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Water Quality, Physical Habitat, and Fish-Community Composition in Streams in the Twin Cities Metropolitan Area, Minnesota, 1997–98

Water-Resources Investigations Report 99–4247

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

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By Philip J. Talmage[1], Kathy E. Lee[2], Robert M. Goldstein[2], Jesse P. Anderson[3], and James D. Fallon[2]

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National Water-Quality Assessment Program

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Foreword

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and 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

Contents

Illustrations

Tables

Conversion Factors and Vertical Datum

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
square mile (mi^2)	2.59	square kilometer
pounds per day per square mile ($lbs/d/mi^2$)	.1751	kilograms per day per square kilometer
degrees Fahrenheit (°F)	(°F - 32)/1.8	degrees Celsius

Chemical concentrations of substances are given in metric units of milligrams per liter (mg/L) and micrograms per liter (µg/L). Milligrams and micrograms per liter express the concentration of the chemical constituent as a mass (mg or µg) per unit volume (L). One thousand micrograms per liter is equivalent to1 milligram 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.

Water Quality, Physical Habitat, and Fish-Community Composition in Streams in the Twin Cities Metropolitan Area, Minnesota, 1997-98

By Philip J. Talmage, Kathy E. Lee, Robert M. Goldstein, Jesse P. Anderson, and James D. Fallon

ABSTRACT

Water quality, physical habitat, and fish-community composition were characterized at 13 Twin Cities metropolitan area streams during low-flow conditions, September 1997. Fish communities were resampled during September 1998. Sites were selected based on a range of human population density. Nutrient concentrations were generally low, rarely exceeding concentrations found in agricultural streams or water-quality criteria. Seventeen pesticides and five pesticide metabolites were detected, with atrazine being the only pesticide detected at all 13 streams. Colony counts of fecal coliform bacteria ranged from 54 to greater than 11,000 colonies per 100 mL. Instream fish habitat was sparse with little woody debris and few boulders, cobble, or other suitable fish habitat. Thirty–eight species and one hybrid from 10 families were collected. Fish communities were characterized by high percentages of omnivores and tolerant species with few intolerant species. Index of Biotic Integrity scores were low, with most streams rating fair to very poor. Percent impervious surface was positively correlated with sodium and chloride concentrations and human population density, but was negatively correlated with fish species richness and diversity. Urban land use and human population density influence fish communities and water quality in Twin Cities metropolitan area streams. Other factors that may influence fish community composition include percent impervious cover, water chemistry, water temperature, geomorphology, substrate, instream habitat, and migration barriers.

INTRODUCTION

In 1994, the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program began studies in the Upper Mississippi River Basin study unit (UMIS). The goals of the NAWQA Program are to document the quality of surface and ground water throughout the nation, to explain natural and human factors affecting water quality, and to document changes in water quality over time.

The UMIS study unit encompasses an area of about 47,000 mi^2 (fig. 1) and includes the drainage area of the Mississippi River from the source to the outlet of Lake Pepin. Land use in the basin can be classified into three zones: an agricultural zone across the southwestern one–third of the basin, a forested zone across the northeastern one–third, and a transitional zone, which includes the Twin Cities metropolitan area (TCMA).

One of the specific objectives of the NAWQA Program is to characterize the geographic and seasonal variation of water quality, aquatic biota, and aquatic habitat conditions in relation to urbanization (Stark and others, 1996). The TCMA is located in the southeastern part of the basin and is the center of population and economic activity in the study unit. The TCMA is one of the largest population centers on the Mississippi River above its confluence with the Ohio River. The population of the TCMA is approximately 2.7 million people (U.S Bureau of Census, 1991).

Climate in the TCMA is subhumid continental. Annual temperatures range from an average January temperature of 11°F to an average of 74°F in July (Stark and others, 1996). Rainfall within the TCMA is approximately 30 in. per year, with 75 percent falling between May and September (Baker and others, 1979). Four distinct seasons are observed and most water bodies have ice cover during the winter.

Norvitch and others (1973) described the TCMA as a glaciated area of moraines, lakes, and outwash plains. The elevations of most areas are between 800 and 1,000 ft above sea level.

Urbanization can have an adverse effect on both stream-water quality and aquatic biota. Urbanization factors in the TCMA that affect water quality and aquatic biota include stream alterations, municipal and industrial point-source discharges or emissions, and runoff (Stark and others, 1996). Urban streams tend to be channelized and impounded with a consequential reduction of geomorphological diversity. Changes in hydrology such as more rapid rises in water levels during storm events are due to a high percentage of impervious surfaces in urban areas (Riley, 1998). Urban streams may also exhibit increased water temperature. These changes in the physical environment may influence fish community composition.

Point or nonpoint sources of dissolved solids, nutrients, bacteria, metals, other trace elements, and pesticides may also inhibit growth, reproduction, and diversity of aquatic biota (Pope and Putnam, 1997). Nonpoint-source contaminants in urban areas originate from automobiles, de-icing materials, construction, lawns, atmospheric deposition, street debris, and animal and plant refuse (Hambrook and others, 1997). A high percentage of impervious surface in urban watersheds can compound the problem of nonpoint-source contaminants by reducing infiltration, and allowing stormwater to reach streams faster than in rural areas with vegetative cover.

The purposes of this report are to (1) characterize the water quality, physical habitat, and fish community composition in 13 TCMA streams during low-flow conditions, and (2) identify factors that influence water quality and fish-community composition in these streams.

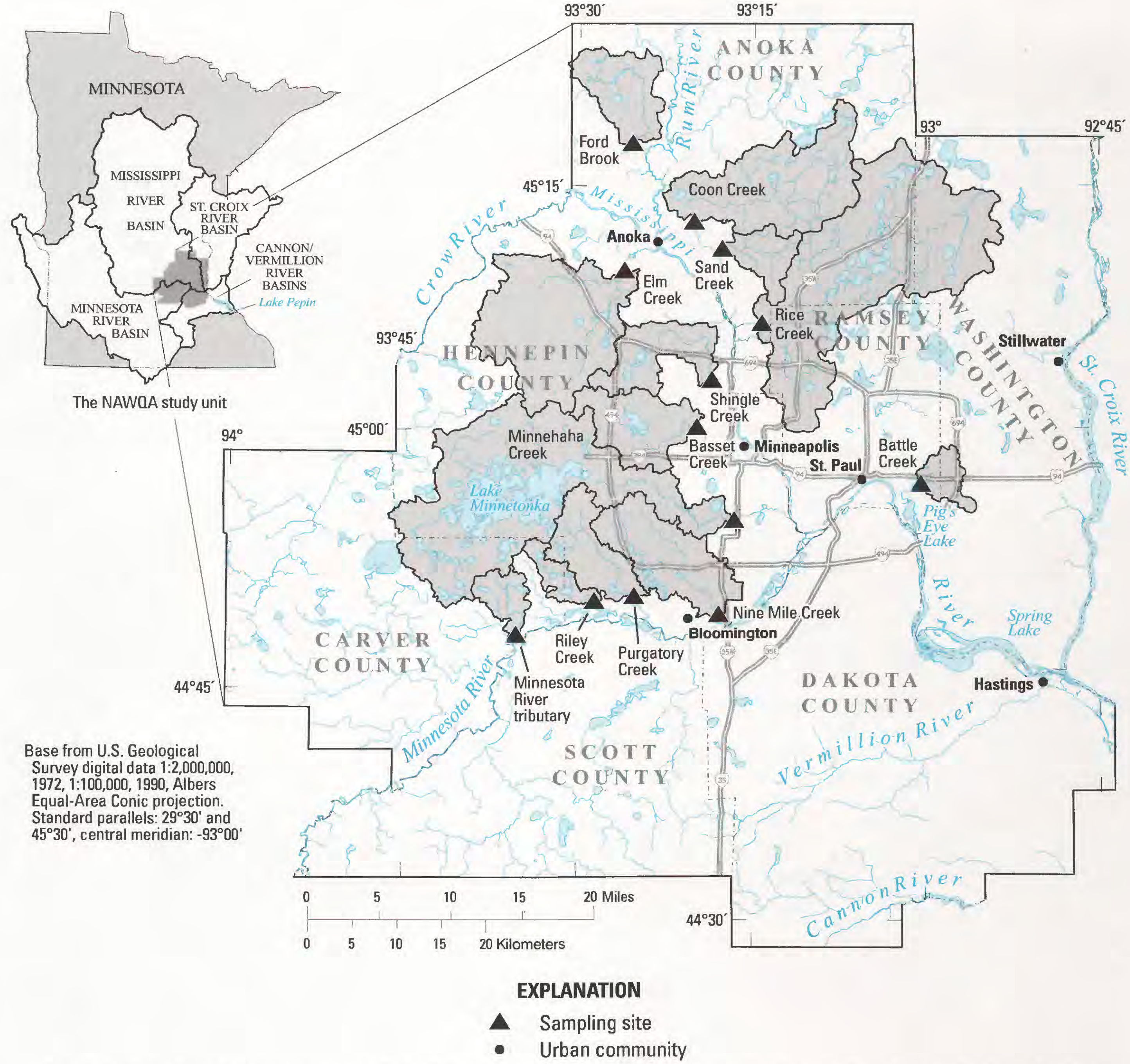

Figure 1.--Location of the seven-county Twin Cities metropolitan area, the urban synoptic sampling sites, and selected urban communities in the Upper Mississippi River Basin study unit.

METHODS

Wadeable, warmwater (greater than 21 degrees; Everhart and Young, 1989) streams in the TCMA with basin areas that ranged from 10 to 150 mi^2 were selected to include a range of population density. Urban land use within the selected basins ranges from less than 1 to 90 percent.

