxa of non-insect benthic invertebrates were collected by sampling the large river sites (Appendix D). Total taxa and family richness were greatest at Danbury and least at Anoka. Benthic invertebrate taxa diversity decreased from Royalton to Hastings in the Mississippi River and from Danbury to St. Croix Falls in the St. Croix River (fig. 12). Taxa richness followed the same pattern in the St. Croix River, but was variable in the Mississippi River downstream from Royalton. The richest and most diverse benthic-invertebrate community in the Mississippi River was found at Royalton, and the least rich and diverse benthic-invertebrate community, with the exception of Anoka, was found at Hastings. The richest and most diverse benthic-invertebrate community on the St. Croix River, as well as among all large river sites, was found at Danbury. Taxa richness and diversity in the Mississippi River increased slightly at Red Wing after the confluence of the Mississippi River with the St. Croix River.

This downstream pattern of decreasing benthic invertebrate taxa richness and diversity in the Mississippi River and St. Croix River is likely attributable

Table 7. Seasonal median physical and mean chemical parameters of large river integrator sites in the Upper Mississippi River Basin study unit, 1996-98

[°C, degrees Celsius; mg/L, milligrams per liter; --, not determined; N, number of samples; µS/cm, microseimens per centimeter at 25° Celsius]

Site	Season	N	Specific conductivity (µS/cm)	Water temperature (°C)	Alkalinity (mg/L)	Chloride (mg/L)	Nitrite + nitrate as nitrogen (mg/L)	Ammonia nitrogen (mg/L)	Dissolved orthophosphorus (mg/L)	Suspended sediment (mg/L)
Mississippi River at Royalton	spring	6	278	~	127	4.6	0.11	0.02	0.01	10
	summer	7	295	22.9	134	4.5	0.13	0.03	0.02	12
	fall	5	289	~	135	5.3	0.19	0.03	0.01	11
	winter	5	259	~	148	4.6	0.30	0.08	0.01	8
Mississippi River at Anoka	spring	6	358	~	151	11.4	0.87	0.08	0.03	17
	summer	5	357	23.1	158	9.5	0.40	0.04	0.04	17
	fall	4	326	~	158	10.4	0.40	0.02	0.01	10
	winter	4	381	~	173	11.8	0.89	0.06	0.03	15
Minnesota River at Jordan	spring	4	822	~	229	19.3	4.7	0.10	0.06	207
	summer	8	789	23.5	234	22.0	2.7	0.04	0.08	241
	fall	6	963	~	279	33.4	2.8	0.02	0.05	135
	winter	4	1030	~	334	36.9	3.9	0.30	0.10	131
Mississippi River at Hastings	spring	7	629	~	191	20.2	3.0	0.11	0.06	48
	summer	7	573	24.3	185	25.3	1.9	0.10	0.13	72
	fall	7	576	~	183	29.9	1.5	0.06	0.10	24
	winter	5	612	~	223	33.9	2.2	0.33	0.15	6
St. Croix River at Danbury	spring	8	109	~	47	2.0	0.06	0.03	0.01	6
	summer	13	123	21.4	51	2.0	0.06	0.01	0.01	5
	fall	7	124	~	47	2.4	0.12	0.02	0.01	9
	winter	6	124	~	62	2.3	0.20	0.02	0.01	3
St. Croix River at St. Croix Falls	spring	8	152	~	58	6.3	0.12	0.04	0.01	13
	summer	10	171	23	70	4.3	0.12	0.02	0.01	5
	fall	6	174	~	74	4.2	0.22	0.02	0.01	5
	winter	6	185	~	89	4.8	0.39	0.06	0.01	5
Mississippi River at Red Wing	spring	5	573	~	175	19.0	3.0	0.04	0.03	50
	summer	6	459	23.9	154	19.2	1.2	0.05	0.08	62
	fall	4	449	~	161	22.7	1.5	0.07	0.06	25
	winter	5	490	~	177	23.9	1.8	0.23	0.10	15

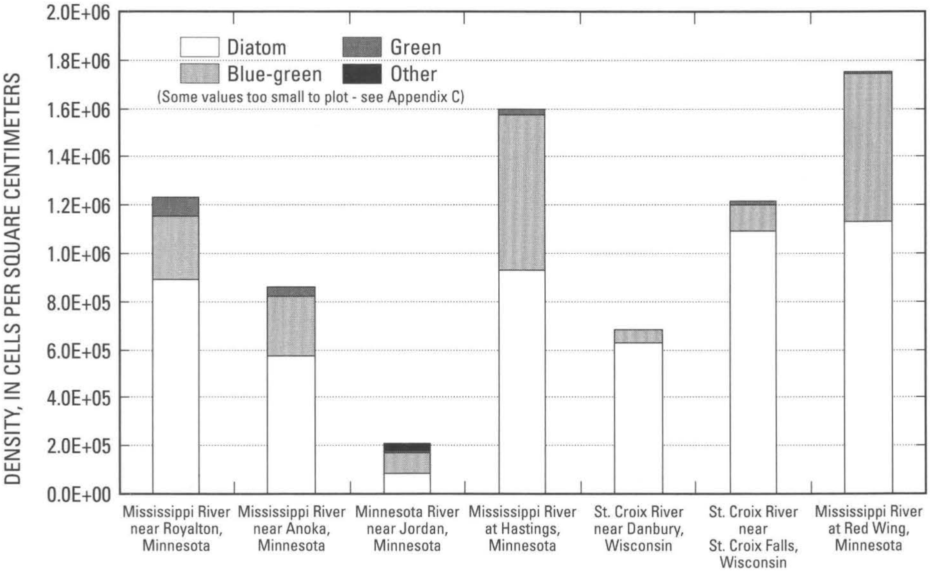

Figure 10. Periphyton density in the large river integrator sites of the Upper Mississippi River Basin study unit during 1996.

to changes in water quality and physical habitat conditions. The Mississippi River upstream from Royalton drains primarily forested land. This site is characterized by substantial amounts of gravel and cobble substrates (table 6), relatively low concentrations of suspended sediment and nutrients (table 7), and diverse instream habitat, including riffles, runs, pools, and woody debris. Beginning at the TCMA, the Mississippi River is primarily a series of impoundments managed for navigation. Here the channels become wider and steeper, the water slows, and the substrate becomes more fine-grained (Goldstein and others, 1999). The Mississippi River at Hastings reflects contributions by both the TCMA and the agricultural Minnesota River. Suspended sediment and nutrient concentrations are greatest in the Minnesota River compared to the other large rivers. The St. Croix River exhibits a similar pattern as the Mississippi River. Upstream from the dam at St. Croix Falls the river has diverse geomorphology, substrate composition, and instream habitat. Downstream from the dam, the St. Croix River becomes wider and slower, and habitat shifts to fine grained sand with interspersed woody debris. Downstream from the confluence of the St. Croix River and the Mississippi River at Red Wing, habitat conditions are similar to the upstream Hastings site. The riverine habitat has little complexity, consisting of silt and sand with scattered woody debris piles. The channel is periodically dredged to maintain depth adequate for shipping. Boat traffic occurs throughout the open water season, resulting in frequent disturbance to the substrate and erosion of banks from wave action produced by these vessels.

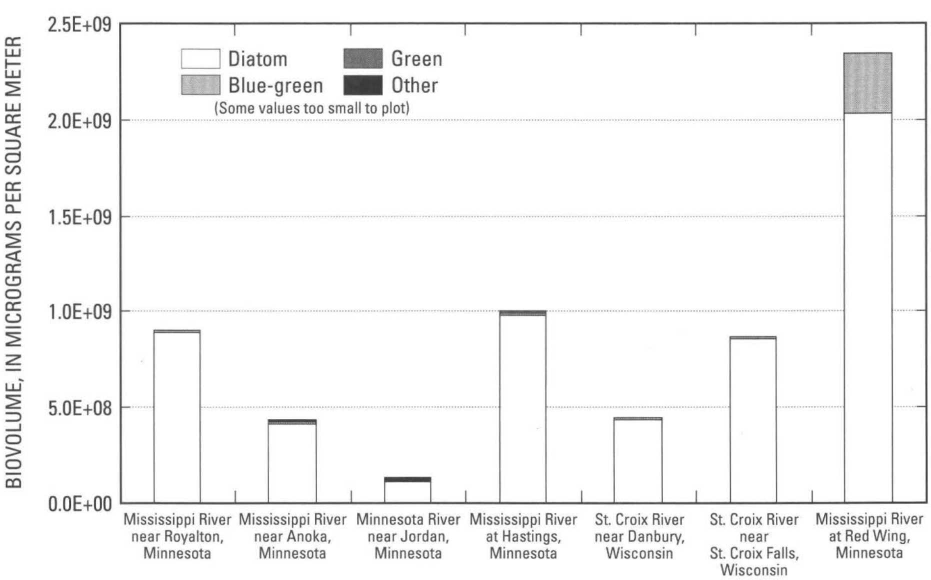

Figure 11. Periphyton biovolume in the large river integrator sites of the Upper Mississippi River Basin study unit during 1996.

RELATION OF BENTHIC INVERTEBRATE AND PERIPHYTON COMMUNITIES TO ENVIRONMENTAL AND LAND USE FACTORS

Establishment of quantitative relations among land use, physical characteristics, and chemical conditions with benthic macroinvertebrate and algal communities was difficult because of the small number of sites within each type of land use and the lack of long term data. Variability between communities at sites with similar land use indicated the influence of site-specific physical characteristics and chemical conditions. Regardless, there were indications of the effects of land use on the biological communities.

