Minnesota Pollution Control Agency

Minnesota Nutrient Reduction Strategy Support

Assessment of Major River Basin Loads and Reductions Needed to Meet Goals

June 11, 2025

Appendix 2-1 of Minnesota's 2025 NRS

REVISED DRAFT

TETRA TECH

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EXECUTIVE SUMMARY

In 2014, Minnesota adopted a statewide Nutrient Reduction Strategy (NRS) as a large-scale planning framework for reducing phosphorus and nitrogen in Minnesota's waterways and the loading that Minnesota waters contribute to downstream waterways. The Minnesota Pollution Control Agency (MPCA) is now working on an update to the 2014 NRS that will be published as Minnesota's 2025 NRS. To this end, MPCA has sought technical support from Tetra Tech, which provided such support to MPCA for Minnesota's 2014 NRS.

To support development of Minnesota's 2025 NRS, MPCA contracted with Tetra Tech to:

- **#1**: Assess major river basin and state-line loads and determine the remaining nutrient load reduction needs to meet downstream goals
- **#2**: Estimate source contributions to the river nutrient loads
- **#3**: Evaluate watershed nutrient load reduction needs to achieve downstream goals

To achieve these broad objectives, MPCA has also defined specific tasks and subtasks.

This report summarizes the results of the first objective. Generally, this report presents assessments of monitoring and modeling data near major river basin outlets and state lines, identifies progress toward meeting the milestones and goals of the 2014 NRS, and makes recommendations on remaining load reduction needs.

Monitoring Data

Total nitrogen (TN) and total phosphorus (TP) load and flow-weighted mean concentration (FWMC) monitoring data and flow monitoring data collected by MPCA, Metropolitan Council Environmental Services (MCES), the U.S. Geological Survey, and the Manitoba Conservation and Water Steward Ship and Environment Canada (CWSEC) were compiled and evaluated. Long-term averages were calculated for baseline periods and current periods.

- ***Mississippi River* major basin**: Between the baseline (1980-1996) and the most recent 10-years (2013-2022 or 2014-2023) periods, flows increased in the Mississippi River at Anoka and at Red Wing and flow increased in the Minnesota River at Jordan.

  TP and TN trends were evaluated using results from FLUX32 and WRTDS. TP FWMCs decreased between baseline and more recent periods (most recent 10-years or 5-years) in the Mississippi River at Anoka, at Red Wing , at Winona, and at La Crosse and decreased in the Minnesota River at Jordan. TP loads decreased in the Mississippi River at Anoka , at Red Wing , at Winona, and La Crosse but increased in the Minnesota River at Jordan.

  TN FWMCs mostly decreased between baseline and more recent periods (most recent 10-years or 5-years) in the Mississippi River and the Minnesota River . TN loads mostly increased in the Mississippi River and increased in the Minnesota River.

  The differences in FWMC and load trends may be the result of increased flow between 1980-1996 and 2013-2022 or 2014-2023.
- ***Lake Winnipeg* major basin**: Between the baseline (1996-2000) and the most recent 10-year (2013-2022 or 2014-2023) periods in the Red River of the North at Emerson, Manitoba Canda, flow decreased by 15% to 16%. TP and TN trends were evaluated using results from monthly extrapolations to annual loads by CWSEC and WRTDS by MPCA. Between the baseline and more recent periods (most recent 10-years or 5-years), TP FWMCs increased and TP increased or decreased, depending on the recent period. TN FWMCs and loads decreased. The differences between FWMC and loads are likely the result of less flow in the Red River of the North.

Insufficient historic data are available to evaluate trends in tributaries most tributaries.

The increase in TP and TN loads at several locations in the Mississippi River major basin between 1980-1996 and 2013-2022 may be due to increased flow over the same period. If changes in flow are not considered, load analysis may not show progress toward achieving 2040 goals. At a few key sites, agencies used WRTDS to calculate flow-normalized concentrations and loads.

- ***Mississippi River* major basin**: Between the 1980-1996 and 2023, flow-normalized TP and TN loads and FWMCs decreased in the Mississippi River (at Red Wing and Winona) and the Minnesota River at Jordan. Across the same periods, flow-normalized TN loads remained the same in the Mississippi River at Red Wing (-0.4%) and flow-normalized TN loads decreased in the Minnesota River at Jordan (-17%).
- ***Lake Winnipeg* major basin**: Between the 1996-2000 and 2023 in the Red River of the North at Emerson, Manitoba Canda, flow-normalized TP loads decreased and flow-normalized TN loads were relatively unchanged, while both flow-normalized TP and TN concentrations decreased

Modeling Data

MPCA has invested in the development of Hydrologic Simulation Program – FORTRAN (HSPF) models across the state of Minnesota. Today, 68 models represent 75 subbasins, wholly or partially, within Minnesota. Since the 2014 NRS many new models have been developed and many existing models have been updated (e.g., recalibrated). RESPEC provided two sets of model results that represent the most recent 10-year (approximately) averages of flow, TP, and TN load: (1) flows and loads delivered to individual model reaches and (2) flows and loads delivered to subbasin outlets.

HSPF models have not yet been developed for six subbasins in the *Mississippi River* major basin. The U.S. Geological Survey has developed SPAtially-Referenced Regression On Watershed attributes (SPARROW) models to estimate long-term loads, delivered loads, yields, and delivered yields. In this study, SPARROW model results from 2002-2014 and delivered to subbasin outlets are used to represent these six subbasins.

TP and TN yields to subbasin outlets were evaluated. Generally, TP yields were low in the more forested and less developed *Lake Superior* (HUC 0401; except the *Nemadji River* subbasin [HUC 04010301]), *Rainy River* (HUC 0903), and *Upper Mississippi River* (HUC 0701) subregions, and TP yields were high in the more agricultural *Lower Mississippi River* (HUCs 0704 and 0706) and *Minnesota River* (HUC 0702) subregions. The geographic distribution of TN yields was similar to the distribution of TP yields, with the notable exceptions of lower TN yields in much of the *Red River* (HUC 0902) subregion and higher TN yields in the subbasins bisected by the Minnesota-Iowa state boundary.

The 2014 NRS set load goals at key locations (e.g., the Mississippi River at the Iowa-Minnesota-Wisconsin boundary). To determine progress since the 2014 NRS, modeled loads needed to be determined for the key locations. Nutrient attenuation factors previously developed by MPCA for each subbasin, wholly or partially, within Minnesota were applied to the HSPF and SPARROW modeled loads delivered to subbasin outlets to estimate the loads delivered to the key locations.

Comparison of Monitored and Modeled Loads

Monitored and modeled loads were compared at key locations along state boundaries. The monitored loads represent the Minnesota-portion of current monitored loads averaged over a recent 10-year period (often, 2013-2022). For most subbasins, the modeled loads represent the Minnesota-portion of the most recent 10-years of HSPF modeled loads. For a few subbasins, the modeled loads represent the Minnesota-portion of SPARROW modeled loads for 2002-2014. Both monitored and modeled loads were reduced by a nutrient attenuation factor to calculate loads delivered to the key locations along state borders.

In most of the comparisons, the monitored and modeled loads were similar. The percent differences between monitored and modeled TP loads ranged from <1% to 6%. The percent differences between monitored and modeled TN loads ranged from <1% to 4% for the Mississippi and Minnesota rivers at the state boundary and the St. Louis River at Lake Superior. The percent differences between monitored and modeled loads were much large for the Cedar, Des Moines, and Missouri rivers at the state boundary (14%), Red River of the North at Emerson, Manitoba, Canada (10%), Rainy River at Manitou Rapids (17%), and the Nemadji River at Lake Superior (19%).

Discrepancies between monitored and modeled loads are likely the result of two factors: (1) the model simulation periods often predate the recent monitoring period (i.e., monitored loads represent recent improvements in water quality, while modeled loads do not), and (2) monitored loads often represent a smaller geography than the modeled loads because monitoring sites were often upstream of the key locations along state boundaries (e.g., an unmonitored tributary discharges to the mainstem between the monitoring site and key location on a state boundary). Additional complicating factors are that (1) modeled loads for certain key locations are the summation of HSPF and SPARROW model results, which are very different models, and (2) monitored in-stream loads were reduced by the out-of-state fraction that was calculated using SPARROW model results.

TABLE OF CONTENTS

APPENDIX

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMNS AND ABBREVIATIONS

Acronym or abbreviation	Definition
CWSEC	Manitoba Conservation and Water Steward Ship and Environment Canada
FNC	flow-normalized concentration
FWMC	flow-weighted mean concentration
GIS	geographic information system
HSPF	Hydrologic Simulation Program - FORTRAN
HUC	hydrologic unit code
L&D	lock and dam
MCES	Metropolitan Council Environmental Services
MnDNR	Minnesota Department of Natural Resources
MPCA	Minnesota Pollution Control Agency
NN	nitrate + nitrite
NRS	Nutrient Reduction Strategy
RM	river mile
SPARROW	SPAtially-Referenced Regression On Watershed attributes
TKN	total Kjeldahl nitrogen
TN	total nitrogen
TP	total phosphorus
TSS	total suspended solids
USGS	U.S. Geological Survey (U.S. Department of the Interior)
WRTDS	Weighted Regressions on Time, Discharge, and Season

Unit of measure	Definition
cfs	cubic feet per second
cms	cubic meters per second
lbs.	pounds
lbs./ac./yr.	pounds per acre per year
mg/L	milligrams per liter
MTA	metric tons annually; metric tons per year

1 INTRODUCTION

Minnesota developed a Nutrient Reduction Strategy (NRS) in 2014 to guide the reduction of nutrient-loading to Minnesota's waters and downstream waters. This large-scale framework established milestones and final load goals at Minnesota's state boundaries. The 2014 NRS recommended reductions for agriculture, wastewater, and other sources to achieve milestones and goals. To collectively achieve these goals and milestones, reductions were estimated for each subbasin, or hydrologic unit defined by an 8-digit code (HUC8).

In 2022, the Minnesota Pollution Control Agency (MPCA) developed interim guidance to refine the necessary reductions by sector for each subbasin (MPCA 2022).The subbasin goals in the interim guidance were developed using modeling results through 2018.

In 2024 and 2025, MPCA developed Minnesota's 2025 NRS.

1.1 OBJECTIVES

To support development of Minnesota's 2025 NRS, MPCA contracted with Tetra Tech for technical support to meet three objectives:

- **Objective #1**: Assess major river basin and state-line loads and determine the remaining nutrient load reduction needs to meet downstream goals
- **Objective #2**: Estimate source contributions to the river nutrient loads
- **Objective #3**: Evaluate watershed nutrient load reduction needs to achieve downstream goals

MPCA also defined specific tasks and subtasks for each objective.

This report presents the data, analyses, and results for Objective #1. The three tasks for Objective #1 are:

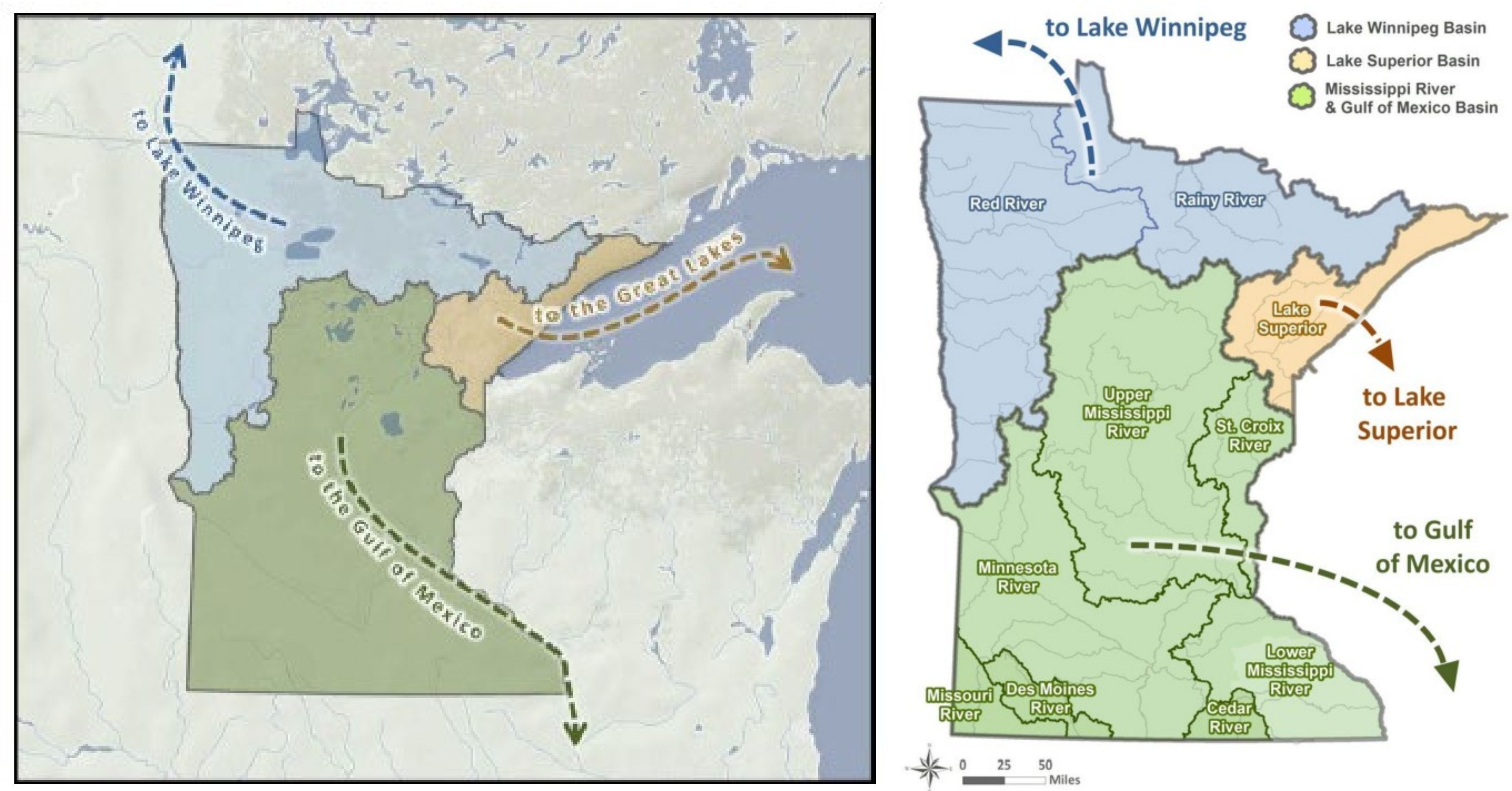
- **Task A**: Assess and plot load monitoring results near major river basin outlets and state lines
- **Task B**: Assess modeled watershed outlet nutrient loads and estimated aggregated modeled loads reaching state lines
- **Task C**: Make recommendations on remaining load reduction needs

In this report, Sections 2, 3, and 4 coincide with Tasks A, B, and C, while the subsections in each section generally coincide with the subtasks within each task.

1.2 MAJOR BASINS

In the 2014 NRS, MPCA (2014) divided the state into three major basins: *Lake Winnipeg*, *Lake Superior*, and *Mississippi River & Gulf of Mexico* (Figure 1). MPCA (2014) established goals and milestones for these major basins.

The Minnesota Department of Natural Resources (MnDNR) developed new names for hydrologic units that were delineated and originally named by the U.S. Geological Survey (USGS). MPCA typically uses the hydrologic unit names defined by MnDNR; however, MPCA has deviated from this naming scheme for the 2014 NRS and the 2025 NRS. Table 1 presents the HUCs and hydrologic unit names developed by USGS, MnDNR, and MPCA (for the NRS).



Source: 2014 NRS (MPCA 2014, Figure 1 [left] and Figure 2-1 [right]).

Figure 1. Major river basins in Minnesota.

Table 1. Hydrologic unit names

HUC	USGS	MnDNR	MPCA (for the NRS)
***Mississippi River* major basin**			
0701	Mississippi Headwaters	Mississippi River – Headwaters	Upper Mississippi River
0702	Minnesota	Minnesota River	Minnesota River
0703	St. Crois	St. Croix River	St. Croix River
0704	Upper Mississippi – Black Root	Lower Mississippi River	Lower Mississippi River
0706	Upper Mississippi – Maquoketa – Plum	Mississippi River – Upper Iowa Rivers	
0708	Upper Mississippi – Iowa – Skunk – Wapsipinicon	Cedar River	Cedar River
0710	Des Moines	Des Moines River	Des Moines River
1017	Missouri – Big Sioux	Missouri River – Big Sioux River	Missouri River
1023	Missouri – Little Sioux	Missouri River – Little Sioux River	
***Lake Winnipeg* major basin**			
0902	Red River	Red River of the North	Red River of the North
0903	Rainy River	Rainy River	Rainy River
***Lake Superior* major basin**			
0401	Western Lake Superior	Western Lake Superior	Lake Superior

Note: HUC = hydrologic unit code; MnDNR = Minnesota Department of Natural Resources; MPCA = Minnesota Pollution Control Agency; NRS = Nutrient Reduction Strategy; USGS = U.S. Geological Survey.

2 ASSESSMENT OF MONITORING RESULTS

To support the development of Minnesota's 2025 NRS, MPCA contracted with Tetra Tech to *assess and plot load monitoring results near major river basin outlets and state lines*. The analysis is summarized in this section of the report, which begins with a presentation of available data (Section 2.2). The section then continues with a comparison of baseline and current loads (Section 2.3), an evaluation of flow-load relationships (Section 2.6), and an assessment of out-of-state nutrient load contributions (Section 2.7). This section concludes with an assessment of progress toward achieving milestones and goals (Section 2.8)

Several appendices contain charts of monitoring data. Charts for trend analysis are presented for the Mississippi River (Appendix A), tributaries to the Mississippi River (Appendix B), the Lake Winnipeg major basin (Appendix C), and the Lake Superior major basin (Appendix D). Charts for assessment of flow and load relationships at key monitoring stations are presented in Appendix E.

2.1 METHODS TO ESTIMATE LOADS

Throughout this report, results from two types of analyses are presented: FLUX32 and *Weighted Regressions on Time, Discharge, and Season* (WRTDS; Hirsch et al. 2010). Software for both types of analyses use daily flow records and available water quality data to estimate annual loads and evaluate load and concentration trends.

MPCA (2024) describes FLUX 32 as user-friendly, Windows-based, interactive software capable of sophisticated "evaluations of data and flow relations and calculation of material fluxes (loads) in streams" that was developed by the U.S. Army Corps of Engineers and MPCA. Typically, MPCA (2024) uses daily streamflow from the U.S. Geological Survey (USGS) or MnDNR and water quality data from a variety of sources.

WRTDS uses weighted regressions of concentrations on time, discharge, and season to represent "the long-term trend, seasonal components, and discharge-related components of the behavior of the water-quality variable of interest" (Hirsch et al. 2010). Additionally, WRTDS can be used to estimate flow-normalized concentrations and loads, where "the influence of year-to-year variations in streamflow" is eliminated.

2.2 AVAILABLE DATA

Estimated total nitrogen (TN) and total phosphorus (TP) loads were provided by MPCA that originated from the Manitoba Conservation and Water Stewardship and Environment Canada (CWSEC), the Metropolitan Council Environmental Services (MCES), MPCA, and USGS.

A map of primary and supplemental monitoring sites is presented in Figure 2 on page 5. Additional information about many of these monitoring sites is presented in the 2014 NRS (MPCA 2014).

For reference Table 2 on page 6 presents the locks and dams on the Mississippi River along Minnesota's eastern border. Monitoring sites from several agencies are collected at or near locks and dams.

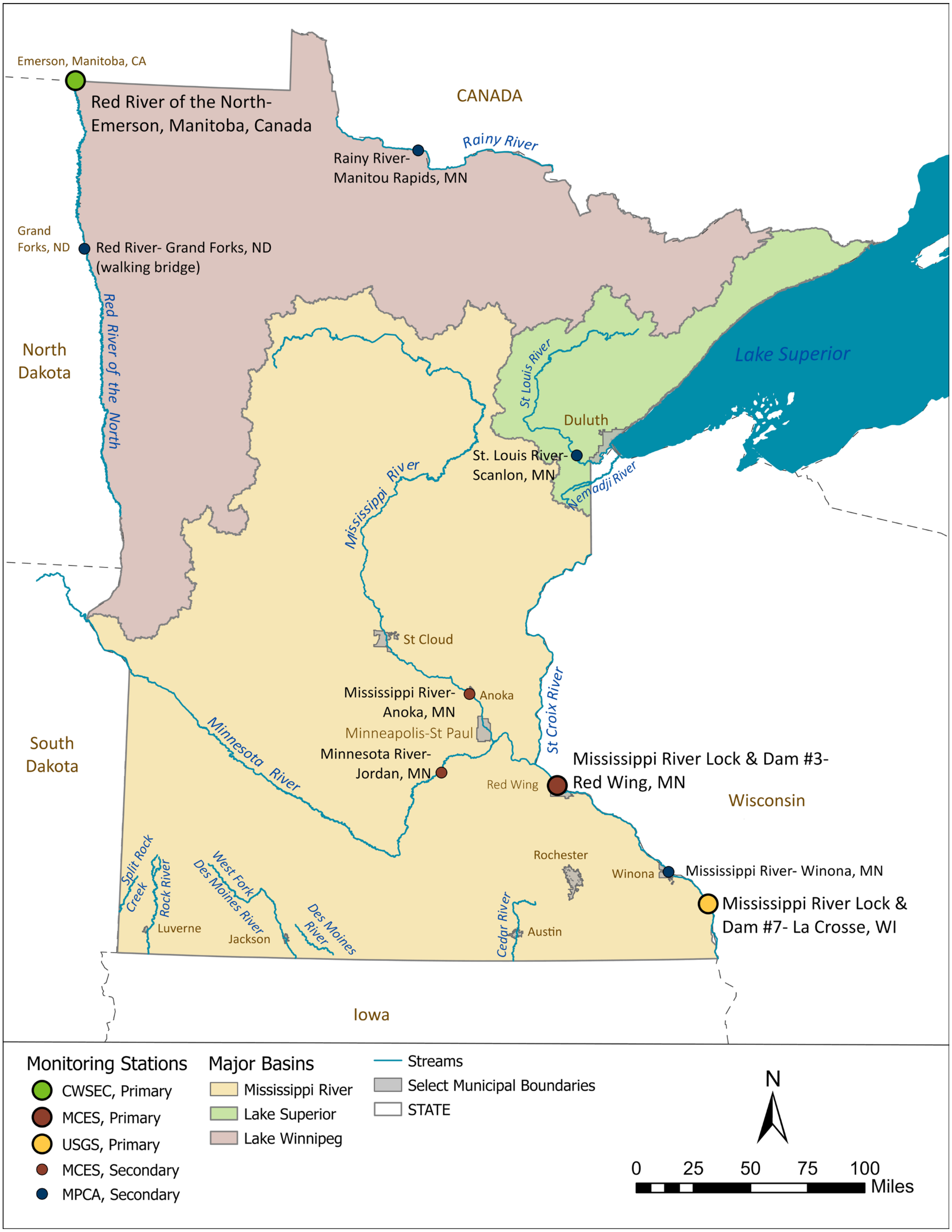


Figure 2. Primary and secondary monitoring sites for NRS revision analyses.

Table 2. Locks and dams along the Mississippi River

Lock and dam	River mile	Location
1	847.9	in Minneapolis, MN
2	815.2	upstream of Hastings, MN
3	796.9	near Red Wing, MN
4	752.8	in Alma, WI
5	738.1	10-miles northwest of Winona, MN
5A	728.5	near Fountain City, WI
6	714.1	at Trempealeau, WI
7	702.5	near La Crescent, MN
8	679.2	near Genoa, WI

Source: Mississippi River Parkway Commission 2020.

2.2.1 Manitoba Conservation and Water Stewardship and Environment Canada

CWSEC provided MPCA with annual flow (cubic meters per second [cms]), annual TP load (metric tons per year [MTA]), and annual TN load (MTA) for 1994 through 2022 for a monitoring site on the Red River of the North at Emerson, Manitoba, Canada.

CWSEC estimated annual loads for the Red River of the North at Emerson, Manitoba, using protocol established in the *State of Lake Winnipeg: 1999 to 2007* (CWSEC 2011). First, monthly loads are estimated by multiplying the TP or TN concentration from a sample collected in a given month (or the average of concentrations from multiple samples collected in a given month) by the monthly average flow, and then the estimated monthly loads are summed to estimate the annual load. [1] If no samples are collected within a given month (e.g., ice conditions prevent sample collection), the monthly load is estimated by averaging the estimated monthly loads for the previous and next month.

2.2.2 Metropolitan Council Environmental Services

MCES provided MPCA with annual flow volume (cubic feet per second [cfs]), annual mass (MTA), and annual concentration (milligrams per liter [mg/L]) for three monitoring sites (Table 3). The annual data were for four nutrients: TP, nitrate plus nitrite (NN), total Kjeldahl nitrogen (TKN), and TN. MCES calculated TN as the sum of NN and TKN.

MCES uses QWTREND to evaluate temporal trends in nutrient concentrations, uses FLUX32 to evaluate loads, and recently began to use WRTDS to evaluate both concentration and load trends. MCES only used WRTDS for their sites on the Minnesota River at Jordan and Mississippi River at Lock and Dam No. 3.

[1] Brian Wiebe, Senior Land-Water Specialist, Manitoba Environment and Climate Change, electronic communication, June 13, 2024.

Table 3. MCES monitoring sites

Code	Name	Period of record
MI39.4	Minnesota River at Jordan	1979 – 2023
UM796.9	Mississippi River at Lock and Dam No. 3	1976 – 2023
UM871.6	Mississippi River at Anoka	1976 – 2023

2.2.3 Minnesota Pollution Control Agency

MPCA provided annual flow volume (acre-feet), annual mass (kilograms), annual flow-weighted mean concentration (FWMC, mg/L; equivalent to annual mass divided by annual flow volume), and annual yield (pounds per acre). MPCA uses FLUX32 to estimate loads from event-based sampling. The annual mass, FWMC, and yields were for seven parameters: dissolved organic phosphorus, NN, TKN, TN, total organic phosphorus, TP, and total suspended solids. MPCA calculated TN as the sum of NN and TKN. MPCA provided monitoring data for nine monitoring sites (Table 4). The period of record varied by parameter, with notable data gaps for TP in 2012 and 2013.

Tetra Tech also obtained annual flow volume, annual mass, and annual FWMC data for MPCA's monitoring site on the Red River of the North at Emerson, Manitoba, Canada (S007-127) for 2009-2019. These data were only used in a comparison with CWSEC's monitoring data for the same site.

Table 4. MPCA monitoring sites

EQuIS ID	Hydstra ID	Name	Period of record
S000-001	E48020001	Cedar River near Austin, MN	2008 – 2021 [a]
S000-008	W61046002	Red River at Grand Forks, ND (walking bridge)	2007 – 2021
S000-096	E40006001	Mississippi River at Winona, MN	2009 – 2021 [a]
S004-528	H82015001	Split Rock Creek near Jasper, MN (201st Street)	2009 – 2021 [a]
S005-089	E03174001	St. Louis River at Scanlon, MN	2009 – 2021 [a]
S005-115	E05011002	Nemadji River near South Superior, WI	2009 – 2021 [a]
S005-381	H83016001	Rock River at Luverne, MN (CR4)	2010 – 2011 [a]
S005-936	E51107001	West Fork Des Moines River at Jackson, MN (River Street)	2007 – 2021 [a]
S006-897	E75005001	Rainy River at Manitou Rapids, MN	2010 – 2021

Note a: Total phosphorus data are not available in 2012 and 2013.

2.2.4 U.S. Geological Survey

USGS provided MPCA with annual discharge (cms), concentration (mg/L), flow-normalized concentration (mg/L), annual flux (kilograms per day), and annual flow-normalized flux (kilograms per day). The concentrations and loads were estimated using WRTDS for three parameters: NN, TN, and TP. USGS provided monitoring data for nine monitoring sites (Table 5).

> This information is preliminary and is subject to revision. It is being provided to meet the need for timely best science. The information is provided on the condition that neither the U.S. Geological Survey nor the U.S. Government shall be held liable for any damages resulting from the authorized or unauthorized use of the information.

Table 5. USGS monitoring sites

Site for water quality	Gage for flow	Period of Record
Black River	05382000	1994 – 2022
Cannon River	05355200	1992 – 2022
Chippewa River (WI)	05369500	1992 – 2022
La Crosse River	05383075	2000 – 2022
Mississippi River below L&D #3 (RM 786)	05344500	1994 – 2022
Mississippi River below L&D #7 (RM 702.5)	-- [a]	1992 – 2023
Mississippi River below Lake Pepin (RM 764)	05344500	1994 – 2022
St. Louis River at Scanlon, MN	04024000	2011 – 2023
Upper Iowa River	05388250	1994 – 2022

Notes

L&D = lock and dam; RM = river mile.

a. USGS estimates load at L&D #7 using flow estimates from the U.S. Army Corp of Engineers.

2.3 COMPARISON OF THE BASELINE AND CURRENT PERIODS

Loads estimated from baseline and recent periods are presented in this section. The years composing baseline and recent periods varied by monitoring site. The recent period is the last ten years of available data, which was 2012-2021, 2013-2022, or 2014-2023. Analyses and results are presented by major basin in the following subsections.

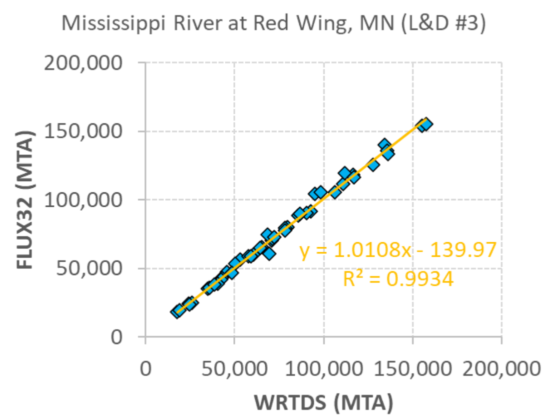
In this section, two sets of results are presented for certain sites. The first set of results are from FLUX32 analyses and the second set of results are from WRTDS analyses. Baseline and recent periods' loads and FWMCs calculated from FLUX32 and WRTDS vary due to the different methodologies for estimating annual loads. WRTDS uses weighted regressions in its estimation methodology. As such, the individual annual results from one inputted dataset will be different from the individual annual results from a second inputted dataset, even when only one datum is different between the two inputted datasets.

FLUX32 versus WRTDS

MCES compare load estimates from FLUX32 and WRTDS for the Mississippi River at Red Wing, MN (L&D #3), and Minnesota River at Jordan, MN. MCES found that load estimates from FLUX32 and WRTDS were very similar at each monitoring site.

The figure to the right is an example of MCES analyses for the Mississippi River at Red Wing, with FLUX32 and WRTDS load estimated plotted together.

MCES is also planning on comparing load estimates and trends from FLUX32, WRTDS, and QWTREND at several monitoring sites.



2.3.1 Mississippi River Major Basin

Analyses and results are presented separately for the Mississippi and Minnesota rivers (Section 2.3.1.1) and tributaries to the Mississippi River (Section 2.3.1.2). Similarly, charts presenting flow, FWMC, and load data are presented separately for the Mississippi River (Appendix A) and tributaries to the Mississippi River (Appendix B).

For the 2025 NRS, the monitoring sites at Red Wing, MN, and La Crosse, WI, are the primary locations for assessing progress. The monitoring sites for the Mississippi River at Winona, MN, and Minnesota River at Jordan, MN, are secondary locations for assessing progress.