Water sampling, fish collections, streamflow measurements, and habitat characterization were accomplished during September 1997. The streams were at low flow with the exception of three sites (Purgatory, Riley, and Minnehaha Creeks). Water sampling and streamflow measurements at these three streams were performed while the stream stages were rising. Equal-width-increment and depth-integrated water samples for chemical analyses were collected and processed according to USGS NAWQA protocols (Shelton, 1994). Constituents analyzed by the USGS National Water-Quality Laboratory included nutrients, major ions, suspended sediment, and pesticides. Selected metabolites of the herbicides were analyzed by the USGS Organic Geochemistry Laboratory in Lawrence, Kansas. Fecal coliform bacteria samples were prepared and counted by field personnel according to USGS protocols (Myers and Wilde, 1997). Prior to fish sampling, specific conductance, pH, water temperature, and dissolved oxygen concentrations were recorded at each stream at 15 minute intervals for a 48-hour period. Fish communities were sampled again the following year, during September 1998, to assess inter-annual variability. Water-quality data were also available from Shingle Creek and Nine Mile Creek based on samples collected monthly beginning March 1996.

Total nitrogen concentrations were calculated by summing ammonia plus organic nitrogen and nitrite plus nitrate nitrogen. Total phosphorus and suspended-sediment concentrations were reported by the laboratory. Nutrient and suspended-sediment data were converted from instantaneous concentrations (mass of constituent per volume of water) to instantaneous yields (mass of constituent per unit time per unit area of watershed, hereinafter referred to as yields), which allowed for direct comparison between streams. To calculate a yield when a concentration was reported as below detection limit, the detection limit was used as the concentration.

Physical measurements were made at three scales—reach level, segment level, and basin level—using protocols described in Sorenson and others (1999). At the reach level, physical habitat was characterized along three equally spaced transects at each stream reach, which was 20 times the average channel width. Physical habitat characterization included riparian, instream, and geomorphic components. Riparian measurements included determination of percent vegetative cover and classification of vegetation. Instream measurements included substrate classification (percent silt, sand, gravel, cobble, and boulder), densiometer readings, and instream habitat characterization (percent rubbish, aquatic macrophytes, root wads, woody debris, overhanging vegetation, and boulders). Average values for riparian and instream measurements along the three transects were calculated. The percent of each type of geomorphic unit (riffle, run, and pool) was determined for each reach.

Segment-level measurements included percent riparian cover, land use and land cover, sinuosity, and channel gradient. These measurements were determined using geographic-information-system analyses of USGS 1:24,000-scale digital raster graphs. To standardize the area of influence, the base-10 logarithm of watershed drainage area (in square miles) was calculated and the result used as the segment length (in miles). For example, a stream draining 100 mi^2 would have a base-10 logarithm equal to 2, and therefore a segment length of 2 mi. Segment width was set at 328 ft (100 meters) on both sides of the center of the stream.

Basin characterizations included land use and land cover classification (percent urban, agricultural, forested, wetlands, lakes, and impervious surface) and population density. Land use and land cover percentages were determined using 1970's land-use data adjusted with 1990 population data for refinement of urban areas (Hitt, 1994). Population density was calculated by dividing the population, from the 1990 census, by the drainage area (table 1). Percent impervious surface was determined by interpreting satellite imagery from September 20, 1991 (table 1). Thematic mapper bands 3 (red), 4 (near infrared), and 7 (middle infrared) were selected because they are most useful for identifying impervious surfaces. Scenes from the three bands were extracted from the satellite image and grouped into 255 clusters. These clusters were manually classified into impervious and pervious surfaces, based on National Aerial Photography Program images

Table 1. Selected characteristics of Twin Cities metropolitan area stream basins, 1997

[mi^2, square miles]

Stream name	Drainage area (mi^2)	Population density (people/mi^2)	Percent impervious	Percent urban land use	Percent agricultural land use
Ford Brook	28.8	93	1	0.1	80
Elm Creek	85.8	340	6	8.7	85
Coon Creek	79.8	308	3	5.6	51
Sand Creek	15.4	93	16	48	40
Rice Creek	152	760	10	29	48
Shingle Creek	28.2	2610	23	71	20
Basset Creek	32.9	2240	22	82	11
Minnehaha Creek	149	964	7	37	38
Minnesota River tributary	11.9	672	14	30	63
Riley Creek	9.90	362	9	3	78
Purgatory Creek	27.0	1760	15	83	12
Nine Mile Creek	44.6	2210	28	87	6
Battle Creek	10.2	1900	25	83	13

(U.S. Geological Survey, 1980) and other current maps. The initial classification was updated for each basin and an adjustment was made to the classification as necessary to improve the estimate of impervious surface.

Fish were sampled at each of the 13 streams using the more appropriately sized electrofishing equipment, either a backpack or tote barge unit. One reach was sampled at each stream. At each reach, one electrofishing pass with pulsed direct-current electricity was performed. All fish were identified to species, measured, and weighed. Voucher specimens were sent to the Bell Museum of Natural History at the University of Minnesota to be preserved for historical records.

Three fish-community descriptors were used to characterize the TCMA streams: (1) species richness—the number of different species, (2) Shannon Diversity Index—a measure of how diverse the fish community is based on the number of species and their abundances (Brower and others, 1990), and (3) Index of Biotic Integrity (IBI)—a combination of measures (metrics) based on the structure and function of the fish community (Karr, 1981).

Regional modification is necessary for an IBI to be an applicable tool. Karr's (1981) IBI concept was modified for application in warmwater streams of Wisconsin by Lyons (1992). The Wisconsin modification of the IBI was used on TCMA streams because the fish species and stream types are similar. This particular modification of the IBI uses 10 metrics and 2 correction factors to arrive at a score that can be used to rate the biotic integrity of a stream. Four of these metrics were based on species composition: (1) number of native species, (2) number of darter species, (3) number of sucker species, and (4) number of sunfish species. Two metrics were based on environmental tolerance: (1) number of intolerant species, and (2) percent tolerant species. The other four were trophic and reproduction function metrics: (1) percent omnivores, (2) percent insectivores, (3) percent top carnivores, and (4) percent simple lithophilic spawners (percents refer to percent of total individuals). Stream size was factored into several of the metric scores. Two correction factors were used, deducting 10 from the IBI score, when fish abundance was low or a high percentage of deformities, eroded fins, lesions, and tumors (DELT) were observed.

Pearson correlations were used to determine the association of fish-community descriptors with water quality and physical habitat variables. Purgatory, Riley, and Minnehaha Creeks were removed from the correlation analyses of water-quality conditions and land use and land cover because they were sampled when stream stages were rising.

WATER-QUALITY CHARACTERIZATION

Water-quality samples were collected only once at a majority of the sites in this study; however, Shingle and Nine Mile Creeks were sampled more frequently. This allowed comparisons to be made between the samples collected for this study and the low-flow samples collected from those two streams during August through October 1996 and 1997 (hereinafter, the fall periods). The concentrations and yields of chemical constituents at Shingle and Nine Mile Creeks were representative of concentrations and yields measured for these two sites during the fall periods. Yields of total phosphorus at Shingle and Nine Mile Creeks during September 1997 were less than median yields, but within the inter-quartile range, of all samples collected during the fall periods. Other water-quality constituents were also within the inter-quartile range, as shown for phosphorus in figure 2. This may indicate that the 1997 study-period concentrations and yields for other streams were also typical of low-flow conditions for fall periods.

Total nitrogen concentrations ranged from 0.79 mg/L at Minnehaha Creek to 2.15 mg/L at Rice Creek. On average, 70 percent of total nitrogen in samples from all sites was ammonia plus organic nitrogen. Ammonia plus organic nitrogen tends to be dissolved rather than associated with particulate matter in the water column. Dissolved nitrite plus nitrate nitrogen concentrations ranged from less than 0.05 to 1.37 mg/L, and did not exceed the 10 mg/L Maximum Contaminant Level for drinking water established by the U.S. Environmental Protection Agency (USEPA) (U.S. Environmental Protection Agency, 1986). The greatest total nitrogen yields (fig. 3) occurred at Riley and Purgatory Creeks (7.9 and 11.4 lbs/d/mi^2, respectively), and probably were due to rainfall runoff prior to sampling. Sand and Rice Creeks had intermediate yields of about 5 lbs/d/mi^2. At all other sites yields were relatively low, ranging from 1 to 3 lbs/d/mi^2.

Total phosphorus concentrations ranged from 0.02 mg/L at Minnehaha Creek to 0.19 mg/L at Elm Creek. The total

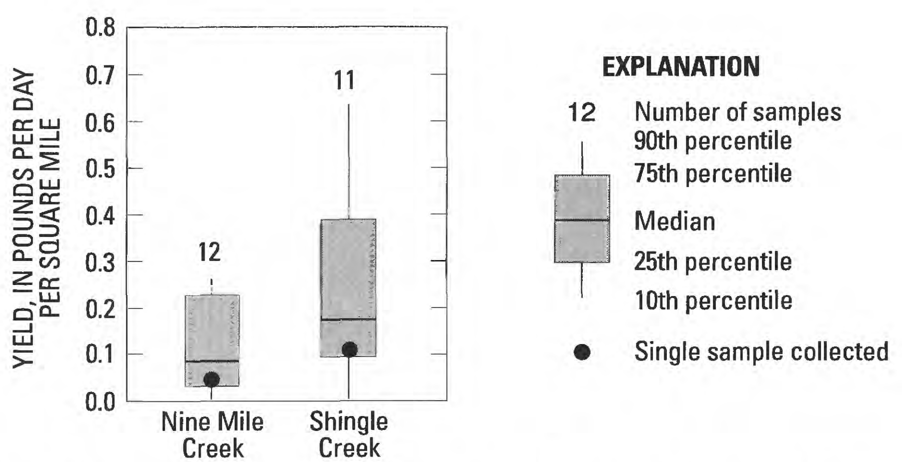

Figure 2.--Instantaneous yields of total phosphorus for all low-flow samples collected at Nine Mile and Shingle Creeks for the Upper Mississippi River Basin study unit (August - October 1996, and August - October 1997) and single samples collected for the urban synoptic study, September 1997.