Benthic-invertebrate and periphyton communities in the small forested stream are minimally affected by physical and chemical disturbance from land use. Minimal land-cover disturbance contributes to low streamflow variability and cool water temperatures. Nutrient concentrations are low owing to the presence of few anthropogenic sources. The combination of cool water temperatures and low nutrient concentrations result in low periphyton abundance and biovolume. The diatom taxa from forest streams generally are more intolerant to

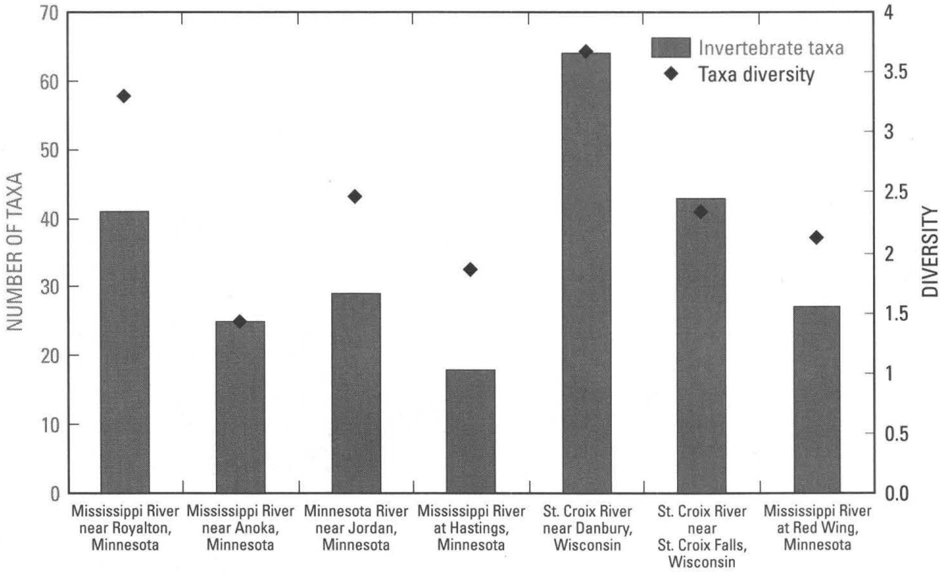

Figure 12. Benthic-invertebrate taxa richness and diversity in the large river integrator sites of the Upper Mississippi River Basin study area during 1996. [Insect taxa are either genus or species, non-insects are lowest level identified.]

physical and chemical disturbances than diatoms found in the agricultural and urban streams. Benthic-invertebrate taxa richness is relatively high, consisting of a greater proportion of taxa intolerant to physical and chemical disturbance factors than those found in either the agricultural or urban streams. Tolerant taxa also are abundant, indicating that the forested stream provides conditions suitable for benthic invertebrate communities consisting of taxa with a wide range of tolerances and physical requirements.

Benthic-invertebrate and periphyton communities of agricultural streams are more affected by physical and chemical disturbance factors than those of the forested stream. The use of tile drainage systems, combined with natural soil characteristics in these agricultural basins, has contributed to greater streamflow variability and increased transport of nutrients and sediment. North Fork Crow evidenced nutrient enrichment by having the greatest periphyton density and biovolume of the small stream sites. The dense riparian canopy and greater suspended-sediment concentrations at Little Cobb compared to the other small stream sites probably limited light availability enough for attached periphyton taxa to be replaced by planktonic taxa.

The high richness and abundance of mayfly taxa in the two agricultural streams indicate that organic enrichment, salinity, and trace metal contamination are not a source of impairment to these streams. Many of the mayfly taxa common to the agricultural streams are considered tolerant to high concentrations of suspended sediment, indicating that sediment may be a source of impairment.

Benthic invertebrate and periphyton communities of urban streams are affected by physical and chemical disturbance factors. Impervious surfaces, channelization, and other hydrologic modifications have resulted in highly variable streamflow. Impervious surface area associated with urban land use limits the infiltration of water, resulting in rapid rises in streamflow following storm events. Physical disturbances from hydrologic variability are important factors affecting benthic invertebrate communities (Wright and others, 1984). Channelization and other hydrologic modifications and increased impervious surface land cover result in variable streamflow and increased concentrations of trace metals, road deicing chemicals, nutrients, and suspended sediment. Low summer densities of the mayfly *Tricorythodes minutus* have been attributed to drift, induced by hydrologic variability (Minshall and Winger, 1968).

Impervious surfaces such as roadways and parking lots contribute trace metals in runoff. Trace metal (antimony, cadmium, copper, lead, nickel, and zinc) concentrations in streambed sediments in the study unit are greatest in urban stream basins (Kroening and others, 2000). Sensitivity of benthic invertebrates to metal contamination varies among orders, with Ephemeroptera being the most sensitive (Clements, 1991). The respiratory structures of Ephemeroptera may make them most succeptible to these influences (Gerhardt, 1992).

De-icing chemicals from roadways and parking lots are the major source of chloride to urban streams (table 4) (Talmadge and others, 2000). Ephemeroptera may be the least tolerant to salinity, and were least abundant in the urban streams (fig. 8). Short and others (1991) found Ephemeroptera taxa richness decreased linearly with increasing concentrations of chloride.

The influence of land use also is reflected in biological communities in large rivers. The Mississippi River integrates effects of land use on small tributary streams, as well as on the large river tributaries, the Minnesota and St. Croix Rivers. The forested basins had greater relative density of diatoms (fig. 10), and greater taxa richness and diversity (fig. 12). The Mississippi River Basin becomes increasingly agricultural downstream from its headwaters, particularly after the confluence with the Minnesota River. Inputs of nutrients associated with the increasing amount of agriculture result in the river becoming more productive, as evidenced by increasing periphyton density and biovolume and greater proportions of blue-green algae (figs. 10 and 11). The effects of increased river size are exacerbated by impoundments and dredging to produce a more lake-like system. These factors contribute to reductions in diatom and benthic-invertebrate community richness and diversity.

SUMMARY

The Upper Mississippi River Basin is one of the hydrologic systems selected for study as part of the National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey. NAWQA utilizes a multi-disciplinary approach to identify, describe, and explain factors that affect water quality. Part of the NAWQA design is to address the relation of land use and environmental factors to periphyton and benthic invertebrate communities in streams.

The study focuses on a 122,000-square-kilometer area of the Mississippi River Basin, including the Twin Cities metropolitan area (TCMA). The northeastern part of the study unit is the primarily forested St. Croix River Basin, the southwestern part is the primarily agricultural Minnesota River Basin, and the central part includes the transition between forest and agriculture, as well as the urban TCMA.

Study sites were selected based on a stratification process that identified small streams in forested, agricultural, and urban environmental settings, and large river sites on the Mississippi River and on two main tributaries. Periphyton and benthic invertebrate communities were evaluated at each site with respect to hydrology, water chemistry, and land use.

Compared to the forested site, periphyton density and biovolume in small streams generally increased as nutrient concentrations associated with urban and agricultural land use increased. Periphyton growth in agricultural and urban areas may be limited by suspended sediment which also increases with these land uses. Periphyton communities varied within agricultural and urban streams, indicating that physical and chemical factors other than land use also affect periphyton communities.

Benthic invertebrate communities also are affected by land use. There were few intolerant taxa (Ephemeroptera and Plecoptera) in urban streams, potentially owing to high streamflow variability from impervious surfaces and contaminants from runoff such as chloride. Ephemeroptera taxa richness was greatest in the agricultural streams. The most abundant Ephemeroptera taxa were those tolerant to high concentrations of suspended sediment. Richness of Plecoptera and Trichoptera taxa were greatest in the forested stream.

Large river biological communities generally reflected land uses in the major basins and changes in water quality as the Minnesota and St. Croix Rivers joined the Mississippi River. Periphyton density and biovolume, and the relative abundance of blue-green algae density increased, while the relative abundance of benthic invertebrate taxa richness and diversity generally decreased downstream as urban and agricultural land use become more prevalent. Impoundments and dredging of the Mississippi River in and downstream from the TCMA exacerbate effects of increasing river size to produce a more lentic, or lake-like, system.

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APPENDIX

Appendix A. Periphyton taxa densities (cells/cm^2) for Upper Mississippi River Basin study unit small stream indicator sites, 1996

