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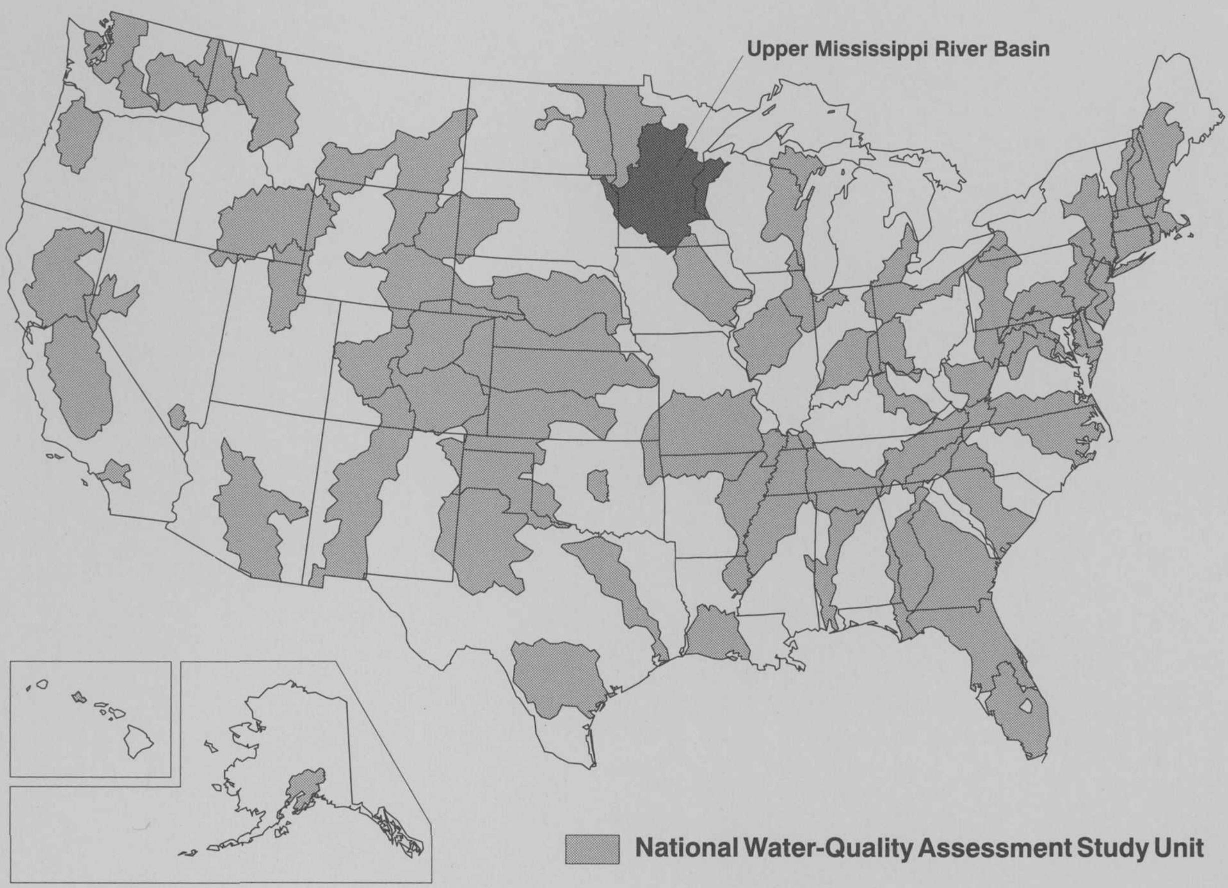
National Water-Quality Assessment Program

Relation of Fish Community Composition to Environmental and Land Use Factors in Part of the Upper Mississippi River Basin, 1995-97

Water-Resources Investigations Report 99-4034



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Relation of Fish Community Composition to Environmental Factors and Land Use in Part of the Upper Mississippi River Basin, 1995-97

By Robert M. Goldstein, Kathy Lee, Philip Talmage[1], Joseph C. Stauffer[2], and Jesse P. Anderson[2]

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National Water-Quality Assessment Program

[1]Minnesota Department of Natural Resources
[2]Minnesota Pollution Control Agency

U.S. Department of the Interior

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Water-Resources Investigations Report 99-4034

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 59 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 59 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

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

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

Robert M. Hirsch
Chief Hydrologist

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Conversion Factors and Abbreviated Water-Quality Units

Multiply	By	To obtain
centimeter (cm)	0.3937	inch
meter (m)	3.281	foot
square kilometer (km^2)	.3861	square mile
cubic meter per second (m^3/s)	0.02832	cubic foot per second
degrees Celsius (°C)	1.8(°C)+32	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: In this report, sea level refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order levels nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Relation of Fish Community Composition to Environmental Factors and Land Use in Part of the Upper Mississippi River Basin, 1995-97

By Robert M. Goldstein, Kathy E. Lee, Philip J. Talmage[1], Joseph C. Stauffer[2], and Jesse P. Anderson[2]

Abstract

Fish communities in the Upper Mississippi River Basin have been affected by changing environmental and land-use factors. Fish communities in small streams in agricultural and urban basins were compared to the fish community in a relatively undisturbed forested basin. In small streams, nutrient inputs from fertilizer, habitat modification from channelization, hydrologic modification from dams and tile drains, and increased water temperatures from loss of riparian shading have contributed to producing a change in fish community composition. In the large rivers, some of the changes that have occurred from sites upstream to downstream of the Twin Cities metropolitan area are primarily caused by the environmental effects of dams constructed as part of the lock and dam commercial navigation system. Although some of the differences upstream and downstream of the Twin Cities metropolitan area are due to zoogeographic variability, the major changes in the downstream community are shifts to more lentic species, species with higher thermal tolerance, and more planktivorous species. These changes are an extension of the changes observed in the small streams due to increased nutrients, increased water temperatures, and habitat alteration.

[1]Minnesota Department of Natural Resources
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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 will occur within 59 hydrologic systems (study units) 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 20 of the study units to be operational during each of three cycles of NAWQA. Each cycle is to include three years of intensive study followed by six years of low-intensity monitoring. Cycles are to be initiated at three-year intervals. In 1994, the USGS began to implement the field studies of the second cycle of NAWQA in part of the Upper Mississippi River Basin (UMIS) as one of 16 study units across the nation. 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, the largest river in the nation, and the study unit represents a major agricultural and urban area.

The goals of the NAWQA Program (Cohen and others, 1988) are to: (1) provide a nationally consistent description of current water-quality conditions for a large part of the nation's water resources; (2) define long-term trends in water quality; and (3) identify, describe, and explain the major factors that affect observed water-quality conditions and trends. These goals were established so the program would not only define the current conditions, but also determine the reasons for observed conditions and monitor long-term trends.

NAWQA is using a multidisciplinary approach to assess water quality. The ecology of aquatic biological communities is one of the disciplines used to provide multiple lines of evidence for the assessment (Gurtz, 1994). Part of the NAWQA study design is to address the relation of environmental factors and land use to the fish communities in streams.

Purpose and Scope

The purpose of this report is to relate the composition of the fish communities of streams in part of the UMIS to environmental factors. Fish communities in small streams are compared among three environmental settings: forest, urban, and agricultural. The fish communities of the large rivers are used to evaluate the effects of a major population center on part of the Upper Mississippi River and to examine the effects of the inflow of two major tributaries from two different land uses: agricultural (the Minnesota River), and forested (the St. Croix River). The report includes information on physical habitat of streams, hydrologic variability, water chemistry, landscape features such as land use and land cover, and fish community composition. Data sources include historical data and measurements and collections made from 1995 through 1997. These analyses are part of the multiple lines of evidence used in NAWQA to assess aquatic-resource quality in part of the Upper Mississippi River Basin.

Environmental Setting

The UMIS includes the 122,000 square kilometer (km^2) drainage basin of the Mississippi River upstream of Lake Pepin (fig. 1). The study area is the 50,000 km^2 core of the UMIS, which includes the Twin Cities metropolitan area (TCMA). Urban centers and urban land use settings are a focus of the second cycle of NAWQA studies; whereas the focus of the first NAWQA cycle was agricultural settings.

The UMIS is located within 400 kilometers (km) of the geographic center of North America. The Mississippi River generally flows southeast from its source at Lake Itasca, Minnesota, through the TCMA where it is joined by the Minnesota River and then the St. Croix River prior to entering Lake Pepin. A series of locks and dams have been constructed on the mainstem of the Mississippi River in and downstream of the TCMA for commercial navigation. Perodically, the channel is dredged to maintain depth for shipping. The topography in the UMIS is generally rolling and altitudes range from a high of 640 meters (m) above sea level to about 200 m above sea level at Lake Pepin (Stark and others, 1996). The two physical features that most affect fish distribution in the basin were the waterfalls at St. Anthony's Falls on the Mississippi River in Minneapolis, and the rapids at Taylor's Falls on the St. Croix River at Taylor's Falls, Minnesota, and St. Croix Falls, Wisconsin (major dams now occupy both sites). Both of these features historically were barriers to fish migration (Underhill, 1989).

Physiography, Geology, and Hydrology

Most of the UMIS is contained in two physiographic provinces (Fenneman and Johnson, 1946). The Superior Upland physiographic province includes much of the eastern portion of the basin (fig. 2), while the western and central portion is in the Central Lowland Province. The area from the TCMA to Lake Pepin is bisected by 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 glacial history of the basin was only recently concluded about 10,000 years ago when the remaining lobes of the Wisconsin glacier retreated (Wright, 1972). The geologic characteristics of the basin are due to the composition of the underlying rock and the results of glaciation. The western portion of the basin is underlain by a combination of Precambrian crystalline and Cretaceous rocks; whereas the eastern portion is underlain by mostly Precambrian and Paleozoic sedimentary rock (Sims and Morey, 1972).

Surficial geology can greatly affect surface-water quality. The Des Moines Lobe, which covered the central and western portion of the basin, left calcareous deposits while the Superior Lobe, which covered the northeastern portion of the basin, 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 dominant hydrologic features of the basin are the three major rivers that join just downstream of the TCMA. The Minnesota River flows into the Mississippi River from the southwest just upstream of St. Paul. The St.Croix River flows from the north to join the Mississippi River at Prescott, Wisconsin. The flow from of these two tributaries almost doubles the discharge of the Mississippi River. The Minnesota River at Jordan, Minnesota, has a mean annual discharge of approximately 120 m^3/s, and the St. Croix River at St. Croix Falls, Wisconsin, has an annual average discharge of about 123 m^3/s (Mitton and others, 1997). The average contribution of the Minnesota and St. Croix Rivers to the total streamflow of the Mississippi downstream of their confluences is about 22 and 26 percent, respectively (Stark and others, 1996). Downstream of the confluences with the other two rivers, the Mississippi River has a mean annual discharge at Prescott, Wisconsin of 507 m^3/s (Mitton and others, 1997). Additionally, there is an abundance of lakes, ponds, and wetlands throughout the basin, although most of the wetlands in the Minnesota River Basin have been drained

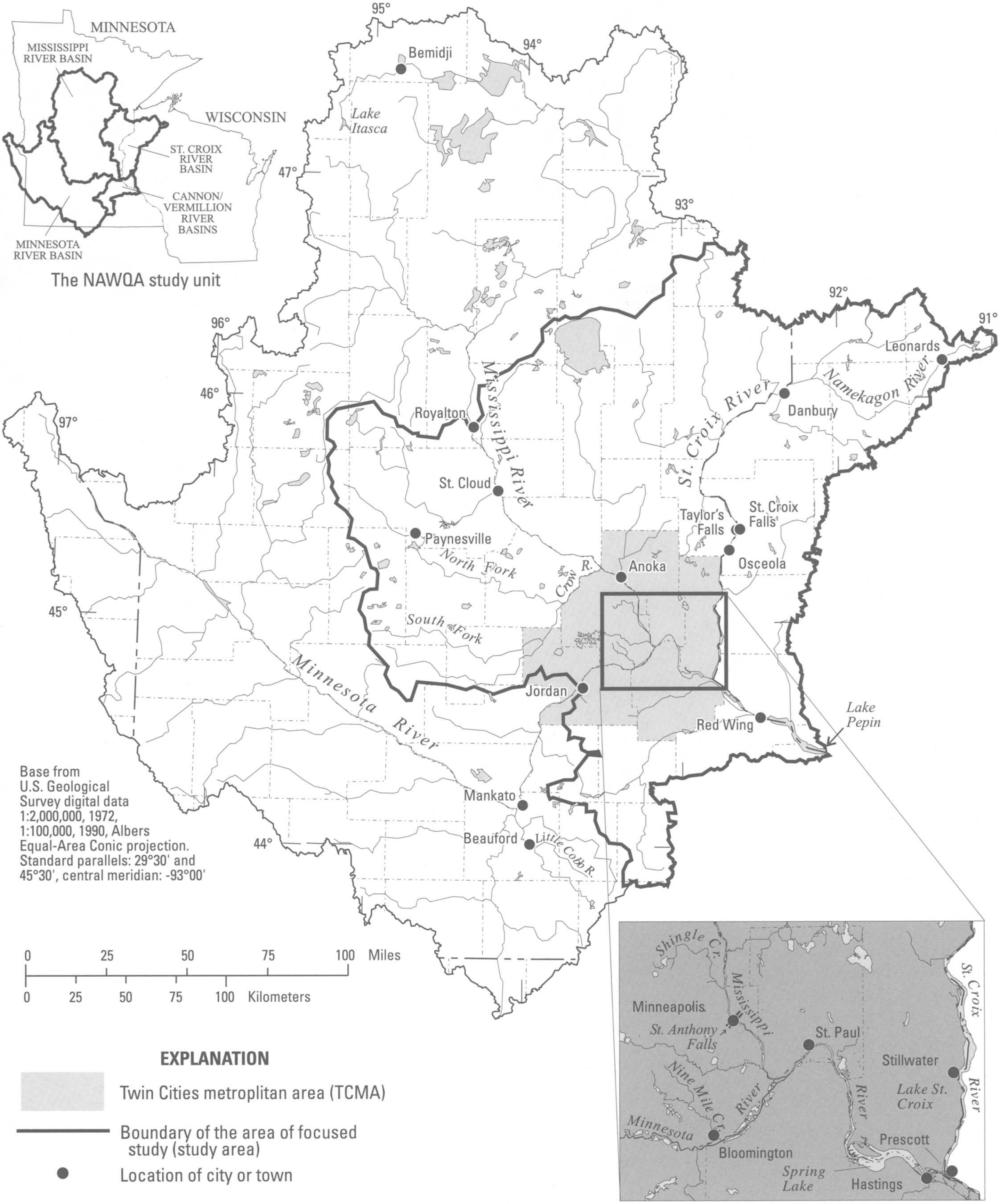

Figure 1.--Location of the Upper Mississippi River Basin study unit, study area, hydrology, and selected towns and cities

to increase agricultural production (Leach and Magner, 1992).