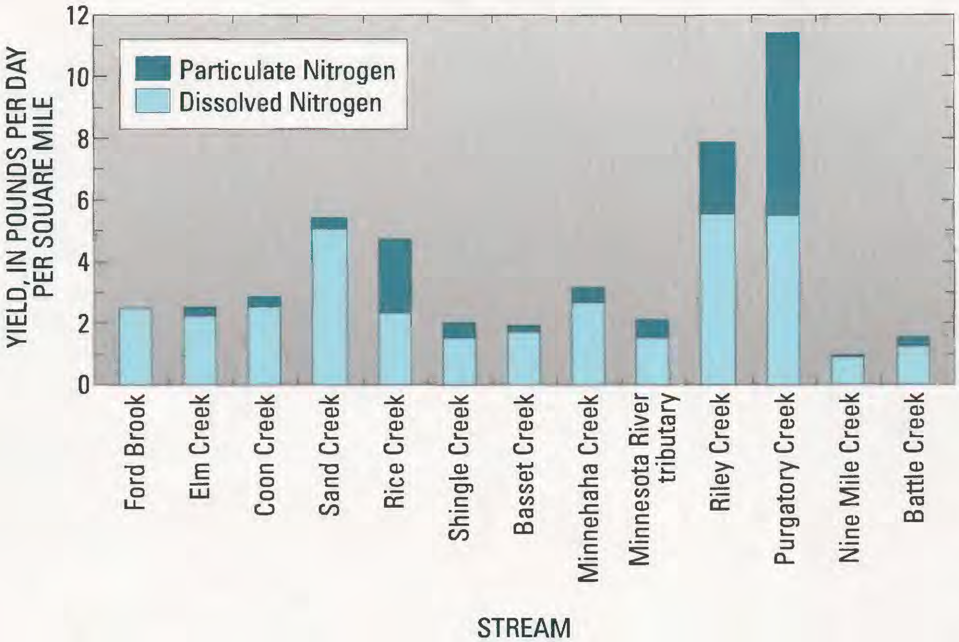

Figure 3.--Total particulate and dissolved nitrogen yields in 13 Twin Cities metropolitan area streams, Minnesota, September 1997.

phosphorus concentrations exceeded the USEPA recommendation of 0.1 mg/L (U.S. Environmental Protection Agency, 1986) for prevention of nuisance plant growth in streams not directly discharging to lake or impoundments in the following streams: Elm Creek (0.19 mg/L), Rice Creek (0.12 mg/L), and the Minnesota River tributary (0.11 mg/L). In terms of yield, Purgatory Creek had the greatest total phosphorus yield, 0.64 lbs/d/mi^2 (fig. 4), followed by Elm, Riley, and Rice Creeks (0.33, 0.28, and 0.27 lbs/d/mi^2, respectively). All other sites had phosphorus yields less than 0.2 lbs/d/mi^2. The majority of the phosphorus (median = 65 percent) in samples from all sites was associated with particulate matter. Dissolved orthophosphorus was not detected at Purgatory, Elm, or Rice Creeks, and contributed only 31 percent of the total phosphorus yield at Riley Creek.

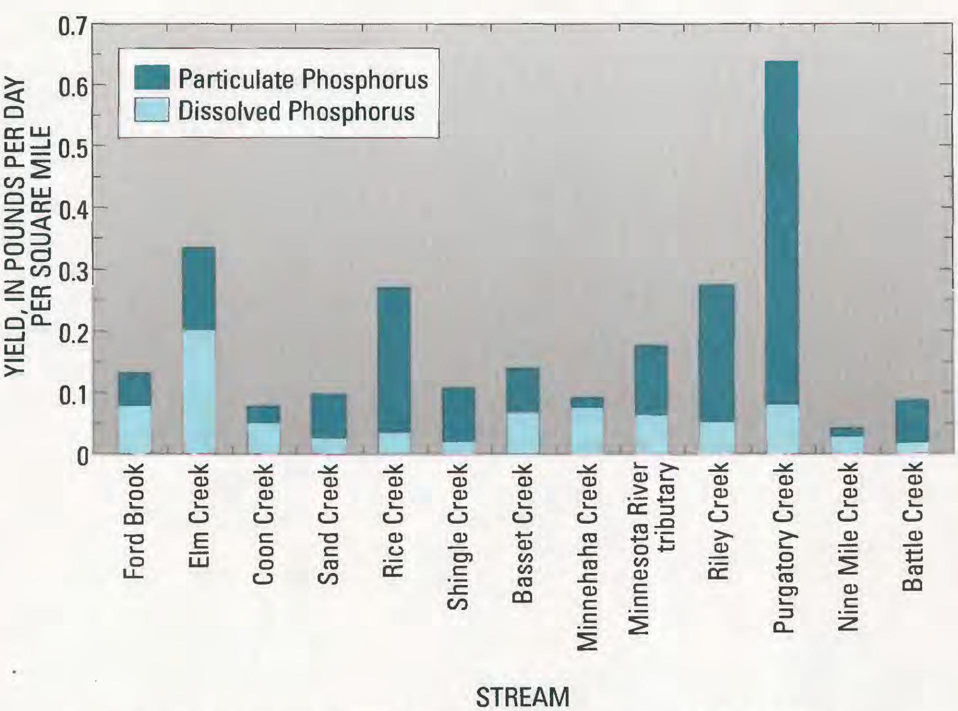

Figure 4.--Total particulate and dissolved phosphorus yields in 13 Twin Cities metropolitan area streams, Minnesota, September 1997.

In general, nutrient yields from TCMA streams were lower than those from basins in the predominately agricultural Minnesota River Basin (Payne, 1994; Kroening and Andrews, 1997; Lee and others, 1998). It is important to consider the rising stages at Purgatory, Riley, and Minnehaha Creeks when comparing these concentrations and yields. The higher flows at these three sites probably contributed to their greater concentrations and yields.

Sodium and chloride concentrations in TCMA streams were compared to North American river means (Allan, 1995; Wetzel, 1983). Sodium concentrations were the least at Ford Brook (7.3 mg/L) and greatest at Shingle Creek (50 mg/L). The median sodium concentration of TCMA streams was 23 mg/L, which is greater than the North American river mean of 8.4 mg/L (Allan, 1995). Chloride concentrations were also greater than the North American river mean of 9.2 mg/L (Allan, 1995). Chloride concentrations ranged from 16 mg/L (Ford Brook) to 120 mg/L (Shingle Creek), with a median concentration of 43 mg/L. These two ions are the primary constituents of road de-icing salt used in the TCMA (K. Nelson, Minnesota Department of Transportation, oral commun., 1998); therefore, sodium and chloride concentrations are often high during the first flush of the spring snowmelt (Oberts, 1990). However, because of the conservative nature of sodium and chloride, these constituents may leach into shallow ground water and be discharged to streams throughout the year.

Suspended-sediment concentrations ranged from 3 mg/L at Nine Mile Creek to 50 mg/L at Rice Creek (fig. 5). All but three sites had concentrations of less than 20 mg/L. Suspended-sediment yields were greatest

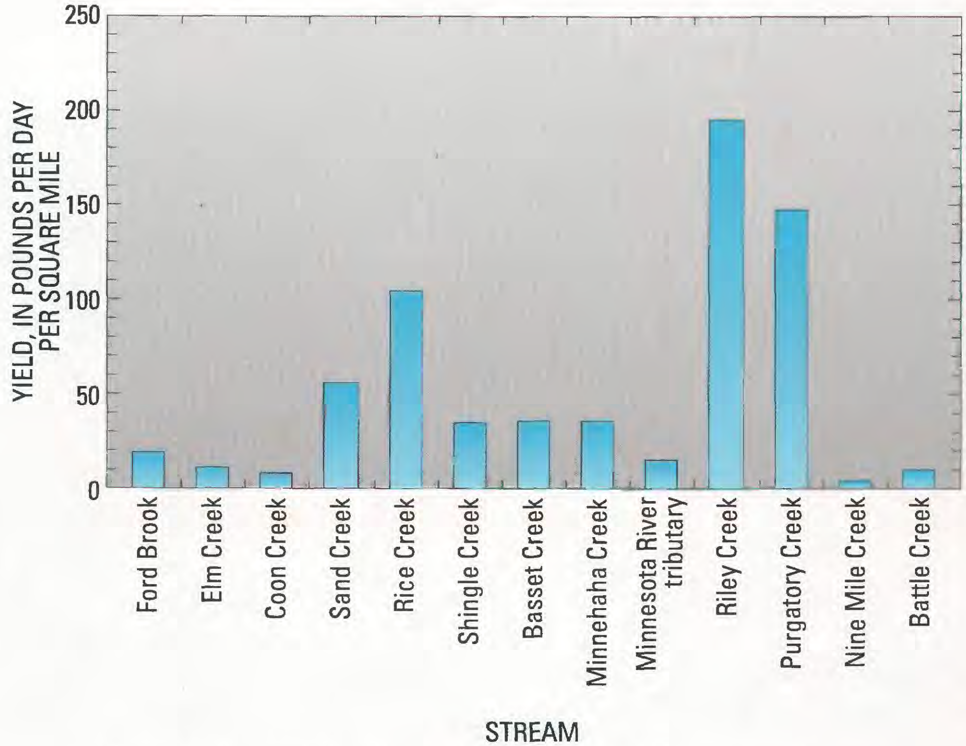

Figure 5.--Suspended sediment yields in 13 Twin Cities metropolitan area streams, Minnesota, September 1997.

at Riley and Purgatory Creeks (fig. 5), probably due to rainfall prior to sampling. Yields ranged from 3.6 lbs/d/mi^2 at Nine Mile Creek to 195 lbs/d/mi^2 at Riley Creek.