Taxon (Divisions, *genera*)	Namekagon River	North Fork Crow River	Shingle Creek	Nine Mile Creek	Little Cobb River
Chrysophycophyta					
Achnanthes biasolettiana (Kütz.) Grun.	24,560	0	0	0	0
Achnanthes clevei Grun.	3,032	0	0	0	0
Achnanthes delicatula (Kütz.) Grun.	606	0	0	0	0
Achnanthes exigua Grun.	606	0	0	0	0
Achnanthes laevis Schimanski	303	0	0	0	0
Achnanthes lanceolata (Bréb. in Kütz.) Grun.	5,155	0	8,063	7,271	2,597
Achnanthes lanceolata dubia Grun.	1,819	0	0	0	0
Achnanthes lauenburgiana Hust.	606	0	0	0	0
Achnanthes marginulata Grun.	303	0	0	0	0
Achnanthes minutissima Kütz.	28,805	0	896	1,454	0
Cocconeis neothumensis Kram.	3,335	0	0	0	0
Cocconeis neothumensis 0A UL NAWQA KM	1,213	0	0	0	0
Cocconeis pediculus Ehr.	3,032	10,200	0	43,623	0
Cocconeis placentula Ehr.	29,715	98,601	15,230	103,969	10,820
Cocconeis placentula euglypta (Ehr.) Cl.	10,006	69,701	0	25,447	3,895
Cocconeis placentula lineata (Ehr.) V. H.	4,245	27,200	3,584	7,271	0
Diatoma vulgare Bory	0	6,800	0	0	0
Fragilaria brevistriata Lange-Bert.	6,974	0	7,167	0	0
Fragilaria capucina gracilis (Østr.) Hust.	0	0	896	0	0
Fragilaria capucina mesolepta Rabh.	606	0	1,792	0	866
Fragilaria capucina vaucheriae (Kütz.) Lange-Bert.	1,819	0	0	0	0
Fragilaria construens (Ehr.) Grun.	11,219	0	896	0	0
Fragilaria construens venter (Ehr). Grun.	4,851	0	0	0	0
Fragilaria lapponica Grun.	10,006	0	0	0	0
Fragilaria leptostauron (Ehr.) Hust.	1,819	0	0	0	0
Fragilaria nanana Lange-Bert.	0	0	18,814	0	0
Fragilaria neoproducta Lange-Bert.	1,213	0	0	0	0
Fragilaria pinnata Ehr.	19,102	0	13,439	0	0
Fragilaria sp. 0A UL NAWQA KM	303	0	0	0	0
Meridion circulare (Grev.) Ag.	0	0	0	727	0
Pseudostaurosira brevistriata 0A UL NAWQA 96 KM	303	0	0	0	0
Synedra delicatissima W. Sm.	606	0	0	0	0
Synedra parasitica (W. Sm.) Hust.	910	0	0	0	0
Synedra ulna (Nitz.) Ehr.	606	18,700	1,792	0	0
Rhopalodia gibba (Ehr.) O. M¸ll.	0	0	0	0	866
Eunotia bilunaris (Ehr.) Mills	910	0	0	0	0
Melosira varians Ag.	0	10,200	4,480	2,181	0
Amphipleura pellucida (Kütz.) Kütz.	0	11,900	0	0	0
Amphora inariensis Kramm.	0	6,800	0	0	0
Amphora libyca Ehr.	0	0	4,480	0	866
Amphora perpusilla (Grun.) Grun.	2,729	35,700	32,253	10,179	0
Amphora veneta Kütz.	0	0	0	0	866
Caloneis bacillum (Grun.) Cl.	303	0	2,688	0	2,597
Craticula cuspidata D.G. Mann	0	1,700	0	0	0
Cymbella cistula (Ehr.) Kirchn.	0	0	3,584	0	0
Cymbella microcephala Grun.	606	0	4,480	0	0

Appendix A. Periphyton taxa densities (cells/cm^2) for Upper Mississippi River Basin study unit small stream indicator sites, 1996 (Continued)

Taxon (Divisions, *genera*)	Namekagon River	North Fork Crow River	Shingle Creek	Nine Mile Creek	Little Cobb River
Cymbella minuta Hilse ex Rabh.	2,729	0	0	0	1,298
Cymbella minuta silesiaca (Bleisch ex Rabh.) Reim.	606	0	0	0	0
Cymbella sp. 0C UL NAWQA KM	910	0	0	0	0
Cymbella tumida (Bréb. ex Kütz.) V. H.	0	17,000	0	0	0
Gomphonema acuminatum Ehr.	0	0	0	0	866
Gomphonema affine Kütz.	0	3,400	6,271	0	0
Gomphonema angustatum (Kütz.) Rabh.	606	0	0	2,908	0
Gomphonema gracile Ehr. emend. V. H.	0	0	0	0	1,731
Gomphonema olivaceum (Lyngb.) Kütz.	0	0	0	1,454	1,298
Gomphonema parvulum (Kütz.) Kütz.	2,122	3,400	3,584	1,454	0
Gomphonema pumilum (Grun.) Reich. & Lange-Bert.	0	3,400	7,167	0	0
Gomphonema sphaerophorum Ehr.	0	0	0	727	0
Gomphonema ssp.	0	6,800	0	0	0
Gomphonema tenellum Kütz.	0	22,100	1,792	2,908	12,551
Gyrosigma acuminatum (Kütz.) Rabh.	0	3,400	0	0	866
Navicula atomus (Kütz.) Grun.	0	5,100	0	1,454	0
Navicula capitata Ehr.	303	0	7,167	1,454	2,597
Navicula capitata lunebergensis (Grun.) Patr.	910	0	0	0	0
Navicula capitatoradiata Germain	910	34,000	0	8,725	1,731
Navicula citrus Krass.	0	0	0	0	866
Navicula cryptocephala Kütz.	2,729	0	2,688	727	0
Navicula cryptotenella L.B. in Kramm. & L.-B.	5,761	20,400	11,647	17,449	1,731
Navicula decussis Østr.	0	0	1,792	8,725	2,164
Navicula exilis Kütz.	0	0	12,543	2,181	1,731
Navicula Gregory Donk.	0	0	0	20,357	1,731
Navicula harderii Hust.	0	0	2,688	1,454	0
Navicula heufleri Choln.	0	0	0	4,362	6,925
Navicula heufleri leptocephala (Bréb ex Grun.) Perag.	0	3,400	0	0	0
Navicula ingenua Hust.	0	0	3,584	0	0
Navicula kotschyi Grun.	0	0	0	0	2,164
Navicula menisculus Schum.	0	3,400	0	8,725	0
Navicula minima Grun.	1,516	17,000	0	21,085	1,298
Navicula molestiformis Hust.	0	8,500	0	3,635	0
Navicula pseudoscutiformis Hust.	303	0	0	0	0
Navicula pupula Kütz.	0	0	8,959	2,908	0
Navicula pupula capitata Skv. & Meyer	0	0	1,792	0	0
Navicula pupula mutata (Krass.) Hust.	0	3,400	0	0	866
Navicula pygmaea Kütz.	0	0	1,792	0	0
Navicula reinhardtii (Grun.) Grun.	0	0	0	1,454	0
Navicula rhynchocephala Kütz.	303	0	0	0	0
Navicula rhynchocephala germainii (Wallace) Patr.	0	22,100	1,792	15,995	2,597
Navicula schadei Krass.	0	0	0	0	433
Navicula schoenfeldii Hust.	910	0	0	0	0
Navicula schroeteri symmetrica (Patrick) Lang.-Bert.	0	0	0	5,816	0
Navicula schroeterii Meist.	0	0	3,584	0	0
Navicula seminuloides Hust.	303	0	0	0	0
Navicula seminulum Grun.	2,426	0	0	1,454	1,298
Navicula subhamulata Grun.	0	0	3,584	8,725	0

Appendix A. Periphyton taxa densities (cells/cm^2) for Upper Mississippi River Basin study unit small stream indicator sites, 1996 (Continued)

Taxon (Divisions, *genera*)	Namekagon River	North Fork Crow River	Shingle Creek	Nine Mile Creek	Little Cobb River
Navicula subminuscula Mang.	0	39,100	0	0	0
Navicula tantula Hust.	0	0	1,792	0	1,731
Navicula tenelloides Hust.	0	3,400	47,483	727	0
Navicula tenera Hust.	0	0	1,792	0	0
Navicula tripunctata (O. F. M¸ll.) Bory	606	0	0	727	2,164
Navicula trivialis Lange-Bert.	0	3,400	10,751	0	6,059
Navicula veneta Kütz.	0	0	1,792	727	866
Navicula viridula (Kütz.) Kütz. emend. V. H.	0	0	896	0	0
Navicula viridula rostellata (Kütz.) Cl.	0	0	3,584	4,362	433
Pinnularia gibba Ehr.	0	0	0	3,635	0
Reimeria sinuata (Greg.) Kociolek & Stoermer	4,245	1,700	0	5,816	0
Rhoicosphenia curvata (Kütz.) Grun. ex Rabh.	0	45,900	0	8,725	15,148
Hantzschia amphioxys (Ehr.) Grun.	0	0	0	0	433
Nitzschia acicularis (Kütz.) W. Sm.	0	3,400	11,647	0	17,312
Nitzschia amphibia Grun.	0	42,500	15,230	7,271	19,043
Nitzschia angustatula Lange-Bert.	0	3,400	0	0	0
Nitzschia calida Grun. in Cl. et Grun.	0	6,800	0	0	0
Nitzschia capitellata Hust.	0	0	4,480	1,454	866
Nitzschia constricta (Kütz.) Ralfs	0	17,000	0	0	0
Nitzschia dissipata (Kütz.) Grun.	910	217,602	0	1,454	1,731
Nitzschia fonticola Grun.	0	0	0	1,454	0
Nitzschia frustulum (Kütz.) Grun.	0	0	896	0	0
Nitzschia gracilis Hantz. ex Rabh.	0	0	3,584	0	0
Nitzschia inconspicua Grun.	303	0	0	0	0
Nitzschia intermedia Hantz. ex Cl. et Grun.	0	0	5,375	0	3,462
Nitzschia linearis (Ag. ex W. Sm.) W. Sm.	0	15,300	3,584	1,454	8,223
Nitzschia palea (Kütz.) W. Sm.	0	37,400	14,335	5,816	23,804
Nitzschia palea debilis (Kütz.) Grun.	0	91,801	35,836	18,176	17,312
Nitzschia palea tenuirostris Grun.	606	11,900	0	0	0
Nitzschia perminuta (Grun.) Peragallo	0	0	0	0	866
Nitzschia pusilla Grun.	0	1,700	0	0	0
Nitzschia recta Hantz. ex Rabh.	0	22,100	4,480	727	0
Nitzschia sigma (Kütz.) W. Sm.	0	0	1,792	0	0
Nitzschia sociabilis Hust.	0	13,600	8,063	8,725	0
Nitzschia solita Hust.	0	6,800	0	0	0
Nitzschia thermaloides Hust.	0	6,800	0	0	0
Nitzschia tropica Hust.	0	3,400	0	0	0
Simonsenia delognei (Grun.) Lange-Bert.	0	0	0	13,087	0
Surirella angusta Kütz.	0	3,400	1,792	0	0
Aulacosira alpigena (Grun.)Krammer	0	0	1,792	0	0
Aulacosira granulata (Ehr.) Simonsen	0	0	896	0	18,178
Aulacosira muzzanensis	0	1,700	12,543	1,454	0
"*Cyclostephanos invisitatus* (Hohn & Hellerman) Theriot, Stoermer, & Hakansson"	0	0	8,959	0	0
Cyclotella atomus Hust.	0	0	53,755	0	12,118
Cyclotella meneghiniana Kütz.	0	20,400	43,004	6,543	11,253
Cyclotella stelligera (Cl. & Grun.) V. H.	0	0	0	0	2,597
Stephanodiscus dubius (Fricke) Hust.	0	0	2,688	0	1,731

