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Introduction

This chapter describes monitoring-based nitrogen results from many of the mainstem rivers in Minnesota, including basin and state outlets and upstream reaches of the Mississippi, Minnesota, St. Croix, and Red Rivers. The following chapter (B3) focuses on a smaller scale, examining monitoring-based results near the outlets of 8-digit Hydrologic Unit Code (HUC8) level watersheds.

Nitrogen (N) load, the amount of N passing a point on a river over a certain amount of time (i.e., pounds per year), can be estimated if river flow is monitored and water samples are collected and analyzed over a range of flow conditions and seasons. In Minnesota, we are fortunate to have numerous monitoring stations where total nitrogen (TN) and nitrite+nitrate (nitrate) loads have been calculated. The primary loads which will be described in this chapter are summarized in Table 1. In this chapter, we describe the results from these monitoring-based loads, yield, and flow-weighted mean concentrations (FWMC) for major rivers and basins.

Table 1. Monitoring programs which provided N load information for this report.

<table>
<thead>
<tr>
<th>Monitoring program</th>
<th>Lead agency</th>
<th>Watershed/stream locations</th>
<th>Nitrogen parameter(s)</th>
<th>Years</th>
<th>Load estimation methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long Term Resource Monitoring Program</td>
<td>US Geological Survey</td>
<td>Mississippi River Upstream and downstream of Lake Pepin; Mississippi River near Iowa at Lock and Dam #7 and 8</td>
<td>Nitrite+Nitrate Total nitrogen</td>
<td>1991-2010</td>
<td>MPCA used multiple year regressions in FLUX32</td>
</tr>
<tr>
<td>Metropolitan Council Major Rivers Monitoring Program</td>
<td>Metropolitan Council Environmental Services</td>
<td>Mississippi River at Anoka and Prescott Minnesota River at Jordan St. Croix River at Stillwater</td>
<td>Nitrite+Nitrate TKN Total Nitrogen</td>
<td>1980-2010</td>
<td>Met Council used one-year concentration/flow data and a single year’s flow to calculate loads in Flux 32.</td>
</tr>
<tr>
<td>Red River</td>
<td>Manitoba Conservation and Water Stewardship and Environment Canada</td>
<td>Emerson Manitoba</td>
<td>Nitrite+Nitrate TKN</td>
<td>1994-2007</td>
<td>Monthly water quality and flow data (average of daily) for full period to estimate monthly and then annual loads</td>
</tr>
<tr>
<td>Watershed Load Monitoring Program</td>
<td>MPCA (with support from other organizations)</td>
<td>Outlets of most HUC8 watersheds in Minnesota</td>
<td>Nitrite+Nitrate TKN Total Nitrogen</td>
<td>2007 - 2009</td>
<td>MPCA used single year regressions in FLUX32</td>
</tr>
</tbody>
</table>
Results overview

Three mainstem rivers (Minnesota River, Upper Mississippi River, and St. Croix River) converge in the Twin Cities Area, where their waters join and continue moving downstream in the Mississippi River along the Minnesota and Wisconsin border. Minnesota and Wisconsin tributaries from the Lower Mississippi Basin add additional N loads into the Mississippi, south of the Twin Cities. At the opposite corner of the state, the Red River flows north along the Minnesota and North Dakota state border into Manitoba.

Total nitrogen

Long term average TN loads were calculated for these mainstem rivers using monitoring results obtained reasonably close to the outlets of the basins and/or at the state borders (Table 2, Figures 1 and 2). Long-term average loads are mostly used in this chapter, since year-to-year variability can be large due to annual precipitation differences and challenges in perfectly capturing monitoring results during storm events. Averaging loads over a longer period of time reduces the effects of these single year climate influences and load calculation uncertainties.

Table 2. TN loads, yields and flow-weighted mean concentrations (FWMC) for certain major rivers in Minnesota.

