# Water Quality in the Upper Mississippi River Basin

## Minnesota, Wisconsin, South Dakota, Iowa, and North Dakota, 1995–98

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

Circular 1211

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*Front cover:* Mississippi River, St. Paul, Minnesota *(Bob Firth ©)*.

*Back cover:* Left, row crops in the Minnesota River Basin *(Scott Murray Photography)*; middle, St. Paul skyline (*Scott Murray Photography*); right, St. Croix River valley *(National Park Service)*.

# Water Quality in the Upper Mississippi River Basin, Minnesota, Wisconsin, South Dakota, Iowa, and North Dakota, 1995–98

*By* J.R. Stark, P.E. Hanson, R.M. Goldstein, J.D. Fallon, A.L. Fong, K.E. Lee, S.E. Kroening, *and* W.J. Andrews

U.S. GEOLOGICAL SURVEY CIRCULAR 1211

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**Library of Congress Cataloging-in-Publications Data**

Water quality in part of the Upper Mississippi Basin, Minnesota, Wisconsin, South Dakota, Iowa, and North Dakota, 1995–98 / by Stark, J.R.…[et al.].
p. cm. -- (U.S. Geological Survey Circular ; 1211)
Includes bibliographical references.
ISBN 0-607-95416-7 (alk. paper)
1. Water quality--Mississippi River Watershed. I. Stark, James R. II. Geological Survey (U.S.) III. Series.

TD224.M64 W38 2000
363.739'42'0977--dc21

00-049466

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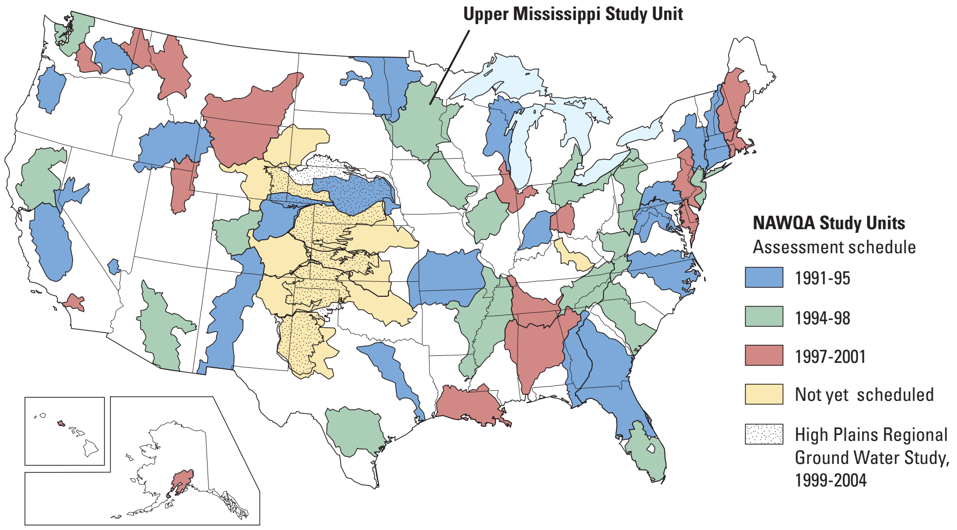
# NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

**THIS REPORT** summarizes major findings about water quality in part of the Upper Mississippi River Basin (referred to as the Study Unit in this report) that emerged from an assessment conducted from 1995 to 1998 by the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program. Water quality is discussed in terms of local and regional issues and compared to conditions in 36 NAWQA study areas, called study units, assessed to date. Findings are also explained in the context of selected national benchmarks, such as those for drinking-water quality and the protection of aquatic organisms. The NAWQA Program was not intended to assess the quality to the Nation's drinking water, such as by monitoring water from household taps. Rather, the assessments focus on the quality of the resource itself, thereby complementing many ongoing Federal, State, and local drinking-water monitoring programs. The comparisons made in this report to drinking-water standards and guidelines are only in the context of the available untreated resource. Finally, this report includes information about the status of aquatic communities and the condition of in-stream habitat as elements of the complete water-quality assessment.

Many topics covered in this report reflect the concerns of officials of State and Federal agencies, water-resource managers, and members of stakeholder groups who provided advice and input during the Study Unit assessment. Basin residents who wish to know more about water quality in the areas where they live will find this report informative as well.



**THE NAWQA PROGRAM** seeks to improve scientific and public understanding of water quality in the Nation's major river basins and ground-water systems. Better understanding encourages effective resource management, accurate identification of water-quality priorities, and successful development of strategies that protect and restore water quality. Guided by a nationally consistent study design and shaped by ongoing communication with local, State, and Federal agencies, NAWQA assessments support the investigation of local issues and trends, while providing a firm foundation for understanding water quality at regional and national scales. The ability to integrate local and national scales of data collection and analysis is a unique feature of the NAWQA Program.

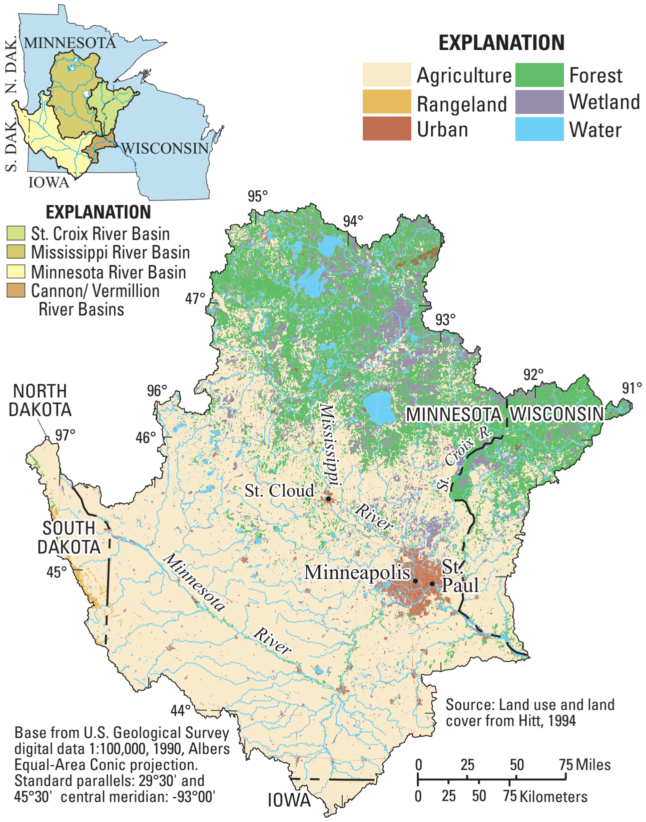
The Upper Mississippi River Basin Study Unit is one of 51 water-quality assessments initiated since 1991, when the U.S. Congress appropriated funds for the USGS to begin the NAWQA Program. As indicated on the map, 36 assessments have been completed, and 15 assessments will conclude in 2001. Collectively, these assessments cover about one-half of the land area of the United States and include water resources that are available to more than 60 percent of the U.S. population.

*The Upper Mississippi River Basin Study Unit encompasses about 47,000 mi$^2$ (square miles) in Minnesota, Wisconsin, South Dakota, Iowa, and North Dakota and includes the Twin Cities (Minneapolis and St. Paul) metropolitan area (TCMA). The three major rivers in the Study Unit are the Mississippi, the Minnesota, and the St. Croix. In 1990, about 3.7 million people resided in the Study Unit, mostly in the TCMA. The Mississippi River is the primary source of drinking water for St. Cloud, Minneapolis, and St. Paul in Minnesota. Ground water is the primary source of drinking water in rural and suburban areas.*

## Highlights of Streams and Aquatic Biology

Elevated concentrations of nutrients (nitrogen and phosphorus) in water are potentially harmful to humans, livestock, and aquatic life. Major sources of nutrients to streams are commercial fertilizers applied to crops, lawns, and gardens; wastewater discharge; leaking septic systems; snowmelt runoff; and animal manure. The total amounts of nitrate and dissolved orthophosphate were greater in streams draining agricultural areas than in streams draining areas with other land uses. Although pesticides (herbicides and insecticides) were commonly detected, most concentrations were less than current drinking-water standards and guidelines and aquatic-life guidelines; however, not all pesticides detected currently have drinking-water standards and guidelines. Samples from most streams in the Study Unit met Federal and State drinking-water standards and guidelines and aquatic-life guidelines. Invertebrate and fish communities were most degraded in urban streams.

- Nitrate concentrations in streams in artificially drained agricultural areas exceeded the U.S. Environmental Protection Agency (USEPA) drinking-water standard of 10 mg/L (milligrams per liter) in about 20 percent of the samples.
- Insecticides and nonagricultural herbicides were detected most frequently in urban areas.
- Agricultural herbicides were detected in streams throughout the Study Unit.
- Urban streams have reduced invertebrate and fish species richness and diversity compared to agricultural streams.
- Algal productivity was greater in agricultural streams than in urban and forest streams, due in part to greater concentrations of nutrients.
- Agricultural streams with wooded riparian cover had greater fish and invertebrate species richness and diversity than agricultural streams lacking wooded riparian cover.



Base from U.S. Geological Survey digital data 1:100,000, 1990, Albers Equal-Area Conic projection. Standard parallels: 29°30' and 45°30' central meridian: -93°00'

Source: Land use and land cover from Hitt, 1994

Land use and land cover in the Upper Mississippi River Basin study unit

### Trends in Stream-Water Quality and Aquatic Biology

Assessing trends in water quality and aquatic biology is difficult because historical data sets are discontinuous and sampling objectives and analysis methods have varied. Some observable trends are increased nitrate concentrations, based on historical data, and decreased ammonia concentrations in streams in the TCMA during 1984–1993 primarily because of process changes at wastewater treatment facilities. Breakdown products of the pesticide DDT, the use of which was discontinued in the 1970's, are still detectable in fish, streams, and streambed sediment.

### Major Influences on Streams and Aquatic Biology

- Application of pesticides and fertilizers in agricultural and urban areas
- Discharges from wastewater treatment facilities
- Runoff from agricultural and urban areas
- Stream modifications and artificial drainage
- Destruction of riparian cover along streambanks
- Contaminants in precipitation and in the atmosphere

## Highlights of Conditions in Ground Water

Shallow ground water in the TCMA (less than 50 feet below land surface) commonly contained pesticides, nutrients, and industrial chemicals and detectable concentrations of numerous volatile organic compounds (VOCs). Deeper ground water, typically used for public supply (water supplied for the general public by municipal and private purveyors), contained few pesticides and lower nitrate concentrations. With the exception of naturally occurring radon, deeper ground water met drinking-water standards and guidelines for most chemicals.

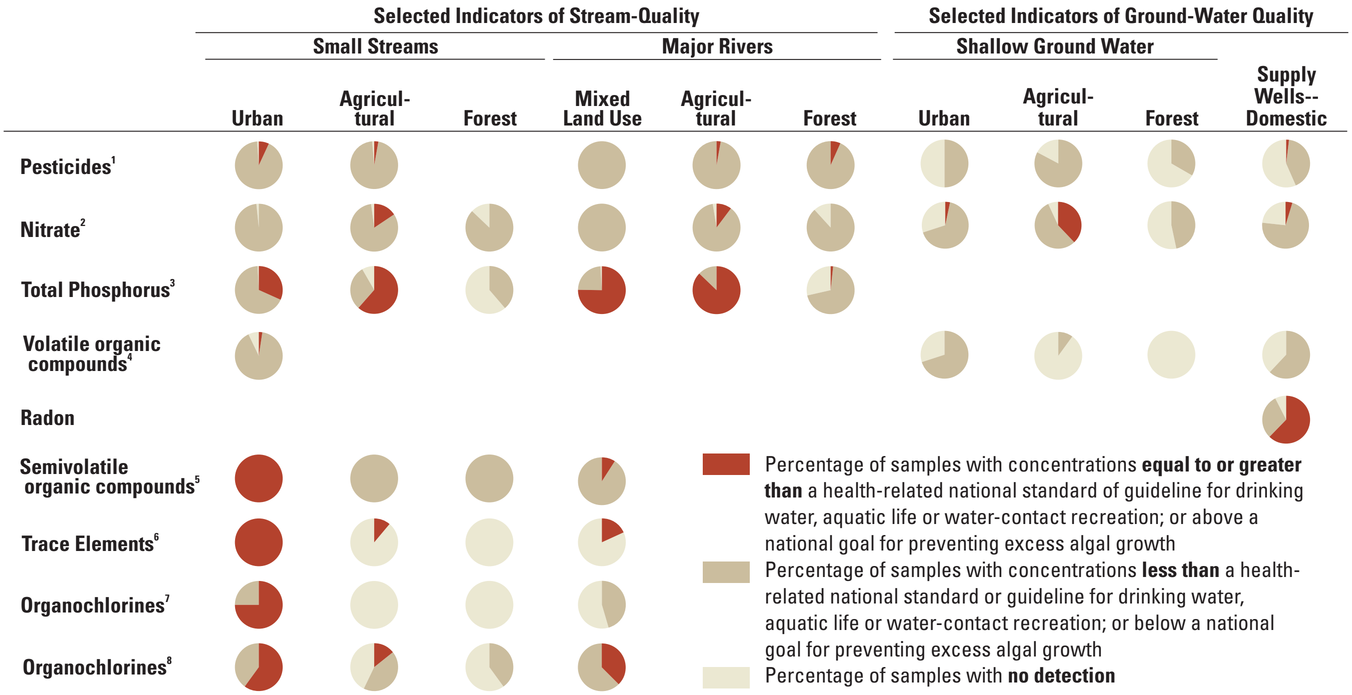
- Nitrate concentrations in water from nearly one-half of shallow ground water sampled beneath agricultural areas exceeded the USEPA drinking-water standard (10 mg/L).
- Road salt constituents (sodium and chloride) were detected at greater concentrations in shallow ground water underlying urban areas than other areas.
- Agricultural pesticides were commonly detected in all land-use settings. Concentrations were greatest in agricultural areas.
- Atrazine was the most frequently detected agricultural pesticide. Concentrations were greater in shallow ground water than in deeper ground water.
- Prometon was the most frequently detected herbicide in urban areas.
- Ground water in the Prairie du Chien-Jordan aquifer, an important source of drinking water, is protected by overlying confining units in some areas. Concentrations of nitrate, atrazine, and VOCs were lower in these areas than where confining units were absent.
- Radon exceeded the USEPA suspended drinking water standard of 300 pCi/L (picocuries per liter) in more than one-half of the water samples from the Prairie du Chien-Jordan aquifer.

### Trends in Ground-Water Quality

Temporal trends in ground-water quality are difficult to define because limited information exists. Spatial trends include greater nitrate and pesticide concentrations in agricultural areas, greater VOC concentrations in urban areas, and few detections of pesticides or VOCs in forested areas.

### Major Influences on Ground Water

- Application of pesticides and fertilizers
- Confining units and depth to water
- Urban contaminants (road salts, VOCs)
- Naturally occurring radon gas



🟥 Percentage of samples with concentrations **equal to or greater than** a health-related national standard of guideline for drinking water, aquatic life or water-contact recreation; or above a national goal for preventing excess algal growth

▨ Percentage of samples with concentrations **less than** a health-related national standard or guideline for drinking water, aquatic life or water-contact recreation; or below a national goal for preventing excess algal growth

□ Percentage of samples with **no detection**

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[1] Insecticides, herbicides, and pesticide metabolites, sampled in water. [2] Nitrate (as nitrogen), sampled in water. [3] Total phosphorus, sampled in water. [4] Solvents, refrigerants, fumigants, and gasoline compounds, sampled in water. [5] Byproducts of fossil-fuel combustion or components of coal and crude oil, sampled in sediment. [6] Arsenic, mercury, and metals, sampled in sediment. [7] Organochlorine compounds including DDT and PCBs, sampled in sediment. [8] Organochlorine compounds including DDT and PCBs, sampled in fish tissue.

*The Upper Mississippi River Basin Study Unit (Study Unit) includes the drainage of the Mississippi River from its source at Lake Itasca, Minnesota, and its major tributaries (the St. Croix and Minnesota Rivers) to the outflow of Lake Pepin, Minnesota (fig. 1). Natural and human factors (climate, hydrology, geology, water use, land use, and land cover) affect surface- and ground-water quality, and aquatic biology in rivers and streams.*

## Natural Factors Affect Water Quality and Aquatic Biology

Differences in precipitation, evaporation, evapotranspiration, air temperature (fig. 1), and drainage basin characteristics (drainage area, slope, geology, and the capacity of soils to transmit water) affect hydrology and water quality. These differ most from southwest to northeast. Mean annual runoff, which is related to precipitation and evaporation, ranges from less than 2 inches in the headwaters of the Minnesota River to greater than 14 inches in the headwaters of the St. Croix River.

The range from minimum to maximum streamflow is greatest in spring and early summer as a result of rain and melting snow. Streamflow variation is greatest during late summer and fall, when precipitation ranges from drought conditions to locally heavy rains (fig. 2). Streamflow varies least during winter, when ground-water discharge to streams is dominant. During the period of sampling (1996–98), precipitation was greater than the 30-year average, resulting in increased runoff and streamflow. As a result, the amount of sediment, nutrients, pesticides, and other contaminants reaching streams may have been greater than during periods of normal streamflow.

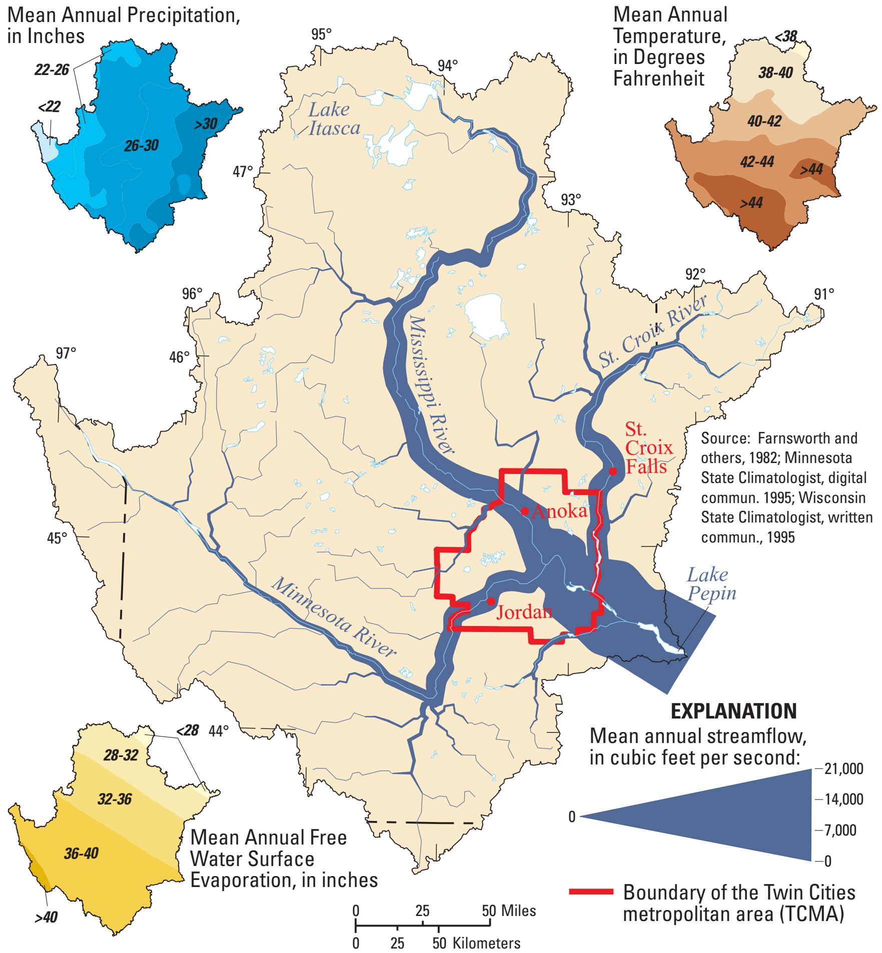


**Figure 1.** Climatic variables such as precipitation, temperature, and evaporation affected streamflow in the Study Unit, 1961-90.

Water quality is also affected by geologic materials. Most streams in the Study Unit drain the Central Lowland physiographic province, which is underlain by clay-rich, calcareous (calcium carbonate) glacial deposits (fig. 3). Fewer streams drain the Superior Upland physio-

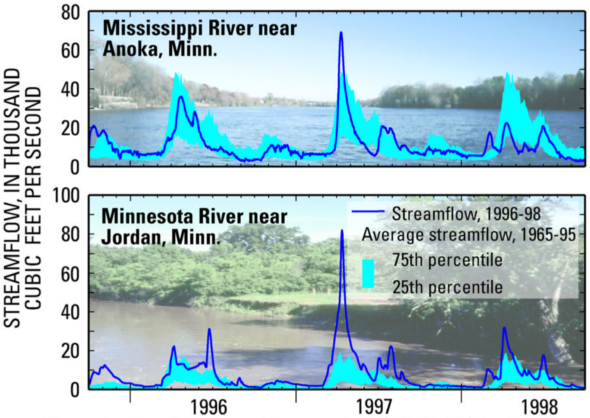


**Figure 2.** Streamflow during the sampling period (1996-98) in the large rivers in the Study Unit differed from their 30-year average, 1965-95.

