Water-Quality Assessment of Part of the Upper Mississippi River Basin, Minnesota and Wisconsin—Review of Selected Literature

By William J. Andrews, James D. Fallon, Sharon E. Kroening, Kathy E. Lee, and James R. Stark

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Foreword

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

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

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

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

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

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 60 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 60 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

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

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

Robert M. Hirsch
Chief Hydrologist

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Conversion Factors and Abbreviations

Multiply	By	To obtain
square mile (mi^2)	2.590	square kilometer

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

MDH—Minnesota Department of Health

MPCA—Minnesota Pollution Control Agency

MRAP—Minnesota River Assessment Program

NASQAN—National Stream Water Quality Accounting Network

NAWQA—National Water-Quality Assessment

TCMA—Twin Cities metropolitan area

UMIS—Upper Mississippi River Basin

USGS—U.S. Geological Survey

VOC's—Volatile organic compounds

Use of trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

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Abstract

The U.S. Geological Survey began full-scale implementation of the National Water-Quality Assessment (NAWQA) Program in 1991. The purposes of NAWQA are to describe the status and trends in the quality of the Nation's water resources and aquatic ecosystems, and to determine factors affecting water quality at local, regional, and national scales. The Upper Mississippi River (UMIS) NAWQA study unit, which includes all of the surface drainage to the Mississippi River Basin upstream from Lake Pepin, encompasses 47,000 mi^2. The study characterizes the geographic and seasonal distribution of water quality and aquatic biota in relation to anthropogenic activities and natural features. The initial phase of the UMIS study, during 1994-99, is focused on an area in Minnesota and Wisconsin that includes the seven-county Twin Cities (Minneapolis and St. Paul) metropolitan area. This report summarizes selected sources of information that are being used to aid in understanding water-quality issues and processes that form the basis of the sampling design for the study. This literature review includes sources of information about surface- and ground-water hydrology, water quality, and aquatic biology and ecology.

Introduction

The USGS began full scale implementation of the NAWQA Program in 1991. The purposes of the NAWQA Program are to describe the status and trends in the quality of the Nation's water resources and aquatic ecosystems, and to determine factors affecting water quality. Study-unit investigations are significant components of the program. Study units are made up of hydrologic systems that include parts of most major river basins and aquifer systems in the United States.

The UMIS NAWQA study unit includes all of the surface drainage to the Mississippi River Basin upstream from Lake Pepin and encompasses 47,000 mi^2 (fig. 1). The Upper Mississippi River Basin was selected as a study unit because water quality of the Mississippi River, the largest river in the Nation, is of national concern.

The purposes of the UMIS NAWQA study are to describe the status and trends in quality of water resources and to provide an understanding of factors affecting water quality and ecosystem status within the study unit. During the initial phase of the study (1994-99), emphasis is focused on a 19,500 mi^2 area in Minnesota and Wisconsin that includes the seven-county Twin Cities (Minneapolis and St. Paul) metropolitan area. The study area includes the UMIS drainage from Lake Pepin upstream to include all of the St. Croix River Basin and to points on the Minnesota (Jordan, Minnesota) and Mississippi (Royalton, Minnesota) Rivers where long-term water-quality data are available (fig. 1). During the initial phase of the study, the focus is on the most prominent water-quality and ecosystem issues, principally the effects of the TCMA on water quality and aquatic ecosystems. The study characterizes the geographic and seasonal variations of water quality, aquatic biota, and aquatic-habitat conditions in relation to anthropogenic activities and natural features. Pesticides, nutrients, volatile-organic chemicals, and biological conditions are of specific interest to NAWQA from a national perspective (Gilliom and others, 1995).

This report describes selected published information on the surface- and ground-water hydrology, water quality, and aquatic biology and ecology of the UMIS study unit. This report summarizes important sources of information that are being used to aid in understanding water-quality issues and processes that form the basis of