Water Chemistry

Water-chemistry characteristics such as alkalinity, hardness, specific conductance, and the concentration of dissolved solids generally follow a consistent pattern among the subbasins in the study area (fig. 3). In general, values of the above measures are highest in the Minnesota River, lowest in the St. Croix River, and intermediate in the Mississippi River below the confluence with its two major tributaries, the Minnesota and St. Croix Rivers. Values of these parameters tend to increase downstream (Stark and others, 1996). A similar pattern occurs for nutrients and suspended sediment.

Urban Area

The population of the core study area was about 3,640,000 in 1990 (U.S. Bureau of Census, 1991), and approximately 75 percent of those people live in the TCMA, in the center of the study area. 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 in the TCMA have increased, the population in the rural Minnesota River Basin has decreased (fig. 4).

Methods

The design for the fish community sampling was based on a stratification of the core study area into subunits called strata, and the selection of representative sites within each of the strata. At each selected site, physical and chemical characteristics were measured and related to the fish community.

Stratification

The study area was stratified by homogeneous natural and anthropogenic features. The stratification was based on dominant physiographic areas, surficial geology, and land use. Further information on the stratification process can be found in Stark and others (1996).

Site Selection and Characterization

After the stratification, sites were selected on both small streams and large rivers. The small streams and their basins were selected to reflect unique strata based on glacial-deposit composition, bedrock geology, and land use. The large river sites were selected to be either upstream or downstream of the TCMA, or on the Minnesota or St. Croix Rivers. Large river sites were also selected to reflect the major basin land uses; forested in the St. Croix, agricultural in the Minnesota, urban in the Lower Mississippi in and downstream of the TCMA, and transitional above the TCMA. Once selected, the five small stream sites and the seven large river sites became part of the fixed site network. The sites in the fixed site network were sampled (water chemistry, fish communities, habitat, and contaminants) in the same manner on a consistent time schedule.

The five small stream sites were selected in basins that represent a range of environmental characteristics and land use (table 1, fig. 5). Shingle Creek and

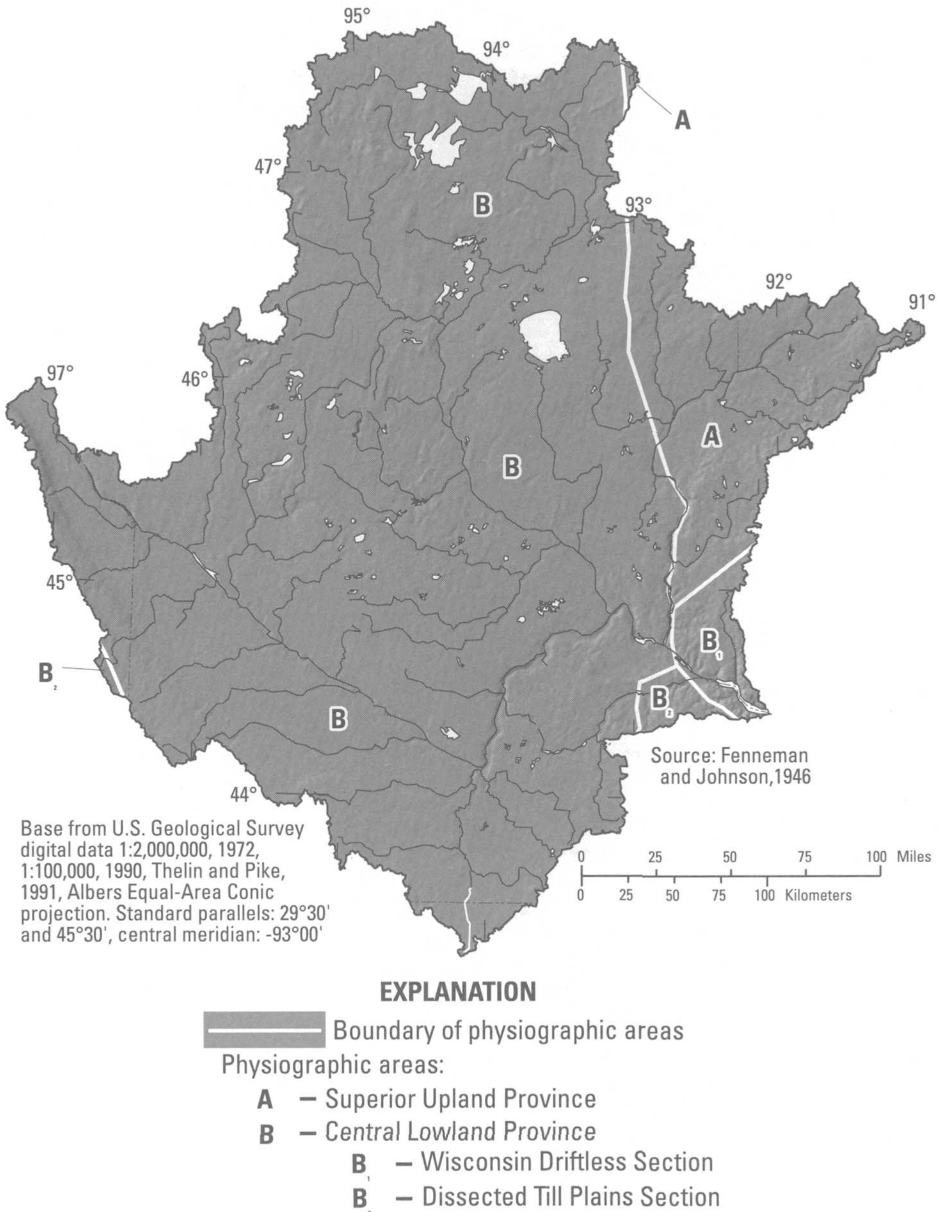

Figure 2.--Physiography in the Upper Mississippi River Basin study unit.

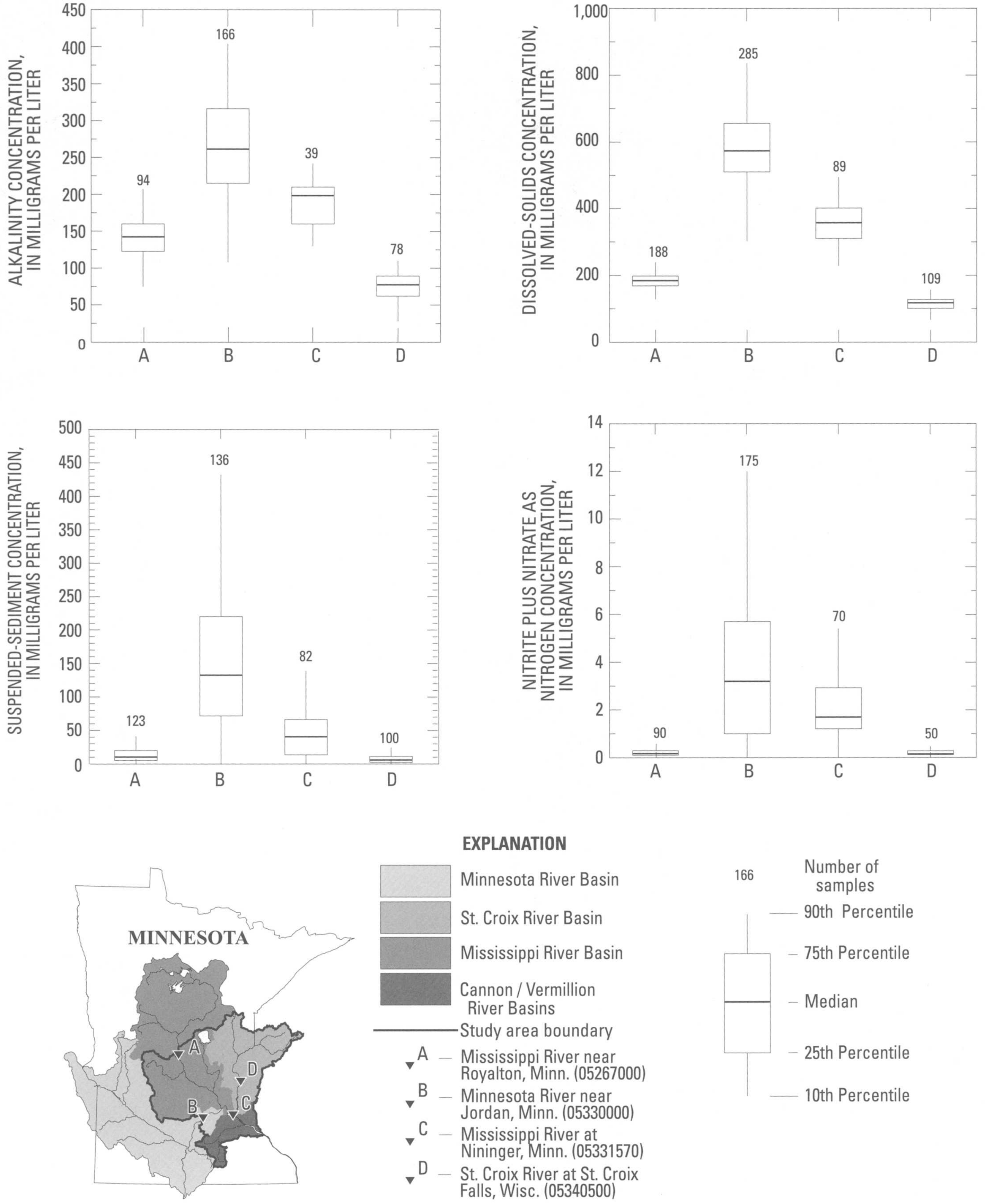

Figure 3.--Generalized water quality at selected sites in the Upper Mississippi RiverBasin study unit, 1977-94.

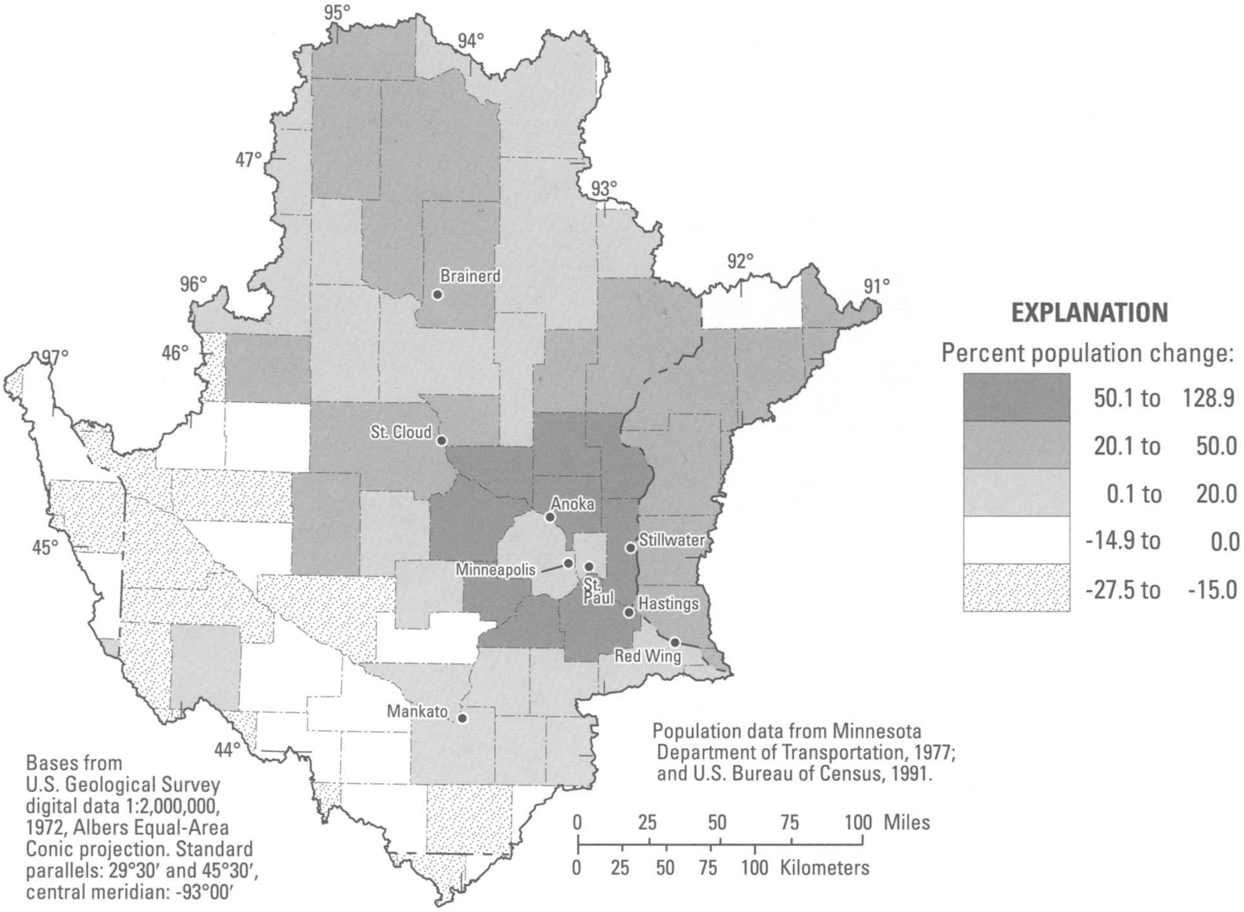

Figure 4.--Population change from 1970 to 1990, by county, in the Upper Mississippi River Basin study unit.