<table>
<thead>
<tr>
<th>River and Location</th>
<th>Load avg. million lbs/yr</th>
<th>Yield avg. lbs/acre/yr</th>
<th>FWMC avg. mg/l</th>
<th>Percent of TN in nitrite+nitrate-N form</th>
<th>Period which average is based on</th>
</tr>
</thead>
<tbody>
<tr>
<td>St. Croix River, Stillwater</td>
<td>10</td>
<td>2.3</td>
<td>1.0</td>
<td>37%</td>
<td>1991-2010</td>
</tr>
<tr>
<td>Minnesota River, Jordan</td>
<td>116</td>
<td>11.3</td>
<td>8.2</td>
<td>84%</td>
<td>1991-2010</td>
</tr>
<tr>
<td>Mississippi River, Anoka (plus Rum R)*</td>
<td>42*</td>
<td>3.3*</td>
<td>2.2</td>
<td>56%</td>
<td>1991-2010</td>
</tr>
<tr>
<td>Mississippi River, Prescott</td>
<td>174</td>
<td>6.1</td>
<td>3.8</td>
<td>72%</td>
<td>1991-2010</td>
</tr>
<tr>
<td>Mississippi River, Lake Pepin Outlet</td>
<td>145</td>
<td>4.7</td>
<td>3.1</td>
<td>83%</td>
<td>1992-2009</td>
</tr>
<tr>
<td>Mississippi River at Minn. – Iowa border</td>
<td>211</td>
<td>5.0</td>
<td>2.6</td>
<td>75%</td>
<td>1991-2010</td>
</tr>
<tr>
<td>Lock and Dam #8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red River Basin at Emerson Manitoba</td>
<td>37</td>
<td>1.5</td>
<td>2.4</td>
<td>46%</td>
<td>1994-2008</td>
</tr>
</tbody>
</table>

*In this table and the rest of the chapter, loads and yields for the Mississippi River Anoka also include Rum River load averages from 2001 to 2010 calculated by Met Council, combined with the Met Council Mississippi River (Anoka) loads; so that the Mississippi River loads at Anoka include all of the Upper Mississippi River Basin N loads except for the Mississippi River Twin Cities watershed. The Rum River loads represent 6.2% of the total N average load of the Mississippi River at Anoka.

The highest loading tributary to the Mississippi River is the Minnesota River, which contributes an average of 116 million pounds of N per year (1991 to 2010). By comparison, the Upper Mississippi River and St. Croix River add lesser amounts of roughly 42 and 10 million pounds of TN per year, respectively (Figure 1). Moving downstream through the Twin Cities Metropolitan Area, TN increases by about
6 million pounds per year on average from point sources, stormwater and groundwater baseflow in the Twin Cities. Between the south part of the Twin Cities and the Iowa border, TN increases by about another 37 million pounds, with contributions from Lower Mississippi River Basin tributaries. In-stream N losses also occur in this lower stretch of the river, so that the actual additions from Lower Mississippi River Basin tributaries are more than the 37 million pound increase observed in the river loads.

The TN yields and FWMCs are substantially higher in the Minnesota River as compared to the other tributaries and sections of the Mississippi (Table 2). If 12% to 22% of N is lost in the major rivers, pools, and Lake Pepin south of the Twin Cities, then the 116 million pounds of TN measured in the Minnesota River at Jordan (upstream of the Twin Cities) will be reduced to 90 to 102 million pounds at the Iowa border, which represents 43% to 48% of the 211 million pounds of TN reaching the Minnesota/Iowa border in the Mississippi River.

The Red River TN loads at the Minnesota/Canada border are in the same general range as the Upper Mississippi Basin loads, transporting about 37 million pounds per year, on average.

Figure 1. Long term average annual TN loads at key points along major rivers. Time period for long term averages: Red River (1994-2008); Minnesota, Upper Mississippi, and St. Croix Rivers (1991-2010); Lower Mississippi (1992-2009).
Nitrate-N

Nitrite+Nitrate-N loads are also dominated by the Minnesota River, which contributes an average 97 million pounds per year. The Upper Mississippi River, St. Croix River, Twin Cities Metropolitan Area streams, and the Lower Mississippi River Basin all add lesser amounts of 23, 4, <1 and 34 million pounds of nitrite+nitrate-N, respectively (Figure 2). The Red River nitrate loads are also low compared to the Minnesota River, transporting about 16 million pounds per year, on average.

