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# Nutrient and Suspended-Sediment Concentrations and Loads, and Benthic-Invertebrate Data for Tributaries to the St. Croix River, Wisconsin and Minnesota, 1997–99

Water-Resources Investigations Report 01–4162


**Prepared in cooperation with the**

**National Park Service,**
**Minnesota-Wisconsin Boundary Area Commission,**
**St. Croix County, and**
**Wisconsin Department of Natural Resources**

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**By Bernard N. Lenz, Dale M. Robertson, James D. Fallon, and Randy Ferrin**

U.S. GEOLOGICAL SURVEY
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(Revised and reprinted January 2003)

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Middleton, Wisconsin
2003

USGS
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## CONVERSION FACTORS AND ABBREVIATED WATER-QUALITY UNITS

| Multiply | By | To Obtain |
|---|---|---|
| millimeter (mm) | 0.03937 | inch |
| centimeter (cm) | .3937 | inch |
| meter (m) | 3.281 | foot |
| kilometer (km) | .6214 | mile |
| square kilometer ($km^2$) | .3861 | square mile |
| cubic meter per second ($m^3/s$) | 35.3107 | cubic foot per second |
| kilogram (kg) | 2.2045 | pound |
| liter (L) | .262 | gallon |
| milligram (mg) | .000002205 | pound |
| liters per second (L/s) | .0353 | cubic foot per second |
| cubic meter per day ($m^3/d$) | .1834 | gallon per minute |
| centimeter per year (cm/yr) | .3937 | inch per year |

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by use of the following equation:

°F = 1.8 (°C) + 32.

**Water year:** water year is defined as the period beginning October 1 and ending September 30, designated by the calendar year in which it ends.

**Abbreviated water-quality units used in this report:** Chemical concentrations and water temperature are given in metric units. Chemical concentration is given in milligrams per liter (mg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million. Specific conductance of water is expressed in mircosiemens per centimeter at 25°Celsius (µS/cm). This unit is equivalent to micromhos per centimeter at 25°Celsius (µmho/cm), formerly used by the U.S. Geological Survey.

### Other Abbreviations Used in this Report:

| | |
|---|---|
| GIS | Geographic Information System |
| MDNR | Minnesota Department of Natural Resources |
| MPCA | Minnesota Pollution Control Agency |
| NAWQA | National Water-Quality Assessment Program |
| NPS | National Park Service |
| NWQL | National Water-Quality Laboratory, U.S. Geological Survey |
| UMIS | Upper Mississippi River Basin |
| USGS | U.S. Geological Survey |
| WDNR | Wisconsin Department of Natural Resources |

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*By* Bernard N. Lenz, Dale M. Robertson, James D. Fallon[1], *and* Randy Ferrin[2]

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## Abstract

Nutrient and suspended-sediment data were collected on major tributaries to the St. Croix River during 1997–99 as part of three studies. The first study, done in 1997 as part of the U.S. Geological Survey's National Water-Quality Assessment Program Upper Mississippi Study Unit, was a widespread synoptic survey of nutrient and suspended-sediment concentrations, loads, and yields during snowmelt. Runoff from snowmelt in agricultural areas and other areas with low permeability soils had significantly greater nutrient concentrations than forested areas, whereas differences in suspended-sediment loading were not detected. In 1998, synoptic samplings of 11 tributaries were done during snowmelt, base-flow, and storm-runoff periods. These studies showed that the Apple, Willow, and Kinnickinnic Rivers were major contributors of suspended sediments and nutrients to the St. Croix River during base flow and storm-runoff events. Nitrate concentrations were high during base flow in the agricultural tributaries—specifically, the Kinnickinnic (4.83 mg/L), Willow (1.53 mg/L), and Apple (0.79 mg/L) Rivers—possibly from ground-water recharge or point-source contributions. Extensive water-quality sampling was done monthly and during high-flow events in water year 1999 (October 1, 1998 to September 30, 1999) in coordination with continuous streamflow monitoring at 12 sites in the St. Croix River Basin. These data were used to compute annual nutrient and suspended-sediment loads and yields at the monitored sites for water year 1999. Relations among environmental characteristics and calculated annual nutrient and suspended-sediment yields were used to estimate loading from unmonitored parts of the basin. The environmental characteristics found to best estimate annual yields were soil characteristics (clay, permeability of soil, and erodibility), basin slope and area, and the percentages of wetland and urban areas in the basins. Variability in 1999 rainfall intensity resulted in annual yields from several northern, forested basins being higher than those from the southern, agricultural basins. The Sunrise River had the highest annual suspended-sediment and nutrient yields in the basin in 1999. Concentrations and instantaneous loading rates varied as much among various flow conditions at individual sites as among sites during the three years of study.

Benthic invertebrates were sampled and indices of water quality were calculated at 16 tributaries in fall 1999. Benthic invertebrate indices indicated excellent to good water quality at all tributaries except Valley Creek, Willow River, and Kettle River. No relations were found between benthic invertebrate indices and the calculated and estimated 1999 annual tributary loads and yields.

## INTRODUCTION

The St. Croix National Scenic Riverway was established in 1968 as one of the original eight components of the National Wild and Scenic Rivers Act (National Park Service, 1995a). The Riverway includes the St. Croix River from Gordon Dam near Gordon, Wis. to the confluence with the Mississippi River at Prescott, Wis., a distance of 247 km. The upper 40 km of the Riverway is solely within Wisconsin, whereas the remaining reaches of the river form the boundary between Wisconsin and Minnesota. The Riverway also includes the entire 158-km-long Namekagon River from Namekagon Dam near Cable, Wis., to the confluence with the St. Croix River. The part of the St. Croix River south of Taylors Falls, Minn., was added to the system in 1972. The St. Croix River Basin drains 20,010 km$^2$ of Minnesota and Wisconsin. The basin includes over 15 major tributaries and hundreds of minor tributaries to the St. Croix River (fig. 1).


**Figure 1.** St. Croix River Basin sampling locations, Wisconsin and Minnesota.

The Riverway, from its headwaters to Stillwater, Minn., is administered by the National Park Service (NPS). The NPS owns a narrow corridor, approximately 0.4 to 0.8 km wide, along the parts of the Riverway it administers. The NPS also has made extensive use of scenic easements for properties near the rivers that remain in private ownership. Less than 1 percent of the river basin is in NPS jurisdiction. The lower reach of the river from Stillwater to the confluence with the Mississippi River is administered cooperatively by a commission with representatives from the Minnesota Department of Natural Resources (MDNR), the Wisconsin Department of Natural Resources (WDNR), and the NPS. This lower reach is more lacustrine than riverine and is called Lake St. Croix.

The Riverway contains more than 60 state and federally listed endangered and threatened species, indicating that it provides one of the few remaining relatively well preserved and biologically diverse aquatic environments in the Upper Midwest. Among the 40 species of freshwater mussels found in the Riverway, 15 are on state endangered species lists and two are on the federal list. Seven of the nearly 90 species of fish found within the Riverway are on state threatened or endangered species lists. More than 200 species of aquatic macroinvertebrates have been identified in the Riverway.

Because the Riverway is within a one hour drive of the Minneapolis/St. Paul metropolitan area, which has a rapidly expanding population that already is over 2 million, the Riverway continues to experience increased use and developmental pressure. Recreational use on the river has doubled since 1973 and has now reached nearly 1 million visitors per year (National Park Service, 1995a,b). Most recreational use in the park involves contact with the water, such as boating and canoeing, accentuating the need for good water quality.

The Riverway is protected effectively by its status not only as a National Wild and Scenic River but also as a unit of the National Park System; however, its tributaries do not have that same status. To protect the Riverway, managing agencies understand the need to protect these tributaries. In 1994, the NPS, WDNR, MDNR, Minnesota Pollution Control Agency (MPCA), and Minnesota-Wisconsin Boundary Area Commission signed a memorandum of understanding that formed the interagency St. Croix Basin Water Resources Planning Team (Basin Team) and agreed to investigate water-resources issues throughout the basin. Issues identified initially in 1994 included effects on the Riverway from point and nonpoint sources of nutrients and suspended sediment, ground-water contamination, storm-water discharge, toxic contaminants, exotic species, impoundments, recreation and biomonitoring. Since 1994, the Basin Team has grown with the addition of other agencies including the U.S. Geological Survey (USGS), Metropolitan Council Environmental Services, University of Minnesota, Minnesota Department of Agriculture, St. Croix Band of Chippewa Indians, and U.S. Environmental Protection Agency. Additional issues including water-quality standards, ammonia toxicity, fish advisories, monitoring and agency coordination have been added to the list of issues to be addressed by the Basin Team.

One of the first accomplishments of the Basin Team was working with the Upper Mississippi River Basin Study Unit of the USGS National Water-Quality Assessment (NAWQA) program (Stark and others, 1996) to include the St. Croix River Basin as part of its study area. Three sites: Namekagon River near Leonards, Wis., St. Croix River near Danbury, Wis., and St. Croix River at St. Croix Falls were intensively monitored as NAWQA "fixed sites." Numerous other sites in the St. Croix River Basin were included as parts of various studies by the NAWQA program (Stark and others, 2000). Another accomplishment was the development of a Water Resources Management Plan for the St. Croix National Scenic Riverway (Holmberg and others, 1997). This plan, required by the NPS, has been instrumental in securing funding for water-quality studies. From this funding, the Basin Team implemented an interagency nutrient and suspended-sediment monitoring project with more than 25 sites monitored by six agencies. These studies included two tributary monitoring projects by the USGS in 1998 and 1999 and continued monitoring at the three NAWQA "fixed sites."

This report summarizes the results of the USGS nutrient and suspended-sediment studies done since 1997. The Basin Team will incorporate results from this report into future plans and studies. The purpose of this report is to summarize information on streamflow, concentrations, and loading rates of phosphorus, nitrogen, and suspended sediment in the major tributaries to the St. Croix River. Thirteen tributaries to the St. Croix River were sampled during 1997–99. Annual phosphorus and suspended-sediment loads and yields (load per unit area) were calculated and used to determine which tributaries were the largest contributors. Relations between environmental characteristics (land use, land cover, slope, permeability, soils) and annual nutrient and suspended-sediment yields at monitored sites were determined and used to estimate loading from unmonitored parts of the basin. Relations between benthic invertebrate populations and nutrients also are discussed.

## APPROACH AND METHODS

The USGS Upper Mississippi River Basin (UMIS) study unit of the NAWQA Program sampled tributaries to the Upper Mississippi River, including many in the St. Croix River Basin, as part of a synoptic study to characterize nutrient and suspended-sediment concentrations, loads, and yields during snowmelt (Fallon and McNellis, 2000). Streams were sampled during March and April 1997, when a combination of melting snowpack and rainfall produced near-record streamflow. Snowmelt-runoff samples were collected from 42 stream sites. The sampled streams drained areas with various combinations of land use and surficial geology common in the UMIS NAWQA study unit. Streams were classified by the predominant land use (forested, agricultural, urban, or mixed) and the predominant type of soil and surficial geology deposit. Drainage areas of sampled streams ranged from 26 to 121,000 $km^2$. Samples were collected during increasing streamflows, when concentrations were expected to be highest. Ancillary data from 12 sites provided comparative concentrations from before and after streamflow increases, as well as data needed to estimate constituent loads delivered during the 1997 snowmelt period (Fallon and McNellis, 2000).

On the basis of results from the snowmelt synoptic study, a study was designed for 1998 to identify spatial and temporal variations in nutrients and suspended-sediment loading from tributaries identified as major contributors and from other tributaries with environmental characteristics thought to be related to high nutrient and suspended-sediment loading. Each site was sampled four times during the year: snowmelt, spring rainfall runoff, summer rainfall runoff, and summer base flow. Instantaneous yields (based on constituent concentration and corresponding one-time streamflow measurement) were compared to environmental characteristics of the sampled tributary basins to identify which characteristics were most strongly related to nutrient and suspended-sediment loading in the tributaries.

A follow-up study was then conducted from October 1998 to September 1999 on a subset of sites from the 1998 study. For each monitored site, continuous streamflow was measured and water samples were collected monthly and during four runoff-producing events. Annual loads and yields of nutrients and suspended sediments were calculated for the monitored tributaries and compared to environmental characteristics in the basins. These relations were used to estimate loads and yields at unmonitored tributaries.

Benthic invertebrates were collected at 15 tributary sites in fall 1999 and used to calculate indices of water quality. The indices of water quality were compared to annual loads and yields calculated during this study to determine whether relations were present between nutrients and sediments transported by the tributaries and the benthic invertebrates at these sites.

### Field and Laboratory Methods

#### Streamflow

Continuous streamflow was calculated at 15-minute intervals at the flow-monitoring stations. Continuous stage was recorded by use of pressure transducers and stilling wells. Flow measurements were made at varying stream stages throughout the year. Relations between stage and discharge were determined from these data and used to convert stage data into flow data. Flows were calculated for each 15-minute interval and were used to determine the daily mean streamflow at each station (Kennedy, 1983).

#### Nutrients and Suspended Sediment

Water samples were collected by USGS and MPCA personnel at 15 major tributaries to the St. Croix River in 1997–99. Data from two long-term USGS-NPS monitoring sites on the St. Croix River (near Danbury, Wis. and at St. Croix Falls, Wis.) also were included in the loading study. All sampling locations are shown in figure 1 and listed in table 1.

Snowmelt-runoff samples were collected in spring 1997 by USGS-UMIS NAWQA personnel. The snowmelt synoptic sampling sites (1997) are described by Fallon and McNellis (2000). In 1998, USGS and MPCA personnel collected four samples representing snowmelt runoff, spring-rainstorm runoff, summer-rainstorm runoff, and summer base flow. The tributaries in the northern part of the basin, however, did not receive a substantial summer storm runoff in 1998 because of the unusually dry summer. Instead, these tributaries were

**Table 1.** Selected sampled tributary streams to the St. Croix River, Wisconsin and Minnesota
[ $km^2$, square kilometers; --, no U.S. Geological Survey (USGS) station number]

| Site name | USGS station number | Drainage area ($km^2$) | Latitude | Longitude |
|---|---|---|---|---|
| Kinnickinnic River near River Falls, Wis. | 05342000 | 449 | 44° 49' 51" | 92° 43' 59" |
| Valley Creek at Afton, Minn. | -- | 49 | 44° 54' 41" | 92° 46' 48" |
| Willow River at Burkhardt, Wis. | 05341752 | 721 | 45° 01' 01" | 92° 42' 23" |
| Browns Creek at Stillwater, Minn. | 05341540 | 88 | 45° 04' 35" | 92° 48' 21" |
| Silver Creek near Stillwater, Minn. | -- | 20 | 45° 04' 33" | 92° 48' 30" |
| Apple River near Somerset, Wis. | 05341500 | 1,420 | 45° 09' 27" | 92° 42' 59" |
| Little Carnelian Lake outlet near Stillwater, Minn. | -- | 11 | 45° 06' 56" | 92° 47' 38" |
| Trade River near Trade River, Wis. | 05340390 | 345 | 45° 35' 54" | 92° 46' 02" |
| Sunrise River at Sunrise, Minn. | 05340050 | 439 | 45° 32' 49" | 92° 51' 23" |
| Wood River near Grantsburg, Wis. | 05338955 | 217 | 45° 47' 07" | 92° 37' 52" |
| Snake River near Pine City, Minn. | 05338500 | 2,525 | 45° 50' 30" | 92° 56' 00" |
| Kettle River below Sandstone, Minn. | 05336700 | 2,252 | 46° 06' 20" | 92° 51' 50" |
| Lower Tamarack River near Markville, Minn. | 05335151 | 470 | 46° 04' 49" | 92° 23' 37" |
| Sand Creek near Hinckley, Minn. | 05335900 | 284 | 45° 57' 08" | 92° 40' 04" |
| Crooked Creek near Hinckley, Minn. | 05335170 | 244 | 46° 00' 42" | 92° 31' 45" |
| Clam River near Webster, Wis. | 05335500 | 926 | 45° 52' 52" | 92° 29' 16" |
| Upper Tamarack River near Markville, Minn. | 05333579 | 245 | 46° 05' 30" | 92° 18' 32" |
| Yellow River near Danbury, Wis. | 05335031 | 940 | 46° 00' 44" | 92° 21' 25" |
| Namekagon River near Leonards, Wis. | 05331833 | 333 | 46° 10' 17" | 91° 19' 45" |
| St. Croix River near Danbury, Wis. | 05333500 | 4,092 | 46° 04' 28" | 92° 14' 50" |
| St. Croix River at St. Croix Falls, Wis. | 05340500 | 16,160 | 45° 24' 25" | 92° 38' 49" |

sampled during base flow and again at extremely low flows late in the summer. All samples from 1997 and 1998 were analyzed for nutrients and suspended sediment. Streamflow was measured at each site concurrently with sample collection, and loads and yields were computed on the basis of these measurements. (These are referred to hereafter as "instantaneous" loads and yields.)

In 1999, USGS and MPCA monitored streamflow continuously and did routine sampling at selected sites in the St. Croix River Basin. Water-quality samples were collected at the monitoring sites monthly and during runoff-producing events (snowmelt, spring storm, and two summer storms) to determine nutrient and suspended-sediment concentrations at differing flow conditions and seasons. The selected tributary monitoring locations were at established stream gaging locations or as close as possible to the St. Croix River while yet enabling sampling and measurements during high water. This location generally was at the first road crossing upstream from the tributary mouth. Care was taken to stay below impoundments so as to measure flow and constituent concentration actually reaching the St. Croix River. This was possible on all but the Willow River, which was sampled above Lake Mallalieu.

Water-quality sampling by USGS personnel followed USGS protocols (Shelton, 1994), and analyses were done at the USGS National Water-Quality Laboratory (NWQL) in Denver, Colo. MPCA personnel followed standard agency protocols (Minnesota Pollution Control Agency, 1993), and analyses were done at the Minnesota Department of Health Chemical Laboratory in St. Paul, Minn. The greatest difference in the sampling methods was that USGS collected samples by use of the equal-width-increment method, whereas MPCA collected grab samples.

Quality-assurance/quality-control testing was done in 1998 and 1999. Each year both agencies collected similar samples at three tributaries that varied in size and environmental characteristics. Each agency used their respective protocols and sent samples to their respective laboratories for analysis. No consistent differences in nutrient concentrations were found among agencies; however, suspended-sediment concentrations measured by the USGS by use of the equal-width-increment method consistently were higher than those measured by other agencies by use of grab samples (appendix 1). No attempts were made to adjust the suspended-sediment concentrations measured at the Kettle, Snake, and Sunrise Rivers to account for these differences; therefore, the concentrations, loads, and yields of suspended sediment may be slightly negatively biased. Similar results have been observed in interagency monitor studies conducted by the Interagency Task Force on Monitoring (Kammerer and others, 1998).

### Benthic Invertebrates

Benthic invertebrates were collected during base flow in fall 1999. The benthic invertebrates collected were in the stream for all or part of their lives, depending on their individual life cycles, during the period that concentrations were measured and loads were estimated. These relatively immobile organisms are subjected continually to changes in water quality. The number, type, and diversity of the organisms found in each tributary are affected by these water-quality changes. Because of this effect, water-quality indices calculated from these invertebrate populations provide an indication of the overall water quality in a stream and are a valuable supplement to discrete chemical analysis of water samples.

Benthic-invertebrate samples were collected from the habitat most likely to have the greatest variety and quantity of organisms, as inferred from substrate, water depth, flow, and canopy cover. Typically, suitable habitats were found at the two largest riffles closest to the chemical water-quality sampling location. Riffles are the part of the stream where the water flows swiftly over completely or partially submerged coarse substrate that produces surface agitation. Sample locations generally had an open canopy, gravel or cobble substrate, high flow velocities, and water depth sufficient to keep most of the benthic invertebrates submerged during low flows.

Invertebrate samples were collected according to NAWQA protocols (Cuffney and others, 1993a,b). Riffle samples were collected using a modified Slack kick sampler with a 425-µm mesh at 13 of the 15 tributaries sampled. A stream-reach sample consisted of a composite of six kick samples—three collected at the upstream riffle and three collected at the downstream riffle in the same reach—that was processed and identified as one sample. Distances between kick samples in the same riffle rarely were greater than 5 m. The sample area for each kick sample was 0.5 m by 0.5 m. Stream reaches near the chemical water-quality sampling sites at the Wood and Kettle River lacked wadeable coarse-grained riffles; therefore, samples were collected at these sites using a D-frame net in vegetation and woody debris and by scraping and picking debris clumps and logs within the main flow.

Samples were processed in the field in accordance with NAWQA protocols, which include swirling and sieving (425-µm mesh) until sample volumes were less than 750 mL. NAWQA protocols do not include the collection of mussels and these were returned to the stream during sieving. Samples, preserved in the field in 70 percent ethanol, were drained within 3 days and refilled with 70 percent ethanol, and were stored until they could be shipped for identification. Enumeration and taxonomic identifications of benthic invertebrates were done at the University of Wisconsin-Stevens Point.

## Methods for Determining Environmental Characteristics

The environmental characteristics examined for the study area include land-use/land-cover types, surficial-deposit types and thickness, slope, and soil characteristics. Methods for determining the characteristics of each basin are described below.

### Land Use

Land-use/land-cover information (hereafter referred to as land use) for the study area was obtained from high-altitude aerial photographs collected by the USGS from the early 1970s to the early 1980s (Feagus and others, 1983) and manually interpreted on the basis of the land-use classification of Anderson and others (1976). In addition, land-use data were updated with urban population information obtained from the 1990 census (Hitt, 1994). Land-use maps were produced from the interpreted data and digitized into a geographic information system (GIS). Land-use types summarized for each basin represent Anderson's Level I categories (Anderson and others, 1976) and include urban, agriculture, forest, water, wetland (further subdivided into forested and nonforested categories), and barren land (fig. 2).

### Surficial Deposits

Surficial-deposit classification and thickness information for the study area was compiled from a digital coverage of Quaternary sediments for the glaciated United States east of the Rocky Mountains (Soller and Packard, 1998). Quaternary-sediment classifications included six categories: coarse-grained, fine-grained, till, patchy, exposed bedrock, and organic-rich. The digital coverage also included an attribute describing ranges of depth to bedrock. Those ranges were generalized by assigning a single depth to bedrock equal to the average of the range values. The digital coverage was intersected with the basin outlines, and the percentage of each surficial sediment type and an area-weighted average depth to bedrock were calculated for each basin.

### Soil Characteristics

Soil-characteristic information for the study area was compiled from USSOILS, a national digital coverage of the State Soil Geographic (STATSGO) (Schwarz and Alexander, 1995). Soil characteristics examined in this study included clay content (percentage of soil less than 2 µm in size), organic-matter content (percentage by weight), soil erodibility (K factor used in the universal soil loss equation), permeability rates (millimeters per hour) (fig. 3), and slope (percent). The USSOILS coverage was intersected with the drainage basin outlines, and each of the soil characteristics of interest was calculated as an area-weighted average.

## Load Estimation

### Monitored Basins

Annual loads (calculated by summing daily loads) and annual standard errors of the predictions of those loads (calculated using daily standard errors of the predictions) were estimated by a regression approach by use of the USGS computer program Estimator (Cohn and others, 1989). In this study, estimated daily loads ($L$) were calculated based on relations between constituent load (in kilograms) and two variables: streamflow ($Q$, in cubic meters per day) and time of the year ($T$, in radians). The general form of the model was

$$\ln(L) = a + b[\ln(Q) - c] + d[\ln(Q) - c]^2 + e[\sin(T)] + f[\cos(T)], \quad (1)$$

where $a, b, c, d, e,$ and $f$ are regression coefficients.

Values for the regression coefficients in equation 1 were calculated for each site and for each time period by the use of multiple regression analyses between daily loads (daily average streamflows multiplied by instantaneous measured concentrations, in milligrams per liter) and daily streamflows ($Q$) and time of the year ($T$). For each sampling strategy and for each time interval, only terms that were significant at $P < 0.05$ were included in the regression. Because a logarithmic transformation was used in equation 1, computed daily loads were adjusted to account for a retransformation bias by use of the minimum variance unbiased estimate procedure. (See Cohn and others (1989) for a complete discussion.)

Equation 1 was calibrated for each site using all available data from 1997 to 1999 in the regression analysis to determine a relation between flow and loads. This relation and the flow data from water year 1999 were used to calculate annual loads and yields for the monitored tributaries. The standard error of prediction was used to calculate the range of loads within a 95-percent confidence interval.

### Unmonitored Basins

Loads and yields from unmonitored tributaries were estimated from the environmental characteristics of their respective basins and the relations found between annual yields and the environmental characteristics of the monitored basins. These relations were found by use of forward stepwise linear regressions. The regression equation for each water-quality constituent was limited to the first three environmental characteristic variables in the stepwise regression that were statistically significant at $P < 0.05$. The 95-percent confidence intervals for the predicted annual yields were computed based on the prediction of a single future observation (Draper and Smith, 1966). When the prediction error was greater than the best approximation of the annual yield, the minimum estimated annual yield was set to zero rather than a negative value.

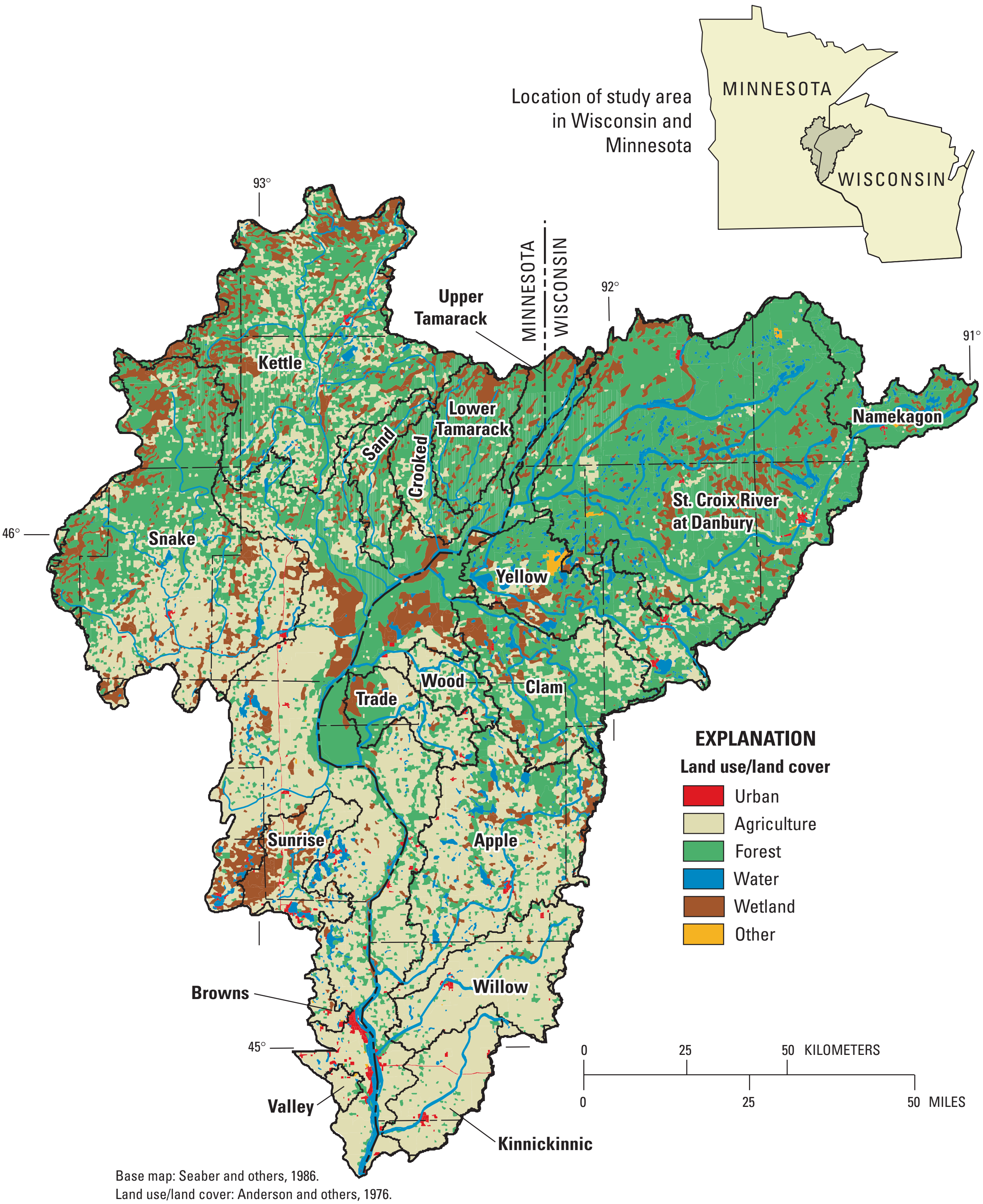



**Figure 2.** Land use/land cover of the St. Croix River Basin, Wisconsin and Minnesota.

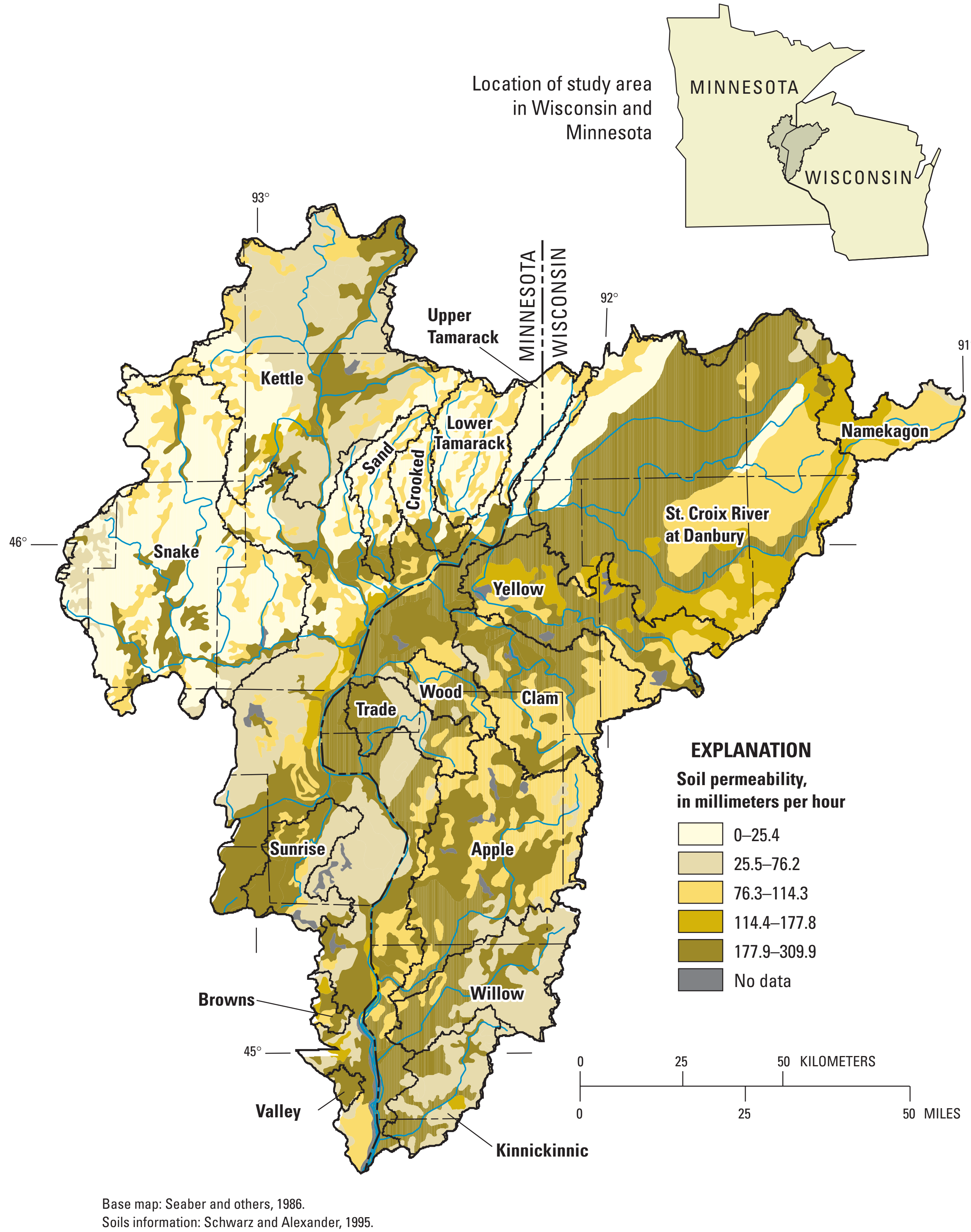



**Figure 3.** Soil permeability of the St. Croix River Basin, Wisconsin and Minnesota (gradations represent quantile distributions).