Seventeen pesticides (fig. 6) and 5 pesticide metabolites were detected among all sites. Of the five metabolites, only deethylatrazine is shown of figure 6 because the others were analyzed at a different laboratory using different analytical methods and detection limits. Types of pesticides detected included 4 insecticides commonly used for household and yard use (azinphos-methyl, carbofuran, chlorpyrifos, and diazinon) and 13 herbicides that are primarily used in row crop application (Sine, 1993). Yields of pesticides were not computed because of the low frequency of detections. Atrazine, a herbicide restricted to agricultural use, was detected at all sites, suggesting atmospheric transport from agricultural areas. Prometon, cyanazine, and metolachlor were each detected in more than one-half of the streams. Similarly, Fallon and others (1997) found that the most frequently detected pesticides in streams within the UMIS from 1974–94 were alachlor, atrazine, cyanazine, and metolachlor. The greatest total pesticide concentration (sum of all pesticide concentrations) was detected at Rice Creek, followed by Riley Creek, Minnehaha Creek, and Ford Brook. Total concentrations of pesticides ranged from 0.03 µg/L (Purgatory Creek) to 0.15 µg/L (Rice Creek). Total pesticide concentrations detected in this study are relatively low compared to sites in the agricultural Minnesota River Basin (Payne, 1994; and Lee and others, 1998).

Selected degradation products, or metabolites, were analyzed for four herbicides used predominantly for row-crop agriculture: acetochlor, alachlor, atrazine, and metolachlor. Five metabolites were detected: alachlor ethanesulfonic acid (ESA), metolachlor ESA, metolachlor oxanilic acid (OXA), deethylatrazine, and hydroxyatrazine. Concentrations ranged from less than 0.02 to 0.35 µg/L for the metabolites of alachlor and metolachlor and from less than 0.002 to 0.35 µg/L for the metabolites of atrazine. Total concentration of metabolites were up to eight times greater than total concentrations of pesticides, with concentrations from less than 0.002 µg/L at Sand Creek to 1.19 µg/L at Ford Brook. Deethylatrazine was the most frequently detected, with detections at 12 of 13 sites. Alachlor ESA had the second highest detection frequency with detections at four sites. Metolachlor ESA and OXA were detected at one site (Ford Brook). The more frequent detections of deethylatrazine likely result, at least in part, from a reporting level four times lower than all other metabolites. Metabolite detections seem to be related to agricultural land use, considering that alachlor ESA was detected at four of the five streams draining areas with greater than 50 percent agricultural land use. Furthermore, Ford Brook, which has the second highest percentage of agricultural land use (80 percent), had the highest number of metabolites detected. However, the presence of deethylatrazine at all but one site indicates that pesticide residues are pervasive at low concentrations, even in areas where they are not used.

Fecal Coliform Bacteria

Fecal coliform ranged from 54 colonies per 100 mL at Elm Creek to greater than 11,000 colonies per 100 mL at Battle Creek (fig. 7). Fecal coliform in samples from eight sites exceeded the State of Minnesota freshwater standard of 200 colonies per 100 mL (Minnesota Pollution Control Agency, 1990). The Minnesota standard is based on a geometric mean of at least 5 samples per month, so additional sampling would be necessary to determine if the sites are in compliance with the standard. The reason for the high value at Battle Creek (11,000 colonies/100ml) is unknown. However, it is unlikely that contaminated runoff caused the high count because the sample was taken during low-flow conditions.

Factors Influencing Water Quality

Statistical analyses indicate that land use and land cover likely affect water quality in the TCMA. Measures of urbanization (population density, percent urban land use and land cover, and percentage of impervious surface) were positively correlated with sodium and chloride concentrations. Fecal coliform

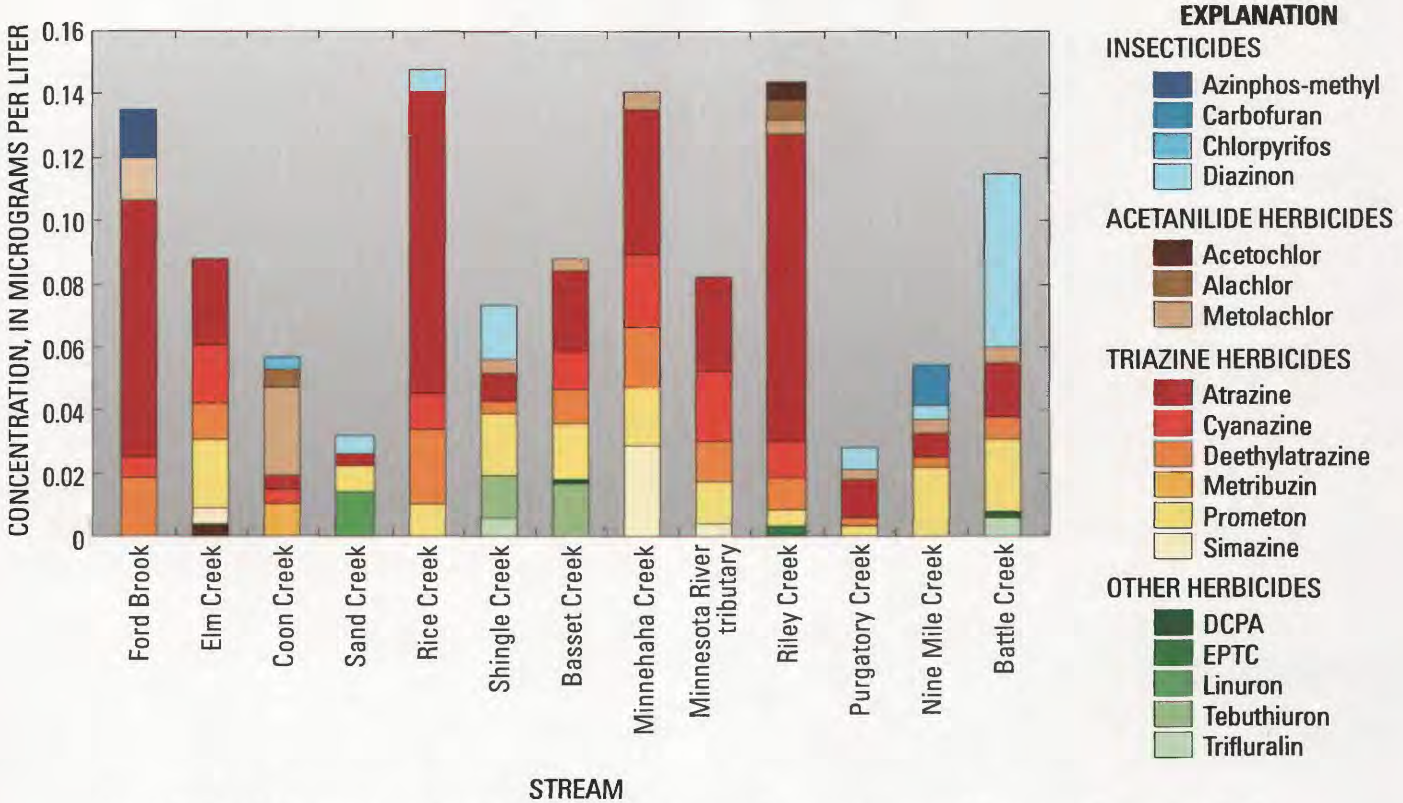

Figure 6.--Pesticide concentrations in 13 Twin Cities metropolitan area streams, Minnesota, September 1997.

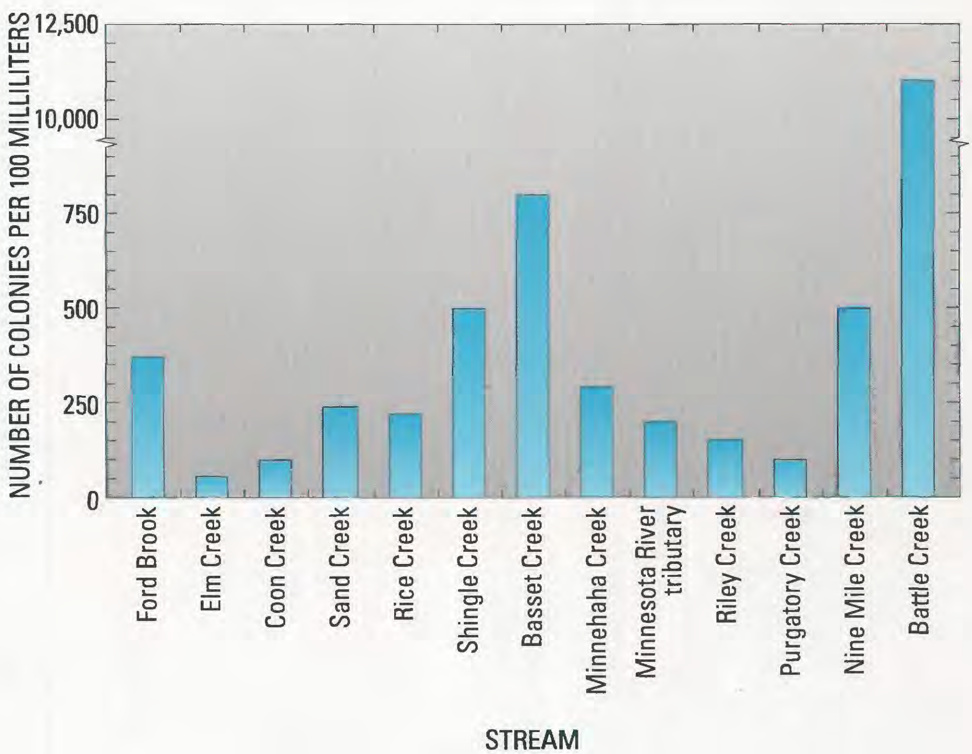

Figure 7.--Fecal coliform colonies in 13 Twin Cities metropolitan area streams, Minnesota, September 1997.

bacteria counts were positively correlated with population density (r = 0.788). Nutrient yields were negatively correlated with measures of urbanization. Total nitrogen and phosphorus yields were negatively correlated with percent urban land use (r = -0.402) and (r = -0.505), respectivley.