For the remainder of this chapter, more specific results are provided for the following rivers:

- the Lower Mississippi River – Lake Pepin to Iowa
- the three mainstem rivers converging in the Twin Cities - Minnesota River, St. Croix River, Upper Mississippi River
- the Red River
Lower Mississippi River – Lake Pepin to Iowa

Mississippi River at Minnesota/Iowa border

The U.S. Geological Survey (USGS) has been taking water quality samples (every other week) since 1991 on the Mississippi River near the Minnesota and Iowa border. The U.S. Army Corps of Engineers has been measuring flow at both Lock and Dam #7 and 8 during the same time period. Two of the monitoring locations for the USGS Long Term Resource Monitoring Program (LTRMP) are located at Lock and Dam #7 and 8, near LaCrescent, Minnesota and Genoa, Wisconsin, respectively. Using USGS collected data, the Minnesota Pollution Control Agency (MPCA) calculated annual loads at Lock and Dam #7 and 8 using the FLUX32 model. The load calculations show annual mean total N loads between 1991 and 2010 of 209 and 211 million pounds at Lock and Dam #7 and 8, respectively. Because the average loads are nearly identical at these two monitoring sites, and they are located close to each other, the results and graphs below include only Lock and Dam #8, the more downstream location.

Most of the watersheds contributing water to the Mississippi River at the Minnesota/Iowa border are located in Minnesota. Overall, based on SPARROW model results, we estimate that about 77% of the TN in the Mississippi River at the Iowa border comes from loading in Minnesota catchment areas and the other 23% comes largely from Wisconsin, but also Iowa and the Dakotas. According to SPARROW model estimates, about 48% and 61% of the St. Croix and Lower Mississippi Basin TN loads are from Wisconsin, respectively. And about 4% of the Minnesota River Basin TN load is from the Dakotas and Iowa.

The annual flow-weighted mean TN concentration calculated for Lock and Dam #8 ranged from 2.4 to 3.0 mg/l between 1991 and 2010, averaging 2.6 mg/l. The annual TN loads varied more during this time period (Figure 3), due largely to year-to-year variability in precipitation and river flow. The lowest annual load occurred in 2009 (135 million pounds) and the highest load occurred in 1993 (344 million pounds). Nitrite+nitrate-N represents approximately 75% of the TN load, with Total Kjeldahl Nitrogen (organic-N + ammonium-N, abbreviated as TKN) making up the other 25% of the TN load (Figure 3).

The average TN and nitrate+nitrate loads peak in April, followed by May and then June (Figure 4). About two-thirds of the annual TN load occurs in the five months between March and July, during periods of spring runoff and early summer storms. Evapotranspiration is high in July through September when the crops are well established, and correspondingly river flow and nitrate loading decreases.
Moving upstream on the Mississippi River to another LTRMP site at the outlet of Lake Pepin, the average TN load is 145 million pounds/year (1992-2009), which is about 66 million pounds/year lower than at Lock and Dam #8 for that same time period. During this same stretch of river, TN concentrations (flow-weighted means) drop from an average of 3.1 mg/l at the Lake Pepin outlet to 2.6 mg/l at Lock and Dam #8.

Several rivers from both Minnesota and Wisconsin enter into the Mississippi between Lake Pepin and Lock and Dam #8, including the Cannon, Zumbro, Root, Chippewa, Trempeleau, and Black River, as well as other smaller streams. The SPARROW model results indicate that 76% of the increased N load in the Mississippi River between Lake Pepin and the Iowa border is from Wisconsin tributaries and 24% is from Minnesota tributaries (see Chapter B-4). Estimates further upstream in Red Wing indicate that between Red Wing and the Iowa border in the Lower Mississippi Basin, Wisconsin tributaries contribute 61% of the TN loads and Minnesota 39%.

The average load at the Lake Pepin inlet (1992-2009) is 160 million pounds. Calculated TN loads at the inlet and outlet of Lake Pepin show that the inlet has consistently higher loads than the outlet (Figure 5). Annual N losses within the Lake Pepin section of the river averaged 8.9% per year between 1992 and 2009. The nitrite+nitrate-N fraction of TN is similar at the inlet and outlet, averaging 81.1% at the inlet and 83.4% at the outlet. The N losses within Lake Pepin and on other stretches of the Mississippi are further discussed in Chapter B5 and Appendix B5-2. Total losses in the Mississippi River dam pools and reservoirs are estimated to be between 12 and 22%.
Figure 5. Average TN Loads at the inlet and outlet of Lake Pepin (1992-2009)