# RESULTS OF NUTRIENT, SEDIMENT, AND BENTHIC-INVERTEBRATE SAMPLING

## 1997 Spring Snowmelt Synoptic Sampling

The USGS sampled snowmelt runoff from 42 stream sites in the Upper Mississippi River Basin, Minnesota and Wisconsin, during March and April 1997 as part of the UMIS-NAWQA synoptic study to characterize nutrient and suspended-sediment concentrations, loads, and yields. A detailed account of this study can be found in Fallon and McNellis (2000). A brief summary is included here.

Total phosphorus concentrations ranged from 0.02 to 0.57 mg/L, total nitrogen concentrations ranged from 0.52 to 7.7 mg/L, and suspended-sediment concentrations ranged from 6.2 to 249 mg/L. Concentrations at sites within the St. Croix River Basin were below median values for the entire Upper Mississippi Basin and generally in the lowest quartile, with the exception of nitrogen at Crooked Creek and suspended sediment at various Upper St. Croix River Basin tributary sites.

Streams in agricultural areas had significantly greater instantaneous yields ($P < 0.05$) of dissolved nitrite, nitrate, total nitrogen, orthophosphate, and total phosphorus than those in forested areas, and significantly greater instantaneous yields ($P < 0.05$) of dissolved nitrate and orthophosphate than all other land uses. In forested areas, instantaneous yields of suspended sediment and all nutrient forms were significantly greater ($P < 0.05$) for streams draining impermeable deposits than for those draining permeable deposits.

Additional water-quality data available for 12 of the sites provided data to estimate constituent loads delivered during the entire period of snowmelt and all of 1997. The snowmelt period contributed from 1 to 50 percent of 1997 annual loads of total nitrogen, total phosphorus, and suspended sediment at small stream sites, and 17 to 70 percent of annual loads at main-stem river sites. Agricultural streams transported the greatest proportions of their annual loads during snowmelt. Small urban streams transported the least proportions of their annual loads during snowmelt. Data collected at 11 sites in the St. Croix River Basin in spring 1997 as part of the UMIS-NAWQA study are listed in appendix 2. Additional data and a detailed account of this study can be found in Fallon and McNellis (2000).

## 1998 Synoptic Sampling

Eleven tributaries were sampled in 1998 to determine how concentrations vary during differing flow regimes: snowmelt, spring storm, summer storm, and typical summer base flow. A summary of the data collected by the USGS as part of this synoptic is presented in appendix 2. A summary of the data collected by the MPCA as part of this study is presented in appendix 3.

### Climatological Factors

The winter of 1997–98 was nearly 6°C above the 30-year normal because of warm temperatures associated with a very strong El Niño event in the Pacific Ocean. Accumulated snow depth was below normal in the northern part of the St. Croix River Basin and moderately below normal in the southern part. A period of warm weather caused what snow had accumulated to melt in mid-February, and the resulting minimal snowmelt runoff was sampled. Snow did not accumulate again. A warm spring began with a large storm on March 30 and April 1, 1998, and spring storm samples were collected at all tributaries during this event. A summer storm occurred in the southern part of the basin on June 25, and samples were collected at the Apple, Willow, and Kinnickinnic Rivers during this event. No large summer runoff events occurred in the northern part of the basin in 1998. Consequently, the study was modified and extreme low-flow samples were collected from northern tributaries on September 22, 24, and October 1. Typical base-flow samples were collected on July 14, 22, and 28 throughout the basin following periods of a week to 10 days without rain.

### Suspended Sediment

Suspended-sediment concentrations ranged from 2 to 424 mg/L and were related positively to flow for each stream. The forested northern tributaries generally had less suspended sediment than the southern agricultural tributaries, but a correlation with land use was not evident. The Apple, Yellow, Snake, and Clam Rivers (fig. 1) routinely had low suspended-sediment concentrations because they were sampled below impoundments. For the stream basins with large amounts of accumulated snow, highest suspended-sediment concentrations were collected during snowmelt runoff events, whereas for those that had only a small amount of snowmelt runoff, the highest suspended-sediment concentrations were collected during the first spring rain event.

The highest suspended-sediment concentration was measured at the Kinnickinnic River during the spring storm (424 mg/L). The Willow River had a very high suspended-sediment concentration (414 mg/L) during the spring storm, probably because the spring runoff caused the highest discharge in the river since a dam upstream was removed in 1997. The exposed accumulated sediments from the former impoundment were transported easily by the river, as evidenced by the bank erosion in the former impoundment basin. Spring-storm runoff samples contained the highest suspended-sediment concentrations of the year at the Apple (13 mg/L), Clam (100 mg/L), and Upper Tamarack (15 mg/L) Rivers. The highest concentrations at the Sand (50 mg/L), Wood (35 mg/L), Trade (136 mg/L), Yellow (9 mg/L) and Lower Tamarack (26 mg/L) Rivers were found in snowmelt samples. Concentrations in base-flow and low-flow samples were less than 10 mg/L everywhere except for the Kinnickinnic (16 mg/L) and Clam Rivers (14 mg/L).

The highest instantaneous suspended-sediment daily loads and yields calculated from 1997–98 sampling data came from the agricultural Kinnickinnic (660,000 kg, 1,530 kg/km$^2$) and Willow River Basins (780,000 kg, 1,100 kg/km$^2$) as well as the heavily forested Crooked Creek Basin (170,000 kg, 700 kg/km$^2$), and the mixed forest and agricultural Trade River Basin (177,000 kg, 510 kg/km$^2$).

### Phosphorus

Total phosphorus concentrations ranged from 1.32 mg/L during snowmelt at the Kinnickinnic River to less than the detection level (< 0.01 mg/L) during base flow at Upper Tamarack, Yellow, and Clam Rivers. Phosphorus concentrations were low in all streams. Only the Kinnickinnic, Willow, Trade, Sunrise, Snake, and Kettle Rivers had one or more samples with concentrations greater than 0.1 mg/L. Base-flow concentrations of phosphorus were all below 0.08 mg/L. Total phosphorus concentrations were highest during events in the tributaries from the southern part of the basin with predominantly agricultural land use.

The Kinnickinnic River had the highest total phosphorus concentrations of 1998 during snowmelt (1.32 mg/L) and a spring storm (0.38 mg/L). The next highest phosphorus concentrations (0.18 mg/L) were from snowmelt at the Trade River and a spring storm at the Sunrise River. Large streams had the highest instantaneous daily phosphorus loads and included the Kinnickinnic (1,003 kg), Sunrise (444 kg), Kettle (398 kg), Apple (195 kg), Snake (188 kg), and Willow (184 kg) Rivers. Several small streams had high instantaneous daily yields, including the Wood (0.34 kg/km$^2$), Crooked (0.25 kg/km$^2$), and Upper Tamarack (0.21 kg/km$^2$) Rivers.

### Nitrogen

Total nitrogen concentrations ranged from 0.30 to 5.53 mg/L. Concentrations of total nitrogen always were less than 2 mg/L except during 1997 snowmelt runoff at the Kinnickinnic River (5.53 mg/L). Base-flow and event samples had relatively similar concentrations in all tributaries; thus, instantaneous daily loads and yields were directly related to flow volume—higher during periods of increased flow. The Kettle River, because of its large flow volume (1,800 cfs), had the highest instantaneous daily load of total nitrogen (4,670 kg). The Kinnickinnic River (9.7 kg/km$^2$) and two smaller basins with high runoff (Upper Tamarack (4.1 kg/km$^2$) and Wood (4.0 kg/km$^2$) Rivers) had the highest instantaneous daily yields.

Dissolved nitrate concentrations were highest in agricultural tributaries in the southern part of the basin: the Kinnickinnic (4.8 mg/L), Willow (4.4 mg/L), and Apple (1.3 mg/L) Rivers. Concentrations were highest at low flows and decreased because of dilution during rainfall-runoff events, an indication that a point source or ground-water recharge or both were possible contributing factors to the amount nitrate in the streams; however, instantaneous loads and yields still were controlled by flow, and the highest instantaneous loads and yields were recorded during events. Nitrogen was not analyzed in samples collected at the Sunrise, Snake, and Kettle Rivers.

### Major Contributing Tributaries

The agricultural land-use basins of the Kinnickinnic, Apple, and Willow Rivers, as well as the clay-rich Kettle River Basin, were the major contributors of suspended sediments and nutrients to the St. Croix River in 1998, not only during events, but also during base flow. The Trade, Wood, Snake, Sand, Crooked, and Lower Tamarack Rivers had greater event and seasonal variations than the other tributaries, but they all appear to be substantial contributors of sediments and nutrients to the St. Croix River during events. The Snake and Sunrise Rivers, though they did not have the highest instantaneous loading rates in 1998, nevertheless were important contributors of nutrients and sediment because of their large flow volumes and the increase in loading rates in these streams during event related increases in flow.

The only statistically significant relation between land use and instantaneous nutrient and sediment concentrations, loads, and yields found in the 1998 data was that the percentage of agricultural land use was related to nitrite plus nitrate concentrations during base flow and to dissolved phosphorus concentrations during the spring storm sampling. Other data showed weak relations to land use but the small data set size resulted in the relations being statistically insignificant.

## 1998–99 Intensive Tributary Monitoring

Ten tributaries (Wood, Trade, Apple, Willow, Kinnickinnic, Upper Tamarack, Lower Tamarack, Kettle, Snake, and Sunrise Rivers) were selected for continuous streamflow monitoring and intensive water-quality sampling. Water-quality data from this monitoring effort are listed in appendixes 3 and 4. Two main-stem sites on the St. Croix River (at St. Croix Falls and near Danbury, Wis.) also were sampled in 1998–99, and data for these sites are listed in appendixes 5 and 6. Summaries of the data used in loading computations are given in tables 2, 3, and 4.

### Climatological Factors

Total precipitation for the period from October 1, 1998, to September 30, 1999, was above normal throughout the basin. During the fall and winter of 1998–99, precipitation and snowfall were normal to less than normal (National Oceanographic and Atmospheric Administration, 1998, 1999). Snowmelt in the spring of 1999 was gradual throughout the basin, resulting in minimal runoff events at most tributaries. Spring and summer rainfall in 1999 was above normal, and May and July were both much wetter than normal. In the northern forested part of the basin, several intense short-duration storms created large runoff events; however, in the more agricultural and mixed agricultural portion of the southern part of the basin, high-intensity storms were rare. Rainfall events in the southern part of the basin generally lasted many hours, sometimes days. Runoff events in the agriculture-dominated southern part of the basin correspondingly were small. Samples were collected near the maximum, the minimum, and throughout the entire range of flows at all sites.

### Suspended Sediment

Suspended-sediment concentrations measured during events were much lower in 1999 than in 1998. Suspended-sediment concentrations, some as low as 1 mg/L, were determined for samples collected under the ice at the Upper Tamarack River in December 1998. Concentrations less than 10 mg/L were typical during base flow across the basin, and even various samples collected during small events had concentrations below 10 mg/L. The highest suspended-sediment concentration measured in water year 1999 was 64 mg/L at the forested Upper Tamarack River (compared to the 424 mg/L measured at the Kinnickinnic River in 1998). The majority of the suspended sediment in base-flow samples was fine grained (less than 0.062 mm), whereas suspended sediment in runoff samples primarily was composed of particles coarser than 0.062 mm. The volume-weighted concentrations (total load divided by total flow) of suspended sediment were highest in the Sunrise River (24.8 mg/L) and Trade River (24.6 mg/L).

### Phosphorus

Concentrations of total phosphorus were highest during the small events at tributaries in the southern, agricultural part of the basin and all year at the Sunrise River, which drains a mixed agricultural, urban, and forested basin. Concentrations in 9 of the 12 samples from the Sunrise River were greater than 0.1 mg/L, even during base flow. The average phosphorus concentration at the Sunrise was 0.12 mg/L. Only 16 samples from all 9 other tributaries had concentrations greater than 0.1 mg/L in water year 1999. Of those 16 samples, 5 were collected at the Kinnickinnic River, 4 at the Willow River, and 3 each from the Snake and Upper Tamarack Rivers.

The highest total phosphorus concentration (0.492 mg/L) collected in the basin in water year 1999 came from the Apple River on October 23 and was almost entirely in the particulate form. The next highest concentration (0.264 mg/L) came from the Willow River during a spring event, and nearly half was in the dissolved form. Generally, more particulate phosphorus

**Table 2.** Summary of selected water-quality characteristics analyzed by the U.S. Geological Survey, St. Croix River tributary synoptic sampling sites, 1997–99

[°C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; mm, millimeter; <, less than; %, percent]

| Constituent | Upper Tamarack River near Markville, Minn. | | | Lower Tamarack River near Markville, Minn. | | | Wood River near Grantsburg, Wis. | | | Trade River near Trade River, Wis. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Minimum-maximum | Median | Number of samples | Minimum-maximum | Median | Number of samples | Minimum-maximum | Median | Number of samples | Minimum-maximum | Median | Number of samples |
| Temperature, water (°C) | -0.1–23.1 | 10 | 19 | -0.1–25.5 | 11.0 | 18 | 0–27.4 | 10.8 | 20 | 0.8–21.8 | 9.3 | 21 |
| Specific conductance (µS/cm) | 40–358 | 109 | 19 | 40–257 | 112 | 18 | 129–267 | 202 | 20 | 140–242 | 189 | 21 |
| Oxygen, dissolved (mg/L) | 5.0–18.2 | 10.5 | 18 | 5.6–15 | 9.7 | 17 | 5.4–13.8 | 9.8 | 19 | 5.1–14 | 10.8 | 20 |
| pH, water, field (standard units) | 6.4–7.9 | 7.4 | 19 | 6.3–7.7 | 7.25 | 18 | 7.3–7.9 | 7.6 | 19 | 7.1–8 | 7.7 | 21 |
| Nitrogen, ammonia, dissolved (mg/L as N) | <.02–.192 | .05 | 19 | <.02–134 | .054 | 19 | <.02–.148 | .072 | 20 | <.02–.33 | .09 | 21 |
| Nitrogen, nitrite, dissolved (mg/L as N) | <.01–.014 | <.01 | 19 | <.01–013 | <.01 | 19 | <.01–.021 | <.01 | 20 | <.01–.022 | <.01 | 21 |
| Nitrogen, ammonia + organic, dissolved (mg/L as N) | .43–1.6 | .97 | 19 | .35–1.3 | .89 | 19 | .29–.78 | .58 | 20 | .29–.8 | .47 | 21 |
| Nitrogen, ammonia + organic, total (mg/L as N) | .38–3.1 | 1.26 | 19 | .36–2.3 | 1.15 | 19 | .28–1.6 | .81 | 20 | .05–1.5 | .68 | 21 |
| Nitrogen, nitrite plus nitrate, dissolved (mg/L as N) | <.05–2.7 | .285 | 19 | <.05–.518 | .141 | 19 | <.05–.317 | .174 | 20 | .103–.49 | .297 | 21 |
| Phosphorus, total (mg/L as P) | <.01–.124 | .049 | 20 | .019–093 | .052 | 19 | .018–.098 | .061 | 20 | 017–.22 | .061 | 21 |
| Phosphorus, dissolved (mg/L as P) | <.01–.044 | .023 | 19 | .014–.051 | .026 | 19 | <.01–.046 | .02 | 20 | <.01–.03 | .015 | 21 |
| Phosphorus ortho, dissolved (mg/L as P) | <.01–.032 | .013 | 19 | <.01–.03 | .016 | 19 | <.01–.035 | .015 | 20 | <.01–.031 | .015 | 21 |
| Chloride, dissolved (mg/L as Cl) | .56–12 | 3.34 | 15 | .05–6.6 | 1.95 | 15 | 3.3–6.6 | 5.2 | 14 | 3.6–13 | 5.1 | 14 |
| Sediment, suspended (mg/L) | 1–64 | 13.7 | 18 | 2–26 | 9.3 | 18 | 4–53 | 16.4 | 19 | 3–204 | 33 | 20 |
| Sediment, suspended, % finer than 0.062 mm | 22–96 | 69 | 18 | 67–100 | 85 | 18 | 21–93 | 67 | 19 | 31–96 | 74 | 19 |

| Constituent | Apple River near Somerset, Wis. | | | Willow River near Burkhart, Wis. | | | Kinnickinnic River near River Falls, Wis. | | |
|---|---|---|---|---|---|---|---|---|---|
| | Minimum-maximum | Median | Number of samples | Minimum-maximum | Median | Number of samples | Minimum-maximum | Median | Number of samples |
| Temperature, water (°C) | 0–23 | 10.7 | 20 | 1.1–23.1 | 11.7 | 19 | 0.05–21.3 | 10.6 | 20 |
| Specific conductance (µS/cm) | 173–430 | 270 | 19 | 171–427 | 353 | 19 | 228–496 | 431 | 20 |
| Oxygen, dissolved (mg/L) | 6.8–16.7 | 10.8 | 19 | 8–15.2 | 10.8 | 18 | 7.5–8.8 | 8.1 | 20 |
| pH, water field (standard units) | 7.6–8.5 | 8.0 | 20 | 7.6–9 | 8.2 | 19 | 7.5–8.8 | 8.1 | 20 |
| Nitrogen, ammonia, dissolved (mg/L as N) | <.02–.126 | .048 | 20 | <.02–.298 | .087 | 19 | <.02–2.27 | .138 | 20 |
| Nitrogen, nitrite, dissolved (mg/L as N) | <.01–.052 | .0121 | 20 | .01–.053 | .026 | 19 | <.01–.051 | .020 | 20 |
| Nitrogen, ammonia + organic, dissolved (mg/L as N) | .24–.69 | .36 | 20 | .18–1.2 | .422 | 19 | .05–5.3 | .483 | 20 |
| Nitrogen, ammonia + organic, total (mg/L as N) | .21–.74 | .46 | 20 | .28–1.6 | .70 | 19 | .05–5.5 | .662 | 20 |
| Nitrogen, nitrite plus nitrate, dissolved (mg/L as N) | .439–1.43 | .835 | 20 | .731–4.36 | 2.29 | 19 | 1.70–5.74 | 4.51 | 20 |
| Phosphorus, total (mg/L as P) | .024–.492 | .071 | 25 | .013–.264 | .089 | 24 | .046–1.32 | .154 | 23 |
| Phosphorus, dissolved (mg/L as P) | <.01–.057 | .025 | 20 | <.01–.12 | .038 | 19 | .049–1.03 | .120 | 20 |
| Phosphorus ortho, dissolved (mg/L as P) | <.01–.038 | .0176 | 20 | <.01–.073 | .03 | 19 | .03–.928 | .103 | 20 |
| Chloride, dissolved (mg/L as Cl) | 6.8–13 | 7.8 | 14 | 7.9–91 | 17.8 | 14 | 13–17 | 16.3 | 14 |
| Sediment, suspended (mg/L) | 2–13 | 4.6 | 20 | 3–414 | 32 | 18 | 3–424 | 64 | 19 |
| Sediment, suspended, % finer than .062 mm | 44–100 | 81 | 20 | 25–100 | 84 | 18 | 32–97 | 68 | 19 |

**Table 3.** Summary of selected water-quality constituents at Minnesota Pollution Control Agency, St. Croix River tributary synoptic sampling sites, Minnesota,1998–99
[mg/L, milligrams per liter]

| Constituent | Kettle River, Minn. | | | Snake River, Minn. | | | Sunrise River, Minn. | | |
|---|---|---|---|---|---|---|---|---|---|
| | Minimum-maximum | Median | Number of samples | Minimum-maximum | Median | Number of samples | Minimum-maximum | Median | Number of samples |
| Nitogen, ammonia + organic, dissolved (mg/L) | 0.36–1.29 | 0.85 | 15 | 0.62–1.47 | 0.94 | 15 | 0.63–1.45 | 1.03 | 15 |
| Phosphorus, total (mg/L) | .03–.12 | .06 | 15 | .04–.15 | .07 | 18 | .06–.18 | .12 | 15 |
| Chloride, dissolved (mg/L) | 2.8–8.9 | 3.9 | 10 | 3.5–10.0 | 5.4 | 10 | 11.0–17.0 | 13.5 | 10 |
| Sediment, suspended (mg/L) | 1.5–15.0 | 5.2 | 12 | 1.6–10.0 | 4.7 | 14 | 1.0–46.0 | 15.0 | 12 |

**Table 4.** Summary of selected water-quality constituents at long-term monitoring sites on the St. Croix River, Wisconsin and Minnesota, October 1998 to December 1999
[°C, degrees Celsius; µS/cm, microsiemens per centimeter; µg/L, micrograms per liter; mg/L, milligram per liter; mm, millimeter; <, less than; %, percent]

| Constituent | St. Croix River near Danbury, Wis. | | | St. Croix River at St. Croix Falls, Wis. | | |
|---|---|---|---|---|---|---|
| | Minimum–Maximum | Median | Number of samples | Minimum–Maximum | Median | Number of samples |
| Temperature, water (°C) | -0.1–25.3 | 10.3 | 19 | -0.12–4.9 | 9.6 | 16 |
| Specific conductance (µS/cm) | 48–156 | 110 | 19 | 114–217 | 168 | 15 |
| Oxygen, dissolved (mg/L) | 4.8–14.2 | 9.4 | 16 | 6.3–26 | 10.5 | 16 |
| pH, water, field (standard units) | 6.6–7.9 | 7.4 | 19 | 7.1–8.4 | 7.6 | 16 |
| Alkalinity, dissolved field (mg/L as $CaCO_3$) | 20–74 | 49.5 | 16 | 49–97 | 74 | 15 |
| Bicarbonate, dissolved field (mg/L as $HCO_3$) | 25–90 | 61.2 | 17 | 60–119 | 91 | 15 |
| Nitrogen, ammonia, dissolved (mg/L as N) | <.02–.065 | .20 | 18 | <.02–.094 | .032 | 16 |
| Nitrogen, nitrite, dissolved (mg/L as N) | <.01 | <.01 | 18 | <.01–.018 | <.01 | 16 |
| Nitrogen, ammonia + organic, dissolved (mg/L as N) | .15–1.5 | .40 | 18 | .22–.76 | .43 | 16 |
| Nitrogen, ammonia + organic, total (mg/L as N) | .21–.95 | .45 | 19 | .29–.95 | .59 | 16 |
| Nitrogen, nitrite plus nitrate, dissolved (mg/L as N) | <.05–.214 | .090 | 19 | .087–.445 | .203 | 16 |
| Phosphorus, total (mg/L as P) | <.008–.081 | .031 | 19 | .012–.081 | .042 | 16 |
| Phosphorus, dissolved (mg/L as P) | .004–.021 | .011 | 18 | <.004–.037 | .020 | 16 |
| Phosphorus, ortho, dissolved (mg/L as P) | <.01–.025 | <.01 | 18 | <.01–.257 | .026 | 16 |
| Carbon, organic, dissolved (mg/L as C) | 2.9–20 | 9.1 | 19 | 3.2–20 | 9.5 | 16 |
| Carbon, organic suspended, total (mg/L as C) | .2–2.2 | .65 | 19 | <.20–2.6 | .7 | 15 |
| Magnesium, dissolved (mg/L as Mg) | 2.4–5.8 | 4.5 | 18 | 4.8–9.7 | 7.0 | 16 |
| Sodium, dissolved (mg/L as Na) | 1.2–2.8 | 2.4 | 18 | 2.5–4.2 | 3.5 | 16 |
| Chloride, dissolved (mg/L as Cl) | <.1–3.9 | 2.40 | 19 | 2.4–5.5 | 4.3 | 16 |
| Sulfate, dissolved (mg/L as $SO_4$) | 1.5–5.7 | 3.7 | 19 | .95–6.3 | 3.9 | 16 |
| Fluoride, dissolved (mg/L as F) | <.1 | <.1 | 18 | <.1 | <.1 | 16 |
| Silica, dissolved (mg/L as $SiO_2$) | 8–16 | 11.4 | 18 | 8.1–17 | 12.1 | 16 |
| Iron, dissolved (µg/L as Fe) | 88–790 | 254 | 18 | 88–940 | 306 | 16 |
| Manganese, dissolved (µg/L as Mn) | 7.9–85 | 21.8 | 18 | 15–57 | 29 | 16 |
| Solids, residue at 180°C, dissolved (mg/L) | 71–104 | 90.7 | 19 | 96–140 | 121 | 16 |
| Sediment, suspended (mg/L) | 1–26 | 7.6 | 19 | 2–18 | 7.2 | 12 |
| Sediment, suspended, % finer than 0.062 mm | 40–100 | 76 | 19 | 50–100 | 89 | 12 |

was collected during events, whereas 50 to 100 percent of the phosphorus was in the dissolved form in base-flow samples. Volume-weighted concentrations of total phosphorus were greatest at the Sunrise River (0.118 mg/L) followed by the Kinnickinnic (0.096 mg/L), Willow (0.084 mg/L), Snake (0.083 mg/L), and Kettle (0.070 mg/L) Rivers.

### Nitrogen

The highest total nitrogen concentration measured in 1999 was 3.10 mg/L at the Upper Tamarack River on June 10. Concentrations between 2 and 3 mg/L were collected at the Upper Tamarack River in April and May, and at the Lower Tamarack River in April, May, and June. Both basins have numerous bogs. All other samples had concentrations less than 2 mg/L. Most of the nitrogen was in the dissolved form, except during the events mentioned previously, when only one-half to one-third of the nitrogen was in the dissolved form. Total nitrogen concentrations demonstrated seasonality, the highest concentrations were collected in the spring and summer.

Although the highest total nitrogen concentrations were found at the northern forested sites in water year 1999, concentrations of the nitrite form of nitrogen were highest in tributaries in the agricultural southern part of the basin, including the Apple (0.052 mg/L), Willow (0.037 mg/L), and Kinnickinnic (0.027 mg/L) Rivers. Nitrogen concentrations varied little with flow in all tributaries so the volume-weighted concentrations show similar trends as the measured concentrations.

## Comparison to 1998 Concentrations

Concentrations of nutrients and suspended sediments in 1999 generally were higher in the northern, forested tributaries and lower in the southern, agricultural and mixed agricultural tributaries when compared to those measured in 1998. The highest suspended-sediment concentration in water year 1999 (64 mg/L) was collected at the Upper Tamarack River in the northern-forested part of the basin during a June runoff event. The highest suspended-sediment concentration measured during any 1998 event at that site was 15 mg/L. Similar patterns in suspended-sediment and nutrient concentration were found for all northern sites; much higher in 1999 than in 1998.

Concentrations in the tributaries in the southern part of the basin demonstrated just the opposite pattern between years. There were no major events in the southern part of the basin in 1999, and concentrations were lower than those in measured 1998. The Kinnickinnic River in the southern part of the basin had the highest suspended-sediment concentration sampled in 1999, but was only 56 mg/L (compared to 424 mg/L in a sample collected during a large summer storm event in 1998).

The Upper Tamarack, Lower Tamarack, Kettle, and Snake Rivers in the northern, forested areas had the most variability in flow and concentration in 1999, whereas the Sunrise River had consistently high nutrient concentrations. Tributaries in the southern part of the basin (Kinnickinnic and Willow Rivers) in the agricultural areas showed highly variable flows and concentrations in 1998; however, because of minimal runoff in 1999, flows were much less variable and concentrations consistently were lower than in 1998. These data are good examples of the disparity among concentrations in the basin from the northern, forested areas to the southern, agricultural areas and from 1998 to 1999.

## 1999 Benthic-Invertebrate Sampling

Diverse populations of invertebrates were found throughout the basin. The five most common families of benthic invertebrates identified at each stream are given in appendix 7. The most commonly found families of benthic invertebrates in the basin were Hydropsychidae, Elmidae, Baetidae, and Chironomidae. Benthic-invertebrate taxonomic data were used to calculate the following water-quality indices: Biotic Index (Hilsenhoff, 1982, 1987); Family-level Biotic Index (Hilsenhoff, 1988); Mean Tolerance Value (Lillie and Schlesser, 1994); Shannon-Weaver Diversity Index (Shannon and Weaver, 1949); number of Ephemeroptera, Plecoptera, Trichoptera individuals and genera; number of species; and number of genera (table 5).

Benthic-invertebrate indices indicated no water-quality effects in all but three St. Croix tributaries. Valley Creek and Willow River have diminished invertebrate population health based on species abundance (16 and 12), genera abundance (13 and 12), and diversity measures (3.02 and 2.43). Biotic indices (7.43) results indicated that the Kettle River was affected by excessive nutrients. Although the number of individuals (31) was similar to many other tributaries, the diversity (2.18) at

**Table 5.** Benthic invertebrate water-quality measures calculated for selected tributaries to the St. Croix River, Wisconsin and Minnesota, September 1999

[EPT, Ephemeroptera, Plecoptera, and Trichoptera]

| Stream names | Hilsenhoff Biotic Index | Hilsenhoff Biotic Index water-quality class | Hilsenhoff Family-Level Biotic Index | Mean tolerance value | Shannon-Weaver Diversity Index | Number of EPT genera | Number of EPT individuals | Number of species | Number of genera |
|---|---|---|---|---|---|---|---|---|---|
| Apple River near Somerset, Wis. | 3.90 | Very Good | 4.03 | 4.24 | 4.02 | 20 | 435 | 50 | 41 |
| Browns Creek at Stillwater, Minn. | 3.74 | Very Good | 3.99 | 4.00 | 3.28 | 8 | 118 | 22 | 19 |
| Clam River near Webster, Wis. | 5.54 | Good | 4.11 | 4.73 | 3.21 | 13 | 159 | 29 | 28 |
| Crooked Creek near Hinckley, Minn. | 3.19 | Excellent | 3.58 | 3.10 | 4.13 | 19 | 95 | 35 | 33 |
| Kettle River below Sandstone, Minn. | 7.43 | Fairly Poor | 6.64 | 5.96 | 2.18 | 10 | 38 | 31 | 28 |
| Kinnickinnic River near River Falls, Wis. | 3.42 | Excellent | 4.04 | 3.52 | 3.79 | 11 | 101 | 31 | 22 |
| Lower Tamarack River near Markville, Minn. | 3.33 | Excellent | 3.41 | 3.55 | 4.19 | 21 | 98 | 36 | 33 |
| Sand Creek near Hinckley, Minn. | 2.99 | Excellent | 3.48 | 2.88 | 4.36 | 21 | 119 | 41 | 36 |
| Snake River near Pine City, Minn. | 4.91 | Good | 4.60 | 4.59 | 3.34 | 10 | 178 | 23 | 23 |
| Sunrise River at Sunrise, Minn. | 3.00 | Excellent | 3.62 | 3.60 | 4.53 | 19 | 155 | 39 | 32 |
| Trade River near Trade River, Wis. | 2.98 | Excellent | 3.23 | 3.23 | 4.08 | 15 | 77 | 33 | 29 |
| Upper Tamarack River near Markville, Minn. | 2.56 | Excellent | 3.08 | 3.26 | 4.48 | 26 | 121 | 46 | 42 |
| Valley Creek at Afton, Minn. | 3.53 | Very Good | 3.84 | 4.18 | 3.02 | 6 | 142 | 16 | 13 |
| Willow River at Burkhardt, Wis. | 5.31 | Good | 4.17 | 5.46 | 2.43 | 2 | 78 | 12 | 12 |
| Wood River near Grantsburg, Wis. | 5.56 | Good | 4.71 | 5.35 | 3.78 | 12 | 159 | 34 | 29 |
| Yellow River near Danbury, Wis. | 3.74 | Very Good | 3.79 | 4.44 | 4.50 | 19 | 196 | 42 | 39 |

Kettle River also was low. The Kettle and Wood Rivers were sampled from woody debris rather than gravel riffles because gravel or cobble substrates were not available in the reach near the sample site. Therefore, habitat effects could be a factor in the benthic invertebrate measures at these streams (Shepard, 2001; Hooper, 1993).

## NUTRIENT AND SUSPENDED-SEDIMENT LOADING IN THE ST. CROIX NATIONAL SCENIC RIVERWAY

Loads at the monitored tributaries were calculated by use of water-quality data from 1997 to 1999, flow data from 1999, and the USGS computer program Estimator. Annual loads and yields for water year 1999 from these monitored basins are listed in table 6 and shown in figure 4. In general, the tributaries with the largest drainage areas had the largest calculated loads. Loads transported during events were a large proportion of the annual load for many tributaries.

Annual yields from unmonitored tributaries were estimated from relations found between annual yields and the environmental characteristics of the monitored basins and the environmental characteristics of the individual unmonitored basins. Stepwise regressions indicated that annual nutrient and suspended-sediment yields were most strongly related to runoff, percentage of clay, permeability of the soil, soil erodibility, and basin slope. Also important were drainage area and the percentage of urban land use and wetlands in a basin. Fallon and McNellis (2000) found similar relations between nutrient and suspended-sediment yields during snowmelt and percentage clay and permeability of soil in their 1997 synoptic study.