Agricultural land use and cover was associated with greater nutrient concentrations and yields. Percent agricultural land use and land cover was positively correlated with total nitrogen and phosphorus (r = 0.436 and 0.607, respectively). Concentrations of sodium and chloride were negatively correlated with the percentage of agricultural land use in the basin (r = -0.784). Pesticide concentrations did not significantly correlate with urbanization or agricultural land use.

PHYSICAL-HABITAT CHARACTERIZATION

Instream habitat was generally sparse in urban streams compared to streams draining agricultural areas (Goldstein and others, 1999). Total instream habitat was greatest at Shingle, Coon, Battle, and Elm Creeks, and at the Minnesota River tributary. The components of instream habitat varied among sites (fig. 8). Woody debris (7.3 percent—mean at all sites), overhanging vegetation (6.8 percent—mean at all sites), and undercut banks (3.6 percent—mean at all sites) were the most common instream habitat types in TCMA streams.

Substrates were composed of a high percentage of sand mixed with gravel (fig. 9). Cobbles and boulders were often absent. However, at Nine Mile Creek, the Minnesota River tributary, and Rice Creek, cobble was common. The greatest amounts of gravel, cobble, and boulder substrate were found in Nine Mile Creek, the Minnesota River tributary, Minnehaha Creek, and Rice Creek.

There is generally little geomorphic diversity in TCMA streams (fig. 10). Runs were the most common geomorphic unit, followed by pools. Riffles were uncommon, comprising more than 10 percent of the reach at only four sites (Minnesota River tributary, Nine Mile Creek, Shingle Creek, and Basset Creek). Sinuosity varied from 1.11 at Coon Creek to 2.07 at Nine Mile Creek. Values less than 1.4 indicate that channelization has probably occurred (Leopold and others, 1964).

FISH-COMMUNITY CHARACTERIZATION

Thirty–eight species and one hybrid from 10 families were collected from TCMA streams (table 2). Greater than one–third of the species were from the minnow family. The most common species were white sucker, fathead minnow, and green sunfish. Species richness ranged from 7 at Battle Creek to 23 at Nine Mile Creek (fig. 11).

Community diversity varied greatly among sites. Maximum diversity possible, in terms of the Shannon Diversity Index, would be from 1.94 to 3.13, depending on species richness. TCMA streams ranged from 30 to 75 percent of maximum possible community diversity. Shannon Diversity Index scores ranged from 0.59 at Battle Creek to 2.35 at Elm Creek. A low diversity value can occur due to either few species or a community dominated by one or two very abundant species. Both conditions may reflect degradation.

IBI scores, which can range from 0 to 100, also varied among sites (fig. 12). Battle Creek had the lowest score because

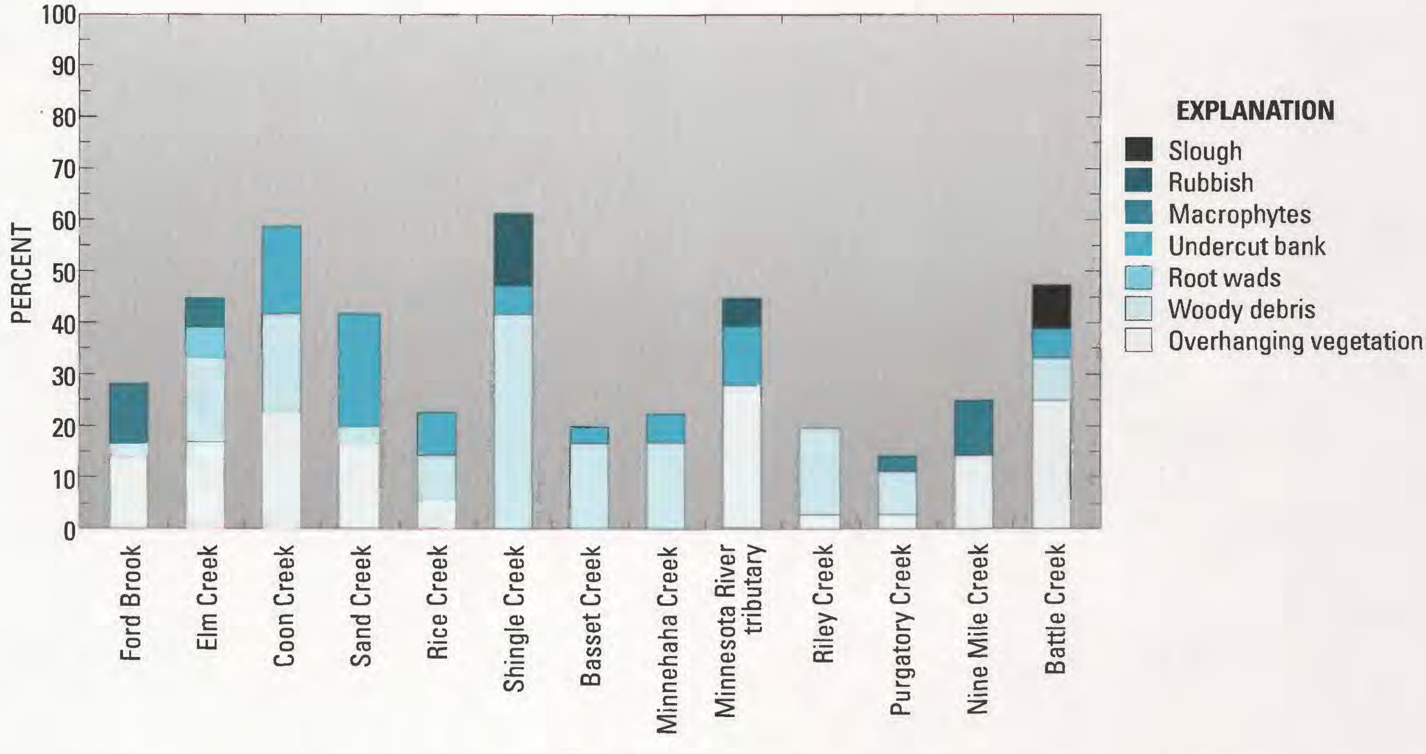

Figure 8.--Composition of instream habitat in 13 Twin Cities metropolitan area streams, Minnesota, September 1997.

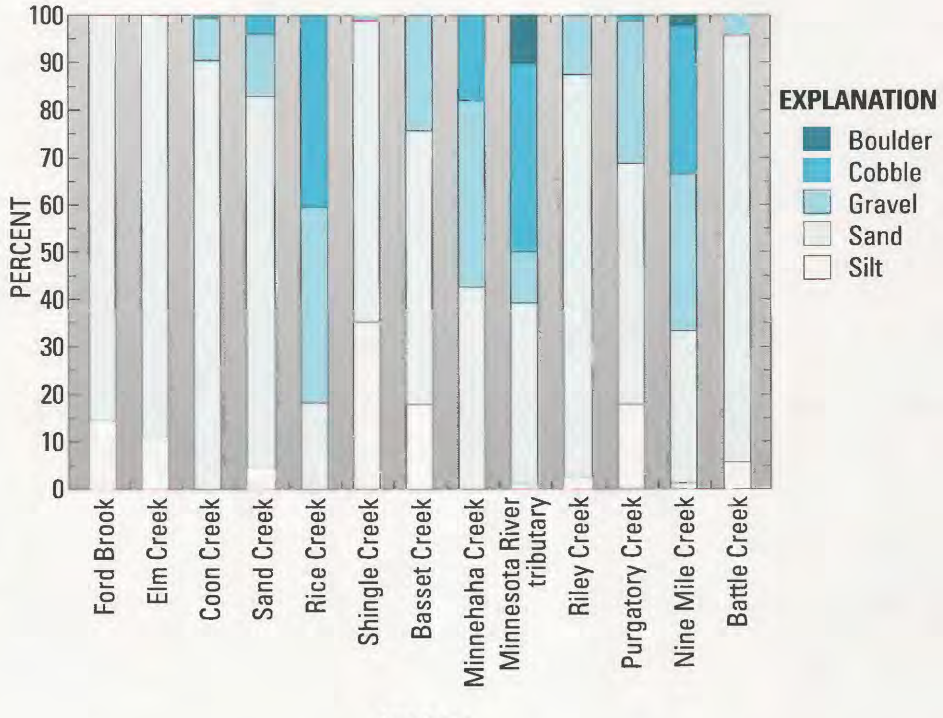

Figure 9.--Substrate composition of 13 Twin Cities metropolitan area streams, Minnesota, September 1997.

