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Variability of Nutrients in Streams in Part of the Upper Mississippi River Basin, Minnesota and Wisconsin

Physical conditions differ among the Mississippi River and its major tributaries in Minnesota and Wisconsin. Analysis of the environmental framework of the basin and analysis of historical water-quality information by the National Water-Quality Assessment (NAWQA) Program shows that nutrients (nitrogen and phosphorus) in streams in the Upper Mississippi River Basin are influenced primarily by land use. In the Mississippi River, nutrient concentrations were greater downstream of the Minnesota River and major wastewater discharge points in the Twin Cities Metropolitan Area (TCMA). Stream loads of nutrients (the amount of the constituent carried past a point on a stream during a given period of time) also increased downstream of the Minnesota River and major wastewater discharge points in the TCMA.

National Water-Quality Assessment Program

In 1994, the U.S. Geological Survey's National Water-Quality Assessment (NAWQA) Program began studies in the Upper Mississippi River Basin. Goals of NAWQA are to document the quality of surface and ground water throughout the Nation and to explain natural and human factors affecting water quality and changes in water quality over time. One of the initial objectives of the Upper Mississippi River Basin study was to summarize existing stream-water nutrient concentrations, loads and yields from samples collected by various agencies from water years 1984-93. Data sources were the Twin Cities Metropolitan Council Environmental Services, Minnesota Pollution Control Agency, Wisconsin Department of Natural Resources, and the U.S. Geological Survey.

The Upper Mississippi River Basin study unit (fig. 1) encompasses an area of about 47,000 square miles (mi^2) and includes the drainage area of the Mississippi River from the source at Lake Itasca to the outlet of Lake Pepin, a natural lake on the river, and its four principal tributaries--the Minnesota, St. Croix, Cannon, and Vermillion Rivers. The seven-county Twin Cities (Minneapolis and St. Paul) metropolitan area (TCMA) is located in the southeastern part of the study unit. Land use in the basin can be categorized by three zones: an agricultural zone across the southwestern one-third of the basin; a forested zone across the northeastern one-third of the basin; and a transitional zone between these areas.

For this paper, water-quality analyses focused on a 19,500 mi^2 study area located in the southeastern part of the study unit. Principal streams draining the study area (in addition to the mainstem of the Mississippi River) include the Minnesota, St. Croix, Sauk, Rum, Namekagon, Kettle, Vermillion, Straight, and Cannon Rivers. Land use in each of these basins is diverse. The Minnesota, Vermillion, Straight, and Cannon Rivers drain areas with predominantly agricultural land. The upper part of the St. Croix River and the Kettle and Namekegon Rivers and drain areas that are primarily forested. The Sauk, Rum, and lower part of the St. Croix River drain areas with mixed forest and agricultural land.