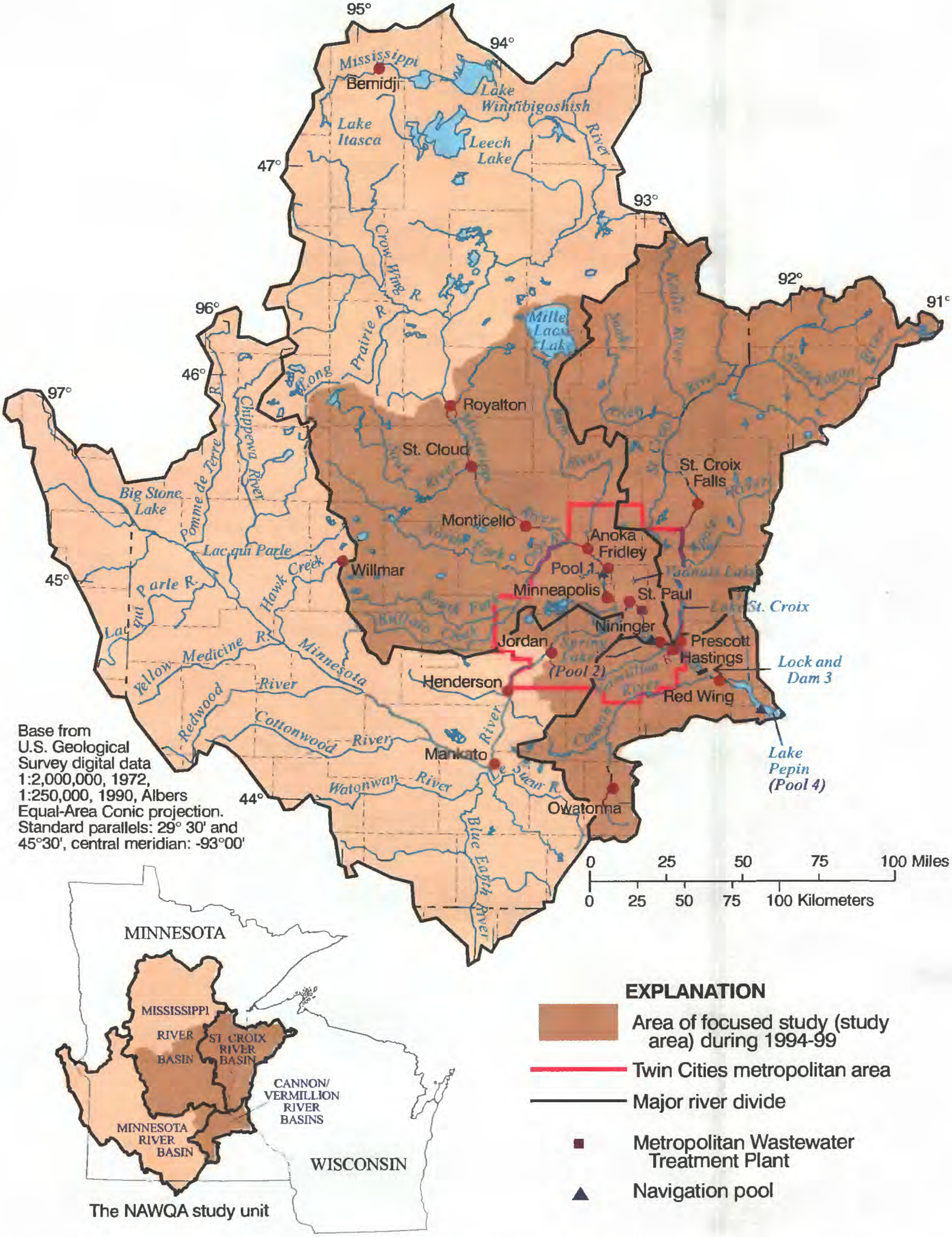

Figure 1.--Location of the Upper Mississippi River Basin NAWQA study unit, focused study area, hydrography, selected towns, and major cities.

the sampling design for the study. Water quality in the study unit is affected by natural and anthropogenic factors. Natural factors include climate, physiography, geology, soils, topography, vegetation and aquatic biology. Anthropogenic factors include hydrologic modification, point- and nonpoint-source contaminant discharges, and changes to land use and to land cover.

Water-quality issues of local importance, and important to the program at a national level, have been defined by the study's liaison committee composed of representatives from Federal, state, and local agencies, private industry, and by NAWQA Program leadership. These issues have guided the literature review. Important sources of information include the Metropolitan Council Environmental Services, Minnesota Department of Agriculture, Minnesota Department of Health, Minnesota Department of Natural Resources, Minnesota Geological Survey, Minnesota Pollution Control Agency, University of Minnesota, U.S. Geological Survey, Wisconsin Department of Natural Resources, and Wisconsin Geological Survey. The list of publications completed for this effort consists of approximately 2,000 citations. Literature data bases searched include Aquatic Sciences and Fisheries Abstracts, Biosis, Compendex Plus, Dissertation Abstracts, Enviroline, Georef, Pollution Abstracts, and Water Resources Abstracts. The list of citations is available at the UMIS Home Page on the World Wide Web at: "http://wwwmn.cr.usgs.gov/umis/index.html".

Surface Water

General descriptions of surface-water hydrology of the Upper Mississippi River Basin are presented by Gunard and others (1986) for Minnesota and by Gebert (1986) for Wisconsin. The USGS has published a series of hydrologic atlases summarizing the water resources of watersheds in the Minnesota, Mississippi, and St. Croix River Basins. These hydrologic atlases include information on climate, streamflow, physical features, and surface- and ground-water resources. In the Minnesota River Basin, hydrologic atlases have been published for Big Stone Lake Watershed (Cotter and others, 1966), Blue Earth River (Anderson and others, 1974a), Chippewa River (Cotter and others, 1968), Cottonwood River (Broussard and others, 1973), Minnesota River and Hawk Creek (Van Voast and others, 1972), Lac qui Parle River (Cotter and Bidwell, 1968), Lower Minnesota River (Anderson and others, 1974b), Pomme de Terre River (Cotter and Bidwell, 1966), Redwood River (Van Voast and others, 1970), and Yellow Medicine River (Novitzki and others, 1969). The locations of cities and towns, rivers, lakes, and reservoirs cited in this section are shown in figure 1. Hydrologic atlases of basins in the Mississippi River Basin include the Cannon River (Anderson and others, 1974), Crow Wing River (Lindholm and others, 1972), Mississippi River headwaters (Oakes and Bidwell, 1968), Mississippi and Sauk Rivers (Helgesen and others, 1975), and Rum River (Ericson and others, 1974). In the St. Croix River Basin, published hydrologic atlases include the Kettle River (Helgesen and others, 1973), Snake River (Lindholm and others, 1974a), the Wisconsin portion of the St. Croix River (Young and Hindall, 1973), and the Minnesota portion of the Lower St. Croix River (Lindholm and others, 1974b).