Table 1. General characteristics of small streams studied in part of the Upper Mississippi River Basin

[km², square kilometer; #/km², people per square kilometer]

Stream	Upstream drainage area (km^2)	Stream order	Land use, 1990 (percent)					Population density, 1990 ($\#/km^2$)
			Urban	Agriculture	Forest	Wetland	Other	
Shingle Creek	73.0	2	70.6	20.3	0.9	0.7	7.5	1,006
Nine Mile Creek	115.5	2	86.7	5.7	2.2	2.0	3.4	853
North Fork Crow River	601.4	4	0.3	90.2	2.1	6.0	1.4	5
Little Cobb River	335.9	4	0.2	94.7	0.5	4.0	0.6	5
Namekagon River	312.1	3	0.7	1.6	77.6	6.0	14.1	3

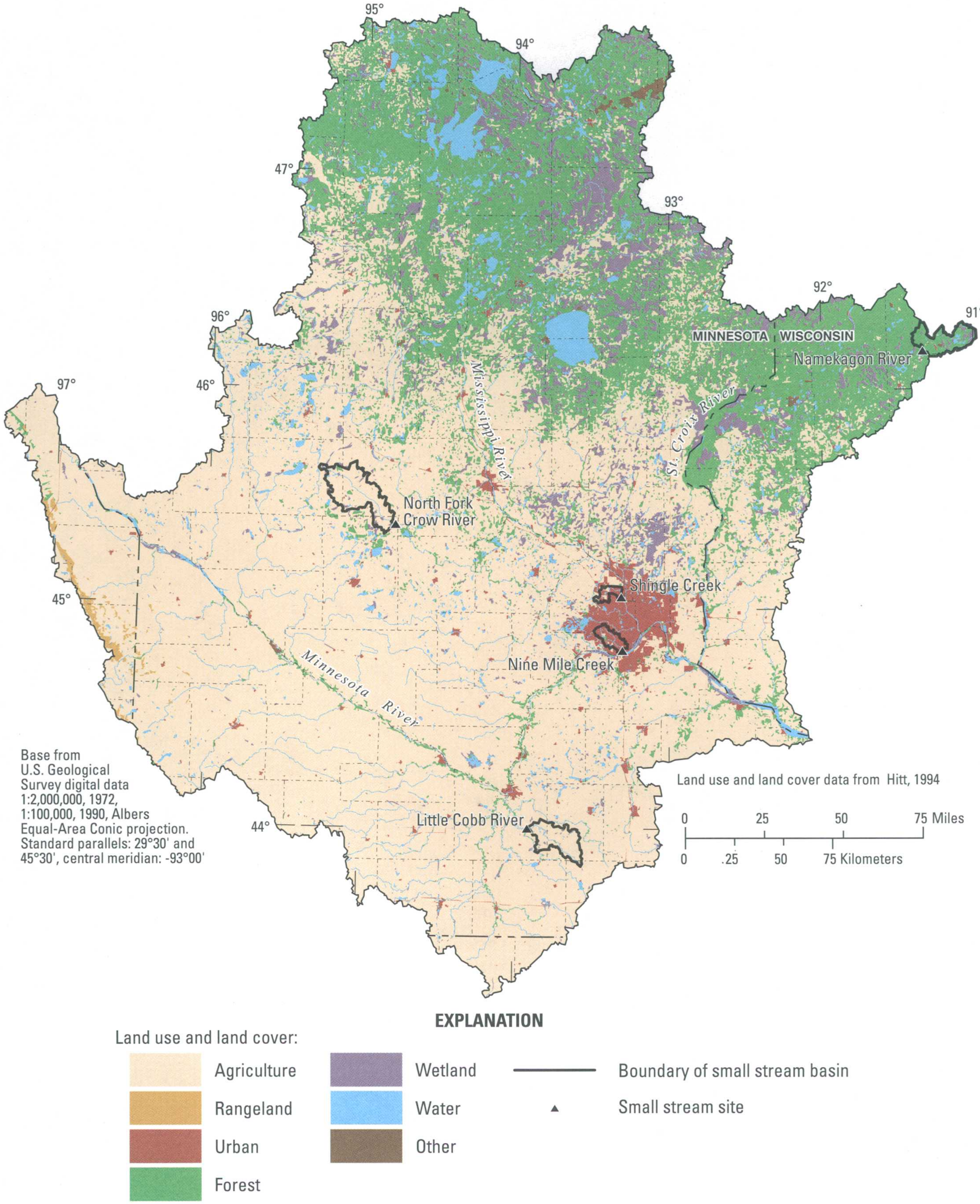

Figure 5.--Land use and land cover in the Upper Mississippi River Basin, 1994, and location of small stream basins selected for characterization of environmental settings.

Nine Mile Creek drain urban basins in the TCMA. The North Fork of the Crow River and the Little Cobb River drain agricultural basins, and the Namekagon River drains a forested basin.

The seven large river sites (fig. 6) were selected based on their location relative to the TCMA and the confluence of the three major rivers in the study area. There were two sites on the Mississippi River mainstem upstream of the TCMA and St. Anthony's Falls, one near Royalton and the other near Anoka. The Anoka site is just within the upstream confines of the TCMA. There is one site on the Minnesota River near Jordan. The Mississippi River site at Hastings is downstream of the confluence of the Minnesota and Mississippi Rivers. There are two sites on the St. Croix River, one near Danbury, Wisconsin (upstream of the dam at Taylors Falls and St. Croix Falls), and the other near Osceola, Wisconsin, at St. Croix Falls (downstream of the dam at Taylors Falls and St. Croix Falls). The Mississippi River site at Red Wing is the most downstream site. It is downstream of all the major tributary confluences with the Mississippi River in the study area.

The characterization of the small stream sites was accomplished from 1995 through 1997 by measuring the physical and chemical characteristics of the basin and stream. The large river sites were characterized in a similar manner although not all measurements could be accomplished due to river width and depth.

The physical characterization of the fixed sites followed a hierarchical system of habitat classification (Frissell and others, 1986). This system begins at the basin level (a scale of kilometers), proceeds through the segment level (hundreds of meters), then the reach level (meters), and ends at the microhabitat level (centimeters). In this characterization, only the basin level and reach level are used.

The basin level of characterization is designed to determine gross differences among the streams. Basin characteristics included basin area, land use, population density, physiography, and hydrologic variability, which includes discharge characteristics and flow modifications such as dams or ditches.

The second level of physical characterization was at the reach level. A reach is defined as the area of stream sampled. A reach was determined in one of three ways: 1) two replications of two geomorphological units, 2) one meander

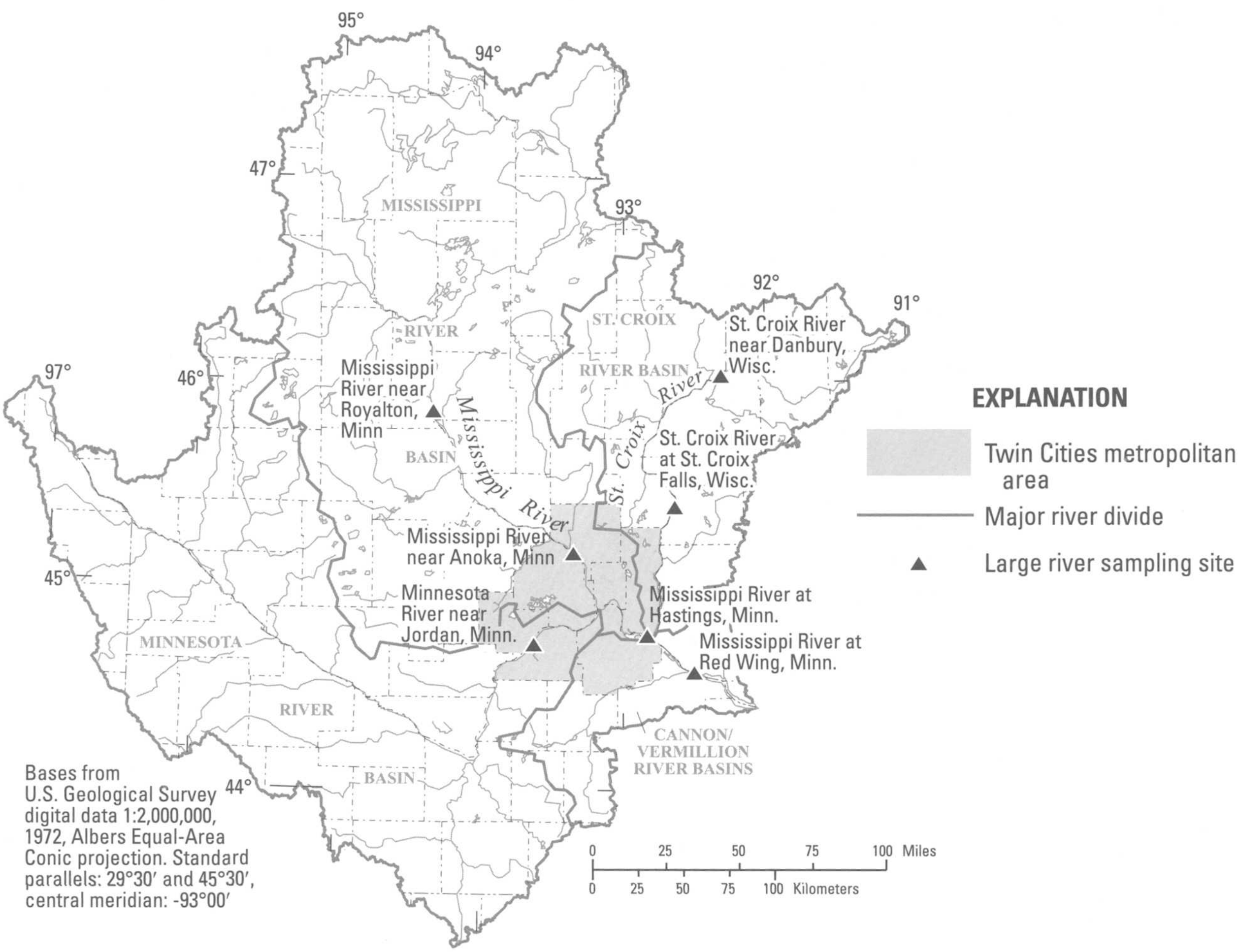

Figure 6.--Large river sampling sites in relation to the Twin Cities metropolitan area (TCMA) in the Upper Mississippi River Basin study unit.

wavelength, or 3) a minimum distance not less than 150 m (Meador and others, 1993a). Stream order (Strahler, 1957) was used to provide an additional measure of stream size for comparison. At the reach level, the physical habitat was quantified by measuring or defining features of the riparian zone, the stream banks, streambed, and channel. Stream gradient and sinuosity were determined from topographic data broader than reach scale due to the small topographic relief at some sites. (Meador and others, 1993a).

The chemical characteristics of each site were determined according to NAWQA procedures (Shelton, 1994). Water-quality parameters included major ions, nutrients, pH, alkalinity, temperature, suspended sediment, chlorophyll *a*, phytoplankton, and organic carbon.

Fish Community Sampling

Fish were collected at each stream and river reach by electrofishing. Fish sampling was conducted during August and September 1996. Additional fish sampling was done during 1995 and 1997, although not all the sites were sampled. To make comparisons of the fish communities unbiased by samples from different years, only the 1996 data were used for this evaluation. Sampling was conducted according to protocols established for the NAWQA Program (Meador and others, 1993b). Briefly, the appropriately-sized electrofishing gear (tow barge for small streams and boat-mounted boom unit for large rivers) were used to make two collection passes within the reach. Sampling time was recorded to normalize catch per unit of effort. All fish were identified to species, counted, and batch weighed by species. Representatives of each species were vouchered at the Bell Museum of Natural History at the University of Minnesota, Minneapolis, to maintain a reference collection and confirm identifications.

Data Analysis

Fish communities in small streams were compared among three environmental settings: forest, urban, and agriculture. Species similarities between sites were compared using the Jaccard coefficient of similarity. The Jaccard coefficient of similarity values range from 0 (no species in common) to 1 (complete similarity, all species common to both sites). Differences in fish community composition in the streams among the three environmental settings were evaluated relative to the physical and chemical characteristics of those sites.

The fish communities of the large rivers were compared in a stepwise manner moving downstream to evaluate the effects of population density of a major urban area on part of the Upper Mississippi River and to determine the effects of the inflow of two major tributaries from two different environmental settings, agriculture (Minnesota River) and forest (St. Croix River).

Fish community composition included measures of the structure and function of the community as expressed by the presence of certain species and trophic groups. The analysis focused on the physical and biological requirements of the species present and trophic composition of the community. Aspects of species requirements such as specific habitats required for spawning, preferred habitat types, thermal requirements for survival and growth, and feeding strategies such as types and sizes of food items were related to the conditions at the sites. The trophic classification follows Gerking (1994), and Goldstein and Simon (1998).

Small Stream Site Comparisons

The common and unique physical, chemical, and biological features of the selected small stream sites were determined by basin characteristics, reach habitat, hydrology, and water chemistry. These are environmental factors that affect the composition of the fish communities.