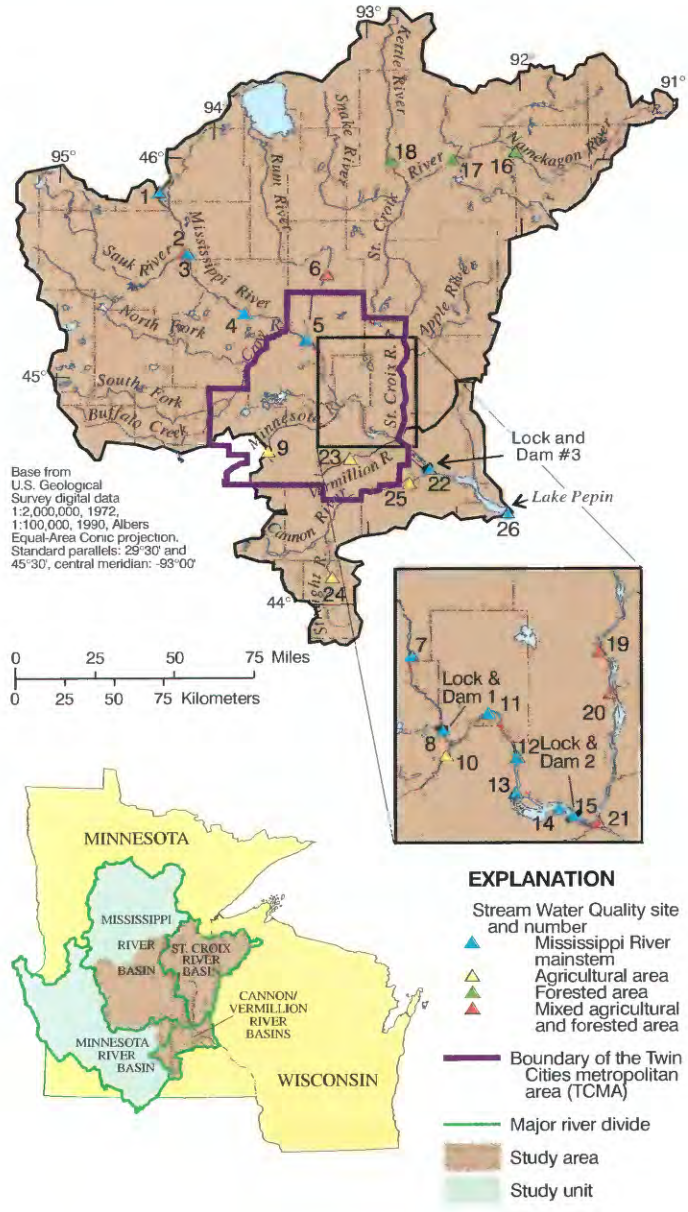

Figure 1. Location of the study unit and hydrography and stream-water quality sites in the Upper Mississippi River Basin study area.

Where Do Nitrogen and Phosphorus in Streams Come From?

Sources of nitrogen and phosphorus include: fertilizer; human, animal and industrial waste; soil; decomposition of plant and animal matter; atmospheric gases; and emissions from vehicles and power plants. Runoff, soil erosion, atmospheric deposition, and direct discharges can transport nitrogen and phosphorus from these sources to streams.

Sources of nitrogen and phosphorus from fertilizer application, livestock manure generation, wastewater treatment-plant discharge, atmospheric deposition, and nitrogen fixation were quantified for the entire study unit. Fertilizer and livestock manure were the largest of the quantifiable sources of nutrients in the study unit (fig. 2). However, municipal wastewater discharge may be a more substantial source of nutrients to streams than indicated because the effluent generally is discharged directly to streams.

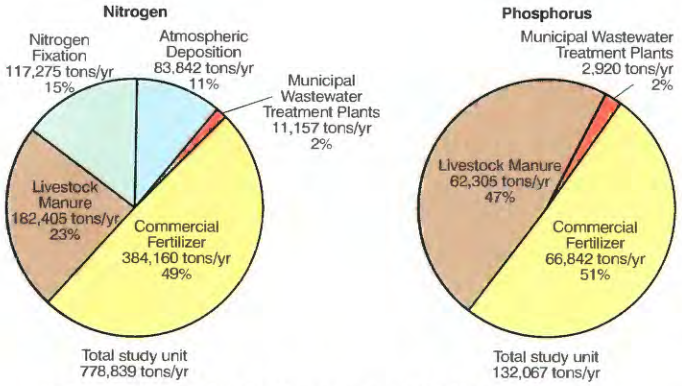

Figure 2. Selected sources of nitrogen and phosphorus in the Upper Mississippi River Basin study unit, 1991-93.

What are the concerns about Nitrogen and Phosphorus?

Nitrogen and phosphorus are essential nutrients for plant and animal growth. The principal forms found in streams are nitrate (NO_3^-), organic nitrogen, ammonia (NH_4^+), orthophosphate (PO_4^{3-}), and organic phosphorus. Of these forms, ammonia, nitrate, and orthophosphate are most readily assimilated by stream biota.

Elevated nitrate concentrations in drinking water pose a human health concern, especially for young children who may develop methemoglobinemia (blue baby syndrome). As a result, the U. S. Environmental Protection Agency (USEPA, 1994) has established 10 mg/L (milligrams per liter) as the maximum contaminant level (MCL) allowed in drinking water. Elevated ammonia concentrations in streams may increase concentrations of un-ionized ammonia (NH_3), which can kill fish and other aquatic life.

