State of the Minnesota River
Summary of Surface Water Quality Monitoring
2003

Chapter 1

Purpose

The purpose of the 2003 State of the Minnesota River Report is to consolidate surface water quality monitoring information collected in the Minnesota River Basin for calendar years 2000 - 2003. This summary report assembles data collected by multiple agencies and organizations and presents the data in a fashion that allows for relative water quality comparisons between the mainstem Minnesota River sites, as well as between the major and minor tributaries in the Minnesota River Basin.

To date, three prior reports have been published in State of the Minnesota River Report series (2000, 2001 and 2002). The 2003 report presents 2003 monitoring data, and compares it with much of the 2000 - 2002 data along with a few additions and some minor corrections. The data and information presented in this report was gathered at 32 surface water quality monitoring stations located throughout the Minnesota River Basin.

Preparation of this report is a joint venture of the Minnesota Department of Agriculture (MDA) Minnesota Pollution Control Agency (MPCA), and the Water Resources Center at Minnesota State University, Mankato. Greg Payne, hydrologist, joined the group for a second year and examined the data, provided in-depth analysis, and wrote major sections of the report. This report helps fulfill the overall mission of the Minnesota River Basin Data Center, which is to inventory, develop, retrieve, interpret, and disseminate information on topics that impact the environment, economy and communities within the Minnesota River Basin. This mission was articulated first by the Minnesota River Citizens Advisory Committee (CAC) in a series of recommendations to the MPCA (MPCA, 1994), and later by the Minnesota River Basin Joint Powers Board (MRBJPB). This report demonstrates that good coordination exists between state and local water quality monitoring agencies in the Minnesota River Basin. The information provided in this report is also consistent with and helps fulfill the "Monitoring Action Strategy" identified in the Minnesota River Basin Plan (MPCA, 2001). The plan was developed with extensive input from researchers and citizens and charts a course for the continued restoration of the Minnesota River. The goal of the Minnesota River Basin Plan is "To restore, protect and maintain the water quality, bio-diversity and the natural beauty of the Minnesota River or to make the Minnesota River fishable and swimmable once again" (MPCA, 2001).

Background

The Minnesota River originates at the Minnesota-South Dakota border, flows for 335 miles through some of the richest agricultural land in Minnesota, and joins the Mississippi River at Minneapolis/St. Paul. The river drains a basin of 16,770 square miles: 14,840 square miles in Minnesota, including all or parts of 37 counties; 1,610 square miles in South Dakota; and 320 square miles in North Dakota and Iowa combined. Minnesota's portion of the Basin is primarily used for agriculture and represents 18.5% of the state's land mass and 29% of its cultivated land. As the state's largest tributary of the Mississippi River, the Minnesota River's volume increases the Mississippi's flow by 57% and adds disproportionately to its pollutant load (MPCA, 1997).

The 1994 Minnesota River Assessment Project (MRAP), at the time the most comprehensive study of water quality in the Minnesota River Basin, concluded that the Minnesota River is impaired by excessive nutrient and sediment concentrations (MPCA, 1994). Since the publication of the MRAP report, several organizations throughout the Basin have taken responsibility for collecting additional data to better define tributary characteristics and learn more about how these tributaries affect the condition of the Minnesota River. In many parts of the Basin, this information is used to target implementation practices that reduce point and non-point source pollution, thereby improving the overall health of the Minnesota River. Local watershed projects are supported mainly by Federal 319 funds and Clean Water Partnership grants administered by the MPCA. Much of the remaining data presented in this summary report is provided through monitoring programs of the MDA and Metropolitan Council Environmental Services (MCES), with contributions from the United States Geological Survey (USGS), Minnesota Department of Natural Resources (MDNR) and the Minnesota State Climatology Office.

In recent years, there have been significant improvements in point source pollution control as well as continued adoption of conservation and non-point source best management practices within the Minnesota River Basin. With these changes has come an increasing expectation that the monitoring data being collected will not only be used to identify potential problem areas but can also be used to document and quantify water quality improvements as best management practices are implemented. Recent publications have questioned the costs of implementation activities if the benefits cannot be readily quantified. As such, efforts like this to coordinate and standardize monitoring activities and information are becoming increasingly important to provide a scientifically defensible assessment of water quality responses to changes in land use throughout the Basin.

This report is available on the Minnesota River Basin Data Center web site at http://mrbdc.mnsu.edu/, to allow wide access and an opportunity to review and comment on its content.

Contributors

Data included in this report were submitted and reviewed by representatives of several organizations, including:

Barr Engineering
- Chris Bonick

Brown-Nicollet-Cottonwood Clean Water Project
- Kevin Kuehner, Scott MacLean, Steve Stauff

Chippewa River Watershed Project
- Kylene Olson, Paul Wymar, Rob Spitzley, Jennifer Churchill

Hawk Creek Watershed Project
- Loren Engelby, Amanda Smith

High Island Creek Watershed Assessment Project
- Scott Matteson, Scott Kudelka

Lac qui Parle-Yellow Bank Clean Water Partnership Diagnostic Studies
- Mary Homan

Martin County Environmental Services
- Becky Schlorf Von Holdt, Darren Newville

Metropolitan Council Environmental Services
- Mike Ahlf, Leigh Harrod, Kent Johnson, Heather Offerman, Tim Pattock, Scott Schellhaass

Minnesota Department of Agriculture Monitoring and Assessment Program
- Bill VanRyswyk, Marie Juenemann

Minnesota Pollution Control Agency
- Patrick Baskfield, Eileen Harris, Wade Gillingham, Bill Thompson, Lee Ganske, Tim Larson

Redwood-Cottonwood Rivers Control Area
- Jim Doering, Kari Howey, Douglas Goodrich

Rush River Assessment Project
- Scott Kudelka, Scott Matteson

Watonwan River Clean Water Partnership Project
- Bruce Johnson

Water Resources Center -Minnesota State University, Mankato
- Cis Berg, Robert Finley, Scott Matteson, Kimberly Musser, Zachary Pagel

Yellow Medicine Watershed District
- Terry Renken, Cindy Potz

The authors would also like to acknowledge the USGS and MDNR for much of the flow data that are utilized throughout this summary report. These agencies are a valuable resource for many organizations throughout the Minnesota River Basin.

To submit comments or questions, please contact:

Patrick Baskfield (MPCA)
507-389-1648 (pat.baskfield@pca.state.mn.us)
Bill VanRyswyk (MDA)
507-389-5772 (bill.vanryswyk@state.mn.us)
Scott Matteson (WRC-MSU)
507-389-5492 (scott.matteson@mnsu.edu)
Heather Offerman (offe0004@umn.edu)

Chapter 2: Monitoring and Data Assessment Methods

Monitoring Sites

For the 2003 monitoring season, data is presented for thirty-two (32) water quality monitoring stations operated throughout the Minnesota River Basin. The number and location of sites has changed slightly over the four year period, with some sites having four years of data and others only having one. In 2003, four monitoring stations are located along the mainstem of the Minnesota River, fourteen stations are located near the outlets of major Minnesota River tributaries (those with watersheds greater than 100,000 acres), and fourteen stations are located near the outlets of minor Minnesota River tributaries (those with watersheds less than 100,000 acres). It is important to note that there are over 40 over minor tributary sites located throughout the Basin. For the scope of this report, it was decided to include only a few representative minor sites. The 32 monitoring stations are listed in Table 2.01. Figure 2.01 depicts the locations of these monitoring stations throughout the Basin.

Table 2.01. Mainstem, Major Tributary, and Minor Tributary Monitoring Sites in the Minnesota River Basin

Mainstem	**Major Tributaries >100,000 acres**	**Minor Tributaries <100,000 acres**
MN River at Judson	Yellow Bank River	Dry Weather Creek
MN River at St. Peter	Lac qui Parle River	WF Beaver Creek
MN River at Jordan	Chippewa River	Clear Creek
MN River at Fort Snelling	Yellow Medicine River	Dutch Creek
	Hawk Creek	Seven Mile Creek
	Redwood River	Bevens Creek
	Cottonwood River	Chaska Creek
	Little Cottonwood R.	Carver Creek
	Watonwan River	Bluff Creek
	Blue Earth River	Riley Creek
	Le Sueur River	Eagle River
	Rush River	Credit Creek
	High Island Creek	Willow Creek
	Sand Creek	Nine Mile Creek

Additional details on each individual monitoring station are presented in Chapter 3 and Appendix D.

Map here

Monitoring Season

Monitoring season length is an important variable to consider when characterizing water quality and evaluating temporal and spatial trends throughout the Minnesota River Basin. The targeted time period for the 2000 monitoring season was April 1 through October 31. To allow additional time for the Clean Water Partnership Projects to analyze water quality data prior to the required reporting deadlines, the 2001 monitoring season was shortened by one month, extending from April 1 through September 30. While October runoff and river flows can be substantial during some years, the April 1 (approximate ice-out date) through September 30 period typically represents the months when nutrient and sediment loads are expected to be the highest, and when the majority of river flow occurs. At monitoring stations where year-round USGS or agency flow gauging occurs, year-round monitoring is also encouraged. The 2003 monitoring season length was very similar to that of 2001 and 2002. Table 2.02 presents the 2003 monitoring season length at each of the 32 monitoring stations in the Minnesota River Basin.

Storm Event Sampling Methodology

Two primary methods of storm event sampling are used in the Minnesota River Basin. Grab sampling is the collection of a discrete, instantaneous sample, either by manual means or with an automatic sampler (autosampler). Flow-based composite sampling is the collection of a composite sample during the time period when the river is responding to the increased runoff associated with a storm event. Flow-based composite samples are collected using an autosampler. The objective of flow-based composite sampling is to determine the pollutant characteristics of the entire stormflow volume, using either equal-time increment (ETI) or equal-flow increment (EFI) sampling. Generally, with ETI sampling, the automatic sampler is used to collect discrete grab samples at pre-specified time intervals (every hour, for example) during a storm event. These discrete grab samples can then be composited based upon time and flow, or analyzed as discrete samples. With EFI sampling, the autosampler is used to obtain a composite sample throughout a storm event by collecting discrete sub-samples representing equal volumes of flow. For example, 200 mL of river water may be collected for every 10,000 cubic feet of river flow, resulting in one composite sample that can represent several days of runoff. In theory, EFI composite sampling provides better pollutant characterization, as all flow conditions are equally represented in one sample.

Table 2.03 presents the 2003 storm event monitoring methodology used at each of the 32 monitoring stations in the Minnesota River Basin.

Table 2.02. 2003 Monitoring Season Length in the Minnesota River Basin

River	Acreage	Time Interval	Years of Operation
Dry Weather	67,759	4/1 – 9/30	5
West Fork Beaver Creek	61,326	4/1 – 9/30	4
Yellow Bank River	281,456	4/1 – 9/30	3
Lac qui Parle River	615,244	3/25 – 9/30	3
Chippewa River	1,203,200	4/1 – 9/30	6
Yellow Medicine River	424,958	3/26 – 9/30	5
Hawk Creek	323,199	4/1 – 9/30	5
Clear Creek	49,280	4/1 – 9/30	14
Redwood River	402,560	3/29 – 9/30	15
Cottonwood River	840,000	4/1 – 9/30	8
Little Cottonwood River	108,760	4/1 – 9/30	6
MN River at Judson	7,186,921	3/15 - 9/30	5
Dutch Creek	8,653	4/1 – 9/30	5
Watonwan River	544,533	4/1 – 9/30	4
Blue Earth River	1,555,270	3/15 - 9/30	5
Le Sueur River	710,400	3/15 - 9/30	5
MN River at St. Peter	9,634,760	3/15 - 9/30	5
Seven Mile Creek	23,551	4/1 – 9/30	5
Rush River	257,775	4/1– 9/30	1
High Island Creek	152,150	4/1 – 9/30	4
Bevens Creek	83,776	3/15 - 9/30	15
Sand Creek	163,071	3/15 - 9/30	15
MN River at Jordan	10,389,757	3/15 - 9/30	15
Chaska Creek	9,640	3/15 - 9/30	6
Carver Creek	53,440	3/15 - 9/30	15
Bluff Creek	5,724	3/15 - 9/30	15
Riley Creek	8,366	3/15 - 9/30	5
Eagle Creek	2,158	3/15 - 9/30	5
Credit River	32,896	3/15 - 9/30	15
Willow Creek	6,558	3/15 - 9/30	5
Nine Mile Creek	24,512	3/15 - 9/30	15
MN River at Fort Snelling	10,849,467	3/15 - 9/30	28

Table 2.03. 2003 Storm Event Sampling Methods in the Minnesota River Basin

Equal Time Increment Auto-sampling	Equal Flow Increment Auto-sampling	Grab Sampling
Redwood River	MN River at Judson	Yellow Bank River
Cottonwood River	Dutch Creek	Lac qui Parle River
Little Cottonwood River	Blue Earth River	Chippewa River
Seven Mile Creek	Le Sueur River	Yellow Medicine River
Clear Creek	MN River at St. Peter	Hawk Creek
	Bevens Creek	Watonwan River
	Sand Creek	Dry Creek
	Chaska Creek	West Fork Beaver Creek
	Carver Creek	Rush River
	Bluff Creek	High Island Creek
	Riley Creek	MN River at Jordan
	Eagle Creek	MN River at Fort Snelling
	Credit River	
	Willow Creek	
	Nine Mile Creek	

Grab or composite sample collection during storm events is typically supplemented by grab sample collection during non-event (baseflow) periods.

Compilation of Water Quality Data

Most of the data used for the 2000 - 2003 State of the Minnesota River Reports were compiled and submitted by the organizations conducting the water quality monitoring work.

Criteria for Data Inclusion

As the 2001 State of the Minnesota River Report was being prepared, it became clear that water quality comparisons between monitoring stations and watersheds are not possible when monitoring season lengths are inconsistent and/or when inadequate sampling has been conducted. Consequently, a multi-agency group established monitoring criteria that are intended to ensure more accurate comparisons of water quality data between monitoring stations and watersheds. These criteria will be used to determine which data are included in these annual reports, and have also proven to be beneficial for guiding monitoring program improvements. These criteria include:

1. Representation of a complete monitoring season (April 1 (or ice-out date) to September 30).
2. Sufficient water quality sampling to accurately characterize all flow periods.
3. A well-defined stage/discharge relationship.
4. Frequent site visits to ensure the integrity of the monitoring equipment.

5. Similar monitoring and analytical methodologies.
6. Implementation of field quality-assurance measures.

Refer to Appendix A for the document: “Criteria for Inclusion of Monitoring Data in the 2001, 2002 and 2003 State of the Minnesota River Reports.”

Calculation of Loads and Flow-Weighted Mean Concentrations

FLUX is an interactive software program that allows the user to estimate loads and flow-weighted mean concentrations (FWMCs) of water quality constituents at a monitoring location. The FLUX program combines flow and water chemistry data from the monitoring location to make these estimates. Loads and FWMCs can be determined for any time period, but for the purpose of this report, loads and FWMCs were all calculated for the April 1 – September 30 monitoring season. FLUX was the primary tool used by all monitoring partners for assessment of the 2000 – 2003 data. For a more detailed explanation of FLUX, see Appendix B.

Because FLUX is designed to use daily average flow data coupled with water chemistry data from discrete grab samples, flow-composited samples that are collected over a time period greater than one day require an estimate of the daily average flow. To estimate the daily average flow for a composite sample, the middle day of the composite sampling period or the day during which the majority of the flow occurred is selected. An average flow for that day is then derived by dividing the total flow volume (cubic feet) for the composite sample collection period by the total number of seconds elapsed during that period, to give an average composite flow in cubic feet per second (cfs).

High water at a ditch site in the Le Sueur Watershed.

Chapter 3: 2003 Monitoring Data

2003 Precipitation and Runoff

State-wide 2003 total precipitation amounts and precipitation departure from normal (MN State Climatology Office, 2003) are presented in Figures 3.01 and 3.02, respectively. Figure 3.01 indicates that the greatest precipitation occurred in the downstream (eastern) part of the Minnesota River Basin. Total precipitation amounts decreased slightly as one moves westward through the Basin. Total precipitation amounts in 2003 ranged from 16 inches in the western part of the Basin to 24 inches in the eastern portion of the Basin. As shown in Figure 3.02, these annual totals represent an approximate 2 - 6 inch decrease from normal in the throughout the whole Basin.

Figure 3.01.

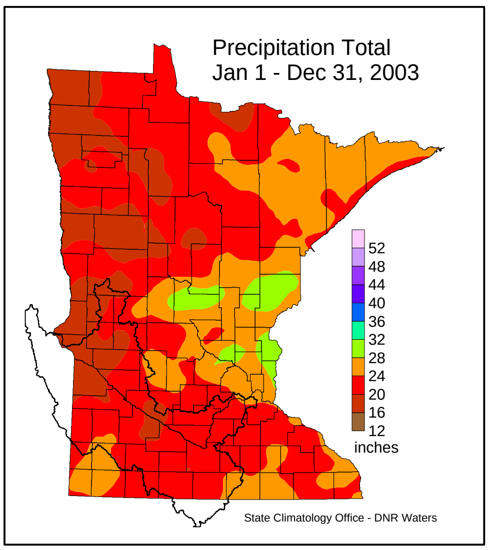
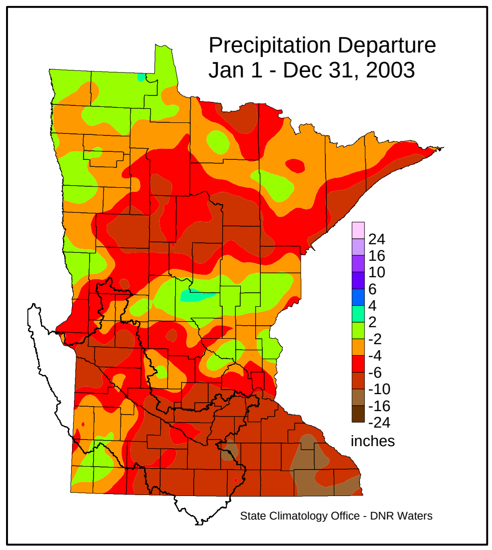


Figure 3.02.



Runoff is the part of precipitation that appears in rivers and streams, including baseflow, stormflow, flow from ground water, and flow from point sources (see Appendix C: Glossary of Terms). Typically, the more precipitation that occurs in a watershed, the more runoff there will be. However, the timing and intensity of precipitation, antecedent soil moisture conditions, soil types, land slopes, land use, as well as other factors, can dramatically influence the seasonal or annual final runoff number. In the Minnesota River Basin, runoff tends to increase from the western portion of the Basin to the eastern portion due to geographical differences in precipitation. By normalizing constituent loading data for runoff, watersheds from different parts of the Basin can be compared on a more relative basis.

Conservation Reserve Enhancement Program Easements

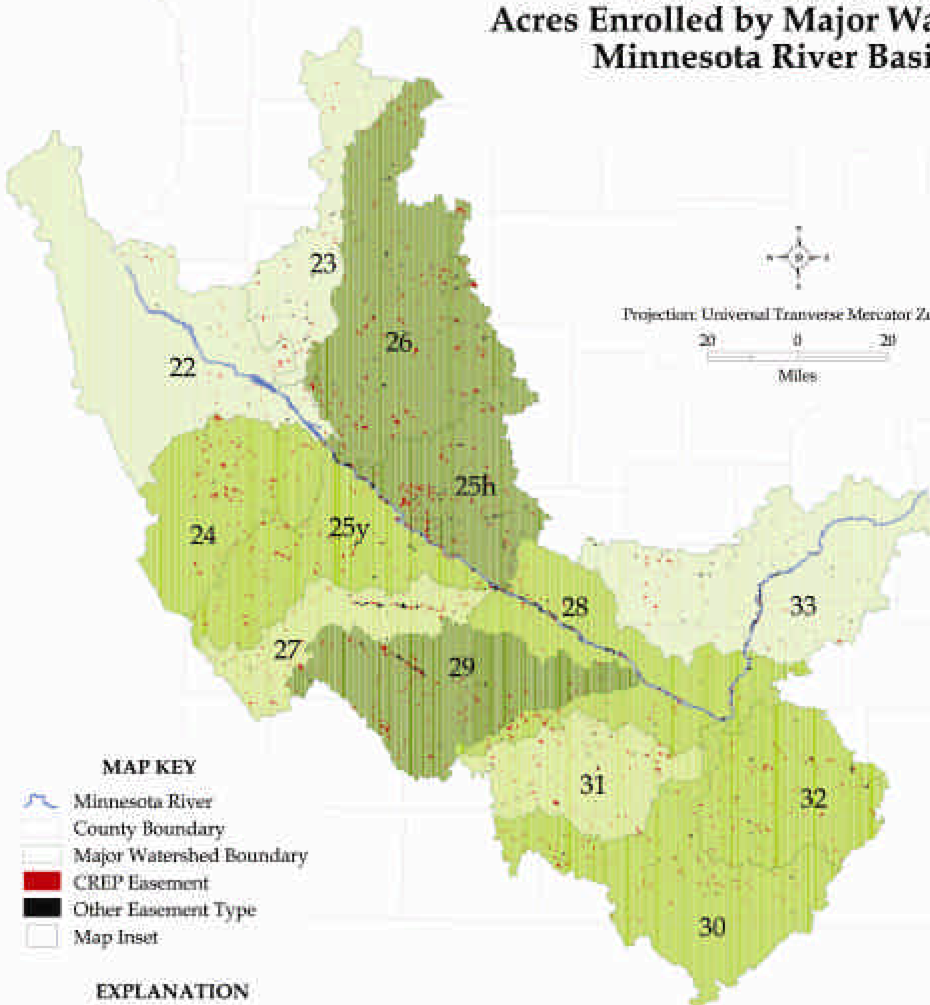
Figure 3.03 depicts acres enrolled in the Conservation Reserve Enhancement Program (CREP) by major watershed in the Minnesota River Basin. The inset table describes by major watershed how many CREP acres there are, followed by the total number of acres of easements throughout the watershed.

2003 Information for Individual Monitoring Stations

Information on each of the 32 individual monitoring stations in the Minnesota River Basin is presented in Appendix D. This information includes a project summary, details regarding site location, a short synopsis of 2003 monitoring season results, numbers and types of water chemistry samples, and a hydrograph for the 2003 monitoring season. Project contact information also is provided.

The 2003 water chemistry data for each of the 32 Minnesota River Basin monitoring sites are presented in Appendix E. The 2000 - 2003 total suspended solids, total phosphorus, orthophosphorus, and nitrate-N loads, yields, runoff-adjusted yields, and FWMCs for each of the 32 Minnesota River Basin monitoring sites are presented in Appendix F. Fecal coliform information are presented in Appendix G.

CREP EASEMENTS
Acres Enrolled by Major Watershed
Minnesota River Basin



MAP KEY

- Minnesota River
- County Boundary
- Major Watershed Boundary
- CREP Easement
- Other Easement Type
- Map Inset

EXPLANATION

The map displays CREP and other easement locations relative to major watershed areas in the Minnesota River Basin. The data analysis classifies each watershed by acres of CREP enrollments in place by May 2004 and does not include final CREP enrollment acres. Total conservation easements include CREP, RIM, PWP, and other easement such as riparian and marginal cropland but may not include other easement data available in programs such as CRP. The acres and percent of CREP and total easements are based on the Minnesota portion of the Minnesota River Basin.

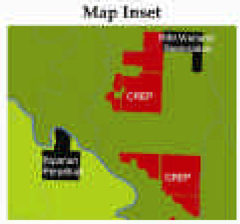
Author: Cis Berg
Water Resources Center
Minnesota State University Mankato
May 31, 2005
ARCINFO 8.2 and ArcView 3.3

Data Sources: BWSR Rimactive file 05-10-04; Minnesota River Basin Data Center GIS files. Data analysis of rimactive file is approximate due to overlapping polygons in source data.

Major Watershed Classified by CREP Enrollment Acres

- 2,427 - 2,694 acres
- 4,675 - 5,710 acres
- 6,507 - 8,051 acres
- 11,404 - 16,570 acres

Map Inset



CREP and Total Easements by Major Watershed
Easement Acres and Percent of Major Watershed

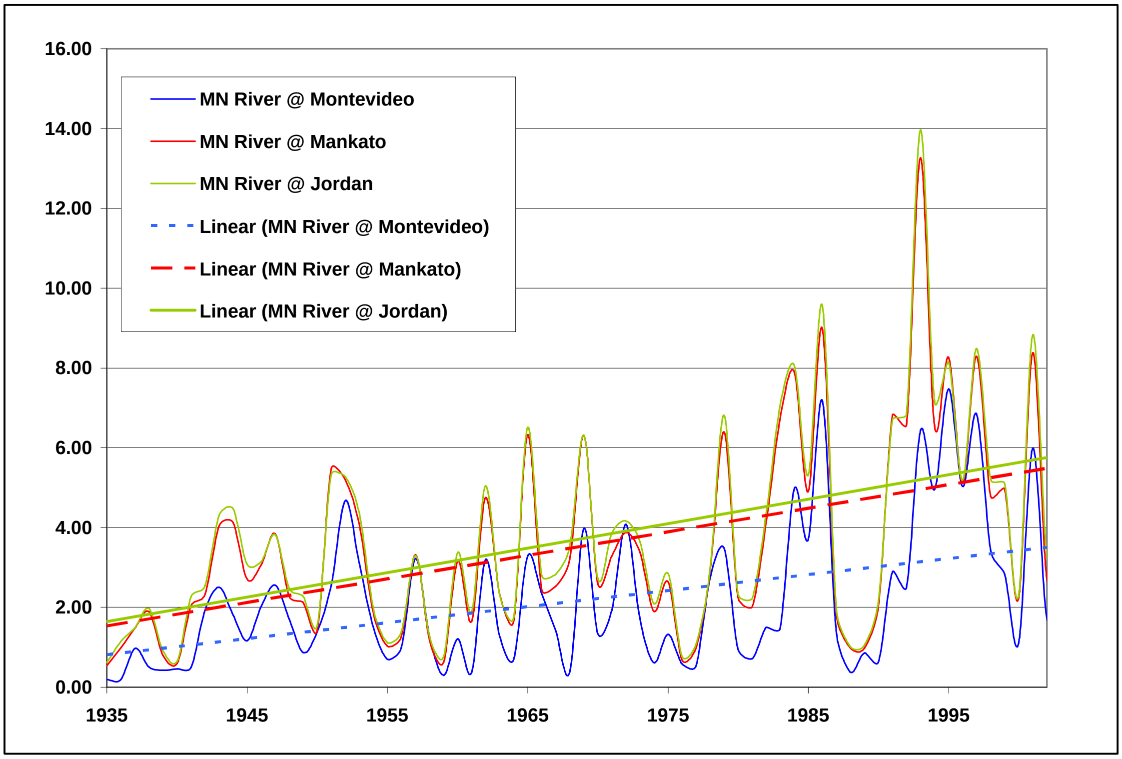
Major Watershed ID	Name	CREP Acres	CREP %	Total Easements Acres	Total Easements %
30	Blue Earth	6,507	0.8	7,713	1.0
26	Chippewa	16,570	1.2	20,809	1.6
29	Cottonwood	11,404	1.4	14,123	1.7
25h	Hawk Creek	12,715	2.0	17,368	2.8
24	Lac qui Parle	8,051	1.7	8,652	1.8
32	Le Sueur	6,936	1.0	8,512	1.2
33	Lower Minnesota	2,653	0.2	6,674	0.6
28	Middle Minnesota	6,727	0.8	12,398	1.4
23	Pomme de Terre	2,427	0.4	3,977	0.7
27	Redwood	4,675	1.0	7,307	1.6
22	Upper Minnesota	2,694	0.6	3,296	0.7
31	Watonwan	5,710	1.0	7,131	1.3
25y	Yellow Medicine	7,971	1.1	10,785	1.5
	Total Acres	95,039	1.0	128,797	1.3

Chapter 4: A Comparison of 2000 - 2003 Monitoring Results

Runoff

Figure 4.01 presents annual runoff amounts at three Minnesota River mainstem locations during the 1935 through 2003 period, as determined by the USGS. Data are presented for the Minnesota River at Montevideo, Mankato, and Jordan, located in the Upper, Middle and Lower Minnesota River Watersheds, respectively.