TP and TN FWMCs and loads are estimated using FLUX32 and WRTDS; these results are not normalized to flow (see Section 2.5 for discussion of flow-normalized results). TP and TN FWMCs and loads are plotted on charts in Appendix A for the Mississippi River at Anoka (Section A.1), Red Wing (Sections A.2 and A.3), Prescott (Section A.4), Lake Pepin Outlet (Section A.5), Winona (Sections A.6 and A.7), and La Crosse (Section A.8). Such charts for the Minnesota River at Jordan, MN, are presented in Appendix B, Sections B.1 and B.2. Charts in several sections also include flow-normalized results, which are discussed in Section 2.5.

For both TP and TN, FWMC and loads are first evaluated during two time periods: 1980-1996 and 2014-2023 (the most recent 10 years). In a second set of analyses, averages from the 1980-1996 period are compared with averages from the 2019-2023 period (the most recent 5 years). For each time period, the annual FWMC or loads are averaged.

2.3.1.1 Mississippi River

Since 1980-1996, flow has increased in the Mississippi River at Anoka (+14%), Red Wing (+26% to +27%), and Winona (+19%) and the Minnesota River at Jordan (+40% to +42%). Flow data are provided in Table 6 and Table 7.

Between 1980-1996 and the most recent 10-years (2014-2023) and most recent 5-years (2019-2023), average annual TP loads (non-flow-normalized) decreased in the Mississippi River (at Anoka, Red Wing, Winona, and La Crosse) but increased in the Minnesota River at Jordan; see Table 8 and Table 9. Over the same time periods, average annual FWMCs decreased in the Mississippi River (at Anoka, Red Wing, Winona, and La Crosse) and the Minnesota River at Jordan. Changes between the time periods were very similar in the WRTDS analyses (Table 9), whereas changes between time periods were more variable in the FLUX32 analyses (Table 8). Differences between the Mississippi and Minnesota rivers' loads may be partially explained by the larger increases in flow in the Minnesota River.

Similar evaluations for TN were more variable than for TP. Between 1980-1996 and 2014-2023, average annual TN loads increased in the Mississippi River (at Anoka, Red Wing, Winona, and La Crosse) and the Minnesota River at Jordan; see Table 10 and Table 11. Average annual FWMCs decreased in the Mississippi River (at Anoka and La Crosse) and the Minnesota River at Jordan but increased in the Mississippi River at Red Wing and Winona.

Between 1980-1996 and 2019-2023, annual average TN loads increased at all monitoring sites except the Mississippi River at Anoka; these TN load increases were smaller than the TN load increases between 1980-1996 and 2014-2023. Between 1980-1996 and 2019-2023, the annual average TN FWMCs decreased at all monitoring sites. When both the 1980-1996 to 2014-2023 and 1980-1996 to 2019-2023 periods had decreases in annual average TN FWMCs, the decreases were larger for the 1980-1996 to 2019-2023 time period. When the 1980-1996 to 2014-2023 period had increases in annual average TN FWMCs, the 1980-1996 to 2019-2023 time period had slight decreases.

Table 6. Flow estimates for the Mississippi and Minnesota rivers for FLUX32 analysis

Monitoring sites	1980-1996 (cfs)	2013-2022 (cfs)	Change (%)
Mississippi River			
at Anoka, MN (RM 872)	8,830	10,083 [a]	+14%
at Red Wing, MN (RM 797; above L&D #3)	22,636	28,557	+26%
at Winona, MN	--	42,838 [b]	--
Minnesota River			
at Jordan, MN	6,549	9,147	+40%

cfs = cubic feet per second; L&D = lock and dam; RM = river mile.

a. The recent period is 2014-2023.

b. The recent period is 2013-2021.

Table 7. Flow estimates for the Mississippi and Minnesota rivers for WRTDS analysis

Monitoring sites	1980-1996 (cfs)	2014-2023 (cfs)	Change (%)
Mississippi River			
at Red Wing, MN (RM 797; above L&D #3)	22,635	28,661	+27%
at Prescott, WI (RM 786) [a]	--	28,564 [a]	--
at Lake Pepin Outlet (RM 764) [a]	--		
at Winona, MN	36,453	43,493	+19%
at La Crosse, WI (RM 703; L&D #7)	--	46,714	--
Minnesota River			
at Jordan, MN	6,549	9,279	+42%

cfs = cubic feet per second; L&D = lock and dam; RM = river mile.

a. The U.S. Geological Survey estimates loads at Prescott, WI, and the Lake Pepin outlet using the same flow gage. The recent period is 2013-2022.

Table 8. TP estimates for the Mississippi and Minnesota rivers from FLUX32 analysis (non-flow-normalized)

	Load					Flow-weighted mean concentration				
	Load (MTA) [a]			Change (%) [b]		Concentration (mg/L) [a]			Change (%) [b]	
Monitoring sites	1980-1996	2014-2023	2019-2023	2014-2023	2019-2023	1980-1996	2014-2023	2019-2023	2014-2023	2019-2023
Mississippi River										
at Anoka, MN	1,079	854	755	-21%	-30%	0.14	0.09	0.08	-34%	-40%
at Red Wing, MN	3,676	3,226 [c]	3,564 [d]	-12%	-5%	0.18	0.12 [c]	0.12 [d]	-37%	-32%
at Winona, MN	--	4,103 [e]	4,512 [f]	--	--	--	0.10 [e]	0.10 [f]	--	--
Minnesota River										
at Jordan, MN	1,532	2,100 [c]	2,487 [d]	+37%	+62%	0.28	0.26 [c]	0.25 [d]	-7%	-11%

Notes

FWMC = flow-weighted mean concentration; mg/L = milligram per liter; MTA = metric ton annually.

Refer to Table 6 for the full monitoring site names.

a. Arithmetic mean of the annual loads or concentrations (non-flow-normalized) for the specified period.

b. The change from 1980-1996 to 2014-2023, and the change from 1980-1996 to 2019-2023.

c. The recent period is 2013-2022.

d. The recent period is 2018-2022.

e. The recent period is 2014-2021. No total phosphorus data are available for 2012 and 2013.

f. The recent period is 2017-2021.

Table 9. TP estimates for the Mississippi and Minnesota rivers from WRTDS analysis (non-flow-normalized)

Monitoring sites	Load					Flow-weighted mean concentration				
	Load (MTA) [a]			Change (%) [b]		Concentration (mg/L) [a]			Change (%) [b]	
	1980-1996	2014-2023	2019-2023	2014-2023	2019-2023	1980-1996	2014-2023	2019-2023	2014-2023	2019-2023
Mississippi River										
at Red Wing, MN	3,664	3,191	3,079	-13%	-16%	0.18	0.12	0.12	-35%	-35%
at Prescott, WI	--	3,169 [c]	3,563 [d]	--	--	--	0.12 [c]	0.12 [d]	--	--
at Lake Pepin Outlet	--	2,700 [c]	3,002 [d]	--	--	--	0.10 [c]	0.10 [d]	--	--
at Winona, MN	5,915	4,002	4,088	-32%	-31%	0.18	0.10	0.10	-45%	-43%
at La Crosse, WI	4,976 [e]	4,670	4,672	-6%	--6%	0.14 [e]	0.11	0.11	-22%	-23%
Minnesota River										
at Jordan, MN	1,556	2,162	2,144	+39%	+38%	0.28	0.26	0.26	-9%	-9%

Notes

FWMC = flow-weighted mean concentration; mg/L = milligram per liter; MTA = metric ton annually.

Refer to Table 6 for the full monitoring site names.

a. Arithmetic mean of the annual loads or concentrations (non-flow-normalized) for the specified period.

b. The change from 1980-1996 to 2014-2023, and the change from 1980-1996 to 2019-2023.

c. The recent period is 2013-2022.

d. The recent period is 2018-2022.

e. This load and FWMC are for the *Mississippi River near State Border* in the 2014 NRS (MPCA 2014, Table 3-7, p. 3-27), and were not calculated using WRTDS.

Table 10. TN estimates for the Mississippi and Minnesota rivers from FLUX32 analysis (non-flow-normalized)

Monitoring sites	Load					Flow-weighted mean concentration				
	Load (MTA) [a]			Change (%) [b]		Concentration (mg/L) [a]			Change (%) [b]	
	1980-1996	2014-2023	2019-2023	2014-2023	2019-2023	1980-1996	2014-2023	2019-2023	2014-2023	2019-2023
Mississippi River										
at Anoka, MN	17,778	18,887	15,543	+6%	-13%	2.18	2.04	1.76	-6%	-19%
at Red Wing, MN	75,982	95,890 [c]	95,134 [d]	+26%	+25%	3.57	3.68 [c]	3.48 [d]	+3%	-2%
at Winona, MN	--	107,790 [e]	117,735 [f]	--	--	--	2.76 [e]	2.72 [f]	--	--
Minnesota River										
at Jordan, MN	45,752	61,333 [c]	59,552 [d]	+34%	+30%	7.80	7.55 [c]	6.02 [d]	-3%	-23%

Notes

FWMC = flow-weighted mean concentration; mg/L = milligram per liter; MTA = metric ton annually.

Refer to Table 6 for the full monitoring site names.

a. Arithmetic mean of the annual loads or concentrations (non-flow-normalized) for the specified period.

b. The change from 1980-1996 to 2014-2023, and the change from 1980-1996 to 2019-2023.

c. The recent period is 2013-2022.

d. The recent period is 2018-2022.

e. The recent period is 2012-2021.

f. The recent period is 2017-2021.

Table 11. TN estimates for the Mississippi and Minnesota rivers from WRTDS analysis (non-flow-normalized)

	Load					Flow-weighted mean concentration				
	Load (MTA) [a]			Change (%) [b]		Concentration (mg/L) [a]			Change (%) [b]	
Monitoring sites	1980-1996	2014-2023	2019-2023	2014-2023	2019-2023	1980-1996	2014-2023	2019-2023	2014-2023	2019-2023
Mississippi River										
at Red Wing, MN	73,447	96,026	82,187	+31%	+12%	3.46	3.66	3.31	+5%	-4%
at Prescott, WI	--	90,825 [c]	92,942 [d]	--	--	--	3.49 [c]	3.27 [d]	--	--
at Lake Pepin Outlet	--	84,483 [c]	85,178 [d]	--	--	--	3.24 [c]	3.00 [d]	--	--
at Winona, MN	89,325	108,024	92,979	+21%	+4%	2.64	2.73	2.43	+3%	-8%
at La Crosse, WI	97,996 [e]	113,887	105,831	+16%	+8%	2.73 [e]	2.66	2.63	-3%	-8%
Minnesota River										
at Jordan, MN	46,073	60,657	46,871	+32%	+2%	7.75	7.22	5.77	-7%	-25%

Notes

FWMC = flow-weighted mean concentration; mg/L = milligram per liter; MTA = metric ton annually.

Refer to Table 6 for the full monitoring site names.

a. Arithmetic mean of the annual loads or concentrations (non-flow-normalized) for the specified period.

b. The change from 1980-1996 to 2014-2023, and the change from 1980-1996 to 2019-2023.

c. The recent period is 2013-2022.

d. The recent period is 2018-2022.

e. This load and FWMC are for the *Mississippi River near State Border* in the 2014 NRS (MPCA 2014, Table 3-7, p. 3-27), and were not calculated using WRTDS.

2.3.1.2 Tributaries to the Mississippi River

Nine additional major tributaries to the Mississippi River were evaluated. Limited data were available during the baseline period; as such, only the recent period data are summarized herein. MPCA used FLUX32 to calculate loads (Table 12), while USGS used WRTDS to calculate loads (Table 13). Loads and FWMCs at these sites are not evaluated with NRS milestones and goals but are provided here for reference.

Table 12. Recent flow, TP, and TN in the tributaries to the Mississippi River from FLUX32 analyses (non-flow-normalized)

Monitoring sites	Recent period	Flow (cfs)	Total phosphorus		Total nitrogen	
			Load (MTA)	FWMC (mg/L)	Load (MTA)	FWMC (mg/L)
Cedar River near Austin, MN	2012-2021[a]	416	370	0.37	3,742	10.15
West Fork Des Moines River at Jackson, MN	2014-2021	848	118	0.30	4,579	6.47
Rock River at Luverne, MN	2012-2021[a]	279	157	0.17	2,006	7.85
Split Rock Creek near Jasper, MN	2014-2021[a]	168	93	0.29	1,112	7.14

Notes
cfs = cubic feet per second; FWMC = flow-weighted mean concentration; mg/L = milligram per liter; MTA = metric ton annually.
Tributaries are sorted from top to bottom as east to west along Minnesota's southern boundary, which is also the order that these tributaries eventually discharge to the Mississippi River in other states.
a. The recent period for total phosphorus is 2014-2021, while the recent period for total nitrogen is 2012-2021.

Table 13. Recent flow, TP, and TN in the tributaries to the Mississippi River from WRTDS analyses (non-flow-normalized)

Monitoring sites	Recent period	Flow (cfs)	Total phosphorus		Total nitrogen	
			Load (MTA)	FWMC (mg/L)	Load (MTA)	FWMC (mg/L)
Cannon River at Welch, MN	2013-2022	1,245	2,100	0.26	5,389	4.89
Chippewa River at Durand, WI	2013-2022	10,149	218	0.19	13,097	1.45
Black River near Galesville, WI	2013-2022	2,392	889	0.10	3,192	1.50
La Cross River near La Crosse, WI	2013-2022	512	358	0.17	1,067	2.32
Upper Iowa River near Dorchester, IA	2013-2022	1,000	78	0.17	5,999	6.61

Notes
cfs = cubic feet per second; FWMC = flow-weighted mean concentration; mg/L = milligram per liter; MTA = metric ton annually.
Tributaries are sorted from top to bottom as upstream to downstream along the Mississippi River.

2.3.2 Lake Winnipeg Major Basin

Analyses and results are presented separately for the Red River of the North (Section 2.3.2.1) and Rainy River (Section2.3.2.2). Charts presenting flow, FWMC, and load data are presented separately in Appendix C.

For the 2025 NRS, the monitoring site for the Red River of the North at Emerson, Manitoba, Canada, is the primary location for assessing progress. The monitoring sites for the Red River of the North at Grand Forks, ND, and Rainy River at Manitou Rapids, MN, are secondary locations for assessing progress.

TP and TN FWMCs and loads are estimated using FLUX32 and WRTDS; these results are not normalized to flow (see Section 2.5 for discussion of flow-normalized results). TP and TN FWMCs and loads are plotted on charts in Appendix C for the Red River of the North at Emerson, Manitoba, Canada (Sections C.1 and C.2), Red River of the North at Grand Forks, ND (Section C.3), and Rainy River at Manitou Falls, MN (Section C.4). Charts in Section C.2 also include flow-normalized results, which are discussed in Section 2.5.

For both TP and TN, FWMC and loads are first evaluated during two time periods: 1980-1996 and 2014-2023 (the most recent 10 years). In a second set of analyses, averages from the 1980-1996 period are compared with averages from the 2019-2023 period (the most recent 5 years). For each time period, the annual FWMC or loads are averaged.

2.3.2.1 Red River of the North

CWSEC and MPCA monitored the Red River of the North at Emerson, Manitoba, Canada, and MPCA monitored the Red River at Grand Forks, ND. Throughout this report, the Red River of the North at Emerson is represented by the CWSEC monitoring data. A comparison of loads and FWMCs from the CWSEC and MPCA datasets for 2012-2019 indicated that loads and FWMCs were very similar between the two datasets, with an average difference of 2%[2].

In the Red River of the North at Emerson, annual average flow decreased between 1996-2000 and the most recent decade (2013-2022 or 2014-2023;Table 14).

Between 1996-2000 and the most recent 10-years (2014-2023) and most recent 5-years (2019-2023), average annual TP FWMCs increased, with larger increases between 1996-2000 and 2014-2023 (Table 15). Average annual TP loads increased between 1996-2000 and 2014-2025 but decreased between 1996-2000 and 2019-2023.Average annual TN FWMCs and loads decreased between both sets of time periods (Table 16). The decreases were larger between 1996-2000 and 2014-2023 than between 1996-2000 and 2019-2023.

[2] The differences between average annual loads and average annual FWMCs for 2012-2019 were 0% to 5% for TP and 0% to 3% for TN. The average of differences for the eight years was 2% for both TP and TN, for both load and FWMCs.

Table 14. Flow estimates for the Red River of the North

Monitoring sites	1996-2000 (cfs)	2014-2023 (cfs)	Change (%)
Red River of the North at Emerson, Manitoba, Canada			
CWSEC	9,625	7,642 [a]	-21%
CWSEC (WRTDS by MPCA)	9,631	7,527	-22%
Red River of the North at Grand Forks, ND			
MPCA (FLUX32)	--	5,593 [a]	--

Notes

cfs = cubic feet per second.

a. The recent period is 2013-2022.

Table 15. TP estimates for the Red River of the North (non-flow-normalized)

Monitoring sites	Load					Flow-weighted mean concentration				
	Load (MTA) [a]			Change (%) [b]		Concentration (mg/L) [a]			Change (%) [b]	
	1996-2000	2014-2023	2019-2023	2014-2023	2019-2023	1996-2000	2014-2023	2019-2023	2014-2023	2019-2023
Red River of the North at Emerson, Manitoba, Canada										
CWSEC	2,715	2,635 [c]	2,949 [d]	-3%	+9%	0.32	0.37 [c]	0.35 [d]	+18%	+11%
CWSEC (WRTDS by MPCA)	2,858	2,640	3,310	-8%	+16%	0.33	0.38	0.38	+15%	+13%
Red River of the North at Grand Forks, ND										
MPCA (FLUX32)	--	1,863 [c]	2,178 [d]	--	--	--	0.35 [c]	0.36 [d]	--	--

Notes

FWMC = flow-weighted mean concentration; mg/L = milligram per liter; MTA = metric ton annually.

a. Arithmetic mean of the annual loads or concentrations (non-flow-normalized) for the specified period.

b. The change from 1996-2000 to 2014-2023, and the change from 1996-2000 to 2019-2023.

c. The recent period is 2013-2022.

d. The recent period is 2018-2022.

Table 16. TN estimates for the Red River of the North (non-flow-normalized)

Monitoring sites	Load					Flow-weighted mean concentration				
	Load (MTA) [a]			Change (%) [b]		Concentration (mg/L) [a]			Change (%) [b]	
	1996-2000	2014-2023	2019-2023	2014-2023	2019-2023	1996-2000	2014-2023	2019-2023	2014-2023	2019-2023
Red River of the North at Emerson, Manitoba, Canada										
CWSEC	19,571	14,603 [c]	16,176 [d]	-25%	-17%	2.33	2.09 [c]	1.93 [d]	-10%	-17%
CWSEC (WRTDS by MPCA)	20,682	15,665	19,844	-24%	-4%	2.42	2.29	2.36	-5%	-3%
Red River of the North at Grand Forks, ND										
MPCA (FLUX32)	--	11,032 [c]	12,667 [d]	--	--	--	2.14 [c]	2.15 [d]	--	--

Notes

FWMC = flow-weighted mean concentration; mg/L = milligram per liter; MTA = metric ton annually.

a. Arithmetic mean of the annual loads or concentrations (non-flow-normalized) for the specified period.

b. The change from 1996-2000 to 2014-2023, and the change from 1996-2000 to 2019-2023.

c. The recent period is 2013-2022.

d. The recent period is 2018-2022.

2.3.2.2 Rainy River

MPCA monitored the Rainy River at Manitou Rapids, MN (Table 17). No goals or milestones were assigned for the Rainy River in the 2014 NRS (MPCA 2014).

Table 17. Recent flow, TP, and TN in the Rainy River (non-flow-normalized)

Monitoring site	Recent period	Flow (cfs)	Total phosphorus		Total nitrogen	
			Load (MTA)	FWMC (mg/L)	Load (MTA)	FWMC (mg/L)
Rainy River at Manitou Rapids, MN	2013-2022	14,006	381	0.03	8,446	0.67

Note: cfs = cubic feet per second; FWMC = flow-weighted mean concentration; mg/L = milligram per liter; MTA = metric ton annually.

2.3.3 Lake Superior Major Basin

TP and TN FWMCs and loads are estimated using FLUX32 and WRTDS; these results are not normalized to flow (see Section 2.5 for discussion of flow-normalized results). TP and TN FWMCs and loads are plotted on charts in Appendix D for the Nemadji River near South Superior (Section D.1) and St. Louis river at Scanlon (Sections D.2 and D.3). Charts in Section D.3 also include flow-normalized results, which are discussed in Section 2.5.

Two monitoring sites in the Lake Superior major basin were evaluated; however, MPCA and USGS did not provide long-term data. Available data are presented in

Table 18.

To evaluate progress for the Lake Superior major basin, the 5-year averages of annual WRTDS estimates for the St. Louis River at Scanlon were evaluated for two periods: 2011-2016 and 2019-2023. For TP at this monitoring site, FWMCs (-25%) and loads (-20%) decreased. For TN, FWMCs decreased (-9%) and loads increased (1%).

This monitoring site is upstream of the St. Louis River Estuary and the Duluth urban area; as such, changes in FWMCs and loads do not represent changes in the direct tributaries of the St. Louis River Estuary or Duluth urban area.

Table 18. TP in the Lake Superior major basin (non-flow-normalized)

Monitoring entity and method	Period	Flow (cfs)	Total phosphorus		Total nitrogen	
			Load (MTA)	FWMC (mg/L)	Load (MTA)	FWMC (mg/L)
Nemadji River near South Superior, WI						
MPCA (FLUX32)	2009-2022	414	101 [a]	0.249 [a]	461	1.21
St. Louis River at Scanlon, MN						
MPCA (FLUX32)	2009-2021	2,437	98 [a]	0.212 [a]	2,321	1.06
USGS (WRTDS)	2011-2016	1,406	178	0.079	2,375	1.12
	2019-2023	2,740	142	0.059	2,393	1.02
	Change	+95%	-20%	-25%	+1%	-9%

Notes

cfs = cubic feet per second; FWMC = flow-weighted mean concentration; mg/L = milligram per liter; MPCA = Minnesota Pollution Control Agency; MTA = metric ton annually; USGS = U.S. Geological Survey; WRTDS = Weighted Regressions on Time, Discharge, and Season.

a. No phosphorus data are available for 2012 and 2013.

2.4 FLOW-CORRECTED TRENDS

MPCA (2023) evaluated flow-corrected and non-flow-corrected trends with nitrate plus nitrite and TP for the 2008-2020 timeframe at select monitoring sites across the state. Pertinent results are summarized herein. MPCA (2023) presents this information in an interactive map within an online Tableau report. A tabular summary of this information is presented in Appendix E.

2.4.1 Mississippi River Major Basin

MPCA (2023) found statistically significant trends, decreasing TP trends at two sites of four sites on the Mississippi River, including at Winona, MN (S000-096) and found no statistically significant trends with nitrate plus nitrite (Table 41 in Appendix E).

One site along the upper Minnesota River shows a statistically significant, decreasing TP trend, while another site shows a statistically significant trends, increasing nitrate plus nitrite trend (Table 42 in Appendix E). Both sites in the middle Minnesota River exhibit no statistically significant trends. MPCA (2023) found statistically significant, increasing nitrate plus nitrite trends in two tributaries to the upper Minnesota River and statistically significant, decreasing TP trends in the upper and middle Minnesota River. Four of the ten sites on tributaries to the Minnesota River indicated no trend.

Several tributaries to the upper Mississippi River and all three tributaries to the lower Mississippi River show statically significant, decreasing TP trends (Table 41 in Appendix E); several such tributaries also exhibit statistically significant, increasing nitrate plus nitrite trends. At the Minnesota-Iowa border, some tributaries show statistically significant, decreasing TP trends and some tributaries show statistically significant, increasing nitrate plus nitrite trends (Table 41 in Appendix E).

2.4.2 Lake Winnipeg Major Basin

MPCA (2023) found no statistically significant trends for three sites on the Red River of the North, including at Grand Forks, ND (S000-008), and at Emerson, Manitoba, Canada (S007-127). Additionally, MPCA (2023) found no statistically significant trends for seven tributaries to the Red River of the North (Table 43 in Appendix E). MPCA (2023) did find statistically significant trends for two tributaries to the Red River of the North.

2.4.3 Lake Superior Major Basin

MPCA (2023) found no statistically significant trends with nitrate plus nitrite or TP at three of four sites in the *Lake Superior* major basin, including the Nemadji River near South Superior, WI (S005-115) and the St. Louis River near Scanlon, MN (S005-089). MPCA (2023) found a statistically significant increasing TP trend at one site (Table 44 in Appendix E).

2.5 FLOW-NORMALIZED CONCENTRATIONS AND LOADS

In Section 2.3, non-flow-normalized annual loads and FWMCs estimated using WRTDS were presented for several key sites. In this section, flow-normalized loads and concentrations estimated using WRTDS are presented. Flow-normalization "eliminate[s] the influence of year-to-year variations in streamflow" (Hirsh et al. 2010). As such, flow-normalized loads and concentrations can be evaluated to determine the impacts of flow and other factors on load and concentration trends. Generally, trends from non-flow-normalized and flow-normalized annual results over a long time period are similar; however, considerable differences do occur, especially when comparing data over shorter timespans.

2.5.1 Mississippi River Major Basin

MCES, MPCA, and USGS used WRTDS to estimate flow-normalized concentrations and loads at several key monitoring sites. In Section 2.3.1.1, analysis of average annual streamflow in the Mississippi and Minnesota rivers indicated that annual streamflow increased considerably between the baseline and recent periods.

Flow-normalized TP and TN concentrations and loads are plotted on charts in Appendix A for the Mississippi River at Red Wing (Section A.3), Prescott (Section A.4), Lake Pepin Outlet (Section A.5), Winona (Section A.7), and La Crosse (Section S.8); these sections have "WRTDS" in the section name. The other sections in Appendix A present charts using FLUX32 results that are not flow-normalized. Additionally, such charts for the Minnesota River at Jordan, MN, are in Appendix B, Sections B.1 and B.2.

For both TP and TN, flow-normalized concentrations and loads are first evaluated during two time periods: 1980-1996 and 2014-2023 (the most recent 10 years). For each time period, the annual flow-normalized concentrations or loads are averaged (TP in Table 19 and TN in Table 22). In a second set of analyses, the flow-normalized loads from 2023 (the most recent year) are compared with the 1980-1996 averages.

Finally, TP and TN flow-normalized concentrations and loads are evaluated for long-term trends and statistical significance across two or three time periods. In these evaluations, changes due to watershed or management and changes due to flow regime are quantified.

2.5.1.1 Total Phosphorus

Flow-normalized TP concentration averages s are consistent along the Mississippi River (0.09-0.10 mg/L), while the flow-normalized TP concentration average is nearly twice as large in the Minnesota River at Jordan (0.17 mg/L; Table 19). Flow-normalized TP load average decreased in the Mississippi River from Red Wing downstream to the Lake Pepin outlet, then increased at Winona, MN, and increased again at La Crosse, WI.

Between the 1980-1996 and 2014-2023 periods, flow-normalized TP concentration averages decreased considerably in the Mississippi River at Red Wing (-50%) and Winona (-47%) and the Minnesota River at Jordan (-29%; Table 19). TP load averages also decreased between these periods in the Mississippi River at Red Wing (-36%) and Winona (-43%) and the Minnesota River at Jordan(-7%).

Between 1980-1996 and 2023, flow-normalized TP loads decreased in the Mississippi River at Red Wing (-32%), Winona (-11%), and La Crosse (-39%) and in the Minnesota River at Jordan (-2%; Table 19).

Long-term trends with TP concentrations (Table 19. Flow-normalized TP load estimates for the Mississippi and Minnesota rivers from WRTDS analysis

	Flow-normalized loads					Flow-normalized concentrations				
	Load (MTA)			Change (%) [a]		Concentration (mg/L)			Change (%) [a]	
nitoring sites	1980-1996 [b]	2014-2023 [b]	2023	2014-2023	2023	1980-1996 [b]	2014-2023 [b]	2023	2014-2023	2023
ssissippi River										
Red Wing, MN	3,817	2,447	2,505	-36%	-34%	0.18	0.09	0.09	-50%	-51%
Prescott, WI	--	2,499 [c]	2,464 [d]	--	--	--	0.09 [c]	0.09 [d]	--	--
Lake Pepin Outlet	--	2,208 [c]	2,132 [d]	--	--	--	0.09 [c]	0.09 [d]	--	--
Winona, MN	5,604	3,197	3,585	-43%	-36%	0.17	0.09	0.10	-47%	-41%
La Crosse, WI	--	4,475	4,432	--	--	--	0.10	0.10	--	--
nnesota River										
Jordan, MN	1,638	1,525	1,604	-7%	-2%	0.24	0.17	0.18	-29%	-28%

Notes

mg/L = milligram per liter; MTA = metric ton annually.

Refer to Table 6 for the full monitoring site names.

a. The change from 1980-1996 to 2014-2023, and the change from 1980-1996 to 2023.

b. Arithmetic mean of the annual flow-normalized loads or concentrations for the specified period.

c. The recent period is 2013-2022.

d. The most recent year is 2022.

Table 20) and loads (Table 21) were evaluated for three time periods at the Mississippi River at Red Wing, MN, at Winona, MN, and La Crosse, WI, and the Minnesota River at Jordan using WRTDS. The long-term trends are summarized as follows:

- **Mississippi River at Red Wing, MN**: Downward trends in TP concentration are very likely to highly (1976-2023, 1992-2023, and 2014-2023), while downward trends in TP load are highly likely (1976-2023 and 1992-2023) to about as likely as not (2014-2023). The highly likely downward concentration trend for 1992-2023 is significant ($p<0.1$)
- **Mississippi River at Winona, MN**: This dataset includes two gaps: 1974-1981 and 1994-2000. Downward trends in TP concentration are highly likely for 1962-2023 and downward trends in TP load for the same time period are very likely.
- **Mississippi River at La Crosse, WI**: Downward trends in TP concentration are highly likely (1992-2023) to very likely (2014-2023), while downward trends in TP load are very likely (1992-2023) to about as likely as not (2014-2023). The highly likely downward concentration trend for 1992-2023 is significant ($p<0.1$)
- **Minnesota River at Jordan, MN**: Downward trends in TP concentration are very likely (1980-2023) to highly likely (1992-2023) to about as likely as not (2014-2023). Downward trends in TP load are very likely (1980-2023) to about as likely as not (2014-2023) to very unlikely (2014-2023). The highly likely downward concentration trend for 1992-2023 is significant ($p<0.1$)

TP trends for the Mississippi River may be best exemplified with flow-normalized TP loads at Red Wing, MN, which has the longest, continuous monitoring record of the sites on the Mississippi River. At this monitoring site, downward trends are apparent during two periods: 1992-1998 and 2004-2012 (Figure 15 in Appendix A, Section A.3).