Annual loads and yields estimated from regression equations using the environmental characteristics of the unmonitored tributaries are listed in table 6 and shown in figure 4, along with those calculated by use of the USGS computer program Estimator at monitored basins. Data are subdivided into quartiles in the figures. The range of the 95-percent confidence limits of loads and yields often were quite large because of the weakness of some of these relations (table 6). Errors of greater than 100 percent were not uncommon for the estimates at unmonitored tributaries. Volume-weighted concentrations are given in table 7.

Annual suspended-sediment loads in the tributaries were highest at the St. Croix River at Danbury (7,100,000 kg), Kettle (5,970,000 kg), Sunrise (3,690,000 kg), and Snake (3,050,000 kg) Rivers, whereas annual suspended-sediment yields were highest at the Sunrise (8,400 kg/km$^2$), Sand (7,860 kg/km$^2$), and Upper Tamarack (6,350 kg/km$^2$) Rivers. Annual total phosphorus loads were highest at Kettle (43,400 kg), Snake (37,400 kg), Apple (25,800 kg), and Sunrise (17,500 kg) Rivers, whereas Sunrise (39.9 kg/km$^2$), Upper Tamarack (22.4 kg/km$^2$), and Kinnickinnic (21.2 kg/km$^2$) Rivers had the highest annual total phosphorus yields (table 6).

Nitrogen data were not collected at the Sunrise, Snake, and Kettle Rivers. Of the other tributaries monitored, the Apple and Lower Tamarack Rivers were major contributors of ammonia and organic nitrogen, whereas the Upper Tamarack, Lower Tamarack, and Wood Rivers were the tributaries with the highest annual total nitrogen yields. The tributaries in the southern, agricultural part of the basin (Kinnickinnic, Willow, and Apple Rivers) were those with the highest annual nitrate and nitrite loads and yields. The Sunrise River had the highest annual suspended-sediment and total phosphorus yields of the monitored tributaries in 1999.

### Relation Between Streamflow and Tributary Loading

Examination of the hydrographs and concentrations of samples collected through the 1999 water year (fig. 5) helps to better explain why 1999 annual loads from the northern, forested basins were higher than loads from the southern, agricultural basins. A large portion of the annual loading to the St. Croix River tributaries comes from storm runoff events. Most of the 1999 loading from the northern, forested sites occurred during runoff-producing storm events when flows were orders of magnitude above base flow and concentrations were elevated as much as 10 to 50 times above base-flow levels. Runoff-producing events were fewer and smaller in the southern part of the basin in 1999 resulting in increases in flows that were less than double base flow and concentrations only slightly above base- flow levels. The southern tributaries had small annual loads in 1999 because of the lack of runoff events at those tributaries.

The Upper Tamarack River had the highest suspended-sediment and nutrient concentrations and yields of the northern tributaries. Loading at the Upper Tamarack River, similar to most of the loading from the small northern tributaries, was driven by runoff during events.

**Table 6a.** Calculated and estimated 1999 annual sediment and nutrient loads of St. Croix River Tributaries, Wisconsin and Minnesota

[The best value is from Estimator or from a regression equation. The error represents the 95th-percent confidence range from Estimator or the regression equation. Max and min refer to the upper and lower 95th- percent confidence limits (best value plus or minus the error). All data are annual loads for water year 1999; USGS, U.S. Geological Survey, MPCA, Minnesota Pollution Control Agency; kg/yr, kilograms per year; best, best statistical estimate; error, standard error of prediction; NA, not available]

| | | Sediment | | | | Phosphorus, total | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Annual load (kg/yr) | | | | Annual load (kg/yr) | | | |
| Sample locations | Agency | best | error | max | min | best | error | max | min |
| Kinnickinnic River near River Falls, Wis. | USGS | 1,420,000 | 469,000 | 1,890,000 | 949,000 | 9,520 | 1,940 | 11,500 | 7,580 |
| Valley Creek at Afton, Minn. | Estimated | 1,840,000 | 162,000 | 346,000 | 21,300 | 748 | 714 | 1,460 | 34 |
| Willow River at Burkhardt, Wis. | USGS | 1,300,000 | 401,000 | 1,700,000 | 897,000 | 10,300 | 2,540 | 12,800 | 7,720 |
| Browns Creek at Stillwater, Minn. | Estimated | 280,000 | 292,000 | 572,000 | 0 | 2,950 | 1,640 | 4,580 | 1,310 |
| Silver Creek near Stillwater, Minn. | Estimated | 45,400 | 69,900 | 115,000 | 0 | 306 | 274 | 581 | 32 |
| Apple River near Somerset, Wis. | USGS | 1,810,000 | 346,000 | 2,150,000 | 1,460,000 | 25,800 | 5,600 | 31,400 | 20,200 |
| Little Carnelian Lake outlet near Stillwater, Minn. | Estimated | 24,500 | 37,900 | 62,300 | 0 | 65 | 136 | 201 | 0 |
| Trade River near Trade River, Wis. | USGS | 1,690,000 | 1,470,000 | 3,160,000 | 228,000 | 3,700 | 1,400 | 5,100 | 2,300 |
| Sunrise River at Sunrise, Minn. | MPCA | 3,690,000 | 2,710,000 | 6,400,000 | 982,000 | 17,500 | 3,360 | 20,900 | 14,200 |
| Wood River near Grantsburg, Wis. | USGS | 945,000 | 227,000 | 1,170,000 | 717,000 | 3,530 | 658 | 4,180 | 2,870 |
| Snake River near Pine City, Minn. | MPCA | 3,050,000 | 1,270,000 | 4,320,000 | 1,780,000 | 37,400 | 7,970 | 45,400 | 29,500 |
| Kettle River below Sandstone, Minn. | MPCA | 5,970,000 | 2,320,000 | 8,290,000 | 3,660,000 | 43,400 | 8,430 | 51,800 | 34,940 |
| Lower Tamarack River near Markville, Minn. | USGS | 1,600,000 | 519,000 | 2,120,000 | 1,080,000 | 8,100 | 1,680 | 9,780 | 6,420 |
| Sand Creek near Hinckley, Minn. | Estimated | 2,230,000 | 1,180,000 | 3,410,000 | 1,050,000 | 4,490 | 3,540 | 8,030 | 948 |
| Crooked Creek near Hinckley, Minn. | Estimated | 1,190,000 | 774,000 | 1,960,000 | 413,000 | 4,140 | 2,990 | 7,130 | 1,140 |
| Clam River near Webster, Wis. | Estimated | 1,750,000 | 3,110,000 | 4,850,000 | 0 | 7,740 | 11,500 | 19,300 | 0 |
| Upper Tamarack River near Markville, Minn. | USGS | 1,560,000 | 974,000 | 2,530,000 | 581,000 | 5,490 | 1,500 | 6,990 | 4,000 |
| Yellow River near Danbury, Wis. | Estimated | 1,400,000 | 3,330,000 | 4,730,000 | 0 | 12,600 | 14,100 | 26,800 | 0 |
| Namekagon River near Leonards, Wis.[1] | USGS | 520,000 | 104,000 | 624,00 | 415,000 | 1,570 | 651 | 2,220 | 918 |
| St. Croix River near Danbury, Wis.[2] | USGS | 7,100,000 | 2,120,000 | 9,210,000 | 4,970,000 | 16,900 | 6,370 | 23,300 | 10,500 |
| St. Croix River at St. Croix Falls, Wis.[2] | USGS | 35,600,000 | 8,880,000 | 44,500,000 | 26,700,000 | 118,000 | 40,100 | 159,000 | 78,400 |

[1]Loads calculated with 1996–98 data, calculated with 1999 flows.

[2]Loads calculated with 1997–99 data, calculated with 1999 flows.

[3]Because many concentration values were less than the detection limit, the estimated loads were negative and, therefore, set to 0.

**Table 6a.** Calculated and estimated 1999 annual sediment and nutrient loads of St. Croix Tributaries, Wisconsin and Minnesota—Continued

[The best value is from Estimator or from a regression equation. The error represents the 95th-percent confidence range from Estimator or the regression equation. Max and min refer to the upper and lower 95th-percent confidence limits (best value plus or minus the error). All data are annual yields for water year 1999; kg/yr, kilograms per year; best, best statistical estimate; error, standard error of prediction; NA, not available]

| | Phosphorus, dissolved | | | | Phosphorus ortho, dissolved | | | |
|---|---|---|---|---|---|---|---|---|
| | Annual load (kg/yr) | | | | Annual load (kg/yr) | | | |
| Sample locations | best | error | max | min | best | error | max | min |
| Kinnickinnic River near River Falls, Wis. | 7,340 | 1,740 | 9,100 | 5,600 | 6,510 | 1,810 | 8,320 | 4,700 |
| Valley Creek at Afton, Minn. | 501 | 492 | 994 | 9 | 267 | 362 | 629 | 0 |
| Willow River at Burkhardt, Wis. | 4,170 | 1,900 | 6,060 | 2,270 | 3,490 | 1,150 | 4,650 | 2,340 |
| Browns Creek at Stillwater, Minn. | 912 | 896 | 1,810 | 16 | 539 | 654 | 1,190 | 0 |
| Silver Creek near Stillwater, Minn. | 204 | 200 | 404 | 4 | 27 | 163 | 190 | 0 |
| Apple River near Somerset, Wis. | 10,300 | 2,000 | 12,300 | 8,260 | 7,550 | 1,870 | 9,420 | 5,670 |
| Little Carnelian Lake outlet near Stillwater, Minn. | 110 | 108 | 218 | 2 | 13 | 89 | 101 | 0 |
| Trade River near Trade River, Wis. | 1,090 | 286 | 1,380 | 805 | 916 | 193 | 1,110 | 723 |
| Sunrise River at Sunrise, Minn. | NA | NA | NA | NA | NA | NA | NA | NA |
| Wood River near Grantsburg, Wis. | 1,140 | 193 | 1,330 | 946 | 905 | 200 | 1,110 | 705 |
| Snake River near Pine City, Minn. | NA | NA | NA | NA | NA | NA | NA | NA |
| Kettle River below Sandstone, Minn. | 2,480 | 587 | 3,060 | 1,890 | NA | NA | NA | NA |
| Lower Tamarack River near Markville, Minn. | 3,850 | 701 | 4,550 | 3,150 | 2,180 | 386 | 2,570 | 1,800 |
| Sand Creek near Hinckley, Minn. | 0[3] | 3,430 | 2,480 | 0 | 555 | 2,150 | 2,710 | 0 |
| Crooked Creek near Hinckley, Minn. | 1,260 | 2,290 | 3,560 | 0 | 71 | 1,910 | 1,980 | 0 |
| Clam River near Webster, Wis. | 6,450 | 8,740 | 15,200 | 0 | 1,770 | 6,950 | 8,720 | 0 |
| Upper Tamarack River near Markville, Minn. | 2,480 | 587 | 3,060 | 1,890 | 1,140 | 272 | 1,410 | 863 |
| Yellow River near Danbury, Wis. | 6,550 | 8,870 | 15,400 | 0 | 0[3] | 8,480 | 5,530 | 0 |
| Namekagon River near Leonards, Wis.[1] | 872 | 515 | 1,390 | 357 | 905 | 422 | 1,330 | 483 |
| St. Croix River near Danbury, Wis.[2] | 11,500 | 1,750 | 13,200 | 9,780 | 12,000 | 2,380 | 14,400 | 9,610 |
| St. Croix River at St. Croix Falls, Wis.[2] | 57,000 | 19,900 | 76,900 | 37,100 | 51,700 | 8,350 | 60,100 | 43,400 |

[1]Loads calculated with 1996–98 data, calculated with 1999 flows.

[2]Loads calculated with 1997–99 data, calculated with 1999 flows.

[3]Because many concentration values were less than the detection limit, the estimated loads were negative and, therefore, set to 0.

**Table 6a.** Calculated and estimated 1999 annual sediment and nutrient loads of St. Croix Tributaries, Wisconsin and Minnesota—Continued

[The best value is from Estimator or from a regression equation. The error represents the 95th-percent confidence range from Estimator or the regression equation. Max and min refer to the upper and lower 95th- percent confidence limits (best value plus or minus the error). All data are annual yields for water year 1999; kg/yr, kilograms per year; best, best statistical estimate; error, standard error of prediction; NA, not available]

| | Nitrogen, ammonia, dissolved | | | | Nitrogen, nitrite, dissolved | | | |
|---|---|---|---|---|---|---|---|---|
| | Annual load (kg/yr) | | | | Annual load (kg/yr) | | | |
| Sample locations | best | error | max | min | best | error | max | min |
| Kinnickinnic River near River Falls, Wis. | 3,140 | 2,220 | 5,360 | 925 | 1,940 | 436 | 2,370 | 1,500 |
| Valley Creek at Afton, Minn. | 2,270 | 10,500 | 12,800 | 0 | 2,150 | 7,350 | 9,510 | 0 |
| Willow River at Burkhardt, Wis. | 8,240 | 2,830 | 11,100 | 5,410 | 3,060 | 644 | 3,700 | 2,420 |
| Browns Creek at Stillwater, Minn. | 0[3] | 27,400 | 20,400 | 0 | 0[3] | 19,200 | 12,000 | 0 |
| Silver Creek near Stillwater, Minn. | 451 | 5,340 | 5,790 | 0 | 1,220 | 3,750 | 4,960 | 0 |
| Apple River near Somerset, Wis. | 19,800 | 5,650 | 25,400 | 14,100 | 5,130 | 1,450 | 6,580 | 3,690 |
| Little Carnelian Lake outlet near Stillwater, Minn. | 503 | 3,060 | 3,560 | 0 | 908 | 2,140 | 3,050 | 0 |
| Trade River near Trade River, Wis. | 4,500 | 2,080 | 6,580 | 2,430 | 723 | 157 | 880 | 565 |
| Sunrise River at Sunrise, Minn. | NA | NA | NA | NA | NA | NA | NA | NA |
| Wood River near Grantsburg, Wis. | 4,110 | 1,290 | 5,400 | 2,830 | 515 | 129 | 643 | 386 |
| Snake River near Pine City, Minn. | NA | NA | NA | NA | NA | NA | NA | NA |
| Kettle River below Sandstone, Minn. | NA | NA | NA | NA | NA | NA | NA | NA |
| Lower Tamarack River near Markville, Minn. | 7,360 | 2,830 | 10,200 | 4,530 | 759 | 1,380 | 2,140 | 0 |
| Sand Creek near Hinckley, Minn. | 93,600 | 59,300 | 153,000 | 34,200 | 71,700 | 41,600 | 113,000 | 30,100 |
| Crooked Creek near Hinckley, Minn. | 73,500 | 50,900 | 124,000 | 22,500 | 57,600 | 35,700 | 93,300 | 21,900 |
| Clam River near Webster, Wis. | 78,900 | 194,000 | 273,000 | 0 | 77,300 | 136,000 | 213,000 | 0 |
| Upper Tamarack River near Markville, Minn. | 4,100 | 2,490 | 6,590 | 1,610 | 310 | 630 | 940 | 0 |
| Yellow River near Danbury, Wis. | 0[3] | 224,000 | 152,000 | 0 | 0[3] | 157,000 | 132,000 | 0 |
| Namekagon River near Leonards, Wis.[1] | 2,740 | 1,070 | 3,800 | 1,670 | 1,050 | 315 | 1,370 | 736 |
| St. Croix River near Danbury, Wis.[2] | 26,400 | 7,080 | 33,500 | 19,400 | 7,080 | 3,260 | 10,300 | 3,820 |
| St. Croix River at St. Croix Falls, Wis.[2] | 174,000 | 59,400 | 233,000 | 114,000 | 29,200 | 10,000 | 39,200 | 19,200 |

[1]Loads calculated with 1996–98 data, calculated with 1999 flows.

[2]Loads calculated with 1997–99 data, calculated with 1999 flows.

[3]Because many concentration values were less than the detection limit, the estimated loads were negative and, therefore, set to 0.

**Table 6a.** Calculated and estimated 1999 annual sediment and nutrient loads of St. Croix Tributaries, Wisconsin and Minnesota—Continued

[The best value is from Estimator or from a regression equation. The error represents the 95th-percent confidence range from Estimator or the regression equation. Max and min refer to the upper and lower 95th-percent confidence limits (best value plus or minus the error). All data are annual yields for water year 1999; kg/yr, kilograms per year; best, best statistical estimate; error, standard error of prediction; NA, not available]

| | Nitrogen, ammonia + organic, dissolved | | | | Nitrogen, ammonia + organic, dissolved, total | | | |
|---|---|---|---|---|---|---|---|---|
| | Annual load (kg/yr) | | | | Annual load (kg/yr) | | | |
| Sample locations | best | error | max | min | best | error | max | min |
| Kinnickinnic River near River Falls, Wis. | 22,800 | 9,250 | 32,000 | 13,500 | 34,700 | 11,400 | 46,100 | 23,400 |
| Valley Creek at Afton, Minn. | 360 | 311 | 671 | 49 | 37,700 | 14,400 | 52,100 | 23,300 |
| Willow River at Burkhardt, Wis. | 44,100 | 6,830 | 50,900 | 37,300 | 79,300 | 18,100 | 97,400 | 61,200 |
| Browns Creek at Stillwater, Minn. | 0[3] | 875 | 0 | 0 | 83,700 | 37,900 | 122,000 | 45,800 |
| Silver Creek near Stillwater, Minn. | 456 | 156 | 612 | 300 | 8,390 | 6,020 | 14,400 | 2,360 |
| Apple River near Somerset, Wis. | 146,000 | 15,300 | 161,000 | 130,000 | 192,000 | 23,800 | 216,000 | 168,000 |
| Little Carnelian Lake outlet near Stillwater, Minn. | 276 | 86 | 362 | 190 | 2,510 | 3,430 | 5,940 | 0 |
| Trade River near Trade River, Wis. | 29,500 | 3,280 | 32,800 | 26,300 | 3,700 | 1,400 | 5,100 | 2,300 |
| Sunrise River at Sunrise, Minn. | NA | NA | NA | NA | NA | NA | NA | NA |
| Wood River near Grantsburg, Wis. | 33,700 | 3,210 | 36,900 | 30,500 | 46,700 | 7,500 | 54,200 | 39,200 |
| Snake River near Pine City, Minn. | NA | NA | NA | NA | NA | NA | NA | NA |
| Kettle River below Sandstone, Minn. | NA | NA | NA | NA | NA | NA | NA | NA |
| Lower Tamarack River near Markville, Minn. | 128,000 | 17,500 | 146,000 | 111,000 | 178,000 | 43,000 | 221,000 | 135,000 |
| Sand Creek near Hinckley, Minn. | 5,070 | 1,770 | 6,830 | 3,300 | 44,000 | 76,900 | 121,000 | 0 |
| Crooked Creek near Hinckley, Minn. | 4,210 | 1,530 | 5,740 | 2,680 | 0[3] | 65,100 | 54,700 | 0 |
| Clam River near Webster, Wis. | 10,600 | 5,450 | 16,000 | 5,120 | 0[3] | 261,000 | 46,800 | 0 |
| Upper Tamarack River near Markville, Minn. | 95,100 | 13,900 | 109,000 | 81,300 | 125,000 | 36,900 | 162,000 | 88,200 |
| Yellow River near Danbury, Wis. | 5,660 | 5,700 | 11,400 | 0 | 0[3] | 273,000 | 10,200 | 0 |
| Namekagon River near Leonards, Wis.[1] | 28,200 | 4,540 | 32,700 | 23,600 | 40,300 | 3,660 | 43,900 | 36,600 |
| St. Croix River near Danbury, Wis.[2] | 349,000 | 67,900 | 417,000 | 281,000 | 455,000 | 51,800 | 506,000 | 403,000 |
| St. Croix River at St. Croix Falls, Wis.[2] | 1,630,000 | 234,000 | 1,860,000 | 1,390,000 | 2,210,000 | 245,000 | 2,460,000 | 1,970,000 |

[1]Loads calculated with 1996–98 data, calculated with 1999 flows.

[2]Loads calculated with 1997–99 data, calculated with 1999 flows.

[3]Because many concentration values were less than the detection limit, the estimated loads were negative and, therefore, set to 0.

**Table 6a.** Calculated and estimated 1999 annual sediment and nutrient loads of St. Croix Tributaries, Wisconsin and Minnesota—Continued

[The best value is from Estimator or from a regression equation. The error represents the 95th-percent confidence range from Estimator or the regression equation. Max and min refer to the upper and lower 95th-percent confidence limits (best value plus or minus the error). All data are annual yields for water year 1999; kg/yr, kilograms per year; best, best statistical estimate; error, standard error of prediction; NA, not available]

| Sample locations | Nitrogen, nitrite plus nitrate, dissolved | | | | Chloride, dissolved | | | |
|---|---|---|---|---|---|---|---|---|
| | Annual load (kg/yr) | | | | Annual load (kg/yr) | | | |
| | best | error | max | min | best | error | max | min |
| Kinnickinnic River near River Falls, Wis. | 483,000 | 23,400 | 507,000 | 459,000 | 1,620,000 | 53,600 | 1,670,000 | 1,560,000 |
| Valley Creek at Afton, Minn. | 174 | 21 | 195 | 153 | 108,000 | 53,200 | 161,000 | 54,500 |
| Willow River at Burkhardt, Wis. | 286,000 | 69,100 | 355,000 | 216,000 | 1,930,000 | 578,000 | 2,510,000 | 1,350,000 |
| Browns Creek at Stillwater, Minn. | 337 | 38 | 375 | 299 | 205,000 | 97,600 | 303,000 | 108,000 |
| Silver Creek near Stillwater, Minn. | 54 | 9 | 63 | 45 | 26,900 | 20,900 | 47,800 | 6,080 |
| Apple River near Somerset, Wis. | 340,000 | 48,700 | 389,000 | 392,000 | 3,110,000 | 270,000 | 3,380,000 | 2,840,000 |
| Little Carnelian Lake outlet near Stillwater, Minn. | 29 | 5 | 34 | 24 | 14,200 | 11,300 | 25,500 | 2,920 |
| Trade River near Trade River, Wis. | 20,600 | 5,520 | 26,100 | 15,000 | 347,000 | 54,000 | 401,000 | 293,000 |
| Sunrise River at Sunrise, Minn. | NA | NA | NA | NA | NA | NA | NA | NA |
| Wood River near Grantsburg, Wis. | 9,330 | 1,450 | 10,800 | 7,880 | 287,000 | 22,600 | 310,000 | 265,000 |
| Snake River near Pine City, Minn. | NA | NA | NA | NA | NA | NA | NA | NA |
| Kettle River below Sandstone, Minn. | NA | NA | NA | NA | NA | NA | NA | NA |
| Lower Tamarack River near Markville, Minn. | 19,300 | 8,990 | 28,200 | 10,300 | 165,000 | 67,900 | 232,000 | 96,700 |
| Sand Creek near Hinckley, Minn. | 29 | 157 | 185 | 0 | 0[3] | 316,000 | 306,000 | 0 |
| Crooked Creek near Hinckley, Minn. | 0[3] | 136 | 0 | 0 | 0[3] | 284,000 | 158,000 | 0 |
| Clam River near Webster, Wis. | 2,540 | 402 | 2,940 | 2,140 | 1,040,000 | 978,000 | 2,020,000 | 64,300 |
| Upper Tamarack River near Markville, Minn. | 19,100 | 12,300 | 31,500 | 6,760 | 177,000 | 29,900 | 207,000 | 147,000 |
| Yellow River near Danbury, Wis. | 1,860 | 527 | 2,380 | 1,330 | 0[3] | 1,060,000 | 895,000 | 0 |
| Namekagon River near Leonards, Wis.[1] | 15,600 | 5,040 | 20,600 | 10,500 | 394,000 | 89,400 | 483,000 | 304,000 |
| St. Croix River near Danbury, Wis.[2] | 126,000 | 32,600 | 158,000 | 93,100 | 2,900,000 | 478,000 | 3,380,000 | 2,430,000 |
| St. Croix River at St. Croix Falls, Wis.[2] | 822,000 | 185,000 | 1,010,000 | 637,000 | 18,300,000 | 2,310,000 | 20,600,000 | 16,000,000 |

[1]Loads calculated with 1996–98 data, calculated with 1999 flows.

[2]Loads calculated with 1997–99 data, calculated with 1999 flows.

[3]Because many concentration values were less than the detection limit, the estimated loads were negative and, therefore, set to 0.

**Table 6b.** Calculated and estimated 1999 annual sediment and nutrient yields of St. Croix River Tributaries, Wisconsin and Minnesota

[The best value is from Estimator or from a regression equation. The error represents the 95th-percent confidence range from Estimator or the regression equation. Max and min refer to the upper and lower 95th- percent confidence limits (best value plus or minus the error). All data are annual yields for water year 1999; USGS, U.S. Geological Survey, MPCA, Minnesota Pollution Control Agency; $kg/km^2/yr$, kilogram per square kilometer per year; best, best statistical estimate; error, standard error of prediction; NA, not available]

| | | Sediment | | | | Phosphorus, total | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Annual yield ($kg/km^2/yr$) | | | | Annual yield ($kg/km^2/yr$) | | | |
| Sample locations | Agency | best | error | max | min | best | error | max | min |
| Kinnickinnic River near River Falls, Wis. | USGS | 3,160 | 1,050 | 4,210 | 2,120 | 21.2 | 4.3 | 25.5 | 16.9 |
| Valley Creek at Afton, Minn. | Estimated | 3,780 | 3,340 | 7,130 | 439 | 15.4 | 14.7 | 30.1 | .7 |
| Willow River at Burkhardt, Wis. | USGS | 1,800 | 557 | 2,360 | 1,240 | 14.2 | 3.5 | 17.8 | 10.7 |
| Browns Creek at Stillwater, Minn. | Estimated | 3,170 | 3,300 | 6,470 | 0 | 33.3 | 18.5 | 51.8 | 14.8 |
| Silver Creek near Stillwater, Minn. | Estimated | 2,300 | 3,540 | 5,840 | 0 | 15.5 | 13.9 | 29.4 | 1.6 |
| Apple River near Somerset, Wis. | USGS | 1,270 | 243 | 1,510 | 1,030 | 18.2 | 3.9 | 22.1 | 14.2 |
| Little Carnelian Lake outlet near Stillwater, Minn. | Estimated | 2,290 | 3,550 | 5,850 | 0 | 6.1 | 12.8 | 18.8 | .0 |
| Trade River near Trade River, Wis. | USGS | 4,910 | 4,250 | 9,150 | 660 | 10.7 | 4.1 | 14.8 | 6.7 |
| Sunrise River at Sunrise, Minn. | MPCA | 8,400 | 6,160 | 14,600 | 2,240 | 39.9 | 7.6 | 47.5 | 32.2 |
| Wood River near Grantsburg, Wis. | USGS | 4,350 | 1,050 | 5,390 | 3,300 | 16.2 | 3.0 | 19.3 | 13.2 |
| Snake River near Pine City, Minn. | MPCA | 1,210 | 502 | 1,710 | 706 | 14.8 | 3.2 | 18.0 | 11.7 |
| Kettle River below Sandstone, Minn. | MPCA | 2,650 | 1,030 | 3,680 | 1,620 | 19.3 | 3.7 | 23.0 | 15.5 |
| Lower Tamarack River near Markville, Minn. | USGS | 3,400 | 1,100 | 4,510 | 2,300 | 17.2 | 3.6 | 20.8 | 13.7 |
| Sand Creek near Hinckley, Minn. | Estimated | 7,860 | 4,150 | 12,000 | 3,710 | 15.8 | 12.5 | 28.2 | 3.3 |
| Crooked Creek near Hinckley, Minn. | Estimated | 4,860 | 3,170 | 8,030 | 1,690 | 16.9 | 12.3 | 29.2 | 4.7 |
| Clam River near Webster, Wis. | Estimated | 1,890 | 3,350 | 5,240 | 0 | 8.4 | 12.4 | 20.8 | .0 |
| Upper Tamarack River near Markville, Minn. | USGS | 6,350 | 3,980 | 10,300 | 2,370 | 22.4 | 6.1 | 28.5 | 16.3 |
| Yellow River near Danbury, Wis. | Estimated | 1,490 | 3,550 | 5,030 | 0 | 13.4 | 15.0 | 28.5 | .0 |
| Namekagon River near Leonards, Wis.[1] | USGS | 1,560 | 314 | 1,880 | 1,250 | 4.7 | 2.0 | 6.7 | 2.8 |
| St. Croix River near Danbury, Wis.[2] | USGS | 1,730 | 518 | 2,250 | 1,220 | 4.1 | 1.6 | 5.7 | 2.6 |
| St. Croix River at St. Croix Falls, Wis.[2] | USGS | 2,200 | 550 | 2,750 | 1,650 | 7.3 | 2.5 | 9.8 | 4.9 |

[1]Loads calculated with 1996–98 data, calculated with 1999 flows.

[2]Loads calculated with 1997–99 data, calculated with 1999 flows.

[3]Because many concentration values were less than the detection limit, the estimated loads were negative and, therefore, set to 0.

**Table 6b.** Calculated and estimated 1999 annual sediment and nutrient yields of St. Croix River Tributaries, Wisconsin and Minnesota—Continued

[The best value is from Estimator or from a regression equation. The error represents the 95th-percent confidence range from Estimator or the regression equation. Max and min refer to the upper and lower 95th- percent confidence limits (best value plus or minus the error). All data are annual yields for water year 1999; kg/km$^2$/yr, kilograms per square kilometer per year; best, best statistical estimate; error, standard error of prediction; NA, not available]

| | Phosphorus, dissolved | | | | Phosphorus ortho, dissolved | | | |
|---|---|---|---|---|---|---|---|---|
| | Annual yield (kg/km$^2$/yr) | | | | Annual yield (kg/km$^2$/yr) | | | |
| Sample locations | best | error | max | min | best | error | max | min |
| Kinnickinnic River near River Falls, Wis. | 16.3 | 3.9 | 20.2 | 12.5 | 14.5 | 4.0 | 18.5 | 10.5 |
| Valley Creek at Afton, Minn. | 10.3 | 10.1 | 20.5 | .2 | 5.5 | 7.4 | 12.9 | .0 |
| Willow River at Burkhardt, Wis. | 5.8 | 2.6 | 8.4 | 3.1 | 4.8 | 1.6 | 6.4 | 3.2 |
| Browns Creek at Stillwater, Minn. | 10.3 | 10.1 | 20.5 | .2 | 6.1 | 7.4 | 13.5 | .0 |
| Silver Creek near Stillwater, Minn. | 10.3 | 10.1 | 20.5 | .2 | 1.3 | 8.3 | 9.6 | .0 |
| Apple River near Somerset, Wis. | 7.2 | 1.4 | 8.6 | 5.8 | 5.3 | 1.3 | 6.6 | 4.0 |
| Little Carnelian Lake outlet near Stillwater, Minn. | 10.3 | 10.1 | 20.5 | .2 | 1.2 | 8.3 | 9.5 | .0 |
| Trade River near Trade River, Wis. | 3.2 | .8 | 4.0 | 2.3 | 2.7 | .6 | 3.2 | 2.1 |
| Sunrise River at Sunrise, Minn. | NA | NA | NA | NA | NA | NA | NA | NA |
| Wood River near Grantsburg, Wis. | 5.2 | .9 | 6.1 | 4.4 | 4.2 | .9 | 5.1 | 3.2 |
| Snake River near Pine City, Minn. | NA | NA | NA | NA | NA | NA | NA | NA |
| Kettle River below Sandstone, Minn. | 1.1 | .3 | 1.4 | .8 | NA | NA | NA | NA |
| Lower Tamarack River near Markville, Minn. | 8.2 | 1.5 | 9.7 | 6.7 | 4.6 | .8 | 5.5 | 3.8 |
| Sand Creek near Hinckley, Minn. | .0[3] | 12.0 | 8.7 | .0 | 2.0 | 7.6 | 9.5 | .0 |
| Crooked Creek near Hinckley, Minn. | 5.2 | 9.4 | 14.6 | .0 | .3 | 7.8 | 8.1 | .0 |
| Clam River near Webster, Wis. | 7.0 | 9.4 | 16.4 | .0 | 1.9 | 7.5 | 9.4 | .0 |
| Upper Tamarack River near Markville, Minn. | 10.1 | 2.4 | 12.5 | 7.7 | 4.6 | 1.1 | 5.7 | 3.5 |
| Yellow River near Danbury, Wis. | 7.0 | 9.4 | 16.4 | .0 | .0[3] | 9.0 | 5.9 | .0 |
| Namekagon River near Leonards, Wis.[1] | 2.6 | 1.5 | 4.2 | 1.1 | 2.7 | 1.3 | 4.0 | 1.5 |
| St. Croix River near Danbury, Wis.[2] | 2.8 | .4 | 3.2 | 2.4 | 2.9 | .6 | 3.5 | 2.3 |
| St. Croix River at St. Croix Falls, Wis.[2] | 3.5 | 1.2 | 4.8 | 2.3 | 3.2 | .5 | 3.7 | 2.7 |

[1]Loads calculated with 1996–98 data, calculated with 1999 flows.