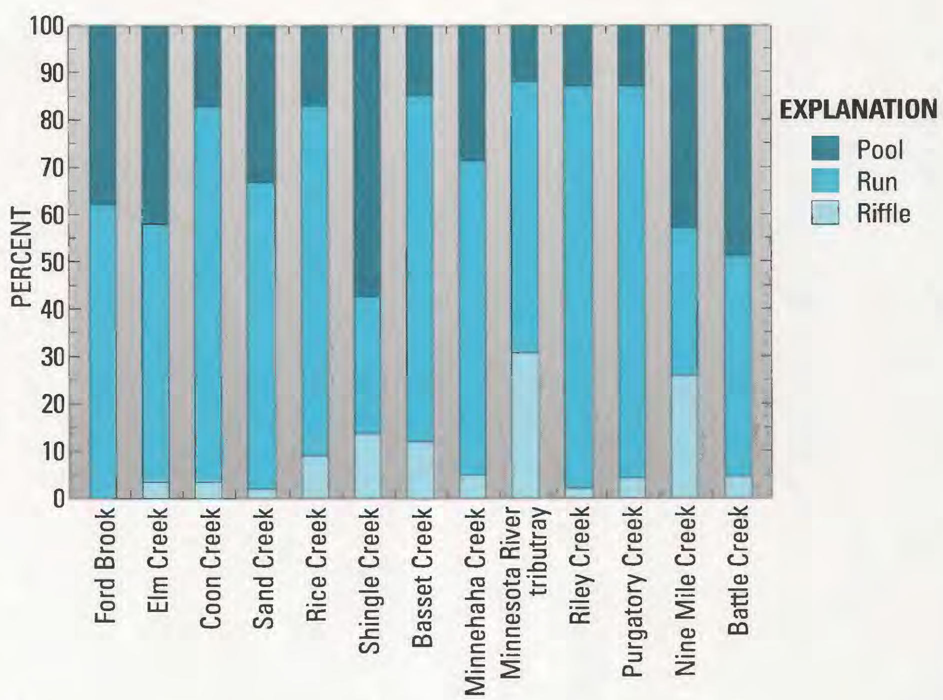

Figure 10.--Geomorphic composition of 13 Twin Cities metropolitan area streams, Minnesota, September 1997.

Table 2. Fish species presence in the Twin Cities metropolitan area stream basins, 1997

Common name	Scientific name	Ford Brook	Elm Creek	Coon Creek	Sand Creek	Rice Creek	Shingle Creek	Basset Creek	Minnehaha Creek	Minnesota River tributary	Riley Creek	Purgatory Creek	Nine Mile Creek	Battle Creek
Sucker family	**Catostomidae**													
Shorthead redhorse	*Moxostoma macolepidotum*												X	
White sucker	*Catostomus commersoni*	X	X	X	X	X	X	X	X	X	X	X	X	X
Minnow family	**Cyprinidae**													
Bigmouth shiner	*Notropis dorsalis*	X		X		X	X	X					X	
Blacknose dace	*Rhinichthys atratulus*	X	X	X	X		X	X		X	X		X	
Bluntnose minnow	*Pimephales notatus*	X				X			X	X	X		X	
Brassy minnow	*Hybognathus hankinsoni*	X		X					X					
Central stoneroller	*Campostoma anomalum*	X								X			X	
Common carp	*Cyprinus carpio*			X		X	X				X	X		
Common shiner	*Luxilus cornutus*	X				X							X	
Creek chub	*Semotilus atromaculatus*	X	X				X	X	X	X	X	X	X	
Emerald shiner	*Notropis atherinoides*									X				
Fathead minnow	*Pimephales promelas*	X	X	X	X	X	X	X	X	X	X		X	X
Golden shiner	*Notemigonis crysoleucas*		X			X								X
Hornyhead chub	*Nocomis biguttatus*	X												
Longnose dace	*Rhinichthys cataractae*			X		X								
Spotfin shiner	*Cyprinella spiloptera*	X				X				X			X	
Catfish family	**Ictaluridae**													
Black bullhead	*Ameiurus melas*	X	X	X	X	X			X			X	X	X
Brown bullhead	*Ameiurus nebulosus*									X				
Tadpole madtom	*Noturus gyrinus*						X						X	
Yellow bullhead	*Ameiurus natalis*		X			X						X	X	
Mudminnow Family	**Umbridae**													
Central mudminnow	*Umbra limi*	X	X	X	X			X			X	X	X	X
Pike family	**Esocidae**													
Northern pike	*Esox lucius*		X			X	X					X	X	
Sunfish family	**Centrarchidae**													
Black crappie	*Pomoxis nigromaculatus*					X	X				X	X		
Bluegill	*Lepomis macrochirus*					X	X				X	X	X	
Green sunfish	*Lepomis cyanellus*	X	X	X	X	X	X	X	X	X		X	X	
Hybrid sunfish		X	X						X					
Largemouth bass	*Micropterus salmoides*		X	X		X	X			X		X	X	
Orange spotted sunfish	*Lepomis humilis*									X			X	
Pumpkinseed	*Lepomis gibbosus*	X		X		X	X					X	X	X

Table 2. Fish species presence in the Twin Cities metropolitan area stream basins, 1997 (Continued)

Common name	Scientific name	Ford Brook	Elm Creek	Coon Creek	Sand Creek	Rice Creek	Shingle Creek	Basset Creek	Minnehaha Creek	Minnesota River tributary	Riley Creek	Purgatory Creek	Nine Mile Creek	Battle Creek
Smallmouth bass	*Micropterus dolomieui*	X												
Perch family	**Percidae**													
Blackside darter	*Percina maculata*			X										
Iowa darter	*Etheostoma exile*	X		X										
Johnny darter	*Etheostoma nigrum*		X	X	X	X	X	X	X			X	X	
Logperch	*Percina caprodes*								X					
Walleye	*Stizostedion vitreum*			X		X				X		X	X	
Yellow perch	*Perca flavescens*	X	X			X			X			X	X	
Drum family	**Sciaenidae**													
Freshwater drum	*Aplodinotus grunniens*											X		
Sculpin family	**Cottidae**													
Mottled sculpin	*Cottus bairdi*			X										
Stickleback family														
Brook stickleback	*Culaea inconstans*	X		X	X	X								X

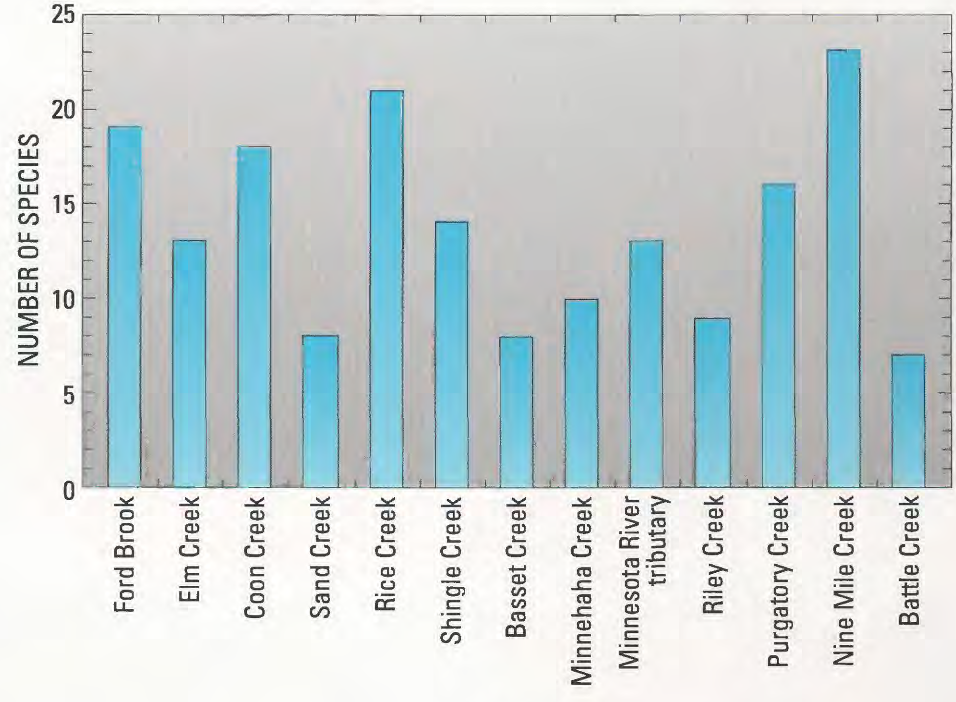

Figure 11.--Fish species richness in 13 Twin Cities metropolitan area streams, Minnesota, September 1997.