Appendix A. Periphyton taxa densities (cells/cm^2) for Upper Mississippi River Basin study unit small stream indicator sites, 1996 (Continued)

Taxon (Divisions, *genera*)	Namekagon River	North Fork Crow River	Shingle Creek	Nine Mile Creek	Little Cobb River
Stephanodiscus hantzschii Grun.	0	0	0	0	3,030
Stephanodiscus tenuis Hust.	0	0	1,792	0	2,597
Thalassiosira weissflogii (Grun.) Fryxell & Hasle	0	0	3,584	0	0
Chlorophycophyta					
Tetraedron minimum (A. Braun) Hansg.	0	0	0	647	0
Pediastrum duplex Meyen	0	0	9,836	0	0
Oedogonium sp. 0C UL NAWQA 96 TS	0	3,353	0	0	0
Ankistrodesmus falcatus (Corda) Ralfs	0	0	7,377	0	0
Gloeocystis vesiculosa Näg.	0	6,706	4,918	1,294	2,056
Protococcus viridis C.A. Ag.	0	0	0	0	7,196
Scenedesmus acuminatus (Lagerh.) Chod.	0	0	9,836	0	2,056
Scenedesmus bijuga (Turp.) Lagerh.	0	0	2,459	0	5,140
Scenedesmus brasilienses Bohlin	1,363	0	0	0	0
Scenedesmus protuberans Fritsch	0	0	9,836	0	9,252
Scenedesmus quadricauda (Turp.) Bréb.	0	0	0	1,294	0
Scenedesmus quadricauda longispina (Chodat) G.M. Sm.	0	0	17,213	0	8,224
Cryptophycophyta					
Cryptomonas sp. C UL 1996 NAWQA	0	0	0	647	0
Cyanochloronta					
Unknown Cyanophyte	0	21,795	2,459	1,294	28,784
Chroococcus dispersus (V. Keiss) Lemm.	0	0	4,918	6,470	0
Merismopedia tenuissima Lemm.	0	0	0	0	190,182
Anabaena constricta Szafer	0	26,824	0	0	0
Lyngbya aerugineo-caerulea (Kütz.) Gom.	77,336	0	68,850	0	6,168
Lyngbya lagerheimii (Moebius) Gom.	13,628	0	0	0	0
Lyngbya limnetica Lemm.	0	20,118	18,442	8,411	0
Oscillatoria formosa Bory	0	5,030	0	0	84,297
Oscillatoria limnetica Lemm.	76,655	343,686	343,022	29,761	13,878
Oscillatoria minnesotensis Tilden	19,760	6,706	4,918	3,882	2,056
Oscillatoria prolifica (Grev.) Gom.	0	0	0	0	2,570
Oscillatoria sp. B UL 1996 NAWQA Vaucher	0	20,118	118,029	0	1,542
Phormidium retzii (C. A. Ag.) Gom.	0	0	0	79,579	0
Euglenophycophyta					
Euglena	0	0	0	0	514
Strombomonas sp. A UL 1996 NAWQA	0	0	1,229	0	0
Trachelomonas curta De Cunha em. Defl.	0	0	18,442	0	514
Trachelomonas lefevrei Defl.	0	0	0	0	1,028

Appendix B. Benthic-invertebrate taxa abundances for Upper Mississippi River Basin study unit small stream indicator sites, 1996

[*, class; **suborder; ***, subfamily; --, no data]

Taxon (ORDER, Family, *genera*)	Namekagon River	North Fork Crow River	Shingle Creek	Nine Mile Creek	Little Cobb River
INSECTA* (insects)					
EPHEMEROPTERA (mayflies)	1	--	--	16	--
Baetidae	512	--	--	609	32
Baetis flavistriga McDunnough	--	--	--	176	48
Baetis sp.	--	--	--	477	--
Caenidae	--	--	--	--	--
Caenis sp.	--	--	--	--	48
Caenis spp.	--	192	--	--	--
Caenis youngi Roemhild	--	48	--	--	--
Ephemerellidae	5,386	--	--	--	--
Ephemeridae	--	16	--	--	--
Hexagenia sp.	--	1	--	--	--
Heptageniidae	--	--	--	--	512
Stenacron sp.	--	--	--	212	--
Stenacron interpunctatum Say	--	--	--	35	--
Stenonema sp.	320	--	--	--	704
Stenonema spp.	--	96	--	--	--
Stenonema mediopunctatum McDunnough	--	16	--	--	--
Stenonema terminatum Walsh	--	16	--	--	--
Stenonema vicarium Walker	132	--	--	--	--
Isonychiidae	--	--	--	--	--
Isonychia sp.	64	--	--	--	52
Leptophlebiidae	--	144	--	--	16
Paraleptophlebia sp.	--	400	--	--	--
Tricorythidae	--	--	--	--	--
Tricorythodes sp.	--	16	--	--	192
PLECOPTERA (stoneflies)	192	--	--	--	--
Perlidae	--	--	--	--	--
Acroneuria sp.	6	--	--	--	12
Paragnetina media Walker	11	2	--	--	--
Pteronarcyidae	--	--	--	--	--
Pteronarcys sp.	47	1	--	--	5
TRICHOPTERA (caddisflies)	--	--	--	--	--
Brachycentridae	--	--	--	--	--
Brachycentrus americanus Banks	128	--	--	--	--
Brachycentrus lateralis Say	148	--	--	--	--
Hydropsychidae	960	16	365	272	208
Ceratopsyche sp.	514	--	1	--	--
Ceratopsyche sparna Ross	2	--	--	--	--
Cheumatopsyche sp.	64	--	155	--	--
Hydropsyche sp.	--	--	108	1	68
Hydropsyche spp.	--	--	--	--	--
Hydropsyche betteni Ross	--	--	120	5	--
Nectopsyche candida Hagen	--	32	--	--	--
Nectopsyche diarina Ross	--	--	--	1	--
Hydropsyche scalaris group	--	--	--	--	1
Nectopsyche sp.	--	--	--	2	--
Hydroptilidae	--	--	--	--	--

Appendix B. Benthic-invertebrate taxa abundances for Upper Mississippi River Basin study unit small stream indicator sites, 1996 (Continued)

[*, class; **suborder; ***, subfamily; --, no data]

Taxon (ORDER, Family, *genera*)	Namekagon River	North Fork Crow River	Shingle Creek	Nine Mile Creek	Little Cobb River
Hydroptila sp.	65	--	--	16	--
Leptoceridae	--	--	--	--	--
Oecetis sp.	--	16	--	--	--
Philopotamidae	--	--	--	--	--
Chimarra sp.	327	16	--	--	--
ODONATA (dragon/damselflies)	--	--	--	--	--
Anisoptera** (dragonflies)	--	--	--	--	--
Aeshnidae	--	--	--	--	--
Boyeria vinosa Say	1	--	--	--	--
Gomphidae	128	--	--	--	--
Gomphus sp.	1	--	--	--	--
Ophiogomphus sp.	2	--	--	--	--
Zygoptera** (damselflies)	--	--	--	--	--
Calopterygidae	--	--	--	--	--
Calopteryx sp.	1	24	9	34	--
Calopteryx aequabilis Say	--	4	--	--	--
Coenagrionidae	--	33	9	--	--
Enallagma sp.	--	--	1	--	--
Hetaerina sp.	--	18	--	--	--
HEMIPTERA (true bugs)	--	--	--	--	--
Belostomatidae	--	--	--	--	--
Belostoma flumineum Say	--	6	1	8	8
Corixidae	--	--	32	--	--
Sigara sp.	--	--	9	--	--
Trichocorixa sp.	--	--	1	--	--
Nepidae	--	--	--	--	--
Ranatra fusca Palisot de Beauvois	--	--	--	1	--
MEGALOPTERA (dobsonflies/hellgrammites)	--	--	--	--	--
Corydalidae	--	--	--	--	--
Chauliodes pectinicornis Linnaeus	--	--	--	--	2
Nigronia serricornis Say	64	--	--	--	--
Sialidae	--	--	--	--	--
Sialis sp.	--	16	--	--	--
COLEOPTERA (beetles)	--	--	--	--	--
Curculionidae	--	--	--	--	16
Dytiscidae	--	--	--	--	--
Laccophilus maculosus Say	--	--	--	--	1
Liodessus sp.	--	--	--	16	--
Elmidae	--	--	--	--	--
Dubiraphia sp.	--	297	9	--	--
Macronychus glabratus Say	64	--	--	--	--
Optioservus sp.	196	16	--	--	--
Stenelmis sp.	--	96	--	--	49
Stenelmis spp.	--	111	--	--	--
Stenelmis crenata group	--	--	--	1	--
Stenelmis sexlineata Sanderson	--	1	--	--	--
DIPTERA (true flies)	--	--	--	--	--
Chironomidae	128	16	40	16	16

Appendix B. Benthic-invertebrate taxa abundances for Upper Mississippi River Basin study unit small stream indicator sites, 1996 (Continued)