Basin characteristics

Drainage area and stream order differed among the small streams (table 1). The agricultural streams have larger basins and greater stream order than either the forest or urban sites. Land use was consistent with the classification. The urban basins of Shingle and Nine Mile Creeks contained at least 70 percent urban land use. Between 23 and 28 percent of the land surface was covered with impervious materials (asphalt, concrete, roofs, etc.). The agricultural basins of the North Fork of the Crow and Little Cobb Rivers had greater than 90 percent agricultural land use; whereas the basin of the Namekagon River contained almost 80 percent forested land (table 1). 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 1).

Reach characteristics

The mean channel widths at the small stream sites ranged from about 6 to 20 m. Average depths ranged from 0.2 to 0.5 m. The forest stream, the Namekagon, had velocities greater than the other streams due to its relatively high gradient and greater water depths (table 2). The high gradient portion of Nine Mile Creek is upstream of the sampled area, but was included to encompass sufficient distance to determine gradient.

Bottom substrate composition is dependent on the local geology, water velocity, depth, gradient, and other factors that cause erosion and affect particle movement in water. The distributions of substrate types at the small stream sites indicate that the forest stream has the greatest amount of large particles (boulders and cobble); whereas the urban and agricultural streams contain more small particles of gravel, sand, and silt. Boulders and cobble provide instream habitat for small benthic fish. The proportion of silt and sand was highest in Shingle Creek, the most channelized stream (lowest sinuosity). Although Shingle Creek had the least riparian vegetation to stabilize its banks, it had the most overhanging vegetation, primarily large root wads from the few riparian trees.

Instream habitat is the living space and structure for fish and invertebrates.

Table 2. Reach level physical habitat of selected small streams in different land use settings in part of the Upper Mississippi River Basin

[m, meters; cm, centimeters; cm/s, centimeters per second; m/km, meters per kilometer; <, greater than]

Characteristic	Stream				
	Shingle Creek	Nine Mile Creek	North Fork Crow River	Little Cobb River	Namekagon River
Mean channel width (m)	7.6	6.7	12.2	13.7	19.8
Mean depth (cm)	27.4	24.4	42.7	36.5	54.8
Mean velocity (cm/s)	<0.3	18.3	39.6	30.5	42.7
Sun angle (degrees)	26	63	87	16	105
Gradient (m/km)	.33	4.41	.83	.38	.95
Sinuosity	1.1	2.1	1.4	2.3	1.4
Substrate frequency (percent)					
Silt	47	0	5	64	0
Sand	43	32	44	11	31
Gravel	5	43	33	22	28
Cobble	8	20	14	3	39
Boulders	0	5	0	0	3
Muck	2	0	0	0	0
Instream habitat (percent of reach area)					
Boulders	0.2	3.8	0.6	0	1.7
Woody debris	4.6	8.2	5.6	27.5	5.0
Overhanging vegetation	7.3	2.3	3.1	0	3.1
Rubbish	1.7	0	0	0	0
Undercut banks	0.2	2.0	0.6	1.7	0
Aquatic plants	1.8	0.1	6.6	0	12.6
Total habitat	15.6	16.8	18.3	30.0	22.4

Generally, the more instream cover creating habitat, the more types of living places for fish and the more fish species. The amount of instream habitat ranged from about 15 to 30 percent, with the Little Cobb River site having the highest amount from woody debris and root wads. This is consistent with the composition of the riparian zone. The riparian tree density was very high at the Little Cobb River as indicated by the sun angle. The sun angle is the arc of sky visible from the center of the stream. At the Little Cobb River site, the sun angle was only 16 degrees, indicating a thick overhead tree canopy shading the stream. The most open or unshaded site was at the Namekagon River, which was due to the width of the stream and not a lack of riparian trees.

Hydrology and Water Chemistry

The seasonal patterns of average discharge among these streams, although similar, are not the same. At the agricultural and forested stream sites, the greatest discharge occurs in spring followed by decreasing discharges in summer. However, in the two urban streams, average seasonal discharge was greatest during summer, rather than spring, and lowest during winter indicating a change to the seasonal hydrologic regime.

Water chemistry, particularly the concentrations of dissolved and suspended constituents, varies with discharge and other factors. Water-chemistry parameters related to the concentrations of major ions (specific conductance and alkalinity) generally were highest during winter due to the lack of dilution during this period of lowest discharge. The stream in the forested basin, the Namekagon River, exhibited lower values of specific conductance, alkalinity, and most major ions and metals (except iron) than the urban and agricultural streams (table 3). The lower concentrations reflect the underlying silicious glacial deposits. Average water temperature during the non-winter seasons was consistently lower as well. Total suspended sediment and the concentrations of fine material (less than 62 microns) were highest during spring at the agricultural and forest sites due to erosional inputs associated with spring runoff. Nutrient concentrations (nitrogen compounds, phosphorus, and potassium) were highest in the agricultural streams and lowest in the forest stream, and, generally, highest in summer (table 3). High summer nutrient concentrations can be the result of fertilizer runoff from agricultural fields and residential use.

Fish communities

A total of 44 species and one hybrid from 12 families were collected from all the small stream sites (table 4). The urban Nine Mile Creek contained the most species (27), while the forest stream, the Namekagon River, had the fewest (15). Comparison of the number of species per family (fig. 7) indicates that the Namekagon River contained the fewest number of species in the major families of minnows (*Cyprinidae*), catfish (*Ictaluridae*), sunfish (*Centrarchidae*), and perch (*Percidae*).

The relative similarity of the fish communities at two sites was determined with a coefficient of similarity. Comparisons of Jaccard coefficients of similarity of the species composition indicates that all the streams are dissimilar (table 5). Jaccard similarity coefficients less than 0.7 indicate a lack of similarity even between the species composition in streams within the same land-use stratum.

The location of the sampling sites on both Nine Mile Creek and the Little Cobb River are within 10 to 20 km of major rivers, the Mississippi and the Minnesota Rivers. The species richness at these sites may be affected by the proximity to a large river. There is probably a movement of large-river species between the main rivers and their tributaries. Although collected in these small streams, species such as the gizzard shad (*Dorosoma cepedianum*), emerald shiner (*Notropis atherinoides*), and channel and flathead catfish (*Ictalurus punctatus* and *Pylodictus olivaris*) are generally considered large-river species and are associated with rivers larger than those sampled (Pflieger, 1971; Becker, 1983; Simon, 1992).

Four species were found at all five small stream sites: white sucker (*Catostomus commersoni*), creek chub (*Semotilus atromaculatus*), northern pike (*Esox lucius*), and johnny darter (*Etheostoma nigrum*). Becker (1983) considers all these species except the northern pike to be either highly tolerant or pioneer species. Tolerant species are able to survive in a wide range of environmental conditions and pioneer species are the first to colonize an area after a disturbance. The commonality of these species indicates that all the sampled streams appear to have been disturbed to some degree.

Other than large-river species, some species were only found in streams within a single environmental setting. In the urban streams, golden shiners (*Notemigonus crysoleucas*), black crappie (*Pomoxis nigromaculatus*), pumpkinseeds (*Lepomis gibbosus*), yellow perch (*Perca flavscens*), and brook sticklebacks (*Culaea inconstans*) were unique. The presence of these species may be due to water-quality conditions, but more likely their presence is related to the construction or presence of small impoundments or ponds in the course of the urban streams. All of these species prefer a still-water environment of a lake or pond to the flowing water of a stream (Eddy and Underhill, 1974; Becker, 1983). Both golden shiners and yellow perch spawn over vegetation, which was rare in the urban streams where channel modifications have discouraged growth of aquatic macrophytes through velocity increases or scouring in areas other than still-water, pond-like habitats. The presence of hybrid sunfish species, however, indicates a reduction in the quality of the habitat (Karr and others, 1986). Sunfish species have a complex reproductive behavior that involves nest construction, recognition of specific color patterns, and courtship displays (Breeder and Rosen, 1966; Becker 1983). When competition for nesting sites occurs due to loss of habitat some of the methods of reproductive isolation, which help to ensure genetic homogeneity of a species, break down, resulting in hybridization (Karr and others, 1986).

There were seven species unique to the agricultural streams: sand shiners (*Notropis stramineus*), bluntnose minnow (*Pimephales notatus*), stonecat

Table 3. Mean seasonal physical and chemical parameters of selected small streams in part of the Upper Mississippi River Basin, 1996-98

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

Stream	N	Season	Discharge (m^3/s)	Water temperature (°C)	Conductance (µs/cm)	Alkalinity (mg/L)	Dissolved iron (µg/L)	Nitrate + nitrite as nitrogen (mg/L)	Total phosphorus (mg/L)	Dissolved potassium (mg/L)	Suspended sediment (mg/L)	Percent fines (<62 microns)	Chlorophyll *a*
Shingle Creek	13	Spring	0.62	12.9	943	192	74	0.40	0.14	4.18	99.9	78	7.12
	13	Summer	1.25	20.2	625	154	70	0.25	0.15	2.97	55.0	88	8.9
	11	Fall	.31	4.8	1130	235	43	0.35	0.08	3.92	50.8	66	5.5
	6	Winter	.17	0.7	1795	202	30	0.52	0.10	5.68	68.8	53	na
Nine Mile Creek	13	Spring	.48	11.9	809	181	58	0.30	0.06	3.64	17.1	85	6.1
	15	Summer	1.64	20.8	426	114	111	0.13	0.10	2.36	57.7	78	3.8
	6	Fall	.76	5.8	715	194	43	0.53	0.04	3.28	14.7	50	6.6
	4	Winter	.20	1.4	1465	227	41	0.58	0.04	4.17	55	na	na
North Fork Crow River	6	Spring	15.21	12.2	500	214	45	1.12	0.17	3.87	1513.0	80	2.2
	7	Summer	3.2	19.6	575	244	21	0.66	0.10	2.82	66.3	64	2.7
	6	Fall	1.13	2.6	655	276	16	1.23	0.03	3.48	57.3	57	6.0
	3	Winter	082	0	663	311	20	1.37	0.02	2.97	58.3	32	na
Little Cobb River	4	Spring	4.00	13.1	628	249	9	8.21	0.12	2.22	132.2	77	15.0
	15	Summer	2.60	21.6	583	229	6	4.94	0.19	1.99	142.1	94	26.5
	6	Fall	0.42	3.3	698	298	6	6.53	0.08	2.54	100.7	51	14.7
	4	Winter	.93	0	617	264	16	6.30	0.24	3.60	77.2	70	na
Namekagon River	6	Spring	6.57	11.0	104	41	199	0.12	0.02	0.59	5.0	81	1.5
	7	Summer	3.51	17.1	123	46	230	0.07	0.02	0.53	4.1	na	0.8
	6	Fall	4.19	2.9	126	50	194	0.11	0.01	0.67	3.0	90	1.0
	3	Winter	3.91	2.0	124	55	164	0.15	0.02	0.61	4.7	na	na

Table 4. Fish species composition at Upper Mississippi River Basin small stream sites, 1996
[C, carnivore; D, detritivore; H, herbivore; I, invertivore; P, planktivore (Gerking, 1994; Goldstein and Simon, 1998)]

Fish species by family	Common name	Trophic group	Stream				
			Shingle Creek	Nine Mile Creek	North Fork Crow River	Little Cobb River	Namekagon River
Petromyzontidae	**Lampreys**						
Ichthyomyzon castaneus	chestnut lamprey	C					X
Clupeidae	**Herrings**						
Dorosoma cepedianum	gizzard shad	P		X			
Salmonidae	**Trout**						
Salmo trutta	brown trout	I,C					X
Catostomidae	**Suckers**						
Catostomus commersoni	white sucker	I,D	X	X	X	X	X
Moxostoma macrolepidotum	shorthead redhorse	I		X	X		
Cyprinidae	**Minnows**						
Campostoma anomalum	central stoneroller	H		X	X		
Cyprinus carpio	common carp	I,D	X			X	
Hybognathus hankinsoni	brassy minnow	D,P		X		X	
Nocomis biguttatus	hornyhead chub	I,H			X		X
Notemigonus crysoleucas	golden shiner	I,P		X			
Notropis atherinoides	emerald shiner	P				X	
Luxilius cornutus	common shiner	I		X	X		X
Notropis dorsalis	bigmouth shiner	I	X	X	X	X	
Cyprinella spiloptera	spotfin shiner	I		X	X	X	
Notropis stramineus	sand shiner	I				X	
Pimephales notatus	bluntnose minnow	D			X	X	
Pimephales promelas	fathead minnow	D,H	X	X		X	
Rhinichthys atratulus	blacknose dace	I	X	X	X		X
Rhinichthys cataractae	longnose dace	I		X	X		X
Semotilis atromaculatus	creek chub	I	X	X	X	X	X

Table 4. Fish species composition at Upper Mississippi River Basin small stream sites, 1996--Continued

[C, carnivore; D, detritivore; H, herbivore; I, invertivore; P, planktivore (Gerking, 1994; Goldstein and Simon, 1998)]

Fish species by family	Common name	Trophic group	Stream: Shingle Creek	Stream: Nine Mile Creek	Stream: North Fork Crow River	Stream: Little Cobb River	Stream: Namekagon River
Ictaluridae	**Catfish**						
Ameiurus melas	black bullhead	C,I	X	X		X	
Ameiurus natalis	yellow bullhead	C,I		X		X	
Ictalurus punctatus	channel catfish	C,I				X	
Noturus flavus	stonecat	I				X	
Noturus gyrinus	tadpole madtom	I	X	X	X		
Pylodictus olivaris	flathead catfish	I				X	
Umbridae	**Mudminnows**						
Umbra limi	central mudminnow	I	X	X	X		X
Esocidae	**Pikes**						
Esox lucius	northern pike	C	X	X	X	X	X
Centrarchidae	**Sunfishes**						
Ambloplites rupestris	rock bass	C,I			X		X
Lepomis cyanellus	green sunfish	C.I	X	X		X	
Lepomis gibbosus	pumpkinseed	C,I	X	X			
Lepomis humilis	orangespotted sun-fish	I		X		X	
Lepomis macrochirus	bluegill	C,I	X	X			X
Micropterus dolomieui	smallmouth bass	C,I			X		
Micropterus salmoides	largemouth bass	C,I	X	X	X		X
Pomoxis nigromaculatus	black crappie	C,I	X				
Lepomis spp.	sunfish hybrid	C,I	X	X			
Percidae	**Perches**						
Etheostoma nigrum	johnny darter	I	X	X	X	X	X
Perca flavescens	yellow perch	I	X	X			
Percina caprodes	logperch	I			X		
Percina maculata	blackside darter	I			X	X	