Table 19. Flow-normalized TP load estimates for the Mississippi and Minnesota rivers from WRTDS analysis

Monitoring sites	Flow-normalized loads					Flow-normalized concentrations				
	Load (MTA)			Change (%) [a]		Concentration (mg/L)			Change (%) [a]	
	1980-1996 [b]	2014-2023 [b]	2023	2014-2023	2023	1980-1996 [b]	2014-2023 [b]	2023	2014-2023	2023
Mississippi River										
at Red Wing, MN	3,817	2,447	2,505	-36%	-34%	0.18	0.09	0.09	-50%	-51%
at Prescott, WI	--	2,499 [c]	2,464 [d]	--	--	--	0.09 [c]	0.09 [d]	--	--
at Lake Pepin Outlet	--	2,208 [c]	2,132 [d]	--	--	--	0.09 [c]	0.09 [d]	--	--
at Winona, MN	5,604	3,197	3,585	-43%	-36%	0.17	0.09	0.10	-47%	-41%
at La Crosse, WI	--	4,475	4,432	--	--	--	0.10	0.10	--	--
Minnesota River										
at Jordan, MN	1,638	1,525	1,604	-7%	-2%	0.24	0.17	0.18	-29%	-28%

Notes

mg/L = milligram per liter; MTA = metric ton annually.

Refer to Table 6 for the full monitoring site names.

a. The change from 1980-1996 to 2014-2023, and the change from 1980-1996 to 2023.

b. Arithmetic mean of the annual flow-normalized loads or concentrations for the specified period.

c. The recent period is 2013-2022.

d. The most recent year is 2022.

Table 20. Statistical trends with flow-normalized TP concentration

Monitoring site	Period	P-value	Estimated change (95% Conf. Int.) [mg/L]	Trend (Likelihood)	Percent change	Change due to watershed or management	Change due to flow regime
Mississippi River at Red Wing, MN	1980-2023	0.05	-0.09 (-0.10 to -0.07)	Down (99%)	-46.4%	-47.9%	+1.6%
	1992-2023	0.05	-0.10 (-0.12 to -0.08)	Down (99%)	-48.7%	-52.2%	+3.5%
	2014-2023	0.41	-0.005 (-0.01 to +0.01)	Down (79%)	-3.0%	-4.2%	+1.3%
Mississippi River at Winona, MN [a]	1981-2023 [b]	0.0059	-0.06 (-0.09 to -0.02)	Down (99%)	-36.5%	-40.5%	+4.0%
	2014-2023	0.084	+0.01 (-0.0025 to +0.03)	Up (96%)	+15.7%	+15.5%	+0.02%
Mississippi River at La Crosse, WI [c]	1992-2023	0.02	-0.04 (-0.06 to -0.01)	Down (99%)	-28.1%	-30.3%	+2.5%
	2014-2023	0.43	-0.01 (-0.02 to +0.01)	Down (79%)	-4.8%	-5.7%	+0.5%
Minnesota River at Jordan, MN	1979-2023	0.22	-0.10 (-0.20 to +0.05)	Down (89%)	-21.0%	-34.4%	+13.4%
	1992-2023	0.05	-0.06 (-0.11 to -0.01)	Down (99%)	-19.5%	-25.7%	+6.1%
	2014-2023	0.68	+0.004 (-0.02 to +0.06)	Up (66%)	+4.9%	+4.3%	+0.6%

Notes

Conf. Int. = confidence interval; mg/L = milligram per liter.

Changes are rounded to the nearest one-tenth percentage point; as such, the sums may not exactly total due to rounding.

a. No data are available for 1974-1981 and 1994-2000. As such, trends are not evaluated for 1992-2023.

b. No data are available for 1994-2000. The 1981-2023 trend excludes these years.

c. No data are available prior to 1992; as such, trends are not evaluated for 1980-2023.

Table 21. Statistical trends with flow-normalized TP load

Monitoring site	Period	P-value	Estimated change (95% Conf. Int.) [1,000 MTA]	Trend (Likelihood)	Percent change	Change due to watershed or management	Change due to flow regime
Mississippi River at Red Wing, MN	1980-2023	0.05	-1.20 (-1.55 to -0.65)	Down (99%)	-0.2%	-38.2%	+38.4%
	1992-2023	0.05	-1.58 (-2.17 to -1.04)	Down (99%)	-22.9%	-38.7%	+15.8%
	2014-2023	0.89	+0.02 (-0.29 to +0.41)	Up (56%)	+4.1%	+1.3%	+2.8%
Mississippi River at Winona, MN [a]	1981-2023 [b]	0.17	-0.81 (-1.70 to +0.47)	Down (92%)	-15.8%	-39.7%	+23.9%
	2014-2023	0.071	+0.65 (-0.08 to +1.39)	Up (97%)	+17.7%	+13.1%	+4.4%
Mississippi River at La Crosse, WI [c]	1992-2023	0.13	-0.76 (-1.67 to +0.38)	Down (94%)	-13.4%	-27.9%	-0.2%
	2014-2023	0.73	-0.19 (-0.89 to +0.74)	Down (64%)	-2.5%	-5.7%	+1.5%
Minnesota River at Jordan, MN	1979-2023	0.57	-0.32 (-1.15 to +1.66)	Down (71%)	+81.4%	-7.7%	+89.1%
	1992-2023	0.93	-0.12 (-0.52 to +0.79)	Down (54%)	+25.0%	-5.2%	+30.2%
	2014-2023	0.42	+0.13 (-0.15 to +0.84)	Up (79%)	+14.1%	+10.8%	+3.3%

Notes

Conf. Int. = confidence interval; MTA = metric tons annually.

Changes are rounded to the nearest one-tenth percentage point; as such, the sums may not exactly total due to rounding.

a. No data are available for 1974-1981 and 1994-2000. As such, trends are not evaluated for 1992-2023.

b. No data are available for 1994-2000. The 1981-2023 trend excludes these years.

c. No data are available prior to 1992; as such, trends are not evaluated for 1980-2023.

2.5.1.2 Total Nitrogen

Flow-normalized TN concentration averages decreased along the Mississippi River from Red Wing, MN, to La Crosse, WI (Table 22). Flow-normalized TN concentration average in the Minnesota River at Jordan was larger than such concentration averages in the Mississippi River. Flow-normalized TN load averages decreased in the Mississippi River from Red Wing downstream to the Lake Pepin outlet, then increased at Winona, MN, and increased again at La Crosse, WI.

Between the 1980-1996 and 2014-2023 periods, flow-normalized TN concentration and TN load averages decreased slightly in the Mississippi River at Red Wing (-2%; Table 22). At Winona, flow-normalized TN concentration averages increased (+10%) and TN load averages slightly decreased (-3%). The decreases between periods were larger in the Minnesota River at Jordan (-20% and -25%, respectively; Table 22).

Between 1980-1996 and 2023, flow-normalized TP loads decreased in the Mississippi River at Red Wing (-6%), Winona (-13%), and La Crosse (-4%) and the Minnesota River at Jordan (32%; Table 22).

Long-term trends with TN concentrations (Table 22. Flow-normalized TN load estimates in the Mississippi and Minnesota rivers from WRTDS analysis

	Flow-normalized loads					Flow-normalized concentrations				
	Load (MTA)			Change (%) [a]		Concentration (mg/L)			Change (%) [a]	
nitoring sites	1980-1996 [b]	2014-2023 [b]	2023	2014-2023	2023	1980-1996 [b]	2014-2023 [b]	2023	2014-2023	2023
ssissippi River										
Red Wing, MN	74,818	73,694	68,807	-2%	-8%	3.09	3.03	2.88	-2%	-7%
Prescott, WI	--	73,128 [c]	67,142 [d]	--	--	--	3.01	2.84 [d]	--	--
Lake Pepin Outlet	--	67,368 [c]	59,883 [d]	--	--	--	2.74	2.50 [d]	--	--
Winona, MN	91,362	88,221	78,093	-3%	-15%	2.43	2.68	2.27	+10%	-7%
La Crosse, WI	--	103,995	94,349	--	--	--	2.45	2.21	--	--
nnesota River										
Jordan, MN	50,064	40,088	31,159	-20%	-38%	6.17	4.64	3.96	-25%	-36%

Notes

mg/L = milligram per liter; MTA = metric ton annually.

Refer to Table 6 for the full monitoring site names.

a. The change from 1980-1996 to 2014-2023, and the change from 1980-1996 to 2023.

b. Arithmetic mean of the annual flow-normalized loads or concentrations for the specified period.

c. The recent period is 2013-2022.

d. The most recent year is 2022.

Table 23) and loads (Table 24) were evaluated for three time periods at the Mississippi River at Red Wing, MN, at Winona, MN, and La Crosse, WI, and the Minnesota River at Jordan using WRTDS. The long-term trends are summarized as follows:

- **Mississippi River at Red Wing, MN**: Upward trends in TN concentration and load are highly likely for the 1976-2023 period, while downward trends in TN concentration and load are very likely for the 1992-2023 and 2014-2023 periods.
- **Mississippi River at Winona, MN**: This dataset includes a large gap: 1994-2008. Downward trends in TN concentration and load are highly likely for the 2014-2023 period, while upward trends for the 1981-2023 are about as likely as not. The highly likely downward trends for the 2014-2023 period are statistically significant ($p<0.1$).
- **Mississippi River at La Crosse, WI**: Downward trends in TN concentration are highly likely (1992-2023) to very likely (2014-2023); both downward trends are statistically significant ($p<0.1$). Additionally, downward trends in TN load are highly likely in both periods but only the downward trend for 2014-2023 is statistically significant ($p<0.1$).
- **Minnesota River at Jordan, MN**: Downard trends in TN concentration and load are highly likely for all three time periods. All these downward trends are statically significant ($p<0.1$).

Table 22. Flow-normalized TN load estimates in the Mississippi and Minnesota rivers from WRTDS analysis

Monitoring sites	Flow-normalized loads					Flow-normalized concentrations				
	Load (MTA)			Change (%) [a]		Concentration (mg/L)			Change (%) [a]	
	1980-1996 [b]	2014-2023 [b]	2023	2014-2023	2023	1980-1996 [b]	2014-2023 [b]	2023	2014-2023	2023
Mississippi River										
at Red Wing, MN	74,818	73,694	68,807	-2%	-8%	3.09	3.03	2.88	-2%	-7%
at Prescott, WI	--	73,128 [c]	67,142 [d]	--	--	--	3.01	2.84 [d]	--	--
at Lake Pepin Outlet	--	67,368 [c]	59,883 [d]	--	--	--	2.74	2.50 [d]	--	--
at Winona, MN	91,362	88,221	78,093	-3%	-15%	2.43	2.68	2.27	+10%	-7%
at La Crosse, WI	--	103,995	94,349	--	--	--	2.45	2.21	--	--
Minnesota River										
at Jordan, MN	50,064	40,088	31,159	-20%	-38%	6.17	4.64	3.96	-25%	-36%

Notes

mg/L = milligram per liter; MTA = metric ton annually.

Refer to Table 6 for the full monitoring site names.

a. The change from 1980-1996 to 2014-2023, and the change from 1980-1996 to 2023.

b. Arithmetic mean of the annual flow-normalized loads or concentrations for the specified period.

c. The recent period is 2013-2022.

d. The most recent year is 2022.

Table 23. Statistical trends with flow-normalized TN concentration

Monitoring site	Period	P-value	Estimated change (95% Conf. Int.) [mg/L]	Trend (Likelihood)	Change, Total	Change due to watershed or management	Change due to flow regime
Mississippi River at Red Wing, MN	1980-2023	0.85	+0.61 (-0.60 to +0.75)	Up (59%)	+8.6%	+1.9%	+6.7%
	1992-2023	0.13	-0.32 (-0.89 to +0.07)	Down (94%)	-8.9%	-11.6%	+2.7%
	2014-2023	0.42	-0.18 (-0.94 to +0.43)	Down (79%)	-8.4%	-7.0%	-1.4%
Mississippi River at Winona, MN [a]	1981-2023 [b]	0.69	+0.05 (-0.45 to +0.50)	Up (65%)	+2.4%	+1.1%	+1.3%
	2014-2023	0.052	-0.37 (-0.75 to +0.0032)	Down (97%)	-13.6%	-13.0%	-0.6%
Mississippi River at La Crosse, WI [c]	1992-2023	0.02	-0.77 (-1.50 to -0.17)	Down (>99%)	-25.1%	-28.0%	+2.0%
	2014-2023	0.05	-0.39 (-1.04 to -0.02)	Down (98%)	-16.7%	-14.9%	-0.2%
Minnesota River at Jordan, MN	1980-2023	0.05	-4.03 (-6.55 to -2.16)	Down (99%)	-34.0%	-56.5%	+22.5%
	1992-2023	0.05	-2.03 (-3.18 to -0.95)	Down (99%)	-34.0%	-35.5%	+1.4%
	2014-2023	0.05	-0.98 (-1.87 to -0.05)	Down (99%)	-26.7%	-19.7%	-6.9%

Notes

Conf. Int. = confidence interval; mg/L = milligram per liter;.

Estimated changes are rounded to the one-hundredth percentage point. Percent changes are rounded to the nearest one-tenth percentage point.

a. No data are available for 1994-2008. As such, trends are not evaluated for 1992-2023.

b. No data are available for 1994-2008. The 1981-2023 trend excludes these years.

c. No data are available prior to 1992. As such, trends are not evaluated for 1980-2023.

Table 24. Statistical trends with flow-normalized TN load

Monitoring site	Period	P-value	Estimated change (95% Conf. Int.) [1,000 MTA]	Trend (Likelihood)	Change, Total	Change due to watershed or management	Change due to flow regime
Mississippi River at Red Wing, MN	1980-2023	0.46	+6.60 (-13.79 to +38.63)	Up (76%)	+60.4%	+10.4%	+50.1%
	1992-2023	0.26	-9.44 (-27.63 to +2.54)	Down (87%)	+6.3%	-14.7%	+21.1%
	2014-2023	0.37	-6.95 (-35.92 to +10.86)	Down (81%)	-9.8%	-8.4%	-1.4%
Mississippi River at Winona, MN [a]	1981-2023	0.74	+1.99 (-20.40 to +23.00)	Up (63%)	+2.3%	-9.7%	+11.9%
	2014-2023	0.054	-15.10 (-32.44 to +0.33)	Down (97%)	-14.6%	-14.2%	-0.3%
Mississippi River at La Crosse, WI [b]	1992-2023	0.54	-11.70 (-39.12 to +15.14)	Down (73%)	-7.7%	-24.0%	+13.0%
	2014-2023	0.07	-15.57 (-43.42 to +1.92)	Down (97%)	-15.2%	-14.4%	+0.2%
Minnesota River at Jordan, MN	1980-2023	0.05	-31.60 (-47.80 to -10.50)	Down (99%)	+7.6%	-72.7%	+80.3%
	1992-2023	0.05	-18.36 (-29.21 to -6.68)	Down(99%)	-24.6%	-40.7%	+16.1%
	2014-2023	0.05	-14.16 (-20.72 to -3.94)	Down (99%)	-35.4%	-24.4%	-10.9%

Notes

Conf. Int. = confidence interval; mg/L = milligram per liter; MTA = metric tons annually.

Estimated changes are rounded to the one-hundredth percentage point. Percent changes are rounded to the nearest one-tenth percentage point.

a. No data are available for 1994-2008; as such, trends are not evaluated for 1992-2023.

b. No data are available prior to 1992; as such, trends are not evaluated for 1980-2023.

2.5.2 Lake Winnipeg Major Basin

Flow-normalized TP and TN concentrations and loads are plotted on charts in Appendix C for the Red River of the North at Emerson, Manitoba Canada (Section C.2); this section has "WRTDS" in the section name. The other sections in Appendix C present charts using FLUX32 results that are not flow-normalized.

For both TP and TN, flow-normalized concentrations and loads are first evaluated during two time periods: 1996-2000 and 2014-2023 (the most recent 10 years). For each time period, the annual flow-normalized concentrations or loads are averaged (Table 25). In a second set of analyses, the flow-normalized loads from 2023 (the most recent year) are compared with the 1996-2000 averages.

Finally, TP and TN flow-normalized concentrations and loads are evaluated for long-term trends and statistical significance across two time periods. In these evaluations, changes due to watershed or management and changes due to flow regime are quantified.

MPCA performed WRTDS analysis on data provided by CWSEC for the Red River of the North at Emerson (Table 25). Between 1996-2000 and 2014-2023, flow-normalized TP load averages (-8%) and concentration averages (-31%) decreased, as did flow-normalized TN load averages (-9%) and concentration averages (-5%).

Between 1996-2000 and 2023, flow-normalized TP load (-17%) and concentration(-31%) decreased, as did flow-normalized TN concentration (-7%; Table 25). However, flow-normalized TN load (-0.4%) decreased only slightly.

Long-term trends with TP and TN concentrations and loads were evaluated for 1994-2023 and 2001-2023 using WRTDS (Table 25. Flow-normalized TP and TN loads in the Red River of the North at Emerson from WRTDS analysis

	Flow-normalized loads					Flow-normalized concentrations				
	Load (MTA)			Change (%) [a]		Concentration (mg/L)			Change (%) [a]	
trient	1996-2000 [b]	2014-2023 [b]	2023	2014-2023	2023	1996-2000 [b]	2014-2023 [b]	2023	2014-2023	2023
tal phosphorus	2,858	2,640	2,385	-8%	-17%	0.24	0.31	0.31	-31%	-31%
tal nitrogen	18,072	16,418	18,002	-9%	-0.4%	1.80	1.88	1.92	-5%	-7%

Notes

mg/L = milligram per liter; MTA = metric ton annually.

a. The change from 1996-2000 to 2014-2023, and the change from 1996-2000 to 2023.

b. Arithmetic mean of the annual flow-normalized loads or concentrations for the specified period.

Table 26). Upward trends in TP concentration and load are highly likely and statistically significant for 1994-2023 ($p<0.05$) but are very likely and not statistically significant for 2001-2023. upward trends in TN concentration and load are likely for 1994-2023 but not statistically significant. Upward TN trends for 2001-2023 are no more likely than not.

Table 25. Flow-normalized TP and TN loads in the Red River of the North at Emerson from WRTDS analysis

Nutrient	Flow-normalized loads					Flow-normalized concentrations				
	Load (MTA)			Change (%) [a]		Concentration (mg/L)			Change (%) [a]	
	1996-2000 [b]	2014-2023 [b]	2023	2014-2023	2023	1996-2000 [b]	2014-2023 [b]	2023	2014-2023	2023
Total phosphorus	2,858	2,640	2,385	-8%	-17%	0.24	0.31	0.31	-31%	-31%
Total nitrogen	18,072	16,418	18,002	-9%	-0.4%	1.80	1.88	1.92	-5%	-7%

Notes

mg/L = milligram per liter; MTA = metric ton annually.

a. The change from 1996-2000 to 2014-2023, and the change from 1996-2000 to 2023.

b. Arithmetic mean of the annual flow-normalized loads or concentrations for the specified period.

Table 26. Statistical trends with flow-normalized concentration and load in the Red River of the North

Parameter	Period	P-value	Estimated change (95% Conf. Int.) [mg/L or 1,000 MTA]	Trend (Likelihood)	Percent change	Change due to watershed or management	Change due to flow regime
Total phosphorus							
Flow-normalized concentration	1994-2023	0.0056	+0.10 (+0.03 to +0.13)	Up (>99%)	+45.7%	+47.6%	-1.9%
	2001-2023	0.15	+0.04 (-0.02 to +0.08)	Up (92%)	+15.5%	+17.1%	-1.6%
Flow-normalized load	1994-2023	0.025	+1.04 (+0.47 to +1.66)	Up (99%)	+50.5%	+41.6%	+8.9%
	2001-2023	0.08	+0.49 (-0.16 to +1.06)	Up (96%)	+18.8%	+11.2%	+7.6%
Total nitrogen							
Flow-normalized concentration	1994-2023	0.50	+0.14 (-0.22 to +0.51)	Up (75%)	+7.9%	+9.0%	-1.1%
	2001-2023	0.91	+0.05 (-0.32 to +0.39)	Up (55%)	+2.8%	+4.1%	-1.2%
Flow-normalized load	1994-2023	0.48	+1.59 (-2.58 to +10.14)	Up (82%)	+9.2%	+2.0%	+7.2%
	2001-2023	0.66	+1.2% (-2.53 to +8.94)	Up (67%)	+6.9%	-0.3%	+7.2%

Notes

Conf. Int. = confidence interval; mg/L = milligram per liter; MTA = metric ton annually.

Changes are rounded to the nearest one-tenth percentage point; as such, the sums may not exactly total due to rounding.

2.5.3 Lake Superior Major Basin

Flow-normalized TP and TN concentrations and loads are plotted on charts in Appendix D for the St. Louis River at Scanlon (Section D.3); this section has "WRTDS" in the section name. The other sections in Appendix D present charts using FLUX32 results that are not flow-normalized.

As previously identified, WRTDS analysis was performed at only one site in the Lake Superior major basin: the St. Louis River at Scanlon, MN (Table 27). Data were only available for 2011-2023; as such, baseline and recent periods were not evaluated. Two sets of results are presented (Table 27): 2011-2023 average and 2023 (most recent year).

Table 27. Flow-normalized TP and TN in the St. Louis River at Scanlon, MN, using WRTDS analysis

Nutrient	Flow-normalized load (MTA)		Flow-normalized concentration (mg/L)	
	2011-2023	2023	2011-2023	2023
Total phosphorus	146	138	0.04	0.03
Total nitrogen	2,571	2,451	0.91	0.84

Note: cfs = cubic feet per second; FNC = flow-normalized concentration; FNL = flow-normalized load; mg/L = milligram per liter; MTA = metric ton annually.

2.6 EVALUATION OF FLOW-LOAD RELATIONSHIPS

Flow-load relationships at key monitoring stations were evaluated using linear regressions of flow and FWMC (Section 2.6.1) and using linear regressions of load and flow (Section 2.6.2). The second set of evaluations (those in Section 2.6.2) are similar to those performed in Minnesota's 2014 NRS (MPCA 2014).

2.6.1 FWMC and Flow

Linear regressions were developed between flow (independent variable) and FWMC (dependent variable) to evaluate the influence of flow on FWMC (Appendix E). FWMC is equivalent to the sum of loads from individual events (calculated as observed concentration times flow) divided by the sum of flows from those events. Generally, FWMC is driven by events with higher flows.

In the context of the NRS, if a linear regression has a statistically significant positive slope and a higher coefficient of determination, then FWMC increases as flow increases. (i.e., event concentration is independent of flow). If a linear regression has a statistically significant negative slope and a higher coefficient of determination , then FWMC decrease as flow increases (i.e., flow may be diluting the FWMC). If the slope of the regression is not statistically significant then the regression equation explains only a minor portion of the changes in FWMC. A low coefficient of determination indicates that flow and concentration are not strongly

Linear Regressions

The coefficient of determination (R2) indicates how much of the variation of the dependent variable is predictable from the independent variable. The coefficient of determination ranges from zero to one, with zero representing no predictability and one representing perfect predictability.

In a linear regression with a higher coefficient of determination, a positive slope of the linear regression indicates that the dependent variable predictably increases as the independent variable increases, while a negative slope of the linear regression indicates that the dependent variable predictably decreases as the independent variable increases.

correlated resulting in flow not being a strong predictor of FWMC. This is important because if FWMC is not correlated to flow but flow increases (e.g., due to climate change), then increased flow will lead to a linear increase in load.

The statistical significance of the slope of the linear regressions and the coefficients of determination of the linear regressions for monitoring sites on the Mississippi River (Table 45), tributaries to the Mississippi River (Table 46), Lake Winnipeg major basin (Table 47), and Great Lakes major basin (Table 48) are presented in the following four tables. The slopes of the linear regressions are only presented if the slope of the linear regression is statistically significant (alpha=0.5). Charts are presented in Appendix E; each table includes the figure cross-reference to the applicable chart.

The slopes of the linear regressions were not statistically significant and the coefficients of determination were lower for most of the tributaries to the Mississippi River, the Lake Winnipeg major basin, or the St. Louis River in the Great Lakes major basin. As such, FWMC is not predictable from flow for these waterbodies.

Seven waterbodies yielded statistically significant linear regression relationships:

- **Black River near Galesville, WI**: Increasing flow decreases TN FWMC (i.e., dilution).
- **Cedar River near Austin, MN**: Increasing flow decreases TP FWMC (i.e., dilution)
- **La Crosse River at La Crosse, WI**: Increasing flow increases both TP and TN FWMC
- **Mississippi River at Anoka, Red Wing, Lake Pepin outlet, and La Crosse**: Increasing flow increases TN FWMC.
- **Upper Iowa River near Dorchester, IA**: Increasing flow increases both TP and TN FWMCs
- **Split Rock Creek near Jasper, MN**: Increasing flow increases TP FWMC
- **Nemadji River near South Superior, WI**: Increasing flow increases both TP and TN FWMCs

In these seven waterbodies, flow may be a predictive factor for FWMC (e.g., runoff-derived sources of TP and TN), and the response of loads to changes in flow will not be linear due to correlation between concentration and flow.

2.6.2 Load and Flow

In the 2014 NRS, MPCA evaluated the influence of flow on TP and TN load in the Mississippi River at L&D #3 (upstream of Lake Pepin) by developing linear regressions between nutrient loads and flow during the baseline period and a (then) recent period and then applying both the baseline period linear regression and (then) recent period linear regression to baseline flows. In this analysis, MPCA found that the (then) recent period linear regression applied to the baseline flows yielded loads that were 31% smaller than loads from the baseline period regression applied to baseline flows. These analyses indicated that "progress toward the NRS phosphorus goals has been made on a portion of the Mississippi River mostly due to phosphorus reductions in Minnesota" (MPCA 2014).

Analyses of this type do not distinguish as to whether trends in loads are due to decreases in loading rates from source areas or due to changes in total runoff volume. The strength of a regression relationship between load and flow (as summarized by R^2) is prone to be overinterpreted because flow is on both sides of the equation. That is, load (equivalent to flow times concentration) is regressed on flow. If concentration is independent of flow, then a strong predictive relationship will be seen solely because total load is dependent on flow volume.

The same analyses as were performed in the 2014 NRS were repeated using more recent data from MCES for the Mississippi River at Anoka, MN and at Red Wing (above L&D #3), and the Minnesota River at Jordan, MN, and data from

CWSEC for the Red River of the North at Emerson, Manitoba, Canada. The baseline and recent[3] periods were 1980-1996 and 2013-2022 (respectively) for the Mississippi River major basin and 1994-2003 and 2013-2022 (respectively) for the Lake Winnipeg major basin. Linear regressions for baseline and recent periods and predicted loads using baseline flows are presented in Appendix G.

Each linear regression was evaluated for significance and all 16 linear regressions were statistically significant. The coefficients of determination ranged from 0.66 to 0.94 for TP (Table 28) and from 0.74 to 0.89 for TN (Table 29). The percent change between baseline and recent periods (relative to baseline load) is presented for three flow percentiles in Table 30. The subsections below present conclusions that were drawn via visual analysis of loads estimated with the baseline and recent linear regressions using baseline flows.

Table 28. Summary of TP load and flow linear regressions

Monitoring site	Baseline		Recent		Figure
	Slope	R^2	Slope	R^2	
Mississippi River at Anoka, MN	+0.1490	0.66	+0.1664	0.87	Figure 95
Mississippi River at Red Wing, MN	+0.2169	0.84	+0.2341	0.89	Figure 97
Minnesota River at Jordan, MN	+0.2675	0.86	+0.3210	0.94	Figure 99
Red River of the North at Emerson, MA	+0.4897	0.90	+0.3145	0.90	Figure 101

Table 29. Summary of TN load and flow linear regressions

Monitoring site	Baseline		Recent		Figure
	Slope	R^2	Slope	R^2	
Mississippi River at Anoka, MN	+3.0837	0.78	+3.2067	0.78	Figure 96
Mississippi River at Red Wing, MN	+5.5809	0.84	+5.2380	0.79	Figure 98
Minnesota River at Jordan, MN	+8.5348	0.77	+7.9863	0.74	Figure 100
Red River of the North at Emerson, MA	+2.3040	0.89	+2.6701	0.81	Figure 102

[3] The current periods were defined as the 10 most recent years with available data. A second current period of only the 5-most recent years with available data was also evaluated but MPCA considered a five year period to be too short.

Table 30. Changes in loads from baseline to recent periods' at key flows

Monitoring site	Total phosphorus			Total nitrogen		
	15th (Low)	50th (Median)	85th (High)	15th (Low)	50th (Median)	85th (High)
Mississippi River at Anoka, MN	-59%	-30%	-25%	-19%	-8%	-6%
Mississippi River at Red Wing, MN	-82%	-40%	-31%	0%	-4%	-4%
Minnesota River at Jordan, MN	-27%	-3%	+4%	+11%	+1%	-1%
Red River of the North at Emerson, MA	+12%	+20%	+27%	-13%	-8%	-4%

Notes

The 15th, 50th, and 85th percentile flows were calculated for the baseline period, which was 1980-1996 for the Mississippi and Minnesota rivers and 1994-2003 for the Red River of the North. A narrative description of the flow condition is presented below each percentile.

Change is relative to the baseline period load. A negative percent (in green font color) indicates a decrease in load from baseline to recent period; a positive percent (in red font color) indicates an increase in load from baseline to recent period.

2.6.2.1 Mississippi River Major Basin

In the Mississippi River at Anoka, MN (RM 872), TP loads predicted using the 2013-2022 linear regression were less than 1980-1996 loads but only met the 45% TP final load reduction goal when flow was at or less than 4.2 million acre-feet/year. TN loads predicted using the 2013-2022 linear regression were slightly less than 1980-1996 loads and never came close to meeting the 45% TN load reduction goal.

In the Mississippi River at Red Wing, MN (RM 797; above L&D #3), TP loads predicted using the 2013-2022 linear regression were less than 1980-1996 loads but only met the 45% TP load reduction goal was flow was at or less than 13.3 million acre-feet/year. However, at the median of baseline flows, the reduction was 40%, which is nearly 90% of the 45% load reduction goal. For TN, the 1980-1996 and 2013-2022 linear regressions were similar, as were their slopes. Reductions at the three key flows (15th, 50th, and 85th percentiles) ranged from 0% to 4%. As such, the 1980-1996 TN loads and TN loads predicted using the 2013-2022 linear regression with 1980-1996 flows were similar. Based on this type of analyses, no appreciable change is evident between 1980-1996 and 2023-2022 TP loads and no significant progress with achieving the 45% TN load reduction goal.

In the Minnesota River at Jordan, the 1980-1996 and 2013-2022 linear regressions were similar for both TP and TN, notably 1980-1996 and 2013-2022 slopes were very close (Appendix G, Figure 99 and Figure 100). As such, the 1980-1996 loads and loads predicted using the 2013-2022 linear regression with 1980-1996 flows were similar. These analyses generally indicate no appreciable change between 1980-1996 and 2012-2013.

2.6.2.2 Lake Winnipeg Major Basin

In the Red River of the North at Emerson, Manitoba, Canada, TP loads predicted using the 2013-2022 linear regression were greater than baseline 1994-2003 loads. The TP load increased at the three key flows (15th, 50th, and 85th percentiles) ranged from 12% to 27% (Table 30).

TN loads predicted using the 2013-2022 linear regression were less than 1994-2003 loads but did not meet the 45% TN load reduction target. At the three key flows (15th, 50th, and 85th percentiles), TN load reductions ranged from 4% to 13% (Table 30), which are far less than the 45% TN load reduction goal.

2.7 ASSESSMENT OF OUT-OF-STATE NUTRIENT LOAD CONTRIBUTIONS

In-stream monitoring data includes TP and TN load from both Minnesota and upstream states. In development of Minnesota's NRS, MPCA needs to determine the load derived from Minnesota. In the 2014 NRS, MPCA (2014) applied load fractions from an analysis of USGS SPAtially-Referenced Regression On Watershed attributes (SPARROW) model data to in-stream loads to estimate the fraction of in-stream loads from Minnesota and the fractions of in-stream load from upstream states.