Physical characteristics including drainage area, stream order, channel length and slope, lake area, and storage area have been published for subbasins of the Minnesota River in U.S. Geological Survey Open-File Reports for the Blue Earth (Lorenz and Payne, 1992), Chippewa (Sanocki and Kumrie, 1994), Cottonwood (Sanocki, 1995b), Lac qui Parle (Lorenz and others, 1994), Le Sueur (Lorenz and Payne, 1991a), Pomme de Terre (Lorenz and Payne, 1994), Redwood (Lorenz and Payne, 1989), and Watonwan Rivers (Lorenz and Payne, 1991b), as well as western drainages of the Upper Minnesota River (Sanocki, 1995a).

Most interpretive literature related to surface-water hydrology of the Upper Mississippi River Basin is related to floods, low flow, or water availability. Floods of historical significance in Minnesota and Wisconsin are summarized by Carlson (1991) and Krug and Simon (1991). The 1993 floods in the Mississippi River Basin are summarized in a series of reports that include analysis of precipitation (Wahl and others, 1993) and flood discharges (Parrett and others, 1993; Southard, 1993). Parret and others (1993) describe flood discharges in five tributaries to the Minnesota River which exceeded peak flows for their respective periods of record. Southard (1993) presented calculations showing that discharge in the Mississippi River at St. Paul during a 27-day flooding period was more than twice the average annual runoff for the period of record. Several reports document flood-prone areas (Carlson, 1971; Guetzkow and Carlson, 1973; Carlson and Guetzkow, 1980) along the Mississippi, Minnesota, and St. Croix Rivers, and changes in flood-prone areas due to land use and navigation effects along the Mississippi River (Olson and Meyer, 1976).

Low streamflow conditions have been studied extensively, especially along the Mississippi River through the Twin Cities. The drought of 1988 prompted several investigations. The Minnesota Department of

Natural Resources (1989) summarized climatic conditions that caused the drought, the effects on streamflow, lake levels, and regulatory activities. The Metropolitan Council (1992) presented a plan for the TCMA water supply. The report focuses on water use, availability, quality, and water-management recommendations in the TCMA. Schoenberg (1989) estimated that the amount of monthly mean flow of the Mississippi River at Prescott, Wisconsin, that was supplied by ground-water discharge varied from 15 percent during a typical wet year to 25 percent during a dry year.

The U.S. Army Corps of Engineers (1990) presented a water-control plan to guide discharge strategy for six headwater reservoirs used to sustain streamflow of the Mississippi River. Norvitch and others (1973) summarized water resources of the TCMA that included a surface-water budget as well as seasonal, long-term and low-flow analyses of streamflow.

Other interpretive studies focused on the effects of urban land use on streamflow and water quality (Ayers and others, 1985; Arntson and Lorenz, 1987). Ayers and others (1985) found total storm rainfall to be the most significant factor controlling the runoff and nutrient and sediment loads of 11 urban and rural watersheds in the TCMA. Brown (1985a) concluded that the amount of precipitation was the main factor affecting the quantity of runoff in selected TCMA watersheds lacking wetlands. Brown (1987) found that wetland channelization substantially decreased the volume of surface storage of runoff and nutrient and sediment load retention in the wetlands, and that erosion of the channelized wetlands was a major source of nutrient and sediment loading.

Several studies have investigated the interaction of lakes and ground water. Lake-level fluctuations were found to be controlled by ground-water discharge and leakage from lakes to ground water into and from the lakes (Brown, 1985b). Ruhl (1994) described net discharge of ground water into and out of Vadnais Lake, north of St. Paul, Minnesota (fig. 1) and found it to be small when compared to surface-water inflow and outflow. Ruhl concluded that seepage from the lake to ground water could enrich phosphorus concentrations in ground water.

Several reports have summarized water quality in streams of the Upper Mississippi River Basin. Have (1991) described spatial and temporal variability in stream-water quality, based on information collected by the USGS-NASQAN Program, for the Mississippi River and its tributaries from Royalton to Hastings, Minnesota. Selected constituent concentrations, including physical parameters, nutrients, major ions, and trace metals were found to vary significantly among streams. The quality of water in the Mississippi River, downstream from the confluences of the Minnesota and St. Croix Rivers, was also shown to have been affected by discharge from the Minnesota River and by effluent discharge from the Metropolitan Wastewater Treatment Plant, downstream of St. Paul, Minnesota.