Mainstem rivers entering and leaving the Twin Cities

For several decades the Metropolitan Council Environmental Services (MCES) has maintained monitoring programs that routinely check water quality of the Metropolitan Area rivers, streams, and lakes. At four major river stations, samples have been taken two times per month since 1976, providing one of the best long term nutrient monitoring data sets available in Minnesota. The four monitoring station locations are shown in Figure 6, and include:

1. Minnesota River at Jordan – with a contributing watershed of 16,023 square miles from southern and southwestern Minnesota, and small portions of Iowa and South Dakota.
2. Mississippi River at Anoka – with a contributing watershed area of about 17,927 square miles of land in central and north-central Minnesota.
3. St. Croix River at Stillwater – with a contributing watershed area of about 7,069 square miles along eastern Minnesota and western Wisconsin.
4. Mississippi River at Prescott, Wisconsin Lock and Dam #3 – reflecting the combination of the above three watersheds along with contributions throughout the Twin Cities Metropolitan Area. The contributing watershed area is about 44,800 square miles.
The loads at these four mainstem river monitoring stations were calculated by MCES and provided to the MPCA. The loads were calculated using the U.S. Army Corps of Engineers’ software Flux32, from monitored daily average flow and grab sample chemistries taken every other week. Since flow in the four mainstem rivers responds relatively slowly to precipitation events, MCES and MPCA staff had determined, based on the MCES sampling frequency, that using a one-year record of average daily flow and grab sample water chemistry data was adequate to estimate annual loads for the mainstem rivers with acceptable uncertainty. The application of a one-year data set to define an annual river load, rather than multiple years, was viewed as acceptable since river events are typically defined as a multi-day record (three days or greater). The subtle nature of the river system hydrograph, along with consistent frequency of monitoring, allows for a strong statistical relationship when using regressions within Flux.
Loading calculations are an estimate based on monitoring results, and as such are subject to a range of variability. This variability depends on the water quality sampling frequency and regimen, as well as complexities in the watershed hydrologic responses to different runoff events. MCES calculated 95% confidence intervals around each estimated annual load. In a high-confidence year such as 2008 the 95% confidence interval ranged from 11% higher than the estimated load to 11% lower than the estimated load. Yet for certain other years the 95% confidence interval exceeded 50%. While the loads were calculated using single year analyses, in this report we use multiple year averages of those single year load estimates to represent typical loads, reducing the variability associated with single year estimates. The averages and medians were very similar in the Metropolitan Council data sets, typically differing by only 1% to 6% when looking at 20 to 30 year periods. Therefore, the results presented in this chapter would be similar whether using long-term means or medians.

Because the early and late 1980’s were relatively dry, the average combined N load during the period 1980-2010 (150,731,000 pounds) is 8.6% lower compared to the 1991-2010 average (164,993,000 pounds). Except where noted, average statistics in this section use the 1991 to 2010 period instead of the complete 30-35 year record, since the 1991-2010 period: a) is more recent and will better represent current loads from more recent land uses, land management and climate, and b) the time period better matches available USGS monitoring data in the Lower Mississippi Basin.

Year to year load variability
The combined N loads from the Mississippi River (at Anoka), the Minnesota River (at Jordan), and the St. Croix River (at Stillwater) between 1980 and 2010, are represented in Figure 7. The drought years in the late 1980s had low N loads; whereas the wet period between 1991 and 1993 had high loads. The river flows show a somewhat similar, but less pronounced, year to year variability (Figure 8).

Figure 7. Annual combined total N loads from the three mainstem rivers entering the Twin Cities Area: the Mississippi River in Anoka, the St. Croix River in Stillwater, and the Minnesota River in Jordan. Time period 1980 to 2010.
Figure 8. Annual combined TN river flow from the three major rivers entering the Twin Cities: the Mississippi River in Anoka, the St. Croix River in Stillwater, and the Minnesota River in Jordan.

The Minnesota River N loads have been much higher than the loads from the St. Croix at Stillwater and Mississippi at Anoka. The Minnesota River Basin contributes 69% of the total N loads and 78% of the nitrate loads which arrive at the Twin Cities Metropolitan Area in the three mainstem rivers, on average (Figure 9); yet represents only 38% of the total combined land area of the Minnesota, Upper Mississippi, and St. Croix River Basins.