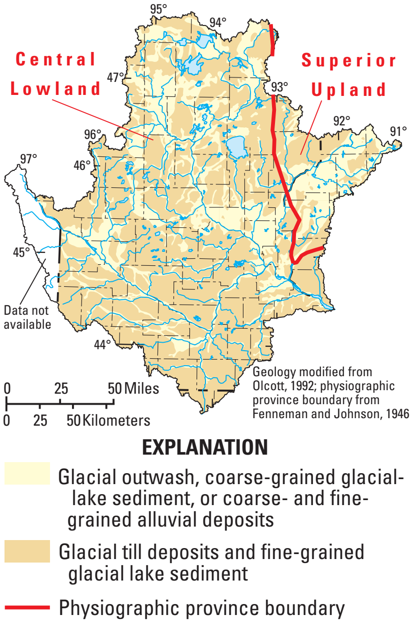


**Figure 3.** Surficial geology and physiographic provinces can affect water quality in the Study Unit.

graphic province, which is primarily underlain by siliceous (rich in silica), sandy glacial deposits. Water in streams draining the Central Lowland generally has greater alkalinity and greater concentrations of suspended sediment than water in streams draining the Superior Upland.

## Human Activities Affect Water Quality and Aquatic Biology

The greatest effects on hydrology, water quality, and aquatic biology occur in areas with the greatest human population densities or where disruption to the natural land cover is substantial. The population of the Study Unit in 1990 was about 3.7 million—16-percent increase from 1970. Seventy-five percent of those people reside in the TCMA.

Land use and land cover in the Study Unit can be categorized into three zones: an agricultural zone across the southwest, a forested zone across the northeast, and a transitional zone between these areas (fig. 4). About 63 percent of the Study Unit is agricultural (cropland and pasture). The remaining land use and land cover consists of forests (about 22 percent), water and wetlands (about 13 percent), urban (about 2 percent), and other categories (less than 1 percent).

The uses of water and the disposal of wastewater also can affect water quality and streamflow. Based on data from 1990, a daily average of 413 Mgal/d (million gallons of water per day) was used for public supply (including drinking water) in the Study Unit—59 percent from ground water and 41 percent from surface water (fig. 5). The total of all water used for public supply is equal to about 7 percent of the average streamflow of the Mississippi River upstream from the TCMA, near Anoka, Minn. Wastewater is discharged to streams from about 270 facilities located throughout the Study Unit (Kroening and Andrews, 1997).

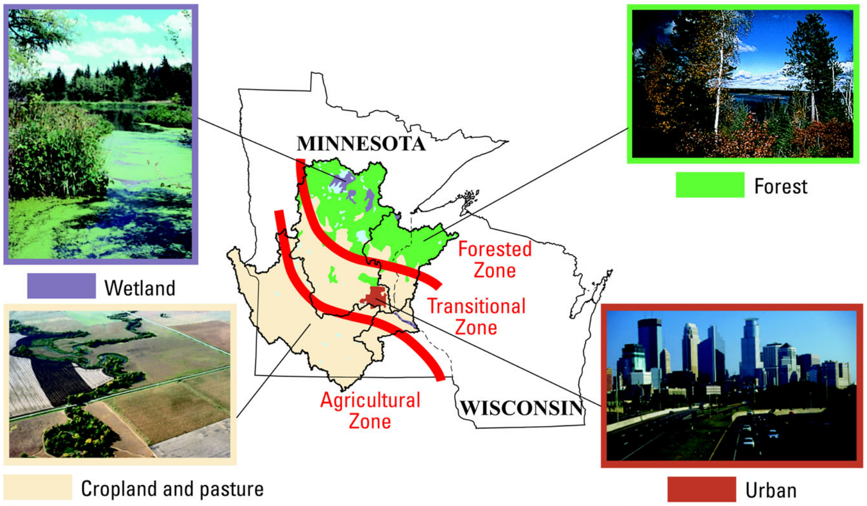


**Figure 4.** Land use and land cover can be categorized into three general zones in the Study Unit.

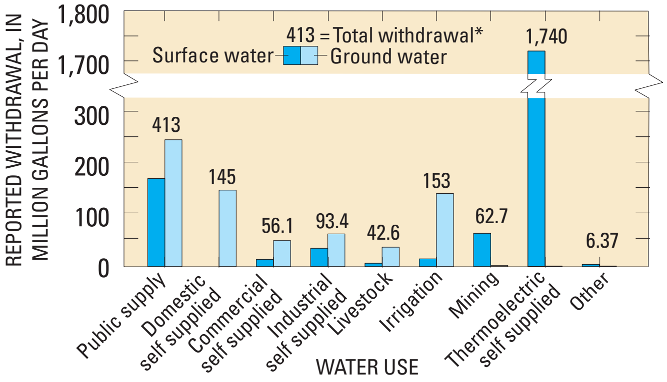


**Figure 5.** Ground water supplies the majority of the public drinking water in the Study Unit in 1990. (* Total refers to the combination of surface and ground water in each category.)

This report presents work by the U.S. Geological Survey's National Water-Quality Assessment Program to assess the quality of the Study Unit's water and aquatic resources (fig. 6). The report summarizes historical data and Study Unit data collected during 1995–98.

## Land Use Influences Water Quality and Aquatic Biology

Point and nonpoint sources of nutrients, sediments, metals, and organic compounds from industrial, agricultural, and urban land uses are important water-quality issues in the Study Unit. Degradation of streams, including the loss of riparian habitat, reduction in fish populations, loss of habitat for bottom-dwelling organisms, eutrophication, and deterioration of the sanitary quality of streams is also important. Additional issues include the introduction of toxic substances, such as organic compounds and trace elements that accumulate in sediments and aquatic biota of the rivers. These contaminants can adversely affect the health of aquatic biota and may biomagnify in fish-eating birds and mammals.

Water-quality issues in the TCMA and other urban areas include surface-water contamination from urban runoff and discharge from industrial and wastewater treatment facilities and the introduction of toxic substances to ground water from industrial activities and nonpoint sources. In agricultural areas, including the Minnesota River Basin, water-quality degradation from artificial drainage systems and point and nonpoint sources of sediment, nutrients, and pesticides are of concern. Both urban and agricultural land uses contribute to the impairment of habitat and eutrophication in the Mississippi River in and downstream from the TCMA. In forested areas, including the St. Croix River Basin and upper reaches of the Mississippi River Basin, water is generally of better quality than elsewhere in the Study Unit. Maintaining the quality of water in the St. Croix River Basin is a priority for the National Park Service and the States of Minnesota and Wisconsin (Minnesota Department of Natural Resources and others, 1995).

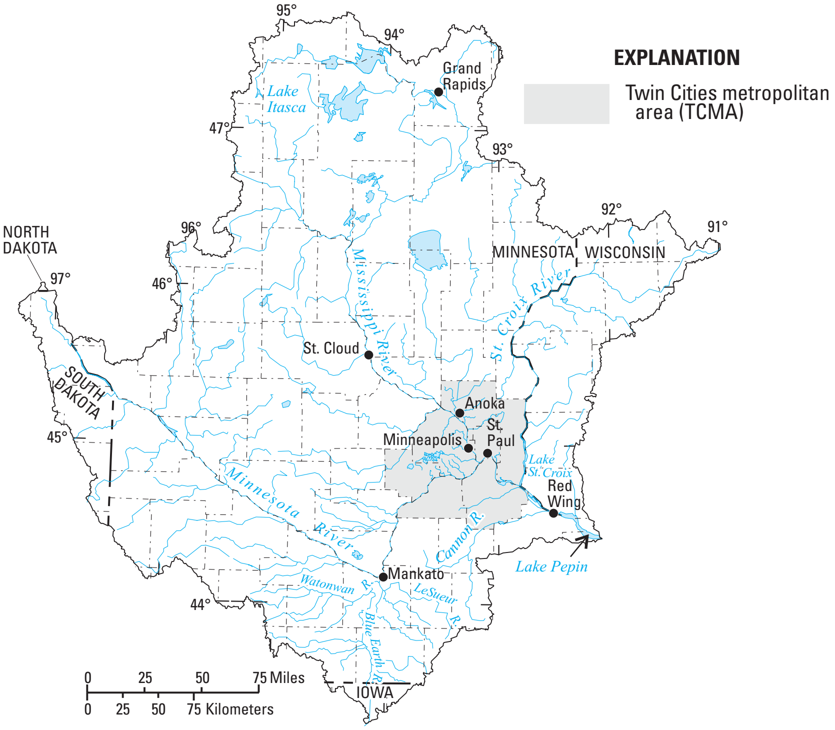


**Figure 6.** Upper Mississippi River Basin Study Unit, Twin Cities metropolitan area, major rivers and streams, and selected cities.

### Water Quality and Aquatic Biological Conditions Remain Relatively Undisturbed in Forested Areas

White pine forests originally covered much of the upper parts of the St. Croix River Basin and the Mississippi River Basin. These forests were logged during the mid 1800s to early 1900s and are now covered by second-growth forests.

Land-cover disturbances in these forested areas have been minimal, although small farms and towns are common, as is increased development for recreation. Water quality in these forested areas has been affected by minor applications of herbicides at small farms, tree farms, and in lakes (for weed reduction); discharges of wastewater effluent; leaks from septic systems; local stream-channel disturbances from forestry; and localized draining of wetlands. These activities result in small increases in nutrient, pesticide, suspended-sediment, and bacteria concentrations relative to natural conditions. Water-quality and aquatic-biological conditions have probably been affected less by human activities in the forested areas than in other areas of the Study Unit. Nutrients and pesticides did not exceed drinking-water standards and guidelines for human consumption in streams and in ground water in forested areas. Nitrate and phosphorus yields were low in streams in forested areas (table 1). Suspended-sediment concentrations, which can contribute to degraded water quality and habitat, also were low in streams draining forested areas compared to the rest of the Study Unit.

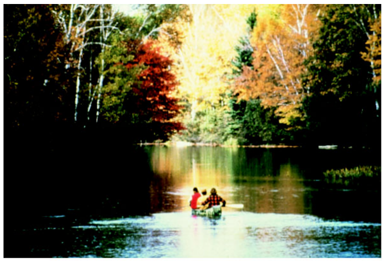
**Table 1.** Nitrate and phosphorus yields in pounds per square mile per year in forest streams, 1996-98

| STREAM | NITRATE | PHOSPHORUS |
|---|---|---|
| Namekagon River | 260 | —[a] |
| St. Croix River | 160 | 50 |

[a] Yield was not calculated because concentrations were below the analytical reporting limits.

Pesticides were periodically detected in streams and in shallow ground water in forested areas, but concentrations and detection rates were lower than in the rest of the Study Unit (Fallon and others, 1997; Fong, 2000). Trace-element concentrations in streambed sediments corresponded to the composition of the surficial glacial deposits (Kroening and others, 2000). For example, increased concentrations of copper in the forested areas are attributed to naturally occurring sources. Although bacteria concentrations in streams in forested areas were below the USEPA criterion for swimming (Kroening, 1999; U.S. Environmental Protection Agency, 1986), these waters would not be suitable for human consumption without treatment because bacteria counts may occasionally exceed USEPA drinking-water standards.

Physical modifications to streams, such as stream dredging or channelization, have been minimal in forested areas of the Study Unit. Consequently, aquatic communities are rich and diverse. Streams generally are more shaded than streams in other parts of the Study Unit, resulting in cooler water temperatures. Greater shading, cooler water, and lower concentrations of nutrients may limit algal productivity in these streams draining forested land. Algal communities in forest streams consist of species such as diatoms that are indicative of low nutrient and suspended-sediment concentrations.



Forests dominate the northern portion of the Study Unit. (Photograph courtesy of the National Park Service.)

Increased urbanization and development for recreation contribute to degraded water quality and aquatic life. Management practices that could benefit the quality of streams in these areas include restoration of natural wetlands and riparian vegetation. Eliminating these practices would improve stream habitat and hydraulic conditions and improve the diversity of fish and invertebrate communities. Many programs and water-quality regulations are in place or are being considered to protect the quality of water in these areas, particularly in the St. Croix River Basin. One example is an effort to restrict increases in phosphorus to the St. Croix River to prevent excessive algal growth in Lake St. Croix (Holmberg and others, 1997).

### Agricultural Activities Increase Nutrient and Pesticide Concentrations in Ground Water and Streams and Degrade Aquatic Biological Conditions

Agricultural areas of the Study Unit (fig. 4) include most of the Minnesota River Basin and parts of the Mississippi and St. Croix River Basins. In these areas, much of the land is used for production of row crops, primarily corn and soybeans. Many streams in agricultural areas have been straightened, ditches excavated, and land is commonly cultivated close to the streambanks. Most wetlands in agricultural areas have artificial drainage systems to increase crop production. Agricultural activities disrupt riparian zones in streams, contributing to erosion and runoff of agricultural chemicals and sediment.

Cultivation of land close to streams, artificial drainage, and stream straightening degrade water quality and aquatic habitat. (Photograph by James D. Fallon.)

Nutrient concentrations in surface water and ground water (much of which eventually discharges to streams) were greater in agricultural areas than in other parts of the Study Unit (Payne, 1994; Kroening and Andrews, 1997; Ruhl and others, 2000). Commercial fertilizers and animal manure applied to agricultural land are sources of nutrients to streams and ground water (Kroening, 1998b; Ruhl and others, 2000). Nutrients that reach streams through artificial drainage or runoff accelerate the growth of algae and aquatic plants, resulting in eutrophication and diminished dissolved oxygen concentrations. In addition to affecting aquatic species, eutrophication also can cause taste and odor problems in water for domestic use.

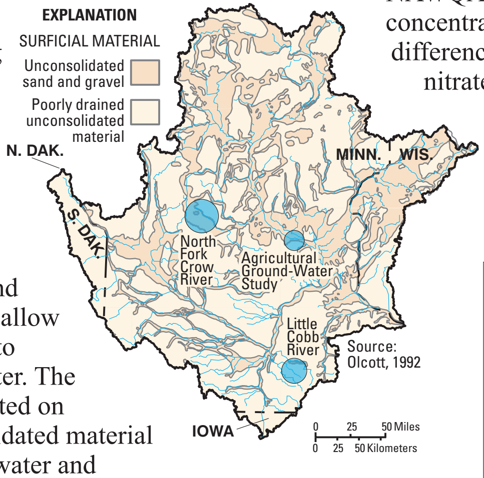
Nitrate concentrations in streams draining the southern and southeastern parts of the Study Unit, most notably in the Blue Earth, Le Sueur, and Watonwan Rivers (Payne, 1994), have exceeded the drinking-water standard of 10 mg/L set by the USEPA to prevent methemoglobinemia in infants. Greater than one-half of the samples collected by Payne (1994) exceeded that drinking-water standard. Nitrate yields were greatest in agricultural streams (table 2). Nitrate yields were about 10 times greater in streams draining artificially drained, fine-grained surficial geologic deposits compared to streams draining coarse-grained deposits (Kroening, 1998a). Nitrate concentrations in shallow ground water are also greatest in the agricultural part of the Study Unit, and generally increased with the intensity of the agricultural activity and decreased with the water-table depth below land surface (Ruhl and others, 2000). (see “Nitrate in a National Context”)

**Table 2.** Nitrate and phosphorus yields in pounds per square mile per year in agricultural streams, 1996-98

| STREAM | NITRATE | PHOSPHORUS |
|---|---|---|
| North Fork Crow River | 1,400 | 190 |
| Little Cobb River | 15,000 | 330 |

## NITRATE IN A NATIONAL CONTEXT--CONCENTRATIONS RELATE TO HYDROGEOLOGY AND AGRICULTURAL DRAINAGE IN THE STUDY UNIT

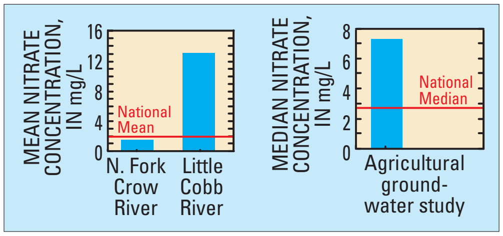
Nitrate concentrations in the Study Unit are related to hydrogeologic setting and agricultural drainage. The application of commercial fertilizers and manure are sources of nitrate in streams and ground water. In general, nitrate concentrations in water are greatest in agricultural areas throughout the Nation (U.S. Geological Survey, 1999) including the Upper Mississippi River Basin. Yet, within agricultural areas within the Study Unit, nitrate concentrations vary due to the hydrogeologic setting.



Source: Olcott, 1992

Two rivers draining agricultural land in the Study Unit were frequently sampled for nitrate (1996-98). The North Fork Crow River is located in an area underlain by unconsolidated, coarse-grained sand and gravel deposits, that allow water and contaminants to infiltrate into ground water. The Little Cobb River is located on poorly drained unconsolidated material that limits the ability of water and contaminants to infiltrate into ground water. Artificial drainage systems (ditches and tiles) have been installed throughout these poorly drained soils to improve agricultural production. These systems also result in more direct transport of contaminants to nearby streams.

Although nitrate application rates from fertilizer and manure were similar in both river basins, nitrate concentrations in the streams were different. The nitrate concentration in the naturally well-drained North Fork Crow River was less than the national average for agricultural streams. In contrast, artificial drainage in the Little Cobb River Basin has contributed to nitrate concentrations in the stream, which rank among the top 2 percent of all streams sampled in the NAWQA Program. Differences between the nitrate concentrations in these two streams (see graph) reflect differences in their hydrogeologic settings. Although nitrate concentrations were low in streams draining surficial sand and gravel deposits, concentrations were greater in ground water--much greater than the national median. (see graph.)



To maintain water quality in streams and ground water, best manage-ment practices could include consideration of hydrogeologic setting.

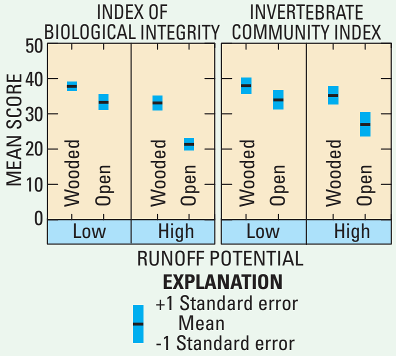
Phosphorus concentrations exceeding the goal of 0.1 mg/L recommended by the USEPA (1986) to prevent eutrophication were measured in agricultural streams (Kroening, 2000). Results from routine sampling showed this concentration was exceeded more frequently (about 75 percent of the samples) in streams fed by artificially drained soils that developed on fine-grained materials than in streams draining coarse-grained materials (about 30 percent of samples). Phosphorus yields were greatest in agricultural streams (table 2). Phosphorus yields were approximately 1.7 times greater in streams draining artificially drained, fine-grained surficial deposits than in streams draining coarse-grained deposits.

Median suspended-sediment concentrations typically ranged from 60 to 120 mg/L in agricultural streams (Kroening, 2000). Suspended-sediment concentrations were greater in streams in artificially drained, fine-grained surficial deposits compared to streams draining coarse-grained deposits. Physical disturbances to stream morphology, hydrology, and instream habitat have been caused by stream straightening, removal of riparian vegetation, drainage of wetlands, and tile drainage systems (see “Riparian Cover and Runoff Potential Affect Aquatic Biology,” and “Riparian Buffer Zones Affect the Quality of Midwestern Streams and Rivers,” p. 9). These disturbances also contribute to increased concentrations of suspended sediment, relative to streams in other land-use settings.

Pesticides frequently were detected in streams and shallow ground water in agricultural areas (Fallon and others, 1997; Fallon, 1998; Ruhl and others, 2000). Few concentrations exceeded applicable drinking-water standards and guidelines or aquatic-life guidelines. Herbicides were detected more frequently than insecticides. Pesticide concentrations in streams typically were greatest from May to July (Fallon and others, 1997). Ground-water samples with detections of one or more pesticides usually coincided with areas of shallow ground water close to the land surface (Hanson, 1998; Ruhl and others, 2000). Organochlorine insecticides were detected in fish tissue but not in streambed sediment (fig. 7, and see “Concentrations of Degradation Products of Agricultural Herbicides were Greater than Their Parent Compounds in Little Cobb River Near Beauford, Minn., 1997,” p. 10).