The Metropolitan Waste Control Commission (1993a) conducted a study of phosphorus in the Mississippi River from Anoka, Minnesota to the downstream part of Lake Pepin during 1990-92. The study evaluated phosphorus loadings from the Metropolitan Wastewater Treatment Plant and from other sources on the water quality of Spring Lake and Lake Pepin. Results included a summary (1976-91) of the water quality of the Mississippi River and its tributaries from Anoka, Minnesota to Lock and Dam 3 at Red Wing, Minnesota (Metropolitan Waste Control Commission, 1993b); a description of the relative contributions of point and nonpoint sources of phosphorus loadings to the Mississippi River (Metropolitan Waste Control Commission, 1993c); a summary of river-bed sediment and its potential contribution to water-column phosphorus concentrations in the Mississippi River and Lake Pepin (Metropolitan Waste Control Commission, 1993d); and results of simulating proposed phosphorus reductions on the water quality of Spring Lake and Lake Pepin (EnviroTech Associates, Inc., 1993a; EnviroTech Associates, Inc., 1993b; Minnesota Pollution Control Agency, 1993c).

Substantial loadings of nutrients, organic compounds, and trace metals enter the Upper Mississippi River at Pool 2, which receives treated effluents from the TCMA and inflow from the Minnesota River (Boyer, 1984; Metropolitan Waste Control Commission, 1993c and 1993d; Steingraeber and Wiener, 1995). The concentrations of polychlorinated biphenyls and trace metals in river sediment decreased downstream from the TCMA (Bailey and Rada, 1984; Beauvais and others, 1995; Dukerschein and others, 1992; Steingraeber and others, 1994; Wiener and others, 1984). Cadmium concentration in sediment downstream from Pool 2 exceeded 2.0 micrograms per gram (Beauvais and others, 1995).

The depletion of oxygen in the Mississippi River downstream from the TCMA, as related to the discharge of sewage into the river and the adverse effect on water quality downstream from Pool 4 is discussed by Wiebe (1927) and Fremling (1964; 1989). In the early 1980's, dissolved oxygen concentrations in this reach of the river increased in response to improved treatment of wastewater from the TCMA (Fremling, 1989; Johnson and Aasen, 1989; Fremling and Johnson, 1990).

Maschwitz (1984) analyzed ammonia-nitrogen concentrations in the Mississippi River within the TCMA to determine an effluent limitation for the Metropolitan Wastewater Treatment Plant. The loading of ammonia to the Mississippi River from the Metropolitan Wastewater Treatment Plant was about equal to the load upstream of the plant during mean summer flow. The results of the study showed total and un-ionized ammonia concentrations in the Mississippi River generally increased downstream from the treatment-plant outfall. Total ammonia concentrations generally decreased in Spring Lake because of algal uptake of ammonia. In contrast, un-ionized ammonia concentrations remained fairly constant through Spring Lake. During extreme low-flow conditions, large concentrations of un-ionized ammonia were measured in Spring Lake and were attributed to greater algal activity (Maschwitz, 1984).

The MRAP, a cooperative study by Federal, State, and local agencies and coordinated by the MPCA, was conducted during 1989-93 to determine sources of point and nonpoint nutrient and sediment loading to the Minnesota River and the effects of this loading on water quality and river ecology. Results were compiled in five volumes, each containing several individual reports (Minnesota Pollution Control Agency, 1994a-1994e). This work included results from monitoring the Minnesota River and its tributaries from Lac qui Parle Reservoir to Henderson Reservoir, Minnesota (Payne, 1991; 1994), and results from monitoring the Lower Minnesota River and its tributaries from Jordan, Minnesota to the confluence with the Mississippi River (Metropolitan Waste Control Commission, 1994b).

Graczyk (1986) described the stream-water quality in the St. Croix National Scenic Riverway. Troelstrup and others (1993b) described water quality in the Lower St. Croix River from St. Croix Falls, Wisconsin, to the confluence with the Mississippi River.

Ground Water

The geology and hydrogeology of the study unit have been the subject of several comprehensive reports. Olcott (1992) summarized the ground-water resources of Iowa, Michigan, Minnesota, and Wisconsin. Young (1992a: 1992b), Mandle and Konitz (1992), and Siegel (1989) presented results of a study of the Cambrian-Ordovician aquifer system in the northern midwest as part of the USGS Regional Aquifer System Analysis Program. Sims and Morey (1972) presented a series of papers describing the geologic setting and origins of unconsolidated deposits (fig. 2) and rocks (fig. 3) of Precambrian-Cenozoic age in Minnesota. Generalized hydrogeology and the quality of water in the major aquifers in Minnesota were summarized in USGS reports by Anderson (1986); Lindholm and Norvitch (1976); Ruhl (1987); Ruhl and others (1982); Ruhl and Wolf (1983, 1984); and Woodward and Anderson (1986). Delin and Woodward (1984) and Woodward (1986) described the hydrogeologic setting, hydraulic properties, and potentiometric surfaces of regional aquifers in the Hollandale Embayment (fig. 3) of southeastern Minnesota. Norvitch and others (1973) described the general hydrologic framework of the TCMA. Schoenberg (1990) described the geologic and hydrologic setting of the TCMA and the development and application of a model to simulate ground-water flow in bedrock aquifers in the TCMA during 1970-79. Hult and Schoenberg (1984) presented an analysis of the ground-water hydrology of a part of the western TCMA as part of an evaluation of ground-water contamination.