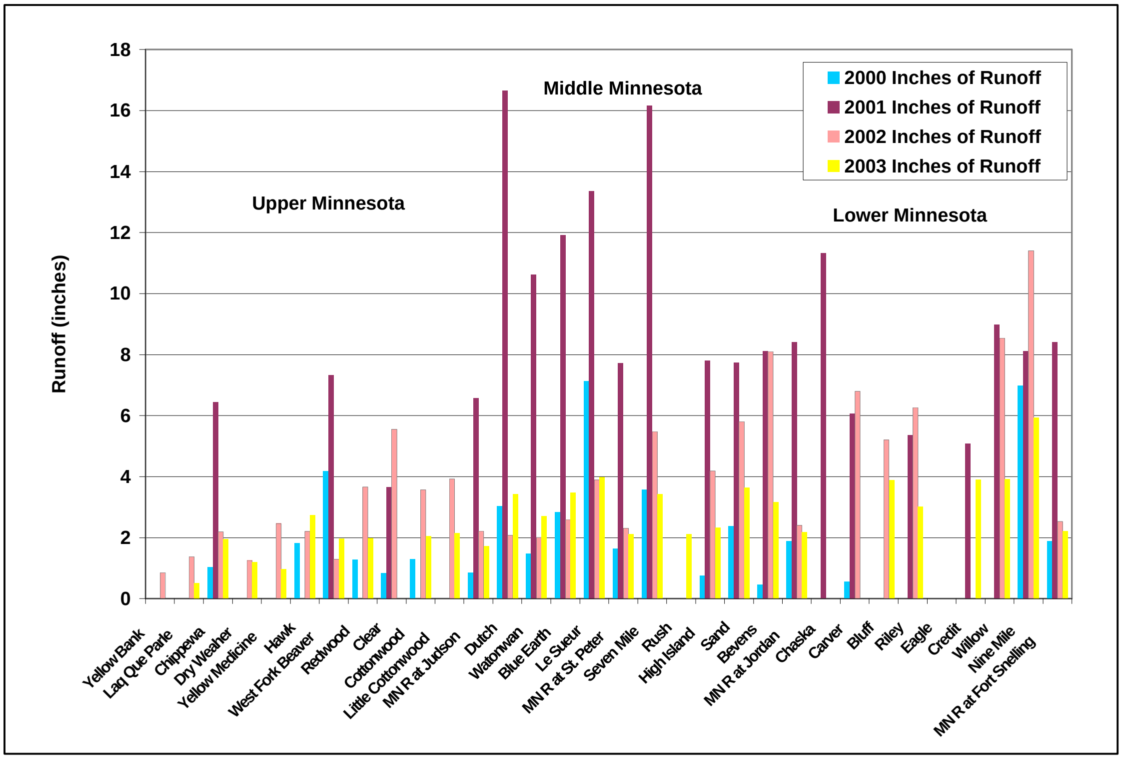
Figure 4.01. Annual Runoff at Minnesota River Mainstem Locations, 1935 - 2003



A clear trend of increasing runoff is apparent in Figure 4.01. During the most recent 13-year period (1991-2003), seven of the top ten runoff years have occurred at Mankato, and six of the top ten runoff years have occurred at Montevideo and Jordan. The increases in runoff indicated in Figure 4.01 are the result of a combination of factors, including increasing precipitation, changes in agricultural and urban drainage, and other landscape and land use modifications. Mallawatantri and Mulla (1998) analyzed long-term flow trends for the Minnesota River and found that 70% of the increased flow was due to climatic changes, with the rest due to non-climatic effects.

Figure 4.02 presents 2000 - 2003 monitoring season runoff amounts at all 32 Minnesota River Basin sites, in an upstream to downstream sequence. This figure shows a substantial difference between the four years with respect to runoff in the Basin. The 2000 monitoring season was relatively dry in most of the Basin, while the 2001 season was relatively wet. In 2002, the runoff amounts were less than 2001 but greater than 2000 in the upper and middle part of the Basin. However, in the Lower Minnesota River Basin tributaries, 2002 runoff exceeded all of the corresponding runoff numbers in 2000, and in some instances, exceeded the runoff in 2001. In 2003, runoff totals were for the generally greater than 2000, but less than 2002 results.

Figure 4.02. 2000 - 2003 Monitoring Season Runoff at Minnesota River Basin Sites



Water Quality

The discussion and graphics presented on the following pages evaluate spatial and temporal differences in 2000 - 2003 monitoring results, and in some instances also evaluate the methodologies used to collect or compile these results. The loading, yield, runoff-adjusted yield, and FWMC data for each of four key water quality constituents (total suspended solids, total phosphorus, orthophosphorus, and nitrate-N) have been grouped into the Minnesota River mainstem, major tributaries, and minor tributaries (See Table 2.01 and Figure 2.01). For each of the three Minnesota Basin groups, the graphics are organized in an upstream to downstream sequence, from left to right.

A glossary of some of the key terms used in the following comparison of 2000 - 2003 monitoring results is presented in Appendix C.

Mainstem Total Suspended Solids

Figure 4.03 presents the 2000 - 2003 monitoring season total suspended solids (TSS) loads for Minnesota River mainstem sites and the Greater Blue Earth River Watershed (including the Blue Earth, Watonwan, and Le Sueur Rivers). Runoff at mainstem sites decreased during 2003 compared to 2002, while runoff in the Greater Blue Earth Watershed during 2003 increased compared to 2002. Total suspended solids load response corresponded to runoff conditions in that TSS loads at mainstem sites were less than loads measured during 2002 and TSS load in the Greater Blue Earth increased slightly compared to 2002 (Figure 4.03). The relation between annual runoff and annual sediment yield is not linear because the magnitude and timing of the individual runoff events that comprise total annual runoff also greatly affect the amount of sediment delivered. For example, runoff in the Greater Blue Earth increased 21 percent during 2003 compared to 2002, but TSS load increased only 8 percent compared to 2002.

In general, TSS loads at mainstem sites during 2003 were among the lowest measured since reporting began in 2000. Three of the mainstem sites, St. Peter, Jordan, and Ft. Snelling recorded the smallest TSS loads of the four-year period. The 2003 TSS load at Judson (184,000 tons) exceeded the previous low of 131,000 tons measured during 2000, but runoff at Judson in 2003 was 1.72 inches, an amount that was more than double the 0.85 inches of runoff recorded at Judson in 2000. Overall, water quality in the mainstem and the Greater Blue Earth River appears to have benefited (TSS loads decreased) from two consecutive years of low to moderate rainfall (with localized exceptions) across most of the Basin. Reduced TSS loads during 2003 are reflected in the FWMC values (Figure 4.04). The FWMC values (85-166 mg/L) have diminished compared to values in 2000, but exceed the impaired waters thresholds of 58 mg/L (Western Corn Belt Plains) and 66 mg/L (Northern Glaciated Plains).

Figure 4.03. 2000 - 2003 Monitoring Season Total Suspended Solids Loads in Thousands of Tons at Minnesota River Mainstem and Greater Blue Earth River Sites

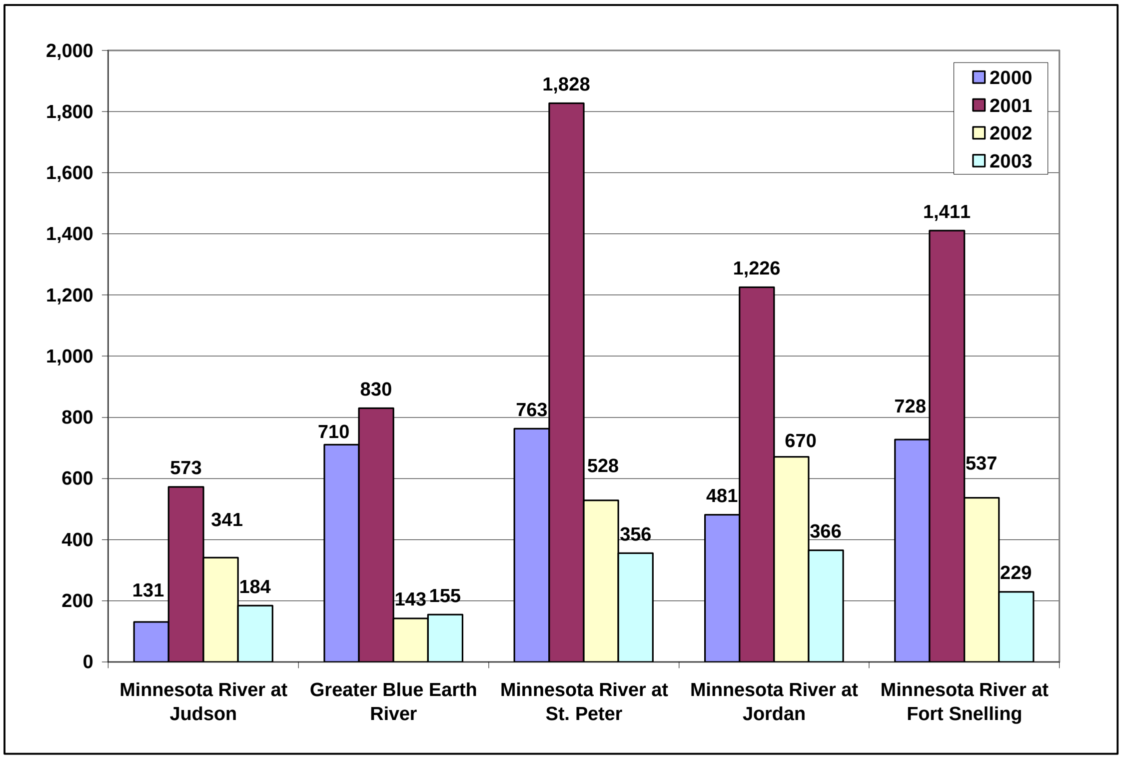
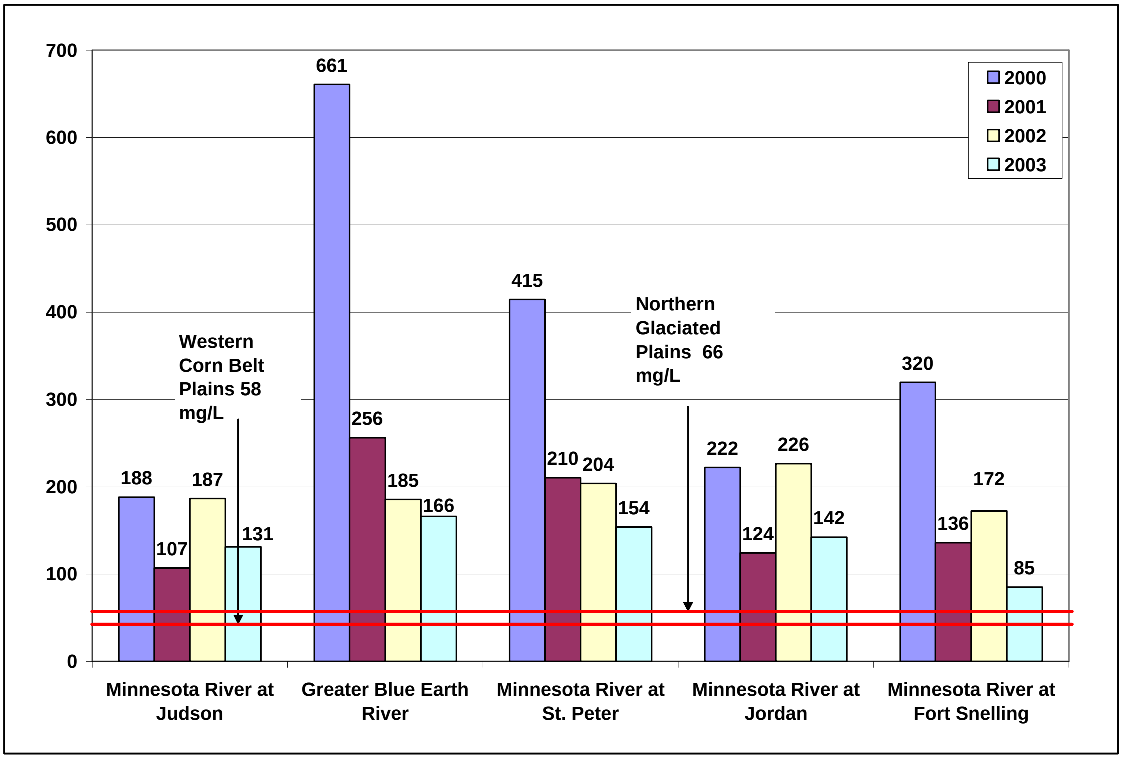


Figure 4.04. 2000 - 2003 Monitoring Season Total Suspended Solids FWMC at Minnesota River Mainstem and Greater Blue Earth River Sites



Major Tributaries Total Suspended Solids

Figure 4.05 shows major-tributary TSS loads in thousands of tons during the past four years. Taken as a whole, major tributaries in the Middle and Lower part of the Minnesota River Basin have contributed the greatest TSS load, most notably the Le Sueur and Blue Earth Rivers, and to a lesser extent, the Cottonwood River. These tributaries drain large watersheds that receive greater than average precipitation, and they have greater than average runoff as compared to tributaries in the upstream part of the Basin. This difference was particularly notable during 2000 and 2001, when loads in the Le Sueur and Blue Earth Rivers greatly exceeded loads in the other major-tributary streams (Figure 4.05).

While TSS loads are useful for assessing the relative sediment contribution from each of the major tributaries to the total sediment burden of the Minnesota River, TSS yields and FWMC's are better indicators of water-quality condition among the tributaries. Yields (Figure 4.06), in general, were moderate during 2003 compared to 2000 and 2001, especially in the Lower part of the Basin. A notable exception is Sand Creek where yields during both 2002 and 2003 were highest among the major tributaries. Examining the yield data from all four years shows that tributaries upstream of the Redwood River have not exceeded 100 lbs/ac, whereas the tributaries downstream of the Redwood River often have exceeded 200 lbs/ac.

As discussed in the 2002 State of the Minnesota River Report, annual precipitation increases from west to east (downstream) across the Basin. The amount of precipitation and associated runoff is a major factor affecting the amount of erosion within a watershed and thus its TSS yield. The data collected during the last four years, however, show that total seasonal runoff amounts are only approximate predictors of watershed yields. The seasonal timing of precipitation (spring, summer, or fall) along with rainstorm intensity (inches of rain per hour) greatly affects the amount of erosion. Spring and early summer rains, in general, result in more erosion and the greater the intensity of rainfall the greater the amount of erosion. Furthermore, the amount of rainfall that has preceded a major precipitation event (antecedent precipitation) may increase the amount of erosion. Data collected over the last four years have shown that some of the greatest storm loads and yields occur when heavy rainfall (generally 2" or greater) falls on watersheds that have soils already moistened by rain that has fallen within the previous 3-7 days. Runoff and erosion can be high during these events, even when the antecedent rains were moderate and produced little erosion of their own.

Given the dynamic response of watersheds to precipitation variables, it often is difficult to determine to what extent a watershed's response (yield) is influenced by other factors such as terrain, land use, and management practices. Separating the effects of these influences remains an important objective of resource managers and policy makers because of the continuing need to properly allocate resources between; (1) mitigating the effects of natural forces (primarily climate and weather), and (2) management of human activities (land use practices). As each year's data is collected and evaluated, more is learned about the response of each watershed to precipitation variables. After four years

Figure 4.05. 2000 - 2003 Monitoring Season Total Suspended Solids Loads in Thousands of Tons at Major Minnesota River Tributary Sites

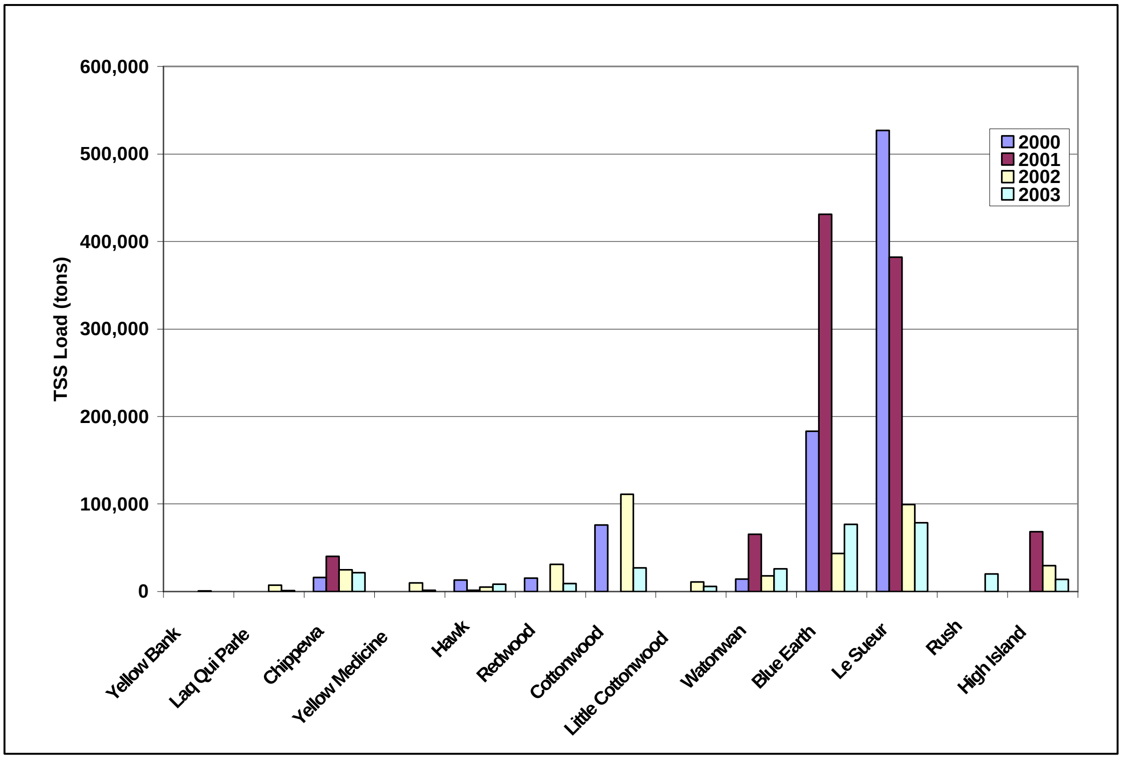
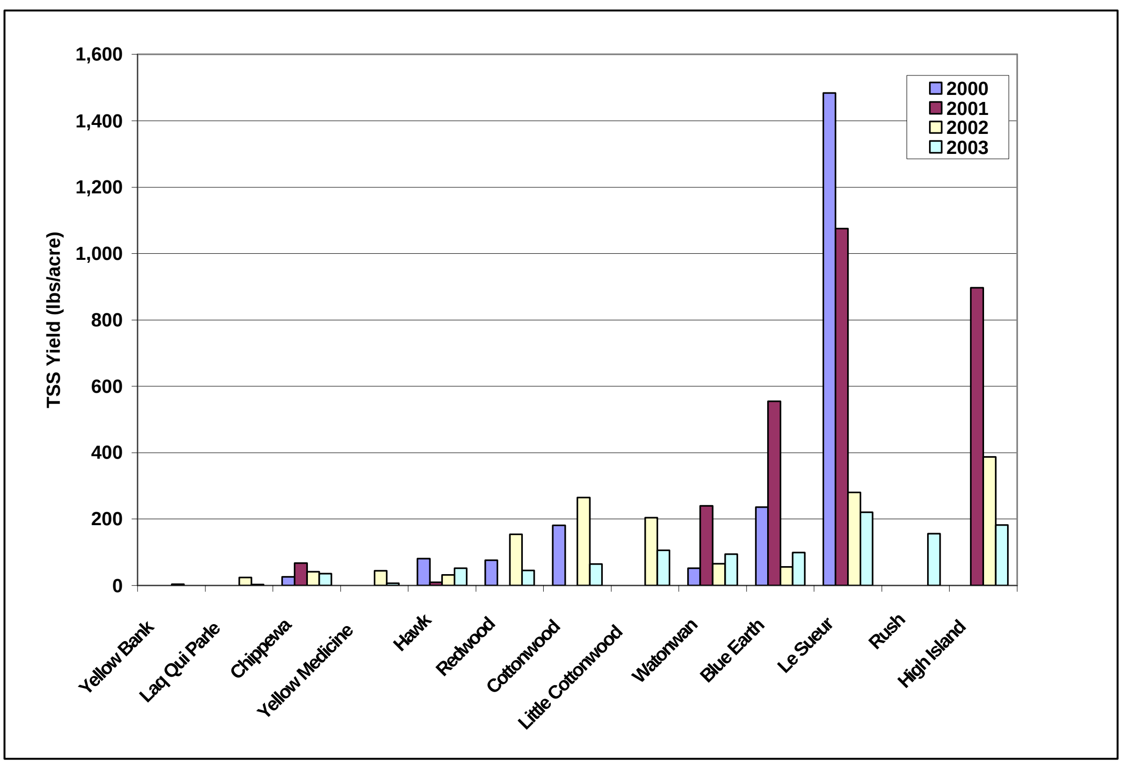


Figure 4.06. 2000 - 2003 Monitoring Season Total Suspended Solids Yields at Major Minnesota River Tributary Sites



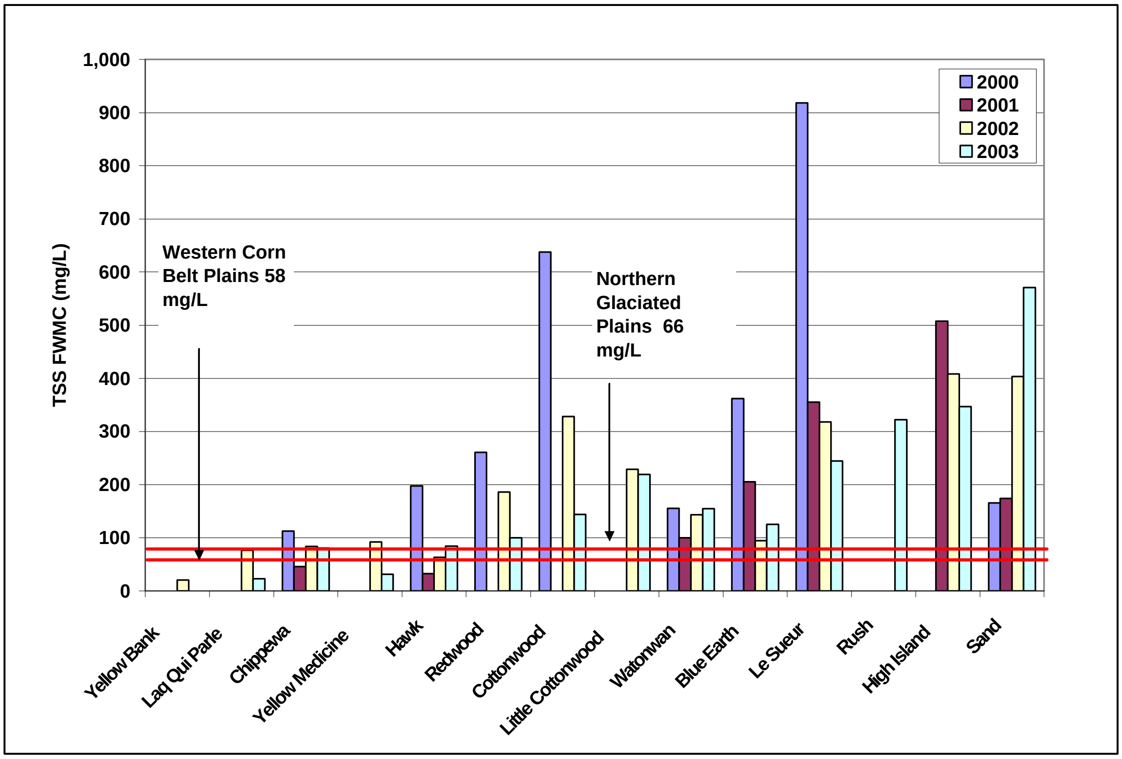
of monitoring, some fairly consistent patterns seem to be emerging from the data, among them the aforementioned lower TSS yields from tributaries in the upstream, western part of the Basin.

When comparing runoff responses among the major tributaries, it is notable that equivalent runoff amounts result in strikingly dissimilar amounts of TSS delivery (yield). As mentioned previously, differences in rainfall intensity, timing, and antecedent rainfall need to be considered when runoff amounts are compared among major watersheds. Comparisons based on total seasonal runoff amounts, nonetheless, provide a starting point for evaluation and may be a useful tool for discovery of other factors (non-precipitation factors) that may be affecting watershed yields. The following discussion examines these comparisons.

The Chippewa River and Cottonwood River Watersheds had nearly equivalent total seasonal runoff during 2003 (1.94 and 2.05 inches, respectively). Both watersheds rank in size among the larger of the major tributaries (1,880 and 1,312 mi^2, respectively). Despite similar runoff amounts, the Cottonwood yielded 65 tons/ac of TSS, an amount nearly double the yield of the Chippewa (35 tons/ac). The higher yield in the Cottonwood resulted in a greater FWMC as well, 144 mg/L, compared to 80 mg/L in the Chippewa River (Figure 4.07). The precipitation and hydrographs in Figures D.02 and D.08 show that total precipitation was, in fact, somewhat greater in the Cottonwood River Watershed. Perhaps of greater significance, antecedent rainfall during two significant runoff events in mid-May and late June was greater in the Cottonwood River Watershed. Seasonal differences are clearly shown by the meager runoff response to rainfall that occurred in September in both watersheds, a time period when crop canopies are generally fully developed and antecedent soil moisture conditions are low. The September rain events, the largest of the 2003 season, resulted in a very small amount of runoff compared to runoff amounts that occurred following smaller rainfalls during May and June. A significant part of the Chippewa Watershed (upstream part) is characterized by less intensive agricultural land use interspersed with lakes and woodlands (land use is 68% agriculture, 62% row crop). This is in contrast to the Cottonwood River Watershed, which supports intensive agriculture, primarily row cropping, across nearly all of its drainage area (land use is 84% agriculture, 92% row crop). These differences in land use may explain some of the differences in TSS yields and FWMC's.

The Rush River and Little Cottonwood River also had similar runoff amounts during 2003, registering seasonal totals of 2.12 and 2.14 inches respectively. Here again, very similar runoff amounts produced dissimilar TSS yields and FWMC's. Yield from the Rush River Watershed was 155 tons/ac, while the Little Cottonwood River Watershed yielded 106 tons/ac (Figure 4.06). The FWMC in the Rush River was 322 mg/L, while the FWMC in the Little Cottonwood River was 219 mg/L. An examination of Figures D.09 and D.17 shows that rainfall totals for the major runoff events were greater in the Little Cottonwood River, opposite of what would be expected given its yield and FWMC values. In this comparison, neither storm precipitation totals nor seasonal runoff totals are good predictors of water quality outcomes.

Figure 4.07. 2000 - 2003 Monitoring Season Total Suspended Solids Flow Weighted Mean Concentrations at Major Minnesota River Tributary Sites



A third comparison can be made using data from the Redwood and Cottonwood River watersheds. Runoff amounts were similar during each of the 2000, 2002, and 2003 monitoring seasons. This might be expected as the two watersheds adjoin each other, and therefore both would tend to be exposed to similar weather patterns and storm tracks. In each of the years, TSS yields were greater in the Cottonwood River Watershed (Figure 4.06). The Cottonwood River also had greater FWMC values during all three years. Examining data from 2000, yields from the Cottonwood River Watershed were about 2.4 times greater than yields from the Redwood River Watershed. The yield difference between these two watersheds diminished somewhat during 2002 and diminished again during 2003. Nonetheless, yields in the Cottonwood were 44 percent greater than yields in the Redwood even during 2003.

Although differences in precipitation variables partly explain TSS yield differences in some of the preceding watershed comparisons, the poor correlation between precipitation, runoff, and water quality in two of the examples points to the need to consider other factors. The primary factor other than precipitation is watershed geomorphology, along with the influence of local land use and land management practices. One aspect of geomorphology, channel slope, has attracted attention as monitoring of the watersheds has progressed. Channel slopes do not differ greatly in the relatively level till-plains that comprise a major part of the watersheds in the Minnesota River Basin. Channel slopes, however, increase as the streams approach the Minnesota River Valley where the tributary channels become incised near their confluence with the Minnesota River mainstem.

The elevation difference between the till-plain portions and the Minnesota River Valley floor varies across the Minnesota River Basin, and the extent (stream miles) of incised channels differs among the tributaries. The more steeply-sloped and incised channel reaches have greater potential for erosion, thereby contributing to greater TSS loads and yields. Channel incision (down cutting) can lead to bank instability and collapse. Another consequence of deeply incised channels is the formation of lateral gullies that head cut into adjacent upland fields. These gully streams tend to form during high-intensity precipitation events, at times forming sizeable ravines and thereby contributing significant amounts of sediment to the major-tributary channels. At times, the gullies extend well into upland areas, intersecting agricultural fields where they receive overland flow and tile discharge resulting in sediment and nutrient transport from the field. The areal extent of these gully-prone areas differs among the major tributaries and may partially explain differences in TSS yields from their respective watersheds. Monitoring in at least one of the major tributaries, High Island Creek, has documented greater TSS yields from the incised-channel areas through use of multiple monitoring stations that bracketed the steeply sloped, incised reaches of that stream.[1]

Terrain features in the steeper channel reaches bear closer scrutiny. In the previous comparison of TSS yields in the Redwood and Cottonwood River Watersheds, the terrain differences are plainly evident. The Redwood River encounters a bedrock outcrop as it approaches the rim of the Minnesota River Valley at Redwood Falls. The bedrock, a series of falls and rapids, has prevented the Redwood River from incising (head cutting) an extensive river valley upstream of Redwood Falls, and much of the lower reach of the Redwood River below the falls is boulder strewn, thereby partially armoring the river channel and reducing channel incision. In contrast, the Cottonwood River flows mostly over unconsolidated material along its course from the upland till plains to its mouth, forming several miles of incised river valley in its downstream reaches. Conditions along that downstream reach of the Cottonwood River may contribute to its higher TSS yields compared to the Redwood River, at least in part. Differences in terrain features among the other major watersheds may be more subtle, but investigating them may lead to a better understanding of the relative significance of the various sediment sources and delivery mechanisms throughout the Minnesota River Basin.

Overall, 2003 marked a year in which TSS yield and FWMC's were moderate compared to values recorded at many sites during 2000 and 2001. The Le Sueur and High Island Watersheds in particular show substantial reductions. Sand Creek, however, has not followed this trend, and values during 2002 and 2003 were substantially greater than they were during 2000 and 2001. Sand Creek Watershed had the greatest TSS yield among all the major tributaries during both 2002 and 2003.

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[1]Two samplesheds in the High Island Creek outlet area represent 26% of the watershed area, but 96% of the TSS load in 2001, and 92% of the TSS load in 2002 (HICWAP, 2002).

Minor Tributaries

Most of the minor tributaries presented in this report discharge directly into the Minnesota River, and are located within the Lower Minnesota River Watershed. Three tributaries were added to this year's report to provide information about streams in the western part of the Minnesota River Basin. Table 2.01 presents the relative size of the minor tributaries listed in this report. Watershed land use for Minnesota River minor tributaries is presented in Table 4.01.

Most of these minor watersheds lie fully or partly within the Twin Cities Metropolitan Area (TCMA). As Table 4.01 indicates, there are significant differences in land use between these watersheds. Land use in Carver, Chaska, and Bevens Watersheds is predominantly agricultural, while land use in the other watersheds tends to be more mixed use. The land use data presented for Chaska Creek and Bevens Creek were obtained during the early 1990's and are presented in the MPCA's Basin Information Document (MPCA, 1997). Land use from Dry Weather, West Fork Beaver, Clear, Dutch, and Seven Mile Creeks was obtained from their respective watershed projects. Land use for the remaining watersheds is from the Metropolitan Council, and is more current.