## RIPARIAN COVER AND RUNOFF POTENTIAL AFFECT AQUATIC BIOLOGY

An investigation of 24 streams in the Minnesota River Basin during August 1997 determined that there were differences in fish- and invertebrate-community compositions due to both riparian cover and runoff potential (which increases when water infiltration decreases) (Stauffer and others, 2000; ZumBerge, 1999). An Index of Biotic Integrity (IBI--a measure of biological conditions based on several fish-community attributes), an Invertebrate Community Index (ICI --a measure of biological conditions based on several invertebrate community attributes), and species richness were used as measures of resource quality. Streams with wooded riparian cover had better IBI scores, ICI scores, and greater fish and invertebrate species richness than streams with open riparian cover indicating better resource quality. Streams with low runoff potential had better IBI scores, ICI scores, and fish species richness than streams with high runoff potential.

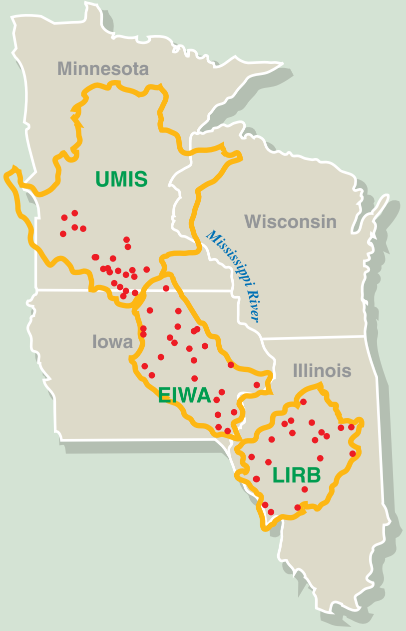


These results suggest that streams with wooded riparian cover had greater resource quality as indicated by fish and invertebrate community measures.

Algal, invertebrate, and fish communities have likely been affected by agriculture. Increased nutrients in agricultural streams have resulted in greater algal abundance and primary production. Algal communities were composed of a large proportion of blue-green algae that are commonly associated with high nutrient concentrations and are not suitable food sources for invertebrates (Kroening, 2000; Lee and ZumBerge, 2000). Contaminants from agricultural practices have likely affected invertebrate communities, which were moderately diverse and composed of mayflies and caddisflies that are relatively sensitive to contaminants. Total fish biomass was high in agricultural streams, probably in response to greater algal abundance and productivity. Although suspended-sediment concentrations were greater in the agricultural streams than in streams in other land-use settings, the presence of fish species such as stonecat and smallmouth bass indicate good water quality in terms of clarity (Goldstein and others, 1999).

# RIPARIAN BUFFER ZONES INFLUENCE THE QUALITY OF MIDWESTERN STREAMS AND RIVERS

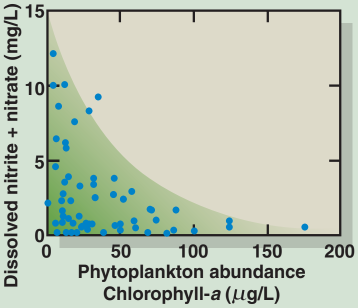
Despite similar land use throughout the Corn Belt region of the Midwest, streams flowing through cropland differ considerably in their ecological characteristics, in part because of differences in riparian buffer zones (*see text boxes*). This conclusion is based on an investigation of 70 streams and rivers within three NAWQA Study Units in the upper Midwest during August 1997 (map shown at right; Sorenson and others, 1999; Porter, 2000a). Specifically, increases in tree cover in buffer zones were associated with aquatic biological communities indicative of good stream quality, reduced nuisance algal growths, and maintenance of sufficient dissolved oxygen concentrations to support diverse communities of aquatic organisms. For example, the number of aquatic insects indicative of good stream quality tended to increase with increases in percentage of tree cover, especially in sites where streamflow and dissolved oxygen conditions were favorable. Fish communities, sampled at 24 sites in the UMIS Study Unit, also indicated better overall conditions in streams with wooded riparian zones than those with more open canopy (Stauffer and others, 2000).



The influence of riparian buffer zones on the quality of 70 midwestern streams and rivers was evaluated in the Upper Mississippi River (UMIS), Eastern Iowa (EIWA), and Lower Illinois River Basins (LIRB).

Streams with less tree cover, and thus less shading, contained relatively large growths of phytoplankton (algae suspended in the water) at levels considered indicative of eutrophication (Porter, 2000b). Organic enrichment resulting from excessive algal production in some midwestern streams may reduce dissolved oxygen concentrations and be detrimental to other requirements of aquatic organisms.

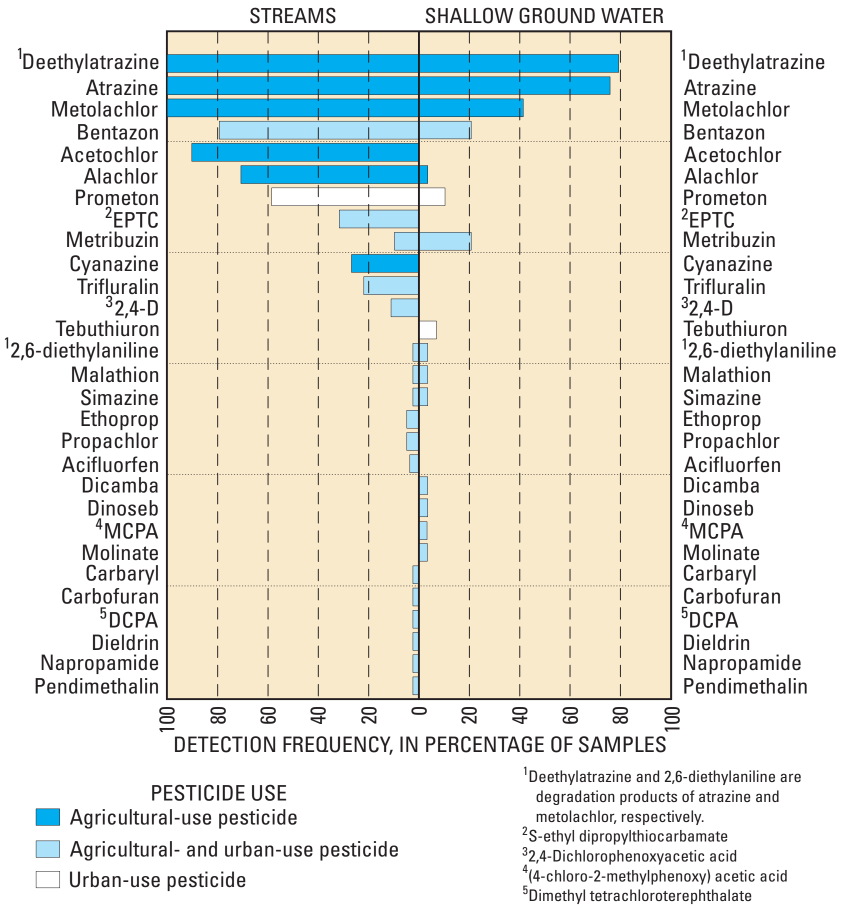
Shading from tree cover in riparian buffer zones may influence nutrient concentrations indirectly by reducing the growth of phytoplankton. In streams where phytoplankton were abundant (often where buffer zones were thin or lacking), dissolved nitrate concentrations were significantly lower (graph shown below; Porter, 2000b). The lower nutrient concentrations may result from uptake by the abundant phytoplankton. Thus, assessments of eutrophication would benefit from consideration of biological communities and the riparian zone, rather than being based solely on nutrient concentrations in the water.



Dissolved nutrient concentrations decreased in eutrophic streams with excessive algal productivity. Rates of nutrient uptake by the algae can exceed rates at which nutrients are transported by streams during low-flow conditions.

Digital images derived from USGS topographic maps were used to estimate the percentage of trees in a riparian buffer zone (a 100-meter width on each side of the stream) for 2- to 3-mile segments upstream from each sampling site, supplemented by vegetation surveys at the sampling site (Sorenson and others, 1999).

Resource agencies, including the U.S. Department of Agriculture, encourage maintenance of strips of trees or grass between cropland and streams as a best management practice. These “riparian buffer zones” are thought to intercept runoff of sediment and chemicals from fields, promote bank stability, and provide shading and habitat for aquatic life (Osborne and Kovacic, 1993). Riparian buffer zones should be considered along with other important factors that affect chemical and biological indicators of stream quality, such as soil drainage properties and stream hydrology (Porter, 2000a).



[1] Deethylatrazine and 2,6-diethylaniline are degradation products of atrazine and metolachlor, respectively.

[2] S-ethyl dipropylthiocarbamate

[3] 2,4-Dichlorophenoxyacetic acid

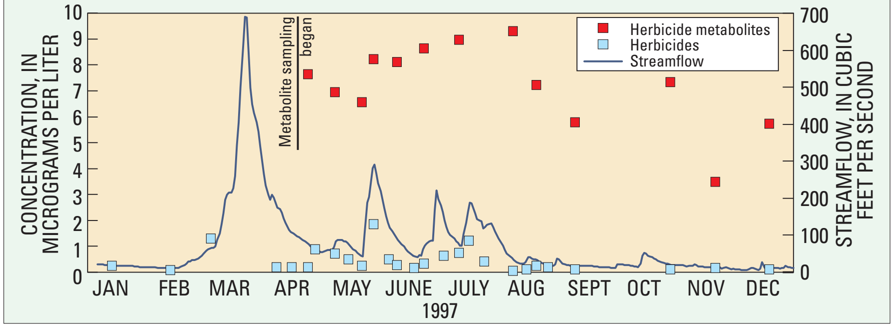
[4] (4-chloro-2-methylphenoxy) acetic acid

[5] Dimethyl tetrachloroterephthalate

**Figure 7.** Atrazine and its degradation product deethylatrazine were the most frequently detected pesticides in streams and shallow ground water in agricultural areas in the Study Unit.

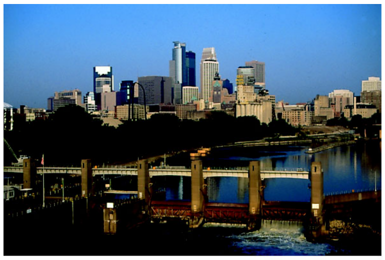
### CONCENTRATIONS OF DEGRADATION PRODUCTS OF AGRICULTURAL HERBICIDES WERE GREATER THAN THEIR PARENT COMPOUNDS IN LITTLE COBB RIVER NEAR BEAUFORD, MINNESOTA, 1997

Eight degradation products (metabolites) of four commonly used agricultural herbicides (acetochlor, alachlor, atrazine, and metolachlor) were detected in samples collected from the Little Cobb River, an agricultural stream. Summed metabolite concentrations were always greater than summed parent compound concentrations. Metabolite concentrations were least during the fall and greatest during the summer. Four metabolites were present year round at substantial concentrations (metolachlor-ethane sulfonic acid and metolachlor-, acetochlor-, and alachlor-oxanylic acid). The affects of these metabolites on aquatic and human health are not known, their persistence and relatively high concentrations are a cause for concern.



## Water Quality and Aquatic Biological Conditions are Adversely Affected in Urban Areas

The intensity of development in urban areas has adversely affected the quality of streams and ground water. Nonpoint-source contaminants to surface and ground water in urban areas originate from automobiles, road de-icing chemicals, construction, application of pesticides and fertilizers, atmospheric deposition, street debris in urban stream-water runoff, and animal and plant refuse (Hambrook and others, 1997). Major sources of contamination to ground water include spills or improper disposal of industrial or manufacturing chemicals, leachate from solid-waste landfills, and spills and leaks from petroleum storage areas and pipelines (Minnesota Pollution Control Agency, 1986).



Minneapolis, Minn., the largest city in the Study Unit. (Photograph by Scott Murray Photography.)

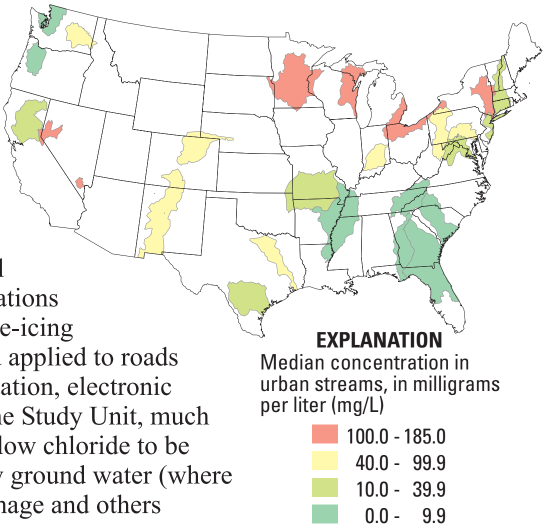
Several factors can affect the occurrence and distribution of contaminants in surface and ground water in urban areas. Factors affecting urban streams include impervious surfaces, drainage of wetlands, construction of detention ponds, loss of riparian cover, and stream-channel modifications (Riley, 1998). Impervious surfaces cause greater peak streamflow rates of shorter duration from runoff than would occur naturally, and increase transport of contaminants from streets and parking lots to streams (Riley, 1998). These factors can increase water temperature and degrade habitat and water quality. Average water temperature in TCMA streams increased as the percentage of impervious surface increased (Talmage and others, 1999). Concentrations of nutrients, trace elements, chloride, sodium pesticides, and counts of bacteria were frequently greater in urban streams than those that occur naturally and may inhibit growth, reproduction, and diversity of aquatic biota (Klein, 1979; Pope and Putnam, 1997). Factors affecting shallow ground-water quality include the composition of surficial material and depth to ground water. Sand and gravel surficial materials increase infiltration and impervious surfaces decrease infiltration to ground water. Shallow ground-water quality generally improves with depth.

Streams and ground water in shallow aquifers in the TCMA contained elevated concentrations of sodium and chloride (Andrews and others, 1998), a result of the application of road de-icers. (see "Chloride in a National Context")

Chloride concentrations in urban streams (Fallon and Chaplin, 2001) frequently exceeded the aquatic-life criterion of 230 mg/L (U.S. Environmental Protection Agency, 1999). Chloride concentrations were greater in streams with greater percentages of impervious surfaces and may have adversely affected fish diversity. (see "Urbanization Affects Fish Communities and Water Quality in Urban Streams of the Study Unit," p. 12)

All nitrate concentrations in streams were less than the USEPA drinking-water standard of 10 mg/L (Kroening, 1998a, 2000). Less than 10 percent of nitrate concentrations in ground water exceeded the standard (Andrews and others, 1998; Fong and others,

## CHLORIDE IN A NATIONAL CONTEXT--CONCENTRATIONS ARE GREATEST IN NORTHERN URBAN AREAS



Chloride concentrations in urban streams of the Study Unit were substantially greater than in most urban streams sampled throughout the Nation. Median chloride concentrations in ground water overlain by urban areas in the Study Unit were also greater than the national median, although not substantially. Elevated chloride concentrations result from runoff of de-icing chemicals applied to roads and highways during winter storms (Granato, 1996). Because winter conditions are similar across the North-Central and Northeastern United States, the greater median chloride concentrations in other northern study units may also be at least partly the result of de-icing compounds. Sodium chloride (salt) is the primary de-icing compound applied to roads and highways in the Study Unit (Minnesota Department of Transportation, electronic commun., 2000). The environmental setting of the urban portion of the Study Unit, much of it covered with permeable sandy soils, wetlands, and lakes, may allow chloride to be more readily transported to and stored in lakes, wetlands, and shallow ground water (where chloride can persist) as well as being flushed directly to streams. Talmage and others (1999) reported that chloride concentrations were positively correlated with impervious areas (buildings and paved surfaces) in 13 urban streams of the Study Unit. The source of elevated chloride concentrations in urban streams in arid study units are likely from naturally occurring salts concentrated by the evaporation of surface water (Hem, 1992).

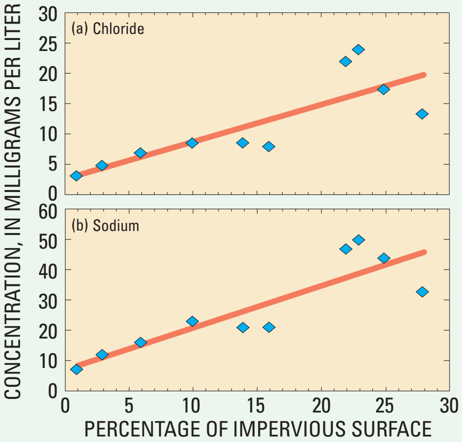
Whereas de-icers are applied to roads in other study units throughout the Nation, concentrations in streams and ground water in this Study Unit are likely greater for several reasons. The amount of snowfall and seasonal duration of subfreezing temperatures may be greater in the Study Unit than most other study units. De-icing compounds other than sodium chloride may be used in other study units.

Many samples had chloride concentrations that exceeded the aquatic-life criteria established by the U.S. Environmental Protection Agency (1999). Elevated chloride concentrations in streams may affect biological communities by altering the species composition. Urban streams in the Study Unit were dominated by fish and invertebrate species that are tolerant to degraded physical and chemical conditions, compared to other streams in the Study Unit.

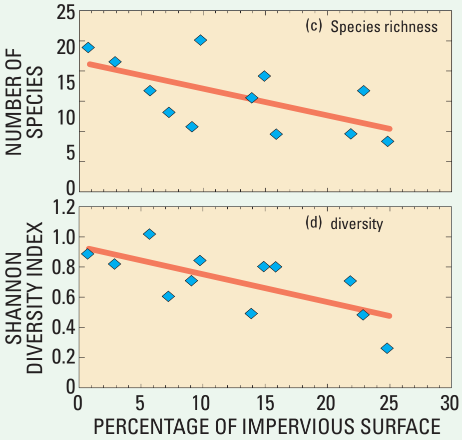
## URBANIZATION AFFECTS FISH COMMUNITIES AND WATER QUALITY IN URBAN STREAMS OF THE STUDY UNIT

Water quality, instream habitat, and fish-community composition were characterized at urban streams of the Study Unit during low-flow conditions, September 1997. The density of impervious cover (roads, parking lots, and rooftops) generally increases as population density increases and was used as a measure of urbanization. Nutrient and pesticide concentrations were generally low, rarely exceeding concentrations found in agricultural streams. Nutrient concentrations did not change with the percentage of impervious area. In contrast, chloride (fig. a) and sodium (fig. b) (used for road de-icing) concentrations were generally elevated in urban streams and increased as the percentage impervious area increased.

Fish communities within most urban streams were characterized by species that are tolerant to degraded physical and chemical conditions, such as the central mudminnow, fathead minnow, and black bullhead. There were, however, differences in the fish communities among streams. Two measures of community health--the species richness and diversity--decreased as the percentage of impervious area increased (figs. c and d). Factors associated with impervious cover, such as reduced instream habitat, presence of contaminants in water and sediment, alterations to stream channels, and migration barriers, may directly affect fish-community composition.



**Concentrations of chloride (a) and sodium (b) in relation to percentage of impervious surface in urban streams of the Study Unit, September 1997**



**Species richness (c) and diversity (d) in relation to percentage of impervious surface in urban streams of the Study Unit, September 1997**

1998). Nitrate and phosphorus yields in urban streams (table 3) were less than in agricultural streams (table 2) and greater than in forest streams (table 1). About 30–37 percent of the total phosphorus concentrations in urban streams exceeded the USEPA's water-quality criterion of 0.1 mg/L (Kroening, 1998a, 2000). The greatest concentrations of nitrate in ground water were from samples of shallow ground water (unconfined surficial sand and gravel aquifers) (Kroening and Andrews, 1997). Areas with the greatest concentrations of nitrate are related to aquifer susceptibility and overlying land use. Nitrate concentrations tend to decrease with increased well depth (Hanson, 1998).