[*, class; **suborder; ***, subfamily; --, no data]

Taxon (ORDER, Family, *genera*)	Namekagon River	North Fork Crow River	Shingle Creek	Nine Mile Creek	Little Cobb River
Tanypodinae**	128	80	144	80	80
Procladius sp.	--	16	--	--	--
Ablabesmyia sp.	--	16	--	16	--
Nilotanypus sp.	--	--	--	--	32
Labrundinia sp.	--	16	--	--	--
Tanypus sp.	--	--	8	--	--
Thienemannimyia group sp.	256	80	136	114	112
Orthocladiinae**	512	16	8	48	--
Corynoneura sp.	256	--	--	--	--
Eukiefferiella sp.	128	--	--	--	--
Thienemanniella sp.	896	16	--	16	--
Brillia sp.	384	--	--	68	--
Cricotopus sp.	388	48	--	--	--
Cricotopus spp.	--	--	--	--	--
Cricotopus/Orthocladius sp.	450	128	--	65	--
Parakiefferiella sp.	--	--	--	16	--
Parametriocnemus sp.	--	--	--	17	16
Rheocricotopus sp.	192	--	--	49	16
Tvetenia sp.	2,576	--	--	2	--
Chironominae**	--	144	41	80	16
Chironomini***	--	--	--	16	--
Chironomus sp.	--	96	8	--	--
Cryptochironomus sp.	--	16	16	--	--
Dicrotendipes sp.	--	16	3	--	--
Endochironomus sp.	--	--	16	--	--
Glyptotendipes sp.	--	--	335	--	16
Harnischia sp.	--	16	--	--	--
Microtendipes sp.	--	32	--	--	--
Nanocladius sp.	--	32	--	--	96
Phaenopsectra sp.	64	64	--	48	--
Polypedilum sp.	--	240	88	148	608
Saetheria sp.	--	--	--	16	--
Stenochironomus sp.	128	32	--	--	80
Tribelos sp.	--	176	--	--	--
Tanytarsini***	--	32	--	--	--
Stempellinella sp.	--	--	--	--	16
Rheotanytarsus sp.	256	336	24	--	112
Paratanytarsus sp.	--	32	8	--	--
Tanytarsus sp.	--	32	8	32	--
Athericidae	--	--	--	--	--
Atherix variegata Walker	2	4	--	--	119
Ceratopogonidae	--	--	--	--	--
Forcipomyia sp.	--	--	8	--	--
Dryopidae	--	--	--	--	--
Helichus lithophilus Germar	--	--	--	--	16
Empididae	--	--	--	--	--
Hemerodromiinae**	64	--	--	--	--
Hemerodromia sp.	258	--	48	--	48

Appendix B. Benthic-invertebrate taxa abundances for Upper Mississippi River Basin study unit small stream indicator sites, 1996 (Continued)

[*, class; **suborder; ***, subfamily; --, no data]

Taxon (ORDER, Family, *genera*)	Namekagon River	North Fork Crow River	Shingle Creek	Nine Mile Creek	Little Cobb River
Psychodidae	--	--	--	16	--
Pericoma/Telmatoscopus sp.	--	--	8	--	--
Simuliidae	1,408	--	--	304	--
Simulium sp.	423	--	--	218	20
Tipulidae	--	48	8	--	1, 026
Antocha sp.	128	--	--	--	--
Tipulinae**	--	--	--	16	--
Tipula sp.	--	--	--	1	--
Chelicerata	--	--	--	--	--
Acari (water mites)	64	32	8	--	128
Hydrachnidia	--	--	--	--	--
"AMPHIPODA (scuds, shrimp)"	--	--	--	--	--
Gammaridae	--	--	--	--	--
Gammarus sp.	195	--	--	--	--
Hyalellidae	--	--	--	--	--
Hyalella azteca Saussure	--	48	1	--	16
ISOPODA (aquatic sow bugs)	--	--	--	--	--
Caecidotea sp.	--	--	88	32	--
"DECAPODA (crayfish, shrimp)"	--	--	--	--	--
Orconectes sp.	1	2	9	2	1
Oligochaeta (aquatic worms)	--	--	--	--	--
ENCHYTRAEIDA	--	--	--	--	--
Enchytraeidae	--	--	8	--	--
LUMBRICULIDA	--	--	--	--	--
Lumbriculidae	2	--	--	--	--
TUBIFICIDA	--	--	--	--	--
Naididae	128	16	355	16	48
Tubificidae	64	--	280	--	--
Hirudinea (leeches)	--	--	--	--	--
ARHYNCHOBDELLAE	--	--	--	--	--
Erpobdellidae	--	--	--	1	--
Glossiphoniidae	--	--	1	--	--
Placobdella sp.	--	--	--	--	1
Bivalvia (bivalve mollusks)	--	--	--	--	--
VENEROIDA	--	--	--	--	--
Sphaeriidae	2	1	9	--	--
"Gastropoda (snails, limpets)"	--	--	--	--	--
Ancylidae	--	--	8	--	--
Ferrissia sp.	--	16	16	32	--
Physidae	--	--	11	--	--
Physella sp.	--	48	5	64	--
Viviparidae	--	--	--	--	--
Viviparus sp.	--	--	16	--	--
Pseudosuccinea columella Say	3	--	--	--	--
Hydrozoa	--	--	--	--	--
Hydridae	--	--	--	--	--
Hydra sp.	--	--	49	--	--
Turbellaria (flatworms)	--	--	--	16	--

Appendix C. Periphyton taxa densities (cells/cm^2) for Upper Mississippi River Basin study unit large river integrator sites, 1996

Taxon (Division, *genera*)	Royalton	Anoka	Hastings	Red Wing	Jordan	Danbury	St. Croix Falls
Chrysophycophyta (diatoms)	0	0	0	0	0	0	0
Achnanthes biasolettiana (Kütz.) Grun.	0	890	0	0	0	40,927	28,220
Karayevia clevei Grun. in Cl. et Grun.	0	0	0	0	0	12,278	9,960
Achnanthes exigua Grun.	0	0	0	0	0	8,185	0
Achnanthes lanceolata (Bréb. in Kütz.) Grun.	7,267	8,012	8,757	0	0	21,487	14,940
Achnanthes lanceolata subsp. rostrata (Øestrup) Lange-Bertalot	9,690	5,341	2,919	0	0	41,950	41,500
Psammothidium marginulatum (Grun) Bukt. and Round	0	0	0	0	0	0	3,320
Achnanthidium minutissimum (Kützing) Czarnecki	25,436	890	0	5,382	404	31,718	53,120
Achnanthes peragalli Brun & Hérib.	0	0	0	0	0	20,46	0
Cocconeis neodiminuta Kramm.	0	0	0	0	0	14,324	3,320
Cocconeis pediculus Ehr.	4,845	1,780	0	7,176	270	14,324	0
Cocconeis placentula Ehr.	30,281	8,902	5,838	10,764	2,966	126,874	59,761
Cocconeis placentula var. euglypta (Ehr.) Cl.	116,279	17,805	5,838	7,176	674	30,695	43,160
Cocconeis placentula var. lineata (Ehr.) V. H.	1,211	3,561	0	0	0	0	19,920
Pleurosira laevis (Ehrenberg) Compere	0	0	0	8,970	0	0	0
Diatoma vulgaris Bory	4,845	0	0	23,321	0	0	9,960
Pseudostaurosira brevistriata (Grun. in V.H.) Williams & Round	0	0	0	0	0	23,533	49,800
Fragilaria capucina Desm.	0	0	0	0	0	0	19,920
Fragilaria capucina var. vaucheriae (Kütz.) Lange-Bert.	0	1,780	0	0	270	6,139	3,320
Staurosira construens (Ehr.) Williams & Round	0	0	0	0	0	10,232	33,200
Staurosira construens var. venter (Ehr.) Hamilton	0	0	0	5,382	0	0	89,641
Fragilaria fasciculata (C. Ag.) Lange-Bert.	0	0	2,919	21,527	0	0	0
Fragilaria nanana Lange-Bert.	0	0	5,838	0	0	0	0
Staurosirella pinnata (Her.) Williams & Round	13,324	5,341	0	3,588	0	18,417	36,520
Opephora pacifica Grun.	0	0	0	0	0	6,139	3,320
Pseudostaurosira brevistriata 0A UL NAWQA 96 KM	0	0	0	0	0	1,023	0
Synedra ulna (Nitz.) Ehr.	0	0	20,434	55,613	0	0	0
Melosira varians Ag.	53,295	0	29,19	87,904	1,348	14,324	46,480
Amphipleura pellucida (Kütz.) Kütz.	0	0	0	0	0	2,046	0
Amphora inariensis Kramm.	0	0	0	0	0	0	6,640
Amphora libyca Ehr.	0	1,780	0	0	0	0	0
Amphora montana Krass.	0	5,341	0	0	539	0	3,320
Amphora ovalis (Kütz.) Kütz.	4,845	3,561	0	0	0	0	0
Staurosirella pinnata (Her.) Williams & Round	32,704	40,061	10,217	41,261	1,078	15,348	11,620
Caloneis bacillum (Grun.) Cl.	0	890	0	0	0	2,046	0
Caloneis schumanniana (Grun.) Cl.	0	0	0	0	0	1023	0
Capartogramma crucicula (Grun. ex Cl.) Ross	1,211	0	0	0	0	0	0
Craticula cuspidata (Kutzing) Mann	0	0	0	0	270	0	0
Cymbella affinis Kütz.	0	0	0	0	0	0	3,320
Cymbella amphicephala Naeg. ex Kütz.	0	0	0	0	0	2,046	0