Table 4.01. Watershed Land Use for Minor Minnesota River Tributaries Sites

	Agriculture	Residential	Commercial	Industrial	Public Semi-Public	Parks and Rec.	Transprt	Undev.	Water
Dry Weather	94%	1%						4%	1%
WFBC	92%	3%						4%	<1%
Clear	94%	<1%	<1%					3%	1%
Dutch	92%	1%						5%	
Seven Mile	86%	3%						8%	3%
Bevens	85%	2%						5%	8%
Chaska	73%	4%						12%	11%
Carver	58%	4%	0%	1%	0%	1%	0%	25%	9%
Bluff	19%	15%	<1%	3%	1%	21%	<1%	33%	6%
Riley	7%	20%	2%	3%	1%	17%	5%	31%	13%
Eagle	<1%	13%	2%	7%	20%	0%	6%	45%	7%
Credit	26%	17%	1%	1%	1%	14%	0%	37%	4%
Willow	0%	36%	11%	14%	2%	8%	3%	22%	4%
Nine Mile	0%	44%	6%	8%	4%	19%	5%	9%	6%

Minor Tributaries Total Suspended Solids

Figure 4.08 presents 2000 - 2003 runoff for the minor tributaries. Runoff for all minor tributaries was below normal during 2003, except for Nine Mile Creek where runoff was about normal. Normal runoff ranges from about 2 inches near Dry Weather Creek to about six inches in the TCMA.

The 2000 - 2003 monitoring season TSS loads at the Minnesota River minor tributary sites are presented in Figure 4.09. Loads in Bevens Creek were substantially reduced from amounts recorded during 2002, reflecting the absence of intensive late-summer runoff events that drove TSS loads to very high levels during 2002. Loads in Bevens Creek remain the highest among the minor tributaries, as might be expected owing to its large watershed. Bevens Creek loads' equal or exceed loads in some of the major tributaries. Overall, the minor tributaries show reduced loading compared to 2002, following the general trend seen in the major tributaries across most of the Minnesota River Basin.

Total suspended solids yields for the 2000 - 2003 monitoring seasons are presented in Figure 4.10. Yields for two of the agricultural watersheds, Seven Mile Creek and Bevens Creek, were substantially reduced compared to 2002, but they are much greater than yields in the other agricultural watersheds (Dry Weather Creek, West Fork Beaver Creek, and Dutch Creek). Smaller TSS yields might be expected in the Dry Weather and West Fork Beaver Creek Watersheds, as they had less runoff during 2003. A comparison of runoff from the Dutch and Seven Mile Creek Watersheds revealed that their runoffs were equal (3.42 inches), but Dutch yielded only 12 lbs/ac of TSS compared to 186 lbs/ac from Seven Mile. Bevens Creek, which has a predominantly agricultural watershed, yielded 147 lbs/ac of TSS from slightly less runoff (3.16 inches).

Total suspended solids yields in four of the urban land use watersheds (Bluff Creek, Riley Creek, Willow Creek, and Nine Mile Creek) were substantially lower during 2003 compared to 2002, probably because of less runoff during 2003. Despite the yield reduction from 2002, TSS yield in Riley Creek was 313 lbs/ac, a value that is more than double yields from the other minor watersheds. Willow Creek Watershed, in contrast, yielded only 27 lbs/ac, even though runoff amounts in Riley Creek and Willow Creek were nearly equivalent at 3.88 and 3.94 inches, respectively. The occurrence of substantial yield differences among watersheds that have similar land use and runoff amounts suggests that the watersheds may differ in geomorphic characteristics or that BMP implementation is lacking in the higher-yielding watersheds. More investigation, in the form of aerial photo interpretation, field reconnaissance, and short-term synoptic sampling during runoff events, may be warranted to identify high-yielding source areas in some of the watersheds. Synoptic sampling, for example, could be used to identify stream subreaches that have elevated turbidity, and then follow up work could be undertaken to identify actively eroding ravines, unbuffered stream reaches, construction sites, and other potential high-yielding areas within the turbid subreaches.

Total suspended solids FWMC values for three streams draining agricultural watersheds (Dry Weather Creek, West Fork Beaver Creek, and Dutch Creek) were within the

Figure 4.08. 2000 - 2003 Monitoring Season Runoff at Minor Minnesota River Tributary Sites

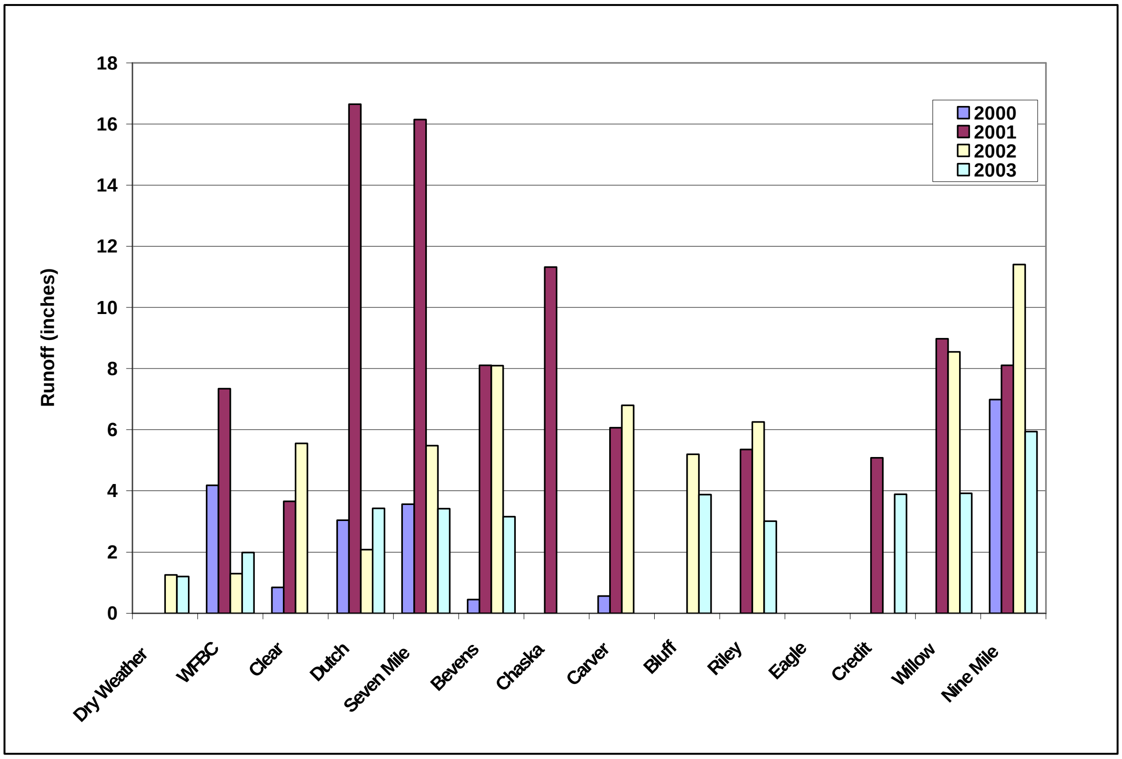
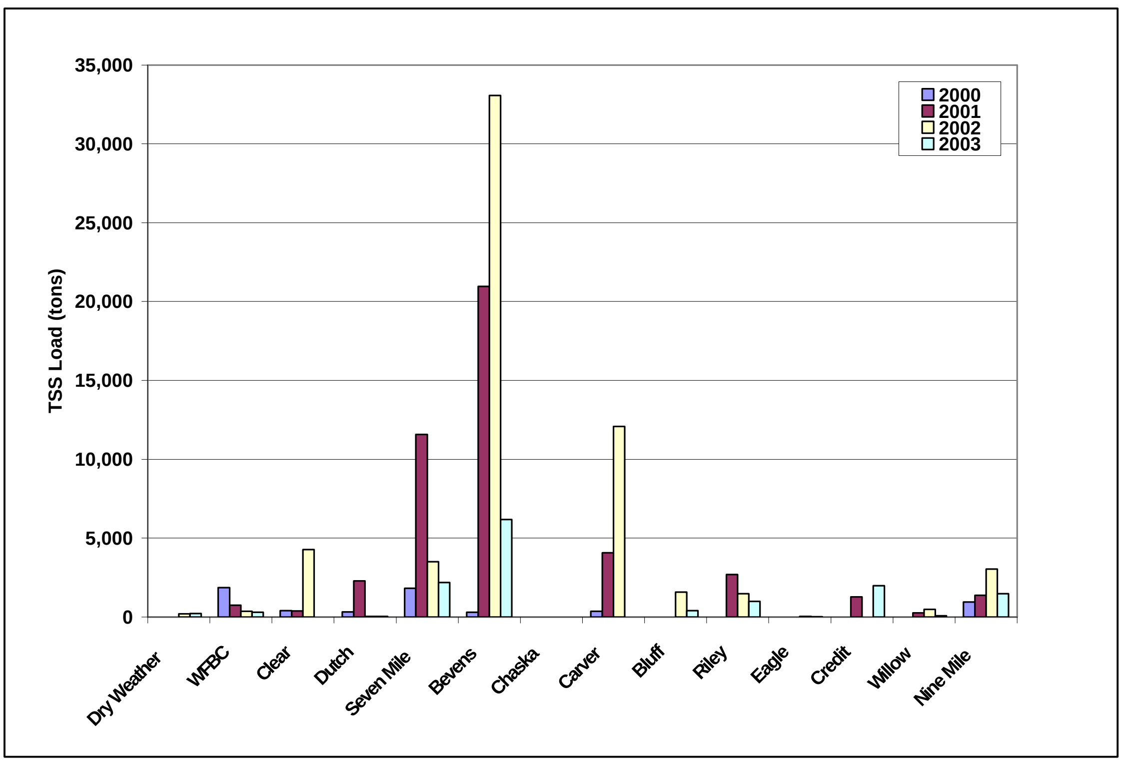


Figure 4.09. 2000 - 2003 Monitoring Season Total Suspended Solids Loads at Minor Minnesota River Tributary Site



threshold values of 58 mg/L and 66 mg/L for the Western Corn Belt Plains and Northern Glaciated Plains ecoregions, respectively, during 2003 (MPCA, 1993). Values for two other agricultural streams, Seven Mile Creek and Bevens Creek were 254 mg/L and 206 mg/L, respectively, exceeding the threshold values. Among the urban watersheds, the TSS FWMC for Riley Creek greatly surpassed its urban counterparts at 516 mg/L (Figure 4.11). Although 2003 runoff, TSS load, and TSS yield values for Riley Creek were reduced compared to 2002, its 2003 TSS FWMC values increased substantially compared to 2002. The increase in TSS FWMC values indicates that runoff from its watershed during 2003, while reduced in total volume, was more concentrated with respect to TSS than it was during 2002. In contrast, the TSS FWMC value for Bluff Creek, which drains a watershed adjacent to Riley Creek Watershed, decreased substantially compared to 2002, dropping from 472 mg/L (2002) to 160 mg/L (2003).

Figure 4.10. 2000 - 2003 Monitoring Season Total Suspended Solids Yields at Minor Minnesota River Tributary Sites

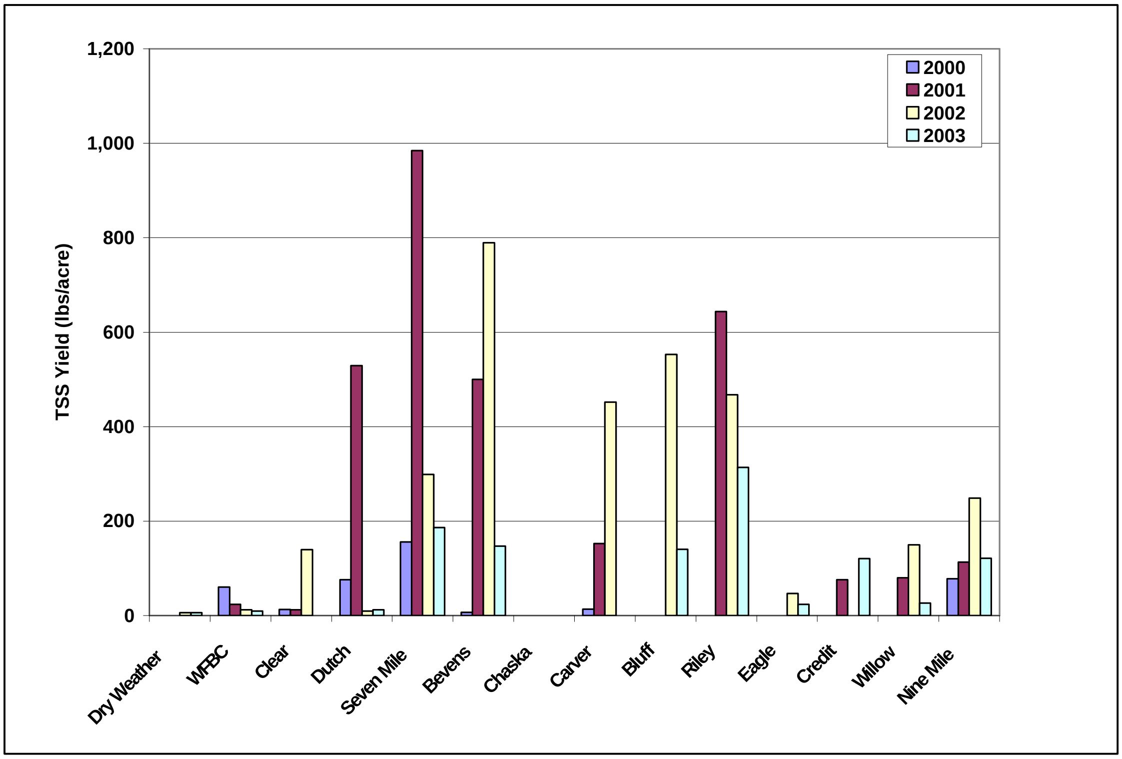
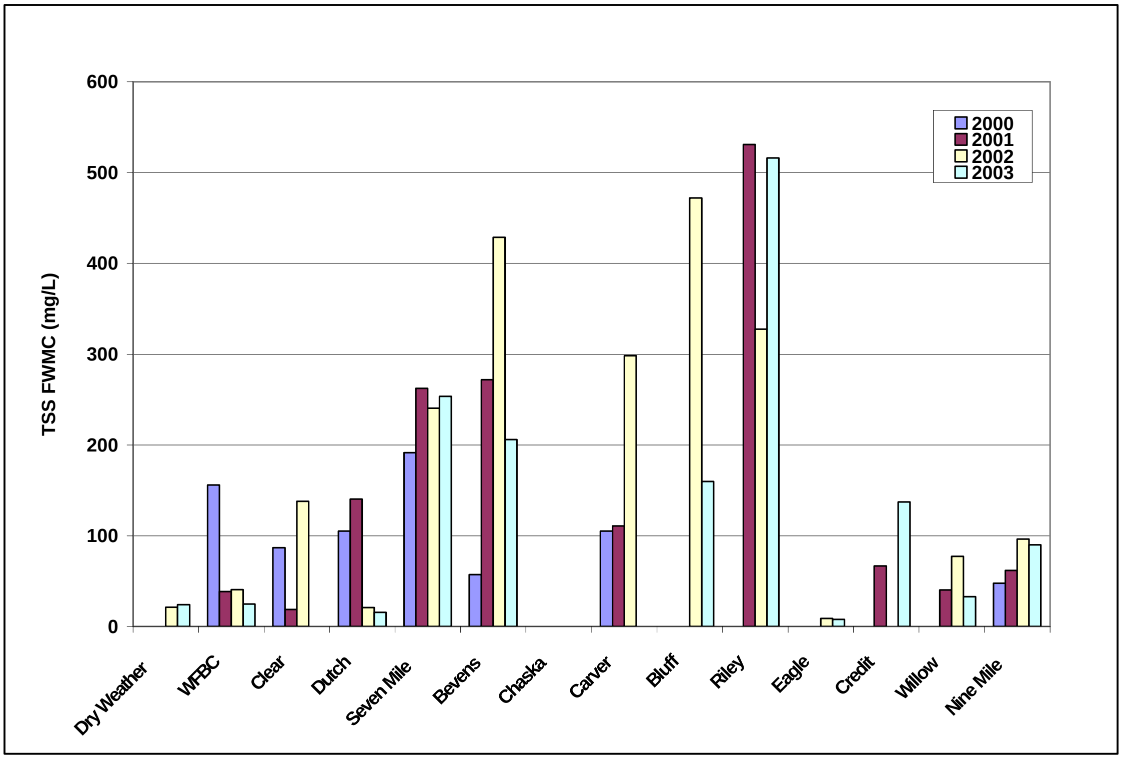


Figure 4.11. 2000 - 2003 Monitoring Season Total Suspended Solids Flow Weighted Mean Concentrations at Minor Minnesota River Tributary Sites



Total Phosphorus

Phosphorus originates from many sources in the Minnesota River Basin and is the primary cause of algal growth, a leading contributor to low dissolved oxygen concentrations in the lower twenty-two mile reach of the Minnesota River during low flow conditions. Point sources of phosphorus are mostly related to municipal and industrial discharges; whereas non-point sources are distributed among agricultural areas, urban areas, construction sites, feedlots, and direct discharge of sewage. Currently, there are no statewide standards for total phosphorus in rivers or streams.

Phosphorus that is in a soluble form (orthophosphorus) is readily available to algae (bio-available), and under certain conditions exerts an immediate impact on the growth of algae and subsequent dissolved oxygen depletion. Generally, a larger proportion of the phosphorus in runoff from cropland is attached to sediment particles, and may not be immediately available to support algae growth. Particulate phosphorus, however, can be transformed to a dissolved bio-available form after runoff discharges to streams. A study of storm runoff in the Redwood River showed that 44% of the particulate phosphorus load was bio-available (James, 2002). Studies in other regions have shown that 20-70% of particulate phosphorus is bio-available (Barr, 2003) Although bio-available phosphorus entering the river has more immediate impact than particulate phosphorus, both sources over time contribute to the total amount of algae producing phosphorus in the Minnesota River (MPCA, 1997).

<u>Mainstem Phosphorus</u>

The load of total phosphorus (TP) transported through the lower reach of the mainstem (St. Peter to Ft. Snelling) during 2003 was reduced from 2002 levels, and was the lowest amount recorded during the four-year reporting period (See Figure 4.12). This load reduction followed reductions seen in 2002 when loads decreased substantially from the relatively high amounts transported during 2001. Total phosphorus loading often strongly correlates with stream flow, and much of the load reduction can be attributed to below-normal runoff across most of the Minnesota River Basin during 2002 and 2003 (Figure 4.02).

Total seasonal runoff amounts, however, are not always straightforward predictors of TP loading, as shown by data collected in the Greater Blue Earth Watershed. During 2003, runoff in the Greater Blue Earth River was 3.63 inches, an amount 20 percent greater than the 3.00 inches of runoff measured during 2002. Total phosphorus load, however, was essentially unchanged during 2003, increasing to only 245 tons from the 244-ton load measured during 2002. Seasonal timing, rainfall intensity, and antecedent moisture conditions for each precipitation event along with watershed terrain determine the characteristics of each watershed’s total annual runoff. These often variable characteristics, in turn, affect the amount of nutrient leaching, water runoff, and soil erosion which, in combination, move phosphorus into streams. Land use and management decisions related to urbanization, tillage methods, fertilizer applications,

Figure 4.12. 2000 - 2003 Monitoring Season Total Phosphorus Loads at Minnesota River Mainstem and Greater Blue Earth River Sites

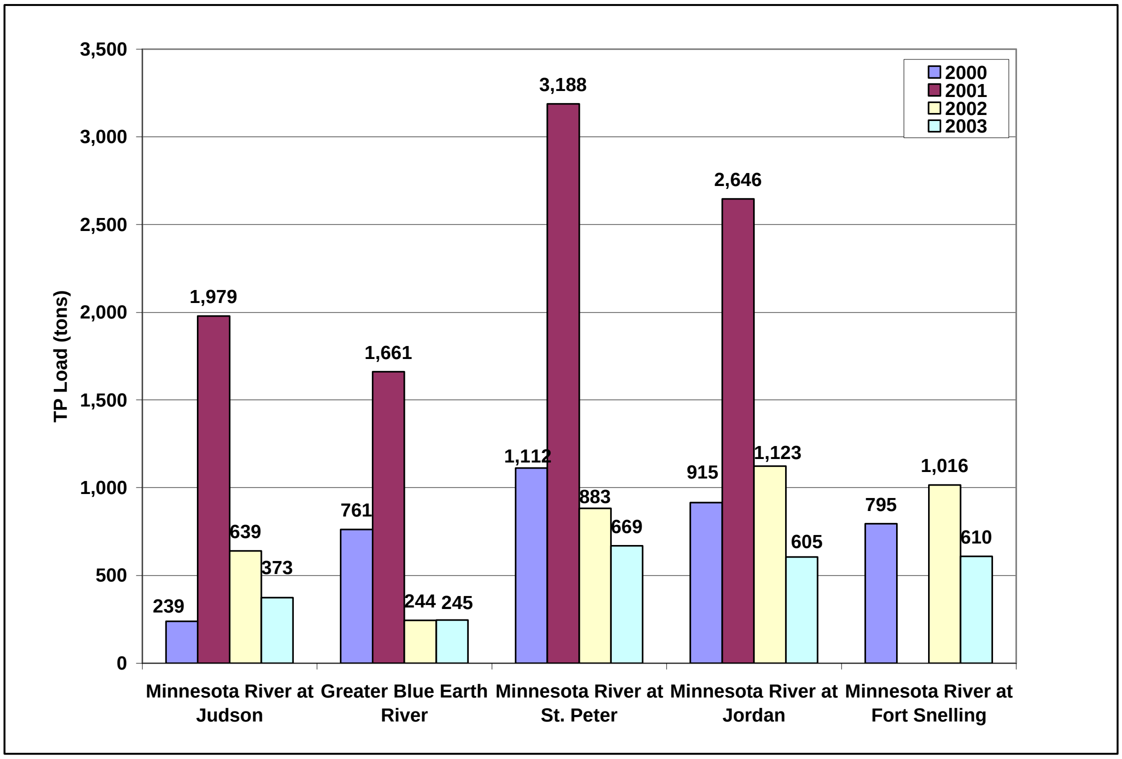
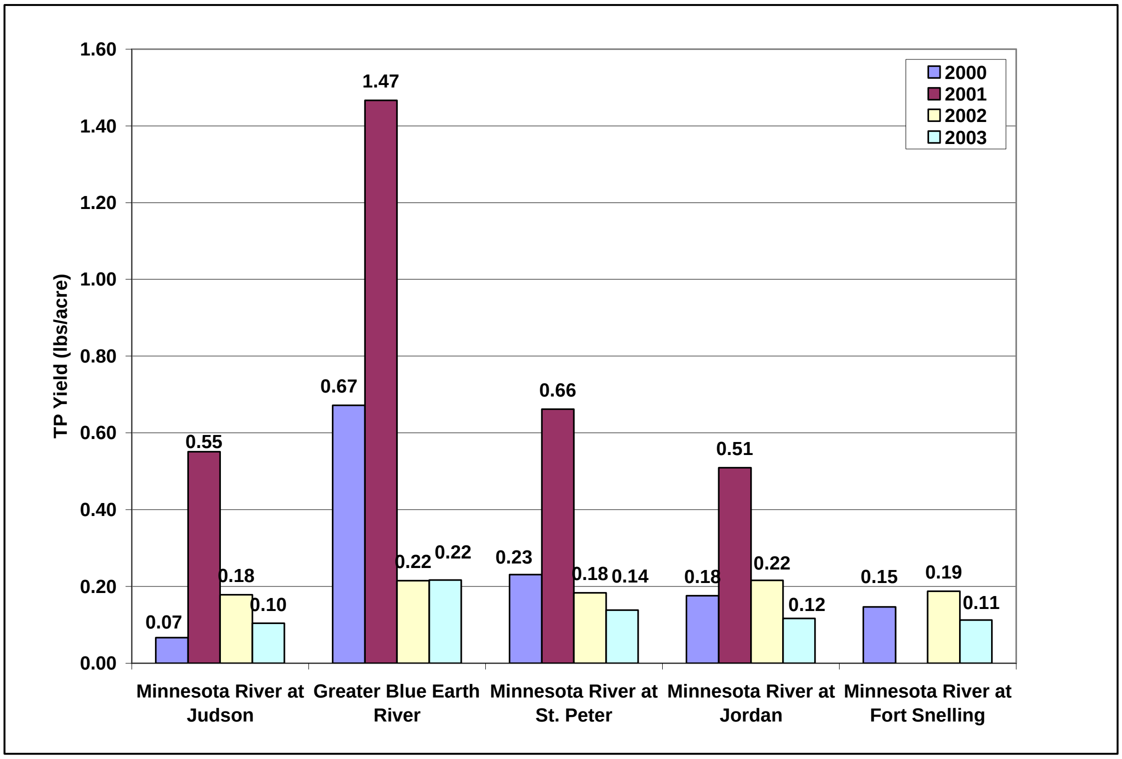


Figure 4.13. 2000 - 2003 Monitoring Season Total Phosphorus Yields at Minnesota River Mainstem and Greater Blue Earth River Sites

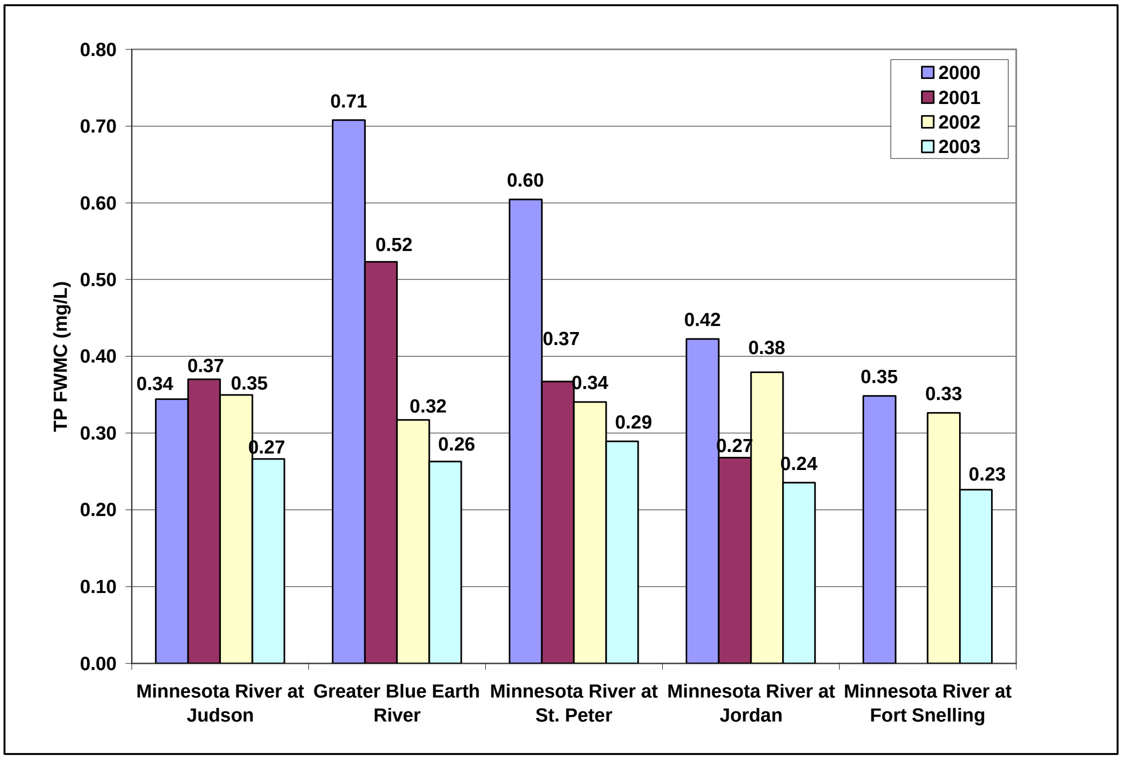


conservation buffers, and many others modify the natural affects of climate, weather, and geomorphic variables. The TP load data for the mainstem sites necessarily represent the combined affects of all these variables spread across very large watersheds that have varied landscapes. Because of these many factors, it is particularly difficult at this large scale to ascribe water quality changes to specific events or actions, whether natural or human influenced.

The TP yield data (Figure 4.13) like the TP load data, show the overall reduction in the amount of phosphorus transported to the Minnesota River during 2002 and 2003. The most marked change is seen in the Greater Blue Earth River Watershed where yield values are now much more closely aligned with yields from the western part of the Basin as represented by data from the Minnesota River at Judson site. Below normal runoff in the Greater Blue Earth River during the past two years likely accounts for much of the yield reduction, but as with load reductions, it is difficult to assign the change to specific factors

The TP FWMC data shown in Figure 4.14 may provide the most useful diagnostic appraisal of the Minnesota River mainstem condition thus far. Researchers generally agree that the Minnesota River is over enriched with respect to phosphorus and that a reduction in phosphorus concentrations could result in reduced algal growth and lower biochemical oxygen demand, thereby enhancing water quality. The 2002 State of the Minnesota River report (State, 2002) described TP concentration thresholds that are sought for the Minnesota River. For example, an analysis by MPCA (MPCA, 1997) showed that a reduction in algal productivity cannot be expected unless TP concentrations in the Minnesota River are brought below 0.26 mg/L. During 2002 and 2003, TP FWMC's in the Greater Blue Earth River and the mainstem at Judson were diminished relative to 2001 levels and presently are at or near the threshold value (Figure 4.14). Fewer high-intensity rainfall events during 2003 and generally reduced runoff throughout the Basin during both 2002 and 2003 probably account for most of the reduction in TP concentrations, but the data also may reflect basin wide efforts to reduce both point and non-point phosphorus inputs. The data from the Jordan and Ft. Snelling sites (Figure 4.14) show that the reductions extend into the Lower reaches of the Minnesota River to its mouth, where TP FWMC's dropped below the 0.26 mg/L threshold during 2003.