USGS (2019a) describes SPARROW as follows

> SPARROW (SPAtially Referenced Regression On Watershed attributes) models estimate the amount of a contaminant transported from inland watersheds to larger water bodies by linking monitoring data with information on watershed characteristics and contaminant sources.

As such, SPARROW watershed-based modeling results can be used to predict long-term average loading that is delivered to waterbodies downstream (USGS 2017). Hence, MPCA (2014) used long-term predicted TP and TN at key in-state and out-of-state locations to determine the fraction of TP and TN at the key locations from within Minnesota.

For Minnesota's 2025 NRS, MPCA needs to know if the in-state and out-of-state nutrient load contributions determined for Minnesota's 2014 NRS are still appropriate to or if new distributions of load contributions would be more appropriate to use. To support MPCA with Minnesota's 2025 NRS, Tetra Tech downloaded simulated TP and TN SPARROW datasets for the Midwest from USGS (2020). The SPARROW results represented long-term averages for water years 2002 through 2014. The SPARROW data were joined to stream hydrography from the National Hydrography Dataset. Loads were reported for both individual segments (incremental) and cumulative including all upstream segments (aggregated).

Tetra Tech plotted the monitoring stations discussed in Section 2.2, along with state and international borders and National Hydrography Dataset Plus V2 catchments in a geographic information system (GIS), to determine the aggregated SPARROW loads at the monitoring sites, state and international boundaries, and key tributaries. The appropriate subtractions and divisions were then performed to calculate the Minnesota fractions. The process is summarized in the steps below:

1. Identify and sum the aggregated loads of all tributaries upstream of the key monitoring site on the mainstem within (a) the state of Minnesota and (b) other states.
2. Determine if any portions of the tributaries in Minnesota include upstream portions in other states. If so, identify and sum the upstream states' portions.
3. Sum all of the Minnesota tributaries (less any portions from upstream states): total Minnesota load
4. Sum all the other states tributaries and upstream states' portions of Minnesota tributaries: total other states' load
5. Calculate the Minnesota percentage at the key monitoring site by dividing the total Minnesota load by the quantity of the summation of the total Minnesota load and total other states' load.
6. Calculate the other states' percentage at the key monitoring site by dividing the total other states' load by the quantity of the summation of the total Minnesota load and total other states' load.

This methodology did not account for direct drainage to the mainstem segments, nor did it account for attenuation along the mainstem. As such, the SPARROW aggregated load at the key monitoring site was sometimes greater and sometimes less than the summation of the aggregated loads of the Minnesota tributaries and other states' tributaries. MPCA deemed this methodology acceptable because the direct drainage to the mainstem was very small relative to the summation of all the tributaries. Additionally, MPCA is concerned with the distribution of loads (e.g., 50% of the load is in-state) and not the absolute loads.

The calculated percentages derived from SPARROW loads are summarized in the list below and presented in the tables in Appendix H:

- **Mississippi River**: Relative to tributaries in Wisconsin, tributaries in Minnesota constitute the vast majority of the TP and TN load to the Mississippi River. Excluding Anoka, in-state loads ranged from 81% to 98% of the TP total load and 78% to 96% of the TN total load (Table 49).

  In the 2014 NRS, in-stream loads apportioned for goal-setting were based on land area: 77% of the area draining to the Mississippi River near the Minnesota-Iowa border was from Minnesota (MPCA 2014). The 77% relative land area is similar to the relative TP (81%) and TN (78%) loading from tributaries to the Mississippi River at La Crosse, WI, determined from SPARROW modeling.

- **Tributaries to the Mississippi River**: Four tributaries to the Mississippi River (north of the Minnesota-Iowa state boundary) are entirely within Minnesota and three tributaries are entirely within Wisconsin. Based on analysis of SPARROW results, the vast majority of loading from the Minnesota River is from Minnesota (97% TP and TN).

  Split Rock Creek, in the Missouri River basin, flows from Minnesota to South Dakota, in the southwest corner of Minnesota. Split Rock Creek is the border between South Dakota and Iowa, before it joins the Big Sioux River. At the Minnesota-South Dakota state boundary, most of the loading in Split Rock Creek is from Minnesota (80% TP and 71% TN). The Upper Iowa River begins in Minnesota and flows east across the Minnesota-Iowa state boundary several times, before eventually discharging to the Mississippi River downstream of the Minnesota-Iowa state boundary. Based on analysis of SPARROW results, the vast majority of loading from the Upper Iowa River is from Iowa (73% TP and 64% TN).

- **Lake Winnipeg major basin**: Analysis of SPARROW results indicated that a minority of the TP and TN loads in the Red River were from Minnesota: 34% to 44% for TP and 39% to 47% for TN (Table 50). The Rainy River load fractions were unique: 53% TP and 27% TN were from Minnesota.

  In the 2014 NRS, in-stream loads apportioned for goal-setting were based on land area: 48% of the area draining to the Red River at Emerson, Manitoba, Canada was from Minnesota (MPCA 2014). The 48% relative land area is larger than the relative TP (34%) and TN (39%) loading from tributaries to the Red River determined from SPARROW modeling.

- **Lake Superior major basin**: The St. Louis River is entirely within Minnesota. Analysis of SPARROW results indicated that 54%of TP loads and 64% of TN loads in the Nemadji River were from Minnesota (Table 51).

The in-state and out-of-state TP and TN load fractions determined using SPARROW model data, as described above and presented in Section H.1 of Appendix H, were applied to the calculated baseline and current loads determined at key monitoring sites, as described in Section 2.3, to estimate the in-state and out-of-state TP and TN loads at key monitoring stations. The in-state and out-of-state baseline and current TP and TN loads are presented in Section H.2 of Appendix H.

Based on Tetra Tech's findings, MPCA asked USGS to determine the distribution of in-state and out-of-state loads for the Red River of the North at Emerson, Manitoba, Canada. Using SPARROW, USGS determined that 38% of TP load and 44%

of TN load were from Minnesota. Like Tetra Tech's estimates (34% and 39%, respectively), the USGS-calculated in-state load distributions were much smaller than the 48% determined for the 2014 NRS.

2.8 ASSESSMENT OF PROGRESS TOWARD ACHIEVING GOALS

In the following subsections, loads calculated from monitoring data using FLUX32 and WRTDS are compared with the 2025 milestone loads and 2040 final goal loads (Table 31). These loads may be used by MPCA to evaluate progress and determine how much additional load reduction is still necessary. Direct comparison between baseline loads, goal loads derived from the baseline loads, and current loads presents a challenge because current flows are much larger than baseline flows.

Table 31. Milestone and final goal reductions

Major basin	Baseline	Milestone by 2025	Final goal by 2040
Mississippi River	1980 – 1996 average	12% TP reduction 20% TN reduction	45% reduction
Lake Winnipeg	1998 – 2001 average	10% TP reduction 13% TN reduction	50% reduction
Lake Superior	1970s	No net increase	No net increase

Based on: MPCA 2022

2.8.1 Mississippi River Major Basin

1980-1996, 2025 milestone, 2040 final goal and 2014-2023 loads were determined for three sites on the Mississippi River and one site on the Minnesota River. Milestone and final goal loads were calculated from 1980-1996 conditions. Thus, 1980-1996, milestone, and final goal loads are all based on 1980-1996 flow conditions. However, 2014-2023 loads are based on 2014-2023 flows. Long-term flow data indicate that 2014-2023 flows are 15% to 27% higher in the Mississippi River and 40% to 42% higher in the Minnesota River, as compared with 1980-1996 flows.

1980-1996, 2025 milestone, 2040 final goal, and 2014-2023 loads for TP and TN are presented in Table 32 and Table 33, respectively. The FLUX32, non-flow normalized WRTDS, and flow-normalized WRTDS loads are presented herein.

Analysis of 1980-1996 and 2014-2023 loads indicates that both TP non-flow-normalized and flow-normalized loads have generally decreased in the Mississippi River (Table 32). In the Minnesota River, non-flow-normalized TP loads have increased, while flow-normalized TP loads have decreased.

A similar analysis for TN shows that both TN non-flow-normalized and flow-normalized loads have generally increased in the Mississippi River (Table 33). In the Minnesota River, non-flow-normalized TN loads have increased, while flow-normalized TN loads have decreased.

Table 32. Load changes in the Mississippi and Minnesota rivers for TP

Monitoring sites	Load estimation method	1980-1996 load (MTA)	Milestone load (MTA) [a]	Final goal load (MTA) [b]	2014-2023 load (MTA)	Needed reduction [c]
Mississippi River						
at Anoka, MN (RM 872)	FLUX32	1,079	950	593	854	261
at Red Wing, MN (above L&D #3; RM 797)	FLUX32	3,676	3,235	2,022	3,119 [d]	1,097
	WRTDS	3,664	3,224	2,015	3,191	1,176
	WRTDS flow-normalized	3,817	3,359	2,099	2,447	348
at La Crosse, WI (L&D #7; RM 703)	WRTDS	4,976 [e]	4,379	2,737 [e]	4,670	1,933
	WRTDS flow-normalized	--	--	--	4,475	--
Minnesota River						
at Jordan, MN	FLUX32	1,532	1,348	843	2,100 [d]	1,257
	WRTDS	1,556	1,369	856	2,162	1,306
	WRTDS flow-normalized	1,638	1,442	901	1,525	624

Notes

L&D = lock and dam; MTA = metric tons annually; RM = river mile.

Loads are rounded to the nearest integer. Totals may not sum exactly due to rounding.

a. The *Milestone load (MTA)* is calculated as 88% of the *1980-1996 load (MTA)*, which is a 12% reduction

b. The *Final goal load (MTA)* is calculated as 55% of the *1980-1996 load (MTA)*, which is a 45% reduction.

c. The *Needed Reduction* is calculated using the *2014-2023 load (MTA)*, which is derived from 2014-2023 flows, and the *Final goal load (MTA)*, which is derived from 1980-1996 flows.

d. The recent period is 2013-2022.

e0 These loads are for the *Mississippi River near State Border* in the 2014 NRS (MPCA 2014, Table 3-7, p. 3-27). These loads were not calculated using WRTDS.

Table 33. Load changes in the Mississippi and Minnesota rivers for TN

Monitoring sites	Load estimation method	1980-1996 load (MTA)	Milestone load (MTA) [a]	Final goal load (MTA) [b]	2013-2022 load (MTA)	Needed reduction [c]
Mississippi River						
at Anoka, MN (RM 872)	FLUX32	17,778	14,222	9,778	19,378	9,600
at Red Wing, MN (above L&D #3; RM 797)	FLUX32	75,982	60,786	41,790	95,890	54,100
	WRTDS	73,447	58,758	40,396	96,026	55,630
	WRTDS flow-normalized	74,818	59,855	41,150	73,694	32,544
at La Crosse, WI (L&D #7; RM 703)	WRTDS	97,996 [d]	78,397	53,898 [d]	113,887	59,989
	WRTDS flow-normalized	--	--	--	103,995	--
Minnesota River						
at Jordan, MN	FLUX32	45,752	36,602	25,164	61,333	36,169
	WRTDS	46,073	36,859	25,340	60,657	35,317
	WRTDS flow-normalized	50,064	40,051	27,535	40,088	12,553

Notes

L&D = lock and dam; MTA = metric tons annually; RM = river mile.

Loads are rounded to the nearest integer. Totals may not sum exactly due to rounding.

a. The *Milestone load (MTA)* is calculated as 80% of the *1980-1996 load (MTA)*, which is a 20% reduction

b. The *Final goal load (MTA)* is calculated as 55% of the *1980-1996 load (MTA)*, which is a 45% reduction.

c. The *Needed Reduction* is calculated using the *2014-2023 load (MTA)*, which is derived from 2014-2023 flows, and the *Final goal load (MTA)*, which is derived from 1980-1996 flows.

d. These loads are for the *Mississippi River near State Border* in the 2014 NRS (MPCA 2014, Table 3-8, p. 3-29). These loads were not calculated using WRTDS.

2.8.2 Lake Winnipeg Major Basin

1998-2001, milestone, final goal, and 2014-2023 loads were estimated for one site: Red River of the North at Emerson, Manitoba, Canada. Milestone and final goal loads were calculated from 1998-2001 conditions. Thus, 1998-2001, milestone, and final goal loads are all based on 1998-2001 flow conditions. However, 2014-2023 loads are based on 2014-2023 flows. Long-term flow data indicate that 2014-2023 flows are 15% to 16% lower than 1998-2001 flows in the Red River of the North at Emerson.

1998-2001, 2025 milestone, 2040 final goal, and 2014-2023 loads for TP and TN are presented in Table 34 and Table 35, respectively. The FLUX32, non-flow normalized WRTDS, and flow-normalized WRTDS loads are presented herein. Analysis of 1998-2001 and 2014-2023 loads indicates that TP changes vary by the load estimation method and whether or not the data were flow-normalized. A similar analysis with TN indicates that TN loads decreased from 1998-2001 to 2014-2023; such a decrease may be due to the decreasing flows in the Red River of the North during this time period.

Table 34. Load changes in the Red River of the North at Emerson, Manitoba, for TP

Monitoring entity	Load estimation method	1998-2001 load (MTA)	Milestone load (MTA) [a]	Final goal load (MTA) [b]	2014-2023 load (MTA)	Needed reduction [c]
CWSEC	Monthly extrapolated [d]	2,367	2,130	1,400 [e]	2,635 [f]	1,235
CWSEC (by MPCA)	WRTDS	2,816	2,534	1,408	2,654	1,246
	WRTDS flow-normalized	2,621	2,359	1,311	2,933	1,622

Notes

CWSEC = Manitoba Conservation and Water Stewardship and Environment Canada; MPCA = Minnesota Pollution Control Agency; MTA = metric tons annually.

Loads are rounded to the nearest integer. Totals may not sum exactly due to rounding.

a. The *Milestone load (MTA)* is calculated as 90% of the *1998-2001 load (MTA)*, which is a 10% reduction

b. The *Final goal load (MTA)* is calculated as 50% of the *1998-2001 load (MTA)*, which is a 50% reduction.

c. The *Needed Reduction* is calculated using the *2014-2023 load (MTA)*, which is derived from 2014-2023 flows, and the *Final goal load (MTA)*, which is derived from 1998-2001 flows.

d. Monthly average sample concentrations were multiplied by monthly average flows and summed to yield annual loads.

e. The final goal load is from the International Red River Board (2019).

f. The recent period is 2013-2022.

Table 35. Load changes in the Red River of the North at Emerson, Manitoba, for TN

Monitoring entity	Load estimation method	1998-2001 load (MTA)	Milestone load (MTA) [a]	Final goal load (MTA) [b]	2014-2023 load (MTA)	Needed reduction [c]
CWSEC	Monthly extrapolated [d]	17,107	14,883	9,525 [e]	14,603 [f]	5,078
CWSEC (by MPCA)	WRTDS	20,719	18,026	10,360	15,727	5,368
	WRTDS flow-normalized	18,117	15,762	9,059	16,444	7,415

Notes

CWSEC = Manitoba Conservation and Water Stewardship and Environment Canada; MPCA = Minnesota Pollution Control Agency; MTA = metric tons annually.

Loads are rounded to the nearest integer. Totals may not sum exactly due to rounding.

a. The *Milestone load (MTA)* is calculated as 87% of the *1998-2001 load (MTA)*, which is a 13% reduction

b. The *Final goal load (MTA)* is calculated as 50% of the *1998-2001 load (MTA)*, which is a 50% reduction.

c. The *Needed Reduction* is calculated using the *2013-2022 load (MTA)*, which is derived from 2013-2022 flows, and the *Final goal load (MTA)*, which is derived from 1998-2001 flows.

d. Monthly average sample concentrations were multiplied by monthly average flows and summed to yield annual loads.

e. The final goal load is from the International Red River Board (2019).

f. The recent period is 2013-2022.

2.8.3 Lake Superior Major Basin

MPCA did not establish 2025 milestone or 2040 final goal loads for the Lake Superior major basin in the 2014 NRS (MPCA 2014, Section 3.4.2), nor did MPCA advocate for new reductions.

Recent average annual loads for the Nemadji and St. Louis rivers are presented in Section 2.3.3, and flow-normalized, recent average annual loads for the St. Louis River are presented in 2.5.3.

3 ASSESSMENT OF MODELING RESULTS

In addition to monitoring data, to support development of Minnesota's 2025 NRS, MPCA contracted with Tetra Tech to *assess modeled watershed outlet nutrient loads and estimated aggregated model loads reaching state lines*. This section begins with a brief summary of available HSPF model data provided by RESPEC (Section 3.1). TP and TN loads delivered to subbasin outlets and state boundaries are presented in Appendix G, with a brief discussion in Section 3.3, and calculated TP and TN yields are presented in Section 3.4, with subbasin loads presented in Appendix F.

3.1 UPDATED MODEL LOADS

RESPEC provided MPCA and Tetra Tech with updated simulation results for 68 HSPF watershed models with outlets in Minnesota. RESPEC provided both flow and loads delivered to reach outlets and subbasin outlets. Model results include 6,633 model reaches in Minnesota and 243 subbasin outlets. While many subbasins had a single outlet, several subbasins had many outlets (e.g., the Lake Superior North model has 47 subbasin outlets).

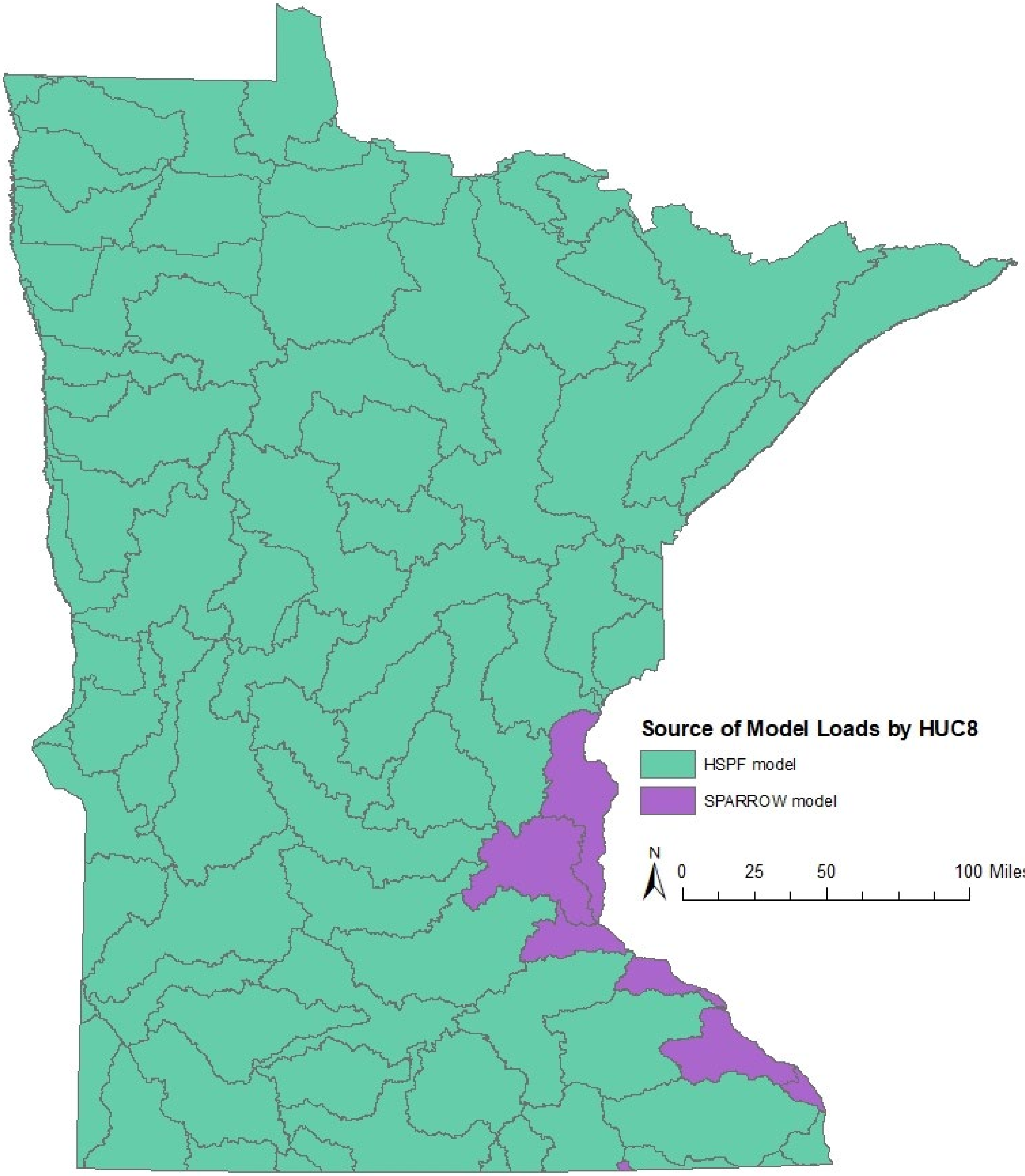


Figure 103. Subbasins simulated by HSPF and SPARROW models

Table 57 in Appendix F presents the simulation period, number of reaches, number of subbasin outlets, number sources, and number of results for each model.

For this task, the main model results datasets were the 10-year average annual TP and TN loads (in lbs./year) delivered to subbasin outlets.

HSPF models have not yet been developed for the following five HUC8 subbasins that are wholly or partially within Minnesota:

- *Mississippi River – Twin Cities* (HUC 07010206) in the *Upper Mississippi River* basin
- *Lower St. Croix River* (HUC 07030005) in the *St. Croix River* basin
- *Mississippi River – Winona* (HUC 07040003) in the *Lower Mississippi River* basin
- *Mississippi River – La Crescent* (HUC 07040006) in the *Lower Mississippi River* basin
- *Upper Wapsipinicon River* (HUC 07080102) in the *Cedar River* basin

Refer to Section 3.2 for a discussion of how these five subbasins were represented in this study. Figure 103 in Appendix J presents a map of these six subbasins where SPARROW modeling was used to estimate loads.

3.1.1 Model Comparability to Previous Versions

The model results provided by RESPEC are not directly comparable to the model results presented in the interim guidance (MPCA 2022), for several reasons. First, about 20 HSPF models were extended (i.e., the model simulation time period was extended) and the calibrations were refined. Second, over 30 more HSPF models were extended, with no calibration refinement. With such extensions, the model results in this study represent different years than the model results from the interim guidance (MPCA 2022). And finally, RESPEC revised the bed/bank in-channel erosion processes.

3.1.2 *Rainy River – Black River* (HUC 09030004)

In 2013, USGS re-delineated hydrologic units in the Rainy River subregion (HUC 0903) to better represent those hydrologic units that are bisected by the international boundary. In doing so, USGS merged the former *Upper Rainy River* (HUC 09030004) subbasin into the *Lower Rainy River* (HUC 09030008) subbasin. In Minnesota, the *Upper Rainy River* subbasin is known as the *Rainy River – Black River* subbasin. While USGS eliminated this HUC and merged its area into the *Lower Rainy River* subbasin, MnDNR retains the HUC and spatial geometry.

In the 2014 NRS and interim guidance, MPCA (2014, 2022) continued to report results for the *Upper Rainy River* or *Rainy River – Black River* (HUC 09030004).

In the recent compilation of HSPF model results to support this study, RESPEC assigned the HUC12s in the current HUC scheme to the model reaches. As such, no HSPF model results are identified as in the *Rainy River – Black River* (HUC 09030004); model results for this former-HUC are contained within the new *Lower Rainy River* (HUC 09030008). Throughout this report, only the *Lower Rainy River* (HUC 09030008) is presented.

3.1.3 Mississippi River – Lake Pepin (HUC 07040001)

An HSPF model was developed several tributaries in the *Mississippi River – Lake Pepin* subbasin[4]. Of the 32 HUC12 subwatersheds in this subbasin, 19 subwatersheds are in Minnesota or bisected by the state border, and 8 of the 19 subwatersheds in the Lake Pepin Tributaries HSPF model[5]. This model excludes the Vermillion River watershed that drains southern St. Paul. Since no HSPF modeling was available for the Vermillion River watershed, SPARROW model results were used to represent the *Mississippi River – Lake Pepin* subbasin in this project.

3.1.4 Loading in Minnesota

The spatial geometry of the HSPF models aligns to watershed boundaries and does not align to the Minnesota state boundary. As such, the HSPF simulated loads for HUC8 subbasins bisected by the Minnesota state boundary include load derived from neighboring states. Since many of the goals for the NRS are for loading derived from within Minnesota, the HSPF simulated load analysis involved the identification and elimination of out-of-state portions of the simulated loads.

Tetra Tech used GIS to identify 219 HUC12 subwatersheds that are bisected by the Minnesota state boundary. GIS was then used to determine the total area of each bisected subwatershed and the area within Minnesota in each bisected subwatershed. The Minnesota area was divided by the total area for each bisected subwatershed to generate the precent of each bisected subwatershed that is within Minnesota.

The HSPF simulated loads for each bisected subwatershed were multiplied by the percent described above. The result was the Minnesota-derived, simulated load for each bisected subwatershed. These loads were summed with the loads for subwatershed entirely within Minnesota to calculate the simulated loads for each HUC8 subbasin.

This area-based approach assumed that sources are uniformly distributed throughout each bisected subwatershed. In reality, the bisected subwatersheds may not be homogenous. No major point sources are known to be in the bisected subwatersheds.

3.2 ESTIMATED LOADS FOR SUBBASINS WITHOUT HSPF MODELS

SPARROW model results were used to represent the five subbasins identified in Section 3.1. Instead of using the fine-scale SPARROW model results discussed in Section 2.7, Tetra Tech downloaded SPARROW model results calculated at the subbasin-scale (USGS 2019b). The subbasin-scale loads (kilograms per year) and yields (kilograms per square kilometer) delivered to subbasin-outlets were calculated for multiple sources[6] (Robertson et al. 2019). Tetra Tech summed the multiple sources to determine the total loads and total yields delivered to subbasin outlets. For certain analyses presented in this section, the SPARROW results were converted to imperial units of measure.

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[4] The Mississippi River – Lake Pepin subbasin is called the Rush-Vermilion subbasin in the USGS HUC system.
[5] The eight HUC12 subwatersheds included in the model are *Hay Creek* (*04 01), *Bullard Creek* (*04 02), *City of Red Wing-Mississippi River* (*04 04), *Upper Wells Creek* (*06 01), *Lower Wells Creek* (*06 02), *Gilbert Creek* (*07 03), *Miller Creek* (*07 04), and *Lake Pepin* (*07 05).
[6] The sources are sewerage point sources (TN and TP), urban land (TN and TP), farm fertilizer (TN and TP), manure (TN and TP), agricultural land (TP only), forest/wetland (TP only), and atmospheric deposition (TN only).

3.3 ESTIMATED LOSSES BETWEEN SUBBASIN OUTLETS AND STATE BOUNDARIES

MPCA (2022) calculated delivery factors (i.e., average annual net attenuation), for both TP and TN, to determine the portion of load delivered to a subbasin outlet that is then delivered to a state boundary. These delivery factors are presented in Table 58 in Appendix G. These delivery factors were originally published in *Approach and Methods for the interim guidance, "Watershed Nutrient Loads to Accomplish Minnesota's Nutrient Reduction Strategy Goals"* (MPCA 2022, Step #3, Figures 8 and 9).

MPCA (2022) determined the delivery factors using HSPF and SPARROW modeling. For subbasins in basins with HSPF models, MPCA (2022, p. 14) "used long-term average nutrient delivery predicted by various HSPF models that simulate transport from multiple HUC8 watershed outlets through major riverine systems to downstream endpoints." For subbasins in basins without HSPF models, MPCA (2022) used relationships between SPARROW and HSPF attenuation factors to predict the delivery factor for a specific subbasin. In this analysis, MPCA (2022) divided SPARROW terminal delivery (e.g., to the Gulf of Mexico) for the upstream-subbasin-of-interest by the SPARROW terminal delivery for the downstream-subbasin-of-interest. MPCA (2022) assigned a delivery factor of 100% for a subbasin intersecting a state or international boundary and any subbasin with outlets on Lake Superior.

TP and TN loads delivered to each subbasin outlet were multiplied by the delivery factors (MPCA 2022) to calculate the TP and TN loads delivered from each subbasin to the state boundaries. The general calculation is presented in the equation below. The loads delivered to subbasin outlets and state boundaries are presented in Table 59 in Appendix G.

$$\mathbf{Load_{State} = Load_{Subbasin} \times Factor_{Delivery}}$$

where

$Load_{State}$ = Load delivered to the state boundary

$Load_{Subbasin}$ = Load delivered to the subbasin outlet

$Factor_{Delivery}$ = Delivery factor that MPCA (2022) calculated from SPARROW model results

An example calculation for TP in the *Mississippi River – Headwaters* subbasin (HUC 07010101) is provided below, where the TP load delivered to the subbasin outlet is 12.5 MTA and the delivery factor for this subbasin is 45%, which yields a TP load delivered to the Minnesota-Wisconsin state boundary of 5.62 MTA.

$$Load_{State} = Load_{Subbasin} \times Factor_{Delivery}$$

$$Load_{State} = (12.5\ MTA) \times (45\%)$$

$$Load_{State} = 5.62\ MTA$$

3.4 CALCULATED ANNUAL YIELDS

HSPF and SPARROW model results were used to calculate annual loads and yields delivered to both (1) subbasin outlets and (2) state boundaries. In both cases, the first step was to sum the loads delivered to subbasin outlets by subbasin because several subbasins had multiple outlets. For example, subbasins along Lake Superior include multiple direct tributaries to Lake Superior that are each an outlet in the HSPF models.

To calculate annual yields delivered to subbasin outlets, the total annual loads delivered to the subbasin outlet(s) were divided by the areas of the subbasins within Minnesota (i.e., out-of-state load and area were excluded). Annual loads delivered to subbasin outlets are presented in Table 58 in Appendix J, and annual yields delivered to subbasin outlets are presented in Figure 3 (TP; page 57), Figure 4(TN; page 58), and Table 59 in Appendix J.

To calculate annual yields delivered to state boundaries, the total annual loads delivered to subbasin outlet(s) (Minnesota-only) were reduced by the delivery factors, as discussed previously in Section 3.3, to calculate total annual loads delivered to state boundaries, and then the total annual loads delivered to state boundaries were divided by the areas of the subbasins. Annual loads delivered to state boundaries are presented in Table 58 in Appendix J. Annual yields delivered to state boundaries are presented in Figure 104 (TP) and Figure 105 (TN) in Appendix J. These two figures include separate maps for yields derived from HSPF models and yields derived from SPARROW models.

Annual loads and yields delivered to state boundaries for the 10 basins and 3 major basins are presented in Table 36.

Table 36. Annual loads and yields (Minnesota-only) delivered to state boundaries

Major basin	Basin	Area in Minnesota (acres)	Delivered load (MTA)		Delivered yield (pounds/acre/year)	
			TP	TN	TP	TN
Lake Superior	Lake Superior	3,804,324	245	4,670	0.14	2.6
Lake Winnipeg	Rainy River	6,876,154	228	4,275	0.07	1.4
	Red River	10,481,948	1,084	8,674	0.23	1.8
	Total	17,358,103	1,312	12,950	0.17	1.6
Mississippi River	Upper Mississippi River	11,493,793	1,396	12,115	0.27	2.3
	Minnesota River	9,399,895	1,192	43,989	0.28	10.3
	St. Croix River	1,627,054	121	1,623	0.16	2.2
	Lower Mississippi River	3,233,412	1,178	22,552	0.80	15.4
	Missouri River	1,135,264	156	4,977	0.30	9.7
	Cedar River	649,823	143	7,657	0.48	26.0
	Des Moines River	969,848	87	1,255	0.20	2.9
	Total	28,509,089	4,183	93,467	0.32	7.2

Notes

MTA = metric ton annually; TN = total nitrogen; TP = total phosphorus.