**Table 3.** Nitrate and phosphorus yields, in pounds per square mile per year in streams in urban areas, 1996-98

| STREAM | NITRATE | PHOSPHORUS |
|---|---|---|
| Shingle Creek | 400 | 130 |
| Nine Mile Creek | 510 | 140 |

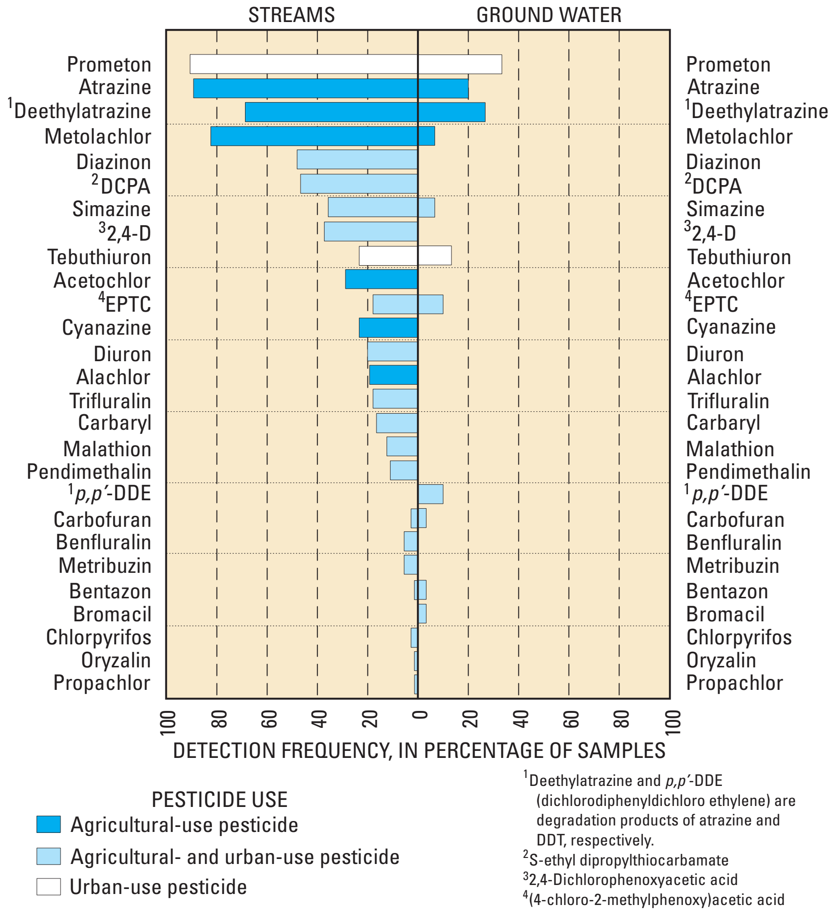
Dissolved-oxygen concentrations in most urban streams usually were greater than the minimum 5 mg/L aquatic-life criterion (U.S. Environmental Protection Agency, 1986) necessary for the protection of aquatic life. Dissolved-oxygen saturation in urban streams during the growing season was generally greater than forest streams and less than agricultural streams.

Pesticides were frequently detected in urban streams and shallow ground water (fig. 8); however, concentrations seldom exceeded applicable standards or guidelines (Andrews and others, 1998). Concentrations in shallow ground water were generally less than in surface water (Fallon and others, 1997; Andrews and others, 1998). Factors affecting pesticides in surface and ground water include land use, application methods, and atmospheric transport and deposition. In streams and shallow ground water, herbicides commonly used on road rights-of-way were detected (prometon and tebuthiuron), as were agricultural herbicides (atrazine and metolachlor). Insecticides were detected in almost 50 percent of stream water samples (Fallon, 1998) but in less than 5 percent of ground-water samples (fig. 8).

Volatile organic compounds (VOCs) were detected in surface and shallow ground water in the urban part of the Study Unit (fig. 9) (Andrews and others, 1995 and 1998). Some VOCs are suspected carcinogens and may be toxic to humans and wildlife. Although many VOCs were detected in urban streams, concentrations generally were below applicable standards and guidelines. The greatest concentrations occurred in stormwater runoff and winter low flows. The most frequently detected VOCs are components of petroleum products and by-products of petroleum combustion. These VOCs are contributed to streams from engine emissions to the atmosphere and from oil and gasoline leaks from vehicles to parking lots and roadways.

Other contaminants such as polycyclic aromatic hydrocarbons (PAHs), organochlorine compounds (OCs), and trace elements are common in urban streams, frequently at concentrations greater than aquatic-life guidelines (McNellis and others, 2000; Talmage and others, 1999) (see “Organic Contaminants in a National Context”). Urban activities and discharges also contribute to increased concentrations of trace elements (particularly cadmium, copper, lead, and zinc) in some urban streambed sediments. Elevated concentrations of some trace elements can be toxic to humans and aquatic life.

Fecal coliform counts differed widely among urban stream samples collected during September 1997, ranging from about 54 col/100mL (colonies per 100 mL) to more than 11,000 col/100 mL (Talmage and others, 1999). Fecal coliform counts at 8 of 13 sites



[1] Deethylatrazine and *p,p′*-DDE (dichlorodiphenyldichloro ethylene) are degradation products of atrazine and DDT, respectively.
[2] S-ethyl dipropylthiocarbamate
[3] 2,4-Dichlorophenoxyacetic acid
[4] (4-chloro-2-methylphenoxy)acetic acid

**Figure 8.** Pesticides typically used in agricultural areas were frequently detected in streams and ground water in urban areas in the Study Unit.

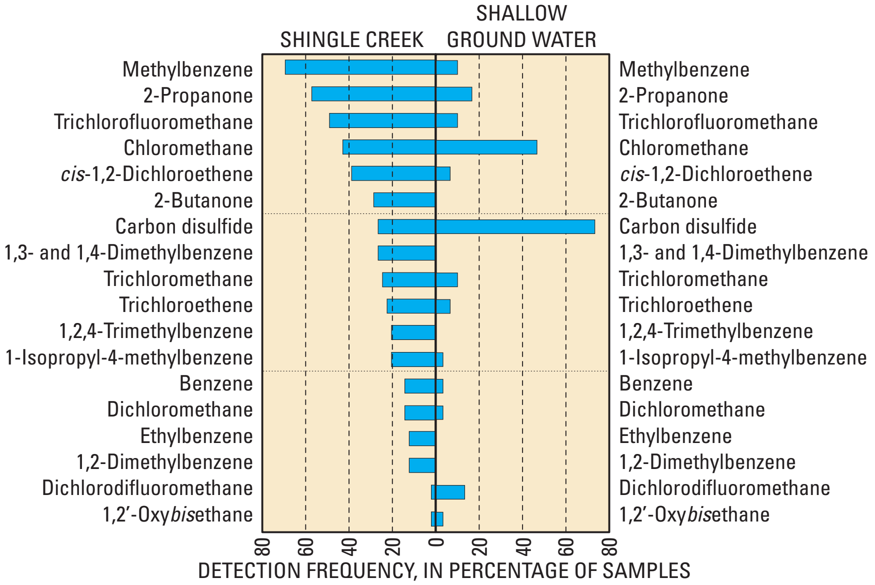
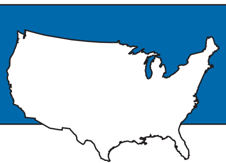


**Figure 9.** More volatile organic compounds (VOCs) were detected in Shingle Creek (an urban stream) than in the shallow ground water in the same land-use setting, indicating that many VOCs break down before infiltrating the shallow ground water.



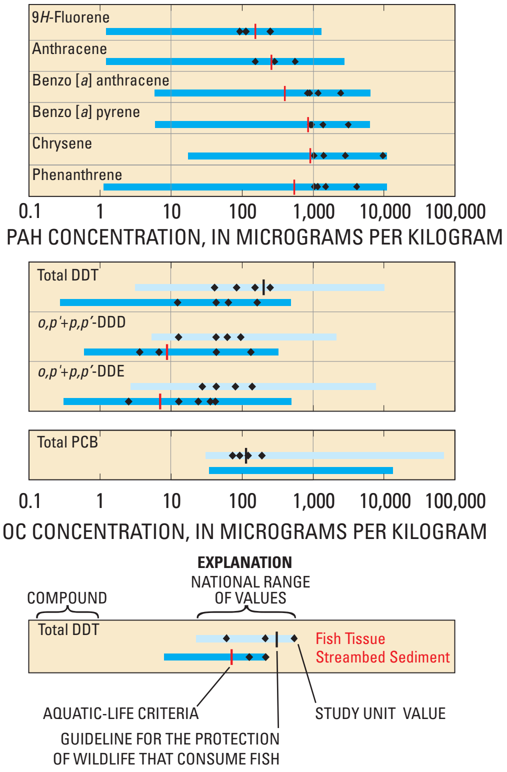
## ORGANIC CONTAMINANTS IN A NATIONAL CONTEXT--CONCENTRATIONS WERE GREATEST IN URBAN STREAMS IN THE STUDY UNIT

**Polycyclic aromatic hydrocarbon concentrations in streambed sediment in urban areas are among the greatest in the Nation.**

Six polycyclic aromatic hydrocarbon compounds (PAHs) were detected at concentrations above U.S. Environmental Protection Agency (USEPA) aquatic-life criteria. Some are known carcinogens and are toxic to aquatic life. These compounds are generally by-products of combustion of fossil fuels or the burning of wood. Concentrations of PAHs at sites in other land uses were 10 to 100 times less than those in urban areas.

**Organochlorine detections are prevalent in urban areas. Some sites had concentrations greater than recommended for the protection of aquatic life or wildlife.**

Streambed sediment and fish tissue were analyzed for organochlorine compounds (OCs). Although uses of the insecticide DDT for mosquito control and polychlorinated biphenyls (PCBs) for industrial applications were discontinued in the 1970s, these compounds were still detected in urban streambed sediment in the Study Unit. Twelve of the 13 OCs (insecticides and PCBs) detected in streambed sediment in the Study Unit were found at urban sites. Three OCs including DDT, DDT metabolites (DDE and DDD), and total PCBs were detected in fish tissue at all urban sites in the Study Unit. Total DDT and metabolites in streambed sediment exceeded USEPA water-quality guidelines. PCB concentrations in fish exceeded USEPA standards for wildlife that consume fish.



exceeded the State of Minnesota freshwater standard for recreational use (200 col/100 mL) (Minnesota Pollution Control Agency, 1991). The greater bacteria counts may indicate localized leaking sewer or septic systems or animal waste.

Relatively low nutrient concentrations, stream shading, and contaminants may lead to low algal production in urban streams (Lee and others, 1999). However, nutrient concentrations are a concern because urban streams commonly drain to lakes that are more sensitive to eutrophication. The warmer temperatures and longer residence times of the water in lakes allow greater algal productivity. Invertebrate taxa that indicate good water quality, such as mayflies and stoneflies, were absent (see “Urban Biological Communities in a National Context”). Fish communities were characterized by a large proportion of species that can tolerate degraded water-quality conditions, such as central mudminnows and fathead minnows (Goldstein and others, 1999; Talmage and others, 1999). Factors that affect biological communities in urban streams include water and sediment chemistry and physical conditions such as hydrology and instream habitat.

Physical alterations, such as channelization and the high percentage of impervious area in urban basins, contribute to greater hydrologic variability (rapid streamflow increases and decreases during storm events). Waterfalls and dams are common in urban streams in the Study Unit and may be barriers to fish migration (Talmage and others, 1999). Migration barriers can limit the total number of fish species.

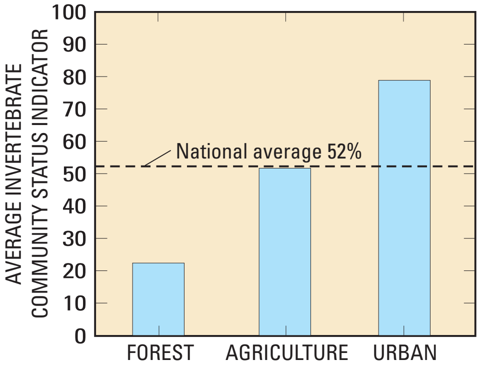
### Water Quality and Aquatic Biological Conditions have Characteristics Indicative of Dominant Land Uses

Sodium and chloride concentrations were greater in shallow ground water and streams in urban areas than in agricultural or forested areas. Chloride concentrations commonly exceeded the USEPA aquatic-life criteria of 230

## URBAN BIOLOGICAL COMMUNITIES IN A NATIONAL CONTEXT--INVERTEBRATE COMMUNITIES REFLECT POOR RESOURCE QUALITY WITHIN URBAN STREAMS IN THE STUDY UNIT

Invertebrate communities indicated that the most degraded conditions occurred in 13 urban streams compared to 26 agricultural streams and 1 forest stream in the Study Unit. Urban streams were also among the most degraded in the Nation. Invertebrate communities in urban streams were composed of pollution tolerant species, such as true flies, with few sensitive species, such as mayflies and stoneflies.

Factors influencing invertebrate communities in urban streams may include elevated concentrations of PCBs, organochlorine pesticides (DDT, DDE and DDD), PAHs, and trace elements in streambed sediments. Concentrations of some of these compounds rank among the greatest in the Nation (McNellis and others, 2001; Kroening and others, 2000). In addition to chemical characteristics, modification to stream hydrology and removal of instream habitat may contribute to degraded conditions for aquatic communities in urban streams in the Study Unit.



**Invertebrate Community Status Indicators (ICSI) scores were greatest in urban streams indicating poor aquatic resource (habitat and water) quality. The ICSI is a measure that summarizes species richness, tolerance, dominance, and trophic conditions, and that are associated with water-quality degradation. The indicator values increase with greater resource-quality degradation.**

mg/L (Mitton and Payne, 1997; Fong, 2000; Fallon and Chaplin, 2001). Elevated sodium and chloride concentrations are the result of de-icers that are applied more heavily in urban areas.

Concentrations and yields of nutrients and suspended sediment in streams that drain agricultural areas were substantially greater than those that drain urban or forested areas (fig. 10). Increased nutrient concentrations have contributed to accelerated eutrophication and low dissolved-oxygen concentrations (Kroening, 2000), which adversely affect aquatic communities. Eutrophication has been most notable in the Minnesota River Basin. The greatest nitrate concentrations in the Minnesota River Basin were measured during rainfall runoff (Payne, 1994; Kroening and others, 2000). Exceedences of the USEPA drinking-water standard of 10 mg/L for nitrate occurred in less than 4 percent of urban and 38 percent of agricultural ground-water samples, whereas nitrate was commonly undetected (less than 0.05 mg/L) in forested areas (fig. 11). Nitrate concentrations in shallow ground water increased with agricultural intensity, particularly in unconfined sand and gravel aquifers (Hanson, 1998), suggesting that underlying deeper aquifers, typically used for drinking water, have potential to be contaminated with nitrate (fig. 11) (Fong, 2000).

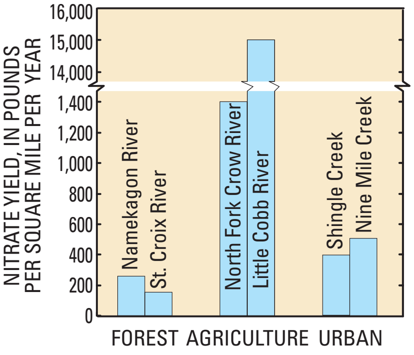


**Figure 10.** Nitrate yields were greatest in streams draining agricultural areas in the Study Unit.

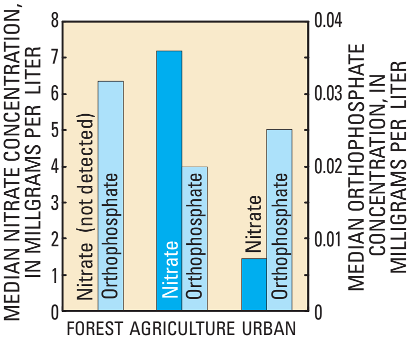


**Figure 11.** Nitrate concentrations were greatest in ground water in agricultural areas of the Study Unit.

The pesticides detected differed by land use. Herbicides were the most frequently detected in surface and ground water. Atrazine and its degradation product, deethylatrazine, were detected in all land-use settings (Fallon and others, 1997; Fong, 2000). Prometon, a herbicide used on road rights-of-way, was the most frequently detected herbicide in ground water in urban settings (Andrews and others, 1998). Organochlorine concentrations in streambed sediment were substantially greater in urban streams than in agricultural or forest streams (McNellis and others, 2001).

Volatile organic compounds were most commonly detected in urban areas. In ground water, the most frequently detected VOCs (carbon disulfide and chloromethane) were in shallow aquifers in urban areas, but at concentrations generally less than 1 µg/L (fig. 12) (Andrews and others, 1998). VOCs also were detected in ground-water samples from agricultural areas, but at concentrations and detection frequencies less than urban areas (Ruhl and others, 2000). In urban streams, the greatest concentrations of VOCs were detected following storm runoff and during winter low flows.

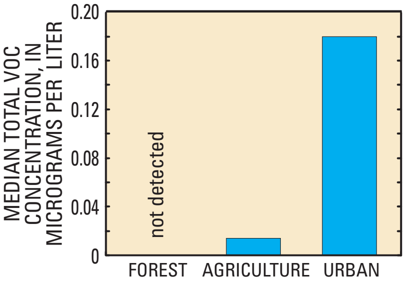


**Figure 12.** Total volatile organic compound concentrations were greatest in ground water in urban areas in the Study Unit.

Trace concentrations of PCBs and DDE (a degradation product of DDT) were detected in fish throughout the Study Unit (Biedron and Helwig, 1991). PCB concentrations in common carp fillet tissue have decreased at different rates in each land-use setting since their use was discontinued in the 1970s (Durfee, 1976) (fig.13). Concentrations of these compounds were greater in fish and sediment from stream reaches near urban areas (Fallon and others, 1997; Lee and Anderson, 1998; McNellis and others, 2001).

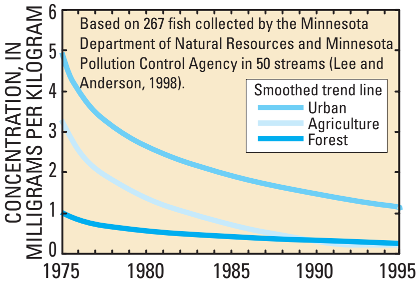


**Figure 13.** Polychlorinated biphenyl concentrations in common carp fillets collected from streams in the Study Unit have decreased since 1975.

Streambed-sediment concentrations of lead, zinc (fig. 14), cadmium, and copper were greater in urban areas than other land-use settings (Kroening and others, 2000). In streams draining agricultural and forested areas, trace-element concentrations in streambed sediment probably reflected natural geochemistry. Mercury concentrations in fish livers were greater in streams draining land uses other than urban settings (Kroening and others, 2000). Agricultural and urban activities contribute to elevated suspended-sediment concentrations and bacteria counts in small streams. Suspended-sediment concentrations were greatest in agricultural streams.

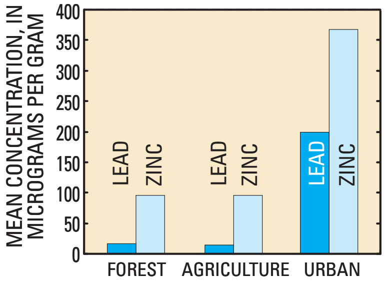


**Figure 14.** Lead and zinc concentrations were greatest in streambed sediments in urban areas in the Study Unit.

Aquatic biological communities are affected by chemical, hydrological, and physical conditions in streams and serve as good indicators of water quality. Community composition indicated more degraded conditions in urban streams than in forest or agricultural streams (Lee and others, 1999; Talmage and others, 1999). Invertebrate communities in urban streams are composed of fewer mayflies, stoneflies, and caddisflies than streams draining agricultural and forested land (fig. 15) (Lee and others, 1999). Fish communities in urban streams were dominated by species tolerant of low dissolved-oxygen concentrations and warm temperatures (Goldstein and others, 1999; Talmage and others, 1999). Fish biomass and phytoplankton biovolume are indicators of stream productivity. The greatest fish biomass (usually in the form of species such as common carp) and phytoplankton biovolumes were measured in agricultural streams (fig. 16).

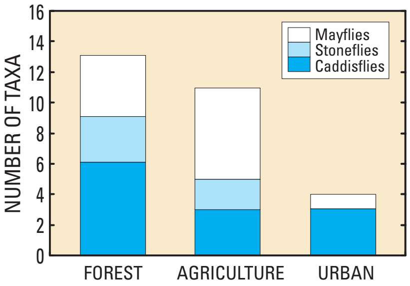


**Figure 15.** Total number of mayflies, stoneflies and caddisflies, indicators of good water-quality conditions, was greatest in streams draining forested areas in the Study Unit.

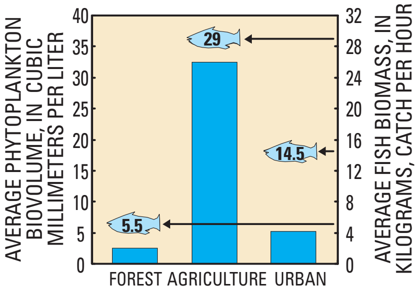


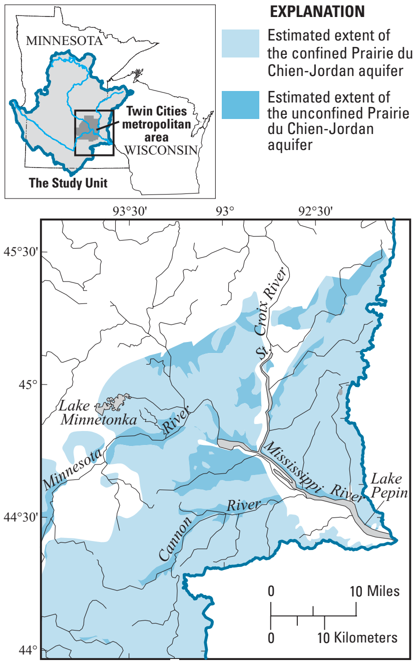
**Figure 16.** Phytoplankton biovolume and fish biomass were greatest in streams draining agricultural areas in the Study Unit.