Table 4. Fish species composition at Upper Mississippi River Basin small stream sites, 1996--Continued
[C, carnivore; D, detritivore; H, herbivore; I, invertivore; P, planktivore (Gerking, 1994; Goldstein and Simon, 1998)]

Fish species by family	Common name	Trophic group	Stream: Shingle Creek	Nine Mile Creek	North Fork Crow River	Little Cobb River	Namek-agon River
Percina phoxocephalus	slenderhead darter	I				X	
Stizostedion vitreum	walleye	C		X	X		
Cottidae	**Sculpins**						
Cottus cognatus	slimy sculpin	I					X
Gasterosteidae	**Sticklebacks**						
Culaea inconstans	brook stickleback	I,P	X				
Total number of species			19	27	21	21	15
Total carnivore species			8	9	5	5	6
Total invertivore species			17	21	17	16	13
Total detritivore species			3	3	2	4	1
Total herbivore species			1	2	2	1	1
Total planktivore species			1	3	0	2	0

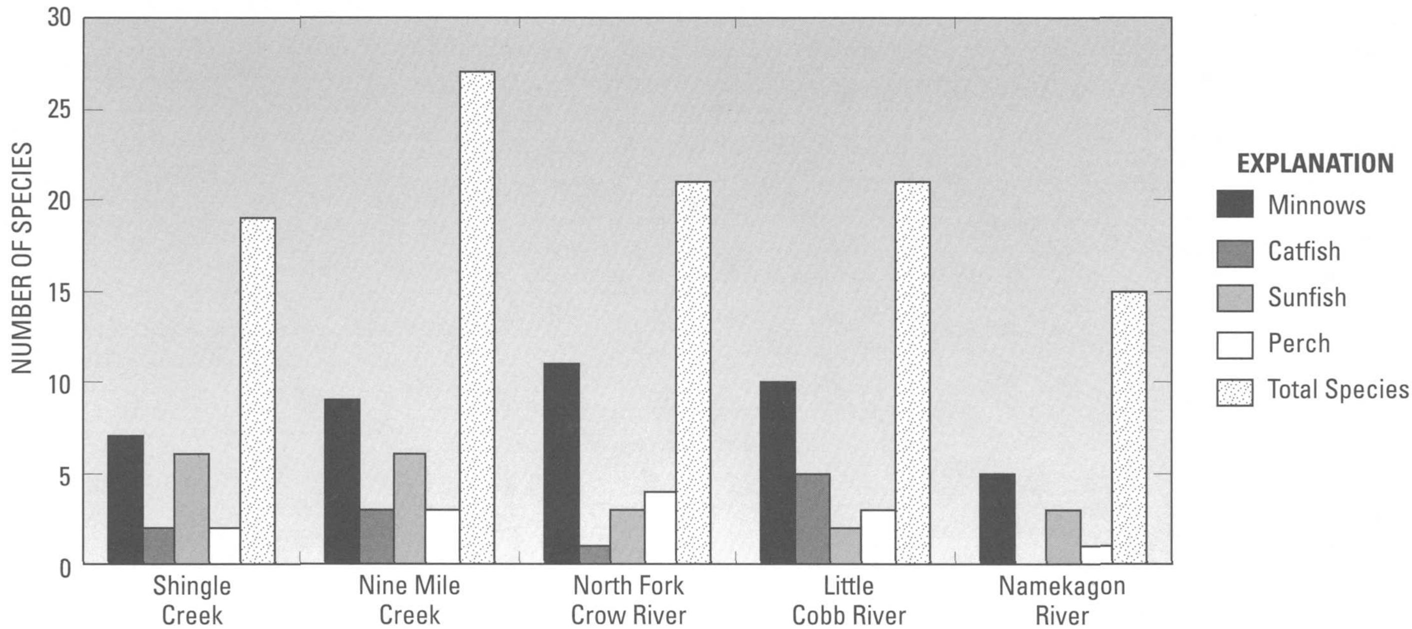

Figure 7.--Total number of species and number of species per family at small stream sites with different surrounding land use and land cover in the Upper Mississippi River Basin.

Table 5. Correlation matrix of Jaccard coefficients of similarity for Upper Mississippi River Basin small stream sites

Stream	Nine Mile Creek	North Fork Crow River	Little Cobb River	Namekagon River
Shingle Creek	0.58	0.29	0.30	0.31
Nine Mile Creek		0.41	0.30	0.31
North Fork Crow River			0.20	0.38
Little Cobb River				0.16

(*Noturus flavus*), smallmouth bass (*Micropterus dolomieui*), logperch (*Percina caprodes*), and slenderhead and blackside darters (*P. phoxocephala* and *P. maculata*). These seven species have very different environmental requirements. The one common feature among them is the requirement of small invertebrates for food during some stage of life (Goldstein and Simon, 1998). The type of invertebrates eaten by these species vary in location. The bluntnose minnow, stonecat, logperch, and the two darters forage on the bottom of the stream and generally require a gravel substrate to provide the appropriate habitat for the invertebrates they consume. The sand shiner, however, feeds on invertebrates drifting in the water column. The smallmouth bass, like the sand shiner, is also a sight feeder. The presence of these sight feeders indicates that water clarity and suspended sediment concentrations are at levels that permit visual acquisition of prey. The sand shiners, while capable of withstanding low dissolved oxygen concentrations, are intolerant to siltation (Eddy and Underhill, 1974; Becker, 1983). The stonecat is also intolerant to siltation (Eddy and Underhill, 1974). Both the stonecat and smallmouth bass prefer streams with rocky substrates and generally clear water. The logperch and darters require a gravel substrate for spawning (Becker, 1983). The bluntnose minnow is tolerant to most disturbances (Becker, 1983). The presence of these species, unique to the agricultural streams, indicates a combination of rocky substrates that include gravel, abundant instream cover, and generally good water quality in terms of clarity and dissolved oxygen. The agricultural sites generally met these criteria except in the spring, when suspended sediment concentrations were high.

Unique species in the urban and agricultural streams cannot be attributed strictly to land use. Land use may contribute to the environmental conditions and the resultant effects on the physical and chemical characteristics of the streams. For example, in the forest stream, the physical and chemical conditions are sufficiently different from the other streams to allow cold-water species such as the slimy sculpin (*Cottus cognatus*) to maintain a population (Symons and others, 1977) and support the introduced cold-water species, brown trout (*Salmo trutta*). Shading from trees contributes to maintaining lower water temperatures. Not only is the stream partially shaded, but within forested basins, the land surface is shaded, thereby reducing the potential for warming of runoff. The cobble/gravel substrate provides unique habitat for sculpins. During the ice-free period, the average seasonal water temperature in the forest stream was about 2° C less than the other streams (table 3), which appears to be sufficient to maintain trout and sculpins. High temperatures can have an exclusionary effect on the ability of some species to inhabit an area. Stress from increased water temperatures can affect species composition (Smale and Rabeni, 1995) even when dissolved oxygen concentrations are sufficient to support fish. Although the two agricultural streams and the forest stream in this study are similar in certain features (both contain rocky substrates, low suspended sediment concentrations, instream cover, and sufficient dissolved oxygen to support fish), the relative amounts or levels of these factors are different. In most cases, the agricultural streams have less area of rocky substrates, lower water clarity, and lower dissolved oxygen. In combination with the thermal differences, these factors determine the fish species composition each type of stream can support.

The trophic composition of the fish community reflects the energy sources and pathways through the ecosystem. Both the number of species in each of the trophic groups and the total biomass of each group indicate the origin and type of food items available in the stream. The species composition of all the streams was dominated by invertivores (table 4). Proportionally, the Namekagon River and Shingle Creek had the most invertivore species and the most carnivore species. The Namekagon River had the fewest planktivore, detritivore, and herbivore species. In low-order, nutrient-poor streams, invertivores dominate, followed by carnivores, detritivores, planktivores, and herbivores (not necessarily in that order). As streams become more nutrient- and organic-rich, the proportion of detritivores and herbivores tends to increase.

In the urban streams, the invertivore/detritivore white suckers dominated the trophic composition; whereas the common carp, also an invertivore/detritivore, dominated the agricultural Little Cobb River. Both white suckers and carp have the ability to utilize a highly diverse food supply; whereas these species may prefer benthic insects and molluscs, they can survive on detritus, fine particulate organic matter. In the urban streams and the Little Cobb River, fine substrates indicate that these species are consuming detritus. The abundance of these species indicates that the streams are organically rich. In comparison, the diverse substrate of the Namekagon River supports a community dominated by invertivores (table 4). These species specialize in consuming aquatic insects from various locations—that is, on the substrate (sculpins, longnose dace) as well as within the water column (trout, common shiners, hornyhead chubs).

Overall, the total biomass (the total weight of fish collected at a site), may indicate the relative amounts of nutrient, light, and thermal inputs to the streams. Biomass tends to increase with each of these factors. Total biomass (normalized to collection effort) was greatest at the agricultural sites (37.5 and 22.5 kilograms per hour (kg/hr) at the Little Cobb and North Fork of the Crow Rivers, respectively) and least at the forest site (4.6 kg/hr). Biomass at each of the sites reflects the ion chemistry, nutrient concentrations, and habitat measures (tables 2 and 3).

Large River Site Comparisons

The confluence of the Minnesota and St. Croix Rivers with the Mississippi River in the TCMA would be expected to produce a community that contains more species than any of the contributors (Goldstein, 1981), and the combined community would be expected to be similar in composition and structure to each of the contributors. Results vary somewhat from those expectations. Urbanization and flow regulation (channelization and the locks and dams) and the combination of the rivers probably have changed the character of the fish community. There are two major factors that confound the effects of urbanization on the fish communities of the UMIS: (1) the great change in the physical habitat upstream and downstream of the TCMA, and (2) the natural differences in the fish communities upstream and downstream of the migration barriers at St. Anthony's and Taylor's Falls/St. Croix Falls.

The physical structure of the riverine habitat upstream of the TCMA is very different from downstream. Upstream of the TCMA, the Mississippi River contains riffles, runs, and pools. Similarly, upstream of the dam, the St. Croix River exhibits diverse geomorphology. In both rivers, upstream of their respective barriers, geomorphologic variability indicates diverse habitats. Downstream of the barriers, the geomorphology changes. The channels become wider and deeper, the water velocity slows and the substrate becomes more fine grained. Within and downstream of 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, or flowing, to a lentic, or lake-like, system has significant consequences on fish species composition.

The fish communities found today in the UMIS originally began colonizing the area during the late Pleistocene and Holocene Epochs (Underhill, 1989) and have continued to change as humans have modified the system. Species have been introduced and species have been lost. Depending on the location of glaciers, fish emigrated from the lower Mississippi River and the Laurentian Great Lakes. The current species composition of the rivers of the UMIS is similar in the basins downstream of the two barriers. All the species reported from the Minnesota River Basin (88) and the St. Croix River Basin downstream of Taylor's Falls (92) are among the 117 species reported from the Mississippi River Basin downstream of St. Anthony's Falls (Underhill, 1989). The Minnesota and lower St. Croix Rivers have 82 species in common (Underhill, 1989). The differences in species composition upstream and downstream of the two barriers are more pronounced. There are 69 species reported from upstream of St. Anthony's Falls in the Mississippi River Basin and 75 species upstream of Taylor's Falls in the St. Croix River Basin (Underhill, 1989).

Urbanization

The population of the TCMA is rapidly expanding (fig. 4) (Stark and others, 1996). As the population grows, the amount of land converted from agriculture and forest to urban uses increases. The population density of the area near the two upstream Mississippi River sites at Royalton and near Anoka, Minnesota, is similar to the densities near the site on the Minnesota River at Jordan, Minnesota, and on the St. Croix River at Danbury, Wisconsin. The population density increases greatly near the sites in and downstream of the TCMA, the St. Croix River at St. Croix Falls, and the Mississippi River at Hastings and Red Wing (fig. 8). The total population increases downstream along all these rivers and peaks in the TCMA near their confluence.

Fish Communities

A total of 72 species and one hybrid in 20 families were collected during sampling at the large river sites (table 6). The number of species collected at each site (fig. 9) is similar to the pattern of total species reported from the rivers and their basins (Underhill, 1989), and indicates that sampling was consistent at all sites. Only two species were collected at all sites, the spotfin shiner (*Cyprinella spiloptera*) and the walleye (*Stizostedion vitreum*). However, there were 16 other species found at five or more sites (table 6). Generally, most species were rare (less than five percent of the total number of fish collected) at most sites, and very few species were common (5-20 percent of the total number of fish collected) or abundant (greater than 20 percent of the number of fish collected).