Areas are rounded to the nearest acre, loads are rounded to the nearest MTA, and yields are rounded to the one-hundredth pound per acre per year for TP and one-tenth pounder per acre per year for TN.

Areas, loads, and yields are for Minnesota only (i.e., out-of-state area and loads are excluded).

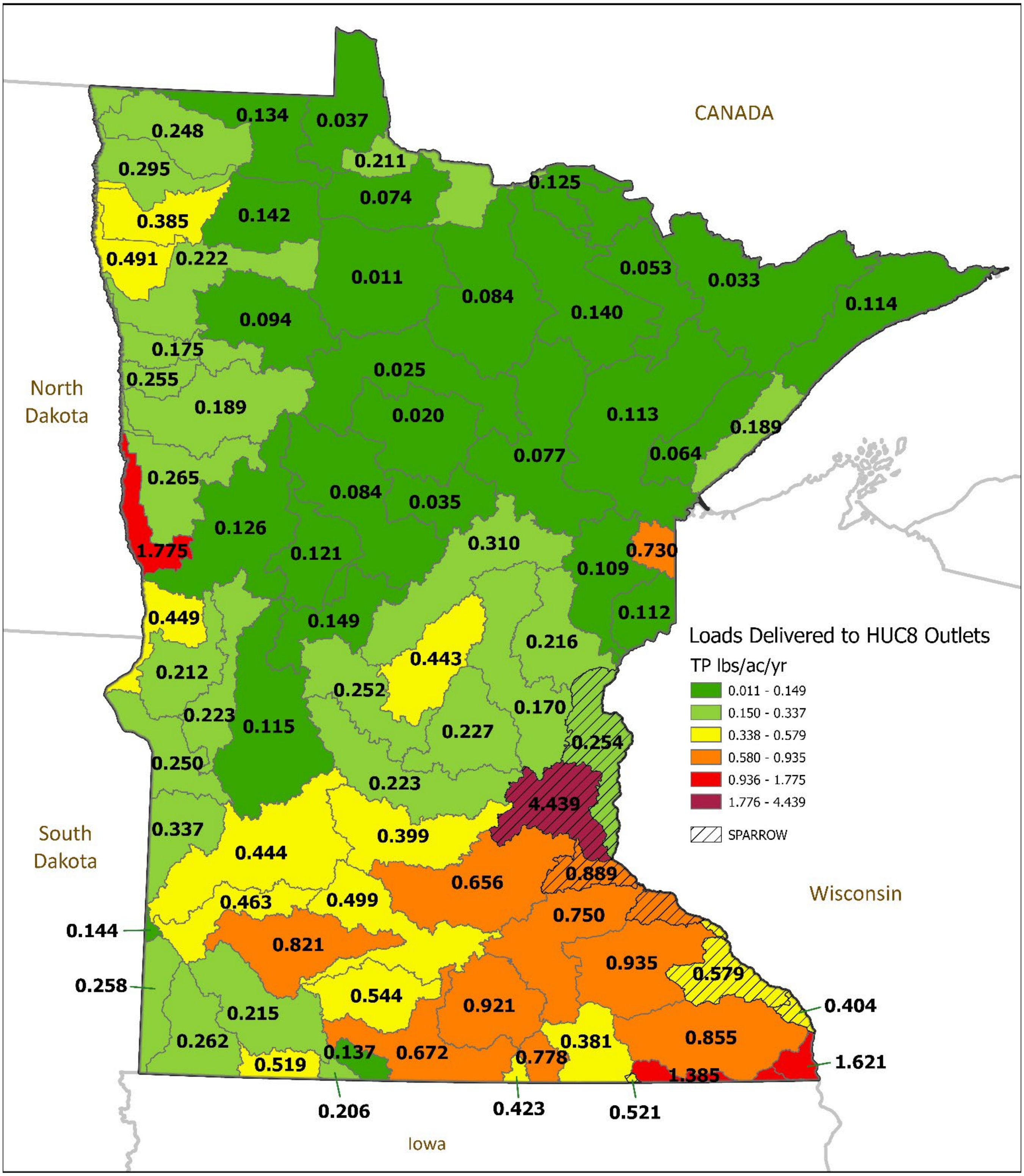


Figure 3. TP yields delivered to subbasin outlets, derived from HSPF model results (except where noted).

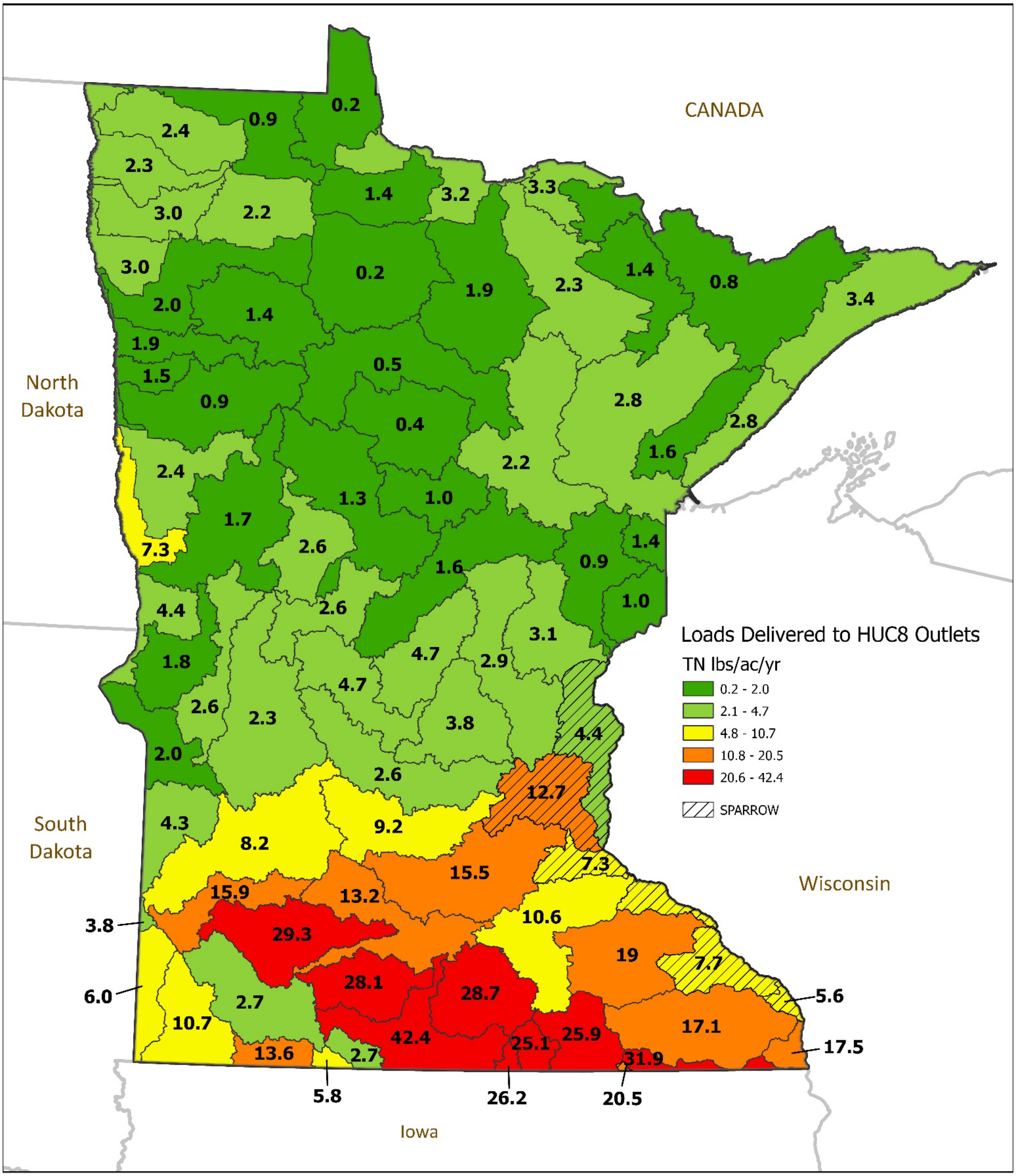
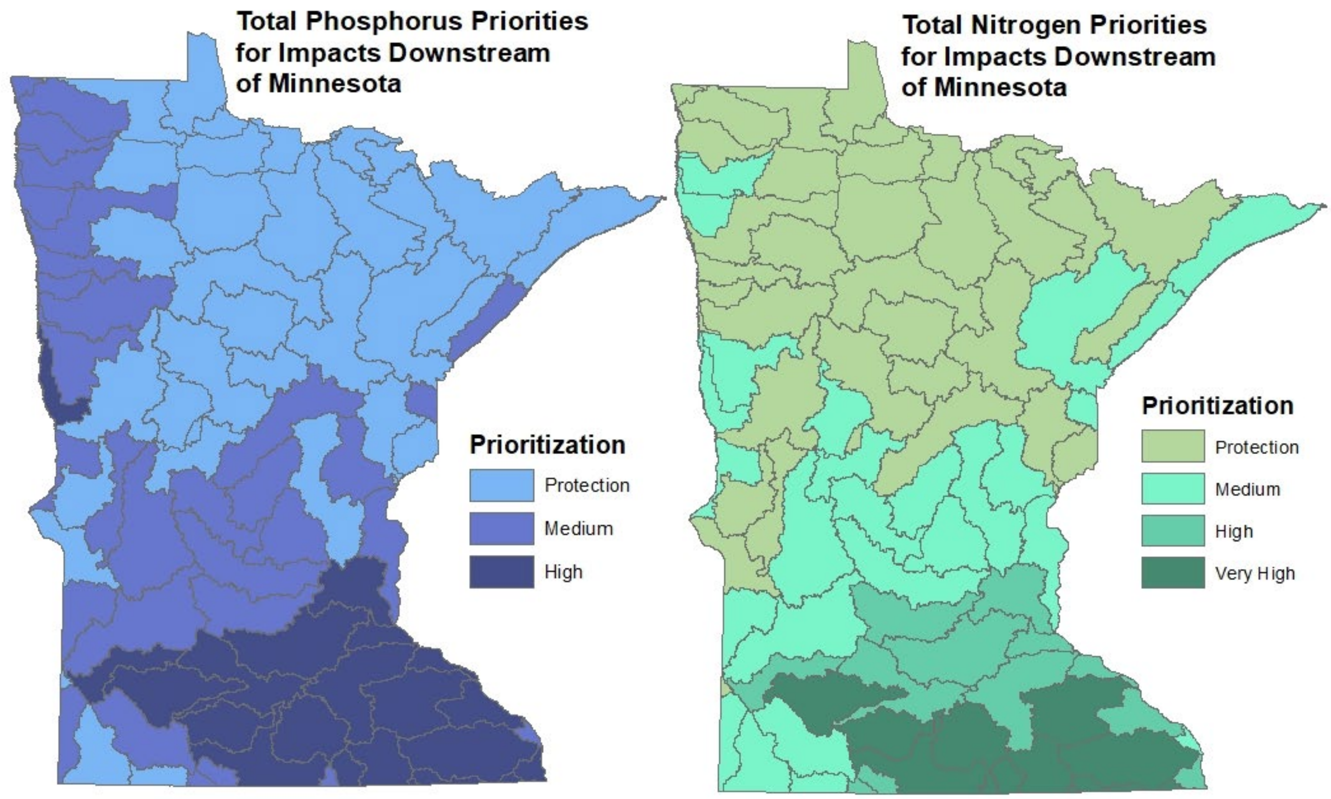


Figure 4. TN yields delivered to subbasin outlets, derived from HSPF model results (except where noted).

3.5 PRIORITY WATERSHEDS

Priority watersheds for restoration and protection were identified using average annual TP and TN yields delivered to state boundaries. For each subbasin, the annual yield delivered to the state boundary derived from HSPF modeling was averaged with the annual yield delivered to the state boundary from SPARROW modeling. The HSPF-derived, SPARROW-derived, and average yields are presented in Table 60 in Appendix J.

To identify priority watersheds and develop priority watershed maps (Figure 5), the average annual TP and TN yields delivered to state boundaries were then grouped into categories: protection, medium priority, high priority, and very high priority (TN only).



Note: Priorities were determined using average annual total phosphorus and total nitrogen yields (Minnesota-only) delivered to state boundaries.

Figure 5. Priority watersheds.

4 LOAD REDUCTIONS TO ACHIEVE MILESTONES AND FINAL GOALS

Minnesota's 2025 NRS will include recommended load reductions at subbasin outlets and state borders. To make such recommendations, MPCA contracted with Tetra Tech to *evaluate remaining load reductions needs* by comparing modeled aggregated loads with monitoring-based loads, which were presented in Section 2 and Section 3, respectively. The comparison of monitored and modeled loads is summarized in Section 4.1. Estimated load reduction needed to achieve 2030 and 2035 milestones and 2040 goals are presented in Section 4.2. Finally, Section 4.3 presents a summary of how climate change will affect future load reduction needs.

4.1 MONITORED VERSUS MODELED LOADS

The 2014 NRS (MPCA 2014) was based on a combination of monitored and modeled loads, and the follow-up study by LimnoTech (MPCA 2022) also evaluated monitored and modeled loads. To support the 2025 NRS, Tetra Tech compared current monitored loads with modeled loads from HSPF and SPARROW.

The calculations of monitored and modeled loads were described earlier in this report. In this section, the monitored and modeled loads are defined as follows:

- **Monitored**: The monitored loads represent the recent, 10-year average of in-stream loads derived from Minnesota (i.e., out-of-state loads are excluded). The period of record, recent 10-year period, and loads were presented in Section 2.3. Monitored loads derived from FLUX32 were used in this analysis instead of flow-normalized loads from WRTDS because the modeled loads (described in the bullet below) are not flow-normalized. The determination of in-state and out-of-state portions of in-stream loads was presented in Section 2.7, and the in-state and out-of-state fractions and loads are presented in Appendix H.
- **Modeled**: The modeled loads represent the most recent 10-year (approximately) loads delivered to the state border (i.e., modeled loads only include loading from sources within Minnesota). Modeling and loads delivered to subbasin outlets are discussed in Sections 3.1 and 3.2. The calculation of modeled loads delivered to state boundaries is discussed in Section 3.3, and the state boundary delivery factors and delivered loads are presented in Appendix J.

4.1.1 Challenges with Comparability

A significant challenge with comparing recent monitored and modeled loads is that that many modeled loads represent simulation periods that predate the recent monitoring period (2013-2022). As such, the modeled loads would not account for recent changes in water quality. However, recent monitored loads may reflect improvements to water quality derived from BMPs installed over the past decade or more since the model simulation periods.

Another challenge with comparing recent monitored and modeled loads is that the recent monitored loads were reduced by the out-of-state fraction that was derived from SPARROW modeling; refer to Section 2.7 for a discussion of these calculations. SPARROW modeling represents long-term averages for 2005-2014, which mostly predates the recent monitoring period (2013-2022). As such, reducing the in-stream loads by the out-of-state fractions to calculate Minnesota's contribution may not represent recent improvements in water quality from BMPs implemented since 2014.

Most modeled loads are derived from HSPF models; however, HSPF models have not been developed for all the subbasins in Minnesota. SPARROW modeled loads for six subbasins were used in this study. HSPF and SPARROW are very different models. To determine the modeled loads at state boundaries, at certain key locations, HSPF and SPARROW loads were summed.

Finally, at some key locations at state borders, another significant challenge with comparing recent monitored and modeled loads is that the monitoring sites are a few to several miles upstream of the key locations. As such, recent monitored loads do not represent loads from tributaries between the monitoring site and key location that are represented in the models.

4.1.2 Summary of Results

Recent monitored and modeled loads at several key locations are presented in Table 37, with further discussion of the methods presented in Appendix K. The watershed contributing to the key locations are presented in Figure 6 on page 62.

Many monitored and modeled loads are similar. The largest discrepancies are with TN for the Mississippi River tributaries at state boundaries, Rainy River at Lake-of-the-Woods, and Red River at Emerson. Such discrepancies may reflect the differences between simulation and recent monitoring periods. Often, the simulation period predates the recent monitoring period. As such, the monitoring data may reflect recent improvements in water quality, while the modeling does not.

In some cases, modeled loads could be larger because they account for additional waterbodies that are not represented in the recent monitored loads. Two situations occur: (1) tributaries discharge to a mainstem between the monitoring site and key location and (2) a subbasin is bisected by a state boundary, with the monitoring site on the main river or stream near the state boundary but the model accounts for additional waterbodies in the subbasin that also flow past the state boundary.

Table 37. Comparison of recent monitored and modeled loads (Minnesota-only load) delivered to key locations

Locations	Total phosphorus (metric tons annually)		Total nitrogen (metric tons annually)	
	Monitored	Modeled	Monitored	Modeled
Mississippi River at the IA-MN-WI boundary [a]	3,117	3,809	81,411	78,465
Minnesota River (delivered to IA-MN-WI boundary) [a,b]	*1,279*	*1,192*	*42,066*	*43,989*
Mississippi River tributaries at state boundaries [a,c]	426	385	7,816	13,889
Nemadji and St. Louis rivers at Lake Superior [a]	163	161	2,800	2,685
Rainy River at Lake-of-the-Woods [a]	191	228	2,092	4,275
Red River at Emerson, Manitoba	999	1,084	5,681	8,674

Notes
Both monitored and modeled loads represent only loads derived from Minnesota that are delivered to key locations.
a. The monitoring site is not located at or near the state boundary, and as such, does not represent a portion of the drainage to the state boundary.
b. The loads from the Minnesota River are a subset of the loads from the Mississippi River.
c. The Cedar, Rock, and West Fork Des Moines rivers at the Minnesota-Iowa state boundary and Split Rock Creek at the Minnesota-South Dakota state boundary.

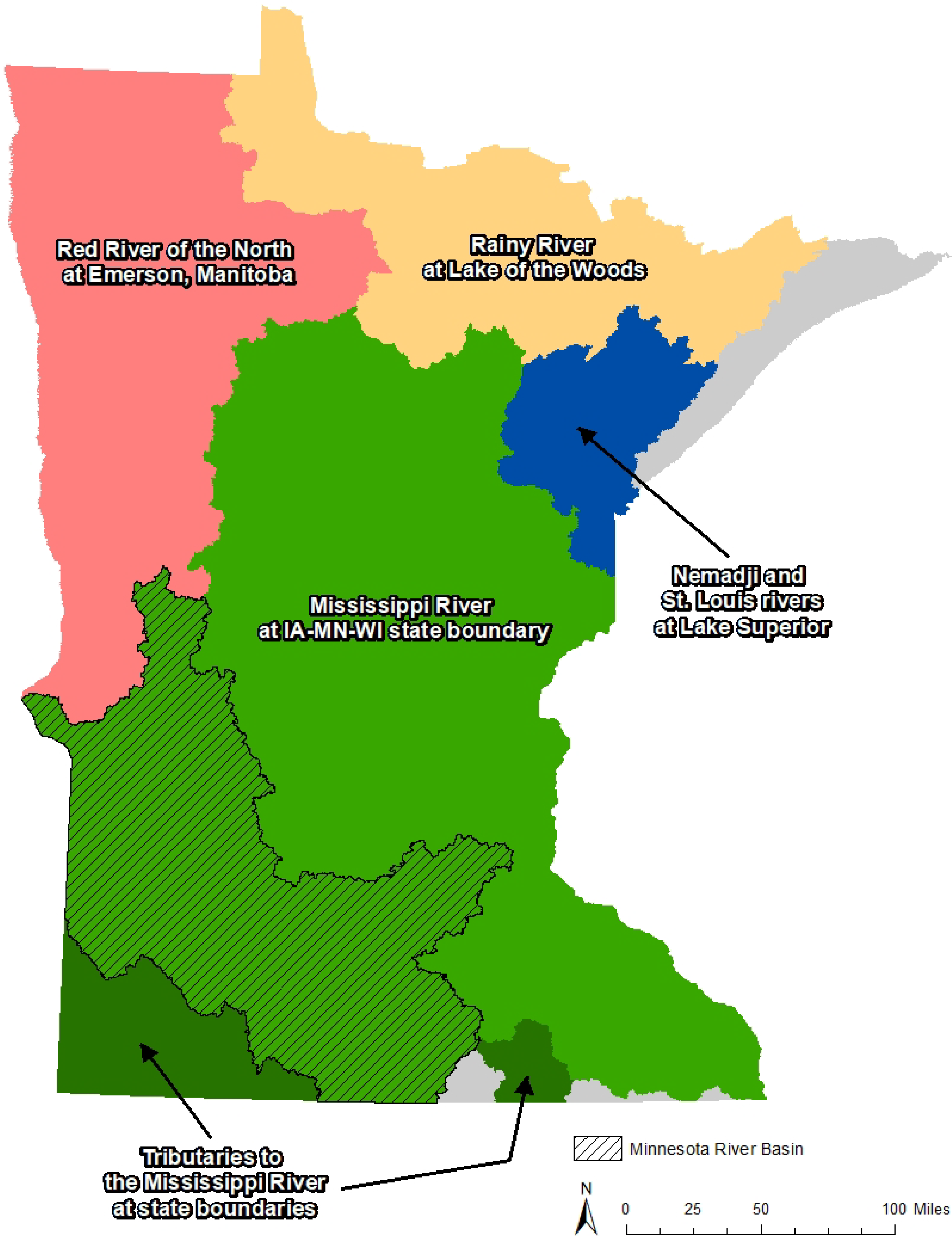


Figure 6. Watersheds draining to key locations.

4.2 ESTIMATE LOAD REDUCTION GOALS

In the following subsections, baseline, current, milestone, and final goal loads for TP and TN are presented. Baseline and final goal loads are from the 2014 NRS (MPCA 2014) or calculated using the same methods at the 2014 NRS. Current loads are estimated using the annual flow-normalized loads from 2023. Milestone loads are linear interpolations between the current loads and the 2040 final goal loads. The final goal loads are derived from Minnesota's 2014 NRS (MPCA 2014). For some analyses, both total in-stream loads (including out-of-state loads) and Minnesota-only loads (excluding out-of-state loads) are presented; refer to Section 2.7 for discussion of the calculation of out-of-state fractions

4.2.1 Mississippi River Major Basin

Historic, long-term monitoring data are available for several locations along the Mississippi and Minnesota rivers. Minnesota's 2014 NRS established goals for the Mississippi River and its major tributaries as 45% of the 1980-1996 baseline for each waterbody. These goals are retained here as the 2040 final goal loads.

The Mississippi River at La Crosse, WI, delivered to the Iowa-Minnesota-Wisconsin state boundary is the key site that baseline, current, milestone, and final goal loads were evaluated (Table 38). Baseline, current, and final goal loads were estimated for two key upstream monitoring sites: the Mississippi River at Red Wing, MN, and the Minnesota River at Jordan, MN (Table 39). The 2014 NRS did not establish baseline or final goal loads for these two sites and this analysis does not now propose milestone loads.

Table 38. Baseline, current, milestones, and final goal loads for the Mississippi at the IA-MN-WI state boundary

Load	Total In-Stream Loads (includes out-of-state loads)		Minnesota Loads [a] (excludes out-of-state loads)	
	TP (MTA)	TN (MTA)	TP (MTA)	TN (MTA)
Baseline (1980-1996)	4,976 [b]	97,996 [b]	4,050	76,143
Current (2023)	3,634 [c]	86,801 [c]	2,958	67,444
2030 milestone [d]	3,265	73,253	2,658	56,917
2035 milestone [d]	3,001	63,575	2,443	49,398
2040 final goal	2,737 [b]	53,898 [b]	2,228	41,879

Notes

MPCA = Minnesota Pollution Control Agency; MTA= metric tons annually; NRS = Nutrient Reduction Strategy; TN = total nitrogen; TP = total phosphorus.

All loads are delivered to the Iowa-Minnesota-Wisconsin state boundary.

a. The *Minnesota Loads* were calculated by reducing the *Total In-Stream Loads* by the percent of load that is from out-of-state sources. The out-of-state percent is 18.6% for TP and 22.3% for TN for the Mississippi River at La Crosse, WI. Refer back to Section 2.7 for discussion of the fractions of in-state and out-of-state loads.

b. The *Baseline (1980-1996)* and *2040 final goal* loads are from the 2014 NRS (MPCA 2014, Tables 3-7 and 3-8, *In-Stream Loads (Mississippi River near State Border)*).

c. Current in-stream loads are the 2023 flow-normalized loads calculated using WRTDS (originally provided by MCES) and reduced by a delivery factor (reduced by 18% for TP and by 8% for TN).

d. The milestone loads are linear interpolations between current (2023) loads and the 2040 final goal loads.

Table 39. Baseline, current, and final goal loads for two key upstream sites

Load	Mississippi River at Red Wing In-Stream Loads (includes out-of-state loads)		Minnesota River at Jordan In-Stream Loads (includes out-of-state loads)	
	TP (MTA)	TN (MTA)	TP (MTA)	TN (MTA)
Baseline (1980-1996) [a]	3,817	74,818	1,638	50,064
Current (2023) [b]	2,505	68,807	1,604	31,159
Final goal (2040) [c]	2,099	41,150	901	27,535

Notes

MPCA = Minnesota Pollution Control Agency; MTA= metric tons annually; NRS = Nutrient Reduction Strategy; TN = total nitrogen; TP = total phosphorus.

In-stream loads at both sites include out-of-state loads (i.e., out-of-state loads were not removed).

a. *Baseline (1980-1996)* loads are the arithmetic mean of 17 annual, flow-normalized loads calculated using WRTDS (originally provided by MCES).

b. *Current (2023)* loads are the 2023 flow-normalized loads calculated using WRTDS (originally provided by MCES).

c. *Final goal (2040)* loads are a 45% reduction from the *Baseline (1980-1996)* loads.

4.2.2 *Lake Winnipeg* Major Basin

Historic, long-term monitoring data are available for the Red River of the North at Emerson, Manitoba, Canada, but are not available for the Red River of the North at Grand Forks, ND, or the Rainy River at Manitou Falls, MN. Minnesota's 2014 NRS established interim goals for the Red River of the North and final goals were established by the International Red River Board (2019).

The Red River of the North at Emerson, Manitoba, Canada, is the key site that baseline, current, milestone, and final goal loads were evaluated (

Table 40). Baseline and current loads were estimated using flow-normalized loads calculated using WRTDS by MPCA from water quality data provided by CWSEC.

MPCA monitors the Rainy River at Manitou Falls, MN but insufficient data are available to use WRTDS to estimate flow-normalized loads. MPCA (2022) established planning goals for the Rainy River: the TP goals is 218 MTA and the TN goals is 4,887; the TP planning goal was based on a draft total maximum daily load for the Lake-of-the-Woods.

Table 40. Baseline, current, milestones, and final goal loads for the Red River of the North at Emerson, Manitoba, Canada

Load	Total In-Stream Loads (includes out-of-state loads)		Minnesota Loads [a] (excludes out-of-state loads)	
	TP (MTA)	TN (MTA)	TP (MTA)	TN (MTA)
Baseline (1998-2001)	2,621 [b]	18,117 [b]	993	8,008
Current (2023)	2,977 [c]	18,007 [c]	1,128	7,959
2030 milestone [d]	2,328	14,514	882	6,415
2035 milestone [d]	1,864	12,020	706	5,313
2040 final goal	1,400 [e]	9,525 [e]	531	4,210

Notes

MPCA = Minnesota Pollution Control Agency; MTA= metric tons annually; NRS = Nutrient Reduction Strategy; TN = total nitrogen; TP = total phosphorus.

All loads are delivered to the Iowa-Minnesota-Wisconsin state boundary.

a. The *Minnesota Loads* were calculated by reducing the *Total In-Stream Loads* by the percent of load that is from out-of-state sources. The out-of-state percent is 62.1% for TP and 55.8% for TN for the Red River of the North at Emerson, Manitoba, Canada. Refer back to Section 2.7 for discussion of the fractions of in-state and out-of-state loads.

a. *Baseline (1998-2001)* loads are the arithmetic mean of 4 annual, flow-normalized loads calculated using WRTDS.

c. Current in-stream loads are the 2023 flow-normalized loads calculated using.

d. The milestone loads are linear interpolations between current (2023) loads and the 2040 final goal loads.

e. The final goal loads were set by International Red River Board (2019).

4.2.3 *Lake Superior* Major Basin

Historic, long-term monitoring data are not available for the Nemadji and St. Louis rivers, nor are such data available for tributaries and direct drainage to Lake Superior in the *Lake Superior North* and *Lake Superior South* subbasins. The 2014 NRS established a TP load goal of 248 MTA using 2002 SPARROW modeling to generally represent baseline conditions in 1979 and a “holding the line” approach to maintaining loads without anthropogenic increases (MPCA 2014). MPCA (2022) estimated the “hold the line” planning goal for TN to be 4,658 MTA.

Insufficient monitoring data are available to evaluate with these goals. The 10-year average of HSPF modeling data results in a TP load about equal to the 1979 baseline load; however, it may not be appropriate to compare recent HSPF model results with SPARROW model results for 1979. Similarly, the 10-year average of HSPF modeling data results in a TN load a little larger than the TN planning goal.

4.3 INFLUENCE OF CLIMATE CHANGE ON LOAD REDUCTION GOALS

In Section 2.3, the analysis of annual average flows monitored in baseline and current 10-year periods indicated that flow increased in the Mississippi River and its major tributaries, while flow decreased in the Red River of the North at Emerson, Manitoba, Canada. Additionally, the evaluation of FWMCs and loads suggest that (1) loads increased in some waterbodies even when corresponding FWMC decreased and (2) loads increased more in some waterbodies than the corresponding increases in FWMC. If flows continue to increase, due to climate change, then Minnesota's NRS load goals may need to be modified because increasing flows may result in larger in-stream loads, and thus, not reflect improved water quality achieved through adoption of BMPs.

Organizations across the United States and World are studying climate change and resilience through the development of climate prediction models and planning tools to evaluate the impact of changing climates. In the Midwest, winter and spring months are generally becoming warmer and precipitation events are becoming more severe and more frequent. Predictions at smaller scales vary considerably. Uncertainty about future changes in precipitation likely necessitates and continued need to track precipitation over time to identify trends. and

Recent research about climate change in the Great Lakes basin (Hyrick 2024) found that (1) the timing and amount of runoff entering the Great Lakes through tributaries has changed drastically since 1950, (2) winter/spring snowmelt is becoming earlier in Great Lakes watersheds, except the Lake Erie watershed, and (3) runoff is occurring at higher volumes and over a more drawn-out time period. A modeling study of 20 large watersheds across the United States (Johnson et al. 2015) had similar results, suggesting that wetter winters and earlier snowmelt are likely in many of the northern and higher elevation watersheds.