[2]Loads calculated with 1997–99 data, calculated with 1999 flows.

[3]Because many concentration values were less than the detection limit, the estimated loads were negative and, therefore, set to 0.

**Table 6b.** Calculated and estimated 1999 annual sediment and nutrient yields of St. Croix River Tributaries, Wisconsin and Minnesota—Continued

[The best value is from Estimator or from a regression equation. The error represents the 95th-percent confidence range from Estimator or the regression equation. Max and min refer to the upper and lower 95th- percent confidence limits (best value plus or minus the error). All data are annual yields for water year 1999; kg/km²/yr, kilograms per square kilometer per year; best, best statistical estimate; error, standard error of prediction; NA, not available]

| | Nitrogen, ammonia, dissolved | | | | Nitrogen, nitrite, dissolved | | | |
|---|---|---|---|---|---|---|---|---|
| | Annual yield (kg/km²/yr) | | | | Annual yield (kg/km²/yr) | | | |
| Sample locations | best | error | max | min | best | error | max | min |
| Kinnickinnic River near River Falls, Wis. | 7.0 | 6.1 | 13.1 | 0.9 | 4.3 | 1.0 | 5.3 | 3.3 |
| Valley Creek at Afton, Minn. | 46.6 | 216 | 263 | .0 | 44.3 | 151 | 196 | .0 |
| Willow River at Burkhardt, Wis. | 11.4 | 3.9 | 15.4 | 7.5 | 4.2 | .9 | 5.1 | 3.4 |
| Browns Creek at Stillwater, Minn. | .0[3] | 310 | 230 | .0 | .0[3] | 217 | 135 | .0 |
| Silver Creek near Stillwater, Minn. | 22.9 | 271 | 293 | .0 | 61.7 | 190 | 251 | .0 |
| Apple River near Somerset, Wis. | 13.9 | 4.0 | 17.9 | 9.9 | 3.6 | 1.0 | 4.6 | 2.6 |
| Little Carnelian Lake outlet near Stillwater, Minn. | 47.2 | 287 | 334 | .0 | 85.2 | 201 | 286 | .0 |
| Trade River near Trade River, Wis. | 13.1 | 6.0 | 19.1 | 7.0 | 2.1 | .5 | 2.6 | 1.6 |
| Sunrise River at Sunrise, Minn. | NA | NA | NA | NA | NA | NA | NA | NA |
| Wood River near Grantsburg, Wis. | 18.9 | 5.9 | 24.9 | 13.0 | 2.4 | .6 | 3.0 | 1.8 |
| Snake River near Pine City, Minn. | NA | NA | NA | NA | NA | NA | NA | NA |
| Kettle River below Sandstone, Minn. | NA | NA | NA | NA | NA | NA | NA | NA |
| Lower Tamarack River near Markville, Minn. | 15.7 | 6.0 | 21.7 | 9.7 | 1.6 | 2.9 | 4.6 | .0 |
| Sand Creek near Hinckley, Minn. | 329 | 209 | 538 | 120 | 252 | 146 | 398 | 106 |
| Crooked Creek near Hinckley, Minn. | 301 | 209 | 510 | 92.3 | 236 | 146 | 382 | 89.5 |
| Clam River near Webster, Wis. | 85.2 | 209 | 295 | 0.0 | 83.4 | 147 | 230 | .0 |
| Upper Tamarack River near Markville, Minn. | 16.7 | 10.2 | 26.9 | 6.6 | 1.3 | 2.6 | 3.8 | .0 |
| Yellow River near Danbury, Wis. | .0[3] | 238 | 162 | .0 | .0[3] | 167 | 141 | .0 |
| Namekagon River near Leonards, Wis.[1] | 8.2 | 3.2 | 11.4 | 5.0 | 3.2 | .9 | 4.1 | 2.2 |
| St. Croix River near Danbury, Wis.[2] | 6.5 | 1.7 | 8.2 | 4.7 | 1.7 | .8 | 2.5 | .9 |
| St. Croix River at St. Croix Falls, Wis.[2] | 10.7 | 3.7 | 14.4 | 7.1 | 1.8 | .6 | 2.4 | 1.2 |

[1]Loads calculated with 1996–98 data, calculated with 1999 flows.

[2]Loads calculated with 1997–99 data, calculated with 1999 flows.

[3]Because many concentration values were less than the detection limit, the estimated loads were negative and, therefore, set to 0.

**Table 6b.** Calculated and estimated 1999 annual sediment and nutrient yields of St. Croix River Tributaries, Wisconsin and Minnesota—Continued

[The best value is from Estimator or from a regression equation. The error represents the 95th-percent confidence range from Estimator or the regression equation. Max and min refer to the upper and lower 95th- percent confidence limits (best value plus or minus the error). All data are annual yields for water year 1999; kg/km$^2$/yr, kilograms per square kilometer per year; best, best statistical estimate; error, standard error of prediction; NA, not available]

| | Nitrogen, ammonia + organic, dissolved | | | | Nitrogen, ammonia + organic, total | | | |
|---|---|---|---|---|---|---|---|---|
| | Annual yield (kg/km$^2$/yr) | | | | Annual yield (kg/km$^2$/yr) | | | |
| Sample locations | best | error | max | min | best | error | max | min |
| Kinnickinnic River near River Falls, Wis. | 50.7 | 20.6 | 71.3 | 30.1 | 77.4 | 25.3 | 103 | 52.1 |
| Valley Creek at Afton, Minn. | 7.4 | 6.4 | 13.8 | 1.0 | 776 | 297 | 1,070 | 479 |
| Willow River at Burkhardt, Wis. | 61.2 | 9.5 | 70.7 | 51.7 | 110 | 25.1 | 135 | 84.9 |
| Browns Creek at Stillwater, Minn. | .0[3] | 9.9 | .0 | .0 | 947 | 429 | 1,380 | 518 |
| Silver Creek near Stillwater, Minn. | 23.1 | 7.9 | 31.0 | 15.2 | 425 | 305 | 730 | 120 |
| Apple River near Somerset, Wis. | 103 | 10.8 | 113 | 91.8 | 135 | 16.7 | 152 | 118 |
| Little Carnelian Lake outlet near Stillwater, Minn. | 25.9 | 8.1 | 33.9 | 17.8 | 235 | 321 | 557 | .0 |
| Trade River near Trade River, Wis. | 85.6 | 9.5 | 95.1 | 76.1 | 10.7 | 4.1 | 14.8 | 6.7 |
| Sunrise River at Sunrise, Minn. | NA | NA | NA | NA | NA | NA | NA | NA |
| Wood River near Grantsburg, Wis. | 155 | 14.8 | 170 | 140 | 215 | 34.5 | 250 | 181 |
| Snake River near Pine City, Minn. | NA | NA | NA | NA | NA | NA | NA | NA |
| Kettle River below Sandstone, Minn. | NA | NA | NA | NA | NA | NA | NA | NA |
| Lower Tamarack River near Markville, Minn. | 274 | 37.3 | 311 | 236 | 380 | 91.7 | 471 | 288 |
| Sand Creek near Hinckley, Minn. | 17.8 | 6.2 | 24.0 | 11.6 | 155 | 270 | 425 | .0 |
| Crooked Creek near Hinckley, Minn. | 17.2 | 6.3 | 23.5 | 11.0 | .0[3] | 267 | 224 | .0 |
| Clam River near Webster, Wis. | 11.4 | 5.9 | 17.3 | 5.5 | .0[3] | 282 | 50.5 | .0 |
| Upper Tamarack River near Markville, Minn. | 388 | 56.5 | 445 | 332 | 511 | 151 | 661 | 360 |
| Yellow River near Danbury, Wis. | 6.0 | 6.1 | 12.1 | .0 | .0[3] | 290 | 10.9 | .0 |
| Namekagon River near Leonards, Wis.[1] | 84.7 | 13.6 | 98.3 | 71.0 | 121 | 11.0 | 132 | 110 |
| St. Croix River near Danbury, Wis.[2] | 85.3 | 16.6 | 102 | 68.7 | 111 | 12.6 | 124 | 98.4 |
| St. Croix River at St. Croix Falls, Wis.[2] | 101 | 14.5 | 115 | 86.1 | 137 | 15.2 | 152 | 122 |

[1]Loads calculated with 1996–98 data, calculated with 1999 flows.

[2]Loads calculated with 1997–99 data, calculated with 1999 flows.

[3]Because many concentration values were less than the detection limit, the estimated loads were negative and, therefore, set to 0.

**Table 6b.** Calculated and estimated 1999 annual sediment and nutrient yields of St. Croix River Tributaries, Wisconsin and Minnesota—Continued

[The best value is from Estimator or from a regression equation. The error represents the 95th-percent confidence range from Estimator or the regression equation. Max and min refer to the upper and lower 95th- percent confidence limits (best value plus or minus the error). All data are annual yields for water year 1999; kg/km$^2$/yr, kilograms per square kilometer per year; best, best statistical estimate; error, standard error of prediction; NA, not available]

| | Nitrogen, nitrite plus nitrate, dissolved | | | | Chloride, dissolved | | | |
|---|---|---|---|---|---|---|---|---|
| | Annual yield (kg/km$^2$/yr) | | | | Annual yield (kg/km$^2$/yr) | | | |
| Sample locations | best | error | max | min | best | error | max | min |
| Kinnickinnic River near River Falls, Wis. | 1,080 | 52.1 | 1,130 | 1,020 | 3,600 | 119 | 3,720 | 3,480 |
| Valley Creek at Afton, Minn. | 3.6 | .4 | 4.0 | 3.2 | 2,220 | 1,100 | 3,310 | 1,120 |
| Willow River at Burkhardt, Wis. | 396 | 95.9 | 492 | 300 | 2,680 | 802 | 3,480 | 1,880 |
| Browns Creek at Stillwater, Minn. | 3.8 | .4 | 4.2 | 3.4 | 2,320 | 1,100 | 3,430 | 1,220 |
| Silver Creek near Stillwater, Minn. | 2.7 | .5 | 3.2 | 2.3 | 1,360 | 1,060 | 2,420 | 308 |
| Apple River near Somerset, Wis. | 240 | 34.3 | 274 | 205 | 2,190 | 190 | 2,380 | 2,000 |
| Little Carnelian Lake outlet near Stillwater, Minn. | 2.7 | .5 | 3.2 | 2.3 | 1,330 | 1,060 | 2,390 | 274 |
| Trade River near Trade River, Wis. | 59.6 | 16.0 | 75.6 | 43.6 | 1,010 | 156 | 1,160 | 850 |
| Sunrise River at Sunrise, Minn. | NA | NA | NA | NA | NA | NA | NA | NA |
| Wood River near Grantsburg, Wis. | 42.9 | 6.7 | 49.6 | 36.2 | 1,320 | 104 | 1,430 | 1,220 |
| Snake River near Pine City, Minn. | NA | NA | NA | NA | NA | NA | NA | NA |
| Kettle River below Sandstone, Minn. | NA | NA | NA | NA | NA | NA | NA | NA |
| Lower Tamarack River near Markville, Minn. | 41.0 | 19.1 | 60.1 | 21.8 | 350 | 145 | 495 | 206 |
| Sand Creek near Hinckley, Minn. | .1 | .6 | .7 | .0 | .0[3] | 1,110 | 1,080 | .0 |
| Crooked Creek near Hinckley, Minn. | .0[3] | .6 | .0 | .0 | .0[3] | 1,160 | 647 | .0 |
| Clam River near Webster, Wis. | 2.7 | .4 | 3.2 | 2.3 | 1,130 | 1,060 | 2,180 | 69.4 |
| Upper Tamarack River near Markville, Minn. | 78.0 | 50.4 | 128 | 27.6 | 724 | 122 | 846 | 602 |
| Yellow River near Danbury, Wis. | 2.0 | .6 | 2.5 | 1.4 | .0[3] | 1,120 | 952 | .0 |
| Namekagon River near Leonards, Wis.[1] | 46.8 | 15.2 | 62.0 | 31.7 | 1,180 | 260 | 1,450 | 915 |
| St. Croix River near Danbury, Wis.[2] | 30.7 | 8.0 | 38.7 | 22.8 | 710 | 117 | 827 | 593 |
| St. Croix River at St. Croix Falls, Wis.[2] | 50.9 | 11.5 | 62.4 | 39.4 | 1,130 | 143 | 1,270 | 988 |

[1]Loads calculated with 1996–98 data, calculated with 1999 flows.

[2]Loads calculated with 1997–99 data, calculated with 1999 flows.

[3]Because many concentration values were less than the detection limit, the estimated loads were negative and, therefore, set to 0.

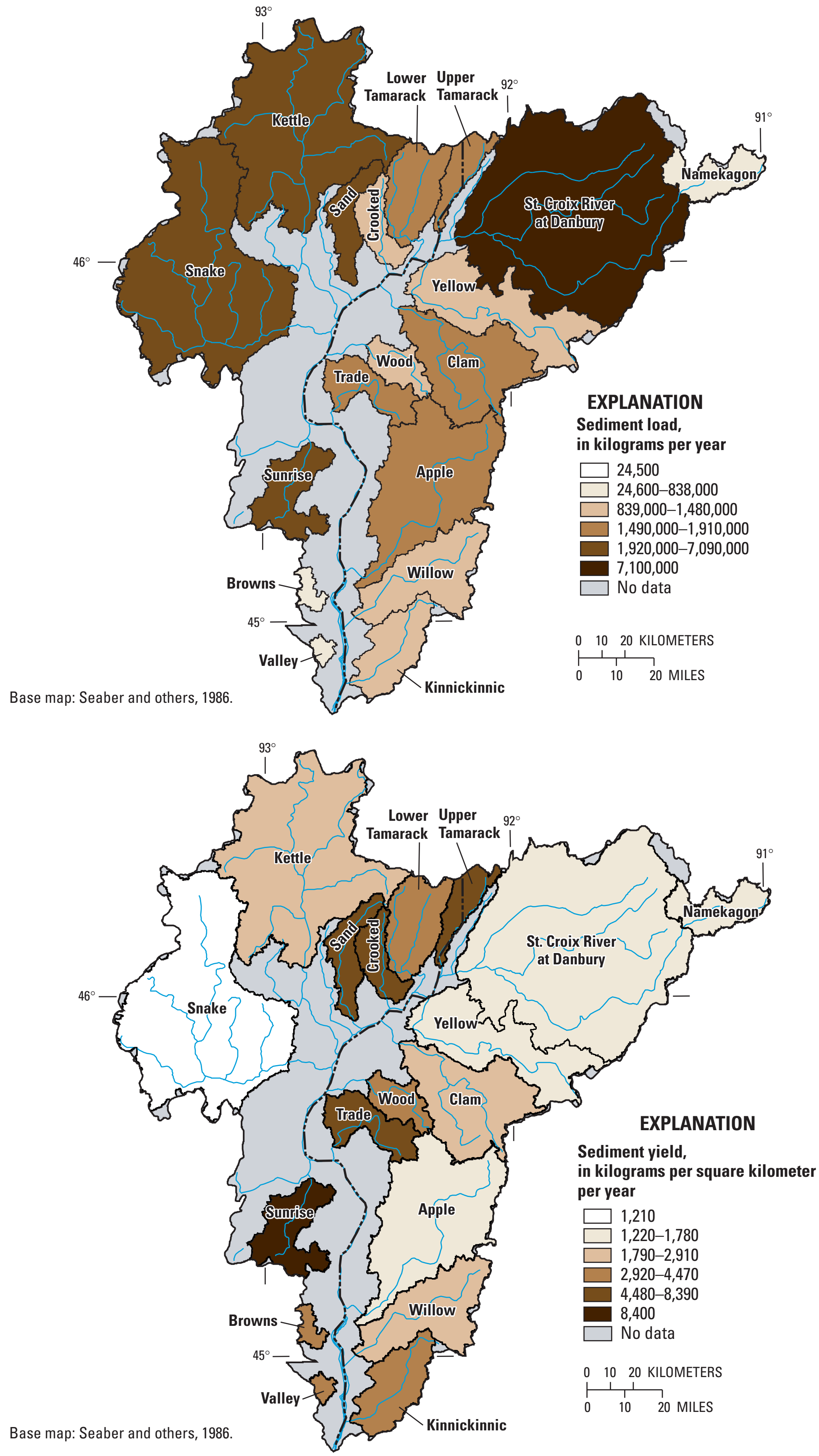



**Figure 4a.** Suspended-sediment loads and yields of the St. Croix tributaries, Wisconsin and Minnesota (categories are minimum, first quartile, second quartile, third quartile, fourth quartile, and maximum).

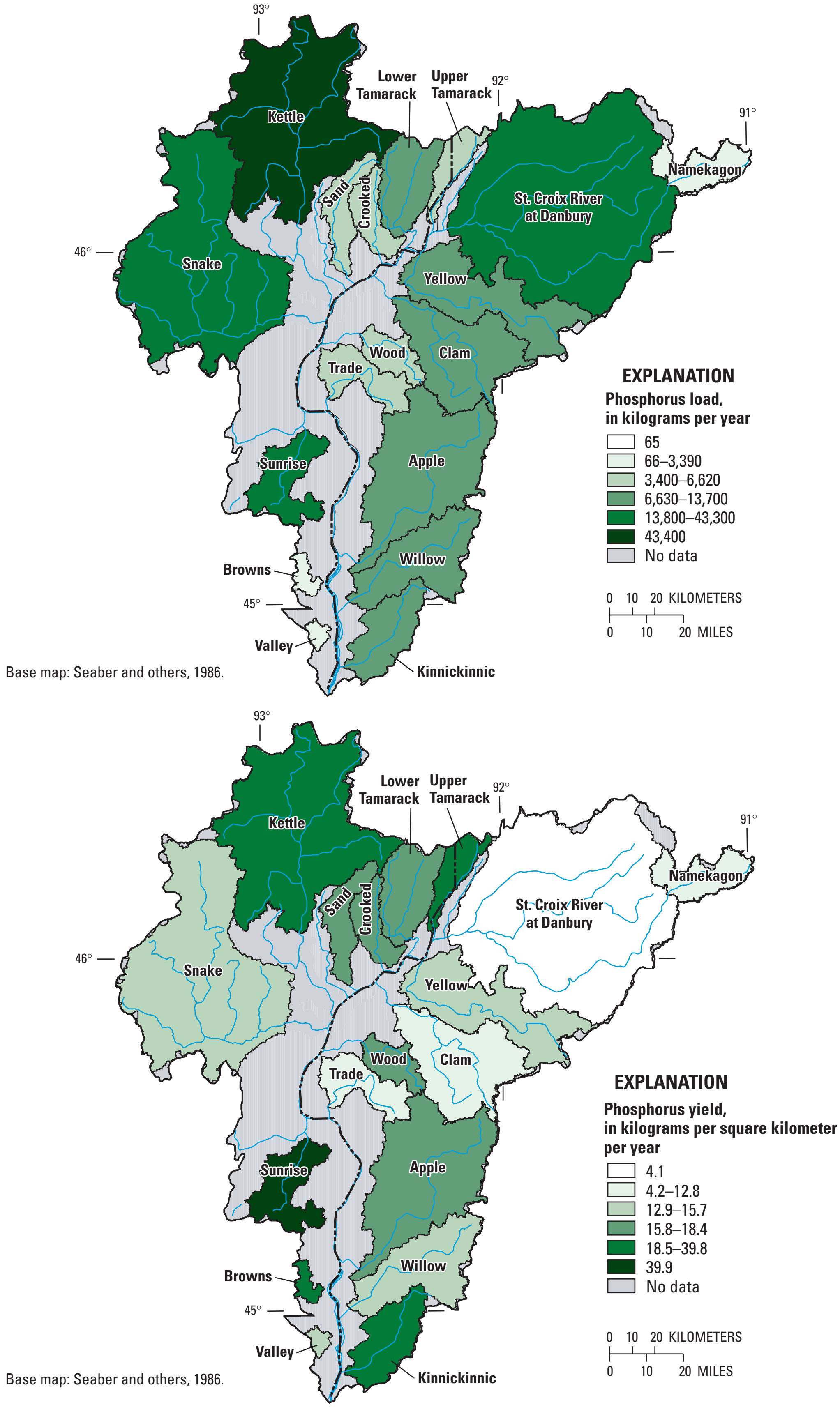



**Figure 4b.** Total phosphorus loads and yields of the St. Croix tributaries, Wisconsin and Minnesota (categories are minimum, first quartile, second quartile, third quartile, fourth quartile, and maximum).

**Table 7.** Volume-weighted concentrations of suspended sediment and nutrients at selected tributaries to the St. Croix River, Wisconsin and Minnesota, October 1, 1998–September 30, 1999

[mg/L, milligrams per liter; NA, not available; USGS, U.S. Geological Survey; MPCA, Minnesota Pollution Control Agency]

| Sample locations | Agency | Drainage area (square kilometers) | Annual mean daily flow (cubic meters per second) | Runoff (centi-meters) | Suspended sediment (mg/L) | Phosphorus, total (mg/L) | Phosphorus, dissolved (mg/L) | Phosphorus, ortho, dissolved (mg/L) | Nitrogen, ammonia, dissolved (mg/L) | Nitrogen, nitrite, dissolved (mg/L) | Nitrogen, ammonia + organic, dissolved (mg/L) | Nitrogen, ammonia + organic, total (mg/L) | Nitrogen, nitrite plus nitrate, dissolved (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Kinnickinnic River near River Falls, Wis. | USGS | 449 | 3.14 | 22.1 | 14.3 | 0.096 | 0.074 | 0.066 | NA | 0.020 | 0.230 | 0.351 | 4.88 |
| Willow River at Burkhardt, Wis. | USGS | 721 | 3.86 | 16.9 | 10.6 | .084 | .034 | .029 | .068 | .025 | .362 | .651 | 2.34 |
| Apple River near Somerset, Wis. | USGS | 1,420 | 13.0 | 28.9 | 4.4 | .063 | .025 | .018 | .048 | .013 | .355 | .467 | .829 |
| Trade River near. Trade River, Wis. | USGS | 345 | 2.18 | 19.9 | 24.6 | .054 | .016 | .013 | .066 | .011 | .430 | .054 | .299 |
| Sunrise River at Sunrise, Minn. | MPCA | 439 | 4.70 | 33.7 | 24.9 | .118 | NA | NA | NA | NA | NA | NA | NA |
| Wood River near Grantsburg, Wis. | USGS | 217 | 1.79 | 26.0 | 16.7 | .062 | .020 | .016 | .073 | .009 | .595 | .826 | .165 |
| Snake River near Pine City, Minn. | MPCA | 2,530 | 14.3 | 17.8 | 6.8 | .083 | .000 | NA | NA | NA | NA | NA | NA |
| Kettle River below Sandstone, Minn. | MPCA | 2,250 | 19.7 | 27.5 | 9.6 | .070 | .004 | NA | NA | NA | NA | NA | NA |
| Lower Tamarack River near Markville, Minn. | USGS | 470 | 4.24 | 28.5 | 12.0 | .061 | .029 | .016 | .055 | .006 | .961 | 1.33 | .144 |
| Upper Tamarack River near Markville, Minn. | USGS | 245 | 2.84 | 36.6 | 17.4 | .061 | .028 | .013 | .046 | .003 | 1.06 | 1.40 | .213 |
| Namekagon River near Leonards, Wis. | USGS | 333 | 4.04 | 38.3 | 4.1 | .012 | .007 | .007 | .021 | .008 | .221 | .316 | .122 |
| St. Croix River near Danbury, Wis. | USGS | 4,090 | 38.3 | 29.6 | 5.9 | .014 | .010 | .010 | .022 | .006 | .289 | .376 | .104 |
| St. Croix River at St. Croix Falls, Wis. | USGS | 16,200 | 127 | 24.7 | 8.8 | .038 | .014 | .013 | .044 | .007 | .407 | .554 | .206 |

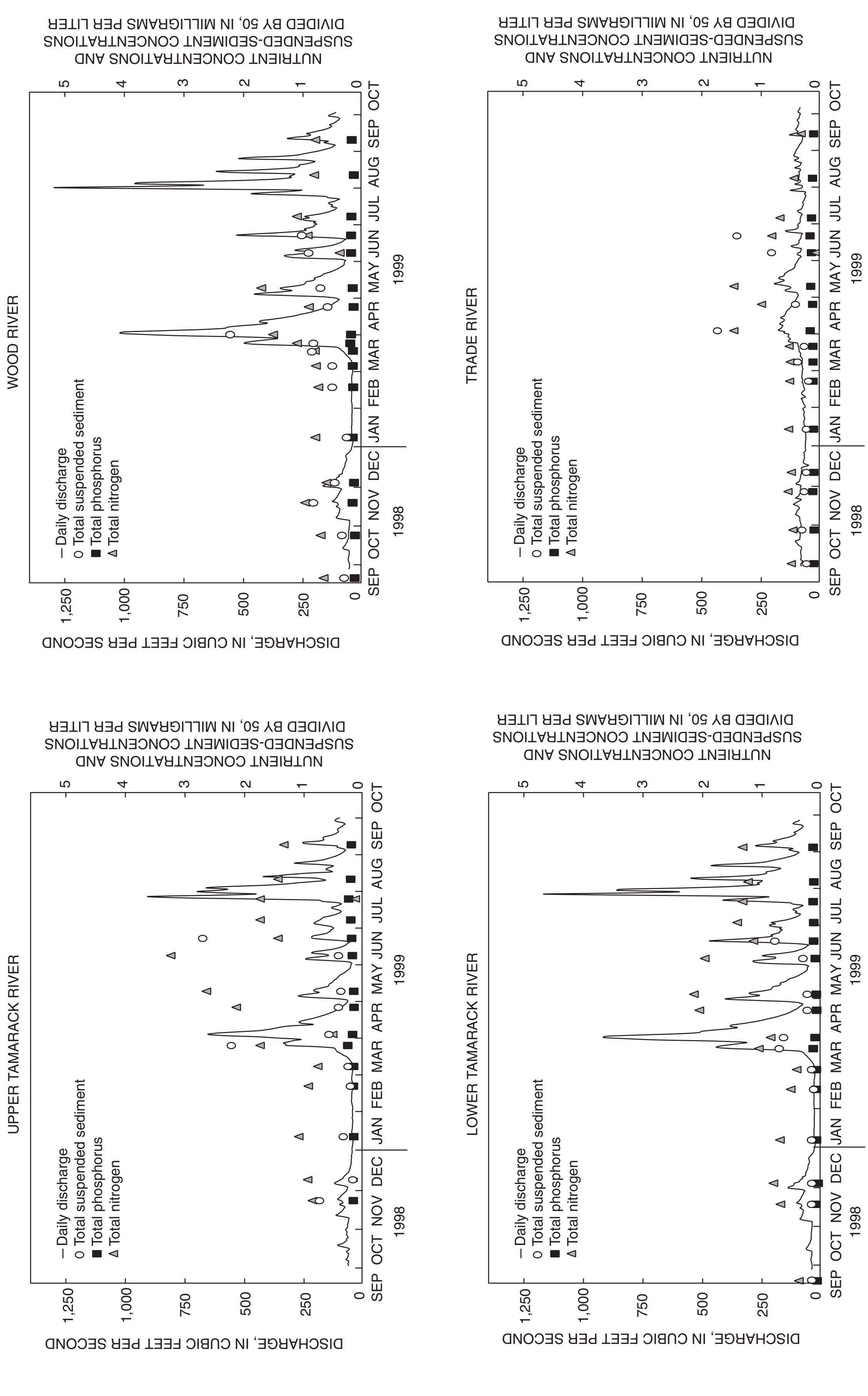



**Figure 5a.** Discharge hydrograph and sample concentrations from the St. Croix River tributary monitoring, Wisconsin and Minnesota, 1998–99.

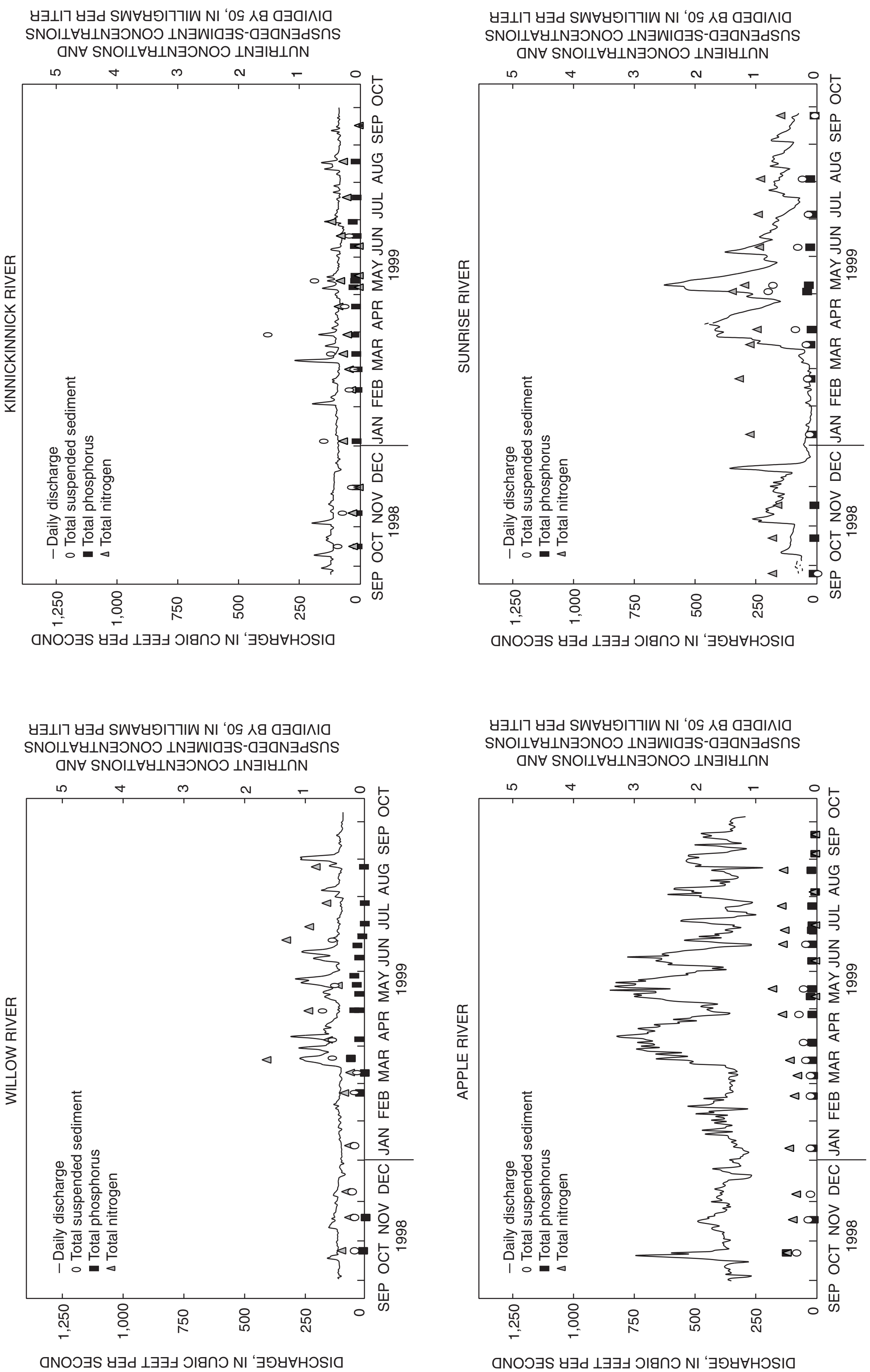



**Figure 5b.** Discharge hydrograph and sample concentrations from the St. Croix River tributary monitoring, Wisconsin and Minnesota, 1998–99.