Figure 4.14. 2000 - 2003 Monitoring Season Total Phosphorus Flow Weighted Mean Concentrations at Minnesota River Mainstem and Greater Blue Earth River Sites



Mouth of the Le Sueur River flowing into the Blue Earth River (middle left corner)

Major Tributaries Total Phosphorus

Figure 4.15 presents 2000 - 2003 TP loads for the monitoring season. The principal value of major-tributary load data lies in identifying which parts of the Minnesota River Basin are transporting the most TP load to the mainstem. The major tributary monitoring sites are distributed throughout the Minnesota River Basin from the Upper Minnesota River Basin to the Lower Minnesota River Basin. As such, a look at Figure 4.15 gives us an overview of the geographical distribution of TP loading to the mainstem. Strict load comparisons, however, need to be tempered by considering the amount of tributary load relative to average streamflow in the mainstem channel at the point of confluence. Tributaries that deliver a total seasonal TP load of 50 tons to the mainstem near its headwaters, for example, are likely to have a greater affect on mainstem water quality than tributaries that deliver an equivalent load near the mouth of the mainstem.

Total phosphorus yield data (Figure 4.16) show which major tributaries are contributing the most TP to the mainstem on a per-acre basis. The yield data can be thought of as a seasonal loading rate. Total phosphorus yields that are consistently elevated relative to yields in other major tributary watersheds are an indication of problems such as excessive soil erosion or large point-source inputs. During 2003, yields for most of the major tributaries were less than they were during 2002, with large reductions noted for High Island Creek and Sand Creek. Despite appreciable reductions in yields during the past two monitoring seasons, the higher-yielding watersheds are still delivering 4-8 times more TP per acre than the lower-yielding watersheds (compare Le Sueur River, High Island Creek, and Sand Creek with Yellow Bank River, Lac qui Parle River, and Chippewa River in Figure 4.16).

Elevated TP yields from watershed landscapes, augmented by point source inputs in some of the watersheds, usually result in elevated TP FWMC values (Figure 4.17). The TP FWMC values, arguably, may offer the best appraisal of the state of the Minnesota River with regard to phosphorus enrichment. While TP loads and yields are useful diagnostic parameters, it is the resulting stream concentration that drives overproduction of algae that in turn reduces water clarity and often causes undesirable levels of oxygen demand. During 2003, TP FWMC values in eight of the major tributaries were reduced from levels measured during 2002, reflecting the reduced loads and yields discussed previously. The 2002 State of the Minnesota River Report stated that none of the major tributary streams had FWMC's that met the goal of 0.1 mg/L TP set by the EPA for protection of aquatic life. One stream, the Yellow Medicine River, met that criterion during 2003 (Figure 4.16). Furthermore, the MPCA threshold level of 0.26 mg/L TP was met in seven streams, three of which exceeded the threshold during 2002. The 0.26 mg/L TP threshold is considered to be the point at which algal production will start to decline because of phosphorus limitation. It is important to note that the FWMC is a seasonal average, and the streams probably exceeded the threshold on some days during the season.

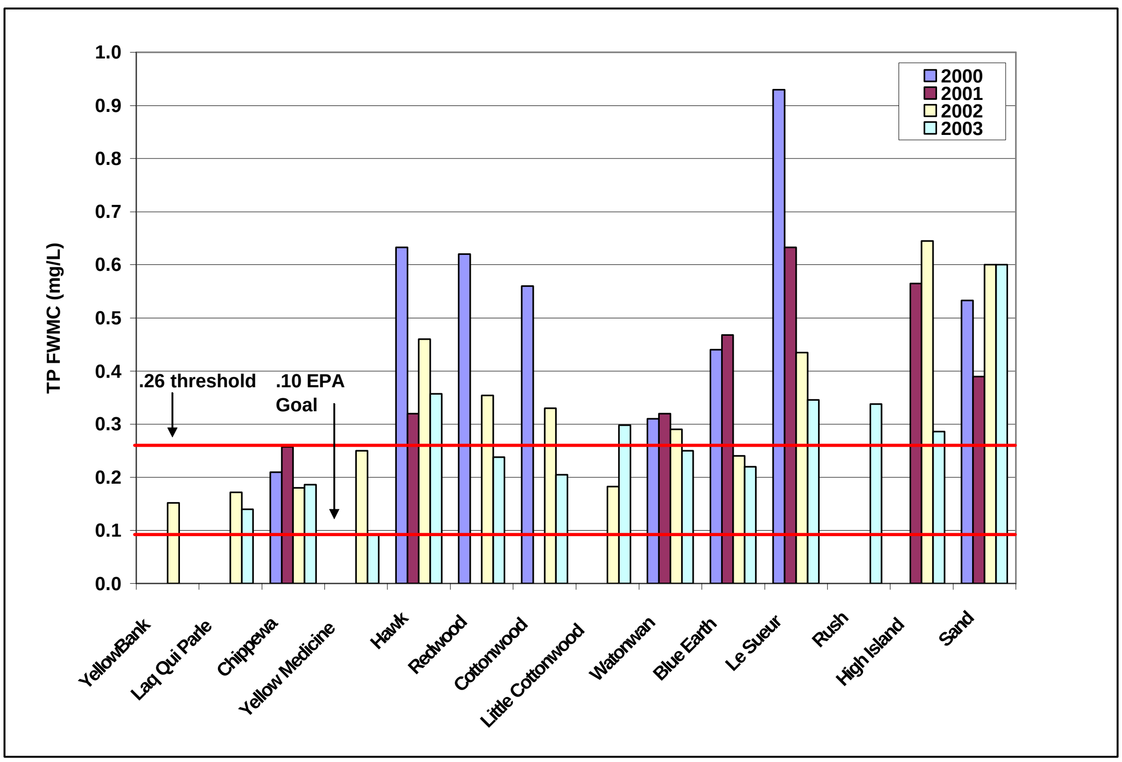
Figure 4.15. 2000 - 2003 Monitoring Season Total Phosphorus Loads at Major Minnesota River Tributary Sites

Figure 4.16. 2000 - 2003 Monitoring Season Total Phosphorus Yields at Major Minnesota River Tributary Sites

Reductions in TP FWMC's were not seen at all major tributary sites during 2003. The TP FWMC for Sand Creek was unchanged from 2002 and remains at a very high level (0.60 mg/L) relative to concentrations in the other major tributaries (Figure 4.17). The Chippewa River also was relatively unchanged during 2003, rising slightly to 0.19 mg/L, but it remains within the 0.26 mg/L threshold.

Assessing results from the past four years, there appears to be a general reduction in TP FWMC's in Hawk Creek, the Redwood River, and the Cottonwood River (Figure 4.17). Concentrations are now substantially reduced from the relatively high concentrations present in these streams during 2000, and are now more closely aligned with the relatively low concentrations that typify major tributaries in the headwaters of the Minnesota River Basin (Yellow Bank to Chippewa). The Le Sueur River has undergone three consecutive and substantial reductions in seasonal FWMC values that started in 2001, but the present value, 0.35 mg/L TP for the 2003 season, remains well above the 0.26 mg/L threshold. Further perspective can be gained by observing that TP FWMC values for the Minnesota River mainstem ranged from 0.23-0.29 mg/L during the 2003 season. These results place the mainstem approximately at the threshold value. If phosphorus loading can be further reduced, it is expected that levels of algal productivity will decline and thereby the River's condition will improve. The major tributaries that presently discharge flows containing TP in excess of the threshold concentration threaten the Minnesota River's recovery because their relatively large watersheds can deliver flow volumes that are sufficient to raise the average TP concentration in the mainstem.

Figure 4.17. 2000 - 2003 Monitoring Season Total Phosphorus FWMC at Major Minnesota River Tributary Sites



Minor Tributaries Total Phosphorus

Figure 4.18 presents the TP loads for the 2000 - 2003 monitoring season for the minor tributaries. Loads decreased at all sites compared to 2002 levels. Loads in Bevens Creek were greatly reduced relative to the very high loads recorded at that site during 2001 and 2002. At most of the sites the load reductions correspond to decreases in runoff, but in West Fork Beaver Creek and Dutch Creek runoff increased about 50 percent compared to 2002 while their TP loads decreased.

Total phosphorus yields for 2000 - 2003 are shown in Figure 4.19. Minor watershed yields during 2003 were relatively modest compared to the very high yields recorded during 2001 and 2002. Yields also were more uniform across the Basin, lacking the very large site-to-site variations present during 2001 - 2002. Despite greater overall uniformity, three of the agricultural land use watersheds, Dry Weather, West Fork Beaver, and Dutch Creeks, have relatively low yields that contrast markedly with yields from Seven Mile Creek and Bevens Creek, which also have agricultural watersheds.

The TP FWMC results, unlike the yield data, show little cross-basin uniformity and site-to-site differences are readily apparent in Figure 4.20. During 2003, TP FWMC values ranged from 0.05 mg/L in Eagle Creek to 0.42 mg/L in Riley Creek. Eleven minor tributaries were monitored during 2003, and TP FWMC values in seven of them were equal to or less than the 0.26 mg/L threshold and three of the streams had FWMC's equal to or less than the EPA goal of 0.10 mg/L. Comparing 2003 data with results from 2002, only one stream, Riley Creek, showed an increase it its TP FWMC value during 2003. Runoff in Riley Creek for 2003 decreased more than 50 percent compared to runoff during 2002 and its TP load and TP yield also decreased. This indicates that the runoff in Riley Creek during 2003, although reduced from 2002 runoff amounts, probably was highly concentrated with respect to TP. These results suggest that Riley Creek, an urbanizing watershed, may be receiving intermittent, but highly concentrated, wash loads from construction sites.

Figure 4.18. 2000 - 2003 Monitoring Season Total Phosphorus Loads at Minor Minnesota River Tributary Sites

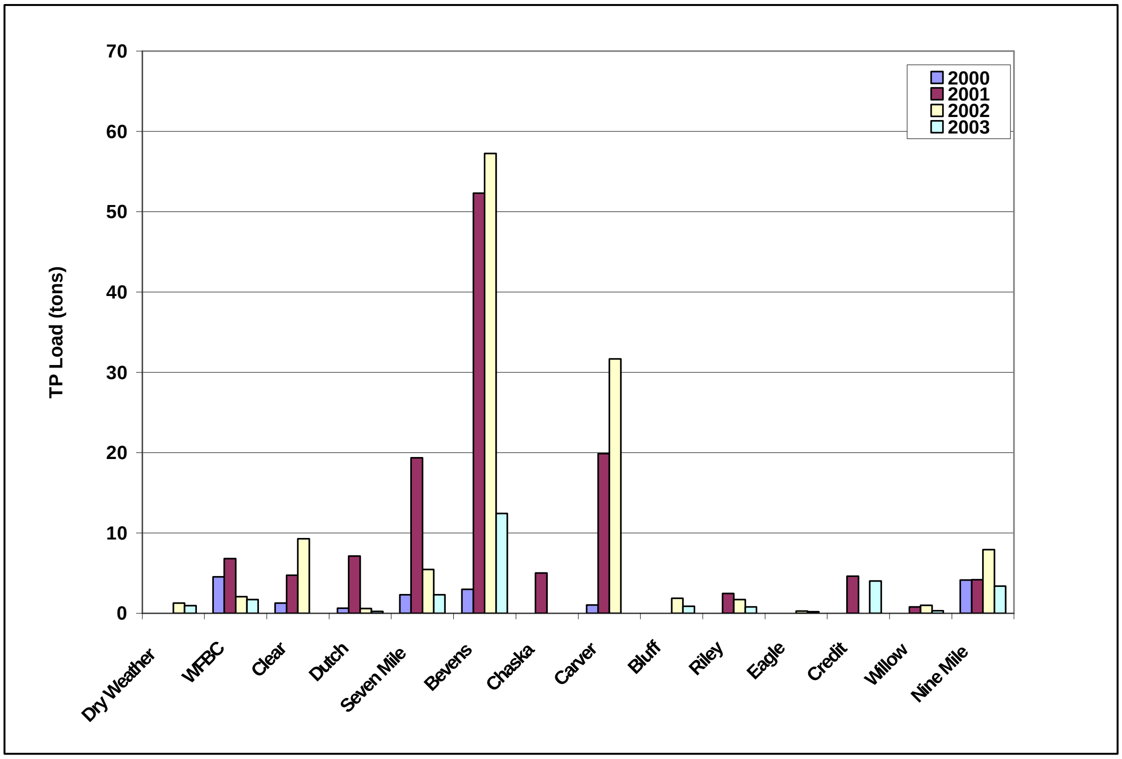


Figure 4.19. 2000 - 2003 Monitoring Season Total Phosphorus Yields at Minor Minnesota River Tributary Sites

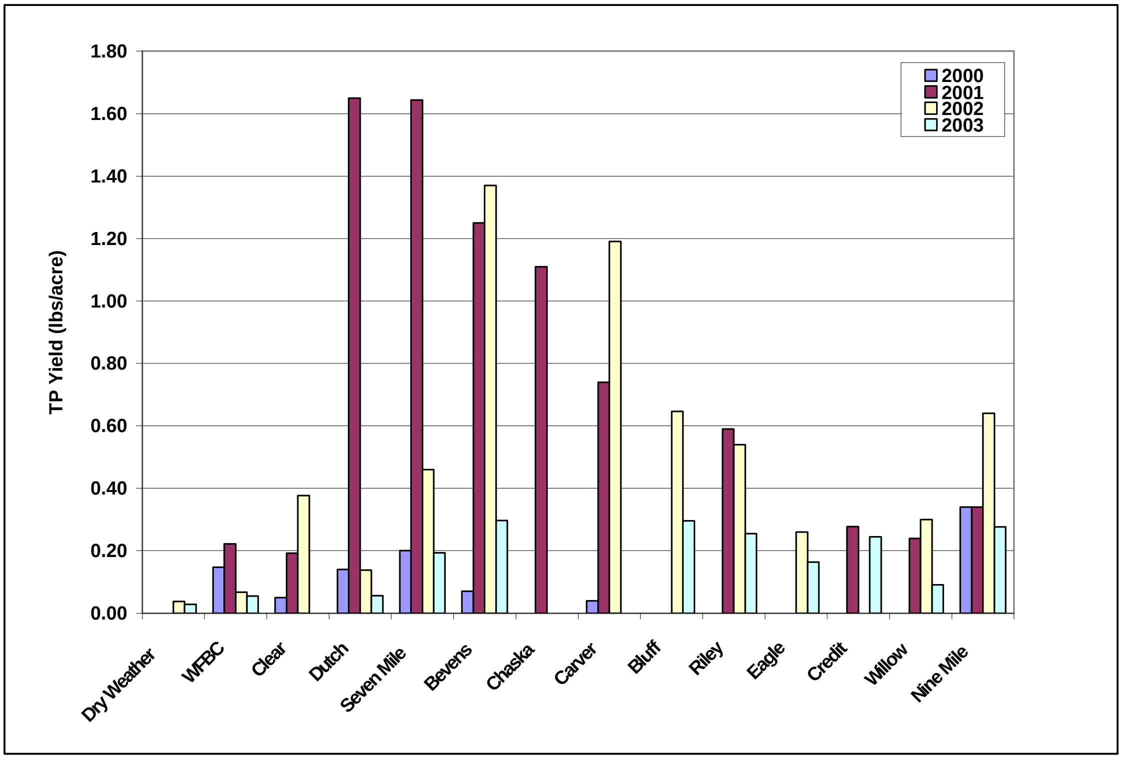
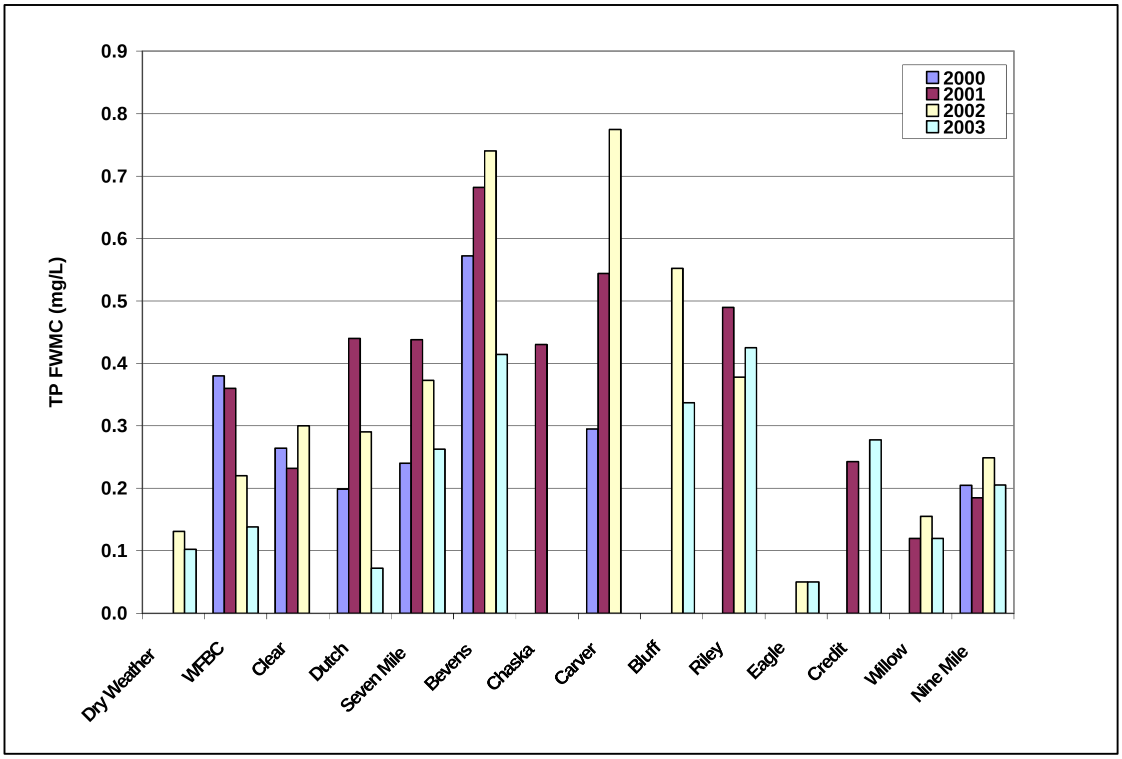


Figure 4.20. 2000 - 2003 Monitoring Season Total Phosphorous FWMC at Minor Minnesota River Tributary Sites



Nine Mile Creek

Mainstem Orthophosphorus

Orthophosphorus (OP) loads at mainstem sites (Figure 4.21) declined during 2003 compared to 2002 loads. The OP loads at mainstem sites were the lowest measured during the four year period with the exception of the Minnesota River at Judson site. The OP load at Judson reflects an increase in OP loading from the Chippewa River during 2003, and relatively high loads from Hawk Creek, Redwood River and Cottonwood River (Figure 4.24). Because of its greater size, the watershed upstream of Judson delivered more OP load than the Greater Blue Earth Watershed. The Greater Blue Earth River Watershed, however, delivered more OP per acre, yielding 0.05 lbs/ac compared to 0.03 lbs/ac from the part of the Minnesota River Basin upstream of Judson (See Figure 4.22).

The OP FWMC data (Figure 4.23) show that the present condition (2003) of the Greater Blue Earth River and the Lower Minnesota River, with respect to OP concentrations, is the best recorded during the four year period. Lower concentrations of OP are expected to result in reduced algal productivity, greater water clarity, and less oxygen demand in the lower mainstem.

The OP data for 2000, 2002, and 2003 stand in marked contrast to the very high OP loads, yields, and FWMC's seen in 2001. The elevated OP values in 2001 occurred in conjunction with ponding of large volumes of water during the snowmelt period. The 2001 snowmelt runoff period was prolonged by a heavy snow pack and ice that blocked many drainage channels and small streams. It is probable that the increased contact time enhanced desorption of OP from vegetation and soils, leading to elevated OP loads in the ponded water which eventually ran off when ditch and stream channels became ice-free.

Figure 4.21. 2000 - 2003 Monitoring Season Orthophosphorus Loads at Minnesota River Mainstem and Greater Blue Earth River Sites

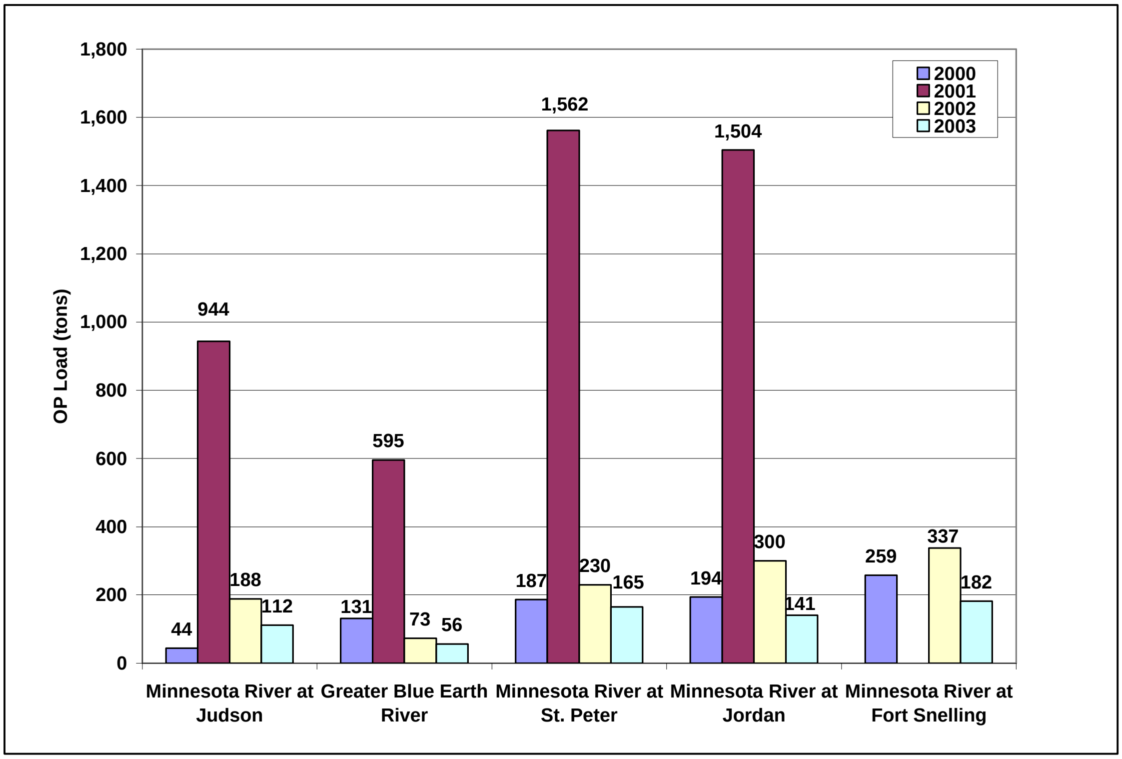


Figure 4.22. 2000 – 2003 Monitoring Season Orthophosphorus Yields at Minnesota River Mainstem and Greater Blue Earth River Sites

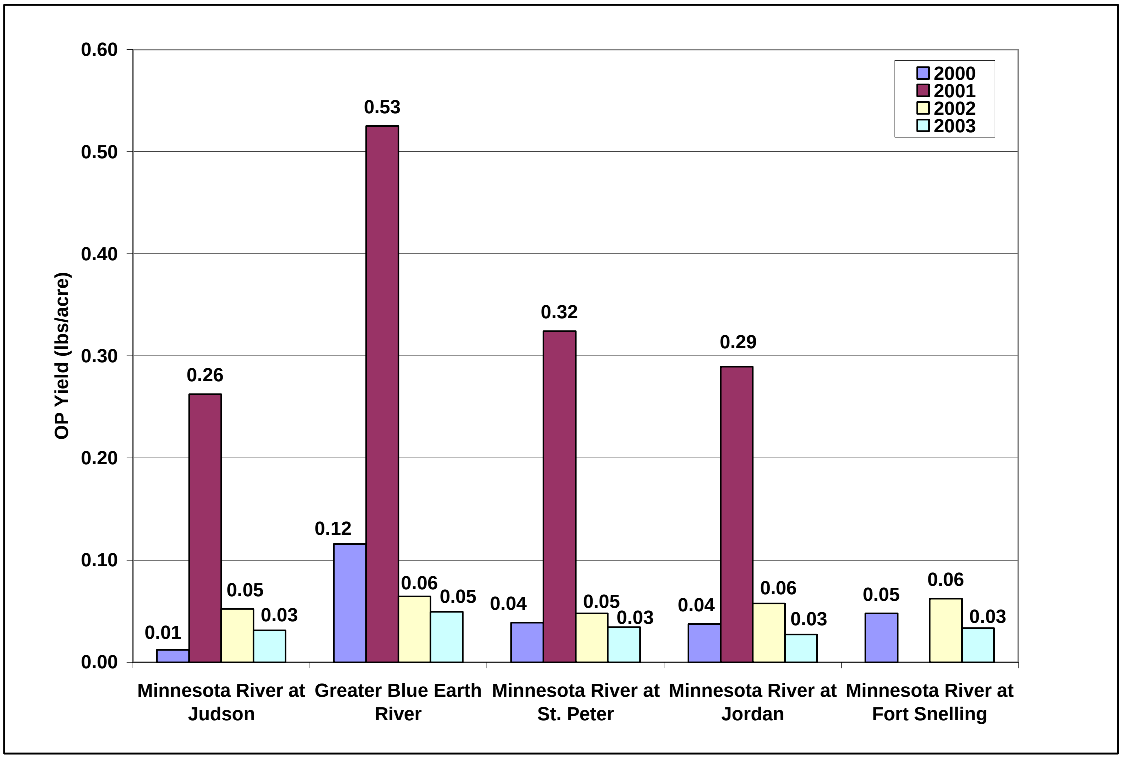
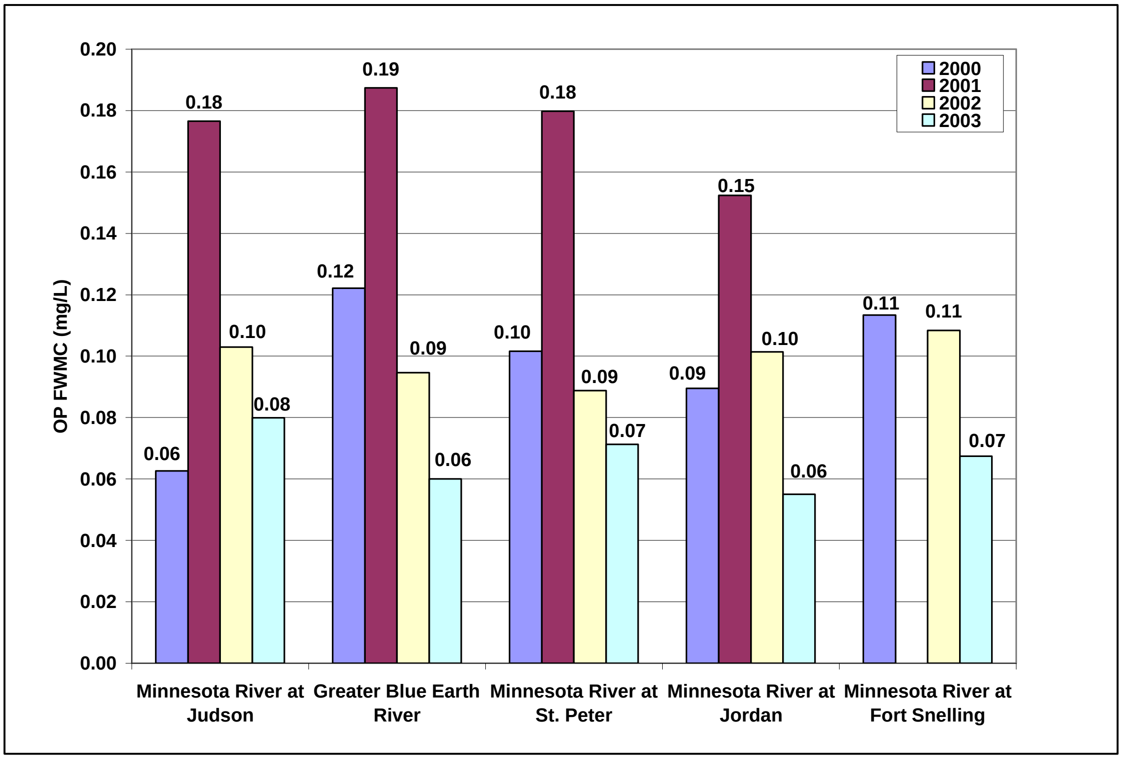


Figure 4.23. 2000 - 2003 Monitoring Season Orthophosphorus FWMC at Minnesota River Mainstem and Greater Blue Earth River Sites



Major Tributaries Orthophosphorus

Figure 4.24 presents OP loads for the major tributaries. Loads and yields (Figure 4.24 and Figure 4.25) for the 2003 season declined at all sites compared to 2002 values except in the Chippewa River and Watonwan River. The yield data show substantial differences in seasonal loading rates among the major tributaries. In the upper part of the Minnesota River Basin, 2003 yields for Hawk Creek and the Redwood River, although reduced from the relatively high yields recorded during 2002, remain at higher levels than yields for the Lac qui Parle, Chippewa, Yellow Medicine, and Cottonwood Watersheds. In the lower part of the Basin, from the Little Cottonwood River to the Rush River, yields during 2003 were more uniform, ranging from 0.04-0.07 lbs/ac, with the exception of Sand Creek, which yielded 0.11 lbs/ac.