The differences in the fish communities upstream and downstream of the TCMA are greater than can be attributed to differences caused by migration barriers alone. Although the lack of a long term-data limits the comparisons that can be made, certain changes are apparent in the composition and relative abundance between the upstream and downstream communities of fish. First, there is a shift to species with a higher thermal range in and downstream of the TCMA and in the

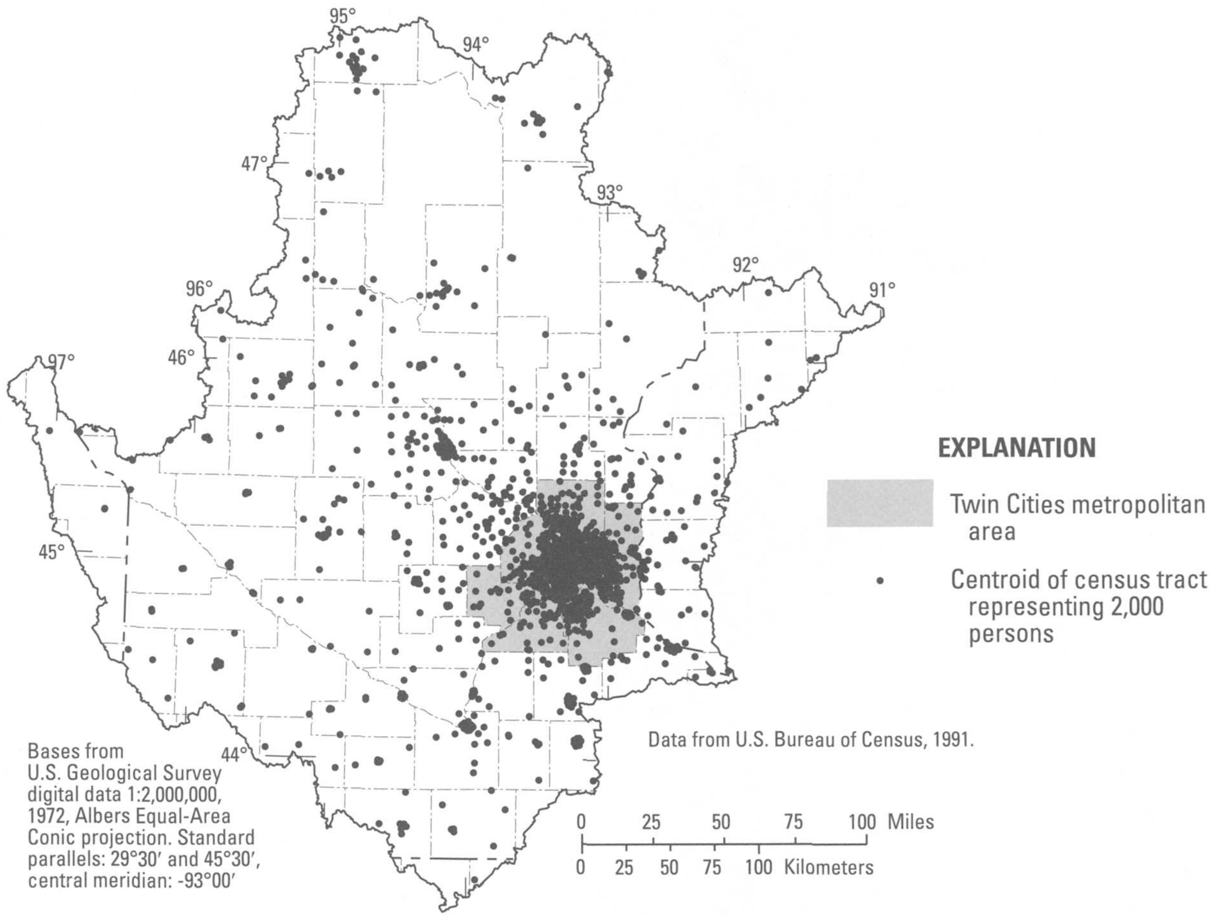

Figure 8.--Population density in 1990 in the Upper Mississippi River Basin study unit.

agricultural Minnesota River. Second, there is a decrease in the proportion of flowing-water (lotic) species compared to still- or slow-moving-water (lentic) species in and downstream of the TCMA. Third, there is a shift in the trophic structure from a community dominated by invertivores and carnivores upstream of the TCMA to a community with more planktivores and detritivores in and downstream of the TCMA.

There are some thermal considerations that may affect the distribution of species within the UMIS. The water temperature regime is a function of the temperature of inflowing tributaries, the amount of ground-water contribution, the amount of runoff, residence time in instream lakes or impoundments, channel width and amount of exposure to solar heating, shading from riparian vegetation, and numerous other factors.

The upstream Mississippi River site at Royalton, Minnesota, and the upstream St. Croix River site at Danbury, Wisconsin, had species with thermal preferences lower than those at the downstream sites (fig. 10, table 6). The fish communities at these sites were dominated numerically by sucker species and smallmouth bass. The Minnesota River at Jordan and the downstream St. Croix River site at St. Croix Falls contained species with thermal regimes similar to the other Mississippi River sites at Hastings and Red Wing. The species with higher thermal maxima include the catfishes, buffalo fishes, freshwater drum, carpsuckers, and shiners. The most abundant species were gizzard shad and emerald shiners, both with high thermal maxima (fig. 10). The Minnesota River Basin is agricultural, and the tributaries have little riparian vegetation for shading. The generally higher concentrations of suspended solids carried by the Minnesota River (Stark and others, 1996) act as heat traps by absorbing radiant energy. Runoff from the cultivated fields tends to gain heat from contact with the dark soils, even though the runoff is rapidly conveyed to the streams by drain tiles. The lower St. Croix River channel expands laterally to a much greater width in Lake St. Croix before becoming narrow again as it joins the Mississippi River. The velocity is reduced, residence time is increased, and solar exposure is increased.

In the TCMA, runoff of surface water from impervious surfaces tends to gain heat from the solar energy stored in the composite materials in roads, buildings, and other man-made surfaces. Evaporation from impervious surfaces reduces the amount of ground-water recharge, thus reducing the amount of cooler ground-water contributions to urban streams. In addition, the pools created by lock and dam construction in and downstream of

Table 6. Species composition and relative abundance at Upper Mississippi River Basin large river sites, 1996
[R, less than 5 percent of number of fish collected; C, 5 to 20 percent of number of fish collected; A, greater than 20 percent of number of fish collected, hybrids not included]

Scientific name	Common name	River site						
		Mississippi River near Royalton	Mississippi River near Anoka	St. Croix River near Danbury	St. Croix River at St. Croix Falls	Minnesota River near Jordan	Mississippi River at Hastings	Mississippi River at Red Wing
Petromyzontidae	**Lampreys**							
Ichthyomyzon castaneus	chestnut lamprey			R				
Ichthyomyzon gagei	southern brook lamprey			R				
Ichthyomyzon unicuspis	silver lamprey							R
Acipenseridae	**Sturgeons**							
Scaphirhynchus platorynchus	shovelnose sturgeon					R		
Lepisosteidae	**Gars**							
Lepisosteus platostomus	shortnose gar					R		
Amiidae	**Bowfins**							
Amia calva	bowfin	R				R		
Hiodontidae	**Mooneyes**							
Hiodon alosoides	goldeye					R		
Hiodon tergisus	mooneye					R		
Clupeidae	**Herrings**							
Dorosoma cepedianum	gizzard shad					C	C	R
Catostomidae	**Suckers**							
Carpiodes carpio	river carpsucker					R	R	R
Carpiodes cyprinus	quillback				R	R	R	R
Carpiodes velifer	highfin carpsucker				R	R		
Catostomus commersoni	white sucker	R	R	R				
Cycleptus elongatus	blue sucker						R	R
Hypentelium nigricans	northern hogsucker		R	C	R			
Ictiobus bubalus	smallmouth buffalo				R	R	R	
Ictiobus cyprinellus	bigmouth buffalo					R	R	R

Table 6. Species composition and relative abundance at Upper Mississippi River Basin large river sites, 1996--Continued
[R, less than 5 percent of number of fish collected; C, 5 to 20 percent of number of fish collected; A, greater than 20 percent of number of fish collected, hybrids not included]

Scientific name	Common name	River site: Mississippi River near Royalton	Mississippi River near Anoka	St. Croix River near Danbury	St. Croix River at St. Croix Falls	Minnesota River near Jordan	Mississippi River at Hastings	Mississippi River at Red Wing
Moxostoma anisurum	silver redhorse	R	R	R	C		R	R
Moxostoma carinatum	river redhorse			R	R			
Moxostoma erythrurum	golden redhorse			C	C			
Moxostoma macrolepidotum	shorthead redhorse	A		C	R	R	R	R
Moxostoma valenciennesi	greater redhorse				R			
Cyprinidae	**Minnows**							
Campostoma anomalum	central stoneroller					R		
Campostoma oligolepis	largescale stoneroller			R				
Cyprinus carpio	common carp	R	C		C	C	R	C
Hybognathus hankinsoni	brassy minnow					R	R	
Macrhybopsis aestivalis	speckled chub					R		
Macrhybopsis storeriana	silver chub						R	R
Nocomis biguttatus	hornyhead chub	R		C				R
Notropis atherinoides	emerald shiner				C	A	A	A
Notropis blennius	river shiner							R
Luxilus cornutus	common shiner	R	R	A				
Notropis dorsalis	bigmouth shiner			R				
Notropis heterolepis	blacknose shiner				R			
Notropis hudsonius	spottail shiner	R	R		R		R	R
Cyprinella spiloptera	spotfin shiner	R	R	R	C	R	R	R
Notropis stramineus	sand shiner	R		R	C	R		
Notropis volucellus	mimic shiner	R			R		R	
Pimephales notatus	bluntnose minnow		R	R	R	C	R	
Pimephales promelas	fathead minnow					R		
Pimephales vigilax	bullhead minnow						R	R
Rhinichthys cataractae	longnose dace	R		R				

Table 6. Species composition and relative abundance at Upper Mississippi River Basin large river sites, 1996--Continued
[R, less than 5 percent of number of fish collected; C, 5 to 20 percent of number of fish collected; A, greater than 20 percent of number of fish collected, hybrids not included]

Scientific name	Common name	River site						
		Missis-sippi River near Royalton	Missis-sippi River near Anoka	St. Croix River near Danbury	St. Croix River at St. Croix Falls	Minne-sota River near Jor-dan	Missis-sippi River at Hastings	Missis-sippi River at Red Wing
Ictaluridae	**Catfish**							
Ameiurus natalis	yellow bullhead	R						
Ictalurus punctatus	channel catfish	R	R			R	R	R
Noturus flavus	stonecat			R				
Pylodictus olivaris	flathead catfish					R	R	R
Umbridae	**Mudminnow**							
Umbra limi	central mudminnow	R		R				
Esocidae	**Pikes**							
Esox lucius	northern pike	R	R	R	R	R		
Anguillidae	**Freshwater eels**							
Anguilla rostrata	American eel							R
Gadidae	**Cod**							
Lota lota	burbot	R		R	R		R	R
Percopsidae	**Trout-perch**							
Percopsis omiscomaycus	trout-perch	R	R					
Atherinidae	**Silversides**							
Labidisthes sicculus	brook silverside						R	
Percichthyidae	**Temperate basses**							
Morone chrysops	white bass					R	R	R
Centrarchidae	**Sunfishes**							
Ambloplites rupestris	rock bass	R	R	R	R			R
Lepomis cyanellus	green sunfish		R		R	R	R	R

Table 6. Species composition and relative abundance at Upper Mississippi River Basin large river sites, 1996--Continued

[R, less than 5 percent of number of fish collected; C, 5 to 20 percent of number of fish collected; A, greater than 20 percent of number of fish collected, hybrids not included]

Scientific name	Common name	River site						
		Missis-sippi River near Royalton	Missis-sippi River near Anoka	St. Croix River near Danbury	St. Croix River at St. Croix Falls	Minne-sota River near Jor-dan	Missis-sippi River at Hastings	Missis-sippi River at Red Wing
Lepomis humilis	orangespotted sun-fish					R	R	
Lepomis macrochirus	bluegill		R	R	R		R	R
Microterus dolomieui	smallmouth bass	C	A	C	C		R	R
Micropterus salmoides	largemouth bass		R		R		R	R
Pomoxis annularis	white crappie				R			
pomoxis nigromaculatus	black crappie	R	R		R		R	R
	Hybrid sunfish		R					
Percidae	**Perches**							
Etheostoma nigrum	johnny darter	R			R	R	R	R
Perca flavescens	yellow perch	R	R	R			R	R
Percina caprodes	logperch	R	R	R	R		R	R
Percina evides	gilt darter			C				
Percina maculata	blackside darter		C	R			R	R
Percina phoxocephala	slenderhead darter					R	R	R
Percina shumardi	river darter						R	
Stizostedion canadense	sauger					R	R	R
Stizostedion vitreum	walleye	R	R	R	R	R	R	R
Sciaenidae	**Drums**							
Aplodinotus grunniens	freshwater drum				R	R	R	R
Cottidae	**Sculpin**							
Cottus bairdi	mottled sculpin	R						
Total Species		26	21	28	30	32	37	35

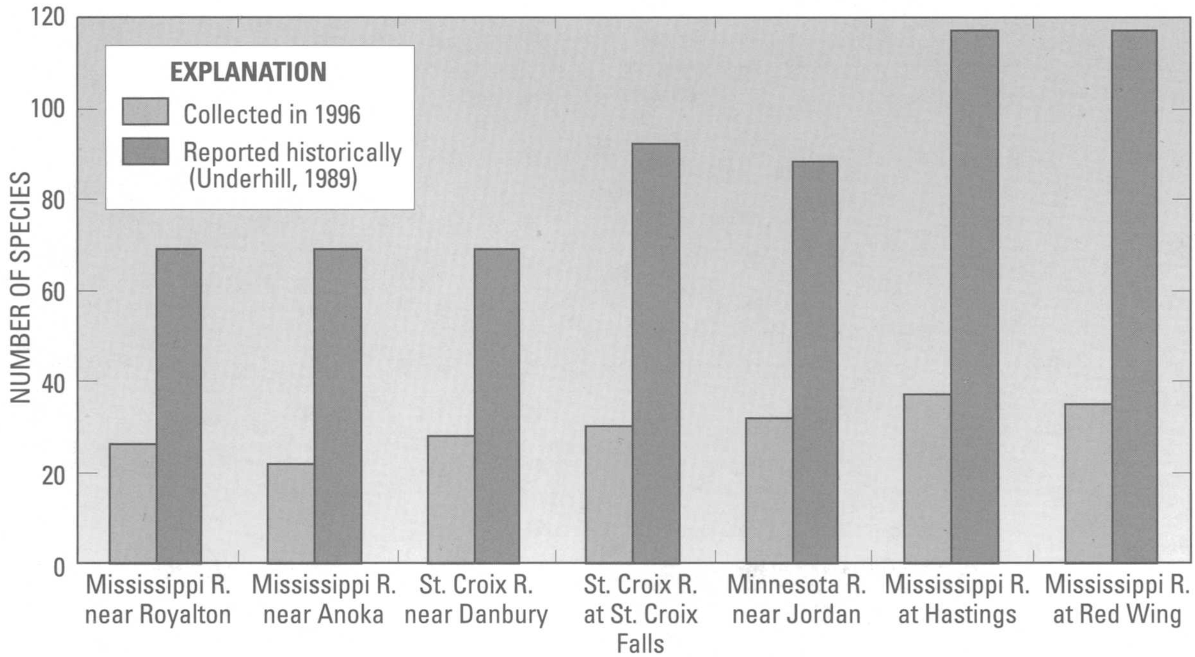

Figure 9.--Comparison between number of species collected in 1996 and the number reported historically at the large river sites in the Upper Mississippi River Basin.