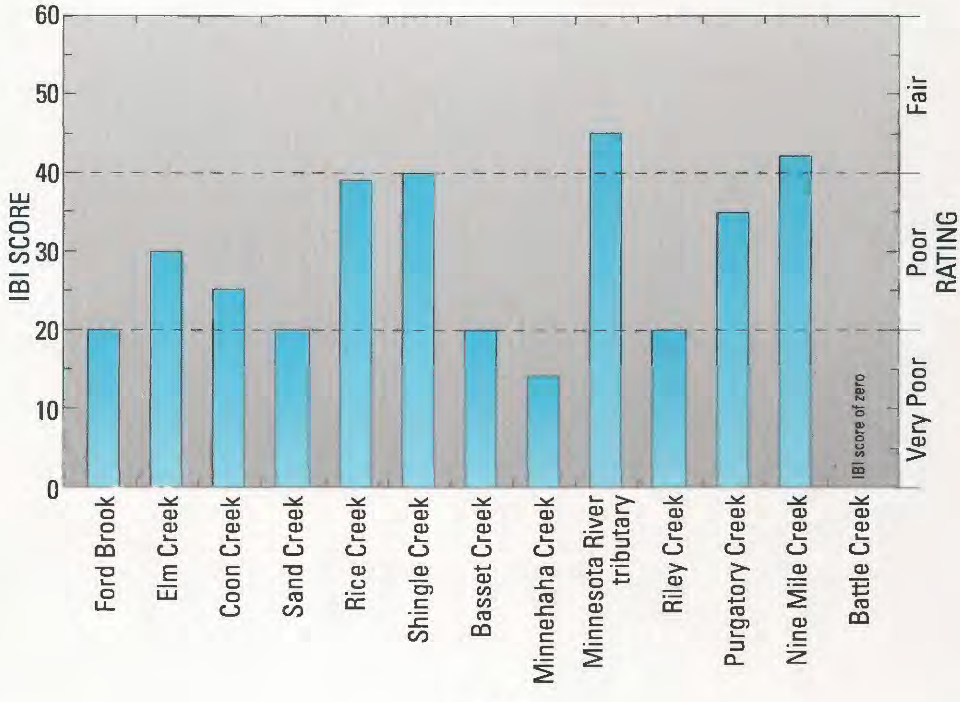

Figure 12.--Index of Biotic Integrity (IBI) scores and ratings (Lyons, 1992) of 13 Twin Cities metropolitan area streams, Minnesota, September 1997.

the fish community contained only 7 species and those species were largely omnivores and tolerant species. The highest score was found at the Minnesota River tributary where the fish community was characterized by a high percentage of insectivores, many simple lithophilic spawners, and low percentages of omnivores and tolerant species. The correction factor, which subtracts 10 points from the IBI score if total fish abundance at a site is less than 50 fish per 300 m^2 (Lyons, 1992), was applied to only one site (Minnehaha Creek). Abundances based on catch rate ranged from 140 fish per hour at Riley Creek to 2,146 fish per hour at Ford Brook. Percentages of DELT were low, less than one percent at all sites; therefore, the DELT correction factor was not applicable. Based on Lyons (1992), IBI scores in TCMA streams allowed for the streams to be classed fair to very poor, in terms of environmental quality. In general, the fish communities were dominated by tolerant species, omnivores, and had few intolerant species.

Fish-community composition was consistent between 1997 and 1998 fish collections. The correlation coefficients for species richness and IBI scores compared between the two years were 0.86 and 0.74, respectively. The concurrence between years indicates that the relations and measures used are consistent. The year-to-year variability in fish-community measures may be attributed to differences in sampling efficiency and natural variations in the fish community (Lyons, 1992).

In accordance with Matthews (1998), a core group of species common to all sites was selected and used to characterize fish assemblages in the TCMA streams. Eight species of fish were commonly found (green sunfish, fathead minnow, white sucker, creek chub, black bullhead, central mudminnow, johnny darter, and blacknose dace). Each of these species were found in 9 or more of the 13 streams. Six of the eight species are classified as tolerant species that have very flexible habitat or substrate requirements and can withstand degraded conditions (Lyons, 1992).

The presence and abundance of uncommon species can indicate unique features of a stream. For example, mottled sculpin, blackside darter, Iowa darter, and longnose dace were collected from Coon Creek. Conditions required by these species include multiple-particle-sized substrates and cover often provided by aquatic vegetation or boulders (Becker, 1983). Similar conditions were found at Ford Brook where hornyhead chub, Iowa darter, and smallmouth bass were collected. The amount of instream habitat and cooler water temperatures were associated with the presence of these species at Coon Creek and Ford Brook. Also, Coon Creek and Ford Brook have relatively low human population densities (table 1).

Factors Influencing Fish-Community Composition

Factors that are often associated with urbanization may influence fish community composition. These factors are impervious cover, water chemistry, water temperature, geomorphology, substrate, instream habitat, and migration barriers. Percent urban land use and human population density are surrogate measures for factors that may have direct influence on fish-community composition.

Two measures of urbanization, percent urbanization and population density, were negatively correlated with species richness (number of species) and diversity (Shannon Diversity Index). Percent impervious surface was positively correlated with percent urbanization ($r = 0.91$) and human population density ($r = 0.84$) and negatively correlated with fish species richness ($r = -0.65$; fig. 13) and diversity ($r = - 0.55$; fig. 14). Nine Mile Creek was omitted from the statistical analysis used to relate fish communities to land use and land cover and habitat variables because habitat restoration, channel improvements, and bank stabilization were performed. The restoration at Nine Mile Creek may have contributed to a more complex habitat. that supported a diverse fish community and resulted in the highest IBI scores.

None of the water-quality constituents, except sodium and chloride concentrations, were significantly correlated with fish community descriptors. Both fish species richness and diversity were negatively correlated with sodium concentrations ($r = -0.57$ and -0.69, respectively). Chloride concentrations also correlated negatively with fish species richness and diversity ($r = -0.53$ and -0.63 respectively). Sodium and chloride concentrations were positively correlated with the percentage of impervious surface ($r = 0.88$, and $r = 0.82$, respectively; figs. 15 and 16). It is likely that basins with greater percentages of impervious surfaces receive more road de-icers.

Urbanization, accompanied by significant increases in impervious surfaces, can contribute to greater water temperatures through a combination of reduced contributions of relatively cool groundwater discharge into the stream and increased contributions of relatively warm storm-water runoff from impervious surfaces. Average water temperatures were positively correlated with percent urbanization, percent impervious surface, and population density. Elm Creek was not included in this analysis because it had a much greater percentage of wetlands than the other streams. The remaining 12 sites appear to follow a similar pattern of increasing water temperature with increased population density and percent urban land use and land cover within the basin ($r = 0.65$ and $r = 0.63$, respectively).

Streams with greater percentages of riffle often had higher IBI scores ($r=0.58$). These streams also had higher percentages of cobble, which provides more habitat for fish. Percent sand within the reach was negatively correlated with IBI scores. Where there was a paucity of boulders and cobble, there was limited habitat for fish.

Fish abundance is positively correlated to the abundance of woody debris (Angermeier and Karr, 1984). Although woody debris was the most common habitat, it was sparse in TCMA streams despite dense riparian tree cover. Channel modification involving dredging, straightening, and removal of woody debris may be responsible for the sparse instream habitat found in TCMA streams. In addition, greater variation in streamflow in basins with more impervious surface could result in scouring of stream chan-

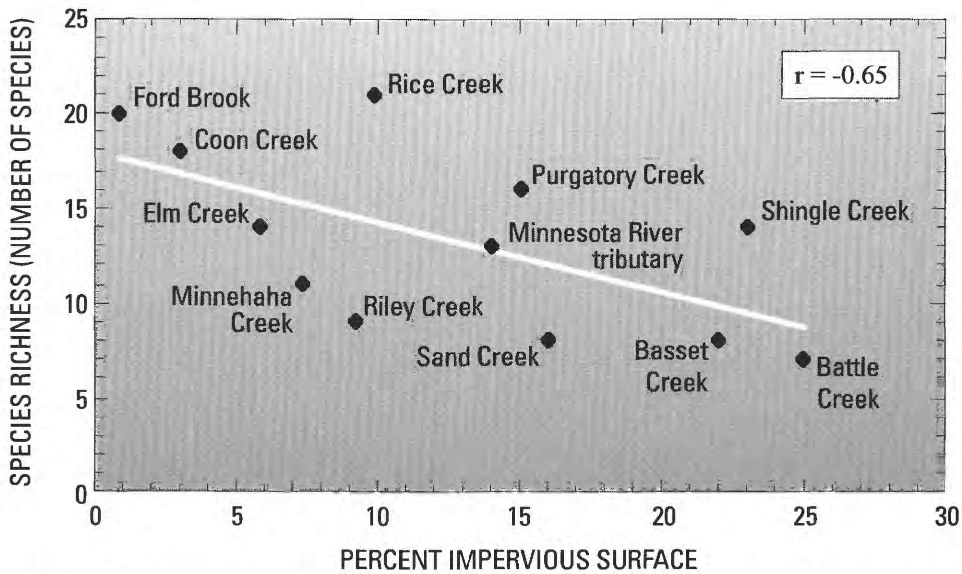

Figure 13.--Fish species richness in relation to percent impervious surface in basins draining 12 Twin Cities metropolitan area streams, Minnesota, September 1997.

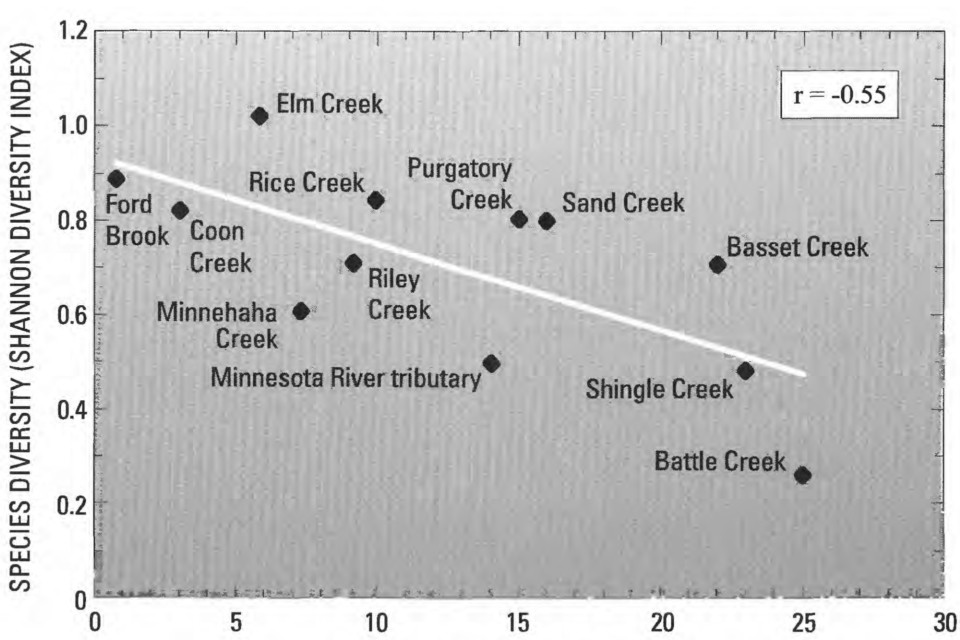

Figure 14.--Fish species diversity in relation to percent impervious surface in basins draining 12 Twin Cities metropolitan area streams, Minnesota, September,1997.