Appendix C. Periphyton taxa densities (cells/cm^2) for Upper Mississippi River Basin study unit large river integrator sites, 1996 (Continued)

Taxon (Division, *genera*)	Royalton	Anoka	Hastings	Red Wing	Jordan	Danbury	St. Croix Falls
Encyonema minutum (Hilse in Rabenhorst) Mann	2,422	0	0	3,588	0	2,046	0
Encyonema silesiacum (Bleic. in Raben.) Mann	0	0	0	0	0	1,023	0
Cymbella tumida (Bréb. ex Kütz.) V. H.	4,845	5,341	1,460	3,588	135	0	0
Diploneis pseudovalis Hust.	1,211	0	0	0	0	0	0
Frustulia rhomboides var. amphipleuroides (Grun.) DeT.	0	0	0	0	0	0	1,660
Gomphonema acuminatum Ehr.	0	0	0	0	0	0	3,320
Gomphonema affine Kütz.	0	0	0	14,352	2,426	0	0
Gomphonema angustatum (Kütz.) Rabh.	0	0	0	7,176	809	0	0
Gomphonema clevei Fricke	0	0	0	0	539	0	0
Gomphonema grovei M. Schmidt	0	0	0	3,588	0	0	0
Gomphonema minutum 1 UL NAWQA 96 KM	2,422	0	0	0	0	0	0
Gomphonema olivaceum (Lyngb.) Kütz.	0	0	0	3,588	0	0	0
Gomphonema parvulum (Kütz.) Kütz.	0	8,902	27,732	3,588	4,988	0	13,280
Gomphonema pumilum (Grun.) Reich. & Lange-Bert.	0	7,122	0	0	944	10,232	3,320
Gomphonema sp. 1?	0	1,780	0	0	0	0	0
Gomphonema minutum (C.A. Agardh) C.A. Agardh	53,295	13,354	20,434	21,527	4,179	9,209	23,240
Gyrosigma attenuatum (Kütz.) Rabh.	4,845	0	0	0	0	0	0
Craticula accomoda (Hustedt) Mann	0	1,780	0	0	0	0	0
Navicula angusta Grun.	0	1,780	0	0	539	0	1,660
Navicula arvensis Hust.	0	3,561	13,136	0	0	0	0
Navicula atomus (Kütz.) Grun.	0	18,695	0	0	0	0	0
Navicula capitata Ehr.	2,422	0	1,460	3,588	0	5,116	0
Navicula capitatoradiata Germain	50,872	29,378	0	3,588	0	4,093	34,860
Navicula citrus Krass.	0	890	0	0	0	0	0
Navicula cryptocephala Kütz.	0	0	5,838	0	0	2,046	11,620
Navicula cryptotenella L.B. in Kramm. & L.-B.	41,182	47,182	0	25,115	2,157	6,139	21,580
Navicula decussis Østr.	0	3,561	0	7,176	0	0	3,320
Placoneis elginensis (Greg.) Cox	0	890	0	0	0	0	0
Navicula exilis Kütz.	0	8,902	5,838	0	0	0	6,640
Luticola goeppertiana Mann	0	1,780	30,651	17,940	0	0	0
Navicula gregaria Donk.	8,479	0	2,919	7,176	0	0	6,640
Navicula harderii Hust.	0	8,012	0	0	0	0	6,640
Navicula heufleri Choln.	0	0	0	10,764	0	0	0
Navicula heufleri var. leptocephala (Brèb ex Grun.) Perag.	0	0	27,732	0	0	0	0
Sellaphora laevissima (Kütz.) Mann	0	0	0	0	0	0	1,660
Navicula menisculus Schum.	3,634	0	7,298	3,588	0	0	3,320
Navicula minima Grun.	19,380	81,902	0	17,940	5,39	22,510	63,081
Navicula molestiformis Hust.	0	5,341	0	0	0	0	0
Luticola mutica (Kütz.) Mann	0	0	143,037	0	270	0	3,320
Luticola ventricosa (Kütz.) Mann	0	0	49,625	0	0	0	0
Navicula phyllepta Kütz.	0	0	1,460	0	0	0	0
Fallacia pygmaea (Kütz.) Stickle & Mann	0	0	0	0	270	0	0

Appendix C. Periphyton taxa densities (cells/cm^2) for Upper Mississippi River Basin study unit large river integrator sites, 1996 (Continued)

Taxon (Division, *genera*)	Royalton	Anoka	Hastings	Red Wing	Jordan	Danbury	St. Croix Falls
Navicula germainii Wallace	20,591	3,561	2,919	8,970	0	0	6,640
Navicula schoenfeldii Hust.	0	0	2,919	0	0	0	0
Navicula schroeteri symmetrica (Patrick) Lang.-Bert.	29,070	0	0	7,176	0	0	0
Navicula schroeterii Meist.	0	0	0	0	0	0	6,640
Navicula seminuloides Hust.	0	0	0	0	0	0	11,620
Sellaphora seminulum (Grun.) Mann	25,436	10,683	0	0	0	11,255	3,320
Navicula sp. 0L UL NAWQA KM	0	0	0	0	0	0	3,320
Navicula subminuscula Mang.	1,9380	9,793	27,732	7,176	0	0	0
Navicula tantula Hust.	0	0	0	0	0	0	3,320
Navicula tenelloides Hust.	2,422	0	5,838	0	0	0	9,960
Fallacia tenera (Hust.) Mann	2,422	0	0	0	0	0	0
Navicula tripunctata (O. F. Müll.) Bory	4,845	8,902	5,838	10,764	539	0	14,940
Navicula tripunctata var. schizonemoides (V. H.) Patr.	0	0	169,309	208,099	4,853	0	0
Navicula trivialis Lange-Bert.	0	3,561	2,919	7,176	1,483	0	9,960
Navicula cryptocephala var. veneta (Kütz.) Rabh.	15,746	1,780	2,919	0	0	0	0
Navicula viridula (Kütz.) Kütz. emend. V. H.	0	0	0	3,588	0	0	0
Navicula viridula var. linearis Hust.	1,211	0	0	0	0	0	11,620
Navicula viridula var. rostellata (Kütz.) Cl.	0	890	0	0	0	0	11,620
Pinnularia spp.	0	1,780	0	0	0	0	0
Pleurosigma angulatum (Quek.) W. Sm.	0	0	0	0	1,887	0	0
Reimeria sinuata (Greg.) Kociolek & Stoermer	2,422	0	0	0	0	6,139	0
Rhoicosphenia curvata (Kütz.) Grun. ex Rabh.	46,027	63,207	51,085	62,788	21,030	2,046	29,880
Stauroneis phoenicenteron (Nitz.) Ehr.	0	0	0	1,794	0	0	0
Stauroneis thermicola (Peters.) Lund	0	0	5,838	0	0	0	0
Bacillaria paradoxa Gmelin in L.	0	0	0	21,527	0	0	0
Hantzschia amphioxys (Ehr.) Grun.	0	0	0	0	270	0	0
Nitzschia acicularis (Kütz.) W. Sm.	0	3,561	0	7,176	0	0	0
Nitzschia amphibia Grun.	23,014	13,354	33,570	55,613	8,762	2,046	9,960
Nitzschia capitellata Hust.	2,422	0	0	0	0	0	0
Nitzschia clausii Hantz.	0	0	0	0	0	0	3,320
Nitzschia dissipata (Kütz.) Grun.	26,647	1,780	8,757	19,733	2,292	4,093	28,220
Nitzschia filiformis (W. Sm.) V. H.	0	0	0	16,146	0	0	0
Nitzschia filiformis var. conferta (Reich.) Lange-Betralot	0	0	27,732	43,055	0	0	0
Nitzschia frustulum (Kütz.) Grun.	0	0	7,298	0	0	0	0
Nitzschia gracilis Hantz. ex Rabh.	2,422	0	0	10,764	2,70	6,139	0
Tryblionella hungarica (Grun.) Mann	2,422	0	2,919	0	0	0	0
Nitzschia inconspicua Grun.	0	0	0	0	0	2,046	0
Nitzschia intermedia Hantz. ex Cl. et Grun.	0	3,561	0	3,588	0	0	0
Nitzschia linearis (Ag. ex W. Sm.) W. Sm.	0	0	0	7,176	674	0	0
Nitzschia palea var. (Kütz.) W. Sm.	0	8,902	17,515	0	0	0	3,320
Nitzschia palea var. debilis (Kütz.) Grun.	12,112	35,609	10,217	3,2291	1,213	4,093	43,160
Nitzschia palea var. tenuirostris Grun.	0	1,780	0	0	0	0	3,320

Appendix C. Periphyton taxa densities (cells/cm^2) for Upper Mississippi River Basin study unit large river integrator sites, 1996 (Continued)