## Land Use Influences Water-Supply Aquifers

The Prairie du Chien-Jordan aquifer, which occurs in dolomite and sandstone of Cambrian to Ordovician age, is the principal bedrock aquifer throughout much of the Study Unit (fig. 17), supplying approximately 75 percent of the ground water withdrawn in the area for public and industrial supply. In certain areas, termed confined portion, bedrock or glacial deposits having low permeability overlie the aquifer. In other areas, termed unconfined portion, glacial sand and gravel deposits having greater permeability overlie the aquifer. The hydrogeologic characteristics of these overlying units affect the downward movement of water and contaminants from the land surface into the aquifer.

Water in the unconfined portion of the aquifer appears to be affected to a greater degree by human-related activities than water in the confined portion of the aquifer. Nitrate concentrations were greater in the unconfined portion of the aquifer. In the unconfined portion of the aquifer, nitrate in 8 percent of the wells sampled exceeded the USEPA drinking-water standard of 10 mg/L. In the confined portion of the aquifer, no samples exceeded 10 mg/L of nitrate. Phosphorus concentrations generally were about one-tenth of nitrate concentrations. In about 40 percent of water samples from confined and unconfined portions of the aquifer, concentrations of iron and manganese in water samples from confined and unconfined portions of the aquifer exceeded drinking-water guidelines.

Radon concentrations ranged from 100 to 2,700 pCi/L and exceeded the suspended USEPA drinking-water standard of 300 pCi/L in 68 percent of the water samples from the unconfined portion of the aquifer and 64 percent from the confined portion of the aquifer. Tritium concentrations in ground water indicated that water in the unconfined portion of the aquifer was recharged more recently than water in the confined portion of the aquifer.



Extent of the confined and unconfined Prairie du Chien-Jordan aquifer used in this study was modified from Brown, 1988; Kanivetsky, 1978; Mudrey and others, 1987; Olcott,1992.

**Figure 17.** Estimated extent of the Prairie du Chien-Jordan aquifer in part of the Study Unit.

Arsenic concentrations in the confined and unconfined portions of the aquifer ranged from less than the method reporting limit (1 µg/L) to 7 µg/L. These concentrations do not exceed the current USEPA drinking-water standard of 50 µg/L.

Seven different pesticide compounds were detected in water samples. Atrazine and its degradation product, deethylatrazine, were most frequently detected. Atrazine was detected in water from 36 percent of wells in the confined portion of the aquifer and 52 percent of wells in the unconfined portion of the aquifer. VOCs were detected in 82 percent of the water samples, but none at concentrations exceeding 1 µg/L. More VOCs were detected in water samples from the unconfined portion of the aquifer than from the confined portion.

## Water Quality and Aquatic Biology of Large Rivers

Water quality and aquatic biology in the large rivers of the Study Unit (the Mississippi, Minnesota, and St. Croix) represent the cumulative quality of their tributaries. The tributaries of the Minnesota River drain primarily agricultural land, the tributaries of the St. Croix River drain primarily forested land, and the tributaries of the Mississippi River drain primarily agricultural and forested land. Because of agricultural activities and natural conditions, water in the Minnesota River contains elevated concentrations and yields of nutrients, suspended sediments, and pesticides (Fallon and others, 1997; Kroening, 2000). The aquatic biological community contains fewer invertebrate and algal taxa, but greater chlorophyll-*a* concentrations associated with greater nutrient concentrations (Kroening, 2000; Lee and ZumBerge, 2000) (fig. 18). In contrast, the St. Croix River and the Mississippi River upstream from the TCMA have low nutrient concentrations, relatively clear water, and low suspended-sediment and pesticide concentrations (Fallon and others, 1997; Fallon, 1998; Kroening, 2000). Downstream from the TCMA, and below the confluence of the Minnesota and St. Croix Rivers, water quality in the

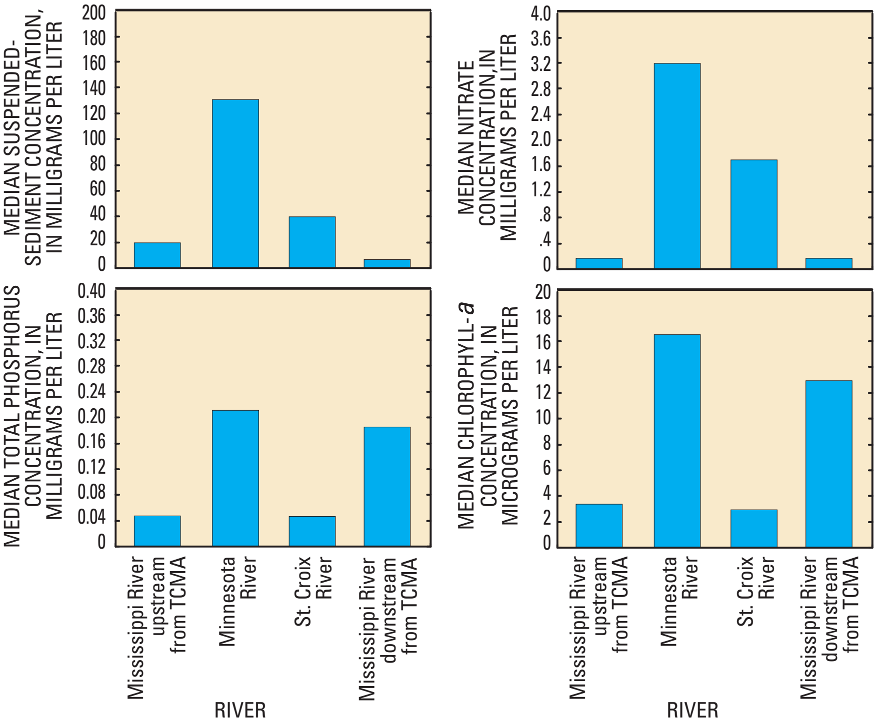


**Figure 18.** Median concentrations of nitrate, total phosphorus, suspended sediments, and chlorophyll-*a* were generally lower upstream from the Twin City Metropolitan Area (TCMA) and were greatest in the Minnesota River.

Mississippi River results from a complex mixture of water and chemical constituents. Concentrations of nutrients, suspended sediments, and pesticides in the Mississippi River increase at the confluence with the Minnesota River and decrease slightly, due to dilution downstream from the confluence with the St. Croix River (fig. 19) (Fallon, 1998; Kroening, 2000).

Aerial view of the confluence of the St. Croix and the Mississippi Rivers. (Photograph by James R. Stark.)

Nitrate concentrations in the Mississippi and St. Croix Rivers did not exceed the USEPA drinking-water standard of 10 mg/L (Kroening, 1998a, 2000). Eleven percent of the samples from the Minnesota River near Jordan, Minn., exceeded the standard. The most noticeable trends in the Mississippi, Minnesota, and St. Croix Rivers during 1984–93 were an increase in nitrate concentrations and a decrease in total ammonia concentrations in the TCMA (fig. 20) (Kroening and Andrews, 1997). These trends were not observed at other sites. These ammonia reductions are probably the result of nitrification processes used at the three largest wastewater treatment facilities in the TCMA, which convert ammonia-nitrogen to nitrate. This process has resulted in wastewater effluents that are less toxic to fish and other aquatic life. Nitrate concentrations, however, may contribute to eutrophication.

Total phosphorus concentrations in parts of the Minnesota River and in the Mississippi River downstream from the TCMA frequently exceeded the USEPA guideline of 0.1 mg/L to prevent eutrophication

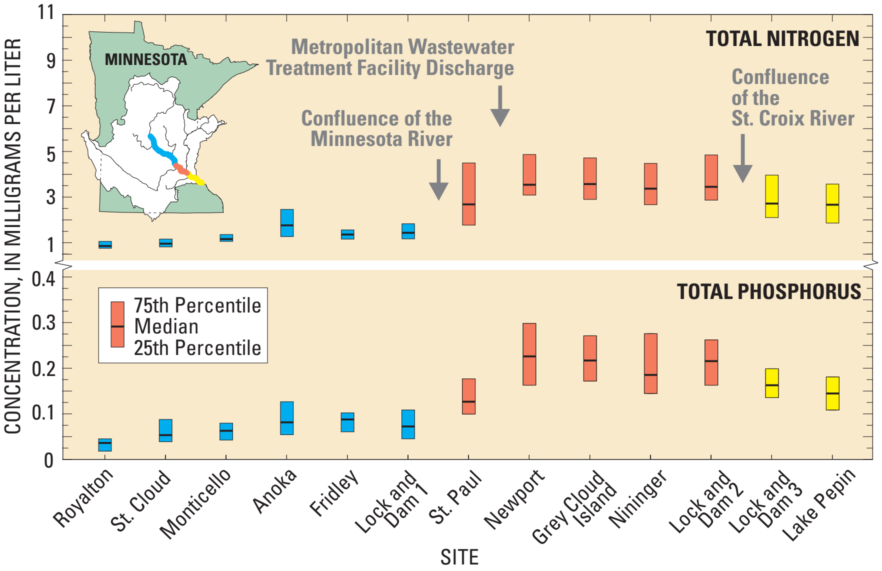
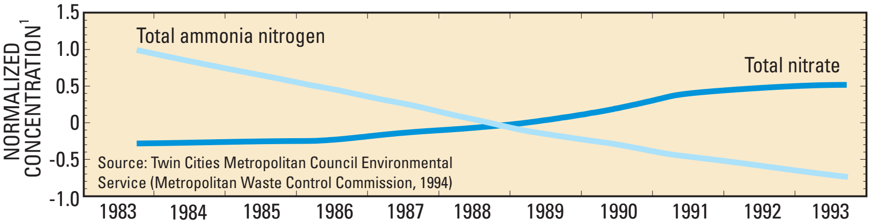


**Figure 19.** Total nitrogen and phosphorus concentrations in the Mississippi River increase downstream from the confluence of the Minnesota River and decrease downstream from the confluence of the St. Croix River.



Source: Twin Cities Metropolitan Council Environmental Service (Metropolitan Waste Control Commission, 1994)

[1] Concentrations were adjusted to account for variations with streamflow.

**Figure 20.** Modifications in wastewater-treatment processes have changed measured total nitrate and total ammonia nitrogen concentrations in the Mississippi River at Newport, Minn.

(Kroening, 1998b, 2000). Phosphorus concentrations and loads to the rivers originate from both point and nonpoint sources. The major point sources are wastewater treatment facilities, whereas the major nonpoint sources are from agriculture in the Minnesota River Basin. During low streamflow conditions, more phosphorus comes from wastewater treatment facilities, whereas during high streamflow conditions, nonpoint sources dominate. Dissolved orthophosphate concentrations generally were greatest at sites downstream from wastewater discharges in the TCMA (Kroening, 1998b, 2000). Eutrophication of Lake Pepin has been linked to elevated phosphorus concentrations in the Mississippi River (Minnesota Pollution Control Agency, 1989).

Wastewater treatment facilities introduce contaminants such as nutrients and chloride to streams. (Photograph by Scott Murray Photography.)

Biochemical oxygen demand (BOD) of materials discharged from wastewater treatment facilities has resulted in dissolved-oxygen concentrations in the Mississippi and Minnesota Rivers (Johnson and Aasen, 1989; Minnesota Pollution Control Agency, 1985) that are sometimes less than the USEPA guideline of 5 mg/L for the protection of aquatic life (U.S. Environmental Protection Agency, 1986).

The runoff of agricultural chemicals and sediment affects water quality in nearby streams and rivers. (Photograph by Scott Murray Photography.)

Suspended sediment adversely affects aquatic life by limiting light and covering habitat. Suspended sediment also transports nutrients, trace elements, and organic compounds attached to particles. The greatest concentration of suspended sediment in the large rivers was in the Minnesota River (Kroening, 2000). The primary contributors of suspended sediment to the Minnesota River are the tributary watersheds in the central and southeastern parts of the Minnesota River Basin (Payne, 1994). Concentrations were lower in the St. Croix River and in the upper reaches of the Mississippi River.

Pesticides frequently were detected in the large rivers, but no concentrations exceeded applicable drinking-water standards or guidelines (Fallon and others, 1997; Fallon, 1998). Herbicides detected in all large rivers include the row crop herbicides alachlor, atrazine, and its degradation product deethylatrazine, cyanazine, and metolachlor. In and downstream from the TCMA, insecticides were frequently detected in water, and although use was discontinued in the early 1970s, DDT and its degradation products DDE and DDD were frequently detected in fish tissue and bed sediment.

Streambed sediment in the Mississippi River within and downstream from the TCMA contained the greatest number of OCs (Fallon and others, 1997; Fallon, 1998). PCB concentrations in streambed sediments have decreased over time (Anderson and Perry, 1999). Fish tissue concentrations have paralleled this decline (Lee and Anderson, 1998).

Human activities have had a strong influence on the occurrence and distribution of trace elements in large rivers of the Study Unit. The TCMA is the largest source of trace elements to rivers in the Study Unit. Trace-element data collected in the TCMA during 1992 by the Metropolitan Waste Control Commission (1994) indicate that concentrations of most trace elements in the water were less than applicable standards and guidelines, with the periodic exceptions of mercury and copper. Concentrations of cadmium, lead, mercury, and zinc were greatest in streambed-sediment samples within or immediately downstream from the TCMA (Wiener and others, 1984; Kroening and others, 2000). An industrial pretreatment program that began in the early 1980s has reduced the amount of trace elements discharged to the Mississippi River. For example, zinc concentrations have decreased an average of 80 percent (Anderson and Perry, 1999) (fig. 21) since the pretreatment program began.

Treated wastewater and untreated animal waste in the Study Unit also contribute to increased counts of fecal bacteria in the large rivers. Fecal bacteria counts were greatest in the Minnesota River and in the Mississippi River as it flowed through the TCMA. Approximately 40 percent of samples collected in the Minnesota River Basin exceeded the Minnesota and Wisconsin State freshwater standards for recreational use of 200 col/100 mL (Payne, 1994; Wisconsin Department of Natural Resources, 1997; Minnesota Pollution Control Agency, 1999). Data collected by the Metropolitan Waste Control Commission (1994) indicate that during 1992, 25 percent of the water samples collected in the Mississippi River immediately downstream from the Minnesota River and the Metropolitan Wastewater Treatment Plant outfall exceeded freshwater standards for recreational use regarding bacteria.

Changes in the habitat of the large rivers have been caused by the construction of locks and dams, dredging to maintain navigation channels, modifications to stream morphology, and changes in land use. (see "Riparian Buffer Zones Affect the Quality of Midwestern Streams and Rivers," p. 9). Instream habitat and fish community conditions in the large rivers differ among areas of forest, urban, and agricultural lands. Diverse aquatic biological communities and relatively undisturbed riffle-pool morphology are found in the St. Croix River and the upper reaches of the Mississippi River in forested areas. Drainage of wetlands, loss of riparian vegetation, and channel straightening in the Minnesota River Basin have reduced habitat, modified hydraulic conditions, and changed water quality.

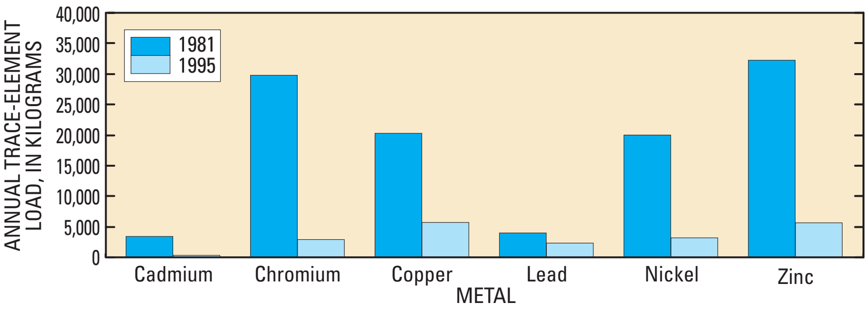


**Figure 21.** Annual trace-element load from the Metropolitan Wastewater Treatment Plant by industrial users has decreased since 1981.

In the Mississippi River, the construction and maintenance of locks and dams have altered physical habitat for fish, invertebrates, and algae by changing streamflow from free-flowing to impounded, and altering the natural hydrology and the physical structure of the channel. As a result, the river has changed from a meandering, flowing system, which periodically overran its banks and flood plain, to a series of impoundments connected by dredged channels where the streamflow and water levels are controlled. The impoundments change the physical structure of the river, the diversity of aquatic habitats, and water quality. Impoundments reduce the velocity and warm the water in the pools. Reduced velocity causes sediment to settle, changing the composition of the substrate on the bottom of impoundments to fine-grained material (sand and silt). Nutrients and contaminants associated with sediment particles are concentrated in the bottom sediments of the pools.

The addition of nutrients from wastewater treatment facilities and from agricultural activities, combined with greater water temperatures and greater light penetration, stimulate algal growth. Concentrations of chlorophyll-*a* and phytoplankton biovolume in the Minnesota River at Jordan, Minn., and in the lower Mississippi River sites at Hastings, Minn., and at Red Wing, Minn., are greater than twice the concentrations measured at the upper Mississippi River site at Royalton, Minn. (Kroening, 2000), indicating greater phytoplankton abundance and primary production (fig. 22). High concentrations of nutrients, coupled with the environmental conditions of sufficient light and temperature, can result in eutrophication and subsequent oxygen deficits. Blue-green algal blooms were suspected of causing low dissolved-oxygen concentrations in Lake Pepin during the summer of 1988 (an abnormally dry period) that resulted in fishkills (Minnesota Pollution Control Agency, 1989).

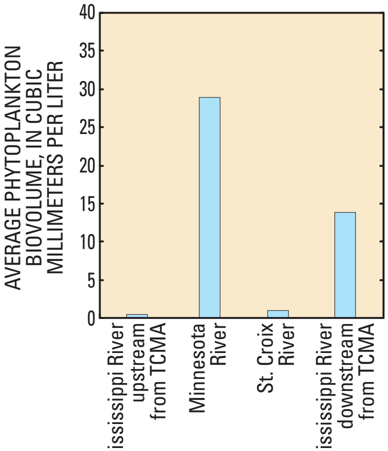


**Figure 22.** Phytoplankton biovolume was least in the Mississippi River upstream from the Twin Cities Metropolitan Area (TCMA) and was greatest in the Minnesota River.

Invertebrate communities also have been influenced by environmental and morphologic conditions in the large rivers of the Study Unit. Sensitive invertebrate species (mayflies, stoneflies, and caddisflies) were most abundant in the St. Croix River, which drains primarily forested land. These sensitive taxa were least abundant in and downstream from the TCMA (fig. 23), where tolerant taxa such as Diptera (true flies) and Oligochaeta (aquatic worms) composed a large portion of the invertebrate community. Several species of mollusks are no longer present, due to commercial harvesting, loss and modification of habitat, water contamination, deposition of silt, and the introduction of zebra mussels (Mueller, 1993). Contaminants such as cadmium and mercury in the sediments have accumulated in burrowing mayflies and may present a substantial source of trace element contaminants to fish, particularly in Lake Pepin (Beauvais and others, 1995).

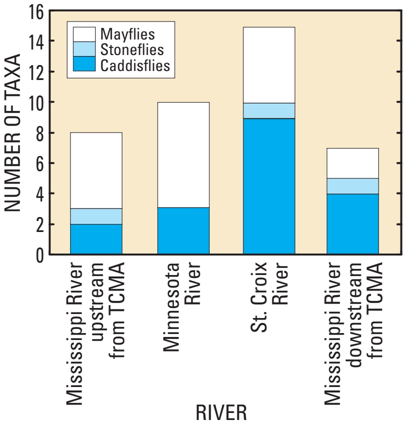


**Figure 23.** Total number of mayflies, stoneflies, and caddisflies was least downstream from the Twin Cities Metropolitan Area (TCMA) and greatest in the St. Croix River.

Several chemical and physical factors affect the abundance and distribution of fish species. St. Anthony Falls in Minneapolis, Minn., on the Mississippi River, and the dam at St. Croix Falls, Wis., on the St. Croix River, form two major barriers to fish migration. These barriers have resulted in differences in fish species composition (Underhill, 1989). More species occur downstream of the barriers (fig. 24) (Goldstein and others, 1999; Underhill, 1989).

Other differences in the fish community distribution exist among large rivers in the Study Unit. The Mississippi River upstream from the TCMA and the St. Croix River upstream from Taylors Falls have fish species that thrive in cold water. Fish communities at these river sections are dominated by cool water and riverine species such as redhorse and smallmouth bass. Farther downstream, particularly in the Mississippi River downstream from the TCMA, the fish community consists of catfish, buffalo fish, freshwater drum, carpsuckers, and gizzard shad that tolerate warm water. The pattern of thermal preference is also consistent in the Minnesota and St. Croix Rivers. Lake species that are adapted to still water with high thermal ranges are found in and downstream from the TCMA.