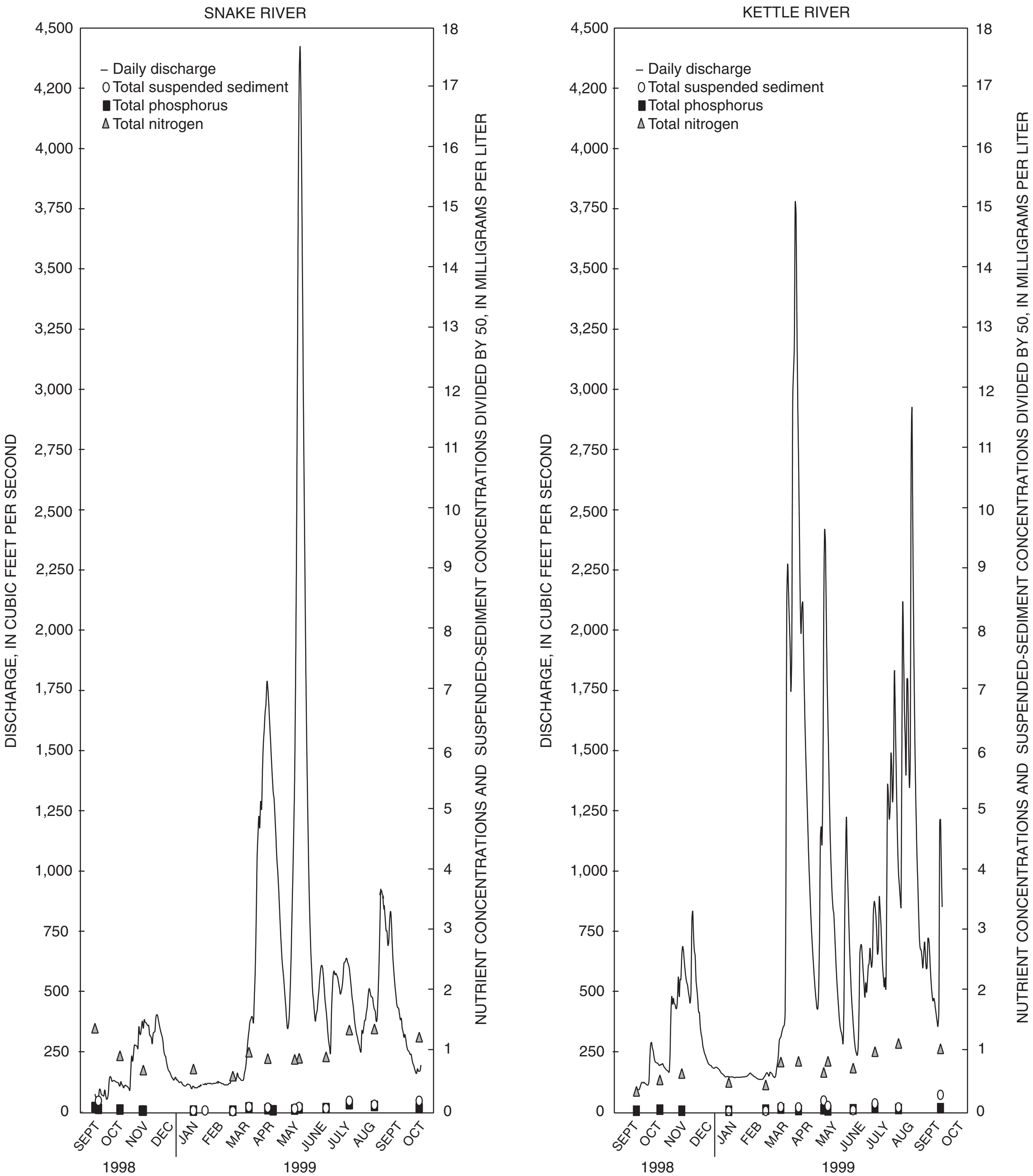



**Figure 5c.** Discharge hydrograph and sample concentrations from the St. Croix River tributary monitoring, Wisconsin and Minnesota, 1998–99.

At the Wood and Lower Tamarack Rivers, also, large events were associated with high concentrations of suspended sediment and nutrients. Data from 1997 and 1998 reinforce the finding that these northern tributaries can contribute substantial amounts of suspended sediment and nutrients to the St. Croix River during events but contribute little during base flow. In fact, these northern tributaries become insignificant to the overall nutrient and suspended-sediment loading to the St. Croix River during periods without event runoff.

Because of lack of runoff, event-related streamflow peaks were small and concentrations were consistently low for most of the southern tributaries, leading to the low overall basin loading from these tributaries in water year 1999, especially the Trade, Willow, and Kinnickinnic Rivers. In contrast, instantaneous loads and yields calculated for events sampled in 1998 show that these tributaries are not always characterized by a few small events and low rates of loading as seen in 1999. Data from the Kinnickinnic River can be used to illustrate the substantial between-year differences. The peak discharge at the Kinnickinnic River in 1999 was only 460 cfs, whereas a discharge of 640 cfs was measured on April 1, 1998. Historical records show an estimated peak discharge of 4,800 cfs on March 15, 1920, which shows the intensity of runoff that can occur at the site. The calculated instantaneous daily load for the April 1998 event was about 50 percent (664,000 kg) of the entire 1999 annual suspended-sediment load. Extrapolating loading rates to the record flow in March 1920 produces an estimated suspended-sediment load several orders of magnitude higher than the 1999 annual load, in just that one day. One event (or absence thereof) can greatly affect the year-to-year annual loads at these tributaries.

Base flows during winter at the Sunrise River were low and similar to those of the northern tributaries, although nutrient and suspended-sediment concentrations were higher. Events at the Sunrise River consisted of long periods of elevated flow rather than rapid, short-duration increases in flow. Also, summer base flows of the Sunrise River were high, compared to the northern tributaries. These elevated flows and consistently higher concentrations of nutrients led to the high loads and yields in the Sunrise River in 1999.

In general, loads from the Kettle, Snake, and Apple Rivers were driven by basin size and flow volume. The sheer volume of water entering the St. Croix River from these tributaries makes them substantial contributors to overall basin loading. Samples collected from the Apple River, which were collected below the Apple Falls Flowage, had consistently low concentrations, but the high annual flow volume of the river led to high annual loads. The Snake and the Kettle Rivers also had high flow volumes but were more variable in flow and concentration than the Apple River.

## Relation Between Land Use and Tributary Loading

The 1997-snowmelt synoptic and previous studies examined the relation between land use and loading. Robertson and Saad (1996), for example, have shown that percentage of agriculture in a basin has a major effect on the magnitude of the nutrient yields. During the 1999 study, however, a relation between annual nutrient and sediment loading and the percentage of agriculture was not found. The tributaries with the highest percentage of agriculture are in the southern part of the basin (fig. 2), where only low-intensity, long-duration storms occurred in 1999, causing little runoff and loading. Tributaries with the lowest percentage of agriculture were in the northern part of the basin, where four or more high-intensity, short-duration storms caused large runoff events and high loads. This variability in runoff was caused by climatological factors rather than land use and appears to be more important than the differences in land use. This variability also led to the high errors when estimating loads in the unmonitored parts of the basins using environmental characteristics.

Base-flow, water-quality samples from agricultural areas had higher nitrogen concentrations than other areas of the St. Croix River Basin. Although nitrogen and phosphorus commonly are associated with each other, especially in agricultural areas, nitrogen is more likely than phosphorus to be transported through subsurface flow and released during base flow. Phosphorus is more adhesive to soil particles and is likely to be stored in the soils and released with eroded sediment during high-flow events (Wetzel, 1983). The elevated nitrogen concentrations (relative to other tributaries in the St. Croix River Basin) in base flow, the minimal runoff and suspended-sediment loading in 1999, and the results of the 1997 and 1998 event sampling showing higher phosphorus concentrations during periods of runoff all indicate that high phosphorus loading occurs during runoff events in agricultural areas of the southern St. Croix River Basin. Therefore, more phosphorus loading to the St. Croix River would be expected from agricultural areas in normal to wet years than was calculated in 1999.

An inverse relation between annual yields and the percentage of urban area in the tributary basins was seen and is likely an effect of the less intense runoff and the resultant lower loads in the southern tributary basins, where most of the urban development is located rather than the urban development itself. The highest amount of urban area in any of the monitored tributaries was only 2.6 percent.

### Point-Source Loading

In general, most nonpoint-source nutrient loading occurs during runoff events, which are prominent in the spring and early summer, whereas relative contributions from point sources and ground-water recharge are most consequential during low flows that are typical of fall and winter. Seasonal loads were estimated from the 1999 data in an attempt to document the relative importance of point and nonpoint sources of nutrients in the St. Croix River tributaries (fig. 6a). Most of the loading occurs in spring and summer, the seasons with the most runoff events. Loading in fall and winter varied among basins. Coinciding annual total phosphorus and suspended-sediment yields are shown in figure 6b.

The estimated point-source loadings from permitted discharges on each tributary are shown in figure 6a. These are most, but not all of the point-source discharges on these tributaries. Point-source data were provided by P. Prusak (Wisconsin Department of Natural Resources, written commun., 2000) and R. Wedlund, (Minnesota Pollution Control Agency, written commun., 2000). A large percentage of the annual load can be attributed to point-source discharges on tributaries where runoff was minimal in 1999, such as the Kinnickinnic and Willow Rivers. Whereas, point sources contributed only a small proportion of the annual load in the northern forested tributaries such as the Upper and Lower Tamarack Rivers, where nonpoint-source loads resulting from intense runoff events in the spring and summer dominated the annual loads.

### Historical Loading

Calculated annual loads for 1999 were compared to estimated historical loading rates at four sites where long-term flow records were available, including the Apple and Kettle Rivers and the two St. Croix River sites, at St. Croix Falls and near Danbury, Wisconsin. Annual loads for the previous 10 years were calculated at these long-term gaging stations using 1997–99 load/streamflow relations and historical flow. Annual loading rates varied greatly from year to year, but the 1999 annual loads were near the 10-year average: 75 to 114 percent of the average annual phosphorus load and 70 to 109 percent of the average annual suspended-sediment load, although the 1999 annual loads were lower than those computed for the early to mid-1990's (fig. 7). No long-term flow records were available for stations in the southern part of the basin to use as a comparison to long-term loading.

A study by Graczyk (1986) estimated average annual suspended-sediment and total phosphorus yields for 1974–81 at five tributaries and two main stem St. Croix River sites (fig. 8). Annual suspended-sediment yields in 1999 were greater at Yellow River (152 percent), Snake River (181 percent), and at St. Croix River at St. Croix Falls (157 percent) but less at the Clam River (69 percent), Kettle River (57 percent), and at the St. Croix River near Danbury (72 percent) in comparison. Annual phosphorus yields from 1999 were higher than those reported by Graczyk (1986) at the Kettle (125 percent), Snake (122 percent), and Apple (126 percent) Rivers and lower at the Yellow River (76 percent), Clam River (69 percent), and the two St. Croix River sites (near Danbury (38 percent) and at St. Croix Falls (29 percent)).

### Difficulties with Load Analyses Based on One Year of Data

Data from the 1997 and 1998 synoptic studies demonstrated an increase in nutrient concentrations in agricultural areas and an increase in nutrient and sediment yields from basins with more impervious soils. Although the 1997 snowmelt synoptic (Fallon and McNellis, 2000) and previous studies (Robertson and Saad, 1996) have shown increased amounts of agricultural land in a basin to be related to increased loading, loading data from tributaries to the St. Croix River from 1999 did not show this relation. In water year 1999, nutrient and suspended-sediment yields throughout the St. Croix River Basin appear to be driven more by precipitation intensity than environmental characteristics of the tributary basins.

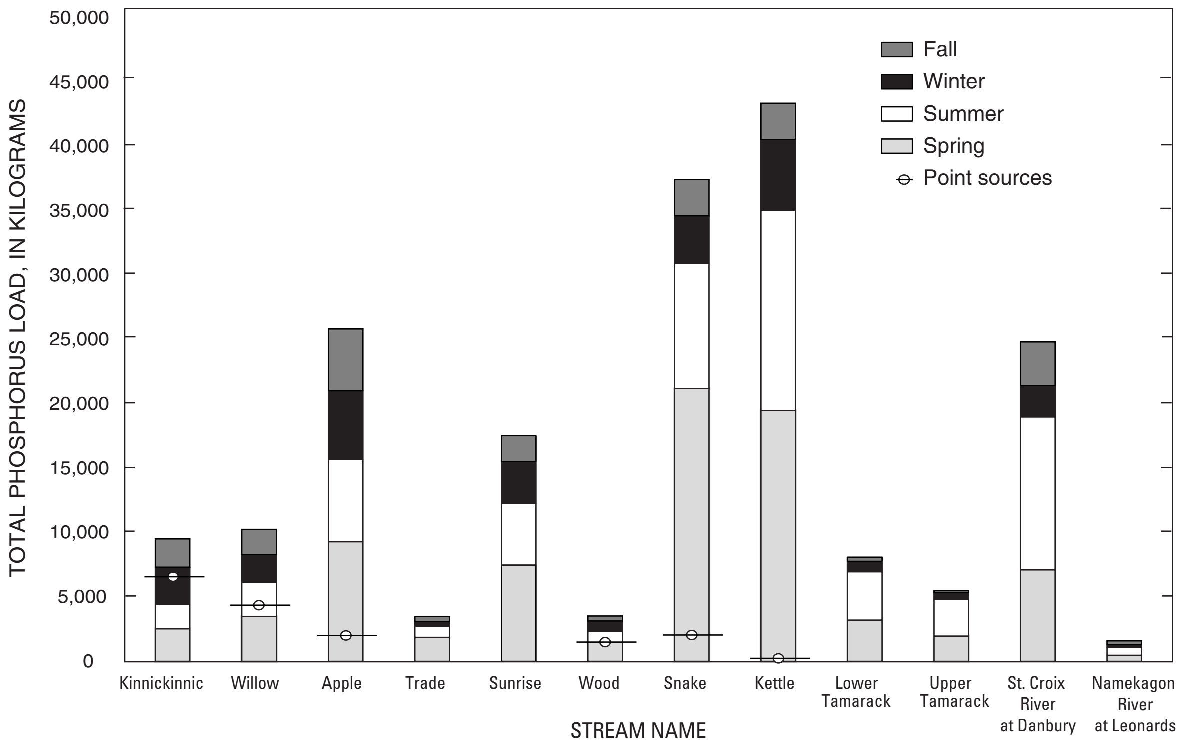



**Figure 6a.** Calculated phosphorus loads by season and from monitored point sources, at tributaries of the St. Croix River, Wisconsin and Minnesota, based on samples collected between October 1, 1998, and September 30, 1999.

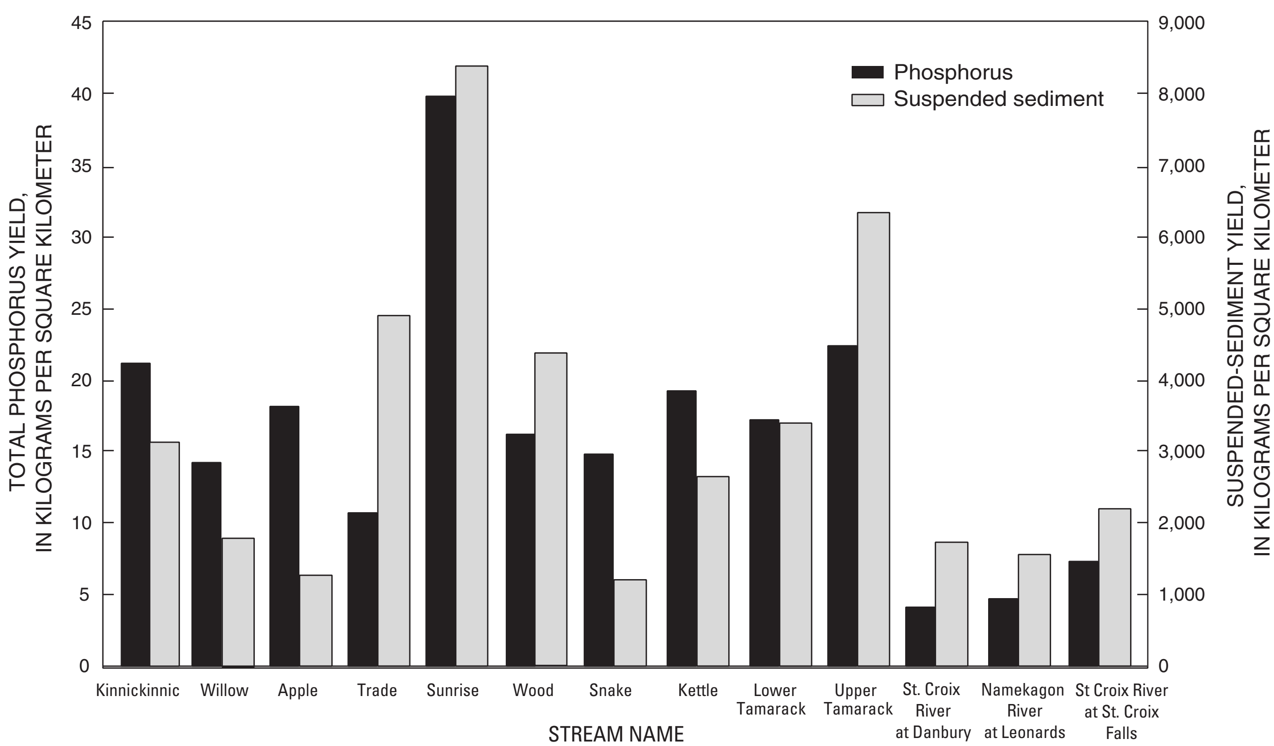
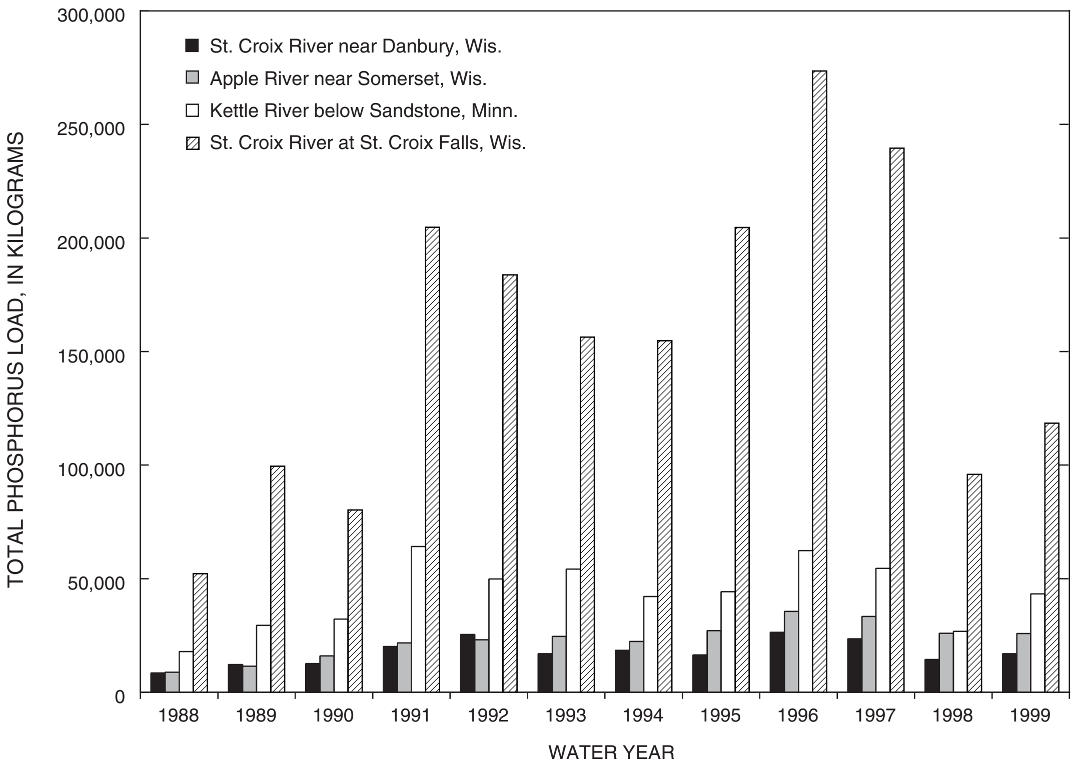



**Figure 6b.** Calculated phosphorus and suspended-sediment yields at tributaries of the St. Croix River, Wisconsin and Minnesota, based on samples collected between October 1, 1998, and September 30, 1999.



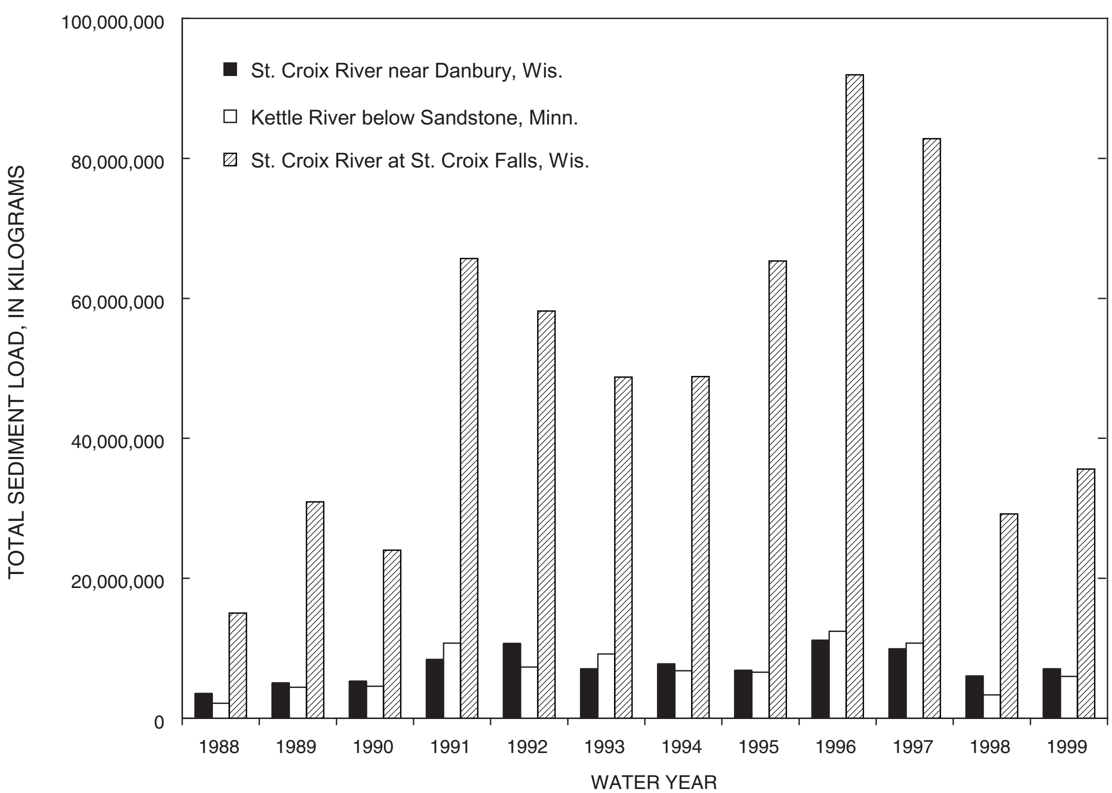




**Figure 7.** Estimated historical annual total phosphorus and suspended-sediment loads, Wisconsin and Minnesota, 1988–99.

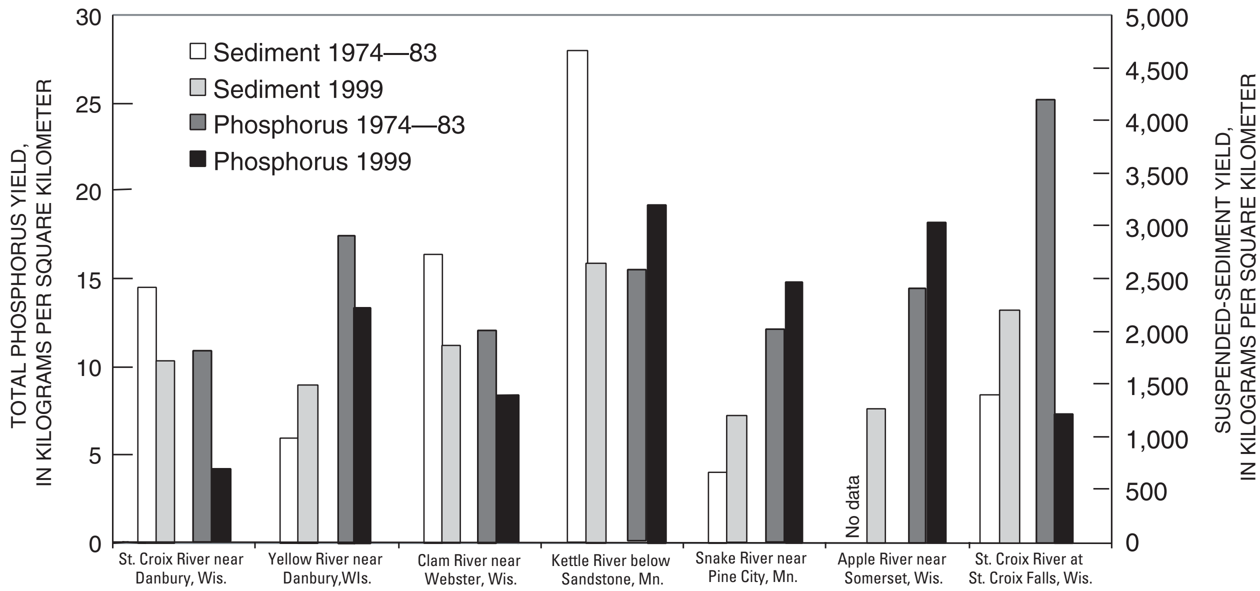



**Figure 8.** Average annual yield for 1974–83 (after Gracyzk, 1986) compared to annual yield for 1999 at tributaries to the St. Croix River, Wisconsin and Minnesota.

Precipitation amounts, intensity, and timing of events all affect the amount of runoff and the resulting magnitude of nutrient and suspended-sediment loading. Variations in weather in 1999 made geographical and temporal comparisons difficult. The lack of spring snowmelt runoff led to lower than average springtime flows and lower than normal springtime loads in the sampled tributaries. Although the entire basin had nearly average rainfall, the rain events in the northern part of the study area were larger, of shorter duration, and of higher erosivity potential. The southern part of the basin received longer duration storms that generated less runoff. Because a large part of the sediment and nutrient loading occurs during events in the St. Croix River Basin, this absence of snowmelt runoff and the disparity in rainfall intensity across the basin was a major explanatory factor for the unusual pattern of loading to the St. Croix River in 1999.

Loading during snowmelt was nearly indistinguishable from base-flow loading because the minimal snow accumulation in winter 1998–99 resulted in minimal runoff. A large portion of the annual load from the tributaries to the St. Croix River usually occurs in the spring, as documented in instantaneous snowmelt-runoff samples collected in 1997 (Fallon and McNellis, 2000) and 1998. The instantaneous daily loads, calculated during runoff events at tributaries to the St. Croix River in 1997 and 1998 often were greater than half the entire 1999 annual loads calculated at those same sites. The 1999 annual loads would have been higher at all tributaries had there been more snowpack and a larger snowmelt event in 1999.

Disparity in rainfall intensity between the northern and southern parts of the St. Croix River Basin in 1999 is shown in figure 9, where size, intensity, and timing of rains in excess of 13 mm recorded by tipping bucket rain gages at two USGS gages are shown. (Rainfall was considered to be from separate events if a period of 2 hours resulted without rainfall.) The northern part of the basin is represented by the station near Danbury Wis., and the southern part of the basin is represented by the station in Wheeler, Wis.

Four storms, each producing more than 50 mm of rainfall occurred at the station near Danbury, Wis., whereas only one storm occurred at the station at Wheeler, Wis. The Wischmeier and Smith's erosivity index (1958), a measure of the kinetic energy and intensity of rainfall, was calculated for each event based on the total accumulation and duration of the precipitation (fig. 10). Five northern storms had erosivities greater than 25, whereas only one storm at Wheeler exceeded this value. The one storm at Wheeler was very localized and developed outside the St. Croix River Basin; daily precipitation that day measured 27 mm from River Falls, Wis. (56 km southwest) and less than 2.5 mm was measured at Amery, Wis. (48.3 km northwest), and

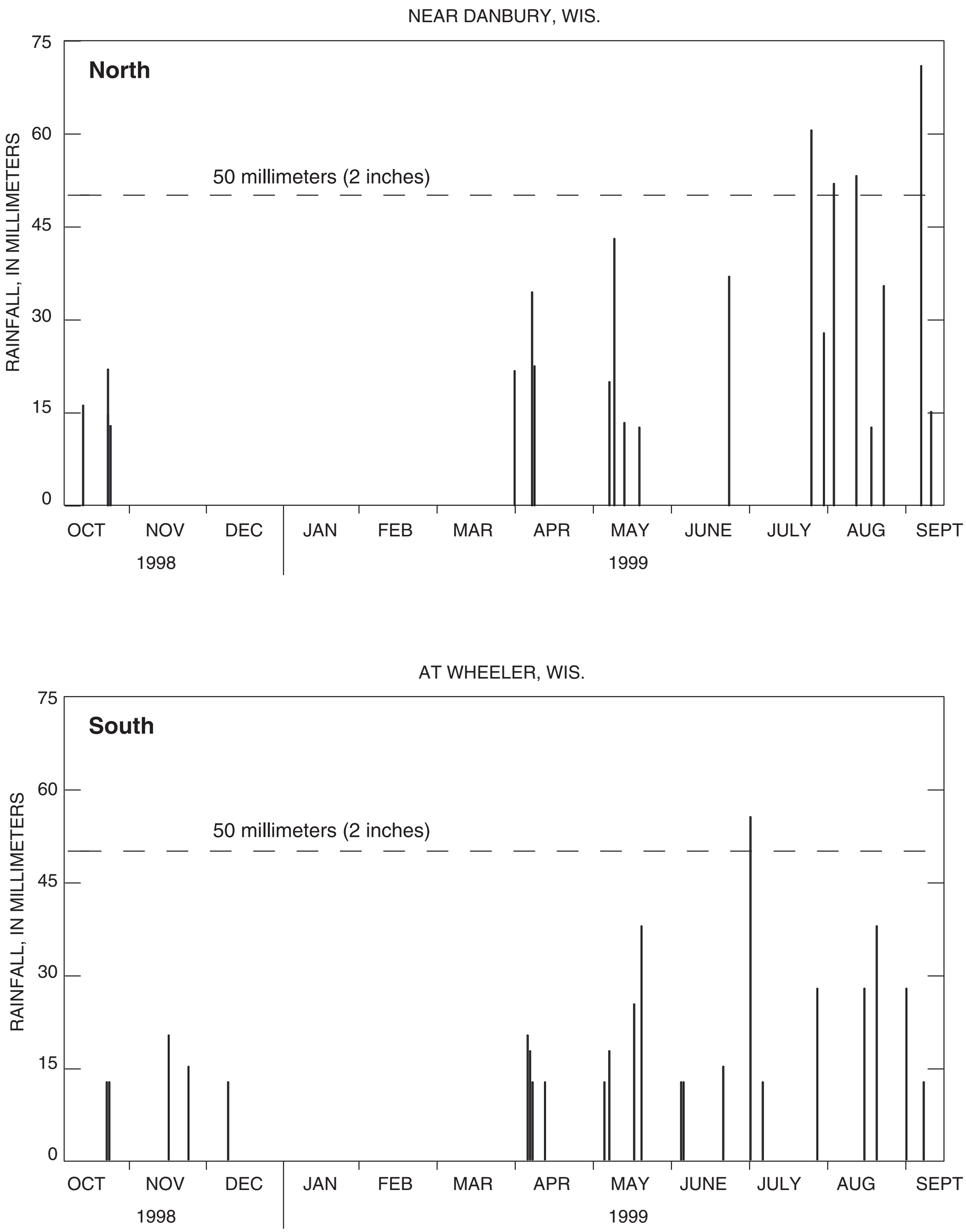



**Figure 9.** Rain events greater than 13 millimeters (0.5 inch) at two USGS stream-gaging stations, Wisconsin, 1998–99.

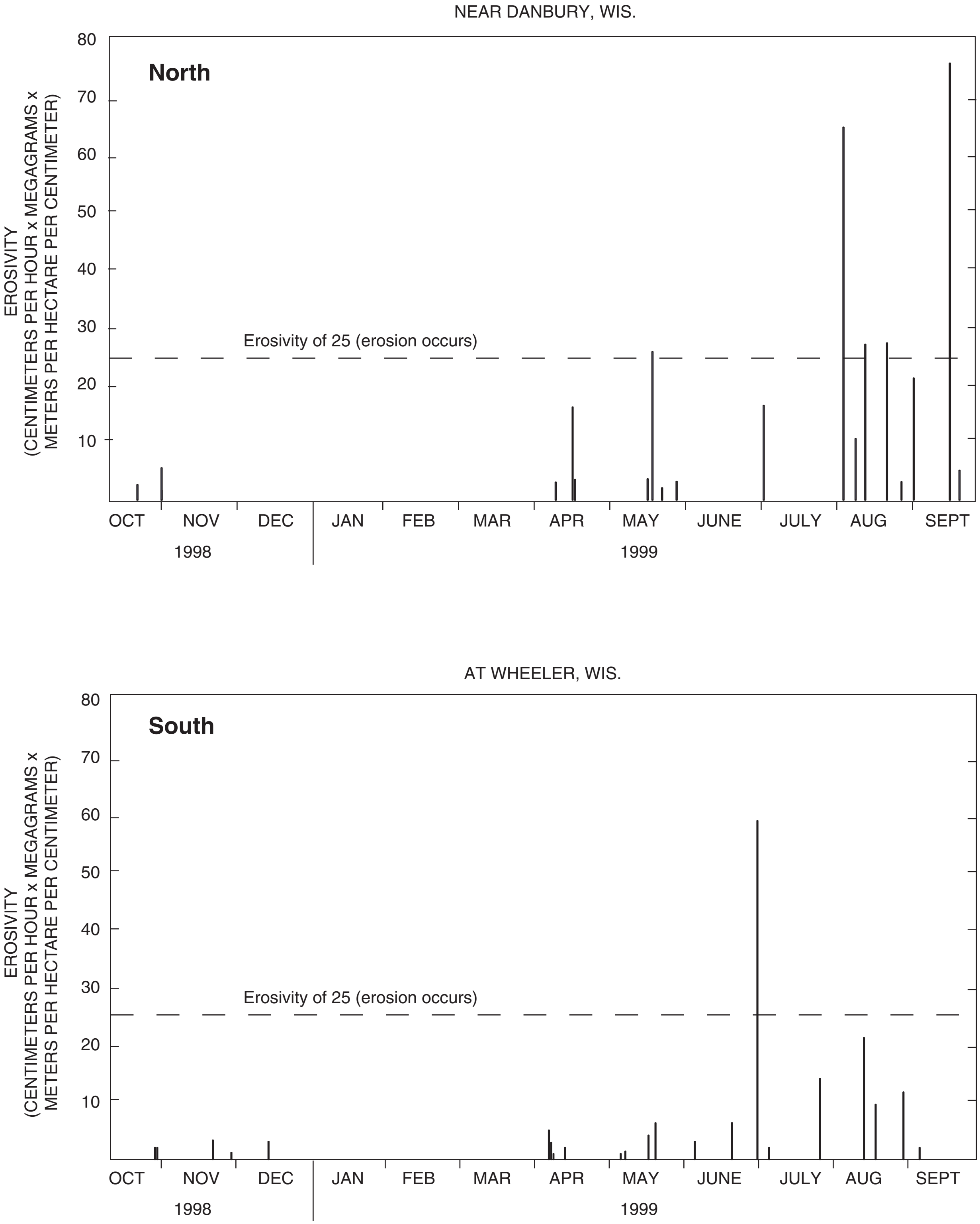



**Figure 10.** Rainstorm erosivity for events greater than 13 millimeters (0.5 inch) at two USGS stream-gaging stations, Wisconsin, 1998–99.

streamflow in the southern tributaries only slightly increased. Because of this disparity in runoff event size and intensity, the loading to the St. Croix River during events from tributaries in the northern part of the basin was far greater than that from the southern tributaries in 1999. Instantaneous loading rates from event samples in 1998 indicate that the southern tributaries can be substantial contributors of loads to the St. Croix River and confirm that event loading is negligible in the 1999 annual loads from these tributaries.