The OP:TP ratio, shown as percent OP in Figure 4.26, is a measure of the portion of total phosphorus that is readily available for algal uptake, and the ratios serve to further characterize and differentiate OP loads in the major tributaries. Orthophosphorus comprises about 20-30 percent of total phosphorus in most of the major tributaries. In three of the tributaries, Watonwan River, High Island Creek, and Rush River, OP is greater than 40 percent of TP. In Hawk Creek and the Redwood River, OP is greater than 50 percent of TP. These differences in the proportion of OP may be indicators of differences in the source of the phosphorus loading. Wastewater from municipalities and septic systems, for example, usually has a high OP:TP ratio.

The OP FWMC data (Figure 4.27) also show substantial differences among the major tributaries, with values that ranged from 0.02-0.20 mg/L during 2003, a ten-fold difference. Mainstem FWMC's, in comparison, were less variable with concentrations ranging from 0.06-0.08 mg/L during 2003 (See Figure 4.23). Six of the major tributaries, Hawk Creek, Redwood River, Watonwan River, Rush River, High Island Creek, and Sand Creek, had OP FWMC's that exceeded the mainstem levels. As such, they have potential to elevate OP concentrations in the mainstem. Orthophosphorus is a readily assimilated form of phosphorus that triggers excessive algal growth when it is present at elevated concentrations. More evaluation of these data and special studies may be needed to learn why some of the major tributaries have OP present in higher proportions and at greater concentrations compared to what is present in other major tributaries.

Figure 4.24. 2000 - 2003 Monitoring Season Orthophosphorus Loads at Major Minnesota River Tributary Sites

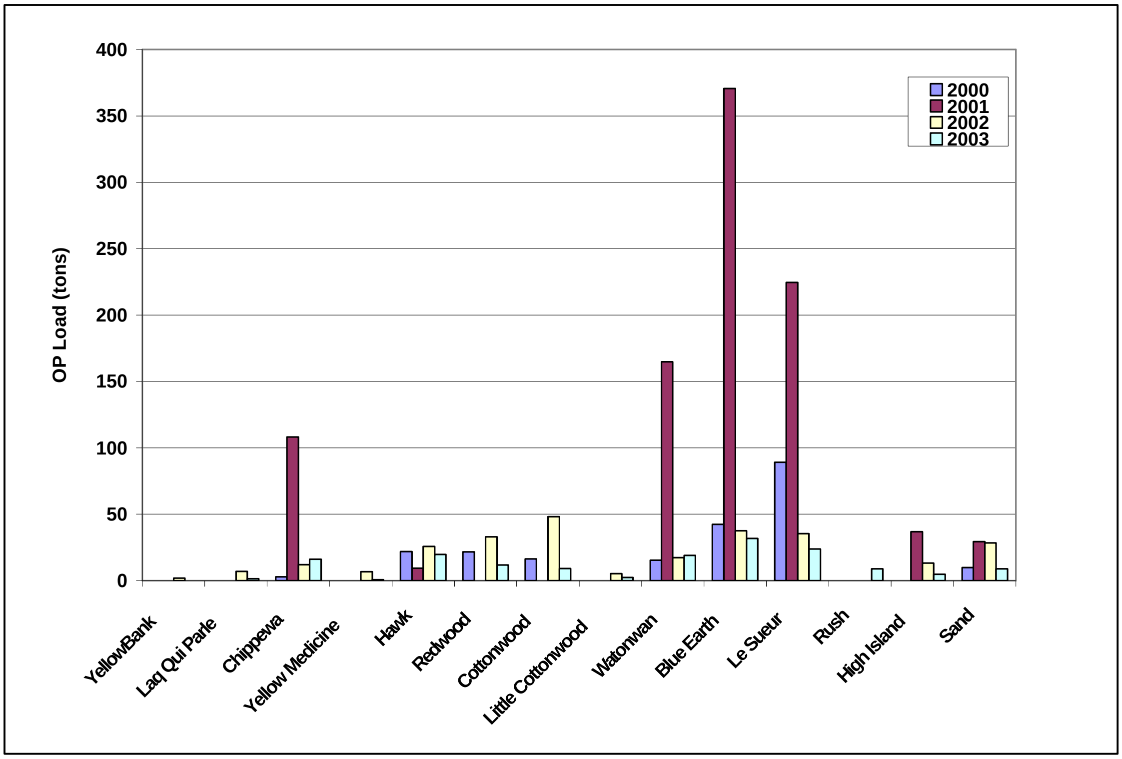


Figure 4.25. 2000 - 2003 Monitoring Season Orthophosphorus Yields at Major Minnesota River Tributary Sites

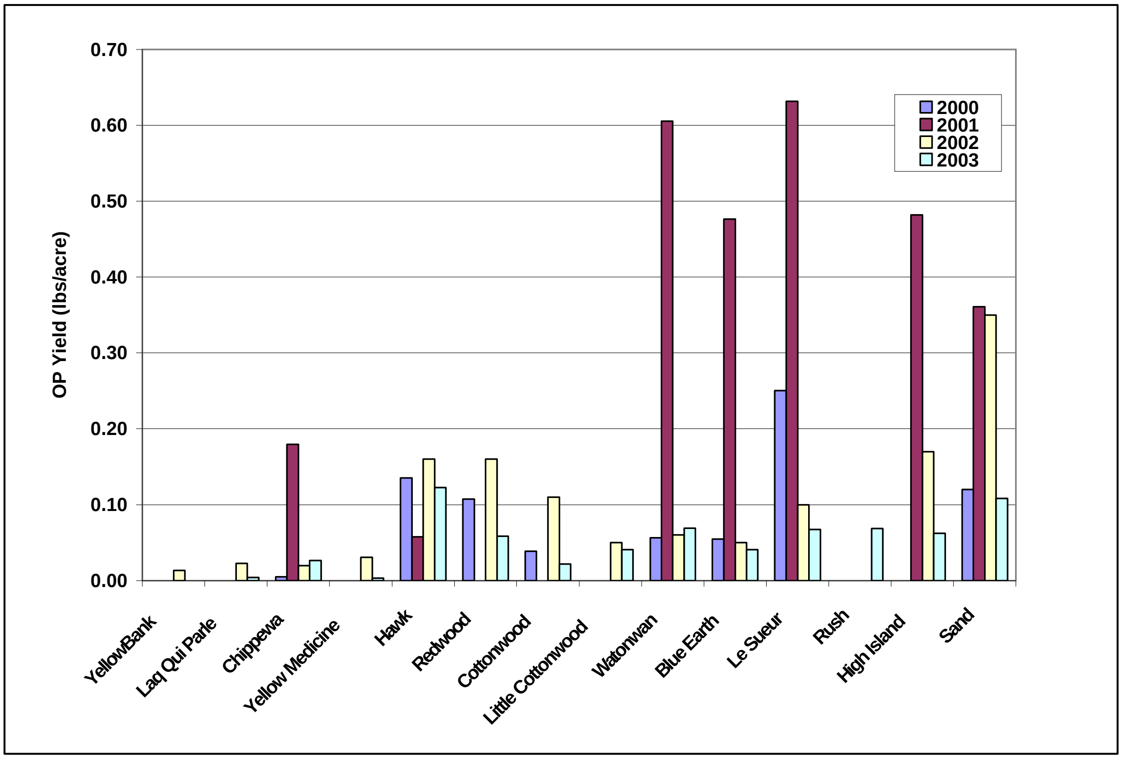


Figure 4.26. 2000 - 2003Monitoring Season Orthophosphorus/Total Phosphorus Ratio at Major Minnesota River Tributary Sites

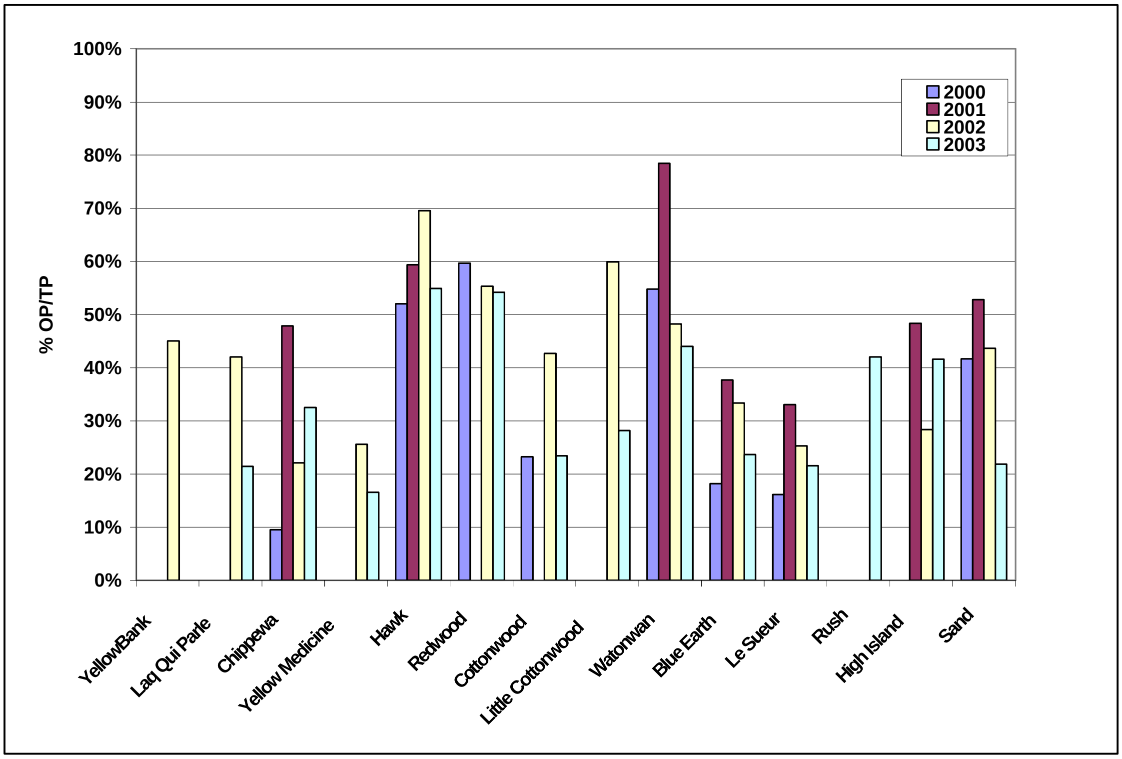
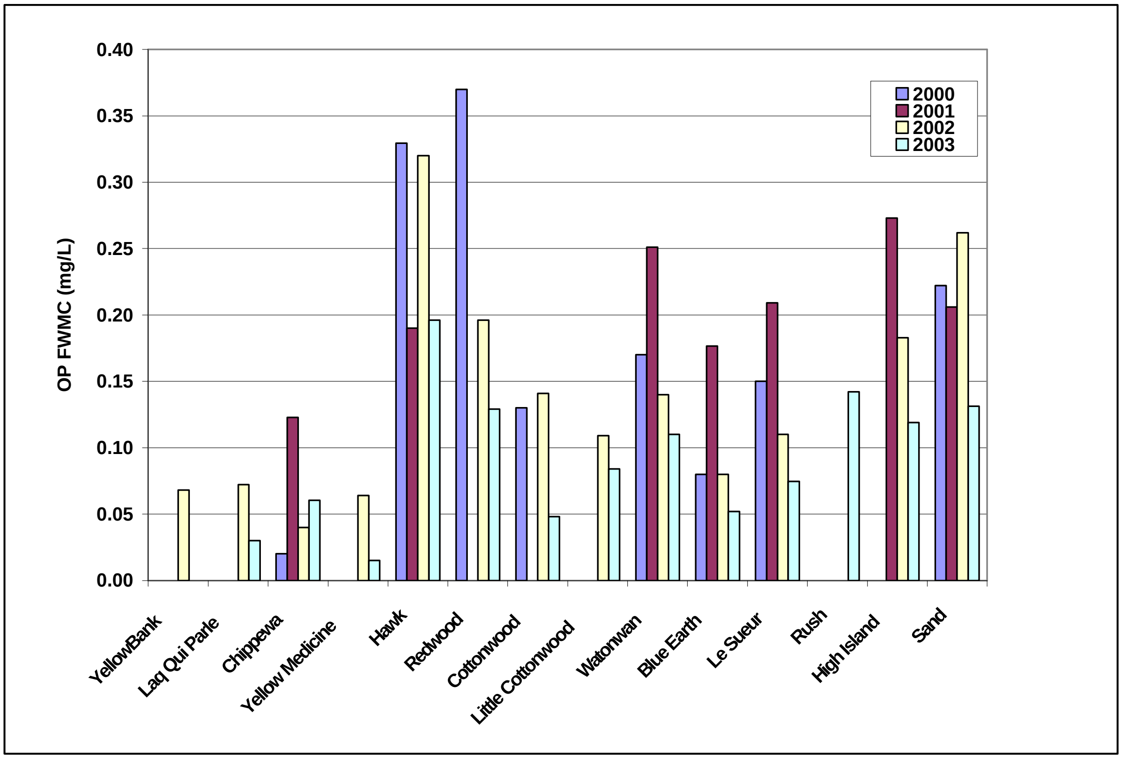


Figure 4.27. 2000 - 2003 Monitoring Season Orthophosphorus FWMC at Major Minnesota River Tributary Sites



Minor Tributaries Orthophosphorus

Figure 4.28 shows orthophosphorus loads in minor tributaries for the 2000 - 2003 monitoring seasons. Comparing 2003 data with results from 2002, loads and yields of OP decreased at all minor tributary sites during 2003. Most notable is the substantial decrease in load and yield for Bevens Creek. Although greatly reduced from 2001-2002 levels, the OP load in Bevens Creek during 2003 greatly exceeds loads in the other minor tributaries and also exceeded the loads in four of the major tributaries.

Minor-tributary OP yields fluctuated widely during the 2000 - 2002 period, showing large site-to-site and year-to-year differences at most sites (Figure 4.29). During 2003, OP yields were comparatively more uniform among sites and lower in magnitude overall, ranging from 0.01 to 0.14 lbs/ac, compared to a range of 0.01 to 0.74 lbs/ac during 2002. Substantial differences are still evident, however, as seen in the Bevens Creek, Bluff Creek, and Credit River Watersheds which yielded about twice as much OP per acre compared to the other minor watersheds.

The OP FWMC data further illustrate differences between the minor tributaries (Figure 4.30). The Dutch Creek, Seven Mile Creek, and Bevens Creek Watersheds have similar land use and had nearly equal runoff amounts (3.42, 3.42, and 3.16 inches, respectively) during 2003. Despite these similarities, the OP FWMC for Bevens Creek was 0.19 mg/L, a value nearly two times greater than the FWMC for Seven Mile Creek (0.10 mg/L) and more than three times greater than the FWMC for Dutch Creek (0.06 mg/L). These differences point to the need for further research into OP sources and the transport processes that deliver OP to streams.

Figure 4.28. 2000 - 2003 Monitoring Season Orthophosphorus Loads at Minor Minnesota River Tributary Sites

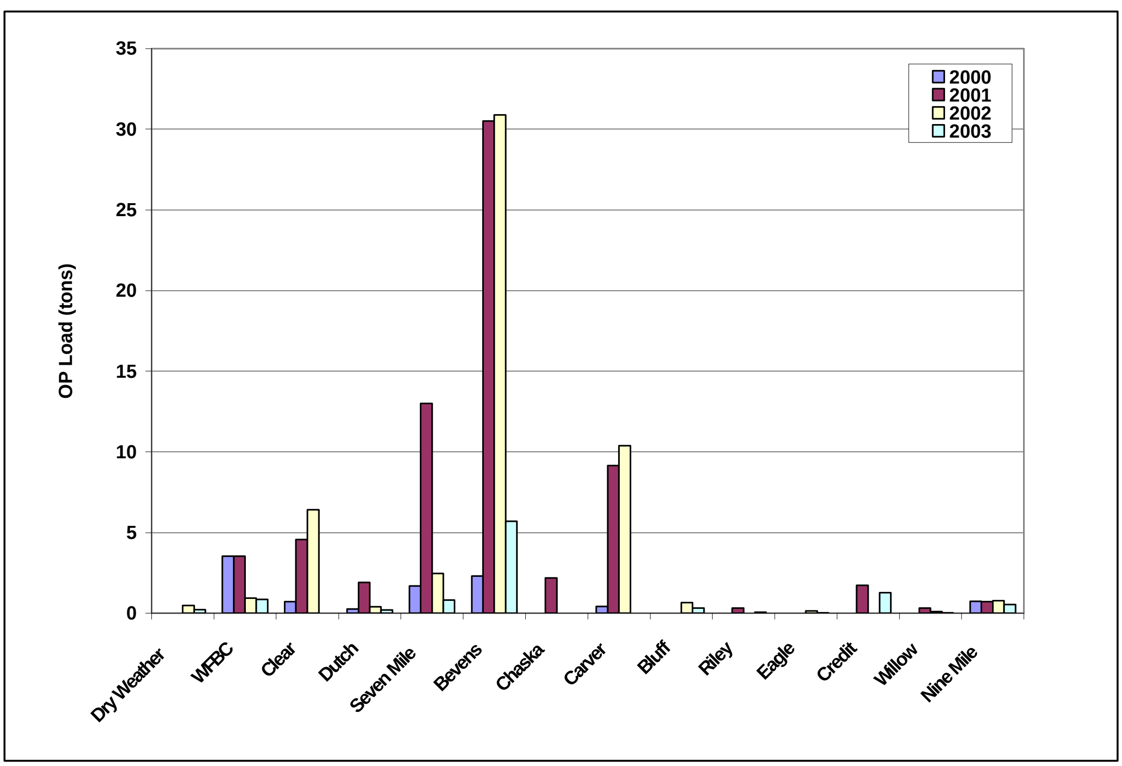


Figure 4.29. 2000 - 2003 Monitoring Season Orthophosphorus Yields at Minor Minnesota River Tributary Sites

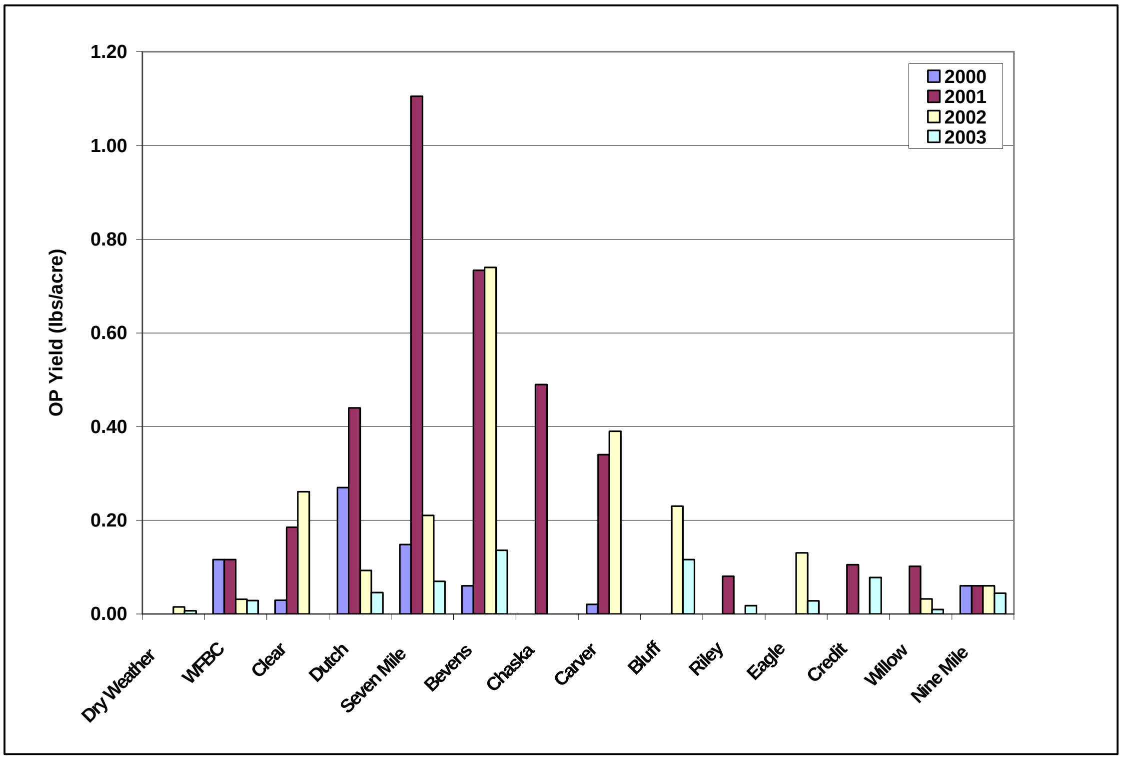
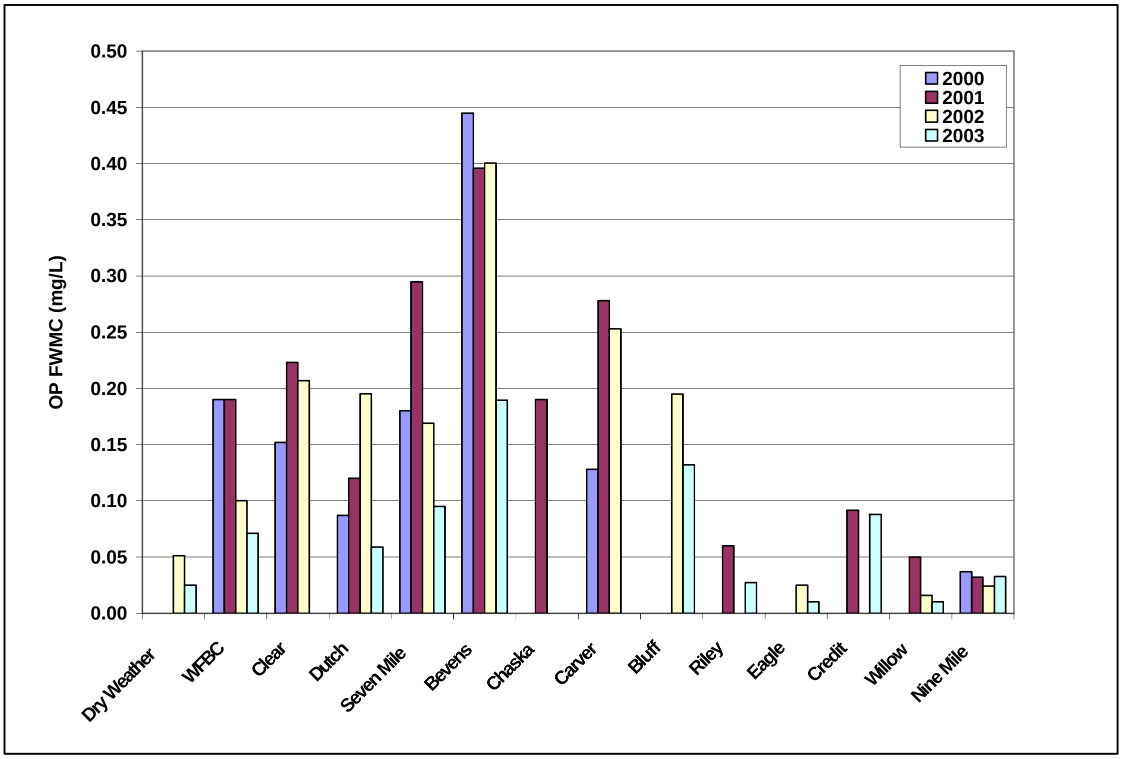


Figure 4.30. 2000 - 2003 Monitoring Season Orthophosphorus FWMC at Minor Minnesota River Tributary Sites



Nitrate-Nitrogen

The primary form of nitrogen monitored in the Minnesota River Basin is nitrate-nitrogen (nitrate-N). Typically the nitrate-N concentration includes nitrite plus nitrate when reported from the laboratory. Ammonia also is monitored at many of the stations for which data are presented, and a few organizations also monitor for Total Kjehldahl Nitrogen (organic nitrogen plus ammonia). However, only nitrate-N data are presented in this report. Nitrate-N is important because it is biologically available to aquatic plants and it is the primary and most abundant nitrogen species with respect to loading and nutrient enrichment of surface waters. Nitrate loading from the Minnesota River Basin has national implications as it is the primary chemical contributing to the hypoxia zone at the mouth of the Mississippi River in the Gulf of Mexico.

Mainstem Nitrate-N

Nitrate-N loads for 2000 - 2003 are presented in Figure 4.31 for the Minnesota River mainstem sites and the Greater Blue Earth River. The Greater Blue Earth River (Upper Blue Earth, Watonwan and Le Sueur Rivers) is included in the mainstem analysis because of the substantial nitrate load contribution from the Blue Earth River Watershed.

Nitrate-N loads declined during 2003 in the Minnesota River at Judson when compared to 2002 levels, but nitrate-N loads increased in the Greater Blue Earth River. Research in recent years (EPA, 2000) has shown that the amount of nitrate reaching streams is strongly associated with the amount of water that infiltrates and percolates through the soil profile. Wet years (such as 2001) are often periods of increased nitrate-N loading, particularly when they are preceded by one or more dry years. Nitrate-N tends to accumulate in soil profiles during dry periods when crops are not able to fully utilize available nitrate. Other factors, such as the type of crop, crop rotation, and nitrogen application rates, also affect the amount of nitrate build up in the soil profile. When this is followed by abnormally high precipitation, the nitrate-N becomes mobilized. In tiled fields, the drainage network collects excess nitrate-laden water from the soil profile and delivers it to ditches and streams. Greatly elevated (> 20 mg/L) nitrate-N concentrations are often found in tile drainage water (Randall et al., 2003 and Randall et al., 2001). The high runoff during the 2001 snowmelt period was followed by a return to dryer conditions that continued through 2002 and 2003 in the western part of the Basin. The lower runoff amounts during 2002-03 were accompanied by reduced nitrate-N loads in that part of the Basin as indicated by data collected in the Minnesota River at Judson (Figure 4.31). In contrast, runoff in the Greater Blue Earth River increased 21 percent during 2003 compared to 2002 while nitrate-N loading increased 54 percent, demonstrating how nitrate-N loading can respond to a moderate increase in runoff.

The Greater Blue Earth comprises 22 percent of the total drainage area of the Minnesota River at Jordan but contributed 68-, 48-, 36-, and 55 percent of the total nitrate-N load at Jordan during 2000, 2001, 2002, and 2003, respectively. For comparison, the Minnesota River upstream of Judson comprises 69 percent of the total drainage area at Jordan but contributed only 23-, 28-, 41-, and 26- percent of the total nitrate-N load at Jordan during those years.

Figure 4.31. 2000 – 2003 Monitoring Season Nitrate-N Loads at Minnesota River Mainstem and Greater Blue Earth River Sites

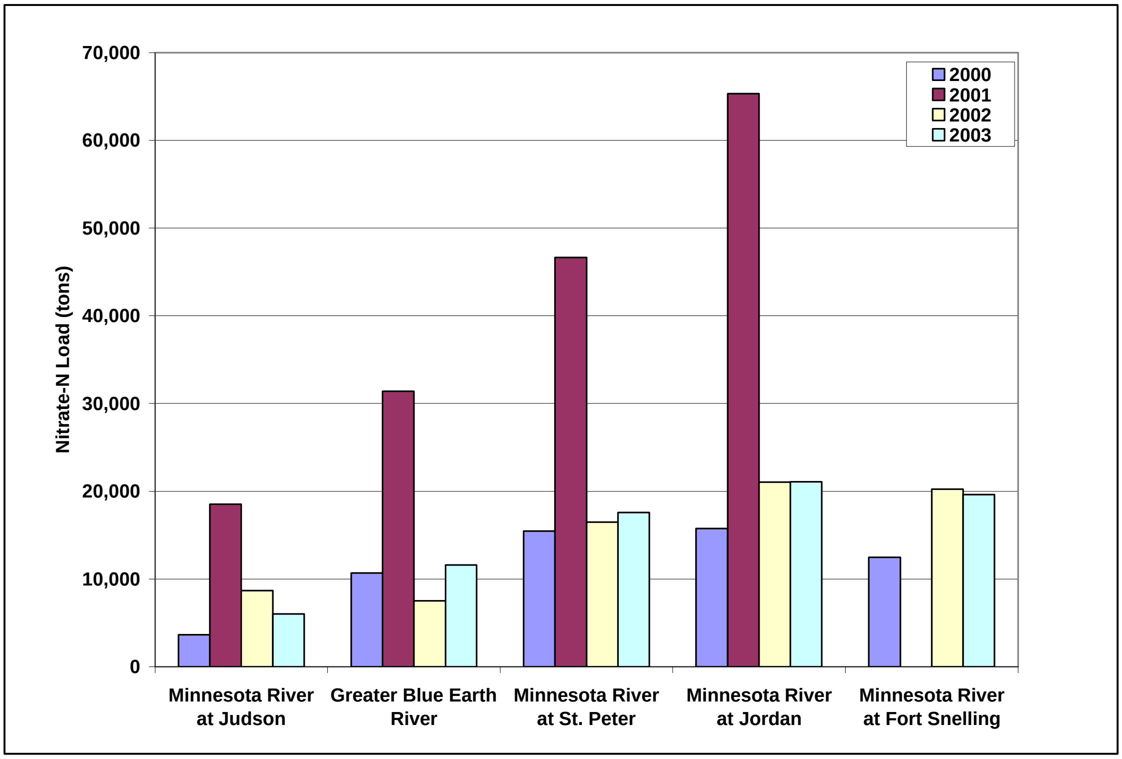
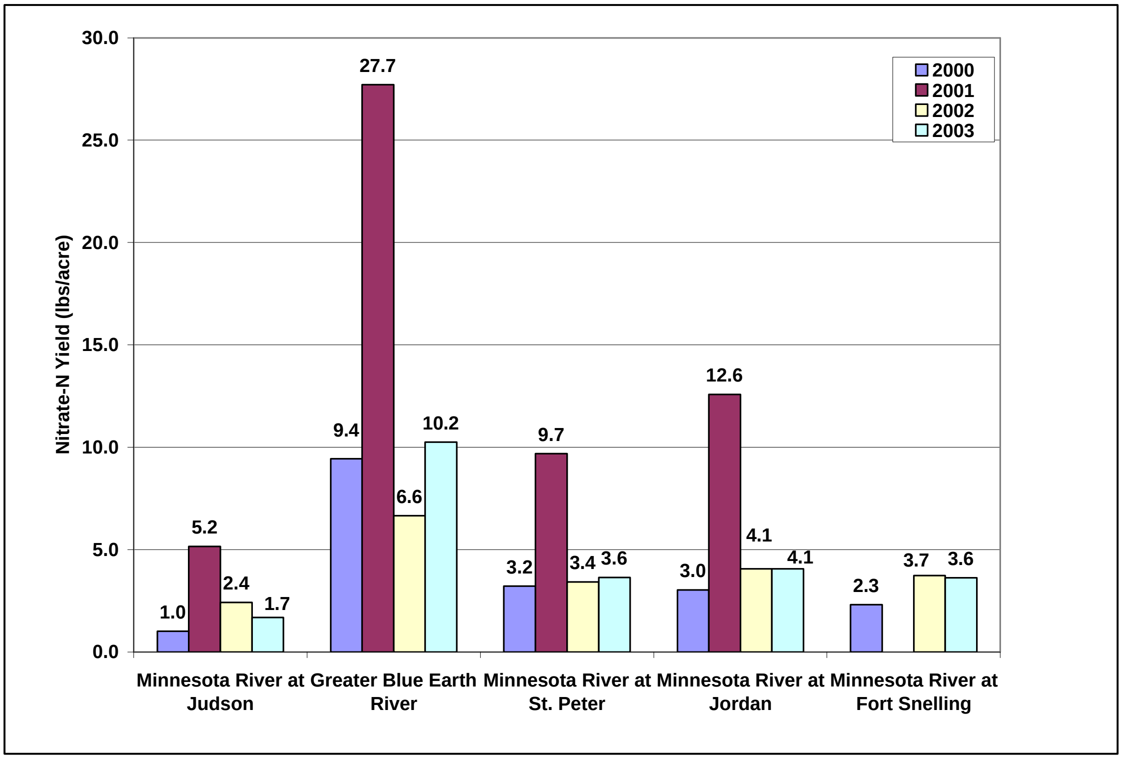


Figure 4.32. 2000 - 2003 Monitoring Season Nitrate-N Yields at Minnesota River Mainstem and Greater Blue Earth River Sites



The yield data (Figure 4.32) illustrate the effect of a wet year (2001) on nitrate-N delivery. An examination of yields during the drier years (2000, 2002, and 2003) shows that the Greater Blue Earth River yields more nitrate-N than the Upper Minnesota River (Judson) even when runoff is below normal levels. The lower yields at Judson reflect inputs of relatively small loads from the lower-yielding tributaries upstream of the Redwood River (Figure 4.36), as well as probable denitrification and assimilation in the 160 mile reach from Lac qui Parle Reservoir to Judson.