Figure 9. Proportions of TN load flowing into the Twin Cities from the three mainstem rivers, the Minnesota, St. Croix, and Mississippi (average of years 1991-2010).
Nitrogen forms in the rivers

Most of the N is in the nitrate and organic forms, together representing between 95% and 99% of the TN (Table 3). Ammonia+ammonium-N and nitrite-N tend to convert to nitrate in the presence of oxygenated waters, and concentrations are much smaller than nitrate, together constituting between 1 and 5% of the TN. Therefore, while N parameter results are often reported as nitrite+nitrate-N and TKN (ammonium+organic-N), the nitrate and organic-N forms typically represent most of the N.

The mean organic-N concentrations range from 0.57 mg/l in the St. Croix River to 1.27 mg/l in the Minnesota River. Long term average FWMC of nitrate-N varies more greatly than organic N in the three rivers, ranging from 0.35 mg/l in the St. Croix River to 6.74 mg/l in the Minnesota River (Figure 11 and Table 3).
Table 3. Annual FWMC for different forms of N averaged for years 1991-2010. Calculated from data provided by MCES. Nitrite was calculated by subtracting nitrate from the laboratory results presented as nitrite+nitrate. Organic-N was determined by subtracting NH3+NH4 from TKN.

<table>
<thead>
<tr>
<th></th>
<th>Nitrate-N FWMC (mg/l)</th>
<th>Organic-N FWMC (mg/l)</th>
<th>Ammonia + Ammonium-N FWMC (mg/l)</th>
<th>Nitrite-N FWMC (mg/l)</th>
<th>Total N FWMC (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minnesota River</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jordan</td>
<td>6.74</td>
<td>1.27</td>
<td>0.09</td>
<td>0.13</td>
<td>8.23</td>
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<tr>
<td>St. Croix River</td>
<td>0.35</td>
<td>0.57</td>
<td>0.05</td>
<td>0.01</td>
<td>0.98</td>
</tr>
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<td>Stillwater</td>
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<tr>
<td></td>
<td>1.32</td>
<td>0.89</td>
<td>0.07</td>
<td>0.01</td>
<td>2.29</td>
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<td>Miss. River</td>
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<tr>
<td>Anoka</td>
<td>2.63</td>
<td>0.99</td>
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</tbody>
</table>

Figure 11. Flow weighted mean concentrations of total N, nitrite+nitrate-N and organic-N in the three mainstem rivers entering the Twin Cities region (average of 1991-2010).

In the Minnesota River at Jordan, nitrite+nitrate-N dominates the load, representing 84% of the TN load (Figure 12). In the lower N loading rivers of the St. Croix and Mississippi at Anoka, the nitrite+nitrate-N fraction is only 37% and 56% of the TN load, respectively.
The organic N concentration is similar, but higher, in the Minnesota River as compared to the Upper Mississippi. One reason for this could be a higher amount of algae growth in the Minnesota River. A negative correlation between TKN concentration and flow in the Minnesota River (Figure 13) suggests that it is unlikely that the elevated TKN is due to the sediment in the river. During the high flow years, TKN concentrations were nearly half of the concentration during very low flow years.

Figure 12. Average annual loads of various N forms in the Minnesota, St. Croix, and Mississippi Rivers entering the Twin Cities Area (1991-2010).

Figure 13. Relationship between long term (1991-2010) annual TKN flow-weighted mean concentrations and annual flow in the Minnesota River at Jordan.
Month to month variability

Average monthly TN and nitrite+nitrate-N loads were determined for the 20-year period 1991 to 2010. Total nitrogen and nitrate loads are highest in the spring months of April to June in the Minnesota, Mississippi, and St. Croix Rivers (Figures 14-16). The peak N loading month is April at all three rivers. Loads are relatively low from August through February.

Figure 14. Long term average monthly TN and nitrite+nitrate-N loads in the Minnesota River at Jordan.