The variability in climatic conditions made it difficult to develop relations between environmental characteristics and annual yields, and weakened those relations that were found. With only 1 year of data, it could not be determined how the absence of snowmelt and the intensity of rain events affected various annual loads or the relation between annual loads and environmental characteristics; however, the variability in the runoff among tributaries was definitely a major factor in 1999 annual loading. Interestingly, the environmental characteristics found to be most related to annual loads in 1999 (increased clay soils in the basin, reduced permeability, and increased slope) are also those that have been shown to be related to runoff.

## RELATIONS BETWEEN WATER QUALITY AND BENTHIC INVERTEBRATES

Benthic invertebrate measures were calculated (table 5) using data collected in the fall of 1999 and compared to 1999 annual loads. There were no significant relations evident between benthic invertebrate indices and 1999 annual loads. Benthic invertebrate indices indicated good to excellent water quality at all St. Croix River tributaries except for diversity and abundance measures at Valley Creek and Willow River and diversity and biotic index at Kettle River. No significant difference in the 1999 loads were evident at these three streams relative to the other tributaries.

The Kinnickinnic River, with the highest suspended-sediment (424 mg/L) and phosphorus (5.74 mg/L) concentrations sampled in 1998–99, and the Sunrise River, with the highest annual suspended-sediment (8,400 kg/km$^2$) and phosporus (39.9 kg/km$^2$) yields in 1999, both had excellent water quality based on benthic invertebrate biotic indexes used to indicate nutrient enrichment (and the associated drop in dissolved oxygen concentration). Diversity and abundance measures at these tributaries also indicated healthy invertebrate populations.

Benthic invertebrate health depends on habitat, chemical water quality, and the effect of the water quality—primarily sedimentation—on the habitat. Many of the tributaries had excellent water quality according to invertebrate indices and appeared not to be affected by nutrient and sediment loading. Those invertebrate indices that did show slight effects do not match the sites with high 1999 annual yields, an indication that invertebrate populations were affected by habitat rather than chemical water quality, that the 1999 annual loading rates were not an accurate representation of the long-term average chemical water quality of the tributaries, or more likely a combination of both of these effects.

The invertebrate indices for the Kettle and Wood Rivers likely were affected by the type of habitat sampled as much as the chemical water quality of the stream. These streams did not have hard substrate of gravel and/or cobble at the sampling sites, so benthic invertebrates were collected from woody debris and detritus. Habitat often has a greater effect on abundance and diversity than on Biotic Index (Rheaume and others, 1995; Lenz and Miller, 1996), although all measures at these streams could be affected. Willow River and Valley Creek had good habitat for benthic invertebrates, but the benthic invertebrate indices indicated that the invertebrate communities were slightly impacted. These streams had minimal runoff and low annual loads in 1999 and may typically have higher average loads and yields than were measured in 1999. The concentrations and instantaneous loads measured at the Willow River in 1997 and 1998 support the possibility that nutrient or sediment loading may be affecting the invertebrates at these sites. Benthic-invertebrate measures can also be affected by other variables not measured in this study.

## SUMMARY AND CONCLUSIONS

The St. Croix River Basin drains 20,010 km$^2$ of Minnesota and Wisconsin. The basin includes over 15 major tributaries and hundreds of minor tributaries to the St. Croix River. The Riverway is protected effectively by its status not only as a National Wild and Scenic River but also as a unit of the National Park System; however, its tributaries do not have that same status. Most recreational use in the park and tributaries involves contact with the water, such as boating and canoeing, accentuating the need for good water quality. In 1994, the NPS, WDNR, MDNR, MPCA, and Minnesota-Wisconsin Boundary Area Commission signed a memorandum of understanding that formed the interagency St. Croix Basin Water Resources Planning Team (Basin Team) and agreed to investigate water-resources issues throughout the basin. Since 1994, the Basin Team has grown with the addition of other agencies including the USGS, Metropolitan Council Environmental Services, University of Minnesota, Minnesota Department of Agriculture, St. Croix Band of Chippewa Indians, and U.S. Environmental Protection Agency.

The USGS Upper Mississippi River Basin (UMIS) study unit of the NAWQA Program sampled tributaries to the Upper Mississippi River, including many in the St. Croix River Basin, as part of a synoptic study to characterize nutrient and suspended-sediment concentrations, loads, and yields during snowmelt in 1997. On the basis of results from the 1997 snowmelt synoptic study, a study was designed for 1998 to identify spatial and temporal variations in nutrients and suspended-sediment loading from tributaries identified as major contributors and other tributaries with environmental characteristics thought to be related to high nutrient and suspended-sediment loading. A follow-up study then was done from October 1998 to September 1999 on a subset of 11 sites from the 1998 study. Extensive water-quality data collected in coordination with continuous streamflow-monitoring data were used to compute annual nutrient and suspended-sediment loads and yields at the 11 tributary sites for water year 1999. Relations between environmental characteristics and calculated annual nutrient and suspended-sediment yields were used to predict loading from unmonitored tributaries of the St. Croix River Basin.

The Kettle River had the highest annual loads of total phosphorus and suspended sediment, whereas the Sunrise River had the highest annual yields of total phosphorus and suspended sediment among the tributaries to the St. Croix River in 1999. Sand Creek, and the Snake and Upper Tamarack Rivers were also substantial suspended-sediment contributors. Browns Creek, and the Snake, Apple, Upper Tamarack, and Kinnickinnic Rivers were also substantial contributors of total phosphorus in water year 1999. Instantaneous loading rates calculated for events in 1997 and 1998 demonstrated that the Willow, Trade, Wood, Crooked, and Lower Tamarack Rivers can also be substantial contributors to the total loading to the St. Croix River Basin.

The most important factor affecting annual yields in 1999 was rainfall intensity and runoff. Loading during storm events was a large portion of the annual loading of the St. Croix River tributaries. Storm events affecting the southern tributary basins were few and small, resulting in loads and yields that were correspondingly small. In contrast, storm events affecting northern tributaries were more frequent and more intense, leading to higher loads and yields. Annual loads for 1999 in the southern St. Croix River Basin tributaries probably were lower than the long-term average loading rates. Trend analyses of loading rates in the St. Croix River Basin are not possible without long-term data.

Loading during events appears to be a large portion of the nutrient and suspended-sediment loading from tributaries to the St. Croix River. In some cases, a single event contributed most of the annual load of a given tributary. Because of the importance of event loads in the St. Croix River Basin, a single year of data collection is inadequate to fully evaluate the variability in annual tributary loading. Results from limited-length sampling depend highly on weather patterns and the amount and duration of runoff throughout the basin during the study period. The disparities in runoff caused by climatological factors throughout the basin may be more important to 1999 annual tributary loading than variability in land use and environmental characteristics.

The 1999 annual loads and yields in monitored tributaries to the St. Croix River calculated using Estimator had lower standard errors of prediction than the loads and yields calculated for unmonitored tributaries using relations between annual yields and environmental characteristics. Because of the climatological variability in the basin, relations between annual yields and environmental characteristics of the tributary basins were poorly defined resulting in large errors when predicting annual loads and yields in the unmonitored basins.

Benthic invertebrate indices indicated excellent to good water quality at all tributaries except Valley Creek, Willow River, and Kettle River. No relations were found between benthic invertebrate indices and the calculated and predicted annual tributary loads. Nutrient and sediment concentrations, loads, and yields from the tributaries to the St. Croix River were low and have had little effect on the benthic invertebrate populations at these streams.

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# APPENDIXES 1–7

**Appendix 1.** Results of St. Croix River tributaries quality-assurance/quality-control sampling, Wisconsin and Minnesota, 1998–99

[mg/L, milligrams per liter; %, percent; USGS, U.S. Geological Survey; MPCA, Minnesota Pollution Control Agency; Met. Council, Metropolitan Council Environmental Services; NA, not available; <, less than]

| | Apple River - June 22, 1998 | | | Willow River - June 22, 1998 | | | Kinnickinnic River - June 22, 1998 | | |
|---|---|---|---|---|---|---|---|---|---|
| | USGS | MPCA | Met. Council | USGS | MPCA | Met. Council | USGS | MPCA | Met. Council |
| Total kjeldahl nitrogen, mg/L | 0.57 | 0.64 | 0.76 | 1.29 | 1.23 | 1.2 | 0.306 | 0.37 | NA |
| Dissolved kjeldahl nitrogen, mg/L | .385 | NA | .53 | .534 | NA | .65 | .206 | NA | .29 |
| Dissolved ammonia nitrogen, mg/L | .035 | .03 | .1 | <.02 | .05 | .05 | .020 | .11 | .05 |
| Dissolved nitrite N, mg/L | .017 | NA | <.03 | .037 | NA | .04 | .023 | NA | <.03 |
| Dissolved nitrite plus nitrate, mg/L | .818 | .77 | NA | 1.18 | 1.10 | NA | 5.05 | 4.6 | NA |
| Total phosphorus, mg/L | .052 | .057 | .02 | .088 | .114 | .09 | .077 | .079 | NA |
| Dissolved phosphorus, mg/L | .023 | NA | <.01 | .011 | NA | <.01 | .063 | NA | <.01 |
| Dissolved orthophosphate as P, mg/L | .021 | .026 | .020 | .02 | .014 | .019 | .060 | .062 | .063 |
| Chloride, dissolved, mg/L | 7.3 | NA | 6 | 10.6 | NA | 9 | 17.0 | NA | 16 |
| Suspended sediment, mg/L | 4 | 3.6 | 3 | 15 | 19 | 17 | 5 | .3 | 4 |
| Sediment, % finer than 0.062 mm | 95.24 | NA | NA | 97.96 | NA | NA | 76.67 | NA | NA |

| | Clam River - Sept. 24, 1999 | | | Wood River - Sept. 24, 1999 | | Trade River - Sept. 25, 1999 | |
|---|---|---|---|---|---|---|---|
| | USGS | MPCA | Met. Council | USGS | MPCA | USGS | MPCA |
| Total kjeldahl nitrogen, mg/L | 0.63 | 0.88 | 0.67 | NA | 0.56 | 0.44 | 0.32 |
| Dissolved kjeldahl nitrogen, mg/L | .370 | NA | NA | NA | NA | .500 | NA |
| Dissolved ammonia nitrogen, mg/L | .035 | .02 | <.02 | .020 | <.02 | .033 | <.02 |
| Dissolved nitrite N, mg/L | <.01 | NA | <.03 | <.01 | NA | <.01 | NA |
| Dissolved nitrite plus nitrate, mg/L | .124 | .08 | .13 | .252 | .25 | .103 | .06 |
| Total phosphorus, mg/L | .034 | .04 | NA | .025 | .022 | .019 | .019 |
| Dissolved phosphorus, mg/L | .010 | NA | NA | <.01 | NA | <.01 | NA |
| Dissolved orthophosphate as P, mg/L | <.01 | NA | .027 | .01 | NA | .010 | NA |
| Suspended sediment, mg/L | 14 | 4.8 | 7 | 5 | <1 | 3 | 1.6 |
| Sediment, % finer than 0.062 mm | 33.65 | NA | NA | 61.11 | NA | 83.33 | NA |

**Appendix 2.** Summary of analytical results from the U.S. Geological Survey 1997–98 synoptic sampling of tributaries to the St. Croix River, Wisconsin and Minnesota

[mi$^2$, square miles; µg/L, micrograms per liter; mg/L, milligrams per liter; mm, millimeter; --, no data; 0 = less than detection]

| Event Type | Date | Drainage area (square kilometers) | Discharge (cubic meters per minute) | Temperature (degrees Celsius) | Specific conductance (mg/L) | Oxygen, dissolved (mg/L) | pH (standard units) | Nitrogen, ammonia, dissolved (mg/L) | Nitrogen, nitrite, dissolved (mg/L) | Nitrogen, ammonia + organic, dissolved (mg/L) | Nitrogen, ammonia + organic, total (mg/L) | Nitrogen, nitrite plus nitrate, dissolved (mg/L) | Phosphorus, total (mg/L) | Phosphorus, dissolved (mg/L) | Phosphorus, ortho, dissolved (mg/L) | Suspended sediment, total (mg/L) | Suspended sediment (percent finer than 0.062 mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Upper Tamarack near Marksville, Minn.** | | | | | | | | | | | | | | | | | |
| Snowmelt | 02/25/98 | 257 | 167 | 0.3 | 97 | 18.2 | 7.7 | 0.192 | 0 | 1.027 | 0.980 | 0.383 | 0.031 | 0.013 | 0.032 | 11 | 78.48 |
| Spring storm | 03/30/98 | 257 | 780 | 3.1 | 51 | 14.1 | 7.8 | .075 | 0 | .788 | .937 | .176 | .049 | .022 | .013 | 15 | 50.00 |
| Base flow | 07/22/98 | 257 | 15 | 19.8 | 138 | 8.3 | 7.5 | .064 | 0 | 1.015 | 1.145 | .053 | 0 | .013 | .015 | 2 | 80.00 |
| Low flow | 09/22/98 | 257 | 5 | 9.6 | 220 | 10.8 | 7.7 | 0 | 0 | -- | -- | .078 | .014 | 0 | 0 | 9 | 76.32 |
| **Yellow River near Danbury, Wis.** | | | | | | | | | | | | | | | | | |
| Snowmelt | 04/03/97 | 808[1] | 758 | -- | -- | -- | | .050 | 0 | 0 | .300 | .460 | .020 | 0 | 0 | 9 | 14.90 |
| Snowmelt | 02/24/98 | 968 | 646 | 3.0 | 190 | 12.5 | 7.8 | 0 | 0 | .201 | .304 | .363 | 0 | 0 | .022 | 2 | 68.18 |
| Spring storm | 03/31/98 | 968 | 870 | 4.5 | 155 | 13.9 | 7.9 | .034 | 0 | .192 | .342 | .241 | .036 | .013 | .014 | 3 | 63.16 |
| Base flow | 07/14/98 | 968 | 498 | 29.2 | 24 | 6.8 | 8.6 | .112 | .028 | .618 | .855 | .124 | 0 | .017 | .016 | 5 | 80.95 |
| Low flow | 09/22/98 | 968 | 306 | 18.9 | 172 | 8.2 | 7.8 | .057 | 0 | .530 | .630 | .175 | .045 | .024 | .026 | 4 | 80.00 |
| **Lower Tamarack River near Marksville, Minn.** | | | | | | | | | | | | | | | | | |
| Snowmelt | 02/24/98 | 487 | 498 | 0.5 | 86 | 15.0 | 7.6 | .134 | 0 | .810 | 1.03 | .518 | .044 | .014 | .031 | 26 | 72.33 |
| Spring storm | 03/30/98 | 487 | 1,208 | 3.9 | 53 | 13.6 | 7.4 | .081 | 0 | .832 | .772 | .133 | .044 | .027 | .015 | 14 | 83.87 |
| Base flow | 07/22/98 | 487 | 49 | 23.4 | 159 | 7.3 | 7.4 | .035 | 0 | .923 | 1.10 | .054 | .024 | .025 | .018 | 4 | 91.67 |
| Low flow | 09/22/98 | 487 | 10 | 13.0 | 257 | 9.5 | 7.5 | 0 | 0 | .350 | .360 | .064 | .019 | .016 | .010 | 2 | 77.78 |
| **Crooked Creek near Hinkley, Minn.** | | | | | | | | | | | | | | | | | |
| Snowmelt | 04/03/97 | 241 | 1,465 | -- | -- | -- | -- | .07 | 0 | .5 | .900 | .200 | .110 | .030 | .010 | 160 | 64.00 |
| Snowmelt | 02/24/98 | 241 | 263 | 1.4 | 103 | 15.8 | 7.8 | .178 | 0 | .879 | 1.09 | .490 | .059 | .018 | .032 | 12 | 76.40 |
| Spring storm | 03/30/98 | 241 | 583 | 4.1 | 72 | 13.5 | 7.7 | .101 | 0 | .774 | .919 | .139 | .072 | .034 | .023 | 201 | 9.89 |
| Base flow | 07/22/98 | 241 | 30 | 19.9 | 202 | 8.8 | 7.6 | .034 | 0 | .466 | .599 | .196 | .019 | 0 | .023 | 6 | 82.35 |
| Low flow | 09/22/98 | 241 | 13 | 11.3 | 256 | 11.4 | 7.7 | .078 | 0 | .630 | .730 | .197 | .023 | .019 | .017 | 4 | 94.74 |
| **Clam River near Webster, Minn.** | | | | | | | | | | | | | | | | | |
| Snowmelt | 04/03/97 | 935 | 1,305 | 4.3 | 112 | 11.4 | 7.3 | .17 | 0 | .500 | .600 | .280 | .07 | .02 | .010 | 78 | 19.05 |
| Snowmelt | 02/23/98 | 935 | 472 | 3.4 | 217 | 13.2 | 7.8 | .155 | .012 | .465 | .597 | .394 | .037 | 0 | .028 | 13 | 43.88 |
| Spring storm | 03/31/98 | 935 | 901 | 5.0 | 152 | 13.3 | 8.0 | .033 | 0 | .211 | .370 | .071 | .038 | .011 | .016 | 100 | 22.13 |
| Base flow | 07/14/98 | 935 | 321 | 28.8 | 214 | 82.1 | 8.3 | .082 | .021 | .712 | .890 | .138 | 0 | .010 | .027 | 7 | 69.77 |
| Low flow | 09/24/98 | 935 | 287 | 15.4 | 214 | 9.1 | 8.0 | .035 | 0 | .370 | .630 | .124 | .034 | .010 | 0 | 14 | 33.65 |
| **Sand River near Hinkley, Minn.** | | | | | | | | | | | | | | | | | |
| Snowmelt | 02/24/98 | 285 | 318 | .4 | 88 | 15.2 | 7.7 | .195 | 0 | .835 | 1.17 | .410 | .067 | .023 | .032 | 50 | 84.37 |
| Spring storm | 03/30/98 | 285 | 532 | 5.0 | 70 | 12.8 | 7.6 | .109 | 0 | .800 | .935 | .161 | .064 | .034 | .022 | 32 | 65.60 |

**Appendix 2.** Summary of analytical results from the U.S. Geological Survey 1997–98 synoptic sampling of tributaries to the St. Croix River, Wisconsin and Minnesota—Continued

[mi², square miles; µg/L, micrograms per liter; mg/L, milligrams per liter; mm, millimeter; --, no data; 0 = less than detection]

| Event Type | Date | Drainage area (square kilometers) | Discharge (cubic meters per minute) | Temperature (degrees Celsius) | Specific conductance (mg/L) | Oxygen, dissolved (mg/L) | pH (standard units) | Nitrogen, ammonia, dissolved (mg/L) | Nitrogen, nitrite, dissolved (mg/L) | Nitrogen, ammonia + organic, dissolved (mg/L) | Nitrogen, ammonia + organic, total (mg/L) | Nitrogen, nitrite plus nitrate, dissolved (mg/L) | Phosphorus, total (mg/L) | Phosphorus, dissolved (mg/L) | Phosphorus, ortho, dissolved (mg/L) | Suspended sediment, total (mg/L) | Suspended sediment (percent finer than 0.062 mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Base flow | 07/22/98 | 285 | 46 | 23.7 | 142 | 9.7 | 7.7 | .031 | .010 | .676 | .793 | .096 | .042 | .024 | .019 | 5 | 89.29 |
| Low flow | 09/22/98 | 285 | 15 | 14.0 | 182 | 10.6 | 7.8 | .021 | 0 | .390 | .460 | .067 | .024 | .010 | 0 | 3 | 46.15 |
| **North Fork of Wood River near Grantsburg, Wis.** | | | | | | | | | | | | | | | | | |
| Snowmelt | 04/03/97 | 412[1] | 999 | -- | -- | -- | -- | .080 | 0 | .500 | .700 | .110 | .070 | .020 | .020 | 76 | 80.60 |
| Snow melt | 02/23/98 | 144 | 155 | 3 | 210 | 12.9 | 7.7 | .146 | .013 | .782 | .944 | .317 | .071 | .025 | .035 | 35 | 55.93 |
| Spring storm | 03/31/98 | 144 | 493 | 3.2 | 129 | 11.8 | 7.4 | .052 | 0 | .686 | .807 | .081 | .069 | .046 | .028 | 25 | 21.34 |
| Base flow | 07/14/98 | 144 | 92 | 27.4 | 240 | 7.7 | 7.8 | .043 | .021 | .648 | .849 | .170 | .073 | .010 | .025 | 17 | 80.00 |
| Low flow | 09/24/98 | 144 | 56 | 15.1 | 250 | 9.5 | 7.6 | .020 | 0 | -- | -- | .252 | .025 | 0 | .010 | 5 | 61.11 |
| **Trade River near Trade River, Wis.** | | | | | | | | | | | | | | | | | |
| Snowmelt | 04/01/97 | 347 | 658 | 3.2 | 160 | 11.55 | 7.2 | .330 | .010 | .800 | 1.10 | .390 | .220 | .030 | .020 | 204 | 31.32 |
| Snowmelt | 04/02/97 | 347 | 906 | 4.8 | 165 | 12.6 | 7.1 | .300 | .010 | .700 | 1.10 | .420 | .180 | 0 | .010 | 136 | |
| Snowmelt | 02/23/98 | 347 | 199 | 5.0 | 212 | 12.6 | 7.9 | .139 | .015 | .583 | .758 | .424 | .049 | 0 | .030 | 18 | 69.17 |
| Spring storm | 03/31/98 | 347 | 372 | 4.0 | 145 | 13.3 | 7.8 | .160 | 0 | .571 | .844 | .360 | .093 | .029 | .031 | 40 | 66.27 |
| Base flow | 07/22/98 | 347 | 124 | 21.8 | 202 | 8.4 | 8.0 | .036 | 0 | .439 | .555 | .105 | .025 | .012 | .014 | 5 | 91.67 |
| Low flow | 09/24/98 | 347 | 82 | 12.2 | 216 | 10.2 | 8.0 | .033 | 0 | .500 | .440 | .103 | .019 | 0 | .010 | 3 | 83.33 |
| **Apple River near Sommerset, Wis.** | | | | | | | | | | | | | | | | | |
| Snowmelt | 04/03/97 | 1,199 | 1,332 | -- | -- | -- | -- | .030 | 0 | .300 | .400 | .950 | .090 | .020 | 0 | 8 | 21.90 |
| Snowmelt | 02/19/98 | 1,199 | 770 | 3.6 | 291 | 14.2 | 8.3 | .122 | 0 | .326 | .379 | 1.29 | .038 | .029 | .032 | 2 | 91.67 |
| Spring storm | 04/01/98 | 1,199 | 2,423 | 4.9 | 173 | 13.1 | 7.6 | .056 | 0 | .476 | .463 | .483 | .056 | .057 | .038 | 13 | 79.05 |
| Summer storm | 06/26/98 | 1,199 | 1,021 | 22.7 | 239 | 7.6 | 7.8 | .022 | .018 | .415 | .576 | .439 | .050 | .031 | 0 | 5 | 80.95 |
| Base flow | 07/28/98 | 1,199 | 440 | 22.8 | 280 | 7.8 | 8.0 | .042 | .013 | .300 | .512 | .804 | .030 | 0 | .017 | 2 | 90.00 |
| **Willow River near Hudson, Wis.** | | | | | | | | | | | | | | | | | |
| Snowmelt | 03/28/97 | 658[1] | 1,431 | -- | -- | -- | -- | .520 | .030 | 1.00 | 1.20 | 2.00 | .330 | .200 | .170 | 19 | 7.10 |
| Snowmelt | 02/18/98 | 717 | 500 | 3.6 | 409 | 14.4 | 8.1 | .231 | .015 | .356 | .611 | 4.36 | .134 | .034 | .036 | 26 | 100 |
| Spring storm | 04/01/98 | 717 | 1,320 | 6.0 | 171 | 12.8 | 7.6 | .298 | .028 | 1.20 | 1.08 | 1.21 | .097 | .106 | .072 | 414 | 25.03 |
| Summer storm | 06/25/98 | 717 | 452 | 23.1 | 343 | 8.9 | 8.6 | .043 | .053 | .516 | .934 | 1.58 | .024 | 0 | 0 | 11 | 83.50 |
| Base flow | 07/28/98 | 717 | 221 | 21.6 | 360 | 8.5 | 8.1 | .078 | .046 | .305 | .700 | 1.58 | .060 | 0 | .011 | 3 | 76.19 |
| **Kinnickinnic River near River Falls, Wis.** | | | | | | | | | | | | | | | | | |
| Snowmelt | 03/21/97 | 432 | 214 | -- | -- | -- | -- | .008 | .020 | 0 | .3 | 5.00 | .08 | .05 | .03 | 9 | 29.20 |
| Snowmelt | 02/18/98 | 432 | 528 | 3.1 | 335 | 14.3 | 7.9 | 2.26 | .051 | 5.28 | 5.53 | 3.31 | 1.318 | 1.029 | .928 | 252 | 44.12 |
| Spring storm | 04/01/98 | 432 | 1,087 | 5.8 | 228 | 12.8 | 7.8 | .114 | .016 | .741 | 1.40 | 1.70 | .381 | .202 | .158 | 424 | 31.70 |
| Summer storm | 06/25/98 | 432 | 511 | 20.6 | 316 | 7.9 | 7.8 | .028 | .043 | .713 | 1.74 | 2.61 | .144 | .125 | .064 | 318 | 57.16 |
| Base flow | 07/28/98 | 432 | 194 | 20.6 | 471 | 11.4 | 8.1 | .027 | .021 | .199 | .353 | 4.85 | .046 | .054 | .041 | 16 | 60.27 |

[1]Sampling location in 1997 differed from that in 1998.