Taxon (Division, *genera*)	Royalton	Anoka	Hastings	Red Wing	Jordan	Danbury	St. Croix Falls
Nitzschia perminuta (Grun.) Peragallo	0	0	7,298	0	0	0	149,40
Nitzschia recta Hantz. ex Rabh.	25,436	0	0	0	0	0	3,320
Nitzschia sociabilis Hust.	32,704	4,451	0	10,764	944	0	0
Nitzschia sp. 0L UL NAWQA KM	1,211	0	0	0	0	0	0
Nitzschia tropica Hust.	0	3,561	0	0	270	0	0
Tryblionella victoriae Grun.	1,211	0	0	0	0	0	0
Simonsenia delognei (Grun.) Lange-Bert.	4,845	1,780	0	0	0	0	0
Cymatopleura solea var. apiculata (W. Sm.) Ralfs	0	890	0	0	0	0	0
Surirella angusta Kütz.	2,422	0	0	0	0	0	0
Surirella brebissonii kuetzingii Kramm. & Lange-Bert.	0	0	0	0	0	0	6,640
Surirella linearis helvetica (Brun) Meist.	1,211	0	0	0	0	0	0
Surirella minuta Bréb.	2,422	0	0	0	0	0	0
Surirella splendida (Ehr.) Kütz.	0	0	0	0	0	2,046	0
Aulacosira alpigena (Grun.)Krammer	25,436	0	0	7,176	0	0	0
Aulacosira ambigua (Grun.) Simonsen	12,112	0	2,919	16,146	2,022	63,437	24,900
Aulacosira granulata (Ehr.) Simonsen	0	0	13,136	5,3819	3,640	8,185	13,280
"*Cyclostephanos invisitatus* ""(Hohn & Hellerman) Theriot, Stoermer, & Hakansson"""	3,634	1,780	10,217	8,970	0	0	9,960
Cyclotella atomus Hust.	8,479	13,354	17,515	25,115	1,887	0	0
Cyclotella meneghiniana Kütz.	27,859	5,341	2,919	3,588	3,370	4,093	3,320
Cyclotella nana Hust.	0	0	5,838	0	0	0	0
Cyclotella ocellata Pant.	0	0	1,460	0	0	0	0
Cyclotella pseudostelligera Hust.	0	1,780	0	0	0	0	0
Stephanodiscus dubius (Fricke) Hust.	0	0	0	17,940	1,078	0	0
Stephanodiscus hantzschii Grun.	0	0	42,327	0	539	0	0
Stephanodiscus minutulus (Kütz.) Cleve & Moller	0	1,780	35,030	16,146	0	0	0
Stephanodiscus niagarae Ehr.	0	0	0	0	0	0	1,660
Stephanodiscus tenuis Hust.	0	6,232	0	0	0	0	0
Thalassiosira weissflogii (Grun.) Fryxell & Hasle	0	890	0	0	0	0	0
Unknown alga Rhodophyte (red algae)	0	0	0	0	0	0	1,262
Unknown Rhodophyte UL NAWQA 1996 TS (filament)	0	0	0	0	30,491	0	0
Chlorophycophyta (green algae)							
Chlamydomonas sp. B UL 1996 NAWQA Ehr.	0	0	0	1,540	0	0	0
Tetraedron caudatum (Corda) Hansg.	1,513	0	0	0	0	0	0
Tetraedron minimum (A. Braun) Hansg.	1,513	0	0	0	0	0	0
Microspora tumidula Hazen	0	0	15,026	0	0	0	0
Ankistrodesmus falcatus (Corda) Ralfs	0	0	0	0	884	664	0
Oocystis solitaria Wittr.	0	0	0	0	221	0	0
Gloeocystis vesiculosa Näg.	0	6,702	1,670	0	0	0	0

Appendix C. Periphyton taxa densities (cells/cm^2) for Upper Mississippi River Basin study unit large river integrator sites, 1996 (Continued)

Taxon (Division, *genera*)	Royalton	Anoka	Hastings	Red Wing	Jordan	Danbury	St. Croix Falls
Coelastrum indicum Turner	24,200	0	0	0	0	0	0
Scenedesmus acuminatus (Lagerh.) Chod.	0	2,872	0	0	2,430	0	0
Scenedesmus bicaudatus (Hansg.) Chod.	6,050	3,830	0	0	0	0	0
Scenedesmus bijuga (Turp.) Lagerh.	12,100	12,447	6,678	0	0	0	0
Scenedesmus dispar Bréb.	0	0	0	0	884	0	0
Scenedesmus protuberans Fritsch	0	3,830	0	0	884	0	0
Scenedesmus quadricauda (Turp.) Bréb.	0	3,830	0	0	0	0	5,049
Scenedesmus quadricauda var. longispina (Chodat) G.M. Sm.	15,125	0	0	0	442	0	0
Scenedesmus quadricauda var. UL NAWQA 1997 TS (extra spine)	12,100	3,830	0	0	442	2,657	0
Scenedesmus quadricuada var. Westii G.M. Sm.	0	0	0	0	0	0	10,098
Tetrastrum staurogeniaeforme (Schröd.) Lemm.	0	0	0	6,159	0	0	0
Cyanochloronta							
Unknown Cyanophyte	0	0	0	15,398	5,082	0	0
Chroococcus dispersus (V. Keiss) Lemm.	0	19,149	0	0	0	0	0
Coelosphaerium kuetzingianum Näg.	0	38,298	0	0	0	0	0
Merismopedia glauca (Ehr.) Näg.	199,651	0	0	0	0	0	0
Merismopedia tenuissima Lemm.	12,100	22,979	13,357	0	17,676	0	0
Microcystis aeruginosa Kütz.	0	57,447	0	0	0	0	0
Lyngbya aerugineo-caerulea (Kütz.) Gom.	0	0	0	0	11,489	10,630	10,098
Lyngbya aestuarii (Mert.) Liebmann	0	0	0	474,249	0	0	0
Lyngbya lagerheimii (Moebius) Gom.	0	0	352,280	0	0	0	50,489
Lyngbya limnetica Lemm.	7,563	6,702	0	50,812	2,651	5,979	0
Oscillatoria formosa Bory	27,225	25,851	0	0	1,105	0	0
Oscillatoria limnetica Lemm.	15,125	37,341	25,044	66,210	45,737	27,903	7,573
Oscillatoria limosa (Dillw.) Ag.	0	0	0	0	0	1,329	12,622
Oscillatoria minnesotensis Tilden	0	15,319	0	0	2,210	1,329	0
Oscillatoria prolifica (Grev.) Gom.	0	26,809	0	0	2,651	0	0
Oscillatoria sp B UL 1996 NAWQA Vaucher	9,075	0	0	0	0	0	0
Oscillatoria tenuis C.A. Ag.	0	0	0	7,699	0	1,329	8,836
Phormidium ambiguum Gom.	0	0	253,775	0	0	0	0
Oscillatoria retzii Ag.	0	0	0	0	0	7,308	15,147
Euglenophycophyta							
Euglena sp. 1996 NAWQA (small)	0	957	0	0	0	0	0
Phacus acuminatus Stokes	0	957	0	0	0	0	0
Strombomonas verrucosa (Daday) Defl.	0	0	0	1,540	0	0	0
Trachelomonas curta De Cunha em. Defl.	0	0	0	0	442	0	0

Appendix D. Benthic-invertebrate taxa abundances for Upper Mississippi River Basin study unit large river integrator sites, 1996

[*, class; **, suborder; ***, family; --, no data]

Taxon ORDER, Family, *genera*)	Royalton	Anoka	Hastings	Red Wing	Jordan	Danbury	St. Croix Falls
Insecta* (insects)	--	--	--	--	--	--	--
EPHEMEROPTERA (mayflies)	--	--	--	--	--	--	--
Baetidae	--	16	--	16	153	96	--
Baetis sp.	--	--	--	--	--	16	--
Plauditus sp.	--	--	--	--	--	80	--
Caenidae	--	--	--	--	--	--	--
Amercaenis ridens McDunnough	--	--	--	--	1	--	--
Caenis sp.	32	--	--	16	8	--	1,009
Ephemerellidae	--	--	--	16	--	368	--
Ephemeridae	--	--	--	--	16	--	--
Ephemera sp.	--	--	--	--	17	--	--
Heptageniidae	16	32	--	--	48	82	32
Heptagenia sp.	--	--	--	--	3	--	--
Stenonema sp.	--	--	8	--	26	130	1
Stenonema mexicanum Ulmer	--	--	--	--	26	--	--
Stenonema vicarium Walker	--	--	--	--	--	16	--
Isonychiidae	--	--	--	--	--	--	--
Isonychia sp.	--	--	--	--	10	48	--
Leptophlebiidae	32	16	--	--	--	32	33
Paraleptophlebia sp.	96	32	--	--	--	1,088	96
Tricorythidae	--	--	--	--	--	--	--
Tricorythodes sp.	16	--	--	--	--	64	--
Potamanthidae	--	--	--	--	--	--	--
Anthopotamus sp.	16	--	--	32	--	--	--
Anthopotamus verticis Say	--	--	--	34	--	--	--
ODONATA (dragon/damselflies)	--	--	--	--	--	--	--
Aeshnidae	--	--	--	--	--	--	--
Boyeria vinosa Say	--	--	--	--	--	3	--
Calopterygidae	--	--	--	--	--	--	--
Calopteryx sp.	3	--	--	--	--	11	--
Coenagrionidae	55	--	--	--	1	--	40
Enallagma sp.	3	--	--	--	--	--	--
Hetaerina sp.	2	--	--	--	--	--	--
Hetaerina americana Fabricius	3	--	--	--	--	--	--
Anisoptera**	--	--	--	--	--	--	--
Corduliidae	--	--	--	--	--	--	--
Neurocordulia molesta Walsh	--	--	--	--	--	--	19
Gomphidae	--	--	--	1	1	4	1
Dromogomphus spinosus Selys	--	--	--	--	--	6	--
Gomphus sp.	--	--	--	--	--	2	--
Hagenius brevistylus Selys	--	--	--	--	--	1	1
PLECOPTERA (stoneflies)	--	--	--	--	--	48	--
Perlidae	--	--	--	17	--	--	--
Acroneuria sp.	--	--	--	--	--	17	--

Appendix D. Benthic-invertebrate taxa abundances for Upper Mississippi River Basin study unit large river integrator sites, 1996 (Continued)

[*, class; **, suborder; ***, family; --, no data]