When nitrate-N yields are adjusted for runoff (Figure 4.33), the Greater Blue Earth yields are approximately two times greater than the adjusted yields at Judson. This suggests that the yield differences between the Upper Minnesota River and the Greater Blue Earth River may not be strictly a result of greater precipitation and runoff in the Greater Blue Earth River. Differences in fertilizer application rates, crop rotations, the extent of tile drainage, soil types, conservation practices and other sources may be factors. Research into understanding which factors influence the relatively low nitrate-N yields in the Upper Minnesota River Basin may lead to ways to reduce yield from the Greater Blue Earth River and other streams in the Lower Minnesota River Watershed.

Nitrate-N FWMC values for 2000 - 2003 are shown in Figure 4.34. As with nitrate-N loads and yields, the Greater Blue Earth River has the greatest values. The FWMC values for the Greater Blue Earth River were nearly constant during the 2000-03 period (9.78-9.95 mg/L), but increased substantially to 12.44 mg/L during 2003. The 2003 results place the Greater Blue Earth River above the 10 mg/L drinking water standard. The 12.44 mg/L FWMC is a seasonal average, but it indicates that water from Greater Blue Earth was not suitable as a source of drinking water during at least part of the 2003 monitoring period. This may have implications for the City of Mankato, which draws its drinking water from an aquifer that is connected to and partially recharged by the Blue Earth River.

The nitrate-N laden water of the Greater Blue Earth River joins the Minnesota River at their confluence at Mankato. As shown in Figure 4.34, the addition of the Greater Blue Earth River to the flow from the Upper Minnesota River (Minnesota River at Judson) increases the nitrate-N FWMC of the Minnesota River, as indicated by data from the Minnesota River at St. Peter. During three of the last four years, there were further increases in nitrate-N FWMC's between St. Peter and Jordan as major and minor tributaries in the Lower Minnesota River Watershed added their nitrate-N contributions. Despite these increases, nitrate-N FWMC's at the St Peter and Jordan monitoring sites have not exceeded the drinking water standard. There is some reduction in nitrate-N FWMC's between Jordan and Ft. Snelling (Figure 4.34), possibly brought about by denitrification or algal uptake within that relatively low velocity reach. While the nitrate-N FWMC's at Ft. Snelling do not exceed the drinking water standard, they indicate substantial nitrate enrichment that may contribute to hypoxia in the Gulf of Mexico (EPA, 2000).

Figure 4.33. 2000 - 2003 Monitoring Season Nitrate-N Runoff-Adjusted Yields at Minnesota River Mainstem and Greater Blue Earth River Sites

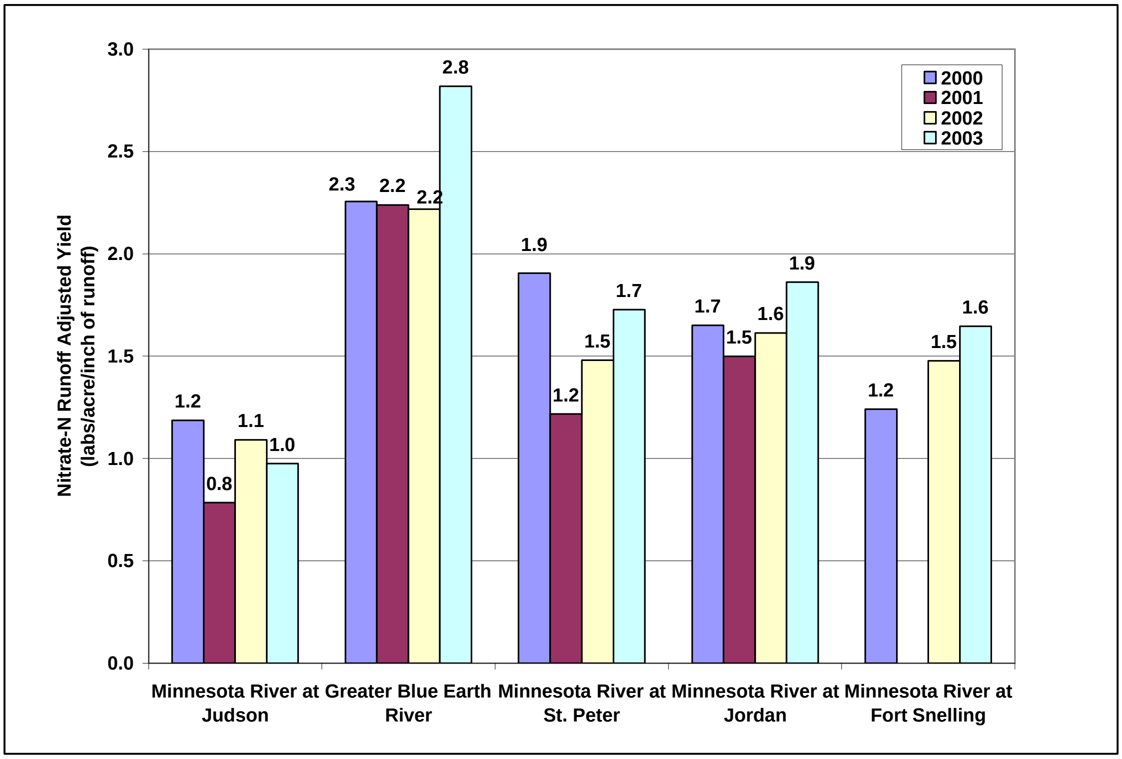
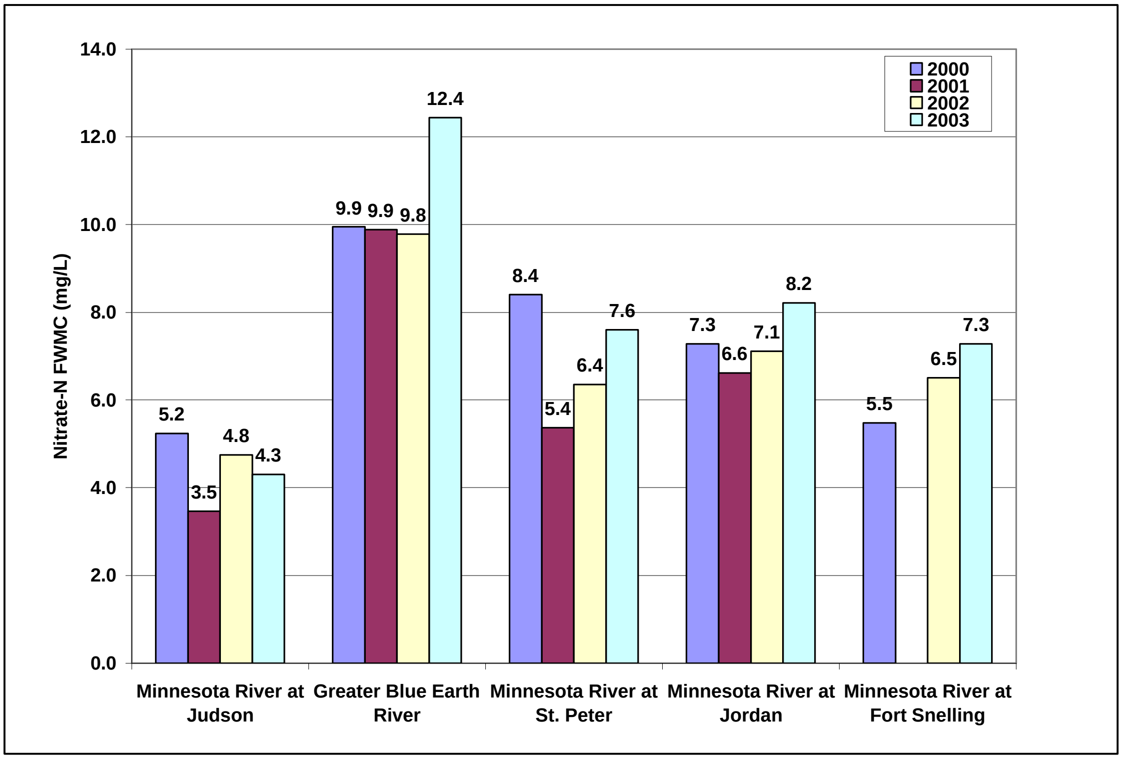


Figure 4.34. 2000 - 2003 Monitoring Season Nitrate-N FWMC at Minnesota River Mainstem and Greater Blue Earth River Sites



Major Tributaries Nitrate-N

Figure 4.35 presents nitrate-N loads for the 2000 – 2003. The data show that major tributaries in the Greater Blue Earth River system delivered a major portion of the total load during 2003, particularly the Blue Earth River and the Le Sueur River. The 2003 results continue to exhibit a pattern of relatively small loads in the western, upstream part of the Minnesota River Basin (Yellow Bank River to Yellow Medicine River Watersheds).

Nitrate-N yield data are shown in Figure 4.36. Yields for tributaries upstream of Hawk Creek have, thus far, been less than 3 lbs/ac, while streams in the Greater Blue Earth and Lower Minnesota River Watersheds have typically ranged from 5-10 lbs/ac, and were much higher during 2001, ranging from 12.4-31.4 lbs/ac. Hawk Creek yields, which were less than 3 lbs/ac during the first 3 years of monitoring, increased about 100 percent to 6.0 lbs/ac during 2003. Nitrate-N yields in the Redwood and Cottonwood Rivers decreased substantially compared to the moderately high yields recorded during 2002 (Figure 4.36). Yield decreases also were recorded for the Yellow Medicine, Little Cottonwood, and Sand Creek Watersheds. In each of those, the yield decrease was approximately proportional to the decrease in runoff from their watersheds. Runoff from the High Island Creek Watershed also decreased compared to 2002 (about 45%), but its nitrate-N yield only decreased about 8 percent.

Runoff-adjusted yields are shown in Figure 4.37. The values indicate the amount of nitrate-N each watershed delivers per inch of water runoff. As discussed in the mainstem section, nitrate-N tends to accumulate in soil profiles during dry periods. Runoff-adjusted yield values may prove useful as a combined surrogate measuring of two important watershed variables; 1) the soil-profile nitrate-N potential, and 2) the delivery efficiency with respect to nitrate. Nitrate-N potential is influenced by soil organic matter, application rates, and crop history. Watershed delivery efficiency is determined by several variables, among them soil type and texture, density of natural and man-made drainage pathways, and contact with denitrifying substrates along those pathways, e.g. stream-bottom materials and wetlands. Comparing the 2003 data for the Le Sueur River with Rush River, the Le Sueur River has a greater yield (Figure 4.36), 11.8 lbs/ac compared to 8.2 lbs/ac for the Rush River, but Rush River has a greater runoff-adjusted yield (Figure 4.37), at 3.9 lbs/ac/in compared to 3.0 lbs/ac for the Le Sueur. This may be an indication that the Rush River Watershed has accumulated more nitrate-N in its soil profiles or that it has a more efficient delivery system, or a combination of both. As can be seen in Figure 4.37, the Yellow Bank, Lac qui Parle, and Chippewa Watersheds have much smaller runoff-adjusted yields than the other major tributaries. The reason for the lower values is uncertain at present, but additional investigation may show that these watersheds have less soil nitrate potential because of differences in such factors as soil type, fertilizer use, and cropping practices or that their nitrate-N delivery pathways are less efficient.

Nitrate-N FWMC values for the major tributaries are shown in Figure 4.38. Flow-weighted mean concentrations increased during 2003 in most of the tributaries that comprise the Greater Blue Earth and Lower Minnesota River Watersheds, and reached

Figure 4.35. 2000 - 2003 Monitoring Season Nitrate-N Loads at Major Minnesota River

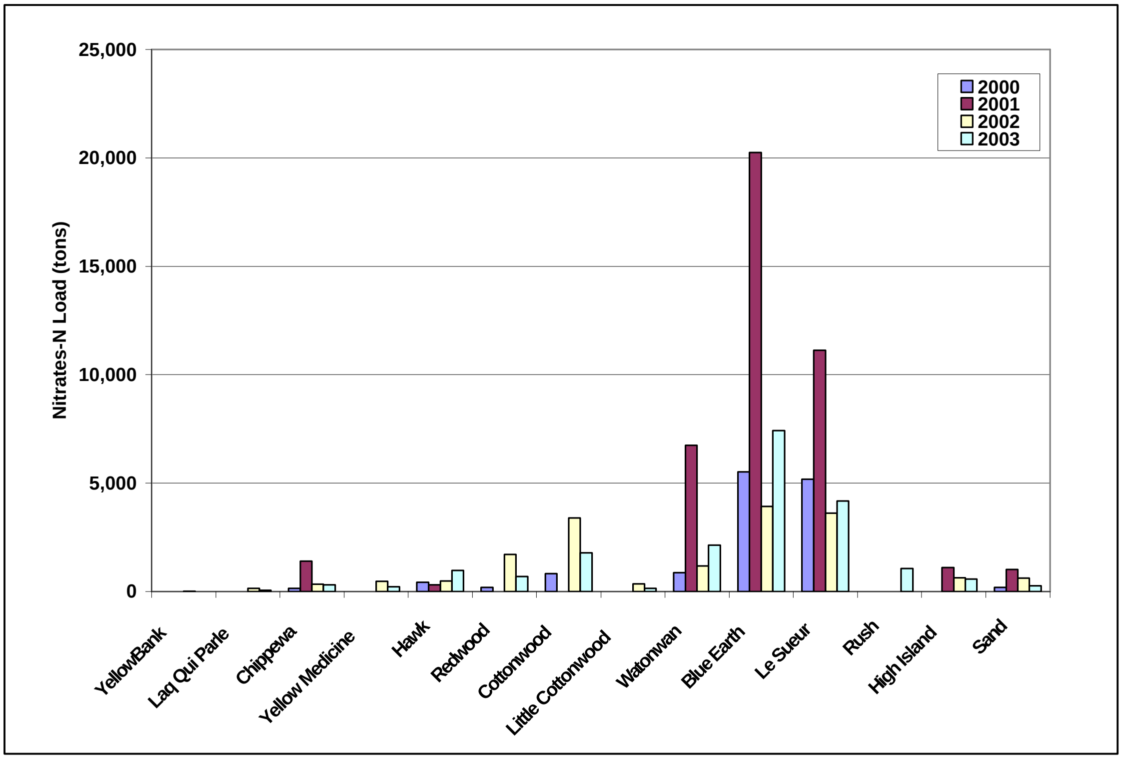
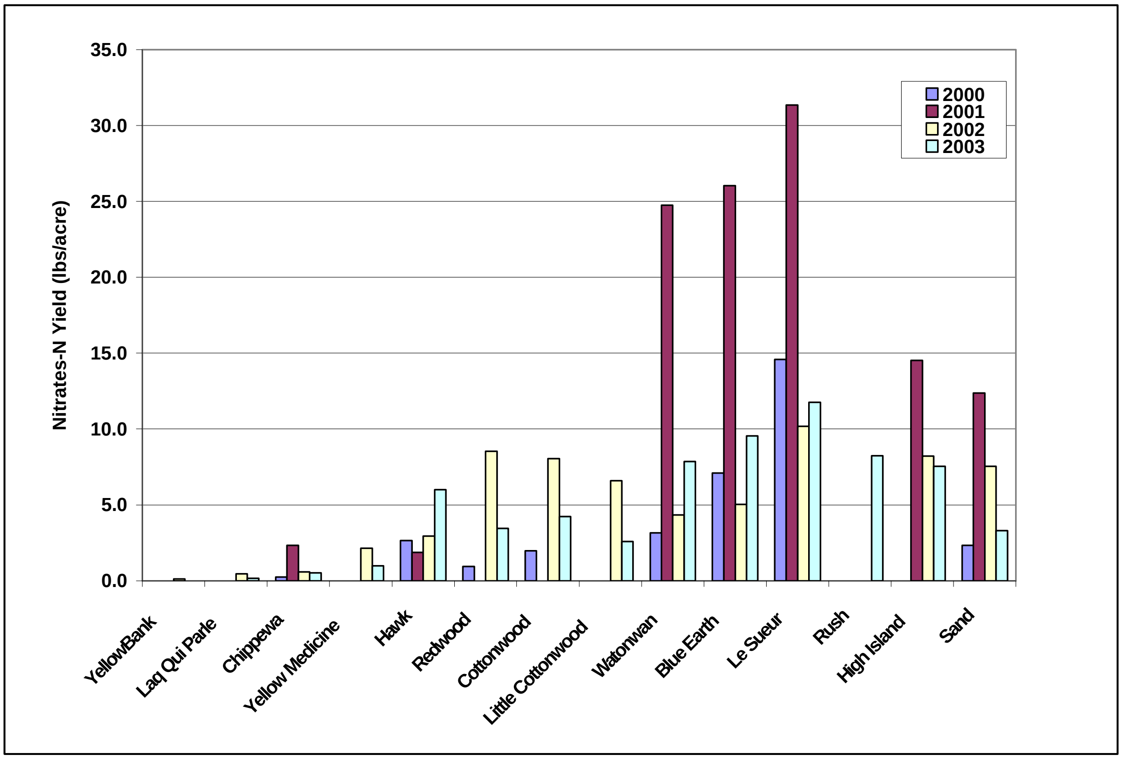


Figure 4.36. 2000 - 2003 Monitoring Season Nitrate-N Yields at Major Minnesota River Tributary Sites



levels that exceed the drinking water standard at five of six sites. Farther upstream in the Basin, the nitrate-N FWMC in Hawk Creek increased from its 2002 level to 9.67 mg/L, a value that places it near the drinking water standard of 10 mg/L. Concentrations in the Redwood River and Cottonwood River, which reached or exceeded the standard during 2002, were reduced during 2003, dropping to 7.7 mg/L in the Redwood River and 9.4 mg/L in the Cottonwood River. In sharp contrast to the other major tributaries, 2003 nitrate-N FWMC's in the Lac qui Parle and Chippewa Rivers remained at levels less than 2.0 mg/L, as they have during previous monitoring seasons.

Figure 4.37. 2000 - 2003 Monitoring Season Nitrate-N Runoff-Adjusted Yields at Major Minnesota River Tributary Sites

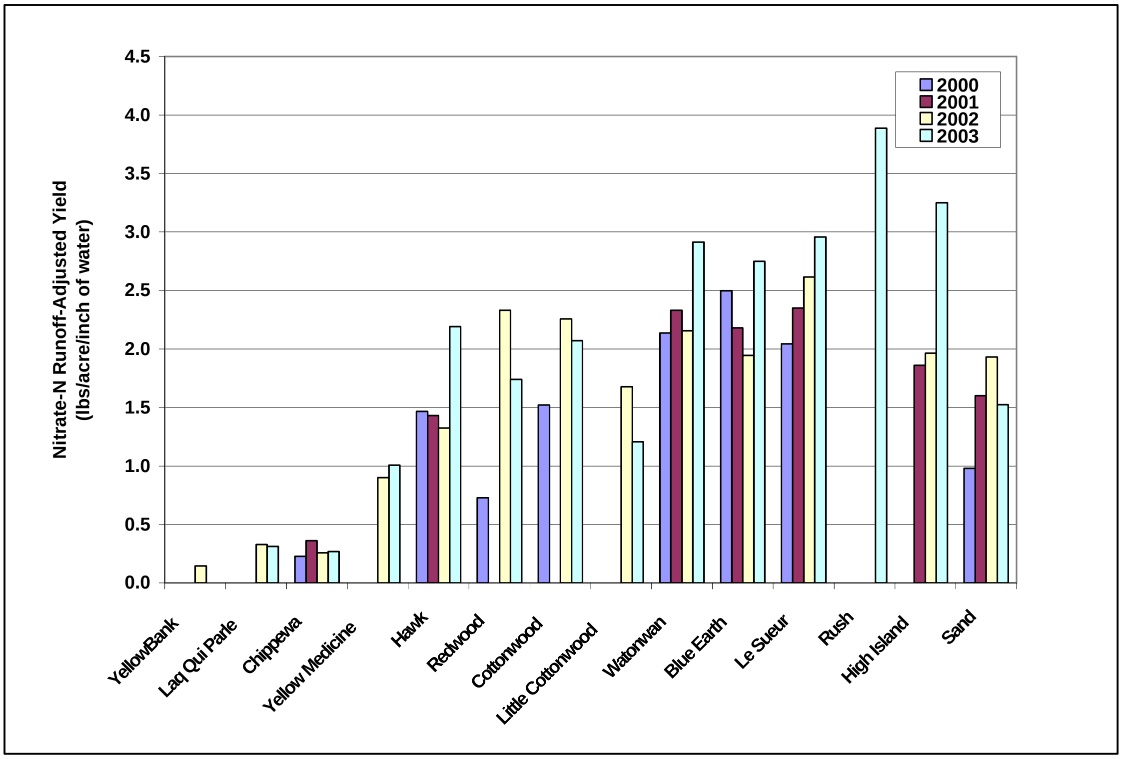
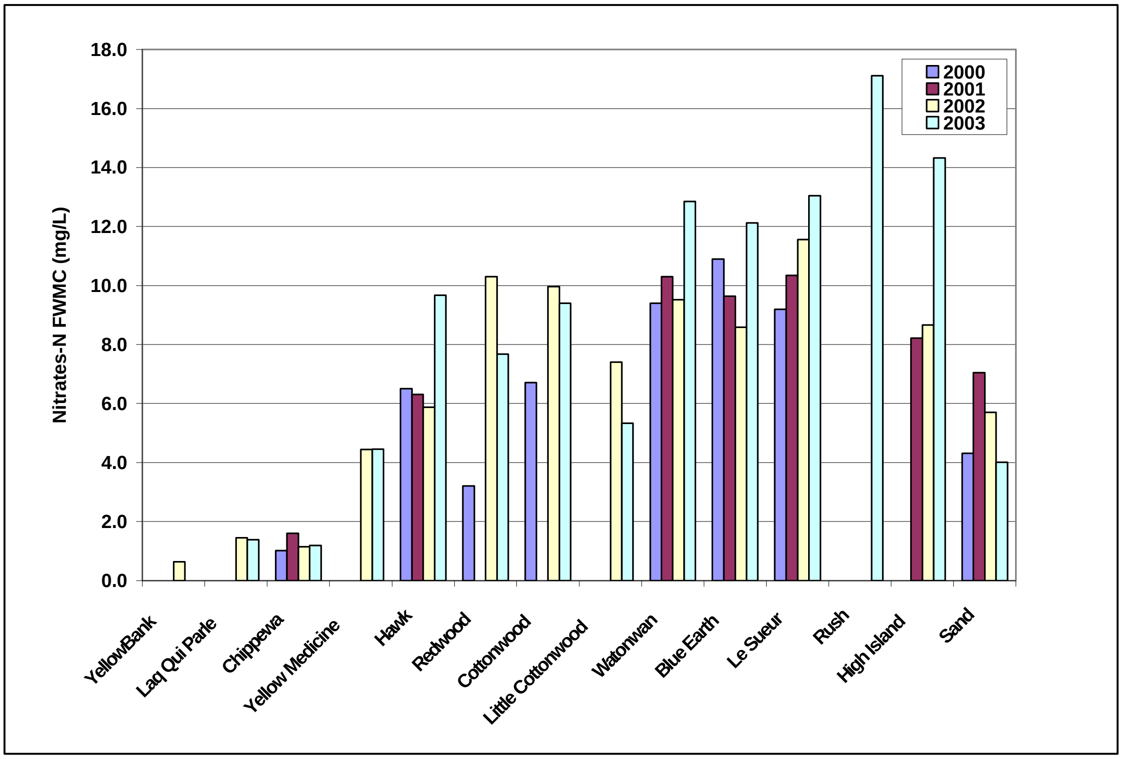


Figure 4.38. 2000 - 2003 Monitoring Season Nitrate-N FWMC at Major Minnesota River Tributary Sites



Minor Tributaries Nitrate-N

Figure 4.39 presents the nitrate-N loads for the 2000 - 2003 monitoring season for the minor tributaries. Nitrate-N loads and yields (Figure 4.40) show an increase from west to east , with relatively low values in Dry Weather Creek and West Fork Beaver Creek that transition to higher values farther east in the Basin followed by diminished yields in the urban and mixed urban land use areas (Bluff Creek to Nine Mile Creek) in the Twin Cities Metropolitan Area. The runoff-adjusted yields (Figure 4.41) show the same general pattern. Clear Creek, which is a tributary to the Redwood River in the western part of the Basin, had a very high runoff adjusted yield during 2002 and is an exception to the general pattern.

The nitrate-N FWMC values generally reflect the same east to west patterns as loads and yields (Figure 4.42). Dry Weather Creek is a tributary to the Chippewa River and has the lowest FWMC value among the minor tributaries that have agricultural land use. Nonetheless, its FWMC value, 8.08 mg/L, places its concentration well above levels in the Chippewa River and other major tributaries in that region, which typically are less than 2 mg/L. These results, and those from West Fork Beaver Creek and Clear Creek, indicate that small streams, even those in the western part of the Basin, can deliver water that is relatively concentrated with respect to nitrate-N. Two of the minor tributaries, Dutch Creek and Seven Mile Creek, had nitrate-N FWMC's that exceeded the drinking water standard during 2003. Dutch Creek flows to a chain of lakes that supplies water to Fairmont, Minnesota. In the Twin City Metropolitan Area, nitrate-N FWMC's were low in comparison, at 1.0 mg/L or less.