Maps of potentiometric altitudes have been constructed for many of the principal aquifers in the TCMA. Potentiometric maps have been prepared by Andrews and others (1995), Delin and Woodward (1984), the Minnesota Department of Natural Resources, Division of Waters (1961), Reeder (1966), and Schoenberg (1984) for the Prairie du Chien-Jordan and Mt. Simon-Hinckley aquifers; by Norvitch and others (1973) for the St. Peter, Prairie du Chien-Jordan, and Mt. Simon-Hinckley aquifers; and by Larson-Higdem and others (1975) and Palen and others (1993) for the unconsolidated aquifers of glacial and alluvial origins. Kanivetsky (1977) estimated available ground-water resources in Minnesota. The Minnesota Geological Survey has published a series of detailed hydrogeologic county atlases which include maps of potentiometric altitudes and well yields for major aquifers in parts of the TCMA (Balaban, 1989; Balaban and Hobbs, 1990; Balaban and McSwiggen, 1982; Meyer and Swanson, 1992; Swanson and Meyer, 1990).

The quality of ground water in the study unit is generally satisfactory for most domestic, public, industrial, and irrigation uses (Kanivetsky, 1986). Most ground water is classified, on the basis of predominant ions, as a calcium-magnesium-bicarbonate type, with less than 1,000 mg/L dissolved solids (Adolphson and others, 1981). Statewide, concentrations of iron and manganese commonly exceed 300 µg/L and 50 µg/L, respectively, which are the maximum recommended

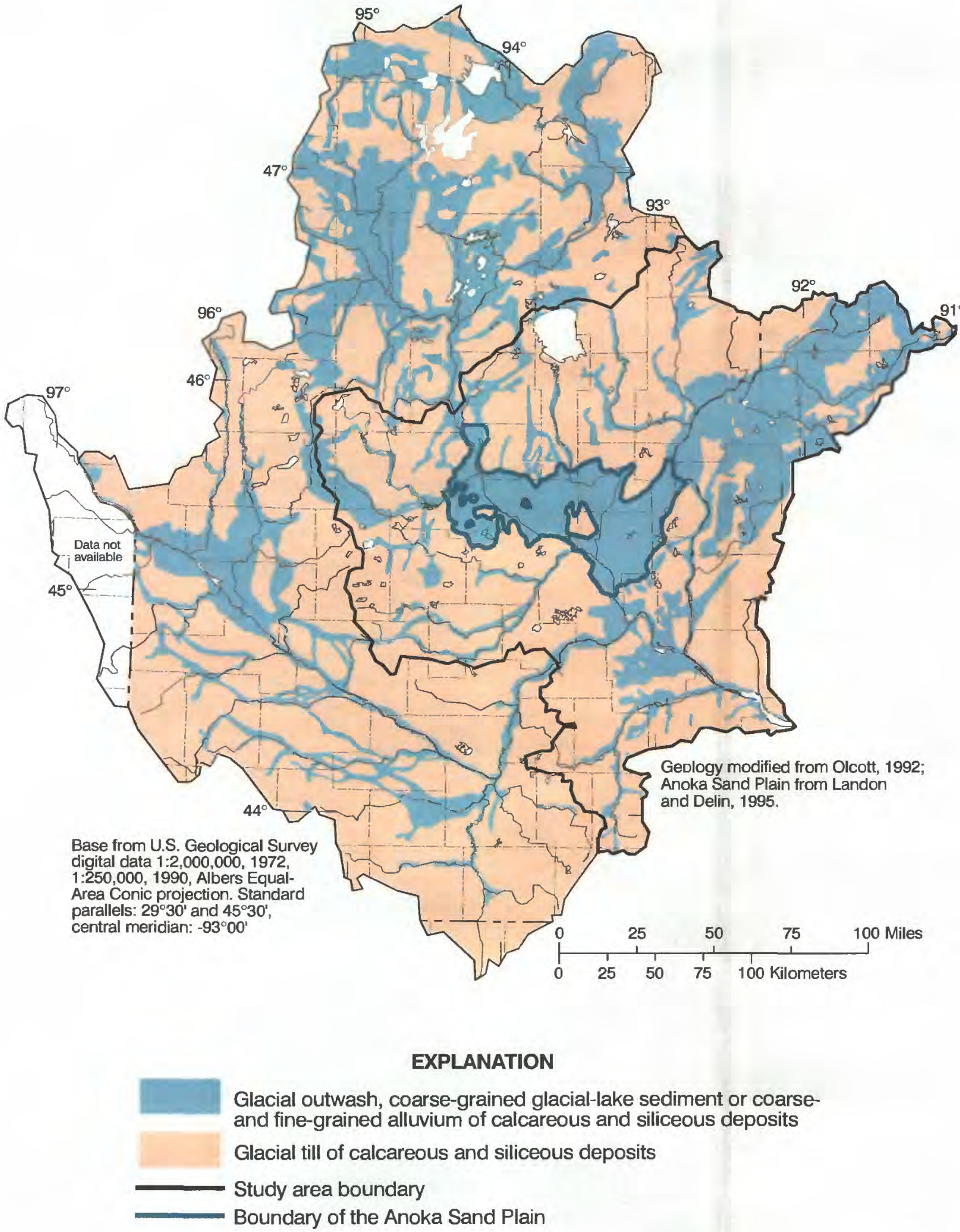

Figure 2.--Surficial geology in the Upper Mississippi River Basin study unit.