Three studies in Minnesota from the 2010s using water quality models evaluated potential changes to streamflow and pollutant loadings due to climate change. Generally, the water quality models suggest increasing temperatures may lead to increasing total flow, sediment and nutrient loads, and peak runoff (Schmidt et al. 2015; Tetra Tech 2015). However, the climate models are not in consensus regarding precipitation and evapotranspiration(Tetra Tech 2015). In the Duluth urban area and Lake Superior South subbasin (HUC 04010102), evapotranspiration is expected to increase significantly, which may result in reduced groundwater flow (i.e., baseflow) and stream temperatures are expected to increase, both of which can impact nutrient dynamics and eutrophication and aquatic life (Tetra Tech 2017). In the Little Cobb River, water quality modeling indicated BMP efficiencies declined due to more intense runoff effects and increased upland loading (Schmidt et al. 2015).

A sample of pertinent literature is briefly summarized in Appendix I. The potential effects of climate change on pollutant loading (including through increased streamflow and reduced BMP efficiency) will necessitate adaptive management for Minnesota's NRS, including potential modification of load goals and recommended BMPs to address climate change.

5 REFERENCES

Note: Appendix L has its own references section. Some references from Appendix K are also cited in the main report and thus are included in this reference section.

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6 USGS DATA DISCLAIMER

Data presented in the following sections were provided by USGS:

- Section 2.3.1.1 (Table 7, Table 9, and Table 11)
- Section 2.3.1.2 (Table 13)
- Section 2.3.3 (Table 18)
- Section 2.5.1
- Section 2.5.3
- Appendix A, Sections A.4, A.5, and A.7.
- Appendix B, Sections B.3, B.4, B.5, B.6, and B.7
- Appendix D, Section D.3
- Appendix F, Section F.1 (Figure 61, Figure 62, and Figure 64) and Section F.2 (Figure 66, Figure 67, Figure 68, Figure 69, and Figure 70)

This information is preliminary and is subject to revision. It is being provided to meet the need for timely best science. The information is provided on the condition that neither USGS nor the U.S. Government shall be held liable for any damages resulting from the authorized or unauthorized use of the information.

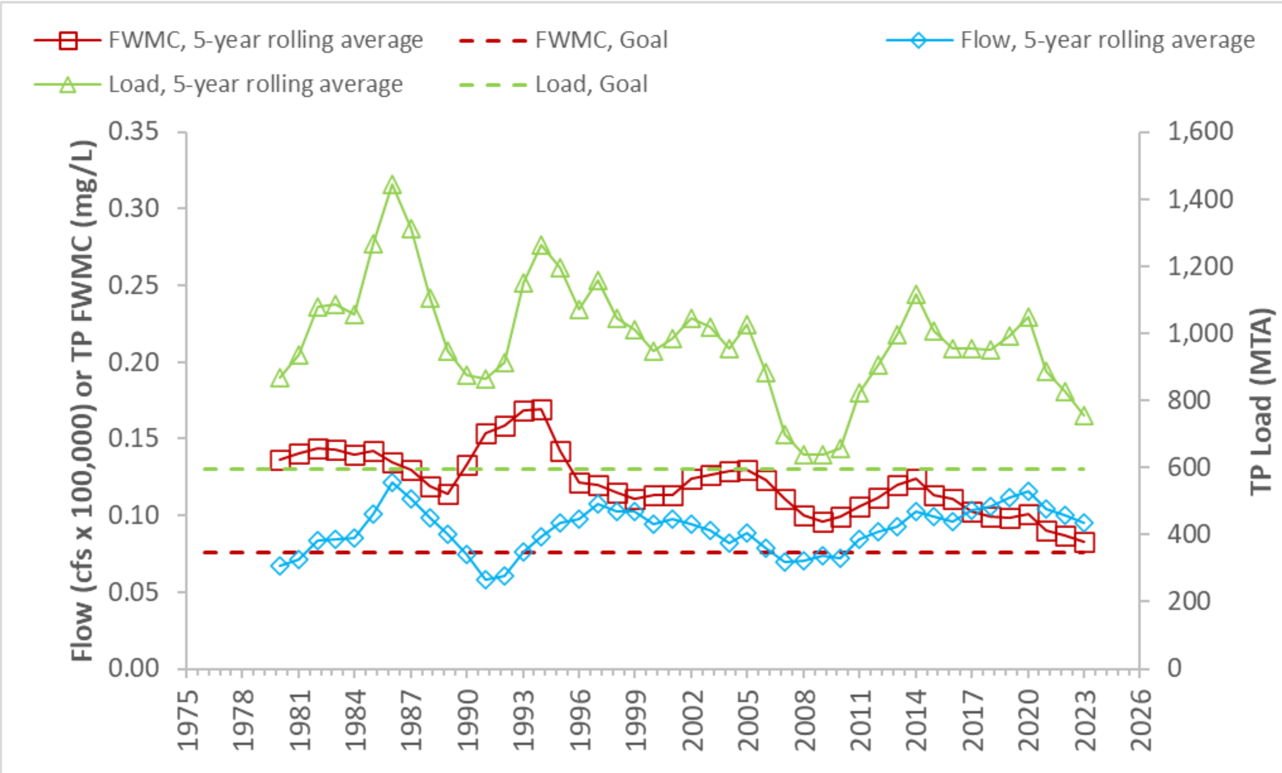
7 LIST OF ACRONYMS AND ABBREVIATIONS FOR APPENDICES A, B, C, AND D

Acronym or abbreviation	Definition
FNC	flow-normalized concentration
FN-Load	flow-normalized load
FWMC	flow-weighted mean concentration
L&D	lock and dam
RM	river mile
TN	total nitrogen
TP	total phosphorus
WRTDS	Weighted Regressions on Time, Discharge, and Season

Unit of measure	Definition
cfs	cubic feet per second
mg/L	milligrams per liter
MTA	metric tons annually; metric tons per year

APPENDIX A. TREND CHARTS FOR THE MISSISSIPPI RIVER

A.1 MISSISSIPPI RIVER AT ANOKA, MN (RM 872) – FLUX32



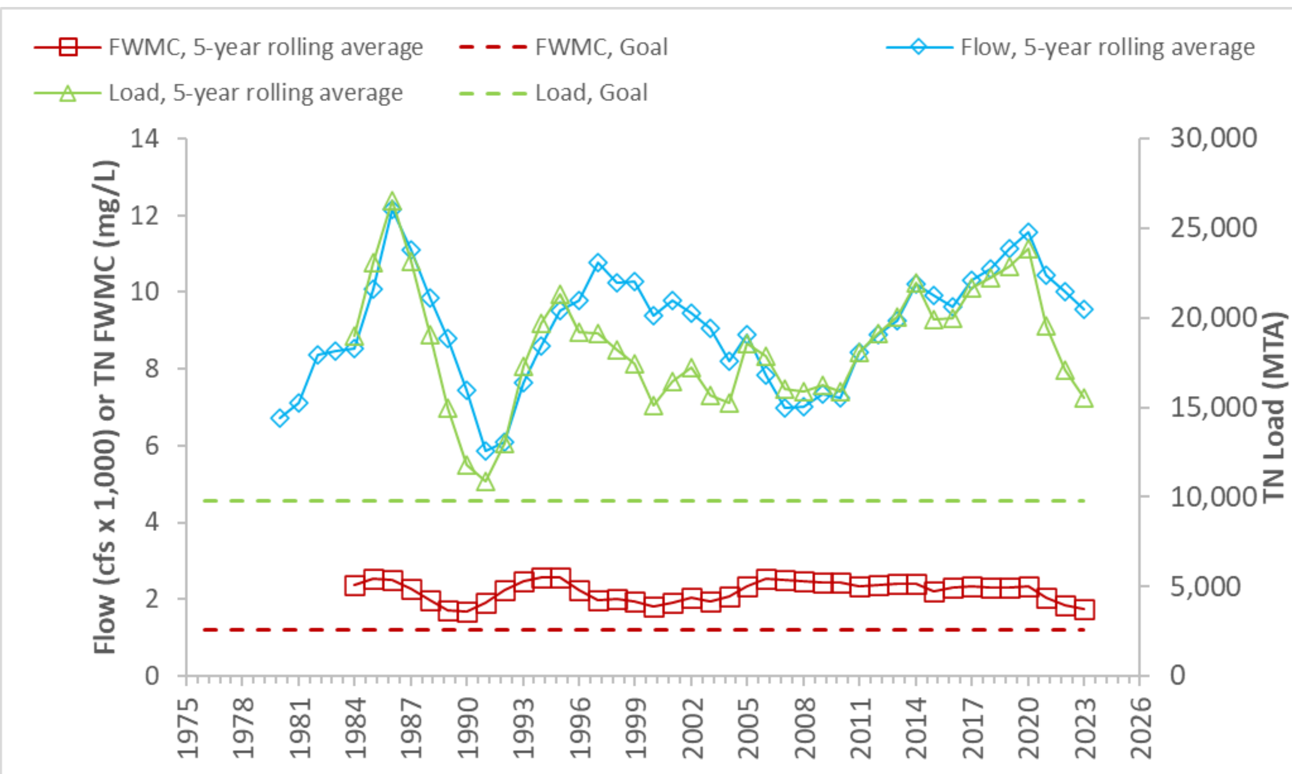


Figure 7. TP (top) and TN (bottom) 5-year rolling averages at the Mississippi River at Anoka, MN.

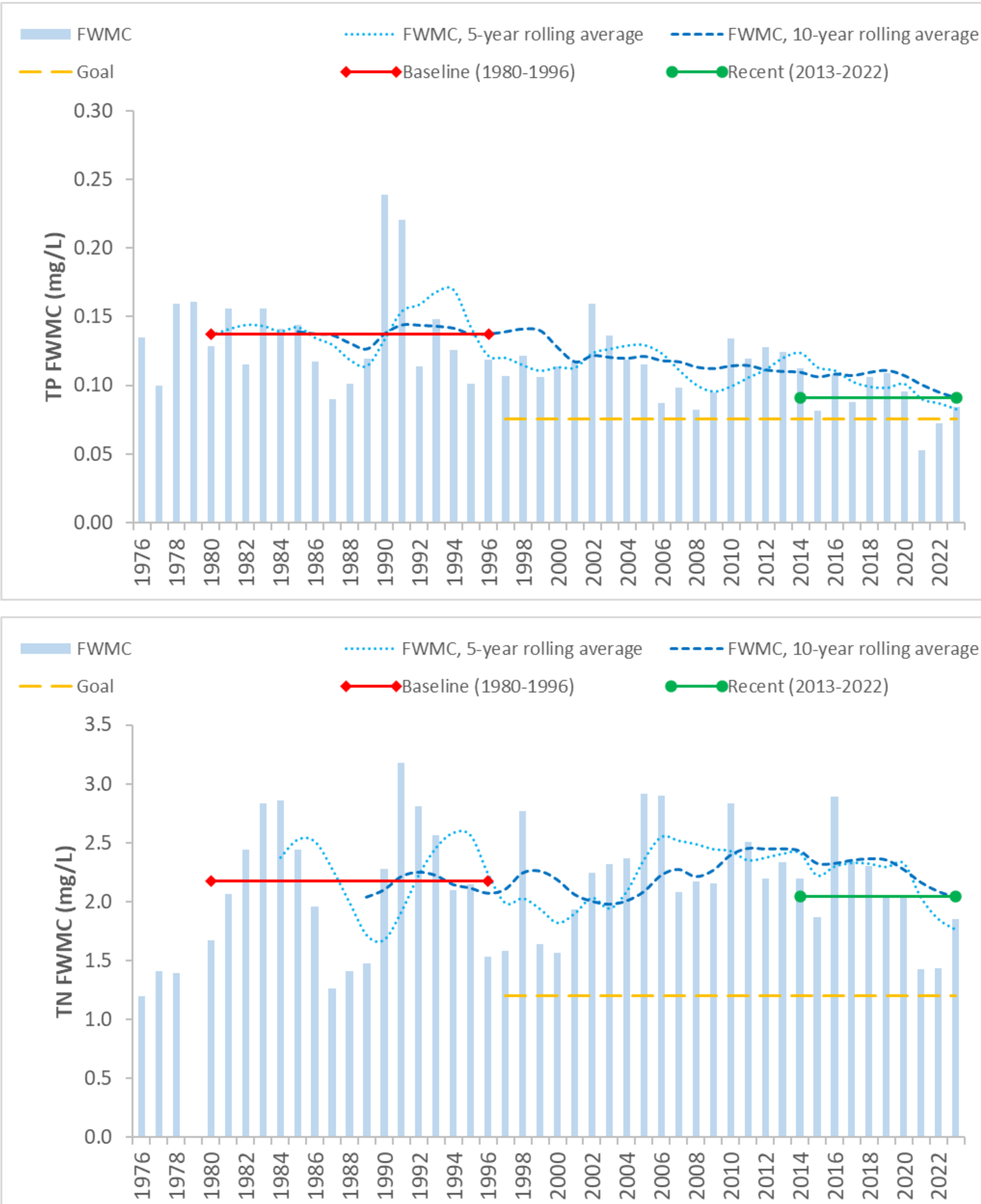


Figure 8. TP (top) and TN (bottom) FWMC trends and goal for the Mississippi River at Anoka, MN.

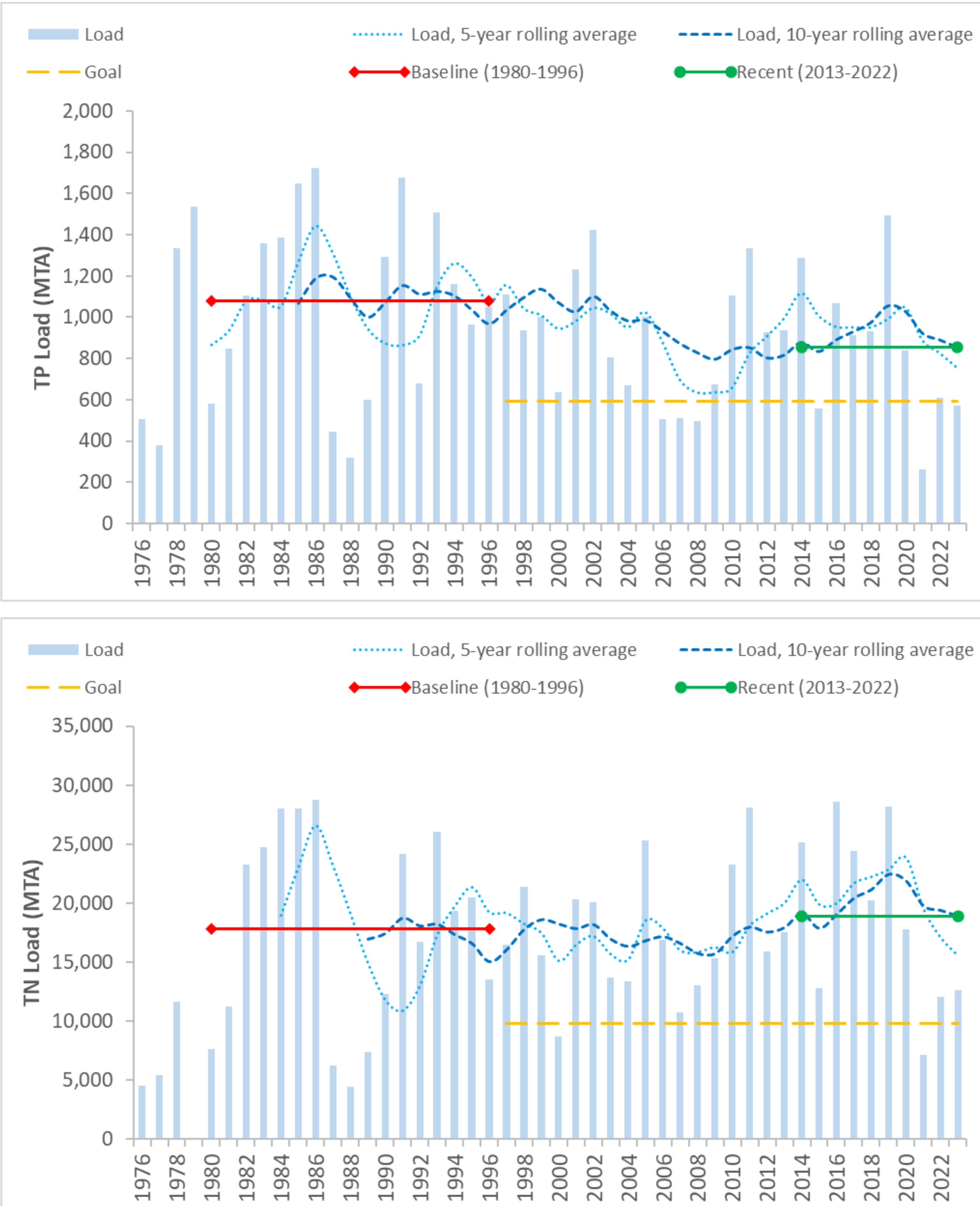
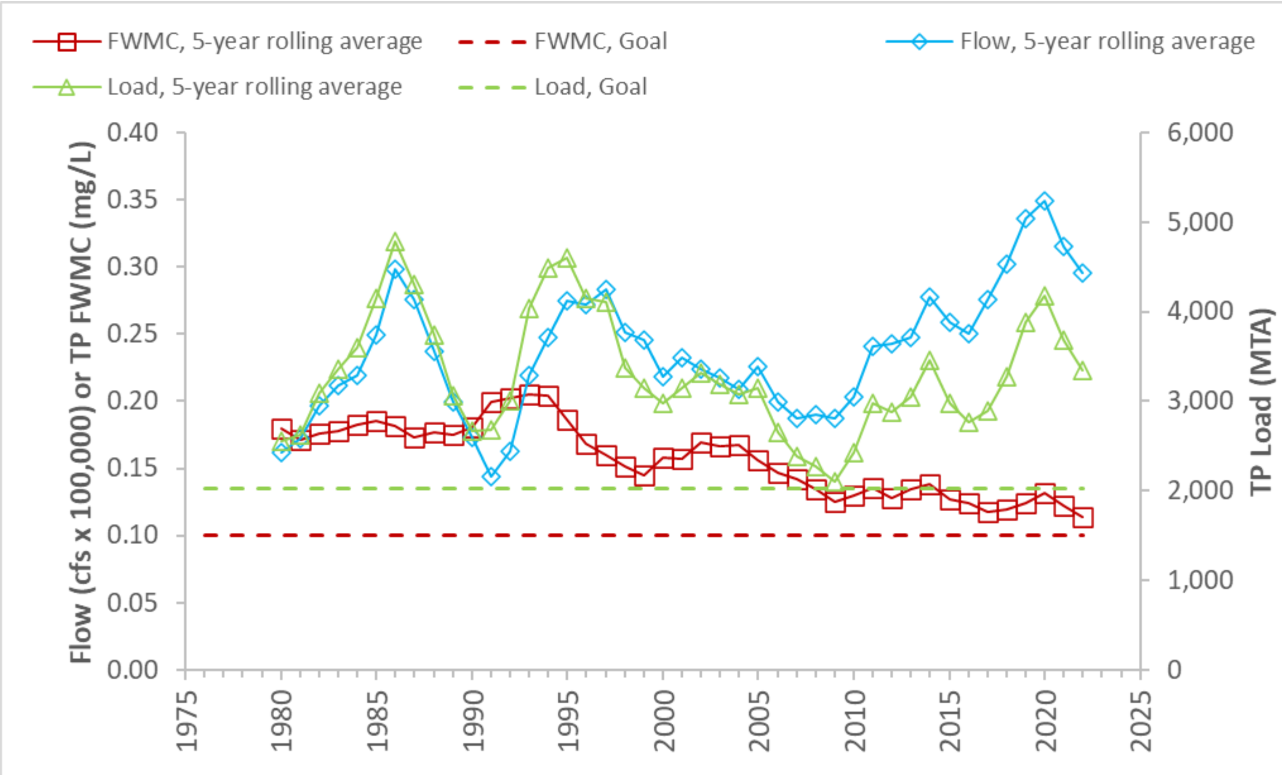


Figure 9. TP (top) and TN (bottom) load trends and goal for the Mississippi River at Anoka, MN.

A.2 MISSISSIPPI RIVER AT RED WING, MN (RM 797; ABOVE L&D #3) – FLUX32



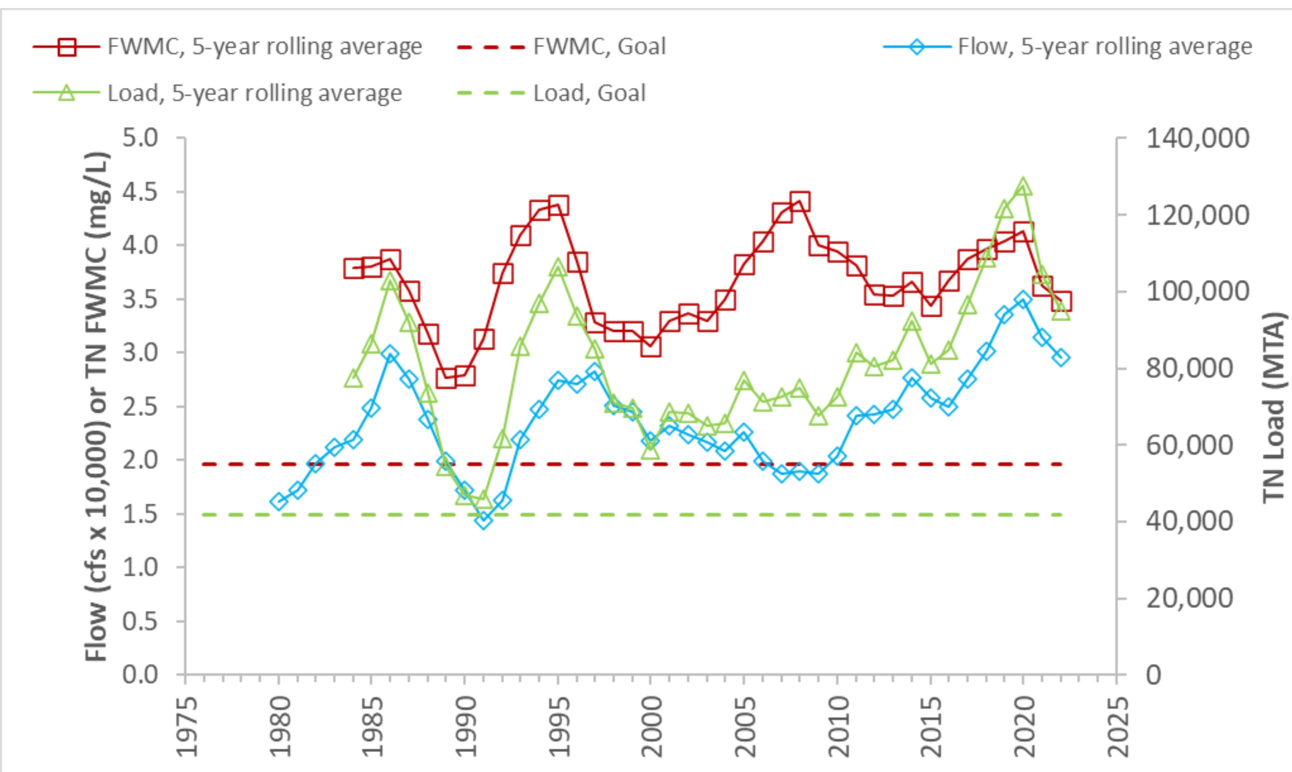
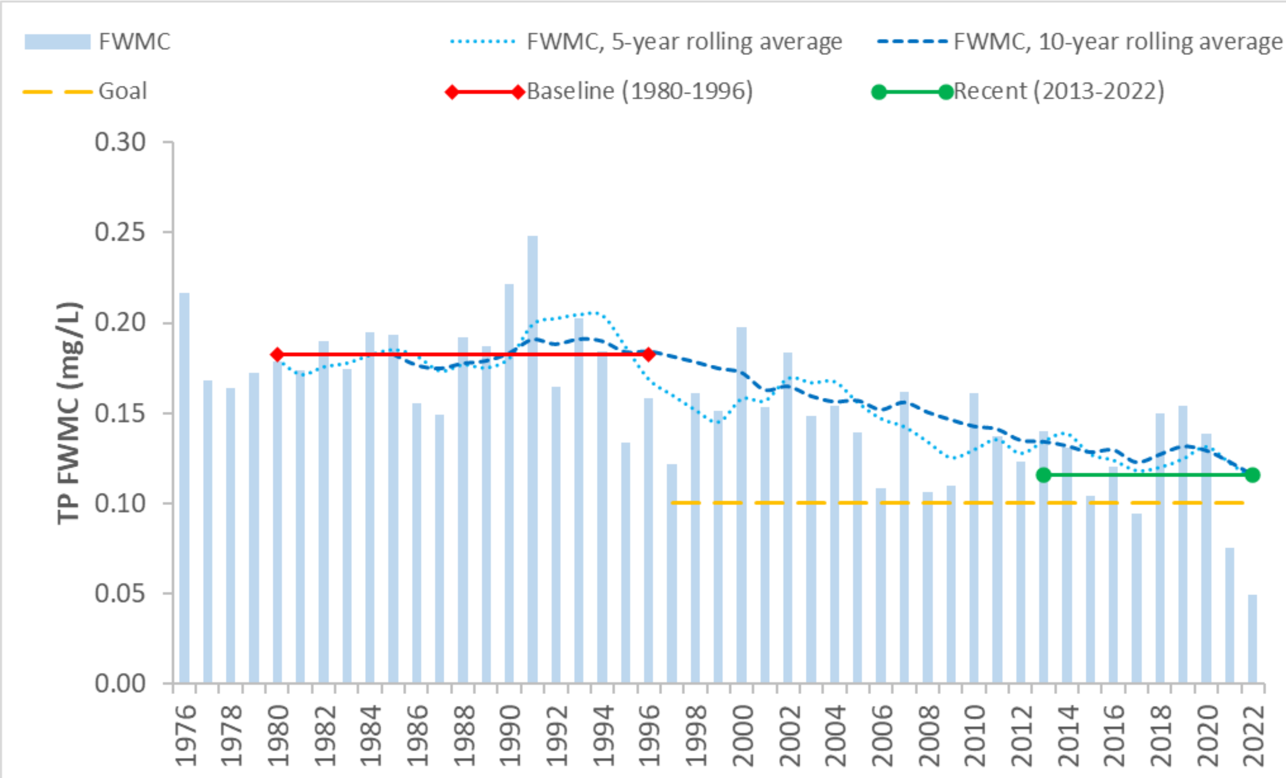


Figure 10. TP (top) and TN (bottom) 5-year rolling averages at the Mississippi River at Red Wing, MN.



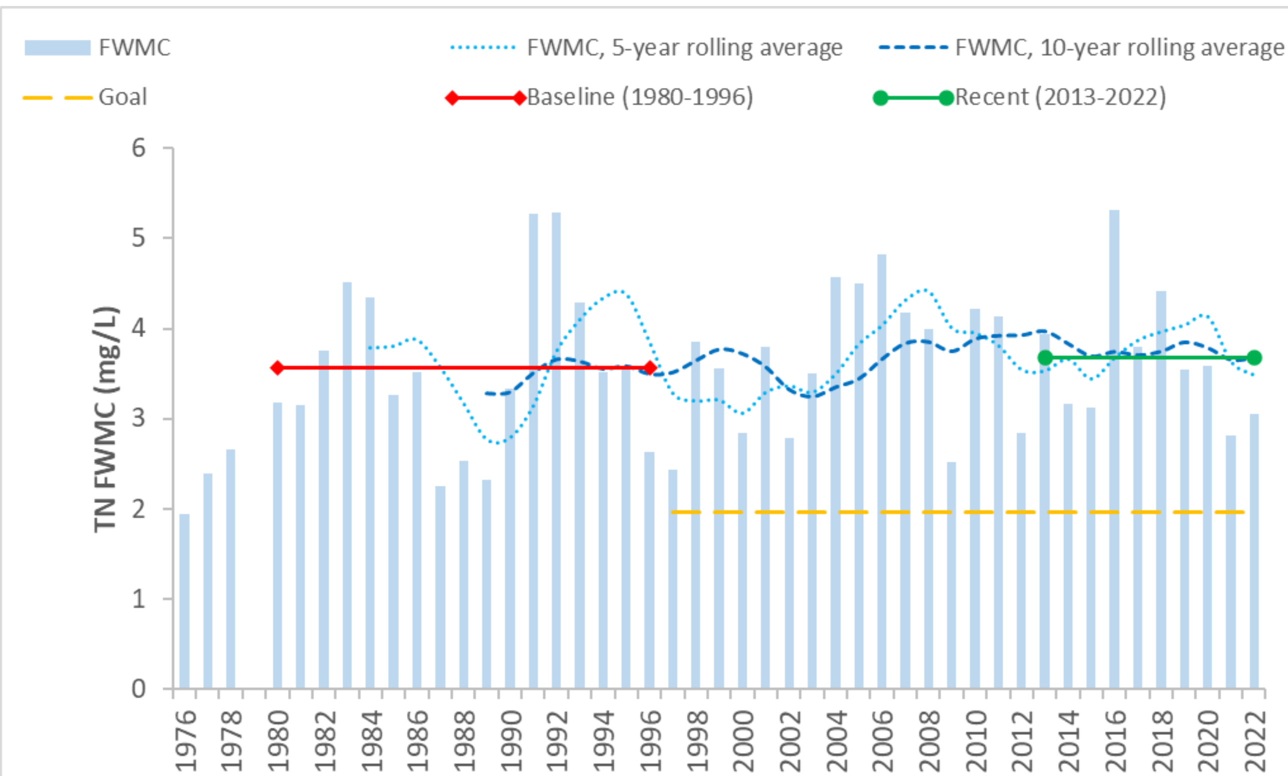
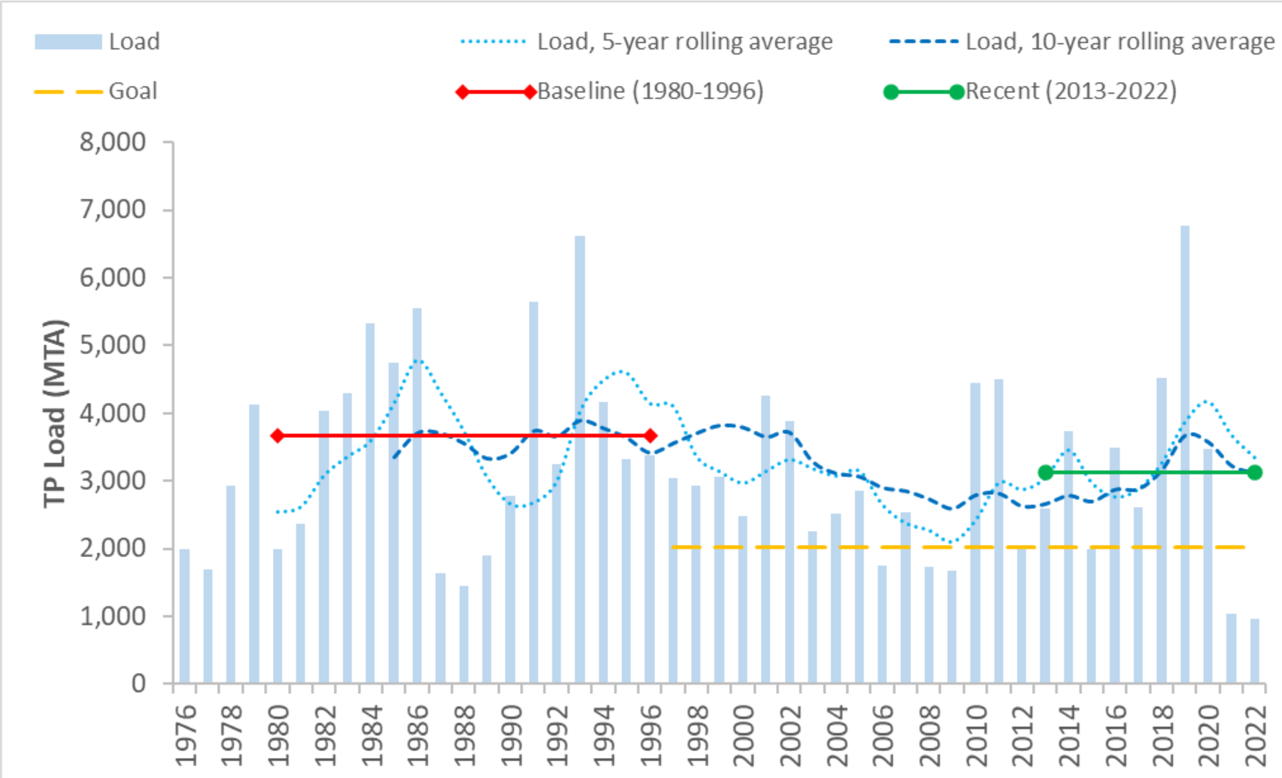


Figure 11. TP (top) and TN (bottom) FWMC trends and goal for the Mississippi River at Red Wing, MN.