Temperature (F)°						
<77	80.6	82.4	86	87.8	89.6	>91.4
Scuplin	Rehorse Walleye Sauger White sucker	Smallmouth bass Bluntnose minnow Fathead minnow	Spotfin shiner	Drum Gizzard shad	Channel Catfish Flathead catfish	Common carp Gar Carsuckers Buffaloes Emerald shiner
<25	27	28	30	31	32	>33
Temperature (C)°						

Figure 10.--Upper thermal perferenda of selected fish of the Upper Mississippi River Basin (after Simon, 1992).

the TCMA served to increase water temperatures by reducing discharge velocity, increasing residence time, and increasing exposure to solar radiation. For example, after impoundment, the surface area of Lake Pepin (Pool #4) increased over 100 percent (Chen and Simons, 1986).

As a consequence of reduced discharge velocities, the species in and downstream of the TCMA tend to be associated with lentic habitats, whereas the species above the TCMA are associated more with lotic habitats. Body morphology is indicative of the type of habitat that a species evolved to inhabit. Flowing-water species are more fusiform and streamlined in shape to help reduce drag and energy requirements for maintaining position against flowing water; whereas slow-moving or still-water species tend to be more laterally compressed to increase their surface area for locomotion. Approximately 80 percent of the species collected at the sites upstream of the TCMA were lotic species, compared to about 65 percent of the species at the sites in and downstream of the TCMA (tables 7 and 8). The shift to more lentic species was observed at all the sites in and downstream of the TCMA (fig. 11a). The change from a lotic system to a more lentic system also affects the trophic composition of the fish community.

According to the river continuum concept (Vannote and others, 1980), the trophic composition of a river changes with river size. As stream and river size increases, there is a shift from organisms that rely on coarse particulate organic sources (leaves, woody debris, plants) from terrestrial sources outside of the stream to species that can utilize finer particulate carbon sources such as plank-

Table 7. Classification of species, collected at the large river sites, by preferred habitat (based on body morphology) and trophic group
[Trophic groups from Gerking (1994) and Goldstein and Simon (1998)]

Scientific name	Common name	Preferred habitat		Trophic group				
		Lotic	Lentic	Carnivore	Invertivore	Detritivore	Planktivore	Herbivore
Petromyzontidae	**Lampreys**							
Ichthyomyzon castaneus	chestnut lamprey	X		X				
Ichthyomyzon gagei	southern brook lamprey	X				X		X
Ichthyomyzon unicuspis	silver lamprey	X		X				
Acipenseridae	**Sturgeons**							
Scaphirhynchus platorynchus	shovelnose sturgeon	X			X			
Lepisosteidae	**Gars**							
Lepisosteus platostomus	shortnose gar		X	X				
Amiidae	**Bowfins**							
Amia calva	bowfin		X	X		X		
Hiodontidae	**Mooneyes**							
Hiodon alosoides	goldeye		X			X		
Hiodon tergisus	mooneye		X			X		
Clupeidae	**Herrings**							
Dorosoma cepedianum	gizzard shad		X				X	
Catostomidae	**Suckers**							
Carpiodes carpio	river carpsucker		X		X	X		
Carpiodes cyprinus	quillback		X		X		X	
Carpiodes velifer	highfin carpsucker		X			X		
Catostomus commersoni	white sucker	X			X	X		
Cycleptus elongatus	blue sucker	X			X			X
Hypentelium nigricans	northern hogsucker	X			X			
Ictiobus bubalus	smallmouth buffalo		X		X			X
Ictiobus cyprinellus	bigmouth buffalo		X		X			
Moxostoma anisurum	silver redhorse	X			X			
Moxostoma carinatum	river redhorse	X			X			

Table 7. Classification of species, collected at the large river sites, by preferred habitat (based on body morphology) and trophic group--Continued

Scientific name	Common name	Preferred habitat		Trophic group				
		Lotic	Lentic	Carni-vore	Inverti-vore	Detriti-vore	Plank-tivore	Herbi-vore
Moxostoma erythrurum	golden redhorse	X			X			
Moxostoma macrolepidotum	shorthead redhorse	X			X			
Moxostoma valenciennesi	greater redhorse	X			X			
Cyprinidae	**Minnows**							
Campostoma anomalum	central stoneroller	X						X
Campostoma oligolepis	largescale stoneroller	X						X
Cyprinus carpio	common carp		X		X	X		
Hybognathus hankinsoni	brassy minnow	X				X	X	
Macrhybopsis aestivalis	speckled chub	X			X	X		
Macrhybopsis storeriana	silver chub	X			X		X	
Nocomis biguttatus	hornyhead chub	X			X			X
Notropis atherinoides	emerald shiner	X					X	
Notropis blennius	river shiner	X			X			
Luxilus cornutus	common shiner	X			X			
Notropis dorsalis	bigmouth shiner	X			X			
Notropis heterolepis	blacknose shiner	X			X			X
Notropis hudsonius	spottail shiner	X			X		X	
Cyprinella spiloptera	spotfin shiner	X			X	X		
Notropis stramineus	sand shiner	X			X	X		
Notropis volucellus	mimic shiner	X			X			X
Pimephales notatus	bluntnose minnow	X				X		
Pimephales promelas	fathead minnow	X				X		X
Pimephales vigilax	bullhead minnow	X			X			X
Rhinichthys cataractae	longnose dace	X			X			
Ictaluridae	**Catfish**							
Ameiurus natalis	yellow bullhead		X	X	X			
Ictalurus punctatus	channel catfish	X		X	X			
Noturus flavus	stonecat	X		X	X			
Pylodictus olivaris	flathead catfish		X	X				
Umbridae	**Mudminnow**							
Umbra limi	central mudminnow		X		X			

Table 7. Classification of species, collected at the large river sites, by preferred habitat (based on body morphology) and trophic group--Continued

Scientific name	Common name	Preferred habitat: Lotic	Preferred habitat: Lentic	Trophic group: Carni-vore	Inverti-vore	Detriti-vore	Plank-tivore	Herbi-vore
Esocidae	**Pikes**							
Esox lucius	northern pike		X	X				
Anguillidae	**Freshwater eels**							
Anguilla rostrata	American eel	X		X				
Gadidae	**Cod**							
Lota lota	burbot	X		X	X			
Percopsidae	**Trout-perch**							
Percopsis omiscomaycus	trout-perch	X		X	X			
Atherinidae	**Silversides**							
Labidisthes sicculus	brook silverside	X			X		X	
Percichthyidae	**Temperate basses**							
Morone chrysops	white bass		X	X	X			
Centrarchidae	**Sunfishes**							
Ambloplites rupestris	rock bass		X	X	X			
Lepomis cyanellus	green sunfish		X	X	X			
Lepomis humilis	orange spotted sunfish		X		X			
Lepomis macrochirus	bluegill		X	X	X			
Microterus dolomieu	smallmouth bass		X	X	X			
Micropterus salmoides	largemouth bass		X	X	X			
Pomoxis annularis	white crappie		X	X	X			
pomoxis nigromaculatus	black crappie		X	X	X			
	Hybrid sunfish		X		X			
Percidae	**Perches**							
Etheostoma nigrum	johnny darter	X			X			
Etheomstoma zonale	banded darter	X			X			
Perca flavescens	yellow perch		X	X	X			
Percina caprodes	logperch	X			X			

Table 7. Classification of species, collected at the large river sites, by preferred habitat (based on body morphology) and trophic group--Continued

Scientific name	Common name	Preferred habitat		Trophic group				
		Lotic	Lentic	Carnivore	Invertivore	Detritivore	Planktivore	Herbivore
Percina evides	gilt darter	X			X			
Percina maculata	blackside darter	X			X			
Percina phoxocephala	slenderhead darter	X			X			
Percina shumardi	river darter	X			X			
Stizostedion canadense	sauger	X		X				
Stizostedion vitreum	walleye	X		X				
Sciaenidae	**Drums**							
Aplodinotus grunniens	freshwater drum		X	X	X			
Cottidae	**Sculpin**							
Cottus bairdi	mottled sculpin	X			X			
Totals		47	27	24	54	14	7	10

Table 8. Number of species at the large river sites summarized by habitat preference and trophic group, 1996. [TCMA, Twin Cities metropolitan area]

Habitat preference or trophic group	Upstream of TCMA			Within and downstream of TCMA			
	Mississippi River near Royalton	Mississippi River near Anoka	St. Croix River near Danbury	St. Croix River at St. Croix Falls	Minnesota River near Jordan	Mississippi River at Hastings	Mississippi River at Red Wing
Lotic	18	12	23	17	15	21	20
Lentic	8	9	5	13	17	16	15
Carnivore	11	11	9	11	10	13	16
Invertivore	23	18	22	25	17	30	28
Detritivore	5	4	5	5	12	5	3
Planktivore	1	1	0	3	4	7	5
Herbivore	2	0	2	3	3	4	3

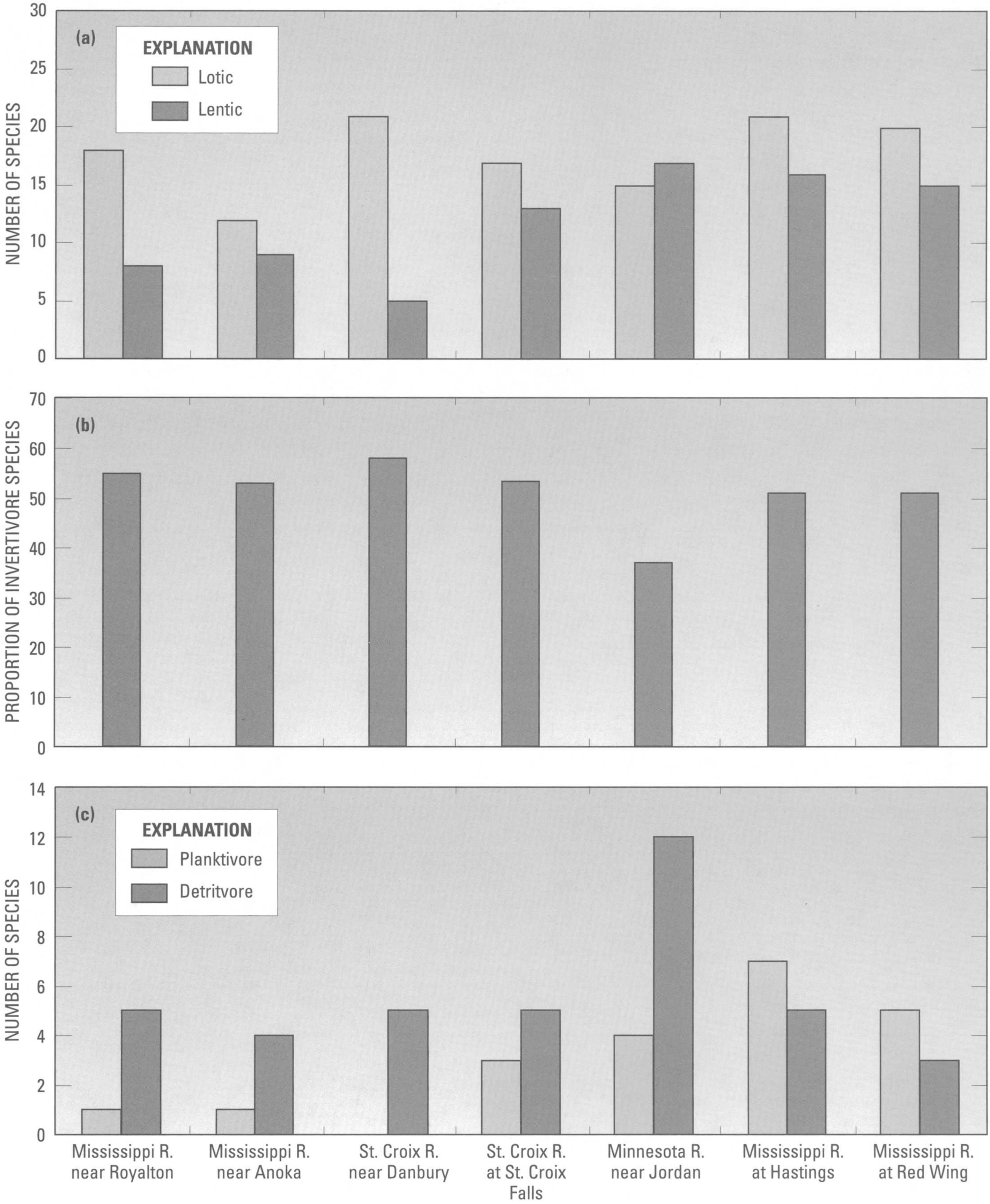

Figure 11.--(a) Comparison between number of lotic and lentic species, (b) proportion of invertivore species, and (c) number of detritivore and planktivore species at the large river sites in the Upper Mississippi River Basin, 1996.

ton and detritus derived from upstream sources. The change from a community dominated by invertivores with few detritivores or planktivores to one where detritivores and planktivores are abundant is expected to occur gradually. The proportion of invertivore species at the sites upstream of the TCMA is only slightly greater than downstream (fig. 11b). Species abundant at the upstream sites include northern hogsucker, golden and shorthead redhorse, hornyhead chub, common shiner, smallmouth bass and two species of darters. These species forage for invertebrates on the river bottom around and on rocks and other substrates as well as in the water column. The primary invertebrate food sources are species that require a gravel or cobble substrate (crayfish, mayfly and caddisfly larvae). Only a few of the fish species would be considered detritivores and only one species, common carp, was abundant at the upstream sites. In the Minnesota River, the total number of detritivore species is greater than at any of the other sites sampled (table 8, fig. 11c); whereas the proportion of invertivore species is the lowest of any large river site sampled. This may reflect the suspended sediment concentration, which is the highest of all the sites (fig. 3). In and downstream of the TCMA, the number of species that are planktivores increases dramatically (fig. 11c). One consequence of impoundments is the development of a plankton community, which contains phytoplankton and zooplankton similar to lakes (Hynes, 1975). The detritivores (common carp) and planktivores (gizzard shad and emerald shiners) are the most abundant species at the sites in and downstream of the TCMA. These fish rely on filter feeding and suctioning of the bottom sediments to acquire sufficient food, reflecting the change to a more lake-like plankton community.