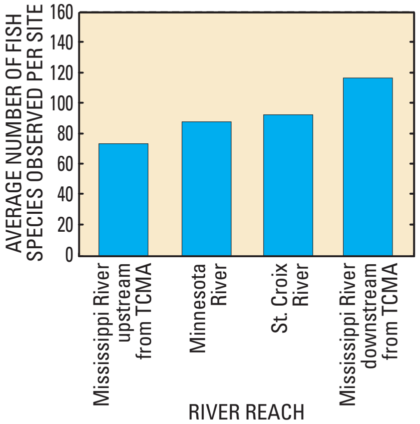


**Figure 24.** Total number of fish species was greatest in the Lower Mississippi River downstream from the Twin Cities Metropolitan Area (TCMA).

The distribution of fish also differs by trophic status in the large rivers. Upstream from the TCMA, fish (northern hogsucker, golden and shorthead redhorse, hornyhead chub, common shiner, smallmouth bass, and two species of darter) that primarily consume invertebrates species that require a gravel or cobble substrate were abundant compared to downstream from the TCMA where fish (common carp and buffalo fish) that primarily consume detritus were more abundant. Downstream from the TCMA, species that feed on detritus rely on filter feeding and suctioning of the bottom sediments for fine particulate organic matter.

The reduction in river velocity resulting from hydrologic modifications, such as impoundments, also alters the composition of the fish communities in the rivers. Species downstream from the TCMA tend to be associated with still-water habitats, whereas species upstream from the TCMA are associated more with flowing-water habitat. The abundance of fish (gizzard shad and emerald shiner) that eat plankton in the Mississippi River downstream from the TCMA indicates that a plankton community more common to lakes exists in that part of the river.

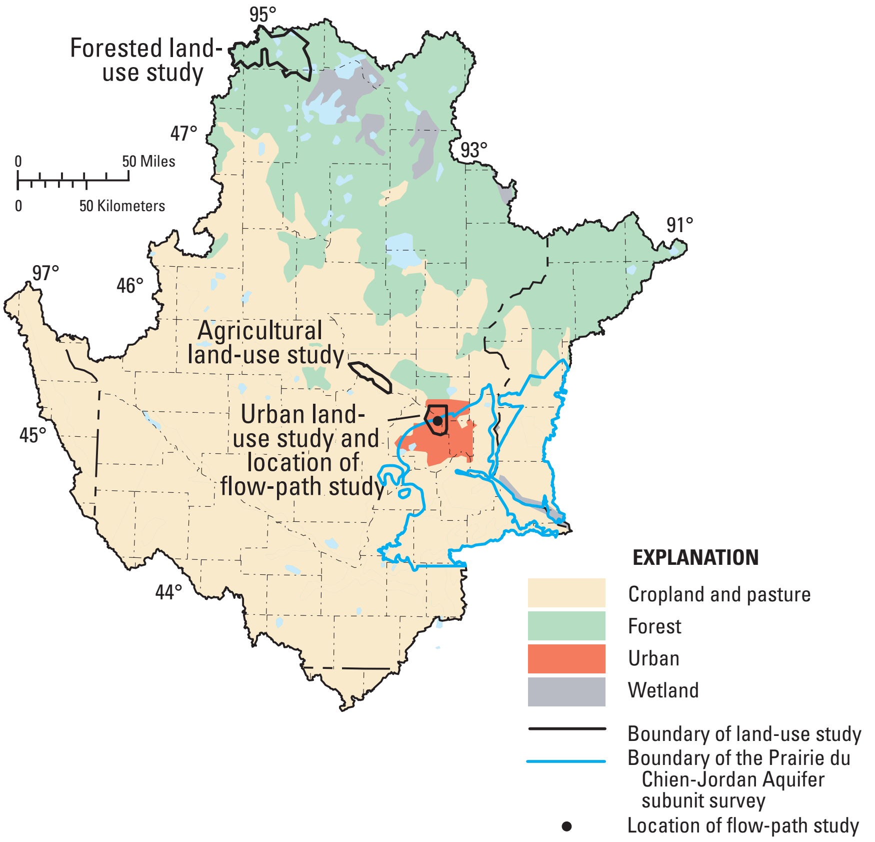
Clean drinking water is important to everyone. (Photograph from U.S. Geological Survey files.)

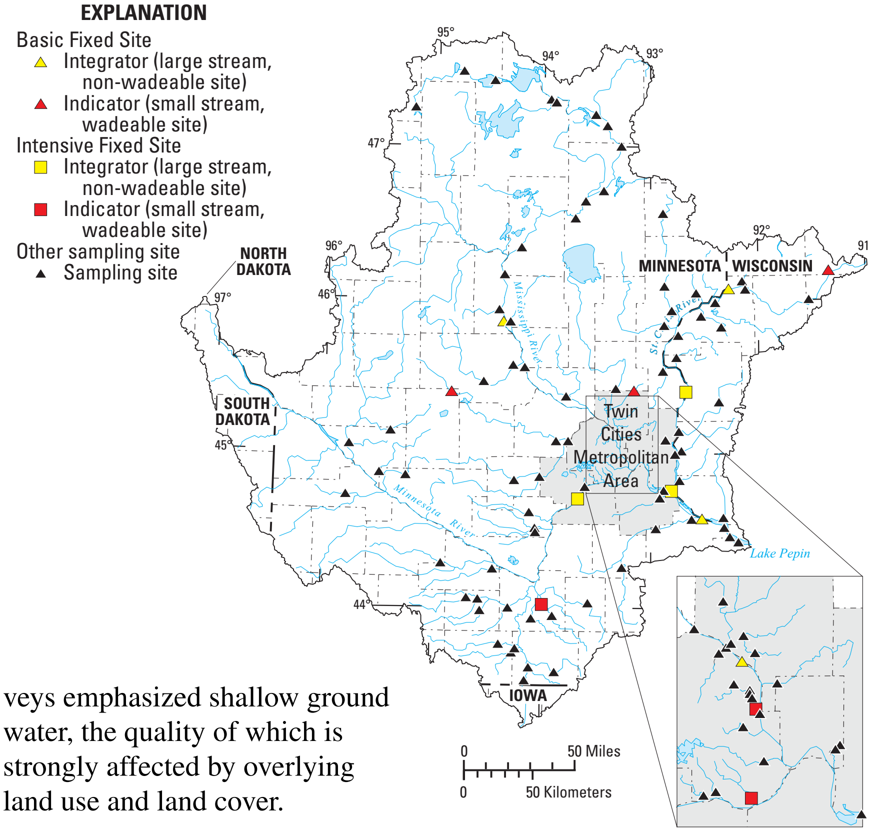
An indicator of the general quality of aquatic resources is the presence of contaminants in fish. Two contaminants, PCBs and DDE (a degradation product of DDT), were the most frequently detected OCs in fish in the Study Unit. These contaminants in fish were greatest in the Mississippi River downstream from the TCMA. PCB and DDE concentrations in common carp tissue generally were greater in the Mississippi than in the Minnesota or St. Croix Rivers, and DDE concentrations generally increased in the Mississippi River main stem from Grand Rapids, Minn., downstream to Red Wing, Minn. Although concentrations have decreased over time (Lee and Anderson, 1998), PCBs and DDE continue to be detected in fish tissue, but at relatively low concentrations of less than 1 µg/kg (micrograms per kilogram).

During 1996–98, about 4,200 water-quality aquatic-biological samples from about 240 sites were collected in the Study Unit, processed, and analyzed, using nationally consistent protocols and methods (Gilliom and others, 1995). The NAWQA design included physical, chemical, and aquatic-biological aspects of surface water and ground water for the entire Study Unit. Six sampling components were included in the sampling design. Each component involved measurements of water-quality or aquatic biological characteristics at one or more spatial or temporal scales. Three of the sampling components addressed surface water and aquatic biology, and three addressed ground water. A detailed description of the design and implementation of these water-quality studies is contained in Stark and others (1999).

Water quality in streams was assessed through water-chemistry and aquatic-biological studies. The surface-water and aquatic biology components included (1) stream sites that integrate multiple land uses and encompass large watersheds (integrator site network), (2) stream sites that indicate homogeneous and more specific land uses (indicator site network), and (3) stream sites sampled for special studies (synoptic surveys).

Ground-water quality was assessed for aquifer/land-use combinations using three sampling strategies: (1) a regional study of a selected major aquifer (subunit survey), (2) targeted-area studies in selected land uses (land-use studies), and (3) a localized study of processes occurring along shallow ground-water-flow paths (flow-path study). These studies and surveys emphasized shallow ground water, the quality of which is strongly affected by overlying land use and land cover.





## SUMMARY OF DATA COLLECTION IN THE UPPER MISSISSIPPI RIVER BASIN, 1995–98

| Study component | Purpose of component and types of data collected | Types of sites sampled | Number of sites | Sampling frequency and period |
|---|---|---|---|---|
| **Stream Chemistry** | | | | |
| Basic Fixed Sites— large rivers | Major ions, organic carbon, suspended sediment, nutrients, and streamflow were measured to describe concentrations and amounts of constituents transported in major tributaries in and from the Study Unit. | Sites on the Mississippi, Minnesota, and St. Croix Rivers draining 1,510 to 46,800 $mi^2$ that integrate the effects of agricultural, urban, and forested land use and physiographic regions. | 4 in 1996–97; 3 in 1998 | Monthly beginning in March 1996 and during selected runoff events |
| Basic Fixed Sites— indicator tributaries | Major ions, organic carbon, suspended sediment, nutrients, and streamflow were measured to determine the effects of land use (undeveloped, urban, or agricultural) and surficial geology on stream-water quality. | Streams draining 27.3 to 232 $mi^2$ of homogeneous agricultural, urban, or forested areas on unsorted or sorted surficial glacial deposits. | 3 in 1996; 2 in 1997–98 | Monthly beginning in March 1996 and during selected runoff events |
| Intensive Fixed Site— large rivers | Major ions, organic carbon, suspended sediment, nutrients, pesticides, and streamflow were determined to define short-term temporal variability. | Sites on the Mississippi, Minnesota, and St. Croix Rivers draining 6,150 to 37,000 $mi^2$. | 3 | Monthly beginning in March 1996 and during selected runoff events |
| Intensive Fixed Site— indicator tributaries | Major ions, organic carbon, suspended sediment, nutrients, pesticides, and streamflow were determined to define short-term temporal variability. Volatile organic compounds were determined at two urban sites. | Streams draining 28.2 to 130 $mi^2$ in homogeneous agricultural and urban areas. | 3 | Weekly or biweekly during April through August 1997 |
| Snowmelt synoptic survey | Nutrients and suspended sediment were determined using modified NAWQA protocols to characterize instantaneous concentrations and yields during increasing streamflow of snowmelt runoff. | Streams draining 10 to 46,800 $mi^2$. | 41 | Once in March or April 1997 |
| **Stream Ecology** | | | | |
| Bed sediment and tissue | Trace elements and hydrophobic-organic compounds in fish tissue and streambed sediment to determine occurrence and distribution of these compounds throughout the Study Unit. | Sites with drainage areas from 20 to 47,300 $mi^2$ draining a variety of land use. | Fish sampled at 25 sites, streambed sediment at 27 sites. | 1995–96 |
| Basic Fixed Sites— indicator tributaries | Fish, benthic invertebrates, phytoplankton, periphyton, and instream habitat were sampled or characterized to determine the community structure and to evaluate the association between land use and aquatic communities. | Same as for stream chemistry | 6 in 1996; 5 in 1997–98 | One each fall 1996–98 |
| Basic Fixed Sites— large rivers | Fish, benthic invertebrates, phytoplankton, periphyton, and instream habitat were sampled or characterized to determine the spatial distribution of aquatic communities and to evaluate the association between land use and aquatic communities. | Same as for stream chemistry | 7 | One each fall 1996–98 |
| Urban synoptic study | Nutrients, suspended sediment, pesticides, organic carbon, phytoplankton, and chlorophyll-*a* were analyzed. Aquatic community sampling included fish and invertebrate community sampling and instream habitat to determine how water quality and aquatic communities differ in response to changes in population density. | Streams with drainage areas ranging from 9.9 to 152 $mi^2$ draining urban areas in the Twin Cities metropolitan area. | 13 | September-October 1997 |
| Mid-continent agricultural synoptic study | Nutrients, suspended sediment, pesticides, organic carbon, phytoplankton and chlorophyll-*a* were analyzed. Aquatic community sampling included fish and invertebrate community sampling and instream habitat characterization to determine how water quality and aquatic communities differ in response to changes in local-scale riparian cover and to basin-scale soils. | Sites with drainage areas from 60 to 317 $mi^2$ draining land that was greater than 87 percent agricultural land use. | 24 | August 1997 |
| Longitudinal synoptic study | Nutrients, suspended sediment, major ions, pesticides, organic carbon, chlorophyll-*a*, and organic compounds indicative of wastewater were analyzed. Aquatic community sampling included fish and invertebrates and instream habitat to characterize the water quality and aquatic communities along the Mississippi River. | Sites with drainage areas ranging from 32 to 46,800 $mi^2$ along the Mississippi River main stem from Lake Itasca to Red Wing, Minnesota. | Sampled aquatic communities at 12 sites and water chemistry at 19 sites. | July and August of 1998 |
| **Ground-Water Chemistry** | | | | |
| Bedrock aquifer survey | Major ions, nutrients, dissolved organic carbon, trace elements, pesticides, volatile organic compounds, radon, and tritium were analyzed to describe the water quality and natural chemical patterns in unconfined and confined portions of the most frequently used bedrock aquifer in the Study Unit. | Existing domestic wells completed in the Prairie du Chien-Jordan aquifer. | 25 wells in the unconfined portion<br>25 wells in the confined portion | July-September 1996 |
| Land-use effects— surficial aquifer | Major ions, nutrients, dissolved organic carbon, pesticides, volatile organic compounds, and tritium were analyzed to determine the effects of specific land uses (urban, agricultural, and forested) on the quality of shallow ground water. | Monitoring wells completed at the water table in the surficial sand and gravel aquifer. | 30 wells in the urban study<br>29 wells in the agricultural study<br>15 wells in the forested study | June-July 1996, May-September 1998, June 1998 |
| Variations along flow— surficial aquifer | Major ions, nutrients, dissolved organic carbon, trace elements, pesticides, volatile organic compounds, radon, tritium, dissolved gases, and chlorofluorocarbons were analyzed to describe the effects of urban land use on the quality of shallow ground water along ground-water flow from an area of recharge to an area of discharge to a stream. | Monitoring and multiport wells (open to the aquifer at different depths) completed in the surficial sand and gravel aquifer. | 1 monitoring well and 6 multiport wells | July 1997, October 1997, August 1998 |

# GLOSSARY

**Alkalinity** - The alkalinity of a solution is the capacity for solutes it contains to react with and neutralize acid.

**Aquatic-life criteria** - Water-quality guidelines for protection of aquatic life. Often refers to U.S. Environmental Protection Agency water-quality criteria for protection of aquatic organisms. See also Water-quality guidelines and Water-quality criteria.

**Bioaccumulation** - The biological sequestering of a substance at a higher concentration than that at which it occurs in the surrounding environment or medium. Also, the process whereby a substance enters organisms through the gills, epithelial tissues, dietary, or other sources.

**Confined aquifer (artesian aquifer)** - An aquifer that is completely filled with water under pressure and that is overlain by material that restricts the movement of water.

**Degradation products** - Compounds resulting from transformation of an organic substance through chemical, photochemical, and/or biochemical reactions.

**Drinking-water standard or guideline** - A threshold concentration in a public drinking-water supply, designed to protect human health. As defined here, standards are U.S. Environmental Protection Agency regulations that specify the maximum contamination levels for public water systems required to protect the public welfare; guidelines have no regulatory status and are issued in an advisory capacity.

**EPT richness index** - An index based on the sum of the number of taxa in three insect orders, Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies), that are composed primarily of species considered to be relatively intolerant to environmental alterations.

**Eutrophication** - The process by which water becomes enriched with plant nutrients, most commonly phosphorus and nitrogen.

**Human health advisory** - Guidance provided by U.S. Environmental Protection Agency, State agencies or scientific organizations, in the absence of regulatory limits, to describe acceptable contaminant levels in drinking water or edible fish.

**Index of Biotic Integrity (IBI)** - An aggregated number, or index, based on several attributes or metrics of a fish community that provides an assessment of biological conditions.

**Load** - General term that refers to a material or constituent in solution, in suspension, or in transport; usually expressed in terms of mass or volume.

**Nonpoint source** - A pollution source that cannot be defined as originating from discrete points such as pipe discharge. Areas of fertilizer and pesticide applications, atmospheric deposition, manure, and natural inputs from plants and trees are types of nonpoint source pollution.

**Organochlorine compound** - Synthetic organic compounds containing chlorine. As generally used, term refers to compounds containing mostly or exclusively carbon, hydrogen, and chlorine. Examples include organochlorine insecticides, polychlorinated biphenyls, and some solvents containing chlorine.

**Point source** - A source at a discrete location such as a discharge pipe, drainage ditch, tunnel, wells, concentrated livestock operation, or floating craft.

**Polychlorinated biphenyls (PCBs)** - A mixture of chlorinated derivatives of biphenyl, marketed under the trade name Aroclor with a number designating the chlorine content (such as Aroclor 1260). PCBs were used in transformers and capacitors for insulating purposes and in gas pipeline systems as a lubricant. Further sale for new use was banned by law in 1979.

**Polycyclic aromatic hydrocarbon (PAH)** - A class of organic compounds with a fused-ring aromatic structure. PAHs result from incomplete combustion of organic carbon (including wood), municipal solid waste, and fossil fuels, as well as from natural or anthropogenic introduction of uncombusted coal and oil. PAHs include benzo(a)pyrene, fluoranthene, and pyrene.

**Tolerant species** - Those species that are adaptable to (tolerant of) human alterations to the environment and often increase in number when human alterations occur.

**Unconfined aquifer** - An aquifer whose upper surface in a water table; an aquifer containing unconfined ground water.

**Water-quality criteria** - Specific levels of water quality which, if reached, are expected to render a body of water unsuitable for its designated use. Commonly refers to water-quality criteria established by the U.S. Environmental Protection Agency. Water-quality criteria are based on specific levels of contaminants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.

**Suspended sediment** - Particles of rock, sand, soil, and organic detritus carried in suspension in the water column, in contrast to sediment that moves on or near the streambed.

**Water-quality guidelines** - Specific levels of water quality which, if reached, may adversely affect human health or aquatic life. These are nonenforceable guidelines issued by a governmental agency or other institution.

**Yield** - The mass of material or constituent transported by a river in a specified period of time divided by the drainage area of the river basin.

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# APPENDIX—WATER-QUALITY DATA FROM THE UPPER MISSISSIPPI RIVER BASIN IN A NATIONAL CONTEXT

For a complete view of Upper Mississippi River Basin data and for additional information about specific benchmarks used, visit our Web site at http://water.usgs.gov/nawqa/. Also visit the NAWQA Data Warehouse for access to NAWQA data sets at http://water.usgs.gov/nawqa/data.

This appendix is a summary of chemical concentrations and biological indicators assessed in the Upper Mississippi River Basin. Selected results for this basin are graphically compared to results from as many as 36 NAWQA Study Units investigated from 1991 to 1998 and to national water-quality benchmarks for human health, aquatic life, or fish-eating wildlife. The chemical and biological indicators shown were selected on the basis of frequent detection, detection at concentrations above a national benchmark, or regulatory or scientific importance. The graphs illustrate how conditions associated with each land use sampled in the Upper Mississippi River Basin compare to results from across the Nation, and how conditions compare among the several land uses. Graphs for chemicals show only detected concentrations and, thus, care must be taken to evaluate detection frequencies in addition to concentrations when comparing study-unit and national results. For example, acetochlor concentrations in the Upper Mississippi River Basin agricultural streams were similar to the national distribution, but the detection frequency was much higher (90 percent compared to 33 percent).