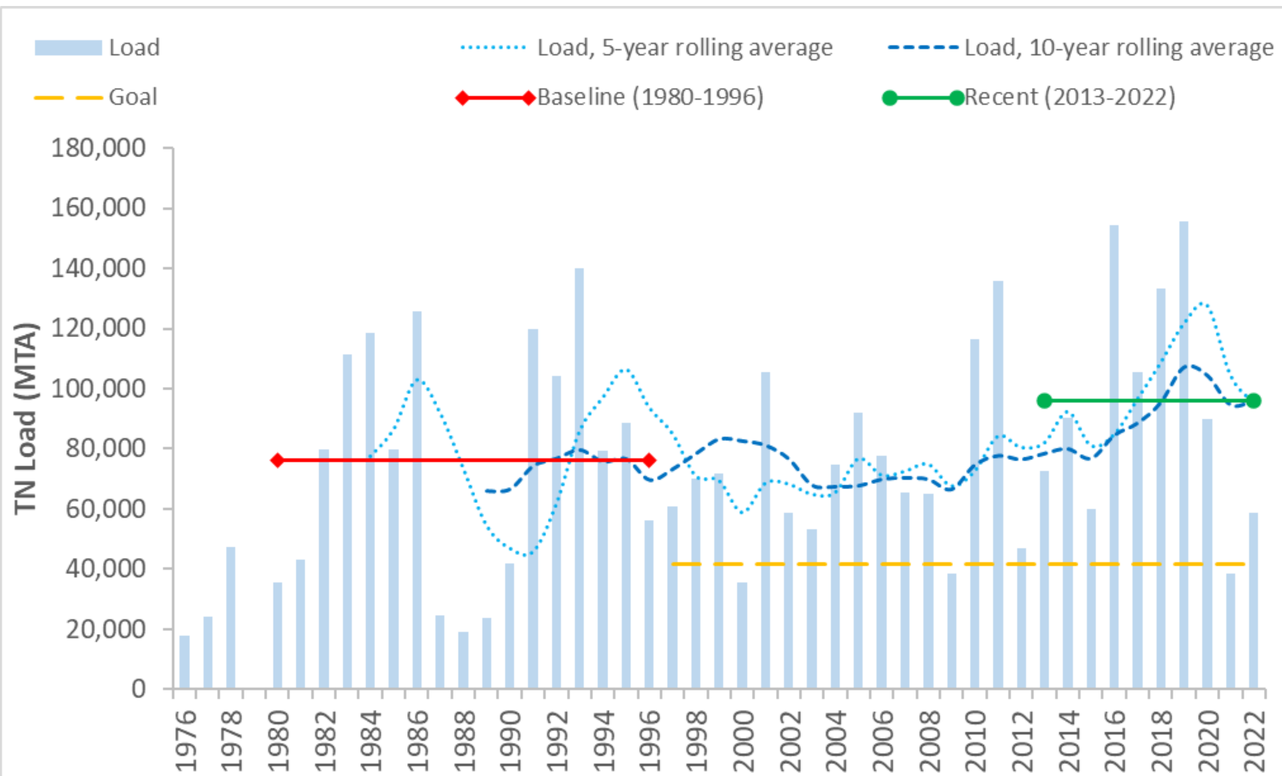
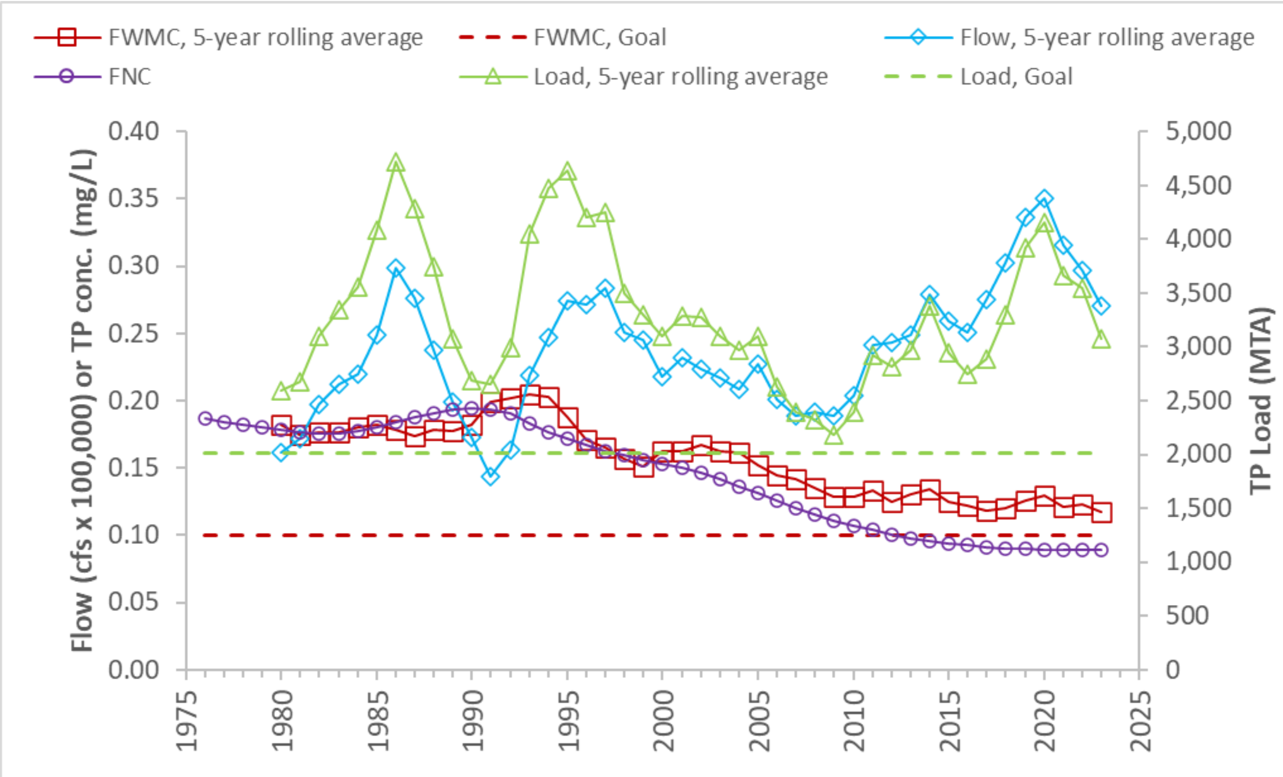


Figure 12. TP (top) and TN (bottom) load trends and goal for the Mississippi River at Red Wing, MN.

A.3 MISSISSIPPI RIVER AT RED WING, MN (RM 797; ABOVE L&D #3) – WRTDS



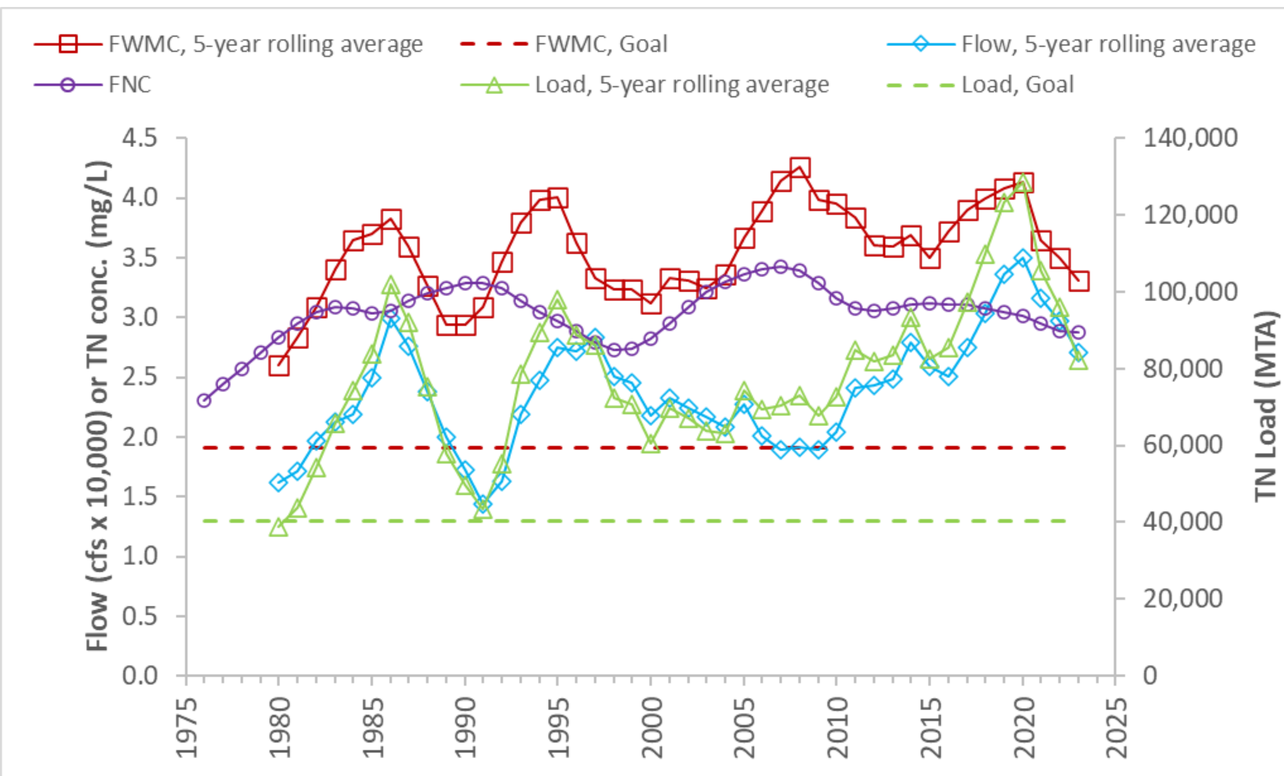
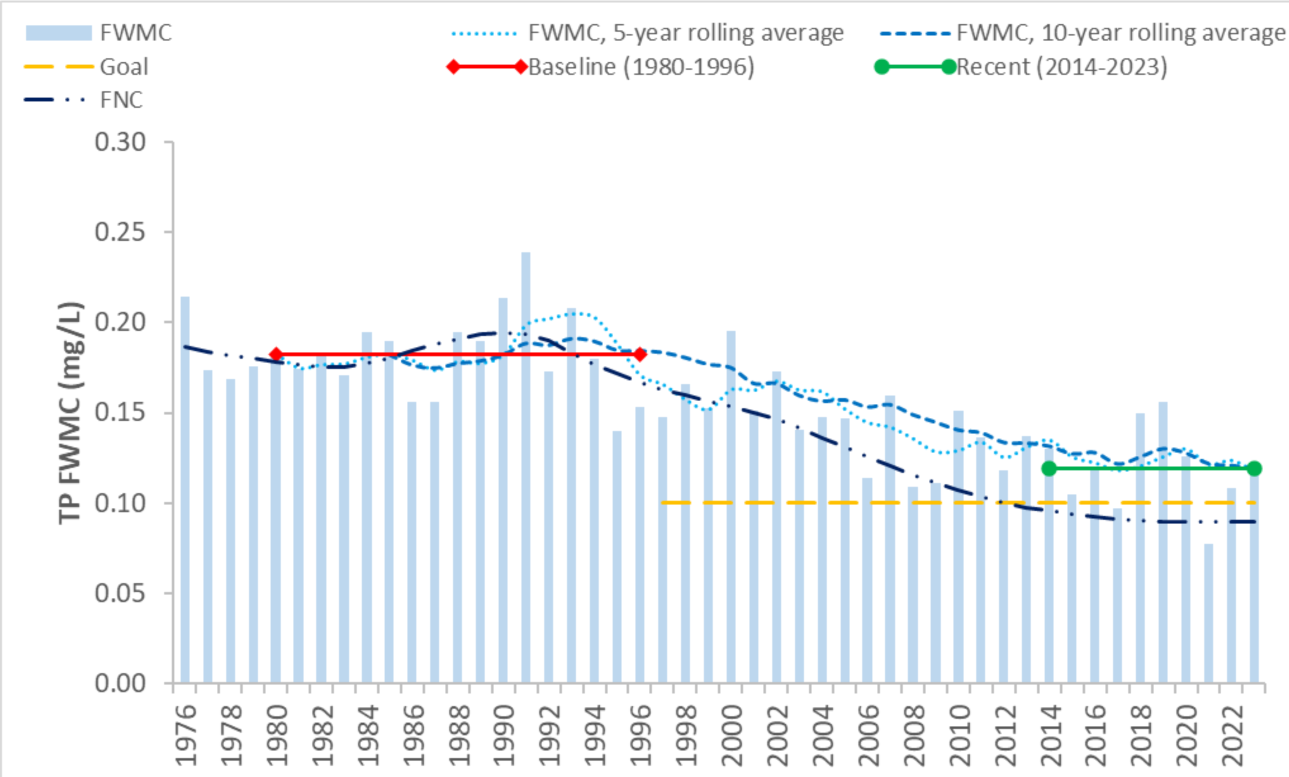


Figure 13. TP (top) and TN (bottom) 5-year rolling averages at the Mississippi River at Red Wing, MN.



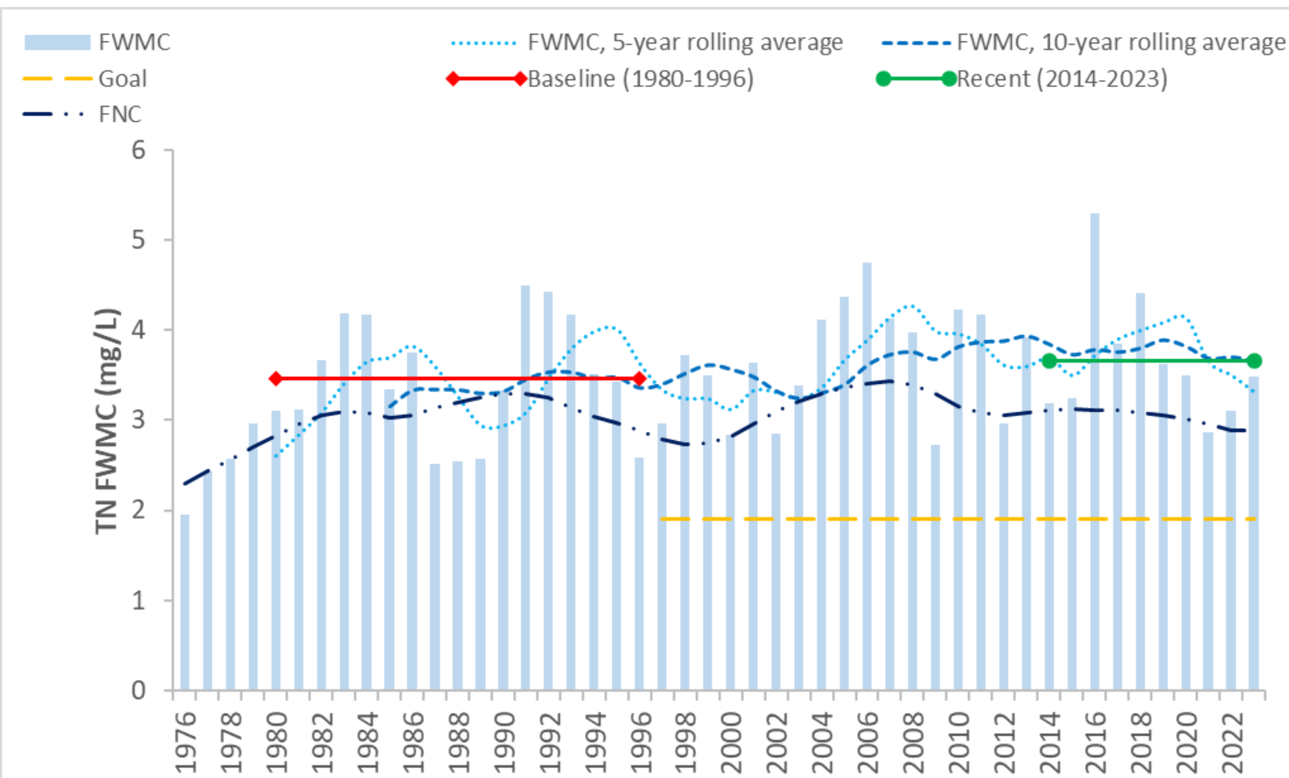


Figure 14. TP (top) and TN (bottom) FWMC trends and goal for the Mississippi River at Red Wing, MN.

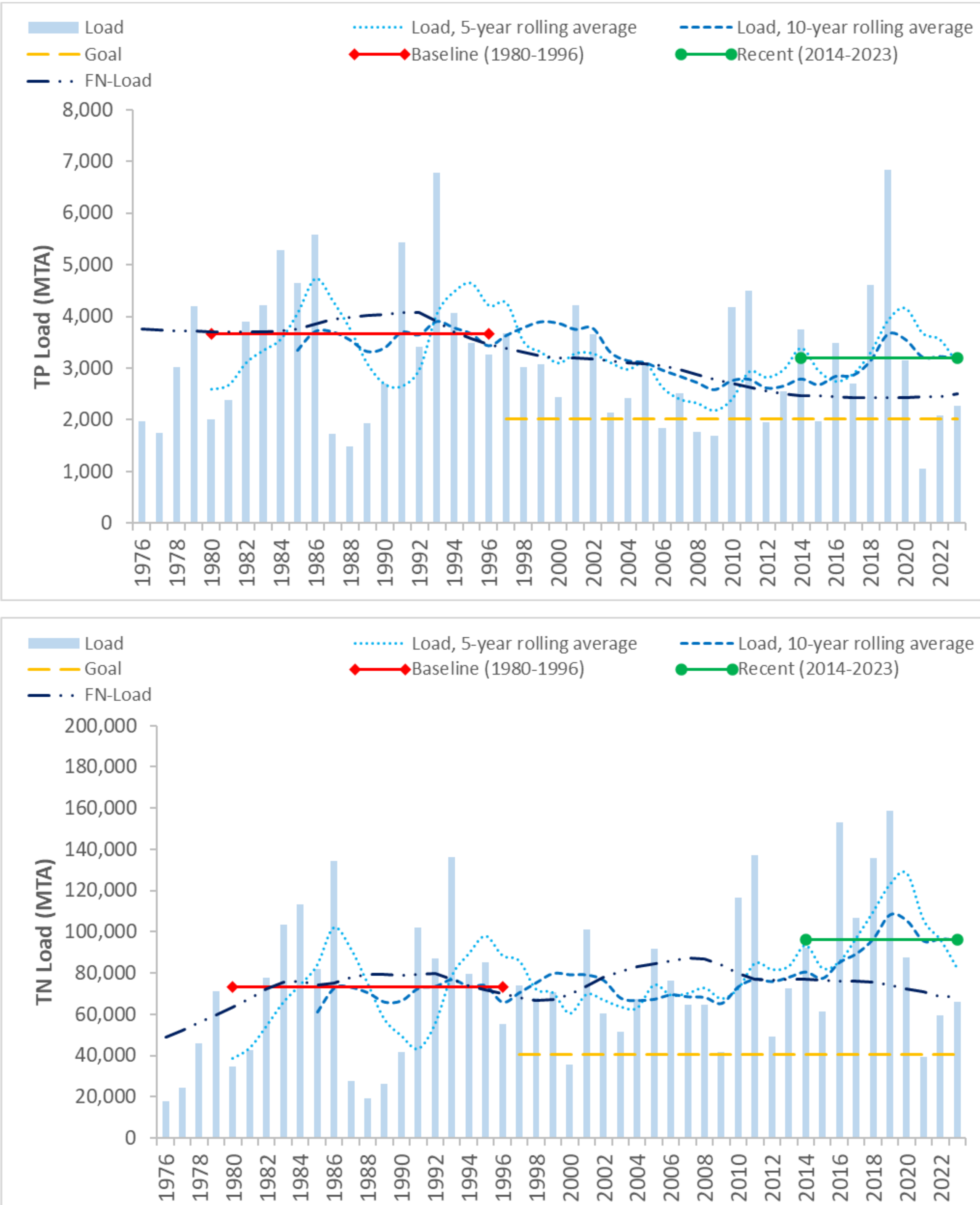


Figure 15. TP (top) and TN (bottom) load trends and goal for the Mississippi River at Red Wing, MN.

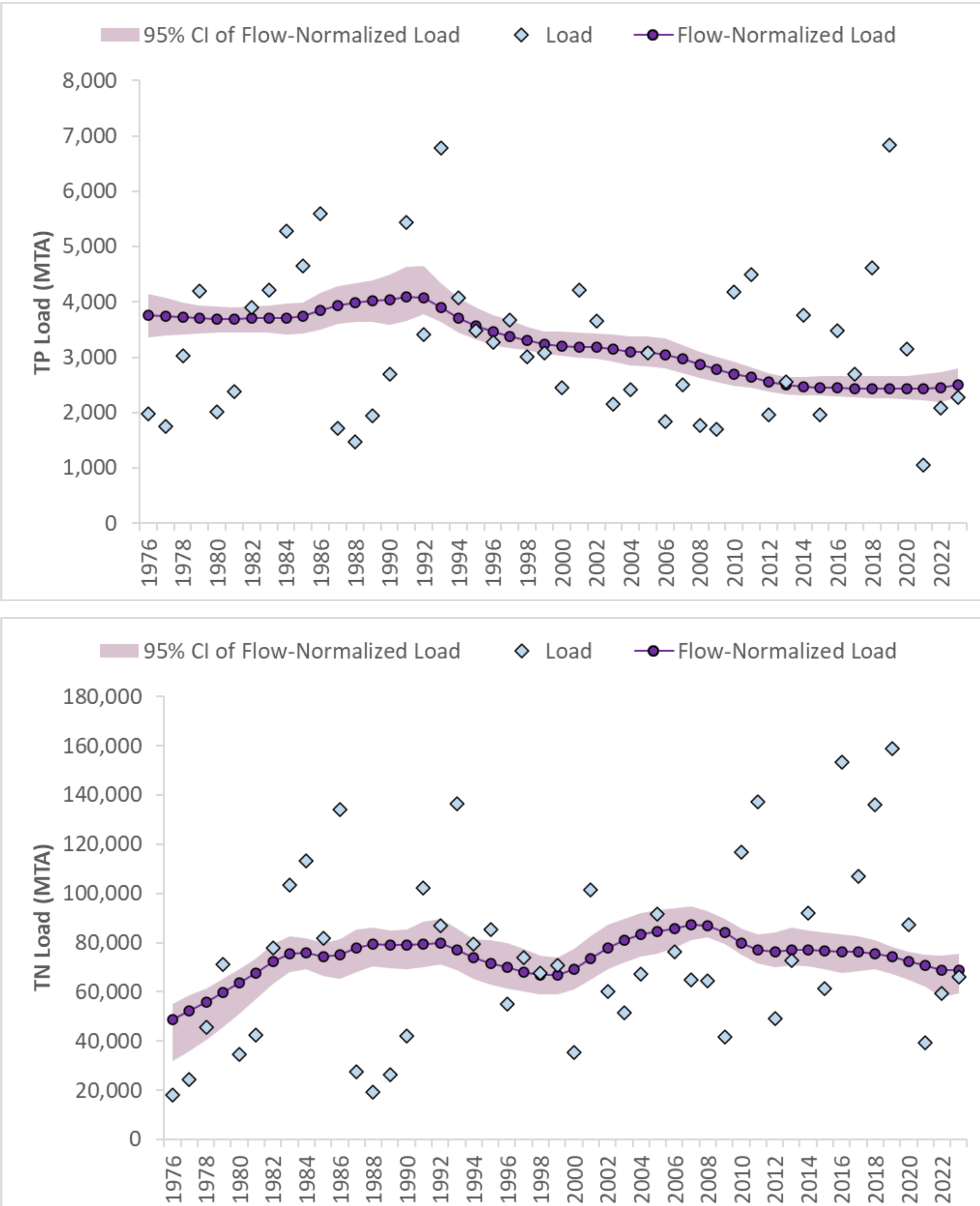


Figure 16. TP (top) and TN (bottom) flow-normalized loads for the Mississippi River at Red Wing, MN.

A.4 MISSISSIPPI RIVER AT PRESCOTT, WI (RM 786) – WRTDS

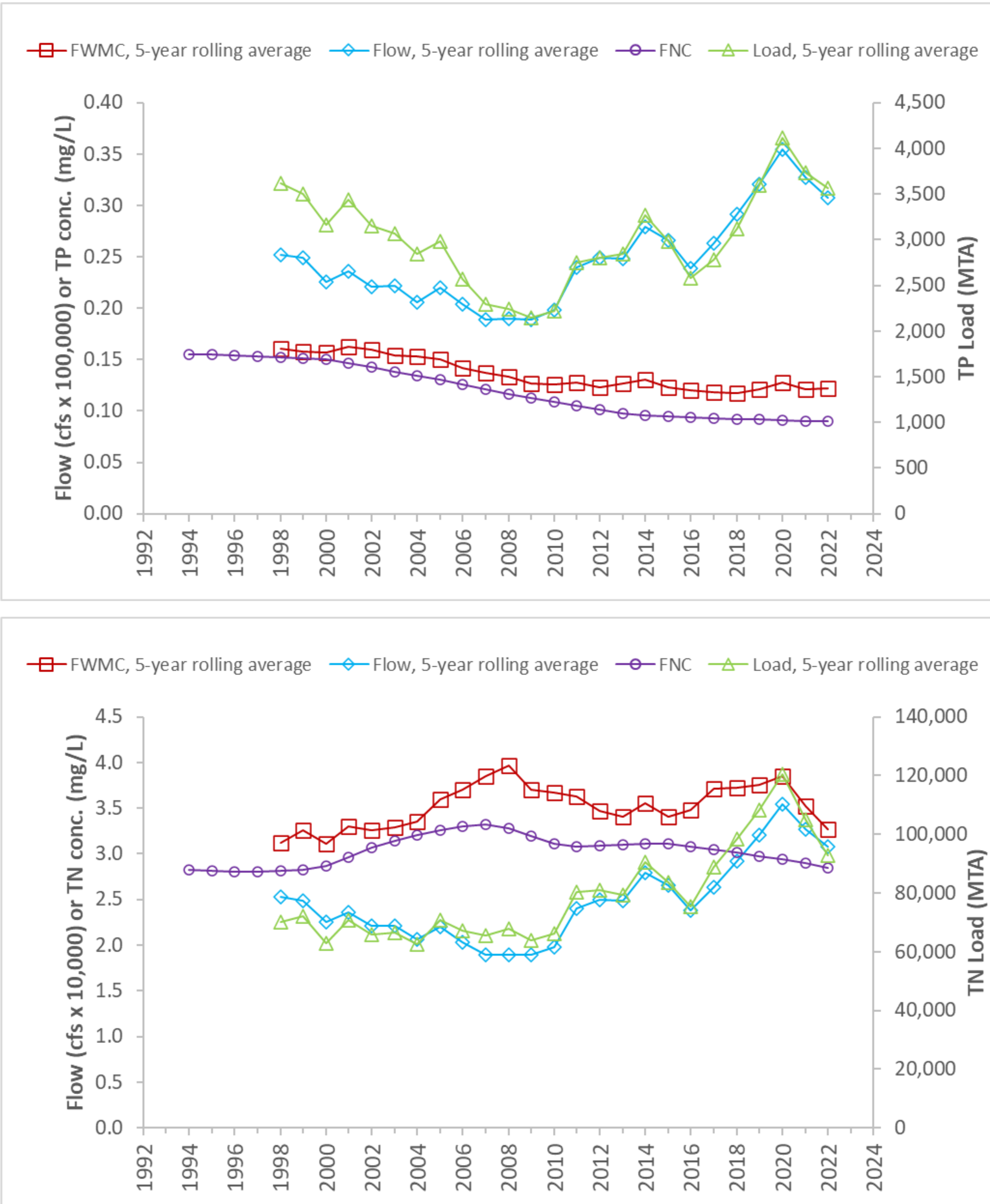


Figure 17. TP (top) and TN (bottom) 5-year rolling averages at the Mississippi River at Prescott, WI.