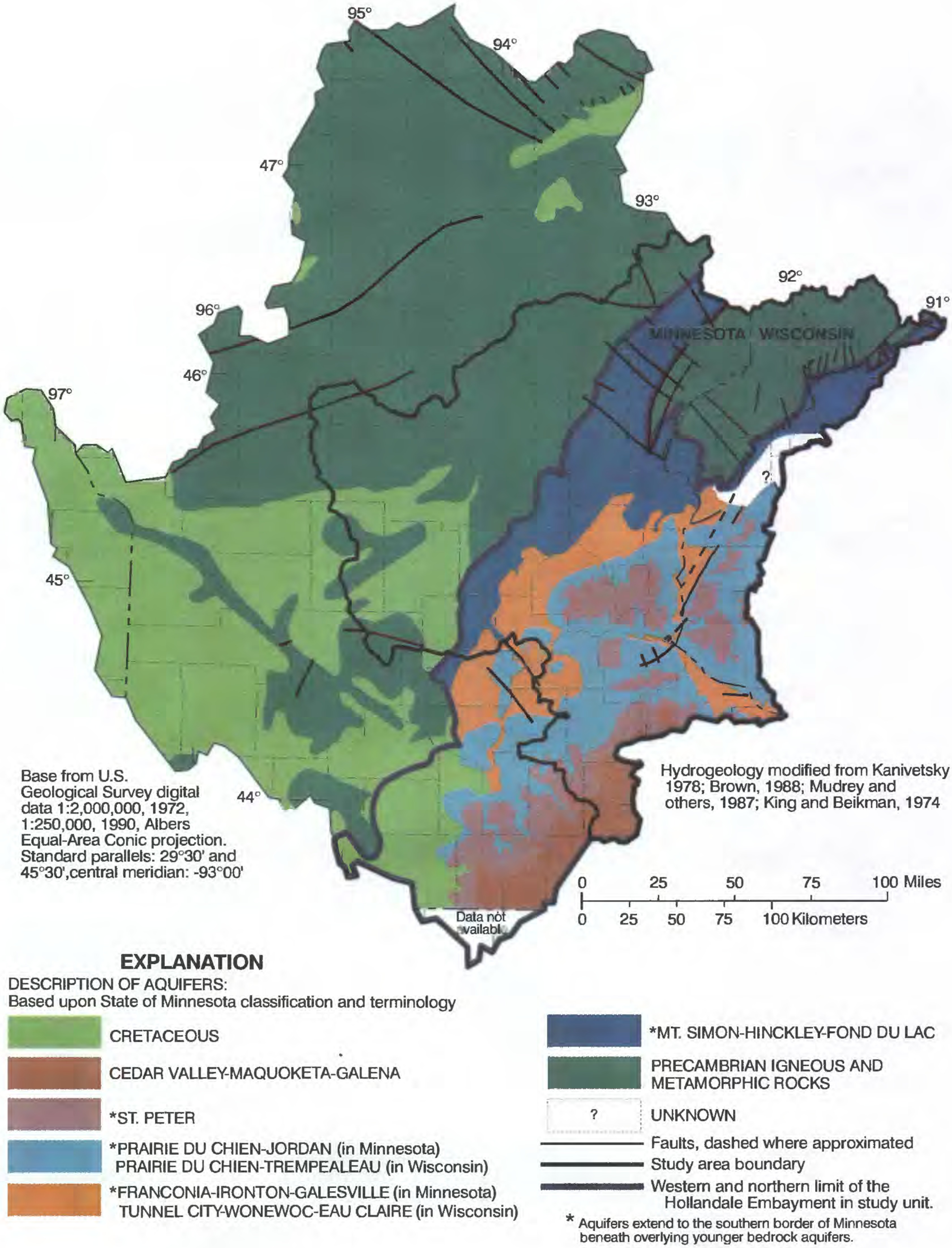

Figure 3.--Bedrock hydrogeology of the Upper Mississippi River Basin study unit.

concentrations for these constituents in drinking water (U.S. Environmental Protection Agency, 1994).