## CHEMICALS IN WATER

**Concentrations and detection frequencies, Upper Mississippi River Basin, 1995–98—**Detection sensitivity varies among chemicals and, thus, frequencies are not directly comparable among chemicals

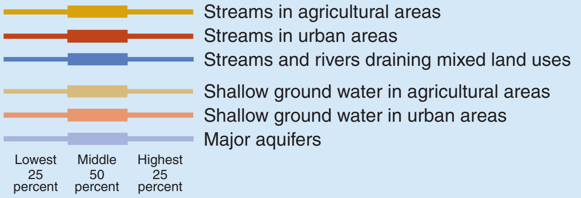
◆ Detected concentration in Study Unit

66 38 Frequencies of detection, in percent. Detection frequencies were not censored at any common reporting limit. The left-hand column is the study-unit frequency and the right-hand column is the national frequency

-- Not measured or sample size less than two

*12* Study-unit sample size. For ground water, the number of samples is equal to the number of wells sampled

**National ranges of detected concentrations, by land use, in 36 NAWQA Study Units, 1991–98—**Ranges include only samples in which a chemical was detected



**National water-quality benchmarks**

National benchmarks include standards and guidelines related to drinking-water quality, criteria for protecting the health of aquatic life, and a goal for preventing stream eutrophication due to phosphorus. Sources include the U.S. Environmental Protection Agency and the Canadian Council of Ministers of the Environment

| Drinking-water quality (applies to ground water and surface water)

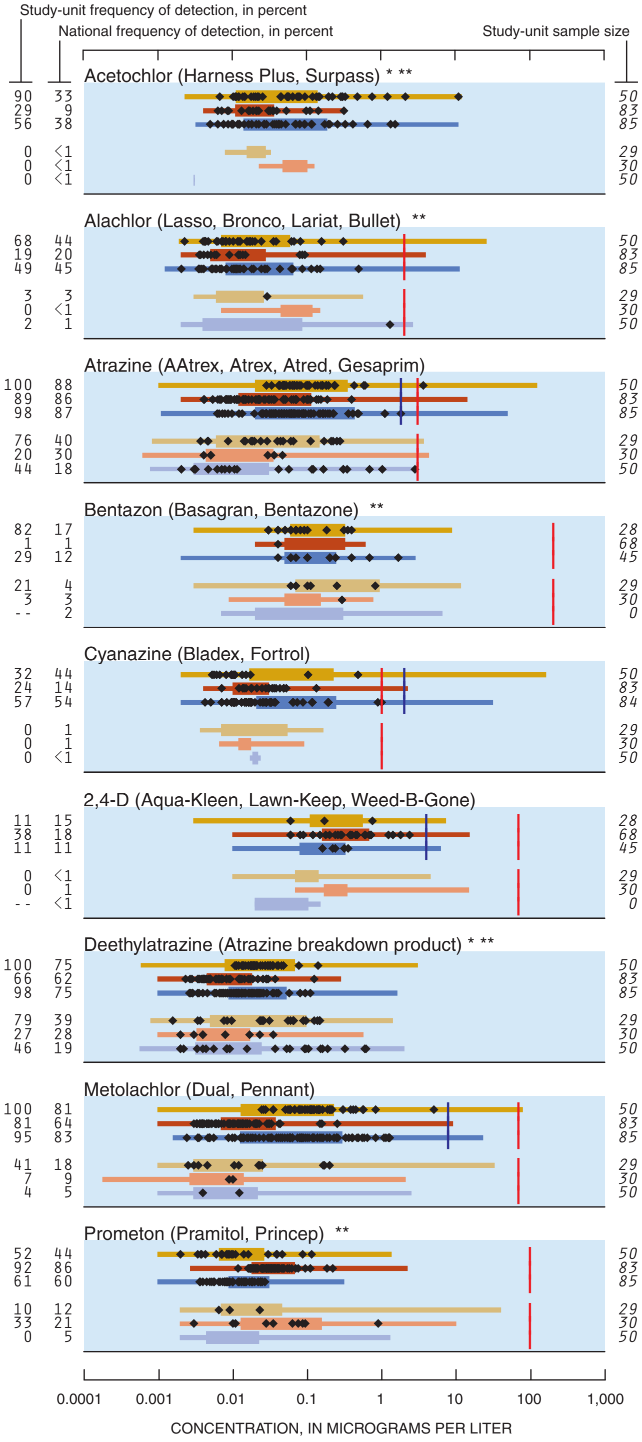
| Protection of aquatic life (applies to surface water only)

| Prevention of eutrophication in streams not flowing directly into lakes or impoundments

* No benchmark for drinking-water quality

** No benchmark for protection of aquatic life

## Pesticides in water—Herbicides



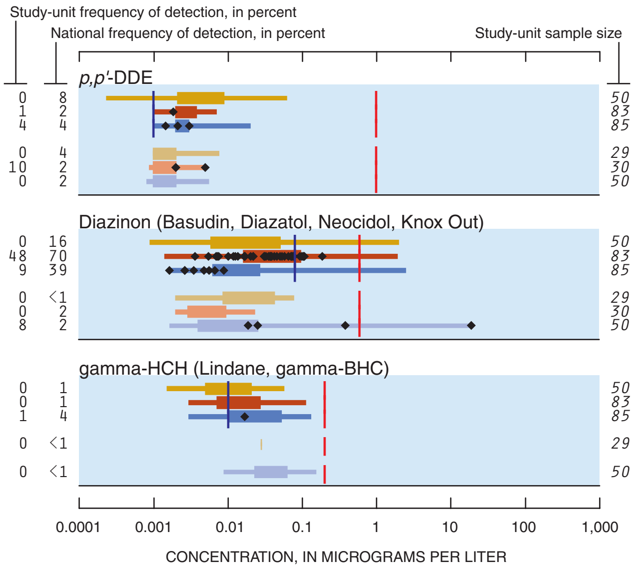
**Other herbicides detected**

Acifluorfen (Blazer, Tackle 2S) **
Benfluralin (Balan, Benefin, Bonalan) * **
Bromacil (Hyvar X, Urox B, Bromax)
Bromoxynil (Buctril, Brominal) *
DCPA (Dacthal, chlorthal-dimethyl) * **

Dicamba (Banvel, Dianat, Scotts Proturf)
2,6-Diethylaniline (Alachlor breakdown product) * **
Dinoseb (Dinosebe)
Diuron (Crisuron, Karmex, Diurex) **
EPTC (Eptam, Farmarox, Alirox) * **
Metribuzin (Lexone, Sencor)
Napropamide (Devrinol) * **
Oryzalin (Surflan, Dirimal) * **
Pendimethalin (Pre-M, Prowl, Stomp) * **
Propachlor (Ramrod, Satecid) **
Simazine (Princep, Caliber 90)
Tebuthiuron (Spike, Tebusan)
Thiobencarb (Bolero, Saturn, Benthiocarb) * **
Trifluralin (Treflan, Gowan, Tri-4, Trific)

**Herbicides not detected**
Butylate (Sutan +, Genate Plus, Butilate) **
Chloramben (Amiben, Amilon-WP, Vegiben) **
Clopyralid (Stinger, Lontrel, Transline) * **
2,4-DB (Butyrac, Butoxone, Embutox Plus, Embutone) * **
Dacthal mono-acid (Dacthal breakdown product) * **
Dichlorprop (2,4-DP, Seritox 50, Lentemul) * **
Ethalfluralin (Sonalan, Curbit) * **
Fenuron (Fenulon, Fenidim) * **
Fluometuron (Flo-Met, Cotoran) **
Linuron (Lorox, Linex, Sarclex, Linurex, Afalon) *
MCPA (Rhomene, Rhonox, Chiptox)
MCPB (Thistrol) * **
Molinate (Ordram) * **
Neburon (Neburea, Neburyl, Noruben) * **
Norflurazon (Evital, Predict, Solicam, Zorial) * **
Pebulate (Tillam, PEBC) * **
Picloram (Grazon, Tordon)
Pronamide (Kerb, Propyzamid) **
Propanil (Stam, Stampede, Wham) * **
Propham (Tuberite) **
2,4,5-T **
2,4,5-TP (Silvex, Fenoprop) **
Terbacil (Sinbar) **
Triallate (Far-Go, Avadex BW, Tri-allate) *
Triclopyr (Garlon, Grandstand, Redeem, Remedy) * **

## Pesticides in water—Insecticides

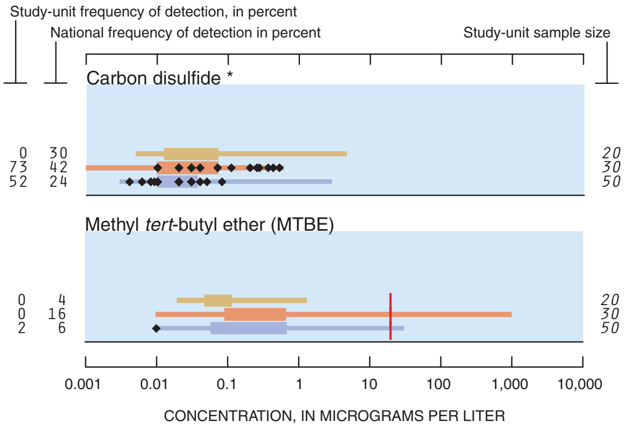


**Other insecticides detected**
Carbaryl (Carbamine, Denapon, Sevin)
Carbofuran (Furadan, Curaterr, Yaltox)
Chlorpyrifos (Brodan, Dursban, Lorsban)
Dieldrin (Panoram D-31, Octalox, Compound 497)
Ethoprop (Mocap, Ethoprophos) * **
Malathion (Malathion)
Methomyl (Lanox, Lannate, Acinate) **
Oxamyl (Vydate L, Pratt) **
Propargite (Comite, Omite, Ornamite) * **

**Insecticides not detected**
Aldicarb (Temik, Ambush, Pounce)
Aldicarb sulfone (Standak, aldoxycarb)
Aldicarb sulfoxide (Aldicarb breakdown product)
Azinphos-methyl (Guthion, Gusathion M) *
Disulfoton (Disyston, Di-Syston) **
Fonofos (Dyfonate, Capfos, Cudgel, Tycap) **
alpha-HCH (alpha-BHC, alpha-lindane) **
3-Hydroxycarbofuran (Carbofuran breakdown product) * **
Methiocarb (Slug-Geta, Grandslam, Mesurol) * **
Methyl parathion (Penncap-M, Folidol-M) **
Parathion (Roethyl-P, Alkron, Panthion, Phoskil) *
*cis*-Permethrin (Ambush, Astro, Pounce) * **
Phorate (Thimet, Granutox, Geomet, Rampart) * **
Propoxur (Baygon, Blattanex, Unden, Proprotox) * **
Terbufos (Contraven, Counter, Pilarfox) **

## Volatile organic compounds (VOCs) in ground water

*These graphs represent data from 16 Study Units, sampled from 1996 to 1998*

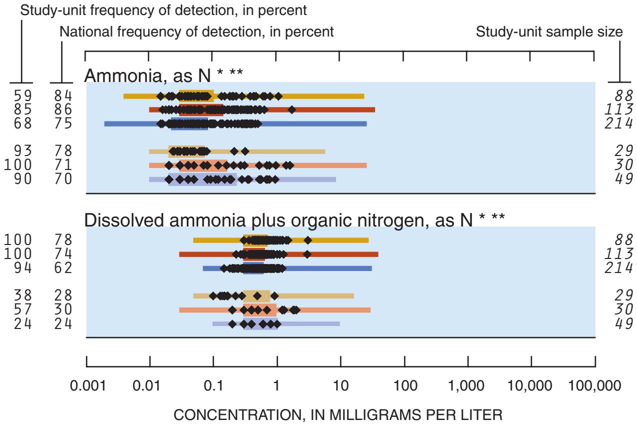


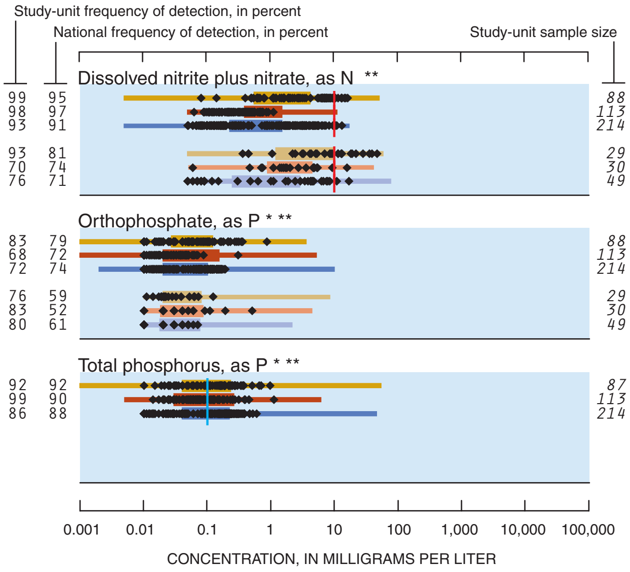
**Other VOCs detected**
Benzene
Bromodichloromethane (Dichlorobromomethane)
2-Butanone (Methyl ethyl ketone (MEK)) *
Chlorobenzene (Monochlorobenzene)
Chlorodibromomethane (Dibromochloromethane)
Chloroethane (Ethyl chloride) *
Chloromethane (Methyl chloride)
Dichlorodifluoromethane (CFC 12, Freon 12)
1,1-Dichloroethane (Ethylidene dichloride) *
*cis*-1,2-Dichloroethene ((Z)-1,2-Dichloroethene)
Dichloromethane (Methylene chloride)
Diethyl ether (Ethyl ether) *
1-4-Epoxy butane (Tetrahydrofuran, Diethylene oxide) *
Ethenylbenzene (Styrene)
Iodomethane (Methyl iodide) *
*p*-Isopropyltoluene (*p*-Cymene) *
4-Methyl-2-pentanone (Methyl isobutyl ketone (MIBK)) *
Methylbenzene (Toluene)
2-Propanone (Acetone) *
Tetrachloroethene (Perchloroethene)
1,2,3,4-Tetramethylbenzene (Prehnitene) *
Tribromomethane (Bromoform)
1,1,1-Trichloroethane (Methylchloroform)
Trichloroethene (TCE)
Trichlorofluoromethane (CFC 11, Freon 11)
Trichloromethane (Chloroform)
1,2,4-Trimethylbenzene (Pseudocumene) *

**VOCs not detected**

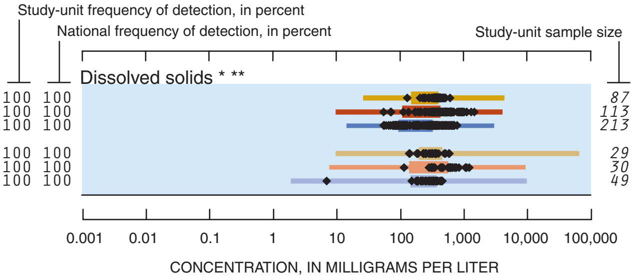
*tert*-Amylmethylether (*tert*-amyl methyl ether (TAME)) *
Bromobenzene (Phenyl bromide) *
Bromochloromethane (Methylene chlorobromide)
Bromoethene (Vinyl bromide) *
Bromomethane (Methyl bromide)
*n*-Butylbenzene (1-Phenylbutane) *
*sec*-Butylbenzene *
*tert*-Butylbenzene *
3-Chloro-1-propene (3-Chloropropene) *
1-Chloro-2-methylbenzene (*o*-Chlorotoluene)
1-Chloro-4-methylbenzene (*p*-Chlorotoluene)
Chloroethene (Vinyl chloride)
1,2-Dibromo-3-chloropropane (DBCP, Nemagon)
1,2-Dibromoethane (Ethylene dibromide, EDB)
Dibromomethane (Methylene dibromide) *
*trans*-1,4-Dichloro-2-butene ((Z)-1,4-Dichloro-2-butene) *
1,2-Dichlorobenzene (*o*-Dichlorobenzene)
1,3-Dichlorobenzene (*m*-Dichlorobenzene)
1,4-Dichlorobenzene (*p*-Dichlorobenzene)
1,2-Dichloroethane (Ethylene dichloride)
1,1-Dichloroethene (Vinylidene chloride)
*trans*-1,2-Dichloroethene ((E)-1,2-Dichlorothene)
1,2-Dichloropropane (Propylene dichloride)
2,2-Dichloropropane *
1,3-Dichloropropane (Trimethylene dichloride) *
*trans*-1,3-Dichloropropene ((E)-1,3-Dichloropropene)
*cis*-1,3-Dichloropropene ((Z)-1,3-Dichloropropene)
1,1-Dichloropropene *
Diisopropyl ether (Diisopropylether (DIPE)) *
1,2-Dimethylbenzene (*o*-Xylene)
1,3 & 1,4-Dimethylbenzene (*m*-&*p*-Xylene)
Ethyl methacrylate *
Ethyl *tert*-butyl ether (Ethyl-*t*-butyl ether (ETBE)) *
1-Ethyl-2-methylbenzene (2-Ethyltoluene) *
Ethylbenzene (Phenylethane)
Hexachlorobutadiene
1,1,1,2,2,2-Hexachloroethane (Hexachloroethane)
2-Hexanone (Methyl butyl ketone (MBK)) *
Isopropylbenzene (Cumene) *
Methyl acrylonitrile *
Methyl-2-methacrylate (Methyl methacrylate) *
Methyl-2-propenoate (Methyl acrylate) *
Naphthalene
2-Propenenitrile (Acrylonitrile)
n-Propylbenzene (Isocumene) *
1,1,2,2-Tetrachloroethane *
1,1,1,2-Tetrachloroethane
Tetrachloromethane (Carbon tetrachloride)
1,2,3,5-Tetramethylbenzene (Isodurene) *
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113) *
1,2,4-Trichlorobenzene
1,2,3-Trichlorobenzene *
1,1,2-Trichloroethane (Vinyl trichloride)
1,2,3-Trichloropropane (Allyl trichloride)
1,2,3-Trimethylbenzene (Hemimellitene) *
1,3,5-Trimethylbenzene (Mesitylene) *

## Nutrients in water

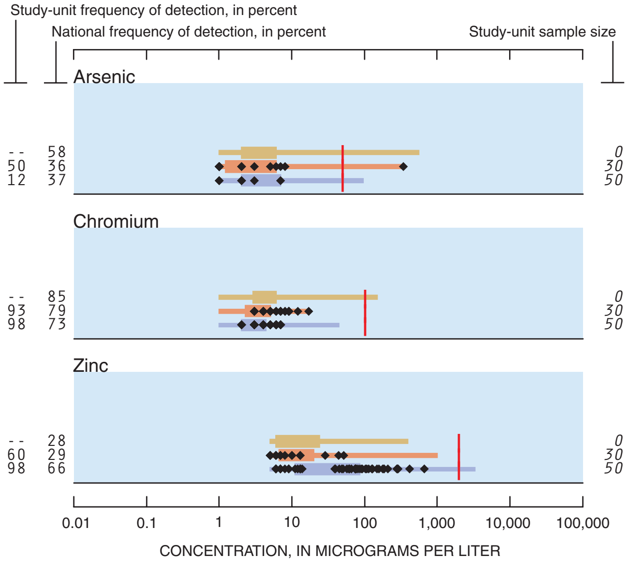


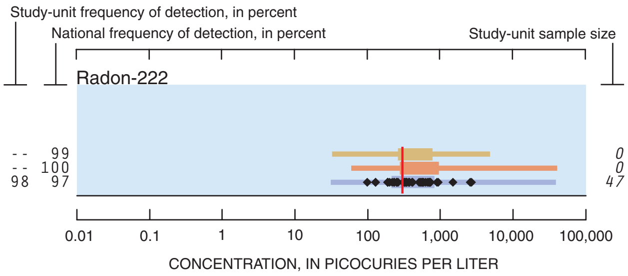


## Dissolved solids in water



## Trace elements in ground water

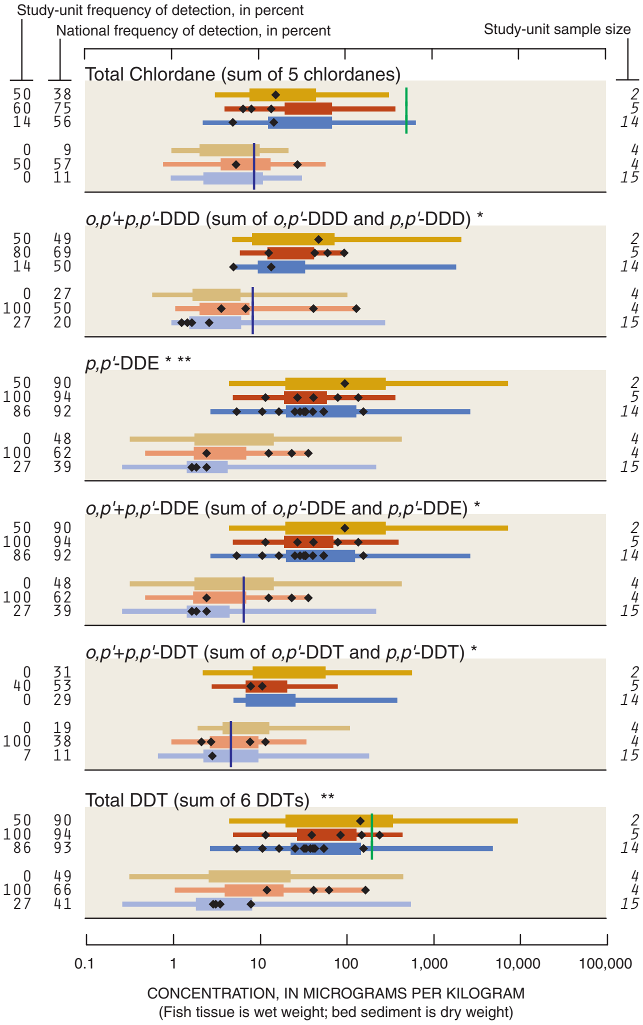




**Other trace elements detected**
Lead
Selenium
Uranium

**Trace elements not detected**
Cadmium

## Organochlorines in fish tissue (whole body) and bed sediment



## CHEMICALS IN FISH TISSUE AND BED SEDIMENT

**Concentrations and detection frequencies, Upper Mississippi River Basin, 1995–98**—Detection sensitivity varies among chemicals and, thus, frequencies are not directly comparable among chemicals. Study-unit frequencies of detection are based on small sample sizes; the applicable sample size is specified in each graph