An overabundance of nitrogen and phosphorus in slow-moving reaches of streams, and in lakes and reservoirs can cause eutrophication, which is the excessive growth of aquatic plants, particularly algae. Excessive plant growth is aesthetically unpleasant for swimming and boating. As the vegetation decays, oxygen is depleted and the water body may become unable to support desirable species of fish. Phosphorus is often the limiting nutrient for plant growth. To control eutrophication, the USEPA (1986) recommends that total phosphate concentrations should not exceed 0.1 mg/L as phosphorus in streams. At a point where a stream enters a lake or reservoir, the USEPA recommends that total phosphate concentrations should not exceed 0.05 mg/L as phosphorus (United States Environmental Protection Agency, 1986).

How Much Nitrogen Is In the Mississippi River and Its Tributaries?

In the Mississippi River, nitrate (nitrite plus nitrate as N) concentrations (based on water years 1984-93 data) were substantially greater downstream of the Minnesota River (figs. 1,3) than upstream. Upstream of the Minnesota River at sites 1, 3, and 4 (fig. 1), the greatest nitrate concentrations generally occurred during the winter (December through March). In contrast, the greatest nitrate concentrations occurred during the spring and early summer (April through July) at all sites downstream of the confluence with the

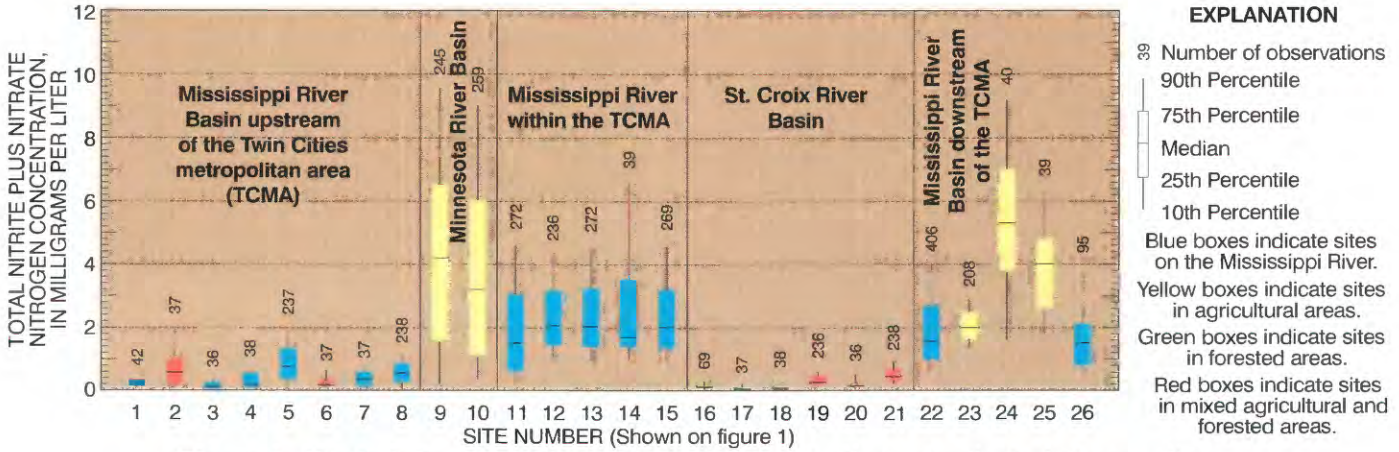

Figure 3. Total nitrite plus nitrate nitrogen concentrations at selected stream sites in the study area, water years 1984-1993 (shown in downstream order).

Minnesota River. Ammonia concentrations generally were greatest at sites located in the TCMA downstream of Minnesota River and the major wastewater discharge points. The greatest ammonia concentrations occurred during the winter months, probably a result of greater concentrations permitted in wastewater effluent during the winter (C. Larson, 1997, personal commun., Metropolitan Council Environmental Services).