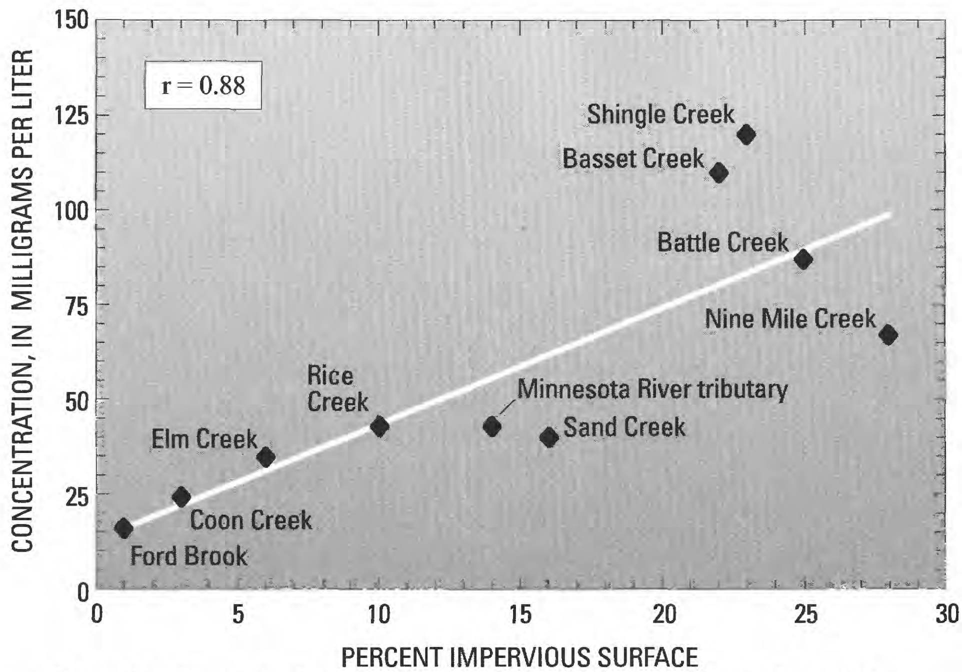

Figure 15.--Concentrations of chloride in relation to percent impervious surface in basins draining 10 Twin Cities metropolitan area streams, Minnesota, September 1997.

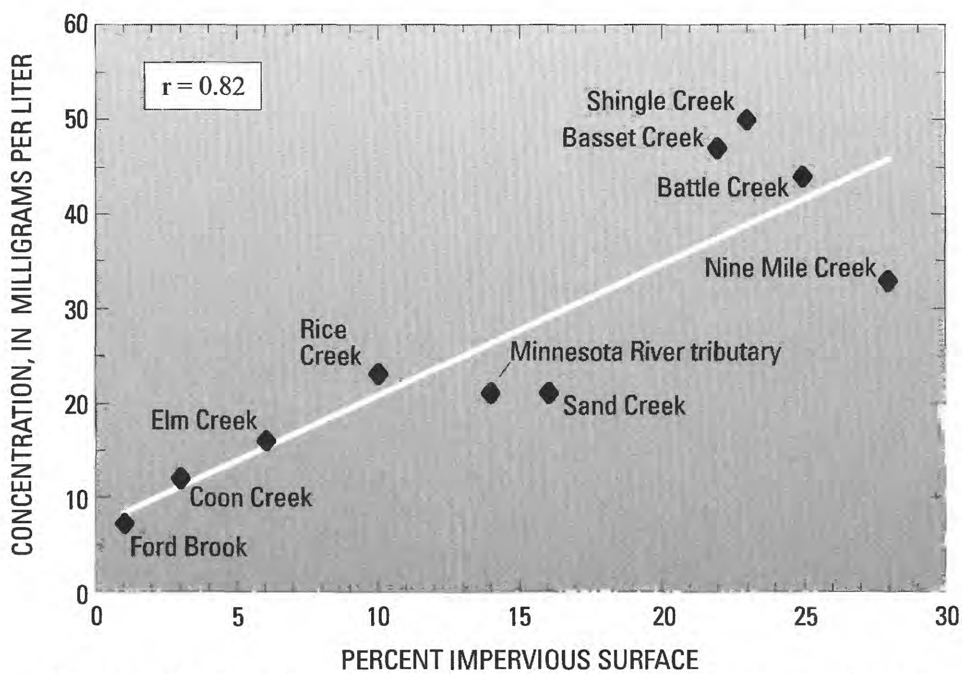

Figure 16.--Concentrations of sodium in relation to percent impervious surface in basins draining 10 Twin Cities metropolitan area streams, Minnesota, September 1997.

nels and removal of woody debris.

The proximity of sites to large rivers may have contributed to the presence of large-river species. This was observed at the Minnesota River tributary (emerald shiner), Nine Mile Creek (shorthead redhorse), and Purgatory Creek (freshwater drum). Large river species often move into smaller streams when there are no barriers.

Waterfalls and dams affect fish communities by acting as migration barriers (Hynes, 1970). The presence of migration barriers can reduce species abundance and decrease IBI scores. Three of the streams had a migration barrier downstream of the sampling site (Shingle, Basset, and Minnehaha Creeks). Species richness at these sites range from 8 at Basset Creek to 14 at Shingle Creek. Dams affect fish communities by altering stream geomorphology, substrate composition, and streamflow. Dams form pools, decrease streamflow variability, and can result in a shift from lotic to lentic species (Goldstein and others, 1999). Siltation behind dams may alter the substrate composition within the pool, causing the pool habitat to become even more homogeneous. Water in small urban impoundments gains heat because the surface area exposed to the sun is increased.

The results from this study suggest that urbanization affects fish-community composition through hydrologic modifications, removal of habitat and cover, increased water temperatures, and increased inputs of ions such as sodium and chloride. Channelization and channel maintenance, associated with urban environments, may reduce fish habitat. Other factors such as migration barriers, proximity to large rivers, and contaminants may contribute to the observed fish-community composition.

SUMMARY

Water quality, physical habitat, and fish-community composition were characterized at 13 Twin Cities metropolitan area (TCMA) streams during September 1997 during low-flow conditions. Fish communities were resampled during September 1998 to assess inter-annual variability. Instantaneous yields of nitrogen ranged from 1 to approximately 11 lbs/d/mi^2. Most of the nitrogen was associated with the dissolved phase. Phosphorus yields were low (less than 0.2 lbs/d/mi^2), with the exception of Purgatory, Elm, Rice, and Riley Creeks where yields ranged from 0.27 to 0.64 lbs/d/mi^2. Most of the of phosphorus was particulate matter. Suspended-sediment yields were also low (ranging from 3.6 lbs/d/mi^2 to 195 lbs/d/mi^2), probably because the samples were collected during low flow.

Seventeen pesticides and five metabolites were detected in TCMA streams. Atrazine was detected in samples from all sites. Total pesticide concentrations ranged from 0.03 µg/L to 0.15 µg/L. Fecal coliform counts varied, from 54 to greater than 11,000 colonies per 100 mL.

Species richness and Index of Biotic Integrity (IBI) scores indicated fair to very poor biotic integrity of TCMA streams due to water quality and physical habitat. Fish communities in TCMA streams were characterized by omnivores and tolerant species with few intolerant species. Common species include white sucker, fathead minnow, green sunfish, creek chub, black bullhead, central mudminnow, johnny darter, and blacknose dace. Six of the eight species are environmentally tolerant because they have flexible habitat and substrate requirements. The amount of instream habitat and cooler water temperatures were associated with the presence of these species at Coon Creek and Ford Brook.

Urban land use and human population density influence fish communities and water quality in TCMA streams. Factors associated with urbanization that may have an influence on fish-community composition are percentage of impervious cover, water chemistry, water temperature, geomorphology, substrate, instream habitat, and migration barriers.

Both fish species richness and diversity were negatively correlated with sodium and chloride concentrations. The percentage of impervious surfaces within the basins were positively correlated with sodium and chloride concentrations.

Impervious surfaces can contribute to warmer water temperatures through a combination of decreased ground-water discharge and increased storm-water runoff. Average water temperature in TCMA streams was positively correlated with percent urbanization, percent impervious surface, and population density.

Instream habitat generally was sparse among all TCMA streams. Woody debris, which is important for fish cover, was also rare, despite the dense riparian tree cover. Additionally, the paucity of boulders and cobble in TCMA streams results in limited physical habitat for fish. Channel modifications such as dredging, straightening, and removal of woody debris are likely responsible for the sparse instream habitat found in TCMA streams.

Waterfalls and dams affect fish communities by acting as migration barriers. The presence of migration barriers can limit the total number of species available to that particular stream reach. Species richness in three streams with downstream migration barriers ranged from 8 to 14, compared to a maximum in species richness of 23.

The results from this study suggest that urbanization affects fish-community composition through hydrologic modifications, removal of habitat and cover, increased water temperatures, and increased inputs of ions such as sodium and chloride. Channelization and channel maintenance, associated with urban environments, may reduce fish habitat. Other factors such as migration barriers, proximity to large rivers, and contaminants may contribute to the observed fish-community composition.

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