Figure 4.39. 2000 - 2003 Monitoring Season Nitrate-N Loads at Minor Minnesota River Tributary Sites

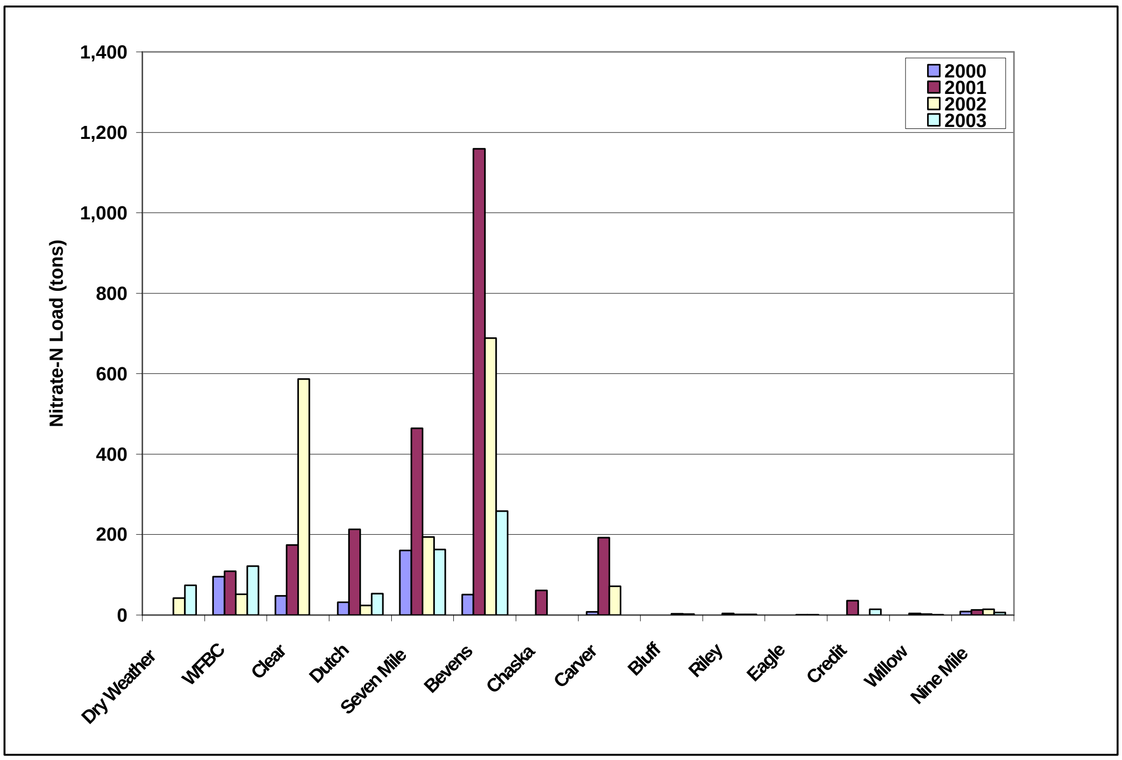


Figure 4.40. 2000 - 2003 Monitoring Season Nitrate-N Yields at Minor Minnesota River Tributary Sites

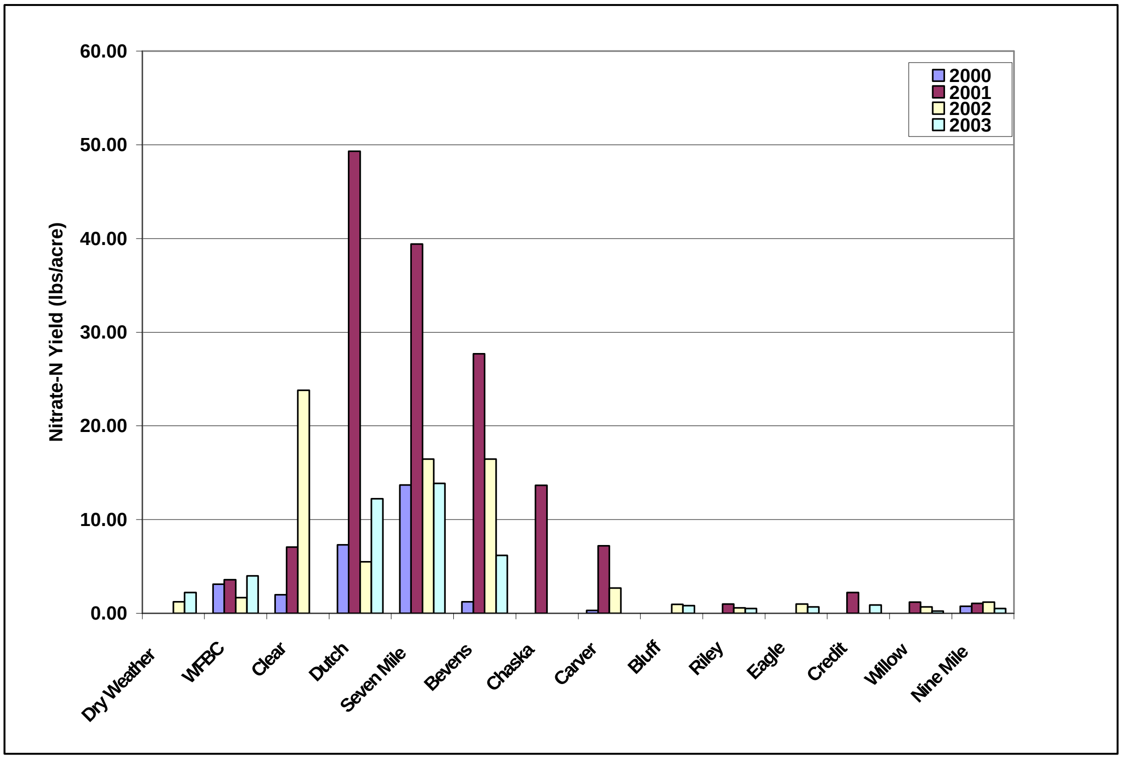


Figure 4.41. 2000 - 2003 Monitoring Season Nitrate-N Runoff-Adjusted Yields at Minor Minnesota River Tributary Sites

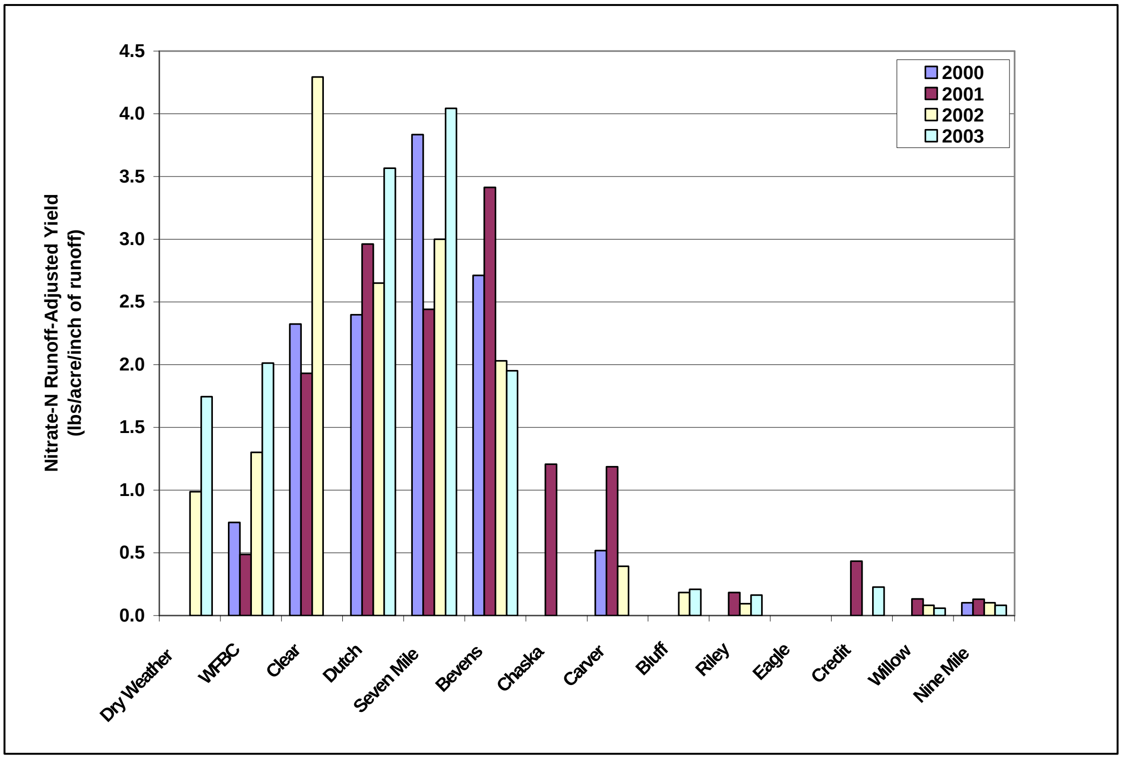
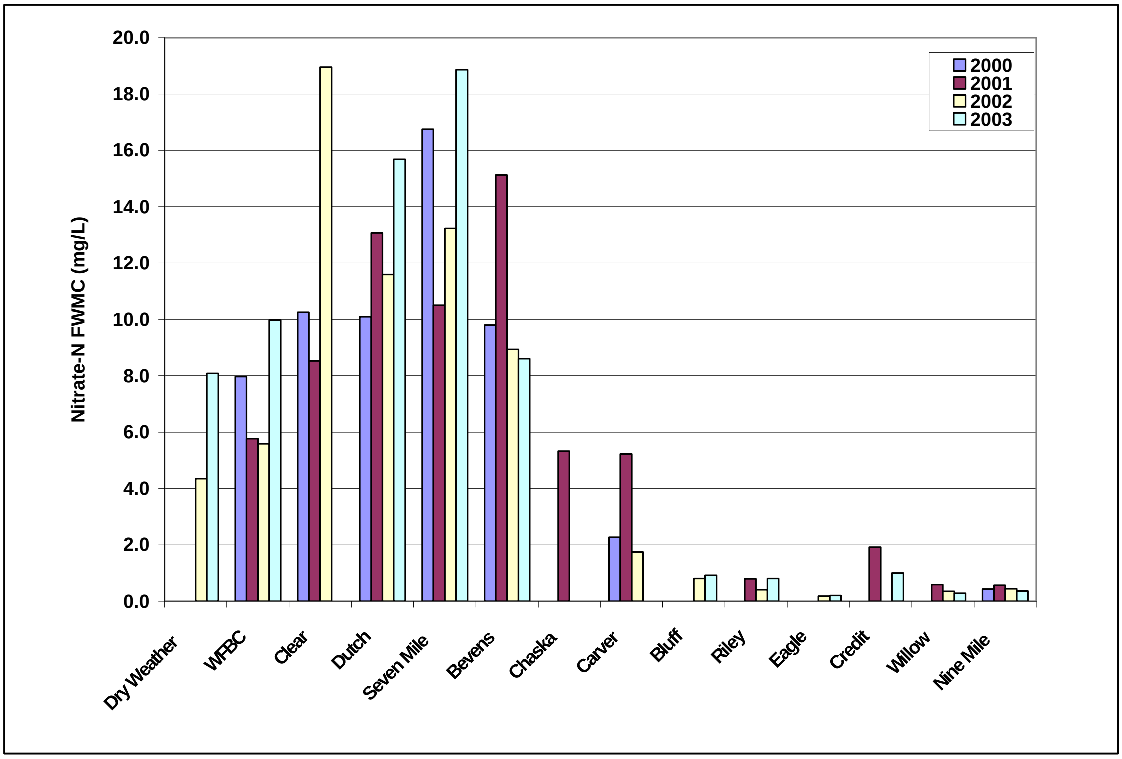


Figure 4.42. 2000 - 2003 Monitoring Season Nitrate-N FWMC at Minor Minnesota River Tributary Sites



Pesticide Monitoring

The Minnesota Department of Agriculture (MDA) Monitoring and Assessment Unit collected pesticide samples from the Le Sueur River at Highway 66, the Blue Earth River below the Rapidan Dam, and the Minnesota River at Judson. Table 4.02 presents a summary of all pesticide samples collected during 2000 - 2003. During this four year period, the herbicides metolachlor, atrazine and acetochlor were the most frequently detected compounds in these rivers. Of these, metolachlor was the most frequently detected pesticide, with detections in approximately 80 percent of the samples collected. During this same four year period, atrazine and acetochlor were detected in 72 and 62 percent of the samples, respectively. The maximum concentration detected during each year as well as the annual flow-weighted mean concentration for each of the detected pesticides are presented in Table 4.02. Compounds qualified as “Present” by the MDA laboratory were quantified at one half the method reporting limit (MRL). The complete pesticide analytical list and corresponding method reporting limits (MRLs) are presented in Table D.02 of the Methods section of this Report. In an effort to reduce costs, analysis for acid herbicides was discontinued by MDA for the 2003 monitoring season. This resulted in a reduction in cumulative pesticide load since no detections of 2,4-D and dicamba, the two most commonly detected acid herbicides, were recorded.

Pesticide concentration for most compounds typically peak in May and June in the rivers of south central Minnesota, although it is not unusual to see peak metolachlor concentrations earlier in the year (March or April) because the product is commonly applied in the fall. Peak concentration periods for the most compounds generally occur with the first significant post-application runoff event.

Annual pesticide loads were calculated for the Le Sueur and Blue Earth Rivers and Minnesota River at Judson for 2000 - 2003. At all three locations, total pesticide load for the four most frequently detected base neutral compounds were down significantly in 2003. However, loads for individual compounds were not consistently lower in 2003. For instance, the Blue Earth and Le Sueur Rivers delivered slightly higher acetochlor and metolachlor loads during 2003 as compared to 2002. Atrazine and dimethenamid loads for all three locations were down considerably from 2002, representing the lowest loads measured in these rivers during the four years of monitoring. The reduction in load is in part a result of pesticide application timing with respect to rainfall events and/or product use patterns which may shift slightly from year to year. The loss of 2,4-D and dicamba from the analytical list also reduced cumulative pesticide load presented in Figure 4.43.

The total pesticide load for these four compounds were divided by the number of square miles of agricultural land in row crops in the given watershed to estimate the yield of pesticide in pounds per square mile. Figure 4.44 presents 2000 through 2003 pesticide yields for each of the watersheds for the four pesticides most frequently detected. The percent landuse in agricultural row crop for the Judson, Le Sueur and Blue Earth watersheds were estimated at 60, 82, and 85 percent respectively (MPCA BID, 1997). As in the previous three years the Le Sueur River Watershed, displayed the highest cumulative pesticide yield, at over 0.72 pounds per square mile.

Table 4.02. Pesticides Detected in the Minnesota River at Judson, Blue Earth and Le Sueur Rivers, 2000 through 2003 by the Minnesota Department of Agriculture

Data		4 Year Detection	Max (ug/l)	Max (ug/l)	Max (ug/l)	Max (ug/l)	FWMC (ug/l)	FWMC (ug/l)	FWMC (ug/l)	FWMC (ug/l)
River	**Compound**	**Frequency**	**2000**	**2001**	**2002**	**2003**	**2000**	**2001**	**2002**	**2003**
Minnesota	Acetochlor	50%	0.66	0.42	1.09	0.43	0.10	0.10	0.18	0.07
Minnesota	Atrazine	68%	0.77	0.98	2.24	0.55	0.17	0.16	0.37	0.12
Minnesota	Metolachlor	66%	6.65	3.36	0.65	0.37	0.51	0.49	0.14	0.1
Minnesota	Dimethenamid	46%	2.05	0.38	0.44	0.14	0.13	0.13	0.08	0.03
Minnesota	2,4-D	*44%	7.10	0.22	3.00	na	0.37	0.02	0.29	na
Minnesota	Dicamba	*40%	0.49	0.61	0.70	na	0.02	0.03	0.08	na
Blue Earth	Acetochlor	68%	3.80	6.50	1.50	0.86	0.60	0.54	0.21	0.22
Blue Earth	Atrazine	73%	1.38	2.20	2.87	0.98	0.55	0.32	0.44	0.14
Blue Earth	Metolachlor	91%	1.13	2.52	0.52	0.46	0.36	0.48	0.12	0.14
Blue Earth	Dimethenamid	46%	0.61	0.89	0.25	0.09	0.12	0.11	0.04	0.02
Blue Earth	2,4-D	*27%	nd	0.10	0.49	na	nd	0.01	0.05	na
Blue Earth	Dicamba	*31%	0.28	1.07	0.52	na	0.02	0.11	0.05	na
Le Sueur	Acetochlor	67%	3.55	9.00	7.10	2.38	0.75	0.84	0.34	0.49
Le Sueur	Atrazine	75%	2.80	3.80	2.97	0.43	0.92	0.65	0.60	0.14
Le Sueur	Metolachlor	83%	1.41	1.44	0.65	0.68	0.31	0.44	0.13	0.20
Le Sueur	Dimethenamid	55%	1.13	2.10	1.80	0.36	0.22	0.28	0.11	0.07
Le Sueur	2,4-D	*44%	0.65	0.97	1.38	na	0.09	0.11	0.16	na
Le Sueur	Dicamba	*37%	0.70	1.27	1.35	na	0.07	0.20	0.11	na

NOTE: nd = not detected
na = not analyzed
* = 3 year detection frequency (not analyzed in 2003)

Annual flow-weighted mean concentrations for each of the sites are presented in Figure 4.45. As was the case for total pesticide load, there was a notable reduction in pesticide concentration for most compounds during 2003. Maximum concentrations presented in Table 4.02 were also down in 2003. The cumulative flow-weighted mean pesticide concentrations presented in Figure 4.45 indicate that for the first time in the four years of monitoring all sites were at levels below 1.0 part per billion (ug/L). The loss of 2,4-D and dicamba from the analytical list also likely contributed to the reduction in cumulative pesticide concentration during 2003.

Figure 4.43. Minnesota River at Judson, Blue Earth and Le Sueur Rivers Cumulative Pesticide Load for 2000 through 2003

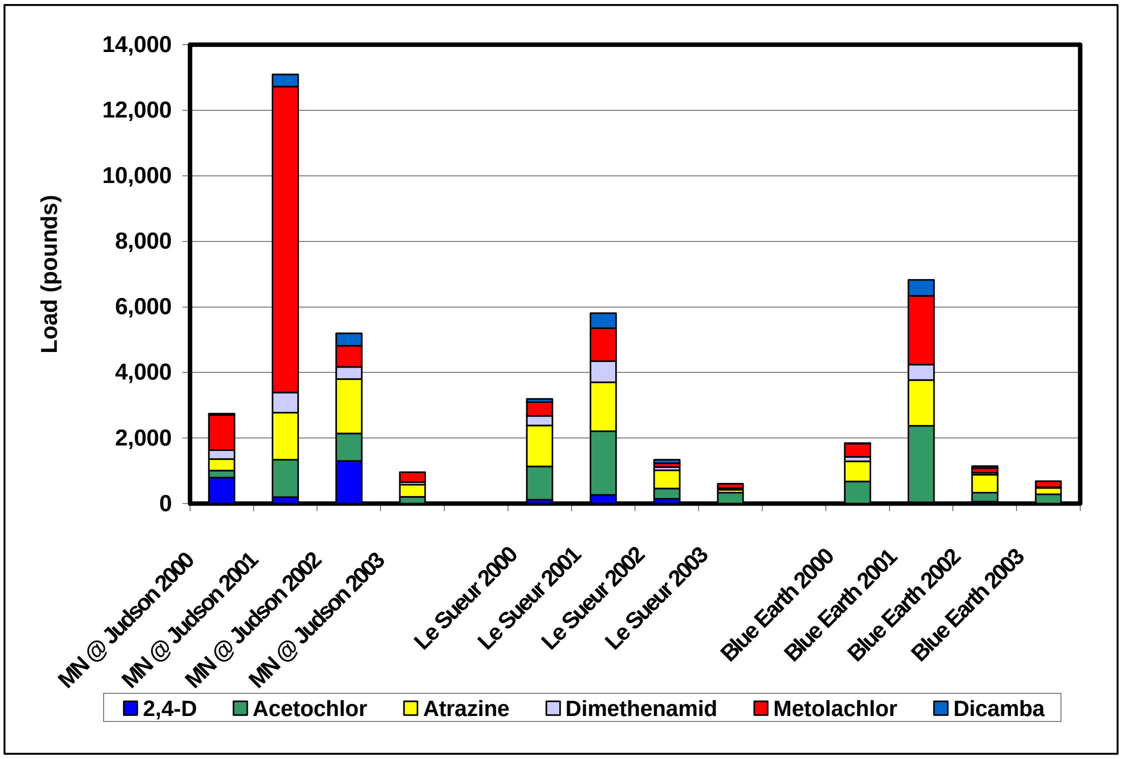


Figure 4.44. Minnesota River at Judson, Blue Earth and Le Sueur Rivers Pesticide Yield for 2000 through 2003

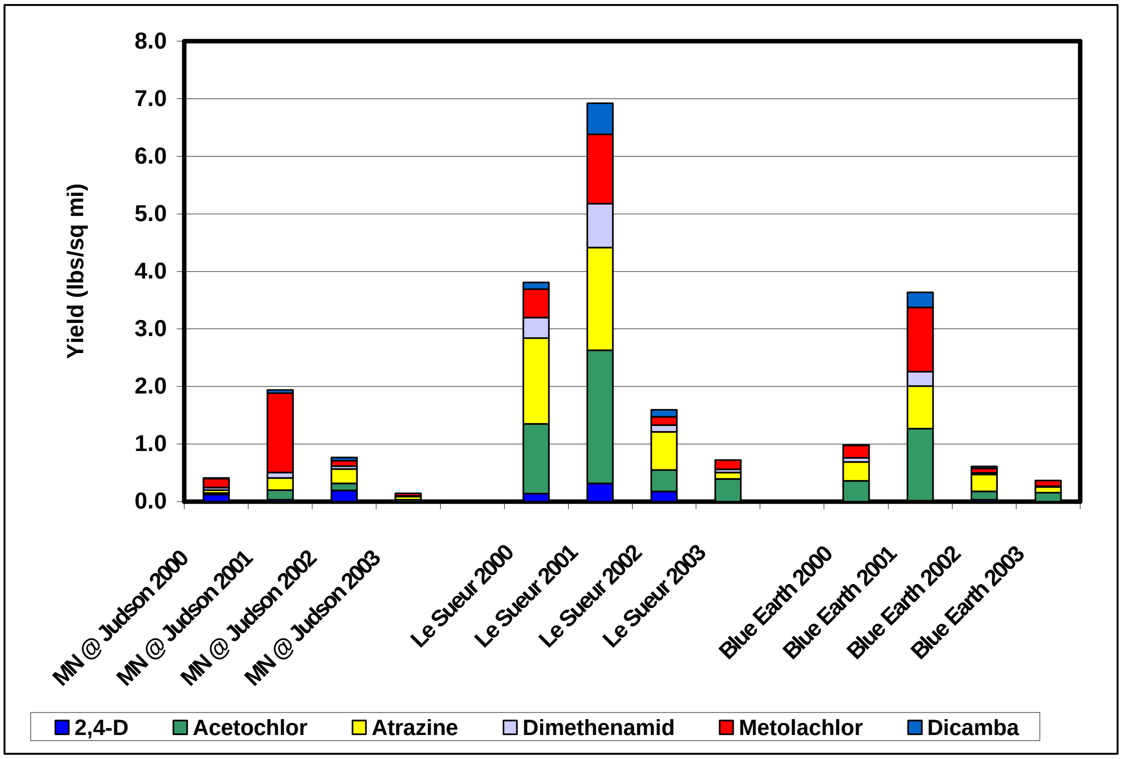
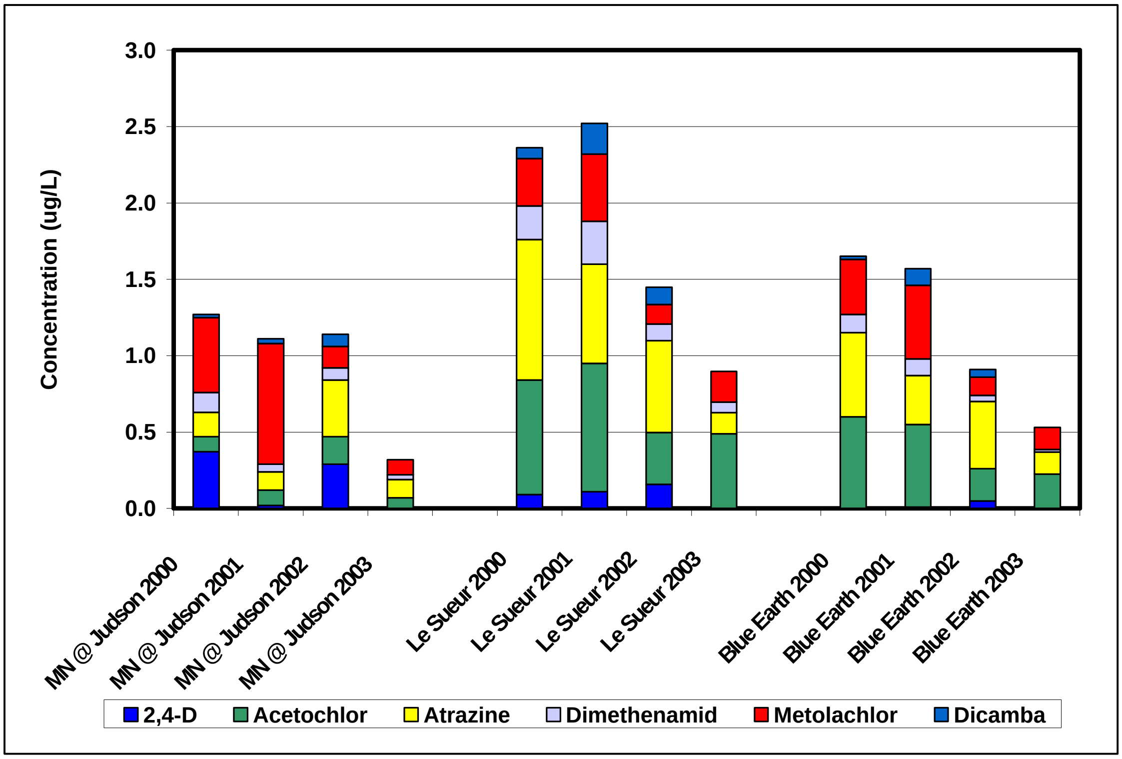


Figure 4.45. Minnesota River at Judson, Blue Earth and Le Sueur Rivers Annual Pesticide Flow-Weighted Mean Concentrations for 2000 through 2003



Fecal Coliform Bacteria

Fecal coliform bacteria are bacteria that are found in the intestines of warm blooded animals. Fecal coliform bacteria are usually not harmful, but do indicate that disease causing pathogens or disease-producing bacteria could be present.

Fecal coliform bacteria are passed through the fecal excrement of humans, livestock and wildlife. These bacteria can enter streams and ditches through direct discharge of waste from mammals and birds, from agricultural and urban stormwater runoff and from poorly or untreated human sewage. Current estimates suggest that more than half of all individual sewage treatments systems (septic systems) in the Minnesota River Basin are not functioning properly, in many cases allowing untreated human waste to enter ditches and streams. Agricultural practices such as spreading manure during wet periods and allowing livestock uncontrolled access to streams can contribute to high levels of fecal coliform bacteria. Wildlife can also be a contributor of fecal coliform bacteria, especially during low flow conditions.

In addition to bacteria and other pathogens, human and animal waste contains high levels of other pollutants such as phosphorus, nitrogen, and oxygen demanding organic material. Additionally, some of the same process (e.g. storm event runoff) and pathways (e.g. gullies) that lead to high suspended sediment concentrations in streams and rivers also contribute to human and animal waste entering the water.

The applicable Minnesota water quality standards for fecal coliform bacteria are listed below (these criteria apply to class 2b and 2 c waters, the classification of almost all streams and ditches in the MN River basin):

1. The geometric mean based on not less than five samples within a 30-day period shall not exceed 200 fecal coliform organisms per 100 milliters of water; and
2. Not more than ten percent of all samples taken in any calendar month can exceed 2,000 organisms per 100 milliters.

The fecal coliform surface water standard applies only between April 1st and October 31st. The criteria are based on an assumed illness rate of 8 per 1000 swimmers (MPCA, 2004).

In the Minnesota River Basin streams monitored for fecal coliform bacteria are often found to exceed water quality standards. Figure 4.46 presents 4/1-10/31 geometric mean fecal coliform for sites that had 10 or more samples for the years 2000 - 2003. These values should not be compared directly to the water quality standards, but do provide an indication of spatial and year-to-year variability.

Figure 4.46. 2000 – 2003, 4/1-10/31 Geometric Means at Minnesota River Sites

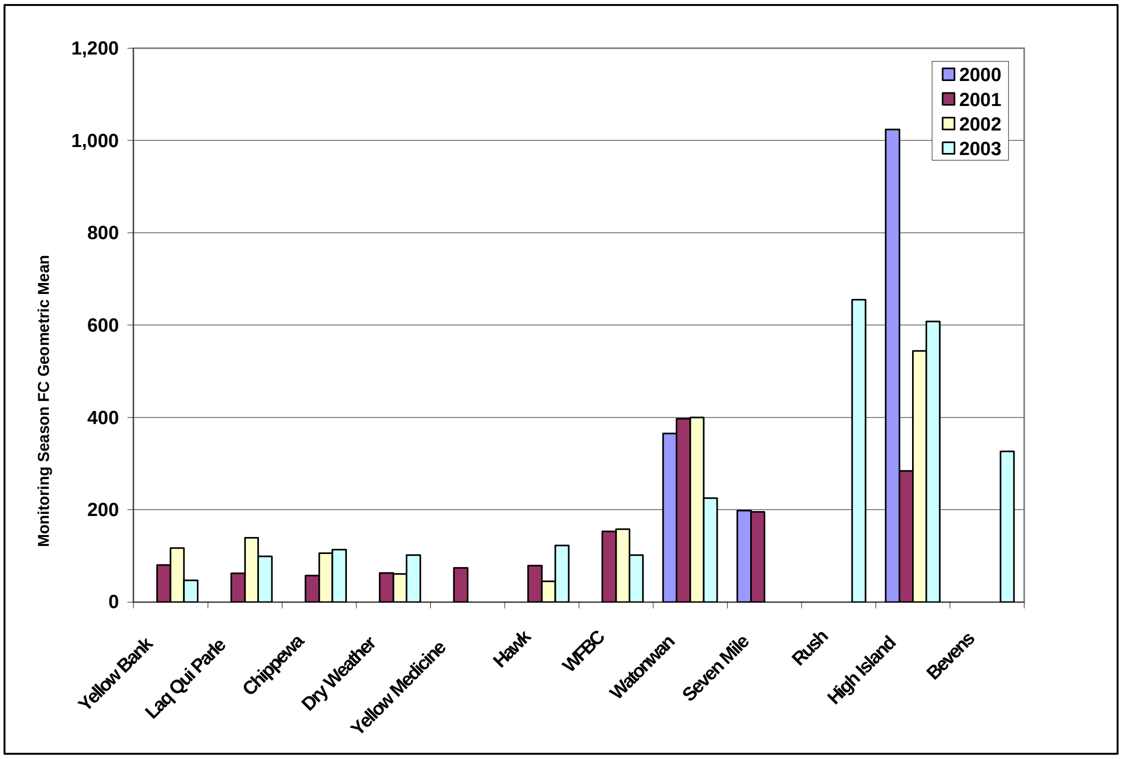


Table 4.03 presents the monthly geometric calculated for each sites based on 2000 - 2003 data sets. In general, the majority of sites with adequate monitoring data were impaired for fecal coliform bacteria. However, several of the eastern watersheds have significantly higher bacterial concentrations than watersheds to the west. Review of individual stream data from streams located in the Blue Earth, Watonwan, Le Sueur and Lower Minnesota Watersheds show fecal coliform bacteria levels that were a magnitude of 2 to 4 times higher than western watersheds.