Figure 15. Long term average monthly TN and nitrite+nitrate-N loads in the Mississippi River at Anoka.
Loads are influenced by both flow and concentration. In the spring months both flow and nitrate concentrations are elevated in the Minnesota River. In the Minnesota River (Jordan) average nitrate concentrations increase from less than 4 mg/l in the winter to about 7 mg/l in May and June (Figure 17). While much less pronounced than in the Minnesota River, an increase in both nitrate and TKN concentrations occurs in the Upper Mississippi River Basin during the spring months (Figure 18). Monthly concentrations in the St. Croix River Basin behave differently, with nitrate concentrations dropping in half during the spring and summer months and peaking in the winter months when flow is dominated by groundwater baseflow and algae production is minimal (Figure 19). In the St. Croix River summer months, organic N increases during the period when algae production increases. Yet, TKN concentrations in the St. Croix remain lower than in the Minnesota River, even during the peak months.

As the three large rivers coming into the Twin Cities Area merge into the Mississippi River south of the Twin Cities (at Lock and Dam #3 near Prescott, Wisconsin), the monthly nitrite+nitrate-N and total N concentration patterns are similar to the patterns observed in the Minnesota River (Figure 20).

The substantial differences in seasonal N concentration patterns among the three mainstem rivers might be explained, in part, by different land uses and flow pathways. The Minnesota River Basin has the highest fraction of tile-drained land. By comparison, the Upper Mississippi River Basin and the St. Croix Basin have less tile drained agricultural lands and more continuously discharging groundwater baseflow inputs (see Chapters D1 and D4).
Figure 17. Long term average monthly TKN and nitrite+nitrate-N flow-weighted mean concentrations in the Minnesota River at Jordan.

Figure 18. Long term average monthly TKN and nitrite+nitrate-N flow-weighted mean concentrations in the Mississippi River at Anoka.
Figure 19. Long term average monthly TKN and nitrite+nitrate-N flow-weighted mean concentrations in the St. Croix River at Stillwater.

Figure 20. Long term average monthly TKN and nitrite+nitrate-N flow-weighted mean concentrations in the Mississippi River at Prescott, Wisconsin (Lock and Dam #3).
Twin Cities influence on river nitrogen

Using the 1991-2010 N loading data sets provided by the Metropolitan Council, we compared nitrate loading in the combined three mainstem river sites coming into the Twin Cities with the Mississippi River location flowing out of the Metropolitan Area at Lock and Dam #3 in Prescott, Wisconsin. Differences between the Twin Cities inputs and outputs can potentially be due to: a) uncertainty/error in the estimates; b) N losses through denitrification and other processes within the river; c) stormwater N additions from the urban, suburban, and rural areas; and d) municipal and industrial wastewater discharges in the Metropolitan region.

The 1991-2010 average annual TN was found to be 6 million pounds (3.5%) higher between the combined Jordan/Anoka/Stillwater monitoring points upstream of the Twin Cities, and the Prescott monitoring point downstream of the Twin Cities (Figure 21). This mean TN difference is similar to that found a decade earlier by Kloiber (2004), who looked at the period 1992 to 2001 and found that TN increased by 2.5% through the Twin Cities Metropolitan Area. Kloiber reported that the 2.5% difference was within the potential range of uncertainty in the load calculations. Similarly, we found that with the high year-to-year variability in loads, the average 1991-2010 TN loads from rivers into the Twin Cities compared to the average loads out of the Twin Cities was not found to be statistically significant (two-sample t-test, p-value = 0.54).

Figure 21. Average annual TN entering the Twin Cities Metropolitan Area in three mainstem rivers: the Minnesota, St. Croix, and Mississippi (average of years 1991-2010), compared to TN leaving the Metropolitan Area in the Mississippi River. The two middle bars represent the added sources of a) estimated point source TN additions to the river in the Twin Cities Area and b) the estimated nonpoint TN sources from stormwater and groundwater in the Metropolitan Area.
We know that some N additions occur in the Twin Cities Area. Point sources plus nonpoint sources add an estimated 13.8 million pounds of N in the Twin Cities Area (12.8 million pounds from point sources and 1 million pounds from stormwater runoff and groundwater contributions – see Chapters D2 and D4). A part of these additions is expected to be offset by in-stream N losses from natural processes as these rivers flow through the Twin Cities. Therefore, while the 6 million pound average increase throughout the Metropolitan Area is not statistically significant, it is within a reasonable range of expected net change considering estimated N inputs and potential N losses within the rivers.

Figure 22 shows the relative amounts of different N forms for the mainstem river inputs into the Twin Cities and the exports out of the Twin Cities. There is a disproportionately higher increase in organic N and ammonium, as compared to nitrate. This could be due to sampling uncertainties, organic N additions and/or in-stream processes where nitrate is used by algae and thereby transformed into organic N.