◆ Detected concentration in Study Unit

66 38 Frequencies of detection, in percent. Detection frequencies were not censored at any common reporting limit. The left-hand column is the study-unit frequency and the right-hand column is the national frequency

-- Not measured or sample size less than two

*12* Study-unit sample size

**National ranges of concentrations detected, by land use, in 36 NAWQA Study Units, 1991–98**—Ranges include only samples in which a chemical was detected

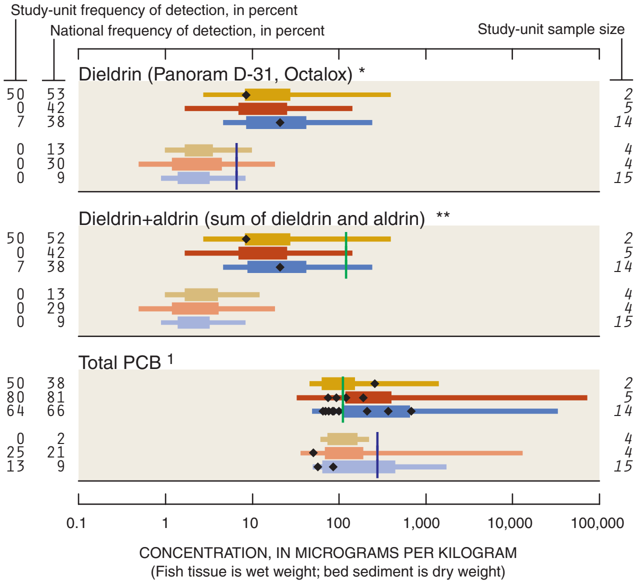
▬ Fish tissue from streams in agricultural areas
▬ Fish tissue from streams in urban areas
▬ Fish tissue from streams draining mixed land uses
▬ Sediment from streams in agricultural areas
▬ Sediment from streams in urban areas
▬ Sediment from streams draining mixed land uses

Lowest 25 percent | Middle 50 percent | Highest 25 percent

**National benchmarks for fish tissue and bed sediment**

National benchmarks include standards and guidelines related to criteria for protection of the health of fish-eating wildlife and aquatic organisms. Sources include the U.S. Environmental Protection Agency, other Federal and State agencies, and the Canadian Council of Ministers of the Environment

| Protection of fish-eating wildlife (applies to fish tissue)
| Protection of aquatic life (applies to bed sediment)
* No benchmark for protection of fish-eating wildlife
** No benchmark for protection of aquatic life



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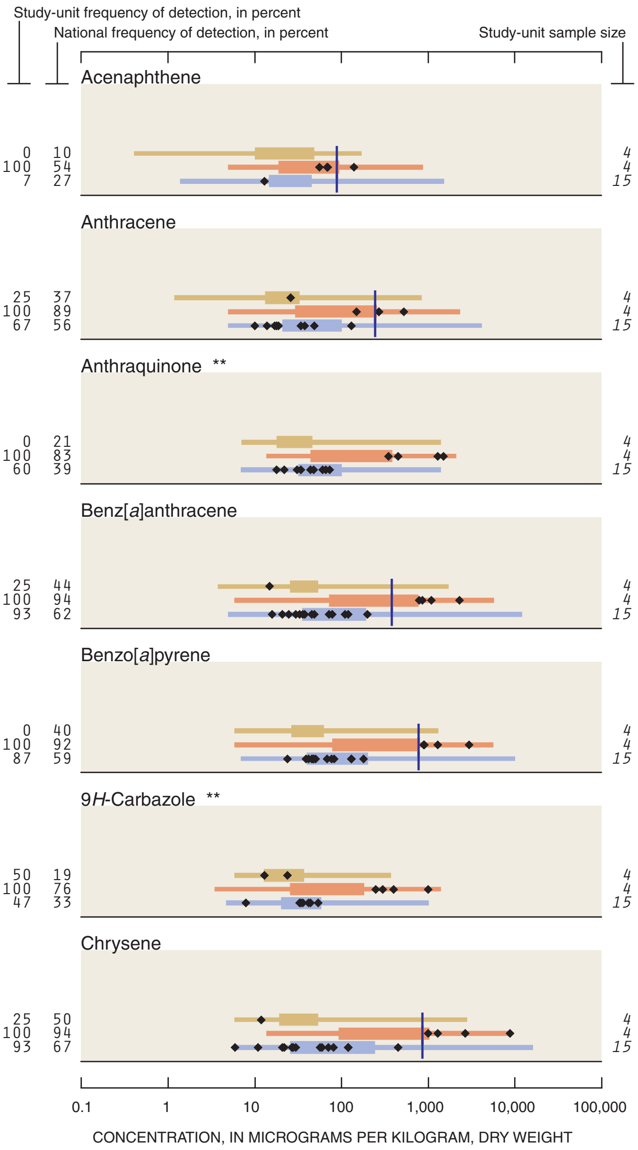
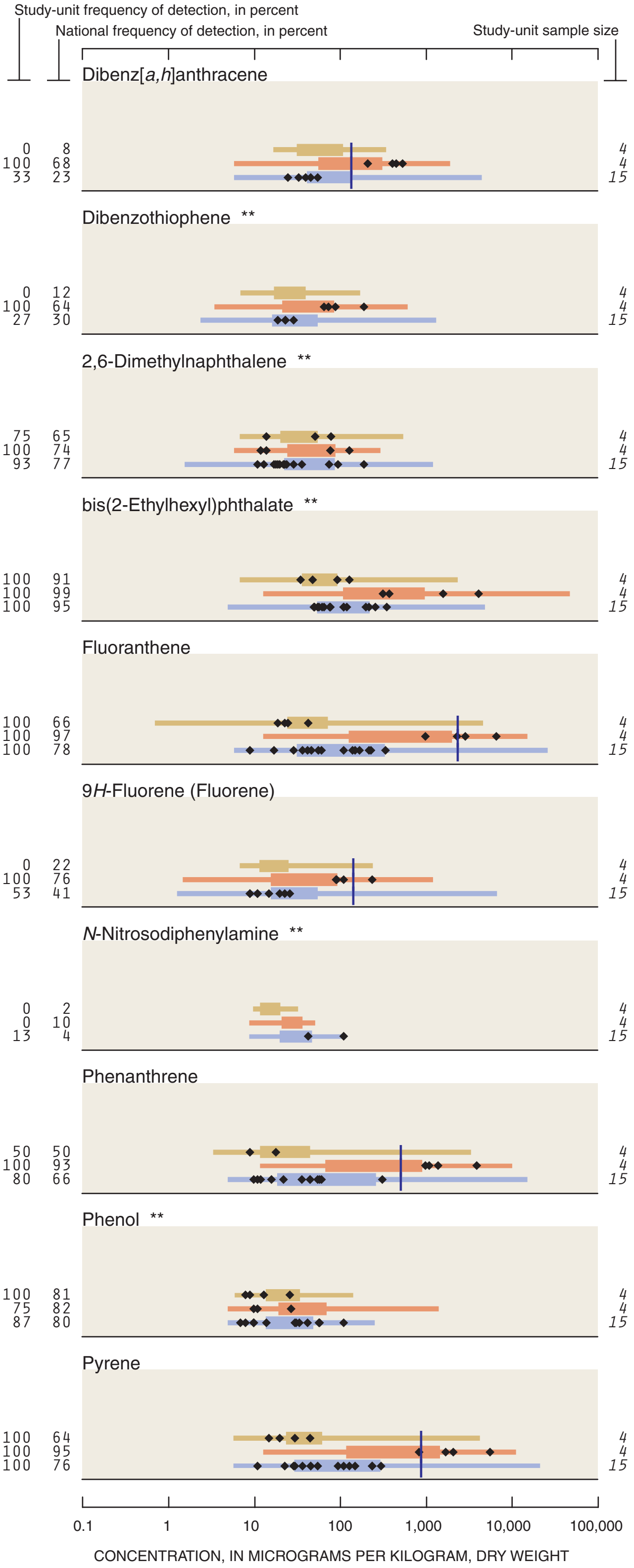
[1] The national detection frequencies for total PCB in sediment are biased low because about 30 percent of samples nationally had elevated detection levels compared to this Study Unit. See http://water.usgs.gov/nawqa/ for additional information.

**Other organochlorines detected**
Endosulfan I (alpha-Endosulfan, Thiodan) * **

**Organochlorines not detected**
Chloroneb (Chloronebe, Demosan) * **
DCPA (Dacthal, chlorthal-dimethyl) * **
Endrin (Endrine)
gamma-HCH (Lindane, gamma-BHC, Gammexane) *
Total-HCH (sum of alpha-HCH, beta-HCH, gamma-HCH, and delta-HCH) **
Heptachlor epoxide (Heptachlor breakdown product) *
Heptachlor+heptachlor epoxide (sum of heptachlor and heptachlor epoxide) **
Hexachlorobenzene (HCB) **
Isodrin (Isodrine, Compound 711) * **
*p,p'*-Methoxychlor (Marlate, methoxychlore) * **
*o,p'*-Methoxychlor * **
Mirex (Dechlorane) **
Pentachloroanisole (PCA) * **
*cis*-Permethrin (Ambush, Astro, Pounce) * **
*trans*-Permethrin (Ambush, Astro, Pounce) * **
Toxaphene (Camphechlor, Hercules 3956) * **

## Semivolatile organic compounds (SVOCs) in bed sediment



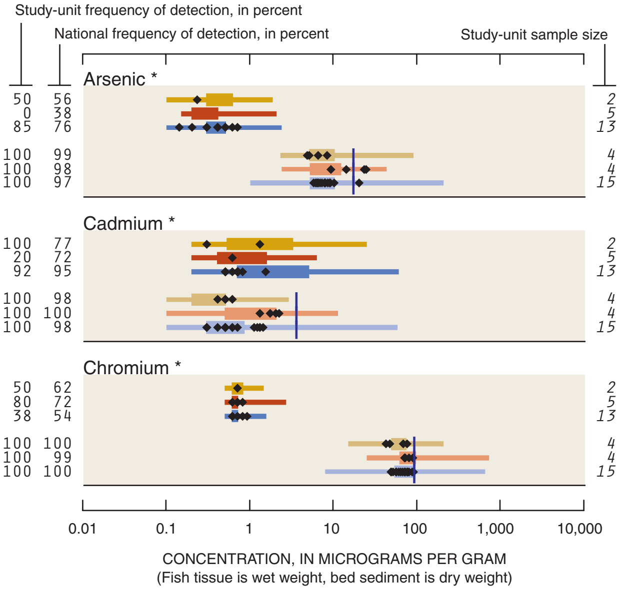


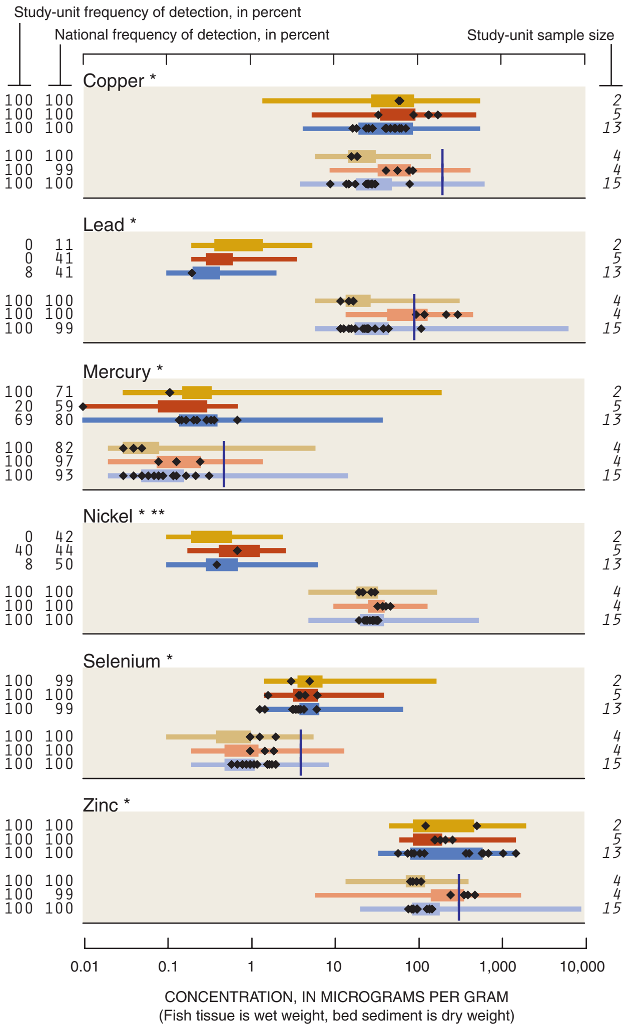
**Other SVOCs detected**
Acenaphthylene
Acridine **
Azobenzene **
Benzo[*b*]fluoranthene **

Benzo[*ghi*]perylene **
Benzo[*k*]fluoranthene **
2,2-Biquinoline **
Butylbenzylphthalate **
4-Chloro-3-methylphenol **
*p*-Cresol **
Di-*n*-butylphthalate **
Di-*n*-octylphthalate **
Diethylphthalate **
1,6-Dimethylnaphthalene **
Dimethylphthalate **
2-Ethylnaphthalene **
Indeno[1,2,3-*cd*]pyrene **
Isoquinoline **
1-Methyl-9*H*-fluorene **
2-Methylanthracene **
4,5-Methylenephenanthrene **
1-Methylphenanthrene **
1-Methylpyrene **
Naphthalene
Phenanthridine **

**SVOCs not detected**
C8-Alkylphenol **
Benzo[*c*]cinnoline **
4-Bromophenyl-phenylether **
bis(2-Chloroethoxy)methane **
2-Chloronaphthalene **
2-Chlorophenol **
4-Chlorophenyl-phenylether **
1,2-Dichlorobenzene (*o*-Dichlorobenzene) **
1,3-Dichlorobenzene (*m*-Dichlorobenzene) **
1,4-Dichlorobenzene (*p*-Dichlorobenzene) **
1,2-Dimethylnaphthalene **
3,5-Dimethylphenol **
2,4-Dinitrotoluene **
Isophorone **
Nitrobenzene **
*N*-Nitrosodi-*n*-propylamine **
Pentachloronitrobenzene **
Quinoline **
1,2,4-Trichlorobenzene **
2,3,6-Trimethylnaphthalene **

## Trace elements in fish tissue (livers) and bed sediment





## BIOLOGICAL INDICATORS

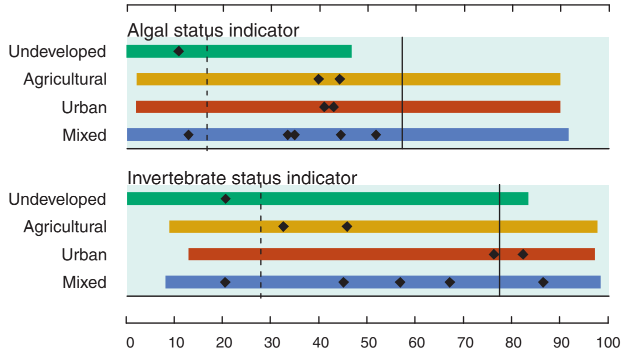
Higher national scores suggest habitat disturbance, water-quality degradation, or naturally harsh conditions. The status of algae, invertebrates (insects, worms, and clams), and fish provides a record of water-quality and stream conditions that water-chemistry indicators may not reveal. **Algal status** focuses on the changes in the percentage of certain algae in response to increasing siltation, and it often correlates with higher nutrient concentrations in some regions. **Invertebrate status** averages 11 metrics that summarize changes in richness, tolerance, trophic conditions, and dominance associated with water-quality degradation. **Fish status** sums the scores of four fish metrics (percent tolerant, omnivorous, non-native individuals, and percent individuals with external anomalies) that increase in association with water-quality degradation

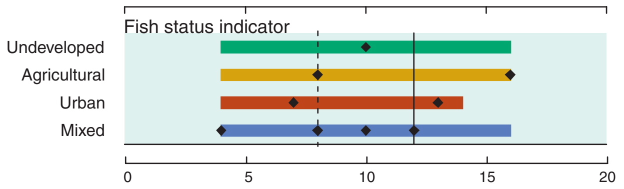
**Biological indicator value, Upper Mississippi River Basin, by land use, 1995–98**

◆ Biological status assessed at a site

**National ranges of biological indicators, in 16 NAWQA Study Units, 1994–98**

🟩 Streams in undeveloped areas
🟨 Streams in agricultural areas
🟥 Streams in urban areas
🟦 Streams in mixed-land-use areas
—— 75th percentile
- - - 25th percentile





# A COORDINATED EFFORT

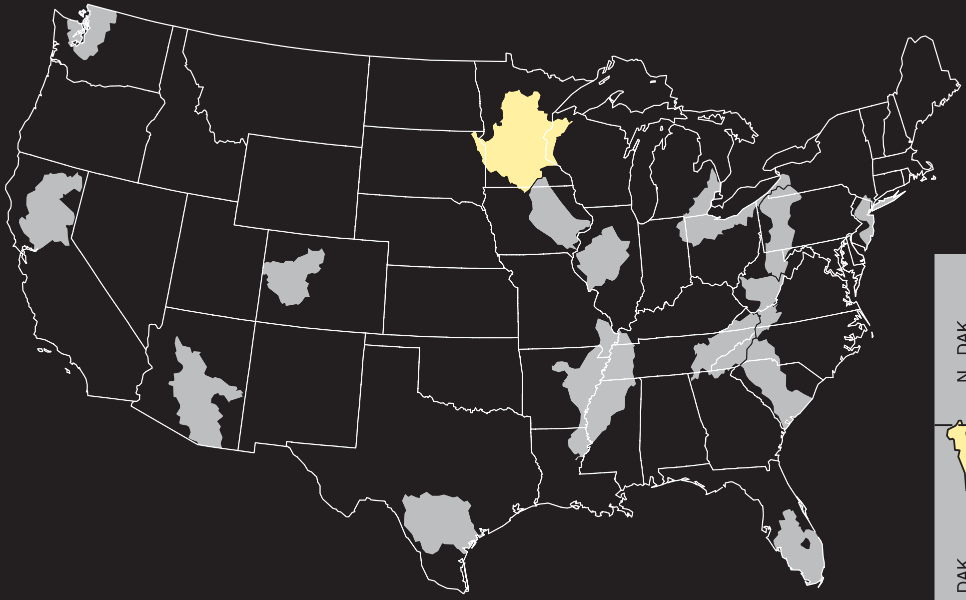
**An integral part of the NAWQA Program is cooperation among agencies and organizations. We with to thank the following agencies and organizations who contributed to this report or participated in the Study Unit liaison committee.**

*American Water Works Association*
*Anoka County, Minnesota*
*Bell Museum of Natural History*
*Cedar Creek Natural History Area*
*Dakota County Planning Department*
*Elm Creek Watershed District*
*Friends of the Mississippi River*
*Hennepin Conservation District*
*Izaak Walton League*
*Legislative Commission on Minnesota Resources*
*McKnight Foundation*
*Metropolitan Council*
*Minneapolis Water Works*
*Minnesota Board of Water and Soil Resources*
*Minnesota Department of Agriculture*
*Minnesota Department of Health*
*Minnesota Department of Natural Resources*
*Minnesota Extension Service*
*Minnesota Geological Survey*
*Minnesota Pollution Control Agency*
*Minnesota State Planning Agency*
*Minnesota-Wisconsin Boundary Area Commission*
*Mississippi River Headwaters Board*
*Montgomery Watson*
*National Park Service*
*National Weather Service*
*Northern States Power Company*
*Rivers Council of Minnesota*
*St. Cloud State University*
*St. Paul Water Utility*
*Science Museum of Minnesota*
*Shingle Creek Watershed District*
*Sierra Club*
*University of Minnesota*
*University of Minnesota Water Resources Center*
*Upper Mississippi River Basin Association*
*U.S. Army Corps of Engineers*
*U.S. Department of Agriculture*
*U.S. Environmental Protection Agency*
*U.S. Fish and Wildlife Service*
*Wisconsin Department of Natural Resources*

Special thanks to U.S. Geological Survey employees for their contributions: Wallace Larson, Todd Schmitt, and Joshua Larson for data collection, and Ginger Amos, and Robert Borgstede for production of the report.

# NAWQA

## National Water-Quality Assessment (NAWQA) Program
## Upper Mississippi River Basin



Stark and others—Water Quality in the Upper Mississippi River Basin
U.S. Geological Survey Circular 1211

ISBN 0-607-95416-7
9 780607 954166