Table 4.03 Monthly Calculated Fecal Coliform Geometric Means using 2000 – 2003 at Minnesota River Sites

Site	April	May	June	July	August	September
Yellow Bank		27	289	154	60	65
Laq Qui Parle		28	208	253	111	87
Chippewa	11	49	169	119	169	151
Dry Weather	8	17	92	143	236	368
Hawk Creek	27	37	129	109	205	123
WFBC	37	54	440	620	226	174
Watonwan	85	368	839	668	213	257
Dutch		570	1780	1854		
Seven Mile		194				
High Island	93	431	2339	1350	95	10
Bevens		637				

(green)	Equal or less than 200 org/100 ml
(orange)	Greater than 200 org/100 ml. Potentially qualifies for listing as impaired water.

Figure 4.47 presents the percentage of samples that exceeded 2000 org/100 ml for each monitoring site. This analysis uses 2000 - 2003 data, with a minimum sample set of 20. According to MPCA guidelines, a sample set (taken over previous ten year period) with more than 10% of samples exceeding 2000 org/100ml would qualify as an impaired water. This data indicates that water quality samples collected in the eastern portion often have severe bacterial concentrations.

Review of monitoring data throughout the Basin also revealed seasonal differences in bacterial concentrations. Figure 4.48 presents the average monthly geometric mean for 11 of the monitoring sites shown in Table 4.03 (all except Dutch). Plotting of the monthly geometric mean values indicate that on average bacterial concentrations are highest during the months of June and July.

Figure 4.47. 2000 - 2003 Monitoring Data at Minnesota River Sites, Percentage of Samples that Exceeded 2000 org/100 ml

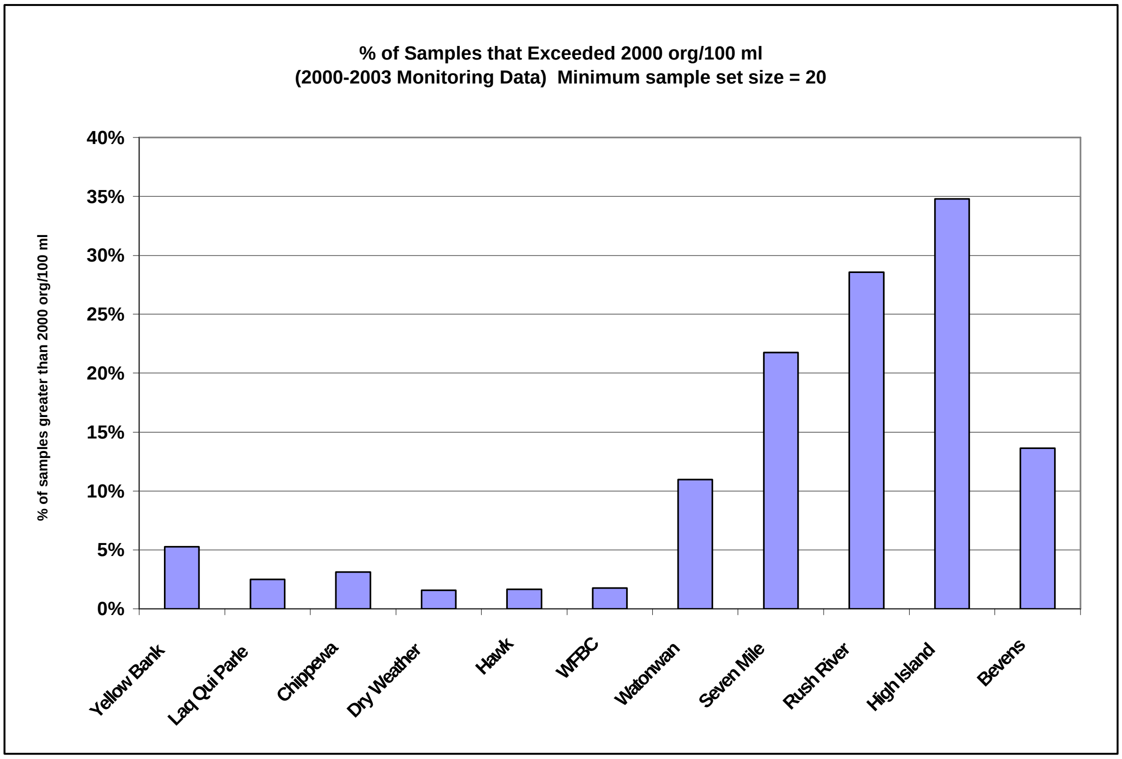
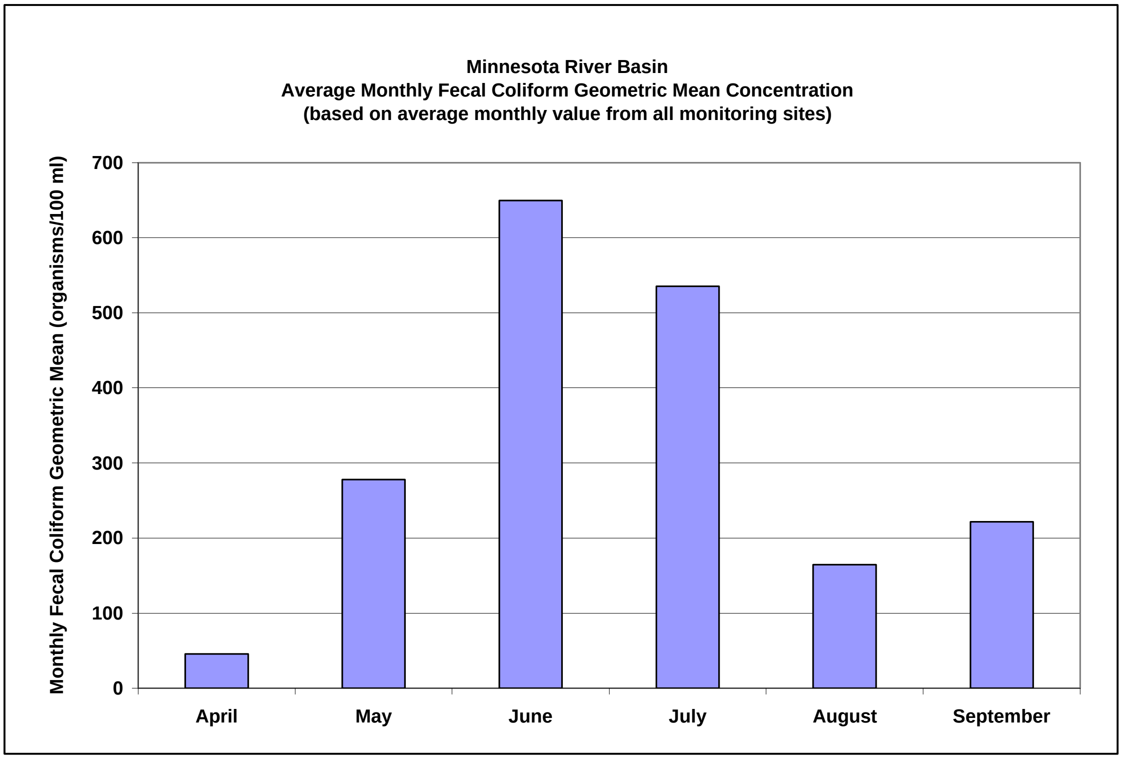


Figure 4.48. Minnesota River Sites Average Monthly Fecal Coliform Geometric Mean Concentration



Stream order (or size) also appears correlated to fecal coliform concentrations. As stream order increases, fecal coliform concentrations on average decrease. Suggested possibilities for this correlation are dieoff of bacteria, deposition of sediment (of which bacteria is often associated) and dilution with downstream water that may have lower concentrations of fecal coliform.

Other observations related to fecal coliform bacteria monitoring:

- The majority of monitoring sites in the basin are impaired for fecal coliform bacteria (2000 - 2003 data). However, in general, moving from the western watersheds to the eastern watersheds, the number of months when impairment occurs and severity of the impairment increases.
- Analysis of fecal coliform bacteria concentrations in the Minnesota River (2000 - 2003 data) indicate geometric means at or near surface water standards.
- Impairments most often occur in June and July.
- Bacterial concentrations in streams are typically highest after high intensity precipitation events.
- In general, when total suspended solids concentrations are high, so are bacterial concentrations.
- Deposition of bacteria in sediments and resuspension during storm runoff, may be a contributor of elevated bacterial concentrations during higher flows.
- Bacterial concentrations in water are influenced by several seasonal and weather related factors, such as precipitation, streamflow, temperature and vegetative cover.

<u>New Bacterial Surface Water Standard</u>

The MPCA is estimating that by December of 2005, the bacterial surface water standard will change from fecal coliform bacteria to E. coli bacteria. E. coli is a better indicator of the risk of contracting gastroenteritis than fecal coliform. The proposed surface water standard for E. coli is 126 coliform forming units (cfu) per 100 ml for a monthly geometric mean or 1260 cfu/100 ml for the 10% maximum standard. The surface water standard for E. coli is also based on an assumed illness rate of 8 per 1000 individual swimmers.

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Chapter 5: Summary and Conclusions

Runoff

Substantial annual and regional differences in runoff were observed across the Minnesota River Basin during the monitoring period 2000 – 2003. While 2000 was relatively dry in most of the Basin, 2001, a flood year, showed runoff values two to ten times greater than 2000. In 2002, runoff amounts were greater than those measured in 2000 and, with the exception of a few watersheds in the lower portion of the Basin, less than those recorded in 2001. 2003 was another dry year, and further reductions in runoff were recorded at most of the monitoring sites. Regional differences in runoff are generally consistent with long-term rainfall distribution patterns in the Minnesota River Basin, with the upper portion of the Basin recording lower rainfall and runoff than the lower portion of the Basin. Year to year differences in pollutant loads often are closely related to annual variations in runoff amounts.

Total Suspended Solids

During the course of four monitoring seasons, 2000 - 2003, flow-weighted mean concentrations of total suspended solids (TSS) for the Minnesota River mainstem sites ranged from a low of 85 mg/L at the Minnesota River at Ft. Snelling during 2003 to a high of 415 mg/L at the Minnesota River at St. Peter during 2000. These values are greater than the turbidity-based TSS threshold of 58 mg/L for the Western Corn Belt Plains ecoregion.

For major tributaries, the 2000 - 2003 results show substantial differences in TSS flow-weighted mean concentrations across the Minnesota River Basin. Concentrations seldom exceed 100 mg/L in major tributaries in the upper part of the Basin. In contrast, concentrations in major tributaries in the lower part of the Basin frequently are much greater than 100 mg/L.

Results obtained over the past four years of monitoring continue to illustrate the strong influence that runoff exerts on the amount of sediment delivered to the Minnesota River. Yields in the Greater Blue Earth River, for example, ranged from 126 lbs/acre during 2002 to 718 lbs/acre during 2001. Magnitude and timing of the individual runoff events also greatly affect the amount of sediment delivered. Whereas precipitation amounts and timing cannot be controlled, management alternatives that maximize water infiltration and retention in upland areas to minimize soil erosion and surface runoff can minimize impacts. Particular attention is needed in the watersheds that have deeply incised stream channels with areas of ravines and unstable stream banks. Given the magnitude of the TSS loads in the Middle and Lower Minnesota Watersheds, widespread implementation of these types of measures may be necessary to have a significant impact on TSS loads.

Total Phosphorus

The load of total phosphorus (TP) transported through the lower reach of the mainstem (St. Peter to Ft. Snelling) during 2003 was reduced from 2002 levels, and was the lowest amount recorded during the four-year reporting period. This load reduction followed reductions seen in 2002 when loads decreased substantially from the relatively high amounts transported during 2001. Total phosphorus loading often strongly correlates with stream flow, and much of the load reduction can be attributed to below-normal runoff across most of the Minnesota River Basin during 2002 and 2003. Seasonal timing, rainfall intensity, and antecedent moisture conditions for each precipitation event along with watershed terrain determine the characteristics of each watershed's total annual runoff. These often variable characteristics, in turn, affect the amount of nutrient leaching, water runoff, and soil erosion which, in combination, move phosphorus into streams. Land use and management decisions related to urbanization, tillage methods, fertilizer applications, conservation buffers, and many others modify the natural affects of climate, weather, and geomorphic variables. The TP load data for the mainstem sites necessarily represent the combined affects of all these variables spread across very large watersheds that have varied landscapes.

The TP FWMC data collected in the past four years provide a useful diagnostic appraisal of the Minnesota River mainstem condition. Researchers generally agree that the Minnesota River is over enriched with respect to phosphorus and that a reduction in phosphorus concentrations could result in reduced algal growth and lower biochemical oxygen demand, thereby enhancing water quality. The 2002 State of the Minnesota River report (State, 2002) described TP concentration thresholds that are sought for the Minnesota River. For example, an analysis by MPCA (MPCA, 1997) showed that a reduction in algal productivity cannot be expected unless TP concentrations in the Minnesota River are brought below 0.26 mg/L. Throughout 2002 and 2003, TP FWMC's in the Greater Blue Earth River and the mainstem at Judson were diminished relative to 2001 levels and presently are at or near the threshold value (Figure 4.14). Fewer high-intensity rainfall events during 2003 and generally reduced runoff throughout the Basin during both 2002 and 2003 probably account for most of the reduction in TP concentrations, but the data also may reflect Basin wide efforts to reduce both point and non-point phosphorus inputs. The data from the Jordan and Ft. Snelling sites (Figure 4.14) show that the reductions extend into the downstream reaches of the Minnesota River to its mouth, where TP FWMC's dropped below the 0.26 mg/L threshold in 2003.

In 2003, the bulk of TP loading from major tributaries occurred in watersheds located in the middle and lower Minnesota River Basin (i.e. downstream of Morton). Load comparisons, however, need to be tempered by considering the amount of tributary load relative to average streamflow in the mainstem channel at the point of confluence. During 2003, TP yields for most of the major tributaries were less than they were throughout 2002, with very large reductions noted for High Island Creek and Sand Creek. Despite appreciable reductions in yields during the past two monitoring seasons, the higher-yielding watersheds are still delivering 4-8 times more TP per acre than the lower-yielding watersheds.

While TP loads and yields are useful diagnostic parameters, it is the resulting stream concentration that drives overproduction of algae that in turn reduces water clarity and often causes undesirable levels of oxygen demand. During 2003, TP FWMC values in eight of the major tributaries were reduced from levels measured during 2002, reflecting the reduced loads and yields. The 2002 State of the Minnesota River Report stated that none of the major tributary streams had FWMC's that met the goal of 0.1 mg/L TP set by the EPA for protection of aquatic life. One stream, the Yellow Medicine River, met that criterion during 2003. Furthermore, the MPCA threshold level of 0.26 mg/L TP was met in seven major tributaries, three of which exceeded the threshold during 2002. Reductions in TP FWMC's were not seen at all major tributary sites during 2003. The Little Cottonwood River FWMC increased from 0.18 mg/L during 2002 to 0.30 mg/L during 2003. The TP FWMC for Sand Creek was unchanged from 2002 and remains at a high level (0.60 mg/L) relative to concentrations in the other major tributaries (Figure 4.17). The Chippewa River also was relatively unchanged during 2003, rising slightly to 0.19 mg/L, but it remains within the 0.26 mg/L threshold.

Assessing results from the past four years, there appears to be a general reduction in TP FWMC's in Hawk Creek, the Redwood River, and the Cottonwood River (Figure 4.17). Concentrations are now substantially reduced from the relatively high concentrations present in these streams during 2000, and are now more closely aligned with the relatively low concentrations that typify major tributaries in the headwaters of the Minnesota River Basin (Yellow Bank to Chippewa). The Le Sueur River has undergone three consecutive and substantial reductions in seasonal FWMC values that started in 2001, but the present value, 0.35 mg/L TP for the 2003 season, remains well above the 0.26 mg/L threshold. Further perspective can be gained by observing that TP FWMC values for the Minnesota River mainstem ranged from 0.23-0.29 mg/L during the 2003 season. These results place the mainstem approximately at the threshold value. If phosphorus loading can be further reduced, it is expected that levels of algal productivity will decline and the River's condition will improve. The major tributaries that presently discharge flows containing TP in excess of the threshold concentration threaten the Minnesota River's recovery because their relatively large watersheds can deliver flow volumes that are sufficient to raise the average TP concentration in the mainstem.

Total phosphorus loads decreased at all minor-tributary sites during 2003 compared to 2002 levels. Loads in Bevens Creek were greatly reduced relative to the very high loads recorded at that site during 2001 and 2002. At most of the sites, the load reductions correspond to decreases in runoff, but TP loads in West Fork Beaver Creek and Dutch Creek decreased despite a runoff increase of about 50 percent compared to 2002 levels.

Total phosphorus yields from the minor-tributary watersheds during 2003 were relatively modest compared to the very high yields recorded during 2001 and 2002. Yields also were more uniform across the basin, lacking the very large site-to-site variations present during 2001 - 2002. Despite greater overall uniformity, three of the agricultural land use watersheds, Dry Weather Creek, West Fork Beaver Creek, and Dutch Creek, have relatively low yields that contrast markedly with yields from Seven Mile Creek and Bevens Creek, which also have agricultural watersheds.

The TP FWMC results, unlike the yield data, show little cross-basin uniformity and site-to-site differences are readily apparent. During 2003, TP FWMC values ranged from 0.05 mg/L in Eagle Creek to 0.42 mg/L in Riley Creek. Eleven minor tributaries were monitored during 2003, and TP FWMC values in seven of them were equal to or less than the 0.26 mg/L threshold and three of the streams had FWMC's equal to or less than the EPA goal of 0.10 mg/L. Comparing 2003 data with results from 2002, only one minor-tributary stream, Riley Creek, showed an increase it its TP FWMC value despite reductions in its annual runoff, TP load, and TP yield during 2003. These results suggest that Riley Creek, an urbanizing watershed, may be receiving intermittent, but highly concentrated, wash loads from construction sites.

Orthophosphorus

Orthophosphorus (OP) loads at mainstem sites during 2003 were reduced compared to loads during 2001, a year of spring flooding, and 2002, which was a relatively low-runoff year. The OP loads at mainstem sites were the lowest measured during the four year period, with the exception of the Minnesota River at Judson site, where the data reflects an increase in OP loading from the Chippewa River during 2003 and relatively high loads from Hawk Creek, Redwood River and Cottonwood River. Because of its greater area, the watershed upstream of Judson delivered more OP load than the Greater Blue Earth Watershed. However, the Blue Earth River Watershed delivered more OP per acre, yielding 0.05 lbs/ac compared to 0.03 lbs/ac from the part of the Minnesota River Basin upstream of Judson. The OP FWMC data show that the present condition (2003) of the Greater Blue Earth River and the Lower Minnesota River, with respect to OP concentrations, is the best recorded during the four year period. Lower concentrations of OP, if sustained, are expected to result in reduced algal productivity, greater water clarity, and less oxygen demand in the lower mainstem.

Orthophosphorus comprises about 20-30 percent of TP in most of the major tributaries. In three of the tributaries, Watonwan River, High Island Creek, and Rush River, OP is greater than 40 percent of TP. In Hawk Creek and the Redwood River, OP is greater than 50 percent of TP. These differences in the proportion of OP may be indicators of differences in the source of the phosphorus loading. Orthophosphorus loads and yields in the major tributaries declined at all sites during 2003 compared to 2002 values except in the Chippewa River and Watonwan River. The OP yield data indicate substantial differences in loading rates among the major tributaries. Focused attention and evaluation of the major-tributary watersheds may be warranted to determine why some yield more OP than others.

The OP FWMC data (Figure 4.27) also show substantial differences among the major tributaries, with values that ranged from 0.02-0.20 mg/L during 2003, a ten-fold difference. Six of the major tributaries, Hawk Creek, Redwood River, Watonwan River, Rush River, High Island Creek, and Sand Creek, had OP FWMC's that exceeded OP levels in the mainstem. As such, their discharges have potential to elevate OP concentrations in the mainstem. More evaluation of these data and special studies may be needed to learn why some of the major tributaries have OP present in higher proportions and at greater concentrations compared to the other major tributaries.

Loads and yields of OP decreased at all minor tributary sites during 2003 compared to 2002. Most notable is the substantial decrease in load and yield for Bevens Creek. Although greatly reduced from 2001 - 2002 levels, the OP load in Bevens Creek during 2003 greatly exceeds loads in the other minor tributaries and also exceeded the loads in three of the major tributaries.

Minor-tributary OP yields fluctuated widely during the 2000 - 2002 period, showing large site-to-site and year-to-year differences at most sites. During 2003, OP yields were comparatively more uniform among sites and lower in magnitude overall, ranging from 0.01 to 0.14 lbs/ac, compared to a range of 0.01 to 0.74 lbs/ac during 2002. Substantial differences are still evident, however, as seen in the Bevens Creek, Bluff Creek, and Credit River Watersheds which yielded about twice as much OP per acre compared to the other minor watersheds.

The OP FWMC data further illustrate differences between the minor tributaries. The Dutch Creek, Seven Mile Creek, and Bevens Creek Watersheds have similar land use and had nearly equal runoff amounts during 2003. Despite these similarities, the OP FWMC for Bevens Creek was 0.19 mg/L, a value nearly two times greater than the FWMC for Seven Mile Creek (0.10 mg/L) and more than three times greater than the FWMC for Dutch Creek (0.06 mg/L). These differences point to the need for further research into OP sources and the transport processes that deliver OP to streams.

Nitrate-N

Results from the past four years of monitoring at Minnesota River mainstem sites continue to show that nitrate-N loads, yields and FWMC's are greatest in the eastern part of the Minnesota River Basin that contains the Greater Blue Earth River Watershed and the Lower Minnesota River Watershed. The nitrate-N FWMC values for the Greater Blue Earth River were nearly constant during the 2000 - 02 period (9.95-9.78 mg/L), but increased substantially to 12.44 mg/L during 2003. The 2003 nitrate-N FWMC for the Greater Blue Earth River exceeds the 10 mg/L drinking water standard.

Results for major-tributary streams also show that nitrate-N loads, yields, and FWMC's generally increase from west to east across the Basin. Nitrate-N FWMC's in the Yellow Bank, Lac qui Parle and Chippewa Rivers (western part of Basin) were less than 2.0 mg/L during 2003, as they have been during previous monitoring seasons. Farther east in the Basin, in the Yellow Medicine River, Hawk Creek, Redwood River, Cottonwood River, and Little Cottonwood River, FWMC's are somewhat greater, generally ranging from 4 to 10 mg/L. The greatest FWMC's are seen in the Watonwan, Blue Earth, and Le Sueur Rivers in the Greater Blue Earth River Watershed, and also in Rush River and High Island Creek, which are part of the Lower Minnesota River Watershed. Nitrate-N FWMC's in these streams have been greater than 8 mg/L during all four monitoring seasons, and have exceeded 10 mg/L at times, reaching a maximum of more than 16 mg/L in the Rush River during 2003.

Nitrate-N loads and yields for minor tributaries show an increase from west to east, with relatively low values in Dry Weather Creek and West Fork Beaver Creek that transition to higher values farther east in the Basin followed by diminished yields in the urban and mixed urban land use areas (Bluff Creek to Nine Mile Creek) in the Twin Cities Metropolitan Area. Clear Creek, which is a tributary to the Redwood River in the western part of the Basin, had a relatively high nitrate-N yield during 2002, and is an exception to the general pattern. Research has shown that the amount of nitrate reaching streams is strongly associated with the amount of water that infiltrates and percolates through the soil profile. Wet years (such as 2001) are often periods of increased nitrate-N loading, particularly when they are preceded by one or more dry years. Nitrate-N tends to accumulate in soil profiles during dry periods when crops are not able to fully utilize available nitrate. The increase in stream nitrate-N from west to east across the Basin generally corresponds to the rainfall and runoff gradient across the Basin. The occurrence of elevated nitrate-N in some streams in the drier, western, part of the Basin (Dry Weather, West Fork Beaver, and Clear Creeks) suggests that fertilizer application rates, crop rotations, drainage density, the extent of tile drainage, soil types, and other nitrate sources also may be factors. Research into understanding which factors influence nitrate-N watershed yields may lead to ways to reduce nitrate-N concentrations in streams.

Pesticides

Pesticide samples were collected from the Le Sueur, Blue Earth and Minnesota Rivers from 2000 - 2003. Over the four-year period, the herbicides metolachlor, atrazine and acetochlor were the most frequently detected compounds in these rivers. Of these, metolachlor was the most frequently detected pesticide, with detections in approximately 80 percent of the samples collected. During this same four year period, atrazine and acetochlor were detected in 72 and 62 percent of the samples, respectively.

Fecal Coliform Bacteria

In the Minnesota River Basin, bacterial monitored streams are often found to exceed the Minnesota surface water standard.

Conclusions

Data in this report illustrate widely varying water-quality conditions in most streams during a relatively short four-year monitoring period. These year-to-year fluctuations underscore the value of long-term data gathering using consistent and technically sound methodology at all sites across the Minnesota River Basin. Such data, collected longer term, will form a solid body of evidence that more accurately portrays stream water quality. These data will enhance the impaired waters listing process by providing an improved perspective of stream water quality during normal, above normal, and below normal runoff periods.

Data in this report show that watershed yields of key water-quality constituents (TSS, TP, OP, and nitrate-N) follow a general pattern of increasing yield, often accompanied by increasing FWMC values, from west-to-east across the Minnesota River Basin. A corresponding west-to-east precipitation and runoff gradient has long been recognized and documented. The magnitude of the constituent yield response, however, appears to be greater than what would be expected from the differences in annual runoff alone. The frequency, intensity, duration, and seasonal timing of precipitation events can greatly affect constituent yield, but other factors also may shape the observed responses. These factors may include differences in watershed geomorphology, vegetative cover, and alluvial progression and adjustment to climate and land-use variables. In addition, direct human influences such as cropping, urbanization, extent and coverage of conservation practices, fertilizer usage (amount and timing), and point source inputs affect constituent yield. The relative importance of these, and perhaps other factors, needs to be better understood as we chart a course of action to reduce pollutant levels in streams, large and small, across the Minnesota River Basin.

Concentrations of TSS, TP, OP and nitrate-N in several of the monitored streams, despite reductions during 2003, are frequently at problematic levels. Affected streams range in size from minor tributaries to the Minnesota River mainstem. Concentrations of these constituents are often at, or well above, thresholds associated with reasonable expectations for water quality in their respective ecoregions. The data clearly show that these impaired conditions develop during various hydrologic cycles ranging from near drought to floods. The data do not make clear the source mobilization and transport mechanisms that deliver pollutants to streams. However, several of the organizations that contributed data for this report are collecting additional data from smaller watersheds and are using that information to identify and target specific sources and areas within their respective watersheds. Inclusion of data from some of these smaller watersheds in this year’s State of the Minnesota River Reports is providing a more comprehensive assessment and will improve our understanding of pollutant source and transport mechanisms. Some of the more complex pollutant source mobilization and transport mechanisms will likely need in-depth focused research studies beyond the scope of the present monitoring program. Some research of this type currently is in progress and more research is proposed. Better communication between researchers and continued coordination of the monitoring effort will improve our understanding of the processes and enhance our ability to reduce pollutant loading.

The present monitoring network has no Minnesota River mainstem sites upstream of Judson. Two additional mainstem monitoring sites are needed, one near Morton and one near Montevideo. Sites near these locations could take advantage of USGS streamflow gaging stations already in place, document conditions in the mainstem, and assist in differentiating effects of the relatively low-yielding major watersheds in the upstream part of the Basin from the moderate-to-high yielding watersheds in the mainstem reach between Morton and Judson.

Questions and Concerns for Further Research:

- More research is needed on potential water-quality and aquatic-ecosystem improvements in streams located in watersheds that have extensive participation in CREP and other BMP programs. Furthermore, there needs to be continued research that will lead to new innovations for managing surface and subsurface runoff and erosion, particularly methods that can be effective during the critical May-July period.

- Monitoring data indicate regional differences in the magnitude of constituent load response to water runoff. Differences are related to watershed soils, geology, and stream morphology, but land use, cropping practices, drainage practices, and conservation practices also may be affecting load response. A better understanding of these processes could help allocate BMP resources more effectively.

- Assessments are needed in major tributaries to determine the nature of the phosphorus sources and the location of source areas. Particular attention should be placed on identifying 1) highly-erodible land that is not presently treated with conservation practices, 2) land adjacent to stream and ditches, 3) actively eroding streambanks, ravines and gullies, 4) municipal and industrial point sources, 5) non-compliant animal-waste systems, and 6) other potential sources.

- More evaluation of the monitoring data and special studies may be needed to learn why some of the major tributaries have greater OP/TP ratios and greater OP concentrations compared to other major tributaries. Investigation of phosphorus sources, phase partitioning, and transport mechanisms may reveal new information about these processes that could, in turn, lead to new approaches for reducing phosphorus loading to streams. Research projects directed at non-point source processes at both field and small-watershed scale may be needed to determine how and why the major tributaries differ in these important aspects of phosphorus dynamics.

- Elevated nitrate-N loads, yields, and FWMC values are present in most of the major tributaries starting with the Redwood River and continuing downstream. The elevated numbers underscore the need for BMPs that reduce nitrate in streams. Source reduction, through effective nutrient management, is an important first step. More research is needed at the minor watershed scale to evaluate why some agricultural watersheds deliver more nitrate-N and what can be done to mitigate this problem.