Taxon ORDER, Family, *genera*)	Royalton	Anoka	Hastings	Red Wing	Jordan	Danbury	St. Croix Falls
Pteronarcyidae	--	--	--	--	--	--	--
Pteronarcys sp.	1	--	--	--		9	--
Taeniopterygidae	--	--	--	--	--	96	--
HEMIPTERA (true bugs)	--	--	--	--	--	--	--
Belastomatidae	--	--	--	--	--	--	--
Belostoma flumineum Say	10	2	--	--	--	2	10
Corixidae	--	16	40	16	8	--	--
Nepidae	--	--	--	--	--	--	--
Ranatra fusca Palisot de Beauvois	1	5	--	--	--	--	--
Nigronia serricornis Say	--	--	--	--	--	2	--
Pleidae	--	--	--	--	--	--	--
Neoplea striola Fieber	--	16	--	--	8	--	32
TRICHOPTERA (caddisflies)	--	--	--	--	--	--	--
Brachycentridae	--	--	--	--	--	--	--
Brachycentrus numerosus Say	--	--	--	--	--	34	--
Hydropsychidae	--	--	--	32	408	416	--
Ceratopsyche sp.	--	--	--	16	--	--	--
Ceratopsyche morosa Hagen	--	--	--	--	--	180	--
Cheumatopsyche sp.	--	--	--	--	--	436	65
Hydropsyche sp.	--	--	--	2	174	--	--
Hydropsyche spp.	--	--	--	--	--	--	--
Hydropsyche bidens Ross	--	--	--	32	134	--	33
Hydropsyche orris Ross	--	--	--	52	--	--	--
Hydropsyche phalerata Hagen	--	--	--	--	--	40	--
Hydropsyche scalaris group	--	--	--	--	--	64	--
Hydropsyche simulans Ross	--	--	--	--	51	--	--
Potamyia flava Hagen	--	--	0	--	65	--	--
Hydroptilidae	--	--	8	1	--	48	--
Agraylea multipunctata Curtis	--	--	--	--	--	--	4
Agraylea sp.	--	--	--	--	--	--	39
Hydroptila sp.	--	--	0	325	8	566	64
Mayatrichia ayama Mosely	--	--	--	--	2	--	--
Orthotrichia sp.	--	--	--	--	--	--	1
Limnephilidae	--	--	--	--	--	16	--
Nectopsyche sp.	--	--	--	--	--	--	33
Nectopsyche candida Hagen	--	--	--	--	--	--	1
Nectopsyche exquisita Walker	--	--	--	--	--	32	--
Leptoceridae	--	--	--	--	--	32	--
Ceraclea sp.	16	--	--	--	--	--	--
Oecetis sp.	--	--	--	--	--	96	324
Philopotamidae	--	--	--	--	--	--	--
Chimarra sp.	--	--	--	--	--	128	--
Polycentropodidae	16	--	0	2	--	--	--
Cyrnellus fraternus (Banks)	--	--	--	1	--	--	--
Psychomyiidae	--	--	--	--	--	--	--

Appendix D. Benthic-invertebrate taxa abundances for Upper Mississippi River Basin study unit large river integrator sites, 1996 (Continued)

[*, class; **, suborder; ***, family; --, no data]

Taxon ORDER, Family, *genera*)	Royalton	Anoka	Hastings	Red Wing	Jordan	Danbury	St. Croix Falls
Neureclipsis sp.	--	--	--	--	--	144	--
COLEOPTERA (beetles)	--	--	--	--	--	--	--
Dytiscidae	--	--	--	--	--	--	--
Agabus sp.	16	--	--	--	--	--	--
Gyrinidae	--	--	--	--	--	--	--
Gyrinus aeneolus LeConte	37	--	--	--	--	--	--
Dineutus discolor Aubé	3	--	--	--	--	2	1
Elmidae	--	--	8	--	--	--	--
Dubiraphia sp.	96	16	--	--	--	82	67
Stenelmis crenata Say	1	--	--	--	--	--	--
Stenelmis sp.	81	16	--	--	--	--	--
Stenelmis spp.	--	18	--	--	--	--	--
Macronychus glabratus Say	8	--	--	--	--	--	2
Scirtidae	--	48	--	--	--	--	--
LEPIDOPTERA	--	--	--	--	--	--	--
Pyralidae	--	--	--	--	--	--	--
Parapoynx sp.	6	--	--	--	--	19	--
COLLEMBOLA	--	32	--	--	--	--	--
DIPTERA (true flies)	--	--	--	--	--	--	--
Brachycera	--	--	--	--	32	--	--
Chironomidae	32	--	8	1	--	32	--
Tanypodinae**	--	16	--	--	8	64	--
Procladius sp.	32	--	--	--	--	48	--
Ablabesmyia sp.	--	--	--	--	--	32	--
Labrundinia sp.	--	--	--	--	--	32	--
Pentaneura sp.	--	--	--	--	--	48	--
Thienemannimyia group sp.	32	--	--	--	--	80	--
Orthocladiinae**	112	16	48	178	8	116	64
Limnophyes sp.	--	16	--	--	--	--	--
Corynoneura sp.	48	--	--	--	--	64	--
Thienemanniella sp.	48	16	--	--	--	48	--
Brillia sp.	--	--	--	--	--	--	1
Cricotopus sp.	256	16	24	--	--	32	128
Cricotopus/Orthocladius sp.	48	--	408	713	--	144	33
Nanocladius sp.	--	32	16	16	--	--	--
Parakiefferiella sp.	16	--	--	17	--	--	32
Pseudorthocladius sp.	--	16	--	--	--	--	--
Parametriocnemus sp.	--	--	--	--	--	16	--
Pseudosmittia sp.	--	--	8	--	--	--	--
Rheocricotopus sp.	--	--	--	--	--	304	--
Tvetenia sp.	--	16	--	--	--	48	33
Chironominae**	48	32	32	18	--	34	130
Chironomini***	--	--	--	--	--	32	--
Chironomus sp.	--	--	--	--	--	16	--
Axarus sp.	--	--	--	16	8	--	--

Appendix D. Benthic-invertebrate taxa abundances for Upper Mississippi River Basin study unit large river integrator sites, 1996 (Continued)

[*, class; **, suborder; ***, family; --, no data]

Taxon ORDER, Family, *genera*)	Royalton	Anoka	Hastings	Red Wing	Jordan	Danbury	St. Croix Falls
Cryptochironomus sp.	--	--	--	--	--	64	--
Dicrotendipes sp.	80	--	--	--	--	16	32
Endochironomus sp.	--	--	8	--	--	--	74
Glyptotendipes sp.	--	--	--	16	16	--	302
Microtendipes sp.	16	--	--	--	--	480	1
Parachironomus sp.	--	--	16	16	--	--	32
Polypedilum sp.	208	1,984	248	288	153	240	2
Pseudochironomus sp.	--	--	--	--	--	16	--
Stelechomyia sp.	--	--	--	--	--	--	33
Stenochironomus sp.	--	16	--	--	24	50	1
Tribelos sp.	80	16	--	--	--	112	66
Tanytarsini***	--	--	--	--	48	16	--
Rheotanytarsus sp.	208	16	--	17	862	242	229
Stempellinella sp.	--	--	--	--	--	64	32
Tanytarsus sp.	16	--	--	--	--	112	1
Ceratopogonidae	--	--	--	--	--	--	--
Bezzia/Palpomyia sp.	--	--	8	--	--	--	--
Probezzia sp.	--	--	8	--	--	--	--
Tipulidae	--	--	8	--	--	--	--
Tipula sp.	--	--	--	--	--	4	--
Limonia sp.	--	--	8	--	--	--	--
Simuliidae	--	--	--	16	176	256	--
Simulium sp.	64	--	--	--	88	104	35
Empididae	--	--	--	--	--	--	--
Hemerodromiinae**	--	--	--	--	--	16	--
Hemerodromia sp.	16	--	107	213	73	64	194
Athericidae	--	--	--	--	--	--	--
Atherix variegata Walker	--	--	--	--	--	--	1
Arachnida							
Acari	16	--	--	--	--	--	32
Hydrachnidia (water mites)	--	--	--	--	--	--	--
Crustacea*	--	--	--	--	--	--	--
"AMPHIPODA (scuds, shrimp)"	--	--	--	--	--	--	--
Gammaridae	--	--	--	--	--	--	--
Gammarus sp.	192	--	56	16	--	--	--
Hyalellidae	--	--	--	--	--	--	--
Hyalella azteca Saussure	161	--	--	--	--	130	453
ISOPODA (aquatic sow bugs)	--	--	--	--	--	--	--
Caecidotea sp.	67	--	--	--	--	80	--
Oligochaeta (aquatic worms)	--	--	--	--	--	--	--
Megadrile	--	--	--	--	--	--	1
TUBIFICIDA	--	--	--	--	--	--	--

Appendix D. Benthic-invertebrate taxa abundances for Upper Mississippi River Basin study unit large river integrator sites, 1996 (Continued)

[*, class; **, suborder; ***, family; --, no data]

Taxon ORDER, Family, *genera*)	Royalton	Anoka	Hastings	Red Wing	Jordan	Danbury	St. Croix Falls
Tubificidae	--	64	2	--	8	144	--
Naididae	80	161	782	1,165	--	266	2,652
Dero sp.	--	64	--	--	--	--	--
Hirudinea (leeches)	--	--	--	--	--	--	--
Glossiphoniidae	--	--	--	--	--	--	--
Placobdella sp.	--	--	--	1	--	--	--
Bivalvia (bivalve mollusks)							
Sphaeriidae	--	--	--	--	--	5	--
"Gastropoda* (snails, limpets)"	--	--	--	--	--	34	--
Ancylidae	176	--	--	--	--	--	--
Ferrissia sp.	--	--	--	--	--	64	--
Turbellaria (flat worms)	--	--	--	--	--	2	--
Nematoda	--	--	--	1	--	--	--

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