Relation of Fish Community Composition to Environmental Factors and Land Use

It is not possible to separate the various effects of habitat alteration, changes to the thermal regime of the rivers, and land uses such as urbanization and agriculture from natural differences in fish species composition of fish species in the Upper Mississippi River Basin. There has been no distinct or discernible pattern of reduction in fish biodiversity, which may be due to the lack of a long-term data (Holland-Bartells, 1992).

Certain factors that have affected species composition, however, are common to both the small streams and large rivers that were evaluated. While certain effects may be associated with a specific land use or environmental factor, the responses of the fish communities tend to be similar in both the small streams and the large rivers.

The fish communities of agricultural streams in the UMIS are influenced by physical and chemical disturbance factors. Physical disturbance to the stream geomorphology, hydrology, and instream habitat results from channelization, destruction of riparian vegetation, drainage of wetlands, and tile drains. Chemically, water quality may be altered by inputs of nutrients and pesticides that reach the streams from nonpoint runoff and tile drains. When the geomorphology is not changed and the streams are left to meander naturally, the types and amount of instream habitat are not as greatly affected. With increased nutrient concentrations, the agricultural streams and rivers become highly productive as evidenced by the amount of fish biomass compared to the other types of sites. Species composition tends to include herbivores in the small streams and planktivores in the larger rivers. Both streams and rivers are dominated by detritivores.

Generally, fish communities of forest streams are not as disturbed as those of agricultural or urban streams. The water quality and aquatic habitat tends to be less disturbed than in agricultural and urban settings. The lack of land-cover disturbance reduces hydrologic variability and maintains lower water temperatures through ground-water input and runoff. Water temperature is an important determinant of the fish community in the UMIS. The fish community of the Namekagon River site is composed of cold- and cool- water species, which are primarily invertivores and carnivores. The invertivores feed primarily on benthic invertebrates (molluscs and insects) or drifting insects. Biomass is not as great as in agricultural or urban streams.

Both small streams and rivers are influenced by urbanization. Channel and hydrologic modifications such as impoundments in combination with increased impervious surface land cover have altered the fish communities of the Mississippi River and its tributaries in and downstream of the TCMA. In addition, dredging for commercial navigation on the Mississippi River has reduced habitat for fish, increased turbidity, and re-suspended particulates and associated contaminants. Fish community composition in the Mississippi River and its tributaries in and downstream of the TCMA is dominated by lentic species. In the small streams, this is due mainly to the presence of small impoundments along the courses of the streams. In the large rivers this is also due to the impoundments that have accentuated the change in the fish community from an invertivore/carnivore-dominated community to a planktivore/detritivore-dominated community. The shift in trophic composition as stream order increases is natural; however, the process has been accelerated by the lock and dam system on the Mississippi River.

Summary

The U.S. Geological Survey is conducting a National Water-Quality Assessment (NAWQA) Program. The Upper Mississippi River Basin is one of approximately 59 hydrologic systems selected for study in a nationally consistent manner. A multidisciplinary approach is used to identify, describe, and explain factors that affect water quality. Part of the NAWQA study design is to address the relation of environmental factors and land-use to the fish communities in streams.

The study focuses on an area of 50,000 square kilometers within the Upper Mississippi River Basin upstream of Lake Pepin and includes the Twin Cities metropolitan area (TCMA). The northeastern part of the study area is the primarily-forested St. Croix River Basin, the southwestern part is the highly agricultural Minnesota River Basin, and the central part is the transitional and urban Mississippi River Basin.

Study sites were selected based on a stratification process that identified small streams in agricultural, forested, and urban environmental settings, and large river sites upstream and downstream of the TCMA and on the major tributaries of the Mississippi River. Each site was characterized with respect to hydrology, water chemistry, habitat, land use, and riparian zone. Fish community composition was evaluated with respect to these features.

The fish communities of the small streams were not similar in species composition. Proximity of a sampling site to a major river tended to increase the number of species found. Environmental factors affecting agricultural streams include increased nutrients from fertilizers, increased temperatures from loss of riparian shading, habitat modifications due to channelization, and hydrologic modification from dams and tile drains. The agricultural streams had fish communities with species that required some cobble and gravel substrates, and that detect prey visually. The trophic structure was dominated by invertivores, but a few herbivores and detritivores were present. The small forested stream contained fewer fish species. Cold-water-stream fish communities tend to have few species, primarily invertivores and carnivores. Most of these species require clear, cold water over a cobble, boulder substrate. The urban streams contained many lentic species due mainly to small urban impoundments. Many of these species are tolerant of silt, low dissolved oxygen, and marginal habitats.

The number of species was different in the large rivers upstream and downstream of barrriers on the Mississippi River at St. Anthony's Falls and on the St. Croix River at Taylor's Falls due in part to zoogeographic differences. However, there is a discernible shift in the composition of the fish community in and downstream of the TCMA beyond zoogeographic factors. Mainstream impoundments, the result of the navigational lock and dam system, decrease water velocities, which allows suspended sediment to sink and water temperatures to increase. Greater light penetration, warmer temperatures, and nutrient inputs from the agricultural Minnesota River Basin promote the growth of phytoplankton. The fish community in and downstream of the TCMA contains more lentic species, species with higher thermal tolerance, and an increase in the number of species that are planktivores. The large river community changes are large scale extentions of the effects of physical and chemical changes, which occur in the small streams.

References

Becker, G.C., 1983, Fishes of Wisconsin: University of Wisconsin Press, Madison, Wisconsin, 1052 p.

Breeder, C.M., and Rosen, D.E., 1966, Modes of reproduction in fishes: T.F.H. Publications, Jersey City, New Jersey, 941 p.

Chen, Y.H., and Simons, D.B., 1986, Hydrology, hydraulics and geomorphology of the Upper Mississippi River system: Hydrobiologia, v.146, p. 5-20.

Cohen, Phillip, Alley, W.M., and Wilber, W.G., 1988, National water-quality assessment—Future directions of the U.S. Geological Survey: Water Resources Bulletin, v. 46, no. 6, p. 1147-1151.

Eddy, Samuel, and Underhill, J.C., 1974, Northern fishes: University of Minnesota Press, Minneapolis, 3rd. edition, 414 p.

Fenneman, N.M., and Johnson, D.W., 1946, Physical divisions of the United States: U.S. Geological Survey, scale 1:7,000,000.

Frissell, C.A., Liss, W.J., Warren, C.E., and Hurley, M.D., 1986, A hierarchical framework for stream habitat classification—Viewing streams in a watershed context: Environmental Management, v. 10, p. 199-214.

Gerking, S.D., 1994, Feeding ecology of fish: Academic Press, San Diego, California, 416 p.

Goldstein, R.M., 1981. Longitudinal succession in impact assessment of river system fish communities: Water Resources Bulletin, v. 17, p. 75-81.

Goldstein, R.M., and Simon, T.P., 1998, Towards a united definition of guild structure of North American freshwater fishes, *in* Simon, T.P., ed., Assessing the sustainability and biological integrity of water-resource quality using fish assemblages: CRC Press, Boca Raton, Florida. p. 123-202.

Gurtz, M.E., 1994, Design of the biological components of the National Water-Quality Assessment (NAWQA) Program, *in* Loeb, S.L. and Spacie, Anne, eds., Biological monitoring of aquatic systems: CRC Press, Lewis Publishers, Boca Raton, Florida, p. 323-354.

Hitt, K.J., 1994, Refining 1970's land use data with 1990 population data to indicate new residential development: U.S. Geological Survey Water-Resources Investigations Report 94-4250, at URL http://wwwrvares.er.usgs.gov/nawqa/WRI94-4250.html.

Hobbs, H.C., and Goebel, J.E., 1982, Geologic Map of Minnesota—Quaternary geology: Minnesota Geological Survey State Map Series S-1, 1 sheet.

Holland-Bartels, L.E., 1992, Water quality changes and their relation to fishery resources in the Upper Mississippi River, *in* Becker, C.D. and Neitzel, D.A., eds., Water quality in North American river systems: Battelle Press, Richland, Washington, p. 160-180.

Hynes, H.B.N., 1975, The ecology of running waters: University of Toronto Press, 555 p.

Karr, J.R., Fausch, K.D., Angermeier, P.L., Yant, P.R., and Schlosser, I.J., 1986, Assessing biological integrity in running waters—A method and its rationale: Illinois Natural History Survey Special Publication 5, 28 p.

Leach, J.A., and Magner, J.A., 1992, Wetland drainage impacts within the Minnesota River Basin: Currrents, v. 2, p. 3-10.

Leahy, P.P., Rosenshein, J.S., and Knopman, D.S., 1990, Implementation plan for the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 90-174, 10 p.

Meador, M.R., Hupp, C.R., Cuffney, T.F., and Gurtz, M.E., 1993a, Methods for characterizing stream habitat as part of the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 93-408, 48 p.

Meador, M.R., Cuffney, T.C., and Gurtz, M.E., 1993b, Methods for sampling fish communities as part of the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 93-104, 40 p.

Minnesota Department of Transportation, 1977, 1977-1978 Official Transportation Map Minnesota, 1 map.

Mitton, G.B., Wakeman, E.S., and Guttormson, K.G., 1997, Water-resources data, Minnesota, water year 1996: U.S. Geological Survey Water-Data Report MN-96-1, 525 p.

Olcott, P.G., 1992, Ground-water atlas of the United States, Segment 9, Iowa, Michigan, Minnesota, and Wisconsin: U.S. Geological Survey Hydrologic Investigations Atlas 730-J, 31 p., scales 1:250,000 and 1:500,000.

Pflieger, W.L., 1971, The fishes of Missouri: Missouri Department of Conservation, Columbia, Missouri, 343 p.

Shelton, L.R., 1994, Field guide for collecting and processing stream-water quality samples for the National Water-Quality Program: U.S. Geological Survey Open-File Report 94-455, 42 p.

Simon, T.P., 1992, Biological criteria development for large rivers with an emphasis on an assessment of the White River drainage, Indiana: U.S. Environmental Protection Agency, Region V, Water Division, Water Quality Standards, Chicago, Illinois, EPA 905/R-92/006, 75 p. [plus appendices].

Sims, P.K., and Morey, G.B., eds., 1972, Geology of Minnesota—A centennial volume: Minnesota Geological Survey, 632 p.

Smale, M.A., and Rabeni, C.F., 1995, Influences of hypoxia and hyperthermia on fish species composition in headwater streams: Transactions of the American Fisheries Society, v. 124, p. 711-725.

Stark, J.R., Andrews, W.J., Fallon, J.D., Fong, A.L., Goldstein, R.M., Hanson, P.E., Kroening, S.E., and Lee, K.E., 1996, Water-quality assessment of part of the Upper Mississippi River Basin, Minnesota and Wisconsin—Environmental setting and study design: U.S. Geological Survey Water-Resources Investigations Report 96-4098, 62 p.

Strahler, H.N., 1957, Quantitative analysis of watershed geomorphology: American Geophysical Union Transactions, v. 33, p. 943-920.

Symons, P.E.K., Metcalfe, J.L., and Harding, G.D., 1977, Upper lethal and preferred temperatures of the slimy sculpin, *Cottus cognatus*: Journal of the Fisheries Research Board of Canada, v. 33, p. 180-183.

Thelin, G.P. and Pike, R.J., 1991, Landforms of the conterminous Unites States—A digital shaded-relief portrayal: U.S. Geological Survey, Miscellaneous Investigation Series Map I-2206.

Underhill, J.C., 1989, The distribution of Minnesota fishes and late Pleistocene glaciation: Journal of the Minnesota Academy of Sciences, v. 55, p. 32-37.

U.S. Bureau of Census, 1991, Census of population and housing, 1990: Public Law (P.L.) 94-171, data from CD-ROM for Iowa, Minnesota, North Dakota, South Dakota, and Wisconsin, Washington, DC.

Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R., and Cushing, C.E., 1980, The river continuum concept: Canadian Journal of Fisheries and Aquatic Science, v. 37, p. 370-377.

Woodward, D.G., 1986, Hydrogeologic framework and properties of regional aquifers in the Hollandale Embayment, southeastern Minnesota: U.S. Geological Survey Hydrologic Investigations Atlas HA-667, 2 sheets, scales 1:1,000,000 and 1:2,000,000.

Wright, H.E., Jr., 1972, Quaternary history of Minnesota, *in* Sims, P.K., and Morey, G.B., eds., Geology of Minnesota—A centennial volume: Minnesota Geological Survey, p. 515-546.

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