Stream load is the total amount of a constituent that is carried past a point on a stream during a given period of time, usually one year. Nitrate loads in the Mississippi River increased substantially downstream of the confluence with the Minnesota River (fig. 4). The nitrogen load in the Mississippi River changes from predominantly organic and

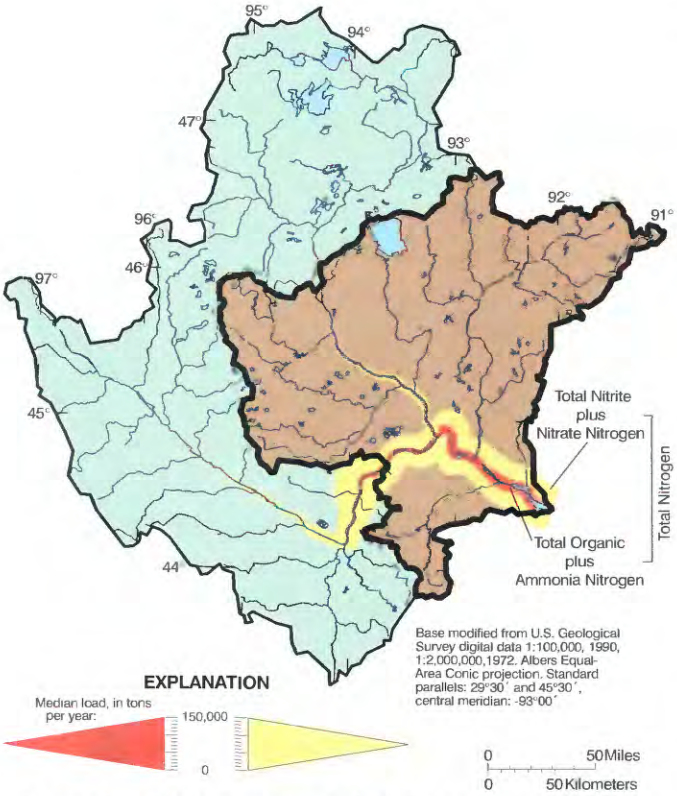

Figure 4. Total nitrogen, total nitrite plus nitrate nitrogen and total organic plus ammonia nitrogen loads in the Upper Mississippi River study unit, water years 1984-93.

ammonia nitrogen upstream of the Minnesota River to predominantly nitrate downstream of the confluence with the Minnesota River. Most of the organic and ammonia nitrogen load in the Mississippi River was primarily contributed by the drainage upstream of the TCMA and the Minnesota River (fig. 4).

In the tributaries to the Mississippi River, nitrate concentrations were greater in the Minnesota, Vermillion, Straight, and Cannon Rivers, which drain agricultural lands, relative to concentrations in the Sauk, Rum, Namekagon, and Kettle Rivers (figs. 1, 3). Concentrations of nitrate were least in the Namekagon and Kettle Rivers, which drain forested areas. In the Minnesota, Straight, and Cannon Rivers, concentrations of nitrate generally were greatest during the spring and summer. In contrast, concentrations of nitrate generally were greatest during the winter in the streams draining forested, and mixed forest and agricultural lands (Kroening and Andrews, 1997).

Yield is the load divided by the stream's drainage area. Nitrate yields were greatest in the Minnesota, Vermillion, and Straight Rivers, which drain areas with predominantly agricultural land (table 1). Nitrate yields were least at sites on the St. Croix and Kettle Rivers, which drain predominantly forested land. Organic and ammonia nitrogen was the predominant form of nitrogen load in tributaries draining these areas.

Table 1. Total nitrite plus nitrate nitrogen and total phosphorus yields at selected sites in the Upper Mississippi River Basin study area, water years 1984-93 (shown in downstream order).

Site number (fig. 1)	Water-quality site	Yield, units are in tons/square mile/year	
	Location	Total nitrite plus nitrate nitrogen	Total phosphorus
6	Rum River	0.24	0.06
9	Minnesota River	3.95	0.10
17	St. Croix River	0.08	0.03
18	Kettle River	0.08	0.05
23	Vermillion River	1.24	0.05
25	Straight River	8.22	0.30

How Much Phosphorus Is In the Mississippi River and its Tributaries?

In the Mississippi River mainstem, total phosphorus concentrations were greatest downstream of the confluence with the Minnesota River and the major wastewater discharge points (sites 12-15, and 22; figs. 1, 5). At these sites, concentrations frequently exceeded the recommended criteria of 0.1 mg/L.

Another study has indicated that total phosphorus concentrations in the Mississippi River within the TCMA were related with streamflow conditions (Kroening, 1994). During low-flow, total phosphorus concentrations increased substantially downstream of the TCMA's major wastewater discharge point. Under average and high-flow, the greatest increases in total phosphorus concentrations were downstream of the confluence with the Minnesota River.