The Cretaceous aquifer, present mainly in southwestern and western Minnesota (fig. 3), consists of shale and sandstone and is not commonly used as a source of water (Adolphson and others, 1981). Water from the Cretaceous aquifer, which is more mineralized than water from other aquifers in Minnesota, commonly contains 450 to 3,600 mg/L dissolved solids (Woodward and Anderson, 1986). Water in the Cedar Valley-Maquoketa-Galena aquifer (commonly referred to as the Upper Carbonate aquifer) has a median dissolved-solids concentration of about 280 mg/L. Concentrations of sodium and sulfate increase to the southwest, where the aquifer is in contact with thick glacial drift and, possibly, with Cretaceous rocks (Ruhl and Wolf, 1984). Water from the St. Peter aquifer has dissolved-solids concentrations generally ranging from 260 to 950 mg/L (Ruhl and Wolf, 1983) and has a median concentration of about 360 mg/L. Water from the Prairie du Chien-Jordan aquifer has a median dissolved-solids concentration of about 250 mg/L in most of southeastern Minnesota (Ruhl and others, 1983). Dissolved-solids concentrations in water in the western part of the aquifer range from 500 to 1,000 mg/L (Wolf and others, 1983). Water from the Mount Simon-Hinckley-Fond du Lac aquifer has concentrations of dissolved solids generally less than 500 mg/L (Wolf and others, 1983). Water in Precambrian igneous and metamorphic rocks has dissolved-solids concentrations generally less than 500 mg/L (Anderson, 1986).

Ground-water quality in Minnesota has been locally degraded by contamination. Major sources of ground-water contamination in Minnesota, according to the Minnesota Pollution Control Agency (1986), include: (1) spills or improper disposal of industrial or manufacturing chemicals, (2) leachate from solid-waste landfills, (3) spills and leaks from petroleum-product storage areas and pipelines, and (4) feedlots and agricultural chemicals. Volatile organic compounds are a type of chemical commonly released to ground water by many of those sources. A survey of 887 community water systems, which includes about 1,800 wells, was made for the purpose of detecting VOC's in drinking water (Minnesota Department of Health, 1985). The survey showed detectable VOC's in water from 109 wells. In 15 communities, the concentrations of VOC's in water from some of the public-supply wells exceeded standards set by the MDH (Minnesota Department of Health, 1985). Andrews and others (1996) determined that VOC's were detectable in samples from 5 percent or less of water from wells in the study area.

Aquatic Biology and Ecology

Numerous reports about aquatic biology and ecology have been published for the streams in the Upper Mississippi River Basin including several large studies that encompass the study unit, and many locally focused projects. The following information describes selected studies, organized by river basin. The locations of cities, towns, rivers, lakes, and reservoirs cited in this section are shown in figure 1.

The Minnesota River has been the subject of various kinds of studies, including: a fisheries survey (Huber, 1959); an investigation of the Lower Minnesota River from Carver Rapids near Jordan, Minnesota to the confluence with the Mississippi River that included coliform, algae, invertebrates, fish and water quality (E.A. Hickock and Associates, 1978; Minnesota Department of Health, 1964); a water quality and fishery reconnaissance from Lac qui Parle to Mankato, Minnesota (Schneider, 1966); a detailed description of the environmental and economic settings (Southern Minnesota River Basin Commission, 1977); a biological survey of fish, invertebrates, and habitat (Kirsh and others, 1985); development potential and the MRAP (Minnesota Pollution Control Agency, 1994d), the most comprehensive biological study of the basin to date.

MRAP was a multidisciplinary and multiagency program to characterize physical, chemical, and biological conditions in the Minnesota River Basin and to recommend management practices for river restoration (Kavanaugh, 1993). Biological assessment consisted of a compilation of six components (Minnesota Pollution Control Agency, 1994d). Diatom community structure was evaluated in 16 streams during 1991-92, and suspended sediment and siltation were identified as factors that may affect the diatom species composition (Richards and Kutka, 1993). Benthic macroinvertebrate communities were assessed at 41 sites in streams during the summers of 1989-92 (Zischke and others, 1993). Stream conditions were found to be moderately to severely degraded at most sites with respect to the macroinvertebrate communities. Bailey and others (1993) evaluated fish communities at 116 sites, and reported that sedimentation had a negative affect on fish communities. Proctor (1993) analyzed trace elements and PCB's in sediments, settleable solids, and clam tissue during 1989-92. One clam species, *Lampgilis ventricosa*, was found to have accumulated high levels of copper, zinc, and nickel. Arthur and others (1993) used standard tests to determine toxicity of sediments and water to phytoplankton, zooplankton, and a freshwater amphipod. Scheld and others (1993) measured liver enzyme activity in fish to determine the effect of organic contaminants on fish, and showed that effects were greater in the Minnesota River than in tributaries during years with low flow. Fish in tributaries were most affected during periods of high flow following a drought year.

Several reports pertain to streams in the St. Croix River Basin. Fago and Hatch (1993) provide a summary of the geology, land use, surface-water quality, and aquatic biota in the St. Croix River Basin. Hanson and others (1987) presented results of a 1986-87 survey conducted by the Minnesota Department of Natural Resources at 20 sites on the Kettle River. Based on comparisons with an earlier study (Kittel, 1962), Hanson and others (1987) reported a decline in diversity of fish communities in portions of the river. Fish abundance in the Kettle River was generally lower than in similar-sized rivers due to low alkalinity, low total phosphorous, low total nitrogen, and the presence of tanic acid-stained water.

Montz and others (1989) presented results from stream monitoring during 1988-89 at 43 sites on the St. Croix River and compared results to a 1959 survey (Kuehn and others, 1961). Golden redhorse *(Moxostoma erythrorum)* were the most common fish species found in 1989. Lake sturgeon *(Acipenser fulvescens)* were commonly found in the 1959 survey, but were rare in the 1989 survey. Chironomidae (midges) and Trichoptera (caddis flies) comprised 54 percent of the 117 aquatic insect taxa collected. Invertebrate diversity was highest in 1989 in the Upper St. Croix River where the substrate was more heterogeneous (Montz and others, 1989).