**Appendix 3.** Summary of analytical results from Minnesota Pollution Control Agency (MPCA) sampling of the St. Croix River tributaries, Wisconsin and Minnesota, 1998–99

[--, no data; mg/L, milligrams per liter]

| Date | Total sediment (mg/L) | Total nitrogen (mg/L) | Total phosphorus (mg/L) | Chloride (mg/L) |
|---|---|---|---|---|
| **Kettle River below Sandstone, Minn.** | | | | |
| 02/25/98 | 15 | 1.29 | 0.121 | -- |
| 03/31/98 | 14 | 1.06 | .090 | -- |
| 10/01/98 | -- | 0.36 | .035 | -- |
| 10/29/98 | -- | .55 | .053 | -- |
| 11/24/98 | -- | .66 | .033 | -- |
| 01/19/99 | 1.5 | .51 | .037 | 6.6 |
| 03/04/99 | 1.6 | .47 | .056 | 8.9 |
| 03/22/99 | 4.8 | .85 | .070 | 8.5 |
| 04/12/99 | 4.4 | .86 | .047 | 3.8 |
| 05/12/99 | 10 | .68 | .058 | 3.3 |
| 05/17/99 | 5.6 | .86 | .043 | 2.8 |
| 06/16/99 | 2.0 | .75 | .057 | 4.6 |
| 07/12/99 | 7.6 | 1.02 | .081 | 4.0 |
| 08/09/99 | 4.4 | 1.16 | .066 | 3.5 |
| 09/28/99 | 15 | 1.07 | .079 | 3.5 |
| **Snake River near Pine City, Minn.** | | | | |
| 02/25/98 | 3.0 | 1.47 | .115 | -- |
| 04/01/98 | 5.0 | .78 | .059 | -- |
| 10/01/98 | -- | 1.42 | .102 | -- |
| 10/05/98 | 10 | -- | .073 | -- |
| 10/29/98 | -- | .96 | .059 | -- |
| 11/23/98 | -- | -- | .044 | -- |
| 11/24/98 | -- | .72 | .044 | -- |
| 02/01/99 | 2.0 | -- | .050 | -- |
| 03/22/99 | 5.2 | 1.02 | .096 | 8.5 |
| 04/12/99 | 4.4 | .91 | .065 | 4.4 |
| 05/17/99 | 5.2 | .92 | .078 | 3.5 |
| 06/16/99 | 4.0 | .94 | .084 | 4.1 |
| 07/12/99 | 10 | 1.39 | .148 | 10 |
| 01/19/99 | 2.0 | .74 | .043 | 6.2 |
| 03/04/99 | 1.6 | .62 | .044 | 8.4 |
| 05/12/99 | 3.6 | .90 | .059 | 4.5 |
| 08/09/99 | 7.0 | 1.41 | .121 | 8.5 |
| 09/28/99 | 10 | 1.27 | .086 | 4.3 |
| **Sunrise River at Sunrise, Minn.** | | | | |
| 02/25/98 | 27 | 1.32 | .131 | -- |
| 04/01/98 | 46 | 1.03 | .182 | -- |
| 10/01/98 | -- | .77 | .072 | -- |
| 10/29/98 | -- | .77 | .062 | -- |
| 11/24/98 | -- | .68 | .060 | -- |
| 01/19/99 | 7.0 | 1.15 | .108 | 15 |
| 03/04/99 | 8.6 | 1.33 | .124 | 17 |
| 03/31/99 | 9.8 | 1.15 | .127 | 12 |
| 04/12/99 | 19 | 1.03 | .106 | 14.0 |
| 05/12/99 | 42 | 1.45 | .182 | 12 |
| 05/17/99 | 38 | 1.24 | .153 | 11 |
| 06/16/99 | 17 | .99 | .130 | 12 |
| 07/12/99 | 8.0 | 1.01 | .107 | 14 |
| 08/09/99 | 13 | .97 | .130 | 14.0 |
| 09/28/99 | 1.0 | .63 | .056 | 13.0 |

**Appendix 4.** Summary of analytical results from the U.S. Geological Survey sampling of St. Croix River tributaries, Wisconsin and Minnesota, used in 1999 annual-load calculations

[µS/cm; microsiemens per centimeter; mg/L, milligrams per liter; mm, millimeter; <, less than; --, no data]

| Date | Discharge (cubic meters per minute) | Water temperature (degrees Celsius) | Specific conductance (µS/cm) | Oxygen, dissolved (mg/L) | pH (standard units) | Nitrogen, ammonia, dissolved (mg/L as N) | Nitrogen, nitrite, dissolved (mg/L as N) | Nitrogen, ammonia + organic, dissolved (mg/L as N) | Nitrogen, ammonia + organic, total (mg/L as N) | Nitrogen, nitrite plus nitrate, dissolved (mg/L as N) | Phosphorus, total (mg/L as P) | Phosphorus, dissolved (mg/L as P) | Phosphorus, ortho, dissolved (mg/L as P) | Chloride, dissolved (mg/L as Cl) | Suspended sediment (mg/L) | Suspended sediment (percent finer than 0.062 mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Upper Tamarack River near Marksville, Minn.** | | | | | | | | | | | | | | | | |
| 02/25/98 | 167 | 0.3 | 97 | 18.2 | 7.7 | 0.192 | <0.010 | 1.0 | 0.98 | 0.383 | 0.031 | 0.013 | 0.032 | -- | 11 | 78 |
| 03/30/98 | 780 | 3.1 | 51 | 14.1 | 7.8 | .075 | <.010 | 0.79 | .94 | .176 | .049 | .022 | .013 | -- | 15 | 50 |
| 07/22/98 | 15 | 19.8 | 138 | 8.3 | 7.5 | .064 | <.010 | 1.0 | 1.10 | .053 | <.010 | .013 | .015 | -- | 2 | 80 |
| 09/22/98 | 5 | 9.6 | 220 | 10.8 | 7.7 | <.020 | <.010 | .43 | .50 | .078 | .014 | <.010 | <.010 | -- | 9 | 76 |
| 11/23/98 | 102 | 2.6 | 107 | 7.6 | 7.9 | .029 | <.010 | .71 | .72 | .189 | .032 | .015 | <.010 | 3.5 | 15 | 62 |
| 12/10/98 | 102 | .1 | 97 | 5.0 | 7.5 | .025 | <.010 | .68 | .80 | .148 | <.050 | .010 | .012 | 2.9 | 1 | 67 |
| 01/14/99 | 19 | .6 | 358 | 12.6 | 7.7 | .069 | .014 | .91 | .95 | 2.70 | .025 | .019 | .017 | 12.0 | 5 | 84 |
| 02/24/99 | 17 | 0 | 206 | -- | 7.3 | .129 | <.010 | .81 | .79 | .209 | .029 | .021 | .015 | 8.4 | 2 | 70 |
| 03/12/99 | 20 | 0 | 192 | 12.7 | 6.8 | .096 | <.010 | .64 | .63 | .241 | .027 | .020 | .018 | 8.1 | 3 | 59 |
| 03/29/99 | 510 | 1.6 | 77 | 13.5 | 7.0 | .108 | <.010 | .83 | 1.60 | .383 | .124 | .023 | .010 | 2.2 | 52 | 79 |
| 04/07/99 | 958 | 2.6 | 40 | 12.9 | 6.4 | .030 | <.010 | .87 | .38 | .224 | .043 | .021 | <.010 | 1.3 | 11 | 61 |
| 04/29/99 | 100 | 14.7 | 62 | 10.9 | 7.9 | .031 | <.010 | .82 | 2.00 | <.050 | .020 | .014 | .017 | 2.4 | 7 | 44 |
| 05/12/99 | 296 | 11.9 | 52 | 10.9 | 7.4 | <.020 | <.010 | 1.10 | 2.50 | <.050 | .025 | .014 | <.010 | 1.4 | 6 | 75 |
| 06/10/99 | 177 | 22.4 | 62 | 7.7 | 7.8 | <.020 | <.010 | 1.20 | 3.10 | .071 | .047 | .026 | .018 | 1.4 | 7 | 91 |
| 06/24/99 | 302 | 20.0 | 56 | 8.7 | 7.1 | <.020 | <.010 | 1.20 | 1.30 | .067 | .060 | .036 | .020 | 1.2 | 64 | 22 |
| 07/09/99 | 1,716 | 19.1 | 62 | 8.8 | 7.4 | .021 | <.010 | 1.60 | 1.60 | .104 | .074 | .044 | <.010 | 1.4 | -- | -- |
| 07/26/99 | 675 | 23.1 | 52 | 8.1 | 7.0 | <.020 | <.010 | 1.40 | 1.60 | .107 | .100 | .042 | <.010 | .6 | 23 | 63 |
| 07/26/99 | 972 | -- | -- | -- | -- | -- | -- | -- | -- | -- | .108 | -- | -- | -- | -- | -- |
| 08/11/99 | 204 | 19.3 | 69 | 9.0 | 7.4 | .038 | <.010 | 1.30 | 1.30 | .113 | .075 | .037 | .011 | 1.4 | 8 | 83 |
| 09/08/99 | 172 | 19.8 | 78 | 9.2 | 7.5 | <.020 | <.010 | 1.10 | 1.20 | .128 | .064 | .038 | .012 | 1.9 | 5 | 96 |

**Appendix 4.** Summary of analytical results from the U.S. Geological Survey sampling of St. Croix River tributaries, Wisconsin and Minnesota, used in 1999 annual-load calculations—Continued

[µS/cm; microsiemens per centimeter; mg/L, milligrams per liter; mm, millimeter; <, less than; --, no data]

| Date | Discharge (cubic meters per minute) | Water temperature (degrees Celsius) | Specific conductance (µS/cm) | Oxygen, dissolved (mg/L) | pH (standard units) | Nitrogen, ammonia, dissolved (mg/L as N) | Nitrogen, nitrite, dissolved (mg/L as N) | Nitrogen, ammonia + organic, dissolved (mg/L as N) | Nitrogen, ammonia + organic, total (mg/L as N) | Nitrogen, nitrite plus nitrate, dissolved (mg/L as N) | Phosphorus, total (mg/L as P) | Phosphorus, dissolved (mg/L as P) | Phosphorus, ortho, dissolved (mg/L as P) | Chloride, dissolved (mg/L as Cl) | Suspended sediment (mg/L) | Suspended sediment (percent finer than 0.062 mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Lower Tamarack River near Marksville, Minn.** | | | | | | | | | | | | | | | | |
| 02/24/98 | 498 | 0.5 | 86 | 15.0 | 7.6 | 0.134 | <0.010 | 0.81 | 1.0 | 0.518 | 0.044 | 0.014 | 0.031 | -- | 26 | 72 |
| 03/30/98 | 1,208 | 3.9 | 53 | 13.6 | 7.4 | .081 | <.010 | .83 | .77 | .133 | .044 | .027 | .015 | -- | 14 | 84 |
| 07/22/98 | 49 | 23.4 | 159 | 7.3 | 7.4 | .035 | <.010 | .92 | 1.1 | .054 | .024 | .025 | .018 | -- | 4 | 92 |
| 09/22/98 | 10 | 13 | 257 | 9.5 | 7.5 | <.020 | <.010 | .35 | .36 | .064 | .019 | .016 | .010 | -- | 2 | 78 |
| 11/23/98 | 136 | 2.3 | 121 | 5.6 | 7.7 | .028 | <.010 | .63 | .70 | .146 | .042 | .016 | .014 | 2.7 | 3 | 100 |
| 12/10/98 | 194 | -- | -- | -- | -- | .028 | <.010 | .71 | .83 | .094 | <.050 | .019 | .014 | 1.7 | 2 | 67 |
| 01/14/99 | 27 | .1 | 192 | 12.8 | 7.6 | .112 | .013 | .67 | .71 | .101 | .032 | .023 | .021 | 4.8 | 3 | 82 |
| 02/24/99 | 31 | 0 | 231 | -- | 7.2 | .113 | <.010 | .48 | .51 | .168 | .037 | .021 | .015 | 5.9 | 2 | 75 |
| 03/12/99 | 25 | .9 | 232 | 12.9 | 7.4 | .067 | <.010 | .41 | .40 | .193 | .034 | .018 | .020 | 6.6 | 3 | 95 |
| 03/29/99 | 646 | 1.8 | 66 | 12.9 | 7.0 | .106 | <.010 | .81 | 1.1 | .485 | .090 | .029 | .017 | 1.2 | 18 | 92 |
| 04/07/99 | 1,689 | 3.3 | 40 | 11.8 | 6.3 | .029 | <.010 | .84 | .88 | .224 | .055 | .026 | .010 | .64 | 16 | 80 |
| 04/29/99 | 194 | 11.9 | 69 | 10.1 | 7.3 | .032 | <.010 | .78 | 2.2 | <.050 | .028 | .016 | .017 | 1.3 | 5 | 89 |
| 05/12/99 | 523 | 11.5 | 55 | 9.8 | 7.3 | .028 | <.010 | 1.0 | 2.3 | <.050 | .034 | .018 | <.010 | .52 | 5 | 89 |
| 06/10/99 | 333 | 21.8 | 67 | 7.0 | 7.2 | .044 | <.010 | 1.2 | 2.1 | .051 | .051 | .029 | .018 | .51 | 7 | 78 |
| 06/24/99 | 895 | 20 | 60 | 7.1 | 6.9 | .038 | <.010 | 1.0 | 1.2 | .055 | .082 | .038 | .026 | .92 | 20 | 87 |
| 07/09/99 | 376 | 19.7 | 77 | 7.4 | 7.2 | .027 | <.010 | 1.3 | 1.5 | .082 | .081 | .051 | .015 | .63 | -- | -- |
| 07/26/99 | 438 | 25.5 | 78 | 6.5 | 6.9 | .049 | <.010 | 1.1 | 1.4 | .119 | .092 | .034 | .010 | <.10 | 10 | 98 |
| 08/11/99 | 460 | 18.8 | 72 | 7.4 | 7.3 | .053 | <.010 | 1.2 | 1.3 | .054 | .079 | .037 | .014 | .68 | 11 | 88 |
| 09/08/99 | 381 | 19.3 | 98 | 8.3 | 7.3 | <.020 | <.010 | 1.1 | 1.4 | .086 | .093 | .036 | .018 | 1.2 | 16 | 89 |

**Appendix 4.** Summary of analytical results from the U.S. Geological Survey sampling of St. Croix River tributaries, Wisconsin and Minnesota, used in 1999 annual-load calculations—Continued

[µS/cm; microsiemens per centimeter; mg/L, milligrams per liter; mm, millimeter; <, less than; --, no data]

| Date | Discharge (cubic meters per minute) | Water temperature (degrees Celsius) | Specific conductance (µS/cm) | Oxygen, dissolved (mg/L) | pH (standard units) | Nitrogen, ammonia, dissolved (mg/L as N) | Nitrogen, nitrite, dissolved (mg/L as N) | Nitrogen, ammonia + organic, dissolved (mg/L as N) | Nitrogen, ammonia + organic, total (mg/L as N) | Nitrogen, nitrite plus nitrate, dissolved (mg/L as N) | Phosphorus, total (mg/L as P) | Phosphorus, dissolved (mg/L as P) | Phosphorus, ortho, dissolved (mg/L as P) | Chloride, dissolved (mg/L as Cl) | Suspended sediment (mg/L) | Suspended sediment (percent finer than 0.062 mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **North Fork of Wood River near Grantsburg, Wis.** | | | | | | | | | | | | | | | | |
| 02/23/98 | 155 | 3 | 210 | 12.9 | 7.7 | 0.146 | 0.013 | 0.78 | 0.94 | 0.317 | 0.071 | 0.025 | 0.035 | -- | 35 | 56 |
| 03/31/98 | 493 | 3.2 | 129 | 11.8 | 7.4 | .052 | <.010 | .69 | .81 | .081 | .069 | .046 | .028 | -- | 25 | 21 |
| 07/14/98 | 92 | 27.4 | 240 | 7.7 | 7.8 | .043 | .021 | .65 | .85 | .170 | .073 | .010 | .025 | -- | 17 | 80 |
| 09/24/98 | 56 | 15.1 | 250 | 9.5 | 7.6 | .020 | <.010 | .41 | .55 | .252 | .025 | <.010 | .010 | -- | 5 | 61 |
| 10/28/98 | 93 | 10.4 | 211 | 10.5 | 7.5 | .060 | <.010 | .52 | .60 | .141 | .018 | <.050 | <.010 | -- | 6 | 78 |
| 11/23/98 | 153 | 3.8 | 192 | 11.0 | 7.7 | .071 | <.010 | .51 | .86 | .148 | .059 | .014 | .013 | 4.9 | 18 | 53 |
| 12/09/98 | 129 | 2.1 | 200 | 5.4 | 7.8 | .058 | <.010 | .58 | .50 | .160 | .035 | <.050 | .017 | 4.3 | 9 | 74 |
| 01/14/99 | 31 | 0 | 230 | 13.8 | -- | .124 | .016 | .50 | .69 | .245 | .058 | .013 | .016 | 6.4 | 4 | 93 |
| 02/23/99 | 37 | 2.1 | 267 | -- | 7.6 | .148 | <.010 | .54 | .64 | .311 | .050 | .009 | <.010 | 5.7 | 10 | 89 |
| 03/12/99 | 22 | 1.6 | 258 | 13.0 | 7.3 | .124 | .010 | .49 | .68 | .291 | .055 | .007 | <.010 | 6.6 | 10 | 80 |
| 03/24/99 | 102 | 3.3 | 207 | 12.3 | 7.3 | .070 | .010 | .45 | .70 | .167 | .053 | .017 | <.010 | 4.6 | 18 | 60 |
| 03/30/99 | 197 | 6.7 | 164 | 7.3 | 7.3 | .122 | <.010 | .78 | 1.0 | .123 | .098 | .037 | .018 | -- | 18 | 58 |
| 04/06/99 | 280 | 6 | 152 | 11.3 | 7.3 | .074 | <.010 | .73 | 1.4 | .119 | .085 | .030 | .016 | 5.8 | 53 | 22 |
| 04/28/99 | 173 | 13.4 | 203 | 10.2 | 7.7 | .060 | <.010 | .45 | .8 | .092 | .042 | .013 | .020 | 4.8 | 12 | 55 |
| 05/13/99 | 180 | 11.7 | 197 | 9.1 | 7.7 | .048 | <.010 | .66 | 1.6 | <.050 | .057 | .016 | .010 | 5.2 | 15 | 72 |
| 06/10/99 | 126 | 21.8 | 192 | 7.6 | 7.6 | .070 | <.010 | .65 | .28 | .134 | .085 | .012 | .017 | 4.3 | 20 | 87 |
| 06/24/99 | 258 | 22 | 131 | 7.1 | 7.3 | .034 | .011 | .68 | .82 | .090 | .086 | .028 | .022 | 3.3 | 22 | 57 |
| 07/09/99 | 151 | 21.2 | 192 | 8.0 | 7.7 | .076 | .015 | .77 | 1.0 | .179 | .079 | .026 | <.010 | 5.8 | -- | -- |
| 08/11/99 | 63 | 21.8 | 234 | 9.4 | 7.9 | .021 | <.010 | .29 | .71 | .274 | .039 | .011 | <.010 | 5.6 | 5 | 87 |
| 09/08/99 | 133 | 19.2 | 184 | 8.4 | 7.6 | <.020 | <.010 | .57 | .69 | .154 | .074 | .030 | .020 | 5.7 | 10 | 87 |

**Appendix 4.** Summary of analytical results from the U.S. Geological Survey sampling of St. Croix River tributaries, Wisconsin and Minnesota, used in 1999 annual-load calculations—Continued

[µS/cm; microsiemens per centimeter; mg/L, milligrams per liter; mm, millimeter; <, less than; --, no data]

| Date | Discharge (cubic meters per minute) | Water temperature (degrees Celsius) | Specific conductance (µS/cm) | Oxygen, dissolved (mg/L) | pH (standard units) | Nitrogen, ammonia, dissolved (mg/L as N) | Nitrogen, nitrite, dissolved (mg/L as N) | Nitrogen, ammonia + organic, dissolved (mg/L as N) | Nitrogen, ammonia + organic, total (mg/L as N) | Nitrogen, nitrite plus nitrate, dissolved (mg/L as N) | Phosphorus, total (mg/L as P) | Phosphorus, dissolved (mg/L as P) | Phosphorus, ortho, dissolved (mg/L as P) | Chloride, dissolved (mg/L as Cl) | Suspended sediment (mg/L) | Suspended sediment (percent finer than 0.062 mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Trade River near Trade River, Wis.** | | | | | | | | | | | | | | | | |
| 04/01/97 | 658 | 3.2 | 160 | 11.6 | 7.2 | 0.330 | 0.010 | 0.80 | 1.1 | 0.390 | 0.220 | 0.030 | 0.020 | -- | 204 | 31 |
| 04/02/97 | 906 | 4.8 | 165 | 12.6 | 7.1 | .300 | .010 | .70 | 1.1 | .420 | .180 | <.010 | .010 | -- | 136 | -- |
| 02/23/98 | 204 | 5 | 212 | 12.6 | 7.9 | .139 | .015 | .58 | .76 | .424 | .049 | <.010 | .030 | -- | 18 | 69 |
| 03/31/98 | 372 | 4 | 145 | 13.3 | 7.8 | .160 | <.010 | .57 | .84 | .360 | .093 | .029 | .031 | -- | 40 | 66 |
| 07/22/98 | 124 | 21.8 | 202 | 8.4 | 7.9 | .036 | <.010 | .44 | .56 | .105 | .025 | .012 | .014 | -- | 5 | 92 |
| 09/24/98 | 82 | 12.2 | 216 | 10.2 | 8.0 | .033 | <.010 | .50 | .44 | .103 | .019 | <.010 | .010 | -- | 3 | 83 |
| 10/22/98 | 122 | 8.5 | 188 | 11.9 | 7.8 | .024 | .022 | .35 | .41 | .300 | .017 | .016 | .013 | -- | 6 | 67 |
| 11/23/98 | 150 | 4.6 | 213 | 14.0 | 7.8 | .075 | .010 | .40 | .50 | .318 | .039 | .016 | .010 | 4.1 | 5 | 78 |
| 12/09/98 | 134 | 1.2 | 208 | 5.1 | 7.3 | .077 | .018 | .37 | .44 | .363 | .019 | .010 | .011 | 4.2 | 4 | 95 |
| 01/14/99 | 73 | .8 | 203 | 13.3 | 7.6 | .144 | .014 | .41 | .49 | .423 | .024 | .012 | .020 | 4.5 | 4 | 91 |
| 02/23/99 | 100 | 1.7 | 242 | -- | 7.8 | .144 | <.010 | .46 | .47 | .490 | .034 | .012 | .010 | 5.0 | 3 | 75 |
| 03/11/99 | 100 | 3.8 | 228 | 12.3 | 7.9 | .111 | <.010 | .41 | .46 | .488 | .036 | .012 | .013 | 5.3 | 8 | 96 |
| 03/24/99 | 129 | 3.1 | 219 | 12.6 | 7.8 | .045 | .013 | .36 | .48 | .426 | .038 | .009 | <.010 | 5.3 | 5 | 87 |
| 04/06/99 | 292 | 6.6 | 148 | 11.7 | 7.6 | .102 | <.010 | .55 | 1.5 | .275 | .087 | .016 | .012 | 4.9 | 45 | 71 |
| 04/28/99 | 165 | 11.8 | 200 | 10.6 | 8.0 | .037 | <.010 | .38 | .99 | .198 | .042 | .013 | .019 | 4.8 | 53 | 76 |
| 05/13/99 | 325 | 10.6 | 144 | 9.9 | 7.6 | .036 | .012 | .52 | 1.5 | .140 | .079 | .010 | <.010 | 4.1 | 53 | 53 |
| 06/10/99 | 112 | 18.9 | 144 | 9.9 | 7.6 | .076 | .011 | .52 | <.10 | .258 | .065 | .020 | .026 | 4.7 | 20 | 81 |
| 06/24/99 | 219 | 21.4 | 140 | 8.3 | 7.6 | .022 | <.010 | .54 | .80 | .121 | .092 | .021 | .017 | 3.6 | 36 | 47 |
| 07/09/99 | 139 | 18.3 | 180 | 8.5 | 7.9 | .020 | <.010 | .51 | .65 | .263 | .064 | .025 | .013 | 3.9 | -- | -- |
| 08/11/99 | 109 | 20.1 | 202 | 8.7 | 8.0 | .020 | <.010 | .29 | .39 | .185 | .044 | .019 | .011 | 4.5 | 8 | 73 |
| 09/17/99 | 127 | 11.9 | 212 | 10.4 | 8.0 | <.020 | <.010 | .31 | .34 | .179 | .025 | .012 | <.010 | 13.0 | 3 | 83 |

**Appendix 4.** Summary of analytical results from the U.S. Geological Survey sampling of St. Croix River tributaries, Wisconsin and Minnesota, used in 1999 annual-load calculations—Continued

[µS/cm; microsiemens per centimeter; mg/L, milligrams per liter; mm, millimeter; <, less than; --, no data]

| Date | Discharge (cubic meters per minute) | Water temperature (degrees Celsius) | Specific conductance (µS/cm) | Oxygen, dissolved (mg/L) | pH (standard units) | Nitrogen, ammonia, dissolved (mg/L as N) | Nitrogen, nitrite, dissolved (mg/L as N) | Nitrogen, ammonia + organic, dissolved (mg/L as N) | Nitrogen, ammonia + organic, total (mg/L as N) | Nitrogen, nitrite plus nitrate, dissolved (mg/L as N) | Phosphorus, total (mg/L as P) | Phosphorus, dissolved (mg/L as P) | Phosphorus, ortho, dissolved (mg/L as P) | Chloride, dissolved (mg/L as Cl) | Suspended sediment (mg/L) | Suspended sediment (percent finer than 0.062 mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Apple River near Sommerset, Wis.** | | | | | | | | | | | | | | | | |
| 03/28/97 | 1,463 | 5.2 | 237 | 11.6 | 7.8 | 0.030 | <0.010 | 0.30 | 0.40 | 0.950 | 0.090 | 0.020 | <0.010 | -- | 8 | 78 |
| 02/19/98 | 770 | 3.6 | 291 | 14.2 | 8.3 | .122 | <.010 | .33 | .38 | 1.29 | .038 | .029 | .032 | -- | 2 | 92 |
| 04/01/98 | 2,430 | 4.9 | 173 | 13.1 | 7.6 | .056 | <.010 | .48 | .46 | .483 | .056 | .057 | .038 | -- | 13 | 79 |
| 06/26/98 | 1,021 | 22.7 | 239 | 7.6 | 7.8 | .022 | .018 | .41 | .58 | .439 | .050 | .031 | <.010 | -- | 5 | 81 |
| 07/28/98 | 440 | 22.8 | 280 | 7.8 | 8.0 | .042 | .013 | .30 | .51 | .804 | .030 | <.010 | .017 | -- | 2 | 90 |
| 10/23/98 | 918 | 9.0 | -- | 11.2 | 7.7 | .026 | .015 | .32 | .49 | .584 | .492 | .017 | .014 | -- | 8 | 56 |
| 11/18/98 | -- | 4.4 | 265 | 16.7 | 7.8 | .028 | <.010 | .24 | .39 | .760 | .024 | .017 | .01 | 7.3 | 3 | 94 |
| 12/08/98 | 595 | 2.1 | 265 | 6.8 | 7.8 | .049 | <.010 | .38 | .33 | .858 | .077 | .047 | .02 | 7.1 | 2 | 91 |
| 01/13/99 | 447 | 0 | 292 | 12.7 | 8.1 | .126 | .017 | .35 | .45 | 1.16 | .043 | .023 | .019 | 8.0 | 2 | 86 |
| 02/23/99 | 578 | 0.5 | 302 | -- | 7.8 | .083 | <.010 | .34 | .36 | 1.31 | .039 | .021 | .021 | 7.8 | 2 | 44 |
| 03/11/99 | 530 | 1.5 | 288 | 13.2 | 7.7 | .045 | .011 | .26 | .31 | 1.25 | .035 | .018 | .019 | 8.2 | 2 | 75 |
| 03/23/99 | 693 | 5.4 | 270 | 13.5 | 8.1 | .032 | .015 | .28 | .44 | 1.02 | .053 | .019 | .012 | 7.3 | 4 | 87 |
| 04/06/99 | 1154 | 7.2 | 213 | 11.6 | 8.5 | .031 | <.010 | .33 | .21 | .619 | .053 | .015 | .011 | 7.4 | 5 | 88 |
| 04/28/99 | 647 | 13.8 | 245 | 10.4 | 8.2 | .035 | <.010 | .32 | .57 | .586 | .050 | .016 | .022 | 7.0 | 7 | 77 |
| 05/12/99 | 1,327 | -- | -- | -- | -- | -- | -- | -- | -- | -- | .079 | -- | -- | -- | -- | -- |
| 05/18/99 | 1,074 | 15.2 | 237 | 9.6 | 8.1 | .072 | .014 | .69 | .74 | .525 | .057 | .023 | <.010 | 6.9 | 5 | 100 |
| 06/09/99 | 1,169 | -- | -- | -- | -- | -- | -- | -- | -- | -- | .053 | -- | -- | -- | -- | -- |
| 06/22/99 | 472 | 20.1 | 281 | 8.5 | 8.0 | .035 | .017 | .38 | .56 | .818 | .052 | .023 | .021 | 7.3 | 4 | 95 |
| 07/03/99 | 673 | 22.3 | 266 | 8.1 | 8.3 | .032 | .011 | .32 | .53 | .588 | .058 | .034 | .034 | 7.2 | 8 | 68 |
| 07/07/99 | 595 | -- | -- | -- | -- | -- | -- | -- | -- | -- | .047 | -- | -- | -- | -- | -- |
| 07/22/99 | 559 | 23.0 | 273 | 7.1 | 8.1 | <.020 | .052 | .42 | .58 | 1.43 | .054 | .016 | <.010 | 13 | 2 | 83 |
| 08/02/99 | 907 | -- | -- | -- | -- | -- | -- | -- | -- | -- | .065 | -- | -- | -- | -- | -- |
| 08/19/99 | 607 | 16.4 | 430 | 11.9 | 8.3 | .068 | .014 | .41 | .55 | .643 | .067 | .046 | .027 | 6.8 | 4 | 67 |
| 09/01/99 | 797 | -- | -- | -- | -- | -- | -- | -- | -- | -- | .048 | -- | -- | -- | -- | -- |
| 09/16/99 | 127 | 14.1 | 279 | 10.0 | 8.1 | <.020 | <.010 | .25 | .45 | .579 | .052 | .031 | .016 | 7.4 | 4 | 89 |

**Appendix 4.** Summary of analytical results from the U.S. Geological Survey sampling of St. Croix River tributaries, Wisconsin and Minnesota, used in 1999 annual-load calculations—Continued

[µS/cm; microsiemens per centimeter; mg/L, milligrams per liter; mm, millimeter; <, less than; --, no data]

| Date | Discharge (cubic meters per minute) | Water temperature (degrees Celsius) | Specific conductance (µS/cm) | Oxygen, dissolved (mg/L) | pH (standard units) | Nitrogen, ammonia, dissolved (mg/L as N) | Nitrogen, nitrite, dissolved (mg/L as N) | Nitrogen, ammonia + organic, dissolved (mg/L as N) | Nitrogen, ammonia + organic, total (mg/L as N) | Nitrogen, nitrite plus nitrate, dissolved (mg/L as N) | Phosphorus, total (mg/L as P) | Phosphorus, dissolved (mg/L as P) | Phosphorus, ortho, dissolved (mg/L as P) | Chloride, dissolved (mg/L as Cl) | Suspended sediment (mg/L) | Suspended sediment (percent finer than 0.062 mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Willow River near Hudson, Wis.** | | | | | | | | | | | | | | | | |
| 02/18/98 | 500 | 3.6 | 409 | 14.4 | 8.1 | 0.231 | 0.015 | 0.36 | 0.61 | 4.36 | 0.134 | 0.034 | 0.036 | -- | 26 | 100 |
| 04/01/98 | 1,320 | 6.0 | 171 | 12.8 | 7.6 | .298 | .028 | 1.2 | 1.1 | 1.21 | .097 | .106 | .072 | -- | 414 | 25 |
| 06/26/98 | 452 | 23.1 | 343 | 8.9 | 8.6 | .043 | .053 | .52 | .93 | 1.59 | .024 | <.010 | <.010 | -- | 11 | 84 |
| 07/28/98 | 221 | 21.6 | 360 | 8.5 | 8.1 | .078 | .046 | .31 | .70 | 1.58 | .060 | <.010 | .011 | -- | 3 | 76 |
| 10/23/98 | 206 | 10.3 | 357 | 10.1 | 7.8 | .041 | .023 | .18 | .43 | 2.56 | .073 | .038 | .042 | -- | 5 | 96 |
| 11/18/98 | 228 | 4.4 | 391 | 13.5 | 7.8 | .042 | .010 | .20 | .30 | 3.00 | .057 | .036 | .036 | 13 | 5 | 87 |
| 12/08/98 | 228 | 5.1 | 385 | 8.2 | 7.8 | .064 | .015 | .32 | .35 | 3.17 | .013 | .031 | .042 | 13 | 6 | 67 |
| 01/13/99 | 180 | 1.1 | 427 | 15.2 | 8.0 | .100 | .027 | .24 | .30 | 4.20 | .064 | .041 | .037 | 14 | 5 | 87 |
| 02/23/99 | 195 | 2.1 | 420 | -- | 7.8 | .075 | .015 | .33 | .38 | 3.83 | .075 | .036 | .032 | 15 | 4 | 77 |
| 03/11/99 | 187 | 2.9 | 400 | 14.0 | 7.8 | .028 | .014 | .18 | .28 | 3.69 | .054 | .026 | .023 | 13 | 4 | 92 |
| 03/22/99 | 491 | 4.1 | 285 | 12.8 | 7.8 | .206 | .023 | .97 | 1.6 | 2.09 | .264 | .120 | .073 | 12 | 14 | 75 |
| 04/06/99 | 343 | 9.1 | 302 | 10.9 | 8.0 | .051 | .021 | .48 | .74 | 2.16 | .121 | .057 | .043 | 12 | 17 | 93 |
| 04/28/99 | 195 | 14.0 | 331 | 11.5 | 9.0 | .042 | .017 | .45 | 1.0 | 1.56 | .072 | .013 | .020 | 12 | 20 | 94 |
| 04/28/99 | 199 | -- | -- | -- | -- | -- | -- | -- | -- | -- | .111 | -- | -- | -- | -- | -- |
| 05/13/99 | 314 | -- | -- | -- | -- | -- | -- | -- | -- | -- | .085 | -- | -- | -- | -- | -- |
| 05/18/99 | 319 | 14.4 | 363 | 10.3 | 8.1 | .220 | .037 | .52 | .46 | 1.76 | .091 | .041 | .032 | 12 | 10 | 83 |
| 05/22/99 | 411 | -- | -- | -- | -- | -- | -- | -- | -- | -- | .100 | -- | -- | -- | -- | -- |
| 06/07/99 | 352 | -- | -- | -- | -- | -- | -- | -- | -- | -- | .096 | -- | -- | -- | -- | -- |
| 06/14/99 | 442 | -- | -- | -- | -- | -- | -- | -- | -- | -- | .158 | -- | -- | -- | -- | -- |
| 06/22/99 | 207 | 19.2 | 327 | 8.2 | 8.2 | <.020 | .037 | .53 | 1.3 | 1.18 | .088 | .011 | .020 | 11 | 15 | 98 |
| 07/03/99 | 206 | 22.5 | 335 | 8.4 | 8.9 | .051 | .03 | .41 | .98 | 1.26 | .071 | .016 | .018 | 12 | 9 | 88 |
| 07/22/99 | 195 | 22.2 | 364 | 8.0 | 8.6 | <.020 | .017 | .27 | .65 | .731 | .076 | .049 | <.010 | 7.9 | -- | -- |
| 08/19/99 | 246 | 20.2 | 342 | 8.9 | 8.5 | .056 | .035 | .30 | .85 | 1.45 | .089 | .013 | <.010 | 12 | 9 | 98 |
| 09/16/99 | 184 | 15.6 | 396 | 10.2 | 8.5 | <.020 | .025 | .25 | .40 | 2.17 | .061 | .040 | .018 | 91 | 3 | 93 |