In tributaries to the Mississippi River, total phosphorus concentrations were greatest in the Sauk, Minnesota, Straight, and Cannon Rivers, which drain mixed forest and agricultural and agricultural lands (sites 2, 9, 10, 24, 25; figs. 1, 5), relative to concentrations in the St. Croix, Namekagon, and Kettle Rivers (sites 16-21; figs. 1, 5). Concentrations frequently were greater than the

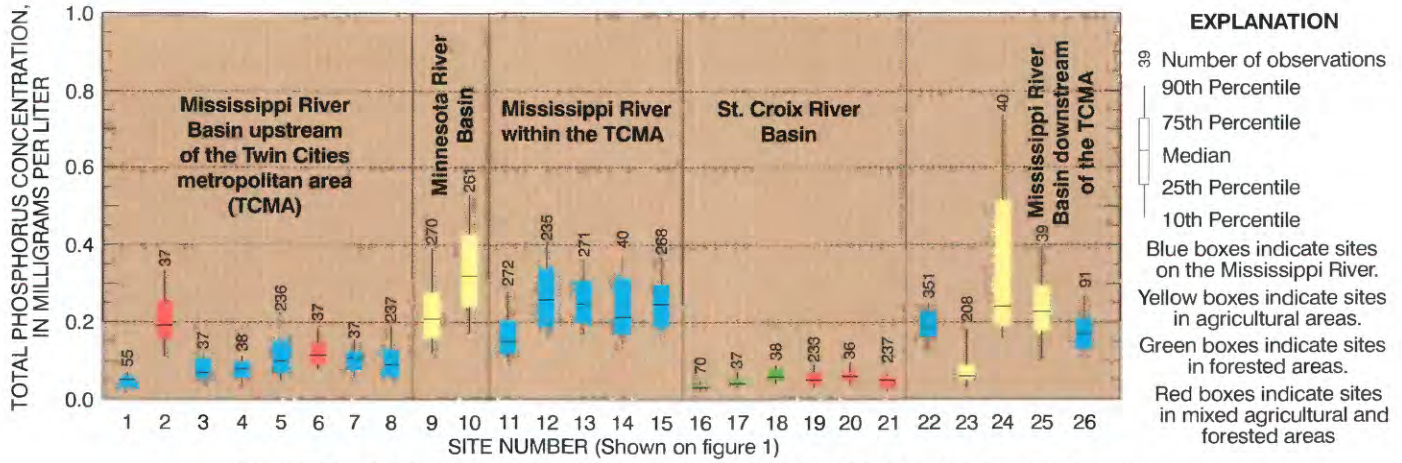

Figure 5. Total phosphorus concentrations at selected stream sites in the study area, water years 1984-93 (shown in downstream order).

recommended criteria of 0.1 mg/L in the Sauk, Minnesota, Straight, and Cannon Rivers.

Total phosphorus concentrations generally peaked during the spring and summer at most sites in the study area. In streams, phosphorus is often associated with clay particles. Greater concentrations during the spring and summer may have been the result of runoff and erosion.

In the Mississippi River, total phosphorus loads followed a pattern similar to nitrate. The greatest total phosphorus loads were downstream of the confluence with the Minnesota River and the major wastewater-discharge points from the TCMA. The Minnesota River has the greatest affect on total phosphorus loads in the Mississippi River during above-average streamflow, when it has contributed approximately 50 percent of the total phosphorus load to the Mississippi River (Kroening, 1994; Metropolitan Waste Control Commission, 1993).

Total phosphorus yields were greater in the Minnesota and Straight Rivers (table 1, fig. 1) than in the Rum, St. Croix, Kettle, and Vermillion Rivers. The greater yield in the Minnesota and Straight Rivers may be the result of drainage from agricultural land.

Have Concentrations of Nitrogen and Phosphorus Changed Over Time?

Despite increases in fertilizer usage from 1982 to 1991, most streams outside of the TCMA have no identifiable trends in concentrations of nitrate or total phosphorus from 1984 through 1993. Most streams had decreases in ammonia concentrations from water years 1984 through 1993, possibly a result of improvements in wastewater treatment. In the TCMA, decreases in ammonia concentrations in the Mississippi and Minnesota Rivers coincided with increases in nitrate concentrations, probably a result of wastewater-treatment plants installing nitrification treatment systems.

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