Mathiak (1979) described the distribution and abundance of 45 species of unionid mussels in the St. Croix River and other Wisconsin streams. Boyle and others (1992) evaluated physical, chemical, and biological conditions in the St. Croix River using benthic macroinvertebrates as biological indicators. A general trend of increase in total dissolved phosphorus from upstream to downstream in the St. Croix River was attributed to changes from forest to agricultural land use. Invertebrate community structure was found to be more complex with respect to diversity and abundance above the dam at St. Croix Falls, Wisconsin than below the dam.

Many studies have focused on the aquatic ecology and biology of the Mississippi River. Wiebe (1927) conducted a study to determine the effects of contaminants from the TCMA on aquatic communities in the Upper Mississippi River. Moyle (1940) completed a biological survey of the Upper Mississippi River watershed. Enblom (1977) conducted a biological survey of the Upper Mississippi River from St. Cloud to Fridley, Minnesota. National Biocentric, Inc. (1979) collected fish, macroinvertebrates, and periphyton in the Mississippi River from Coon Rapids to Pool 2. Fremling and Clafin (1984) summarized the ecological history of the Upper Mississippi River since the 1800's.

Studies of the Mississippi River that focus on fish investigations have been completed. Eddy and others (1963) described fish communities above St. Anthony Falls in Minneapolis, Minnesota and discussed the Falls as a barrier to fish migration. Nord (1976) presented information on the presence and distribution of fish species by river pool, and Rasmussen (1979) updated that information. Scherer (1970) presented data for a 6-mile reach of the Mississippi River near a nuclear power plant at Monticello, Minnesota. That study focused on data collection prior to plant operation with regard to fish population structure, species migration, condition of the species, and microhabitat. The Upper Mississippi River Conservation Committee (Pitlo and others, 1995) compiled a list of fish species present in the Upper Mississippi River from St. Paul, Minnesota to Cairo, Illinois. Three species—gizzard shad *(Dorosoma cepedianum)*, emerald shiner *(Notropis atherinoides)*, and common carp *(Cyprinus carpio)*—were considered common throughout the reach. Swenson and others (1989) described fish populations in the Upper Mississippi River and discussed the relation between stream discharge and the abundance of smallmouth bass *(Micropterus dolomieui)*. That study, based on sampling near power plants near Monticello and Becker, Minnesota, reported 48 fish species at these two sites. Smallmouth bass were the only abundant game fish. Underhill (1989) described the distribution of fish in relation to Late Pleistocene glaciation. Poff and Allan (1995) found a relation between hydrologic variability and fish assemblages for 34 streams in Minnesota and Wisconsin. Lubinski and others (1986) summarized the introduction of common carp into the Mississippi River.

Several studies focused on macroinvertebrate taxa. Hornback and others (1989) reported that mayflies were the dominant macroinvertebrate taxa in a backwater lake of Pool 2, based on density and biomass, and that organic matter was the most important factor influencing the presence or absence of various taxa. The Academy of Natural Sciences completed a survey of unionid mussels in the Upper Mississippi River basin at 40 sites (Fuller, 1978). Mueller (1993) reported a decline in the populations of the winged mapleleaf mussel *(Quadrula fragrosa)* and the Higgin's eye pearly mussel *(Lampsilis higginsi)* in the Mississippi, Minnesota, and St. Croix Rivers since the 1800's, which was attributed to overharvesting, physical barriers which impede migration, habitat-quality degradation, barge traffic, contaminants, and introduction of exotic species. Wilson and others (1995) reported a decline in the populations of fingernail clams (*Musculium transversum*) in Pools 2, 5, 7, 9, and 19 on the Mississippi River for the period 1973-92. The decline of clam population in Pools 2 and 9 were linked to point-source pollution.

Algal investigations within the Mississippi River include Baker and Baker (1979), who discussed the effects of temperature and stream discharge on the concentration and photosynthetic activity of phytoplankton near Red Wing in the Upper Mississippi River. Temperature and discharge were found to regulate phytoplankton concentration, chlorophyll-*a*, and light-saturated photosynthetic rates. An increase in discharge corresponded to an accompanying decrease in chlorophyll-*a* and light-saturated photosynthetic rate. Minnesota Pollution Control Agency (1989) evaluated water quality in Lake Pepin during the summer of 1988 in response to two extensive fish kills that summer, which were attributed to low dissolved oxygen levels or elevated ammonia levels related to blue-green algal blooms. Results showed elevated chlorophyll-*a* levels ranging from 50 to 200 µg/L and algal communities dominated by blue green taxa (*Aphanizomenon spp.* and *Microcystis spp.*) A series of studies focusing on attached algal communities in the Mississippi River near Monticello, Minnesota were completed during 1968-76 (Collingsworth, 1968, 1969; Collingsworth and Brook, 1970, 1971; Knutson, 1972a, 1972b, 1973, 1974, 1975, 1976).

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