**Appendix 4.** Summary of analytical results from the U.S. Geological Survey sampling of St. Croix River tributaries, Wisconsin and Minnesota, used in 1999 annual-load calculations—Continued

[µS/cm; microsiemens per centimeter; mg/L, milligrams per liter; mm, millimeter; <, less than; --, no data]

| Date | Discharge (cubic meters per minute) | Water temperature (degrees Celsius) | Specific conductance (µS/cm) | Oxygen, dissolved (mg/L) | pH (standard units) | Nitrogen, ammonia, dissolved (mg/L as N) | Nitrogen, nitrite, dissolved (mg/L as N) | Nitrogen, ammonia + organic, dissolved (mg/L as N) | Nitrogen, ammonia + organic, total (mg/L as N) | Nitrogen, nitrite plus nitrate, dissolved (mg/L as N) | Phosphorus, total (mg/L as P) | Phosphorus, dissolved (mg/L as P) | Phosphorus, ortho, dissolved (mg/L as P) | Chloride, dissolved (mg/L as Cl) | Suspended sediment (mg/L) | Suspended sediment (percent finer than 0.062 mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Kinnickinnic River near River Falls, Wis.** | | | | | | | | | | | | | | | | |
| 03/21/97 | 214 | 6.3 | 458 | 13.9 | 8.3 | <0.015 | 0.020 | <0.20 | 0.3 | 5.00 | 0.080 | 0.050 | 0.030 | -- | 9 | 71 |
| 02/18/98 | 527 | 3.1 | 335 | 14.3 | 7.9 | 2.27 | .051 | 5.3 | 5.5 | 3.31 | 1.32 | 1.03 | .928 | -- | 252 | 44 |
| 04/01/98 | 1,087 | 5.8 | 228 | 12.8 | 7.8 | .114 | .016 | .74 | 1.4 | 1.70 | .381 | .202 | .158 | -- | 424 | 32 |
| 06/25/98 | 511 | 20.6 | 316 | 7.9 | 7.8 | .028 | .043 | .71 | 1.7 | 2.61 | .144 | .125 | .064 | -- | 318 | 57 |
| 07/28/98 | 194 | 20.6 | 471 | 11.4 | 8.1 | .027 | .021 | .20 | .35 | 4.85 | .046 | .054 | .041 | -- | 16 | 60 |
| 10/23/98 | 199 | 9.8 | 433 | 13.8 | 8.0 | .023 | .018 | <.10 | .14 | 5.14 | .060 | .062 | .064 | -- | 10 | 65 |
| 11/18/98 | 209 | 6.6 | 474 | 17.8 | 7.8 | <.020 | <.010 | <.10 | .15 | 5.43 | .060 | .062 | .057 | 17 | 8 | 61 |
| 12/08/98 | 201 | 2.9 | 471 | 7.4 | 7.5 | .026 | <.010 | <.10 | <.10 | 5.43 | .072 | .067 | .074 | 16 | 4 | 91 |
| 01/13/99 | 160 | 0.5 | 474 | 14.6 | 7.9 | .025 | .025 | .15 | .31 | 5.74 | .078 | .065 | .051 | 17 | 16 | 48 |
| 02/22/99 | 170 | 3.3 | 485 | -- | 8.2 | <.020 | <.010 | .14 | .17 | 5.53 | .062 | .052 | .047 | 17 | 4 | 68 |
| 03/10/99 | 155 | 3.5 | 467 | 15.8 | 8.1 | <.020 | .017 | .15 | .21 | 5.41 | .061 | .049 | .048 | 17 | 3 | 71 |
| 03/22/99 | 184 | 8.2 | 441 | 13.4 | 8.4 | <.020 | .021 | .23 | .31 | 4.62 | .083 | .054 | .039 | 16 | 13 | 36 |
| 04/06/99 | 328 | 6.4 | 400 | 11.8 | 7.9 | .045 | .016 | .29 | .24 | 3.89 | .115 | .063 | .051 | 16 | 40 | 74 |
| 04/28/99 | 148 | 11.7 | 470 | 11.4 | 8.2 | .049 | .018 | .24 | .39 | 4.94 | .087 | .072 | .072 | 17 | 7 | 89 |
| 05/13/99 | 267 | -- | -- | -- | -- | -- | -- | -- | -- | -- | .130 | -- | -- | -- | -- | -- |
| 05/18/99 | 255 | 12.7 | 461 | 11.6 | 8.2 | .020 | .026 | .27 | .36 | 4.25 | .102 | .058 | .048 | 16 | 20 | 72 |
| 05/22/99 | 190 | -- | -- | -- | -- | -- | -- | -- | -- | -- | .095 | -- | -- | -- | -- | -- |
| 06/14/99 | 141 | -- | -- | -- | -- | -- | -- | -- | -- | -- | .106 | -- | -- | -- | -- | -- |
| 06/22/99 | 102 | 18.6 | 496 | 11.6 | 8.4 | .020 | .023 | .21 | .31 | 5.05 | .077 | .063 | .060 | 17 | 5 | 77 |
| 07/03/99 | 231 | 21.3 | 367 | 9.3 | 8.2 | .030 | .020 | .25 | .51 | 3.48 | .143 | .066 | .061 | 13 | 56 | 93 |
| 07/22/99 | 163 | 19.7 | 467 | 13.1 | 8.8 | <.020 | .019 | .22 | .25 | 4.94 | .077 | .064 | .055 | 17 | -- | -- |
| 08/19/99 | 217 | 16.4 | 430 | 11.9 | 8.3 | <.020 | .027 | .26 | .31 | 4.08 | .094 | .078 | .059 | 15 | 6 | 88 |
| 09/16/99 | 161 | 14.4 | 485 | 12.3 | 8.8 | <.020 | .012 | <.10 | .28 | 4.78 | .076 | .066 | .056 | 17 | 7 | 97 |

**Appendix 5.** Selected water-quality constituents analyzed at St. Croix River at St. Croix Falls, Wis., October 1, 1998 to September 30, 1999

[µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; <, less than; --, no data]

| Date | Discharge (cubic meters per second) | Water temperature (degrees Celsius) | Specific conductance (µS/cm) | Oxygen, dissolved (mg/L) | pH (standard Units) | Specific conductance (µS/cm) | Alkalinity (mg/L as $CaCO_3$) | Bicarbonate (mg/L as $HCO_3$) | Nitrogen, ammonia, dissolved (mg/L as N) | Nitrogen, nitrite, plus nitrate, dissolved (mg/L as N) | Nitrogen, ammonia + organic, dissolved (mg/L as N) | Nitrogen, ammonia+ organic, total (mg/L as N) | Nitrogen, nitriite plus nitrate, dissolved | Phosphorus, total (mg/L as P) | Phosphorus, dissolved (mg/L as P) | Phosphorus, ortho, dissolved (mg/L as P) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10/28/98 | 4,571 | 12.0 | 188 | 9.5 | 7.8 | 207 | 87 | 107 | 0.043 | <0.010 | 0.29 | 0.40 | 0.096 | 0.012 | <.050 | <.010 |
| 11/17/98 | 8,258 | 2.8 | 174 | 26.0 | 8.4 | 197 | -- | -- | .028 | <.010 | .29 | .45 | .212 | .023 | <.050 | .010 |
| 12/09/98 | 8,207 | 1.2 | 166 | 6.3 | 7.5 | 167 | 64 | 78 | .029 | <.010 | .32 | .36 | .177 | <.050 | <.050 | .017 |
| 01/14/99 | 3,025 | .1 | 208 | 8.5 | 7.2 | 224 | 90 | 110 | .082 | .010 | .29 | .34 | .357 | .023 | .009 | .014 |
| 02/12/99 | -- | 0 | 199 | 10.3 | 7.1 | 221 | 96 | 117 | .094 | <.010 | .26 | .29 | .428 | .029 | <.004 | <.010 |
| 03/02/99 | 2,736 | .4 | 195 | 11.8 | 7.7 | 217 | 86 | 103 | .055 | .018 | .22 | .29 | .445 | .025 | .008 | <.010 |
| 04/06/99 | 21,240 | 5.0 | 114 | 14.1 | 7.5 | 125 | 49 | 60 | .031 | <.010 | .52 | .88 | .150 | .081 | .022 | <.010 |
| 05/13/99 | 16,159 | 13.0 | 134 | 9.9 | 7.6 | 143 | 58 | 71 | <.020 | <.010 | .62 | .89 | .098 | .054 | .021 | .012 |
| 05/27/99 | 10,399 | 17.4 | 143 | 8.6 | 7.5 | 151 | 60 | 73 | .028 | .013 | .62 | .83 | .096 | .062 | .022 | .013 |
| 06/24/99 | 8,955 | 24.0 | 159 | 6.5 | 7.5 | 163 | 68 | 83 | <.020 | <.010 | .50 | .63 | .209 | .054 | .022 | .019 |
| 07/14/99 | 10,569 | 24.9 | 142 | 6.9 | 7.6 | 148 | 68 | 83 | .022 | <.010 | .65 | .95 | .103 | .065 | .028 | .014 |
| 08/16/99 | 14,919 | 19.5 | -- | 7.9 | 7.6 | 118 | 56 | 68 | .025 | <.010 | .78 | .92 | .140 | .076 | .037 | .014 |
| 09/07/99 | 8,156 | 20.9 | 162 | 6.8 | 7.6 | 169 | 77 | 94 | <.020 | <.010 | .58 | .77 | .193 | .053 | .032 | .013 |
| 10/26/99 | -- | 6.7 | 169 | 13.7 | 8.2 | 182 | 96 | 117 | <.020 | <.010 | .30 | .45 | .087 | .018 | .005 | <.010 |
| 11/03/99 | -- | 6.3 | 147 | 10.1 | 7.8 | 159 | 65 | 80 | .029 | <.010 | .44 | .58 | .123 | .035 | .013 | .257 |
| 12/23/99 | -- | 0 | 217 | 12.2 | 7.5 | 220 | 97 | 119 | <.020 | <.010 | .27 | .37 | .333 | .019 | .007 | <.010 |

**Appendix 5.** Selected water-quality constituents analyzed at St. Croix River at St. Croix Falls, Wis., October 1, 1998 to September 30, 1999—Continued

[mg/L, milligrams per liter; µg/L, micrograms per liter; °C, degrees Celsius; mm, millimeter; <, less than; --, no data]

| Date | Carbon, organic, dissolved (mg/L as C) | Carbon, organic, suspended, total (mg/L as C) | Magnesium, dissolved (mg/L as Mg) | Sodium, dissolved (mg/L as Na) | Chloride, dissolved (mg/L as Cl) | Sulfate, dissolved (mg/L as $SO_4$) | Fluoride, dissolved (mg/L as F) | Silica, dissolved (µg/L as SiO2) | Iron, dissolved (µg/L as Fe) | Manganese, dissolved (mg/L as Mn) | Solids, residue at 180°C, dissolved (mg/L) | Suspended sediment (mg/L) | Suspended sediment, (percent finer than 0.062 mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10/28/98 | 4.6 | 0.4 | 7.9 | 4.1 | 5.5 | 4.6 | <0.10 | 11 | 88 | 24 | 119 | 5 | 92 |
| 11/17/98 | 6.0 | .5 | 7.4 | 3.7 | 5.4 | 4.9 | <.10 | 12 | 140 | 17 | 121 | 3 | 100 |
| 12/09/98 | 7.7 | .4 | 6.5 | 3.6 | 4.3 | 6.3 | <.10 | 12 | 190 | 18 | 118 | 3 | 73 |
| 01/14/99 | 4.4 | <.20 | 8.7 | 3.9 | 4.6 | 5.0 | <.10 | 17 | 160 | 28 | 140 | 2 | 50 |
| 02/12/99 | 3.2 | <.20 | 8.8 | 4.2 | 4.8 | 5.5 | <.10 | 17 | 110 | 30 | 136 | 4 | 100 |
| 03/02/99 | 3.4 | <.20 | 7.9 | 4.0 | 5.2 | 4.6 | <.10 | 15 | 140 | 24 | 135 | 4 | 100 |
| 04/06/99 | 10 | 2.1 | 4.8 | 2.9 | 3.7 | 4.8 | <.10 | 9.2 | 280 | 44 | 96 | 18 | 91 |
| 05/13/99 | 14 | .8 | 5.6 | 3.3 | 3.8 | 4.1 | <.10 | 8.4 | 220 | 31 | 105 | 12 | 81 |
| 05/27/99 | 13 | 2.6 | 5.9 | 3.3 | 3.6 | 3.0 | <.10 | 8.1 | 290 | 35 | 109 | 7 | 95 |
| 06/24/99 | 9.8 | .9 | 6.5 | 3.2 | 4.1 | 3.5 | <.10 | 9.1 | 250 | 27 | 120 | 9 | 99 |
| 07/14/99 | 16 | .8 | 6.3 | 2.8 | 3.9 | 2.5 | <.10 | 11 | 590 | 30 | 119 | 8 | 95 |
| 08/16/99 | 20 | 1.3 | 5.2 | 2.5 | 2.4 | .95 | <.10 | 13 | 940 | 36 | 115 | 12 | 88 |
| 09/07/99 | 16 | <.20 | 6.6 | 3.2 | 3.5 | 2.6 | <.10 | 14 | 740 | 57 | 126 | -- | -- |
| 10/26/99 | 7.4 | -- | 7.8 | 3.9 | 4.2 | 3.6 | <.10 | 11 | 240 | 21 | 116 | 70 | 76 |
| 11/03/99 | 9.9 | .7 | 6.4 | 3.2 | 4.5 | 3.0 | <.10 | 9.7 | 320 | 15 | 124 | 70 | 82 |
| 12/23/99 | 6.4 | .2 | 9.7 | 3.9 | 5.3 | 3.5 | <.10 | 15 | 200 | 33 | 140 | 10 | 100 |

**Appendix 6.** Selected water-quality constituents analyzed at St. Croix River near Danbury, Wis., October 1, 1998 to September 30, 1999

[µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; <, less than; --, no data]

| Date | Discharge (cubic meters per second) | Water temperature (degrees Celsius) | Specific conductance (µS/cm) | Oxygen, dissolved (mg/L) | pH (standard Units) | Specific conductance (µS/cm) | Alkalinity (mg/L as $CaCO_3$) | Bicarbonate (mg/L as $HCO_3$) | Nitrogen, ammonia, dissolved (mg/L as N) | Nitrogen, nitrite, dissolved (mg/L as N) | Nitrogen, ammonia + organic, dissolved (mg/L as N) | Nitrogen, ammonia+ organic, total (mg/L as N) | Nitrogen, nitrite plus nitrate, dissolved (mg/L as N) | Phosphorus, total (mg/L as P) | Phosphorus, dissolved (mg/L as P) | Phosphorus, ortho, dissolved (mg/L as P) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10/02/98 | 1,511 | 11.0 | 131 | 10.7 | 7.9 | 146 | 63 | 77 | 0.037 | <0.010 | 0.19 | 0.21 | <0.050 | <0.050 | <0.050 | <0.010 |
| 11/17/98 | 1,716 | 2.4 | 130 | -- | 7.9 | 147 | -- | -- | .024 | <.010 | 17 | .24 | .101 | .015 | <.050 | <.010 |
| 12/10/98 | 2,175 | .4 | 135 | 4.8 | 7.4 | 144 | 74 | 90 | <.020 | <.010 | 18 | .24 | .110 | <.050 | <.050 | .013 |
| 01/26/99 | -- | 0 | 156 | -- | 6.6 | 161 | 66 | 81 | .065 | <.010 | 19 | .27 | .162 | .018 | .006 | .025 |
| 02/24/99 | -- | 0 | 147 | -- | 7.3 | 160 | 60 | 73 | .030 | <.010 | .19 | .25 | .214 | .018 | .007 | <.010 |
| 03/17/99 | -- | .2 | 130 | 12.2 | 7.3 | 150 | 56 | 68 | <.020 | <.010 | .15 | .22 | .165 | .021 | .006 | <.010 |
| 03/30/99 | 2,889 | 4.1 | 92 | 12.7 | 7.2 | 124 | 42 | 51 | -- | -- | -- | .55 | -- | .039 | -- | -- |
| 04/07/99 | 5,998 | 5.5 | 66 | 12.1 | 6.9 | 75 | 24 | 29 | .028 | <.010 | .47 | .47 | .127 | .040 | .012 | <.010 |
| 05/11/99 | 3,279 | 13.9 | 101 | 9.5 | 7.6 | 117 | -- | -- | .037 | <.010 | .46 | .53 | .054 | .034 | .011 | .014 |
| 06/11/99 | 2,430 | 19.2 | 104 | 8.1 | 7.4 | 113 | 31 | 37 | <.020 | <.010 | .43 | .60 | .079 | .037 | .012 | .010 |
| 06/24/99 | 3,925 | 21.1 | 72 | 7.3 | 7.1 | 96 | 36 | 44 | .021 | <.010 | .59 | .79 | .158 | .045 | .020 | <.010 |
| 07/20/99 | 2,396 | 23.0 | 103 | 7.3 | 7.6 | 112 | 45 | 55 | <.020 | <.010 | .49 | .54 | <.050 | .037 | .013 | .013 |
| 07/26/99 | 4,520 | 25.3 | 71 | 6.5 | 7.0 | 94 | 34 | 42 | <.020 | <.010 | .62 | .95 | .096 | .081 | .018 | <.010 |
| 07/27/99 | 11,657 | 22.1 | 48 | 4.9 | 6.6 | 62 | 20 | 25 | <.020 | <.010 | 1.5 | .90 | <.050 | .062 | .018 | <.010 |
| 08/31/99 | 2,294 | 19.0 | 114 | 8.4 | 7.6 | 121 | 50 | 62 | <.020 | <.010 | .59 | .62 | .128 | .031 | .021 | <.010 |
| 09/27/99 | 2,073 | 14.4 | 115 | 9.5 | 7.6 | 130 | 58 | 71 | <.020 | <.010 | .26 | .30 | <.050 | <.008 | .007 | <.010 |
| 10/12/99 | -- | 10.4 | 119 | 10.4 | 7.9 | 135 | -- | 72 | <.020 | <.010 | .24 | .30 | <.050 | .014 | .004 | <.010 |
| 11/18/99 | 1,463 | 3.4 | 121 | 14.2 | 7.9 | 145 | 64 | 79 | <.020 | <.010 | .21 | .22 | .069 | .010 | .004 | <.010 |
| 12/22/99 | -- | 0 | 142 | 12.2 | 6.9 | 160 | 69 | 84 | <.020 | <.010 | .20 | .35 | .127 | .017 | .007 | <.010 |

**Appendix 6.** Selected water-quality constituents analyzed at St. Croix River near Danbury, Wis., October 1, 1998 to September 30, 1999—Continued

[mg/L, milligrams per liter; µg/L, micrograms per liter; °C, degrees Celsius; mm, millimeter; <, less than; --, no data]

| Date | Carbon, organic, dissolved (mg/L as C) | Carbon, organic, suspended, total (mg/L as C) | Magnesium, dissolved (mg/L as Mg) | Sodium, dissolved (mg/L as Na) | Chloride, dissolved (mg/L as Cl) | Sulfate, dissolved (mg/L as $SO_4$) | Fluoride, dissolved (mg/L as F) | Silica, dissolved (µg/L as $SiO_2$) | Iron, dissolved (µg/L as Fe) | Manganese, dissolved (mg/L as Mn) | Solids, residue at 180°C, dissolved (mg/L) | Suspended sediment (mg/L) | Suspended sediment (percent finer than 0.062 mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10/02/98 | 3.2 | 0.3 | 5.0 | 2.7 | 2.6 | 4.2 | <0.10 | 11 | 88 | 10 | 90 | 1 | 40 |
| 11/17/98 | 3.7 | .3 | 5.1 | 2.6 | 2.9 | 4.2 | <.10 | 12 | 96 | 9.1 | 92 | 3 | 77 |
| 12/10/98 | 5.9 | .3 | 4.7 | 2.4 | 3.9 | 5.6 | <.10 | 12 | 110 | 7.9 | 100 | 1 | 100 |
| 01/26/99 | 3.0 | .4 | 5.5 | 2.8 | 3.4 | 4.8 | <.10 | 16 | 120 | 14 | 100 | 3 | 79 |
| 02/24/99 | 3.2 | .5 | 5.4 | 2.8 | 2.9 | 4.4 | <.10 | 15 | 220 | 9.5 | 96 | 3 | 71 |
| 03/17/99 | 2.9 | .3 | 5.0 | 2.3 | 3.0 | 4.1 | <.10 | 13 | 220 | 14 | 98 | 7 | 52 |
| 03/30/99 | 8.8 | .8 | 4.4 | 2.4 | 2.3 | 5.6 | <.10 | 11 | 270 | 24 | 86 | 14 | 64 |
| 04/07/99 | 12 | .6 | 2.8 | 1.8 | 1.8 | 5.7 | <.10 | 8.6 | 290 | 37 | 75 | 13 | 74 |
| 05/11/99 | 11 | .5 | 4.2 | 2.5 | 2.3 | 3.3 | <.10 | 8.5 | 150 | 12 | 88 | 9 | 83 |
| 06/11/99 | 10 | .5 | 4.2 | 2.2 | 2.1 | 2.8 | <.10 | 8.0 | 210 | 18 | 87 | 13 | 86 |
| 06/24/99 | 20 | 2.2 | 3.7 | 2.0 | 2.2 | 2.2 | <.10 | 9.0 | 400 | 26 | 94 | 14 | 88 |
| 07/20/99 | 16 | .6 | -- | -- | 2.0 | 1.9 | <.10 | -- | -- | -- | 90 | 7 | 77 |
| 07/26/99 | 14 | 2.2 | 3.3 | 1.7 | .53 | 2.1 | <.10 | 9.9 | 390 | 52 | 81 | 26 | 89 |
| 07/27/99 | 19 | 1.6 | 2.4 | 1.2 | <.10 | 1.5 | <.10 | 8.5 | 580 | 85 | 71 | 13 | 63 |
| 08/31/99 | 15 | .3 | 4.8 | 2.4 | 2.3 | 2.2 | <.10 | 14 | 790 | 21 | 104 | 3 | 94 |
| 09/27/99 | 9.3 | .2 | 5.0 | 2.6 | 3.0 | 3.2 | <.10 | 12 | 220 | 12 | 94 | 3 | 86 |
| 10/12/99 | 6.7 | .2 | 4.8 | 2.6 | 2.6 | 3.4 | <.10 | 10 | 160 | 9.8 | 83 | 3 | 85 |
| 11/18/99 | 4.7 | .3 | 5.1 | 2.6 | 2.8 | 3.4 | <.10 | 12 | 120 | 12 | 92 | 4 | 65 |
| 12/22/99 | 4.1 | .3 | 5.8 | 2.8 | 3.0 | 3.2 | <.10 | 15 | 140 | 20 | 103 | 5 | 72 |

**Appendix 7.** Top five dominant benthic-invertebrate families and genera found in selected St. Croix River tributaries, Wisconsin and Minnesota

[(xx%), percent of the total sample that were of a specific family, genera, or species]

| Rank | Family | Genus | Species |
|---|---|---|---|
| **Sunrise River at Sunrise, Minn.** | | | |
| 1 | Hydroptilidae (12%) | *Leucotrichia (9%)* | *pictipes (9%)* |
| 2 | Chironomidae (12%) | *Optioservus (7%)* | *flavida (5%)* |
| 3 | Hydropsychidae (11%) | *Ceratopsyche (7%)* | unidentified (5%) |
| 4 | Baetidae (10%) | *Isoperla (6%)* | *flavistriga (4%)* |
| 5 | Elmidae (10%) | *Psychomyia (5%)* | unidentified (4%) |
| **Snake River near Pine City, Minn.** | | | |
| 1 | Hydroptilidae (31%) | *Stenelmis (19%)* | *unidentified (19%)* |
| 2 | Chironomidae (19%) | *Ceratopsyche (17%)* | *nr. convictum (14%)* |
| 3 | Elmidae (19%) | *Polypedilum (14%)* | *morosa bifida (14%)* |
| 4 | Philopotamidae (14%) | *Chimarra (13%)* | *obscura (13%)* |
| 5 | Baetidae (9%) | *Baetis (8%)* | *flavistriga (8%)* |
| **Kettle River below Sandstone, Minn.** | | | |
| 1 | Talitridae (59%) | *Hyallela* (59%) | *azteca* (59%) |
| 2 | Leptophlebiidae (13%) | *Leptophlebia* (4%) | unidentified (4%) |
| 3 | Chironomidae (7%) | unidentified (3%) | unidentified (3%) |
| 4 | Elmidae (3%) | *Dubiraphia* (2%) | *minima* (1%) |
| 5 | Tubificidae (3%) | *Polypedilum* (2%) | *r. racovitzai* (1%) |
| **Sand Creek near Hinckley, Minn.** | | | |
| 1 | Hydropsychidae (21%) | *Ceratopsyche* (16%) | unidentified (8%) |
| 2 | Tipulidae (13%) | *Optioservus* (9%) | *angulata* (7%) |
| 3 | Baetidae (10%) | *Pseudolimnophila* (8%) | *flavida* (6%) |
| 4 | Elmidae (10%) | *Paracapnia* (7%) | *bronta* (5%) |
| 5 | Capniidae (7%) | *Baetis* (7%) | unidentified (5%) |
| **Crooked Creek near Hinckley, Minn.** | | | |
| 1 | Hydropsychidae (26%) | *Cheumatopsyche* (16%) | unidentified (16%) |
| 2 | Elmidae (16%) | *Optioservus* (15%) | *angulata* (11%) |
| 3 | Baetidae (12%) | *Paracapnia* (11%) | *sparna* (7%) |
| 4 | Chironomidae (11%) | *Ceratopsyche* (9%) | *trivittatus* (6%) |
| 5 | Capniidae (11%) | *Baetis* (6%) | *flavistriga* (5%) |
| **Lower Tamarack River near Marksville, Minn.** | | | |
| 1 | Elmidae (20%) | *Paracapnia* (16%) | *angulata* (16%) |
| 2 | Capniidae (16%) | *Ceratopsyche* (11%) | unidentified (8%) |
| 3 | Hydropsychidae (15%) | *Optioservus* (10%) | *turbida* (6%) |
| 4 | Baetidae (14%) | *Stenelmis* (8%) | *morosa bifida* (5%) |
| 5 | Philopotamidae (5%) | *Baetis* (6%) | *sparna* (5%) |
| **Upper Tamarack River near Marksville, Minn.** | | | |
| 1 | Capniidae (21%) | *Paracapnia* (21%) | *angulata* (21%) |
| 2 | Chironomidae (14%) | *Ceratopsyche* (8%) | *flavida* (4%) |
| 3 | Elmidae (10%) | *Optioservus* (8%) | *vicarium* (3%) |
| 4 | Hydropsychidae (9%) | *Stenonema* (5%) | *mollis* (3%) |
| 5 | Baetidae (8%) | *Psychomyia* (4%) | *trivittatus* (3%) |

**Appendix 7.** Top five dominant benthic-invertebrate families and genera found in selected St. Croix River tributaries, Wisconsin and Minnesota—Continued

[(xx%), percent of the total sample that were of a specific family, genera, or species]

| Rank | Family | Genus | Species |
|---|---|---|---|
| **Browns Creek near Stillwater, Minn.** | | | |
| 1 | Baetidae (25%) | *Baetis* (24%) | *brunneicolor* (17%) |
| 2 | Elmidae (19%) | *Optioservus* (15%) | *tuberosum* (14%) |
| 3 | Hydropsychidae (17%) | *Simulium* (15%) | *occidentalis* (10%) |
| 4 | Simuliidae (15%) | *Brachycentrus* (10%) | *betteni* (9%) |
| 5 | Brachycentridae (10%) | *Hydropsyche* (10%) | *tricaudatus* (6%) |
| **Valley Creek at Afton, Minn.** | | | |
| 1 | Baetidae (26%) | *Baetis* (26%) | *tricaudatus* (15%) |
| 2 | Hydropsychidae (24%) | *Optioservus* (14%) | *pseudolimnaeus* (14%) |
| 3 | Elmidae (14%) | *Gammarus* (14%) | *slossonae* (12%) |
| 4 | Gammaridae (14%) | *Ceratopsyche* (12%) | *occidentalis* (10%) |
| 5 | Brachycentridae (10%) | *Brachycentrus* (10%) | unidentified (9%) |
| **Willow River at Burkhardt, Wis.** | | | |
| 1 | Hydropsychidae (60%) | *Ceratopsyche* (36%) | *morosa bifida* (33%) |
| 2 | Elmidae (31%) | *Stenelmis* (19%) | unidentified (19%) |
| 3 | Chironomidae (5%) | *Cheumatopsyche* (13%) | unidentified (13%) |
| 4 | Athericidae (2%) | *Optioservus* (12%) | *fastiditus* (7%) |
| 5 | Simuliidae (2%) | *Atherix* (2%) | *variegata* (2%) |
| **Yellow River near Danbury, Wis.** | | | |
| 1 | Hydropsychidae (30%) | *Serratella* (14%) | *deficiens* (14%) |
| 2 | Chironomidae (18%) | *Ceratopsyche* (10%) | unidentified (8%) |
| 3 | Ephemerellidae (17%) | *Cheumatopsyche* (8%) | *nr. convictum* (5%) |
| 4 | Hydroptilidae (5%) | *Polypedilum* (5%) | *pictipes* (4%) |
| 5 | Psychomyiidae (4%) | *Leucotrichia* (4%) | *flavida* (4%) |
| **Clam River near Webster, Wis.** | | | |
| 1 | Heptageniidae (46%) | *Stenonema* (37%) | unidentified (10%) |
| 2 | Hydropsychidae (13%) | *Cheumatopsyche* (10%) | *intercalaris* (7%) |
| 3 | Baetidae (10%) | *Baetis* (7%) | *azteca* (4%) |
| 4 | Elmidae (8%) | *Stenelmis* (4%) | unidentified (2%) |
| 5 | Leptophlebiidae (6%) | *Hyallela* (4%) | unidentified (2%) |

**Appendix 7.** Top five dominant benthic-invertebrate families and genera found in selected St. Croix River tributaries, Wisconsin and Minnesota—Continued

[(xx%), percent of the total sample that were of a specific family, genera, or species]

| Rank | Family | Genus | Species |
|---|---|---|---|
| | | **Wood River** | |
| 1 | Baetidae (32%) | *Plauditus* (17%) | *punctiventris* (16%) |
| 2 | Simuliidae (17%) | *Simulium* (16%) | unidentified (11%) |
| 3 | Hydropsychidae (13%) | *Cheumatopsyche* (11%) | *vittatum* (11%) |
| 4 | Chironomidae (13%) | *Hyallela* (8%) | *azteca* (8%) |
| 5 | Talitridae (8%) | *Brachycentrus* (7%) | *numerosus* (7%) |
| | | **Kinnickinnic River near River Falls, Wis.** | |
| 1 | Baetidae (26%) | *Optioservus* (16%) | *punctiventris* (9%) |
| 2 | Elmidae (16%) | *Baetis* (14%) | *tricaudatus* (8%) |
| 3 | Chironomidae (12%) | *Simulium* (10%) | *tuberosum* (7%) |
| 4 | Simuliidae (11%) | *Plauditus* (9%) | *flavistriga* (6%) |
| 5 | Heptageniidae (9%) | *Stenonema* (8%) | *pseudolimnaeus* (6%) |
| | | **Trade River near Trade River, Wis.** | |
| 1 | Chironomidae (21%) | *Ephemerella* (16%) | *subvaria* (11%) |
| 2 | Ephemerellidae (18%) | *Optioservus* (14%) | *unidentified* (8%) |
| 3 | Elmidae (15%) | *Protoptila* (8%) | *sparna* (7%) |
| 4 | Glossosomatidae (9%) | *C. (cricotopus)* (8%) | *flavistriga* (5%) |
| 5 | Hydropsychidae (8%) | *Ceratopsyche* (7%) | *trifascia group* (5%) |
| | | **Apple River near Somerset, Wis.** | |
| 1 | Hydropsychidae (29%) | *Chimarra* (20%) | *obscura* (20%) |
| 2 | Philopotamidae (20%) | *Ceratopsyche* (11%) | unidentified (10%) |
| 3 | Chironomidae (15%) | *Cheumatopsyche* (10%) | *pictipes* (6%) |
| 4 | Heptageniidae (9%) | *Stenonema* (8%) | *trivittatus* (4%) |
| 5 | Hydroptilidae (7%) | *Leucotrichia* (6%) | unidentified (4%) |