![Nitrogen Forms Into & Leaving Twin Cities](image)

**Figure 22.** Annual loads of the three different forms of N comprising TN, showing the difference in N forms in the combined mainstem rivers entering the Twin Cities and N forms in the Mississippi River near Prescott downstream of the Twin Cities.

As the Mississippi River continues to flow downstream into southeastern Minnesota, TN loads decrease between Prescott, Wisconsin and the outlet of Lake Pepin. Within this stretch of the river, N inputs are minimal and in-stream losses are measurable (see Chapter B5).

**Nitrogen additions in upstream reaches**

Nitrogen increases along the upstream reaches of the Mississippi, Minnesota, and St. Croix Rivers were determined from monitoring results collected during 2007 to 2009. The rivers were sampled near the upstream and downstream points of the mainstem HUC8 watershed boundaries as part of the
Minnesota Watershed Pollutant Load Monitoring network, described in Chapter B3. The results for TN and nitrite+nitrate-N are shown in Figures 23 and 24 as a fraction of load measured in the Mississippi River at Lock and Dam #3 in Prescott Wisconsin, south of the Twin Cities.

The N loads remain a relatively low percentage of the Mississippi River at Prescott loads in most upstream river stretches, and show increasing loads moving downstream. The loads increase dramatically in the Minnesota River between Judson and St. Peter where TN increases from 22% of the Prescott loads to 53% of the loads and nitrite+nitrate-N increases from 23% to 59% of the Prescott loads, as the Minnesota River receives flow from the Blue Earth, Watonwan, and Le Sueur Rivers.

Toward the mouth of the Minnesota River, TN and nitrite+nitrate loads represent 63 and 74% of the loads in the Mississippi River at Prescott, Wisconsin. The Upper Mississippi and St. Croix rivers have TN and nitrite+nitrate loads which remain less than 10% of Prescott loads, except that the Upper Mississippi River loads at Anoka increase to 24% (TN) and 19% (nitrite+nitrate) of the loads in Prescott, downstream of the confluence with the Crow River.

Figure 23. Average TN loads (2007-2009) at different points along the Minnesota, Mississippi and St. Croix Rivers, expressed as a percentage of the load measured at the Mississippi River Lock and Dam #3 near Prescott, Wisconsin (after the convergence of the three rivers).
Red River

The U.S. portion of the Red River Basin, depicted in Figure 25, originates mostly in Minnesota and North Dakota, with a small percentage also in South Dakota. After crossing the U.S./Canadian border, additional Manitoba watersheds flow into the Red River before it discharges into Lake Winnipeg.

**Minnesota’s contribution to Emerson nitrogen loads**

Based on unpublished data provided by Environment Manitoba (Manitoba Water Stewardship and Environment Canada, the average Red River annual TN load between 1994 and 2008 at the Canadian border in Emerson, Manitoba was 37,326,000 pounds/year (Figure 26). Nitrate concentrations are relatively low in the Red River, and only 42% of the TN is in the nitrate form, with the remainder as TKN (organic-N and ammonia+ammonium-N). Most of the Red River load in Emerson originates in the United States, with only 5.5% coming from Canadian watersheds which flow into North Dakota before joining up with the Red River in the United States. Therefore, 94.5% of the 37 million pounds of N reaching the

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Figure 24. Average nitrite+nitrate-N loads (2007-2009) at different points along the Minnesota, Mississippi, and St. Croix rivers, expressed as a percentage of the load measured at the Mississippi River Lock and Dam #3 near Prescott, Wisconsin (after the convergence of the three rivers).
Canadian border in the Red River is from Minnesota and the Dakotas. Of the United States contributions, SPARROW modeling results indicate that 48% of the United States load is from Minnesota, and 52% is from the Dakotas (see Chapter B4).

Therefore, if we assume 37,326,000 pounds/year of TN at Emerson, of which 94.5% is from the United States and 48% of that amount is from Minnesota, Minnesota’s N contribution to the Red River is estimated as 16,931,000 pounds/year, on average.

Figure 25. Red River Basin boundaries. From Bourne et al., 2002.

Figure 26. Red River estimated annual N Loads based on monitoring data at Emerson, Manitoba near the U.S./Canadian border. Monitoring and load calculations from Manitoba Conservation Water Stewardship and Environment Canada. Only TN was available for 2000.
United States contributions to Lake Winnipeg

Environment Canada (2011) assessed TN loads from the period 1994 to 2007, including loads from such sources as atmospheric deposition directly into Lake Winnipeg. They concluded that the Red River from the United States and Canada watersheds contributed 34% of the N load to Lake Winnipeg. In an earlier report, Bourne et al. (2002) concluded that 65% of the Red River N comes from the United States. Combining these results, we can assume that approximately 22% of the N load to Lake Winnipeg comes from watersheds in Minnesota and the Dakotas, with about 11% of the Lake Winnipeg TN load from Minnesota.

Summary points

- Long-term (15-30 years) monitoring-based loads, yields and flow-weighted mean concentrations were assessed for the Minnesota River (Jordan), Red River (Emerson), Upper Mississippi River (Anoka), St. Croix River (Stillwater), Mississippi River at Prescott, Wisconsin, Mississippi River at Lake Pepin, and Mississippi River at the Iowa border.
- The Red River is a significant contributor of N to Lake Winnipeg. The United States contributes an average of 37 million pounds of N to the Canadian border each year, and approximately 48% of that amount (16.9 million pounds) is from Minnesota. This export of N compares to 211 million pounds, leaving southern Minnesota in the Mississippi River each year, on average, of which an estimated 162 million pounds are from Minnesota watersheds.
- The Minnesota River N contributions (average 116 million pounds/year) have the greatest influence on N loads leaving Minnesota in the Mississippi River at the Iowa border. Minnesota River TN loads are about twice as high as the combined loads from the Upper Mississippi River, St. Croix River, and Twin Cities additions. The Minnesota River loads increase greatly between Judson and St. Peter, Minnesota, where the Greater Blue Earth River N loads reach the Minnesota River.
- The Mississippi River TN increases by 37 million pounds between the Twin Cities and the Iowa border. About 9% of all N reaching Lake Pepin is lost in the lake (mostly converted to N gas). An estimated 61% of the loads in the Lower Mississippi Basin tributaries are from Wisconsin and 39% from Minnesota, based on SPARROW modeling.
- Long-term average TN yields and flow-weighted mean concentrations are substantially higher in the Minnesota River, and are between 3.5 and 8 times higher than the Red, St. Croix, and Upper Mississippi Rivers.
- Year-to-year variability in TN loads and river flow can be very high, especially in river systems with lower groundwater baseflow contributions and higher tile line contributions. In the Minnesota River Basin, TN loads during low flow years are sometimes as low as 25% of the loads occurring during high flow years.
- The primary forms of N in the mainstem river systems are nitrate-N and organic-N. Nitrite-N and ammonia+ammonium-N are quite low and together comprise only 1% to 5% of the TN. Organic-N FWMCs are more consistent across the state as compared to nitrate, and range from 0.6 mg/l in the St. Croix to 1.4 mg/l in the Red River. Long-term average nitrite+nitrate-N FWMCs range from 0.3 mg/l in the St. Croix to 6.7 mg/l in the Minnesota River. While organic N is equal to or higher than nitrate in some river basins, nitrate is the parameter which most greatly affects TN loads across the state.
• Nitrite+nitrate-N loads in the Minnesota River (Jordan) are more than three times higher than the combined nitrite+nitrate-N loads from the Upper Mississippi, St. Croix, and Twin Cities tributary contributions. The Minnesota River's 97 million pounds constitutes a large fraction of the 158 million pounds leaving the state in the Mississippi River, and is much greater than the 16 million pounds leaving the state in the Red River of the North.

• Total nitrogen loads in the Minnesota, Mississippi, and St. Croix Rivers peak in April and May. About two-thirds of the annual TN load in the Mississippi River at the Iowa border occurs during the five months between March and July. This is due to both increased flow and increases in N concentrations during these months.

• The Twin Cities Metropolitan Area contributes relatively minor amounts of N to the major rivers. The Twin Cities increase river TN by 3% to 4%, on average, which was not found to be a statistically significant increase. Based on information supported in other chapters, over 90% of the added N from the Twin Cities is expected to be from point sources, mostly human wastewater, with relatively little additions from nonpoint sources such as stormwater.

References