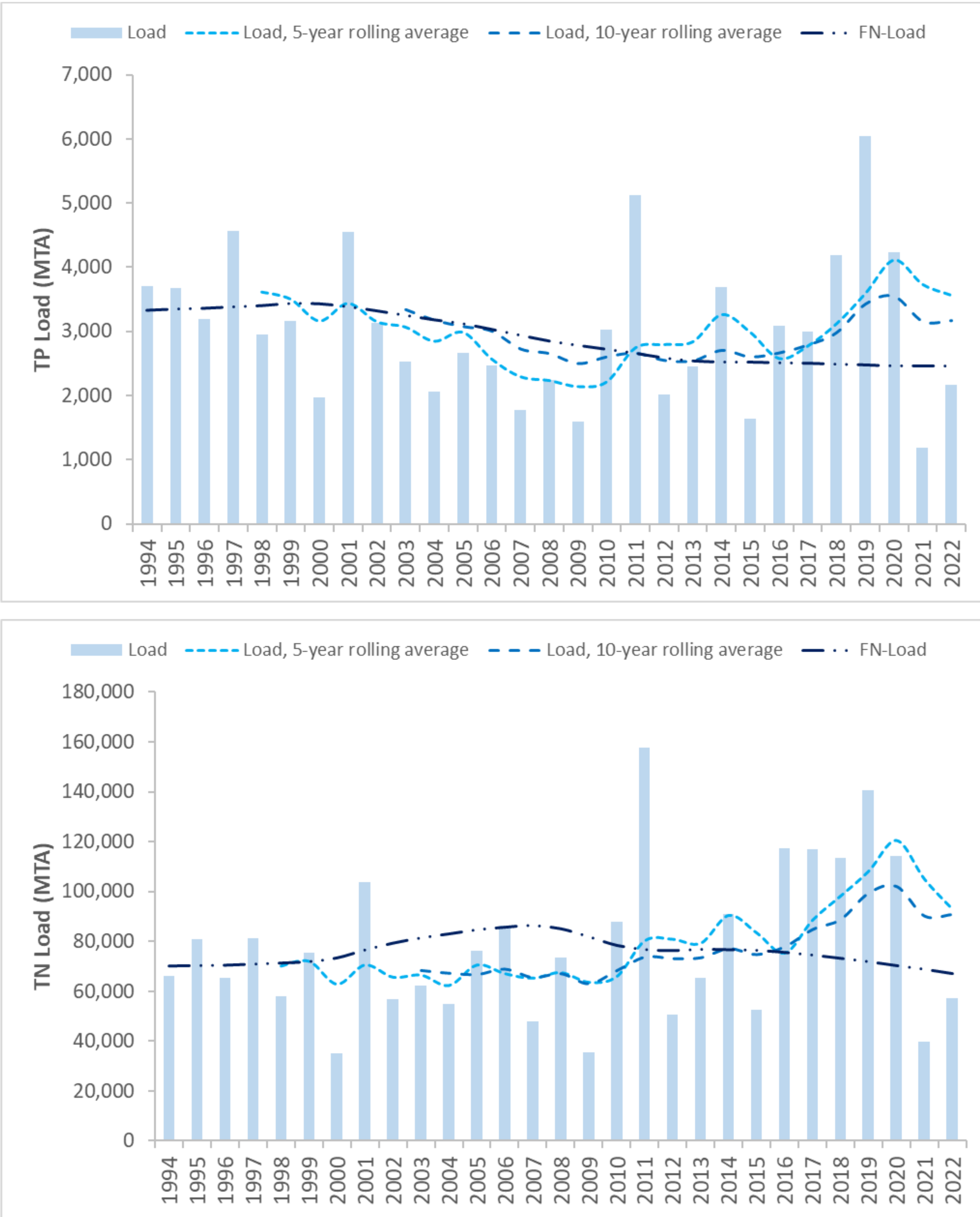
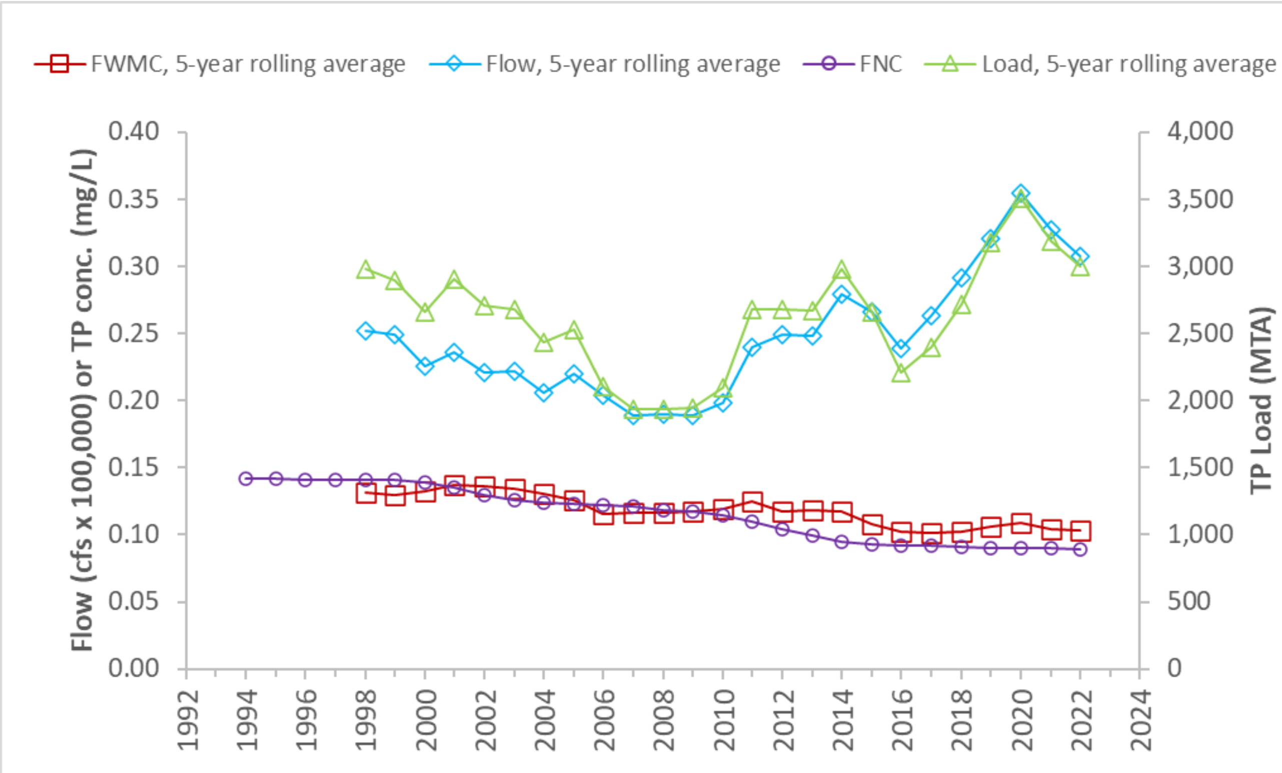


Figure 18. TP (top) and TN (bottom) load trends at the Mississippi River at Prescott, WI.

A.5 MISSISSIPPI RIVER AT THE LAKE PEPIN OUTLET (RM 764) – WRTDS



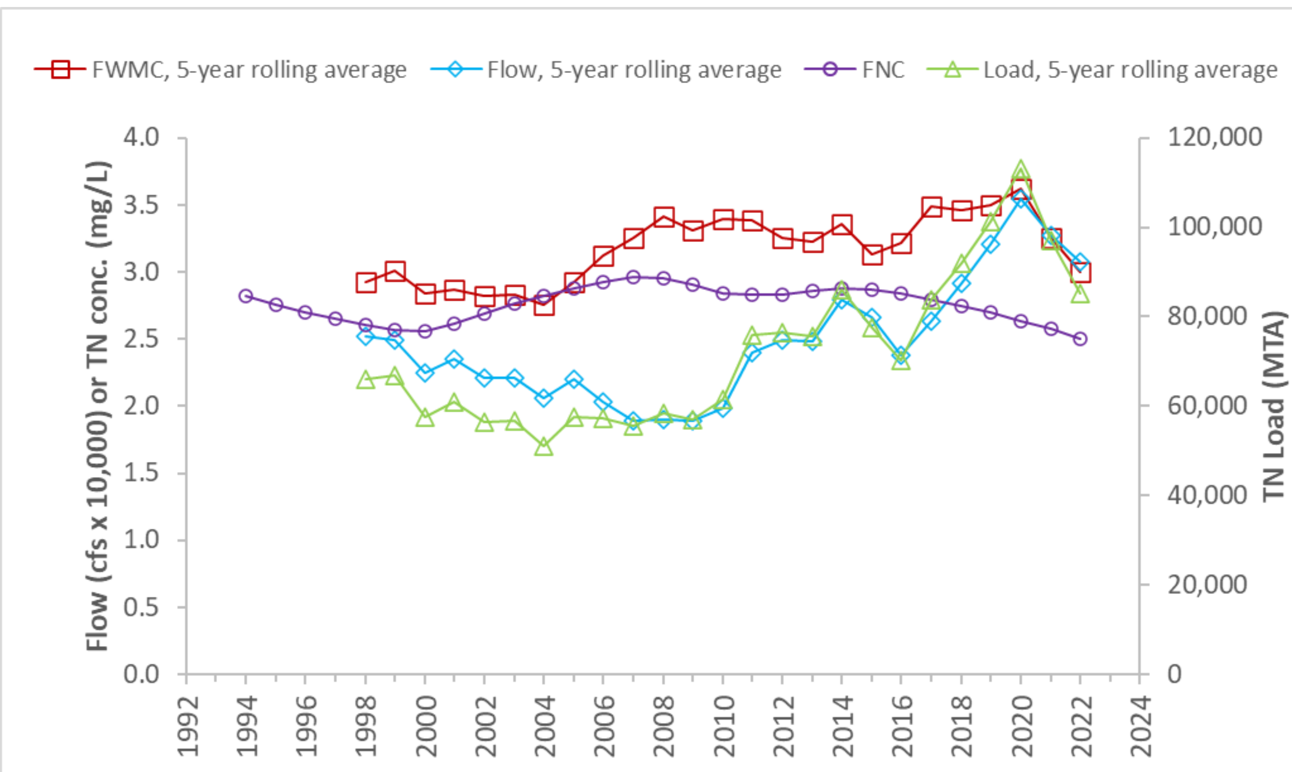


Figure 19. TP (top) and TN (bottom) 5-year rolling averages at the Mississippi River at the Lake Pepin outlet.

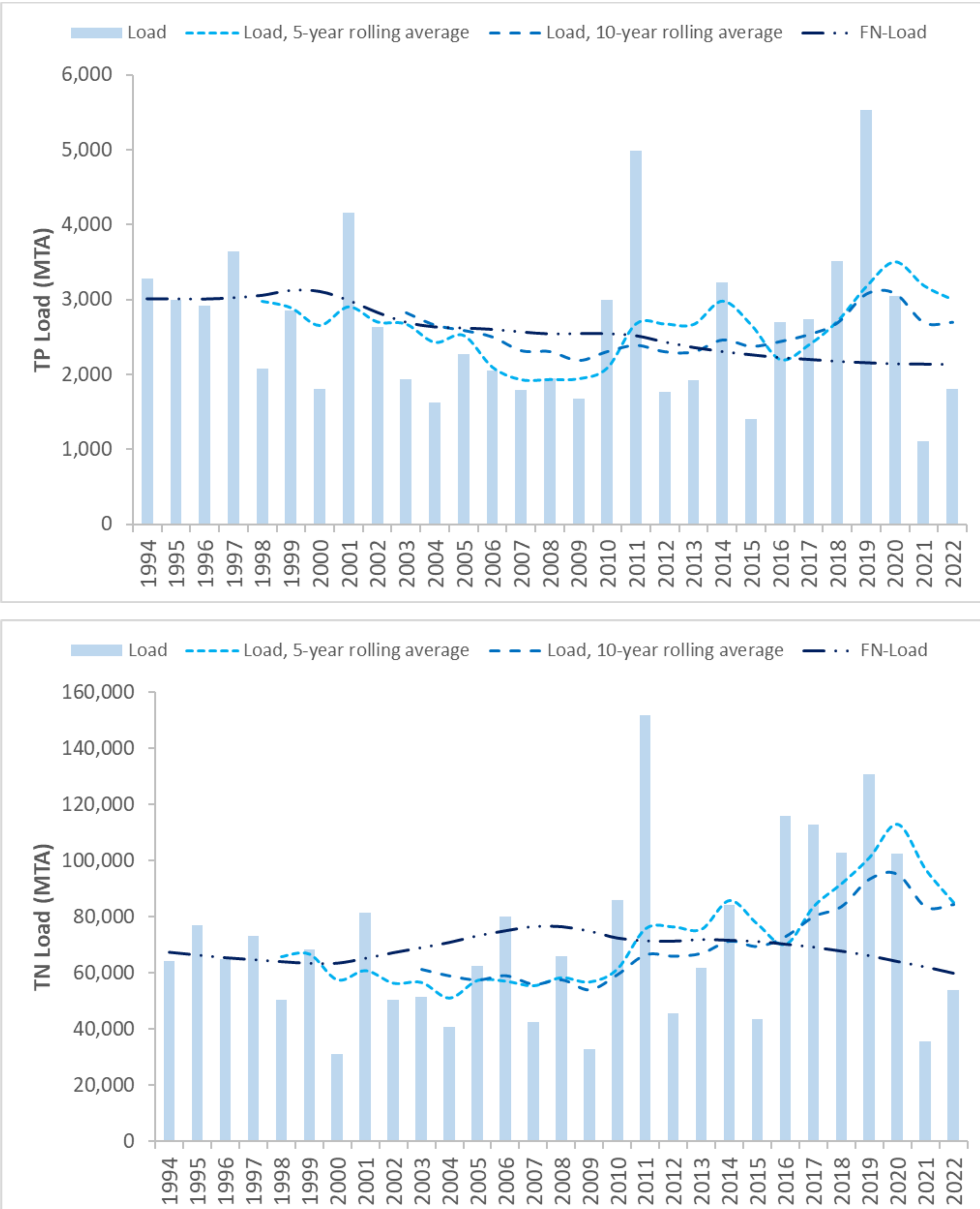
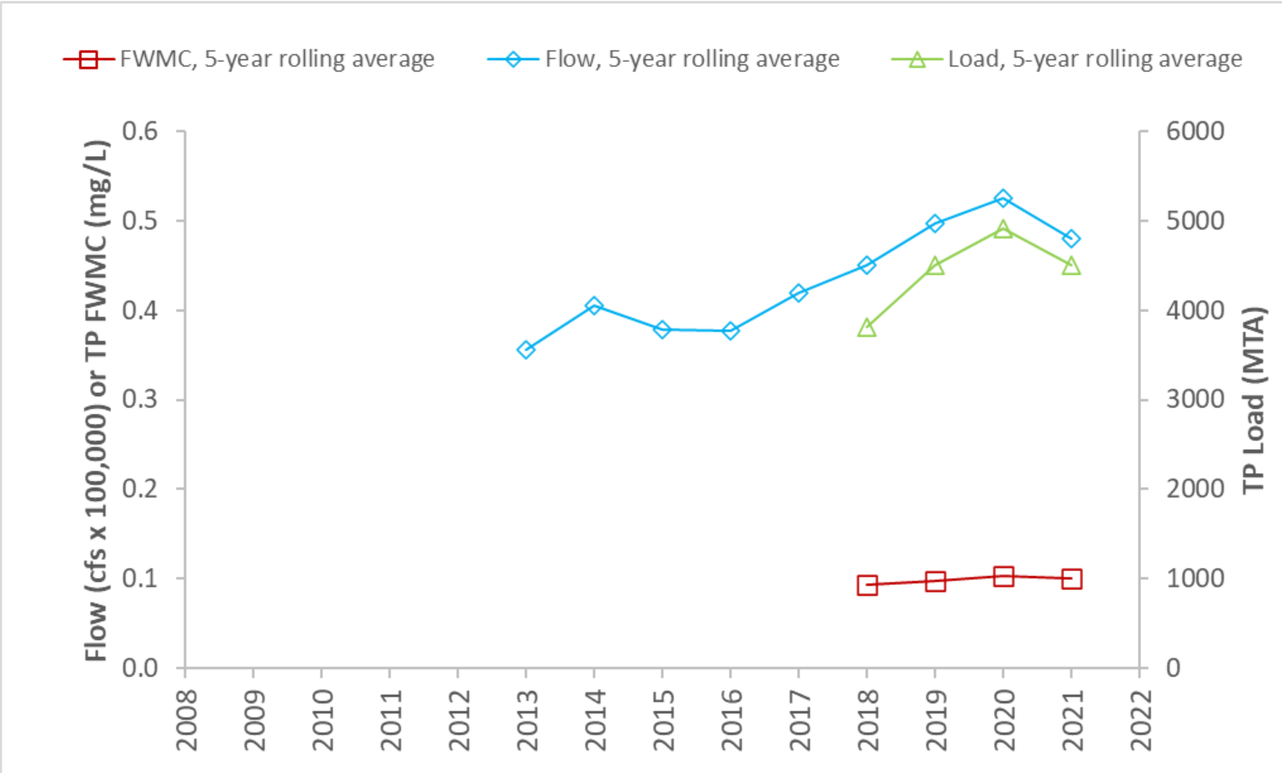


Figure 20. TP (top) and TN (bottom) load trends at the Mississippi River at the Lake Pepin outlet.

A.6 MISSISSIPPI RIVER AT WINONA, MN – FLUX32



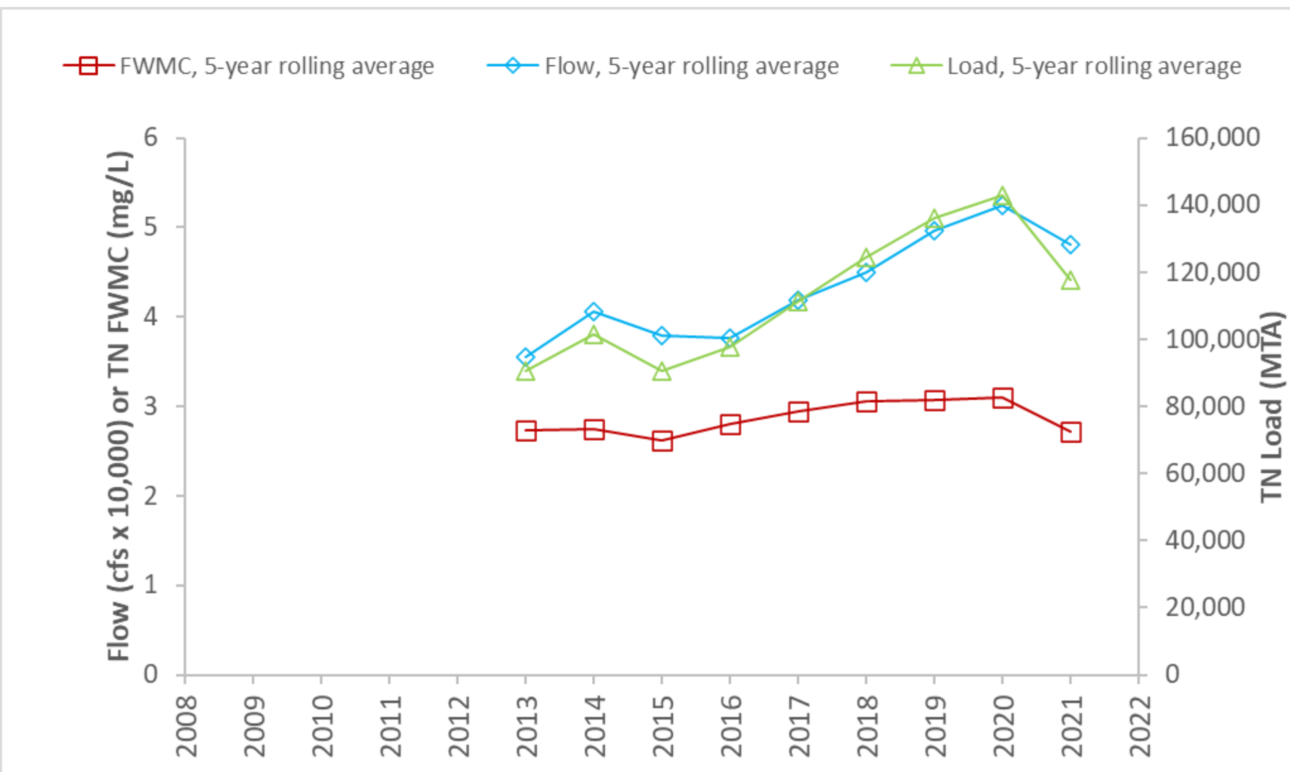
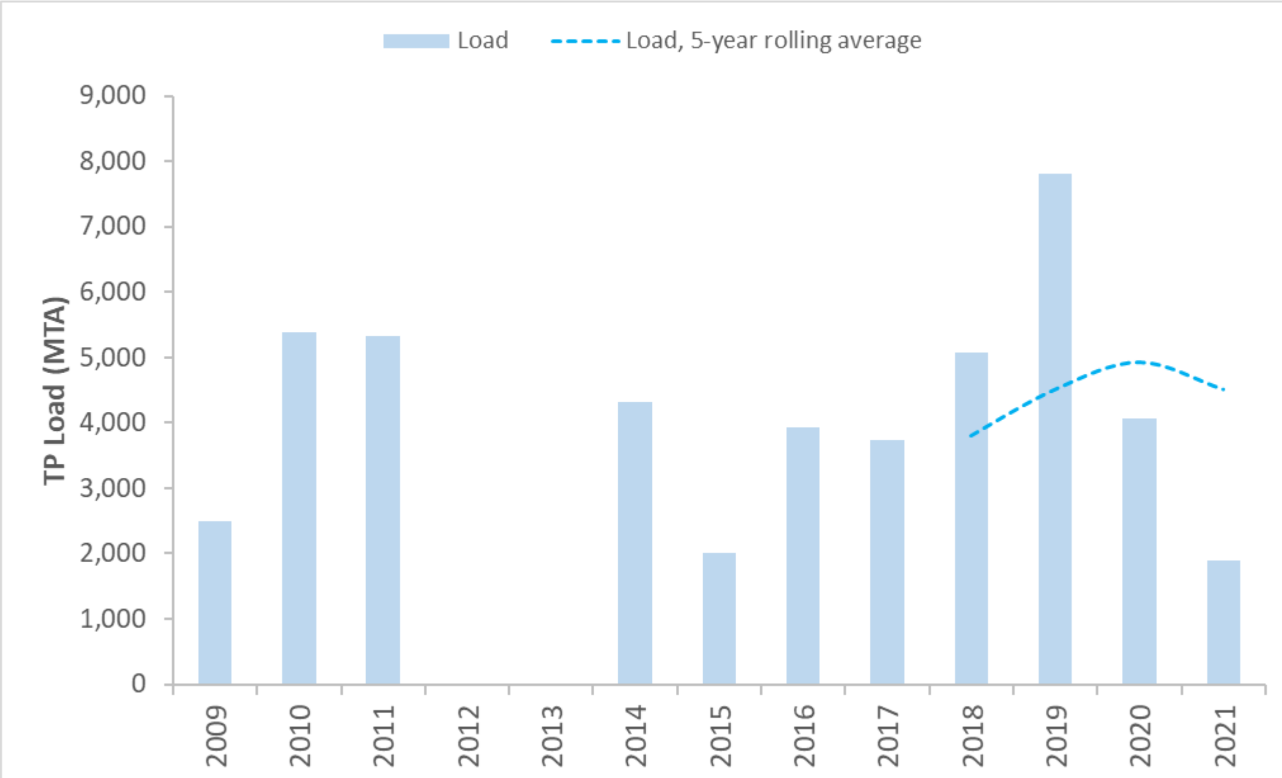


Figure 21. TP (top) and TN (bottom) 5-year rolling averages at the Mississippi River at Winona, MN.



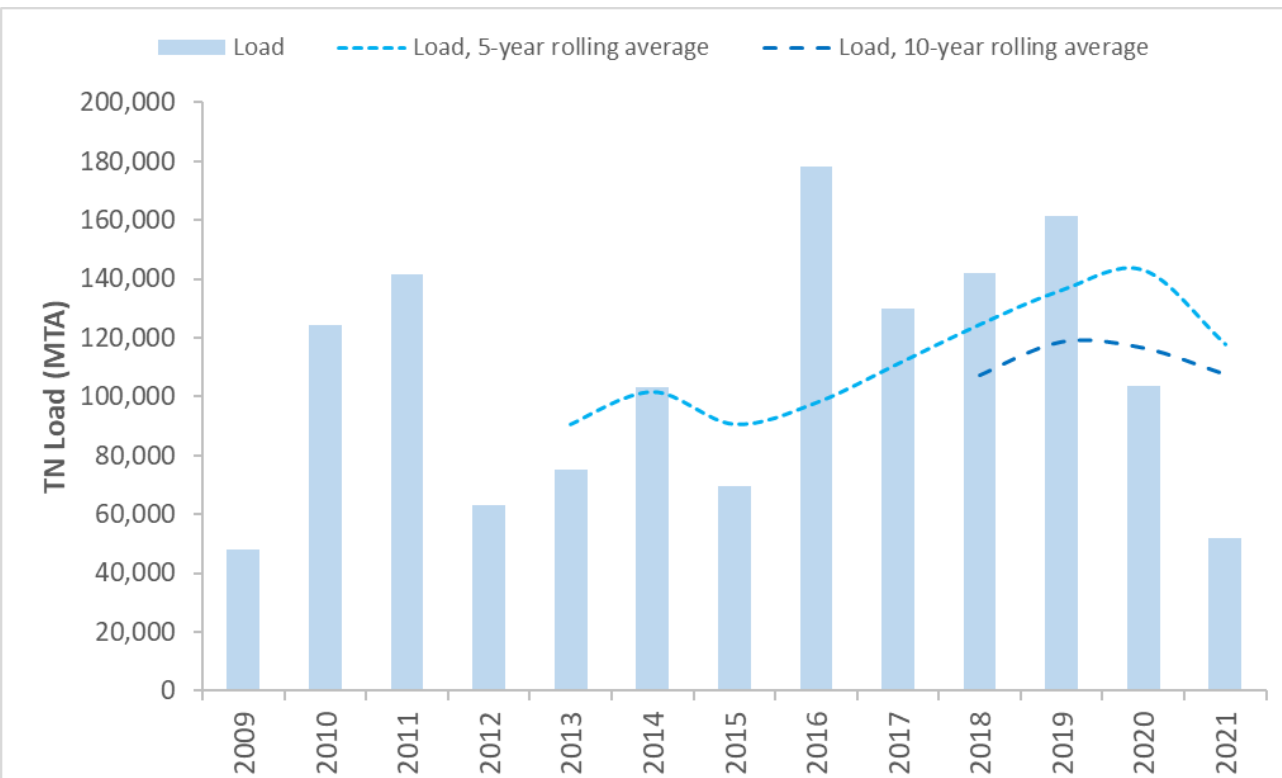
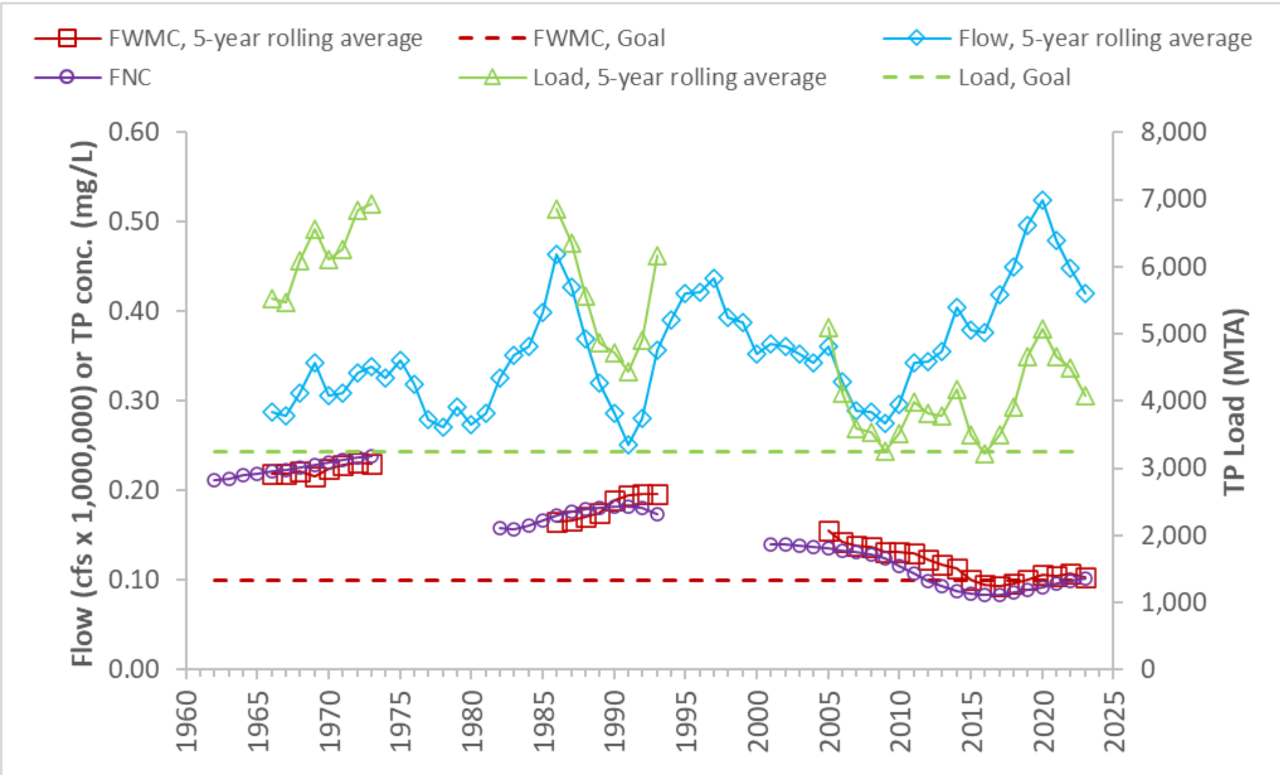


Figure 22. TP (top) and TN (bottom) load trends at the Mississippi River at Winona, MN.

A.7 MISSISSIPPI RIVER AT WINONA, MN - WRTDS



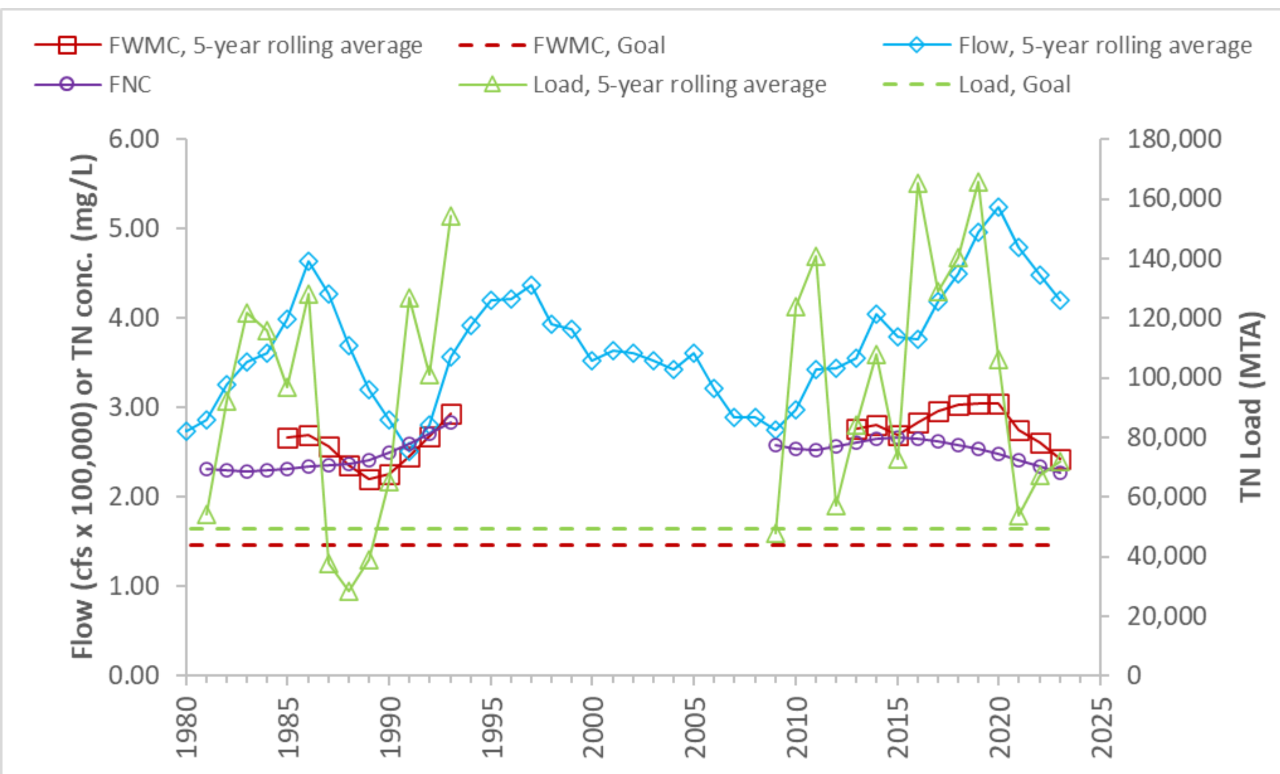


Figure 23. TP (top) and TN (bottom) 5-year rolling averages at the Mississippi River at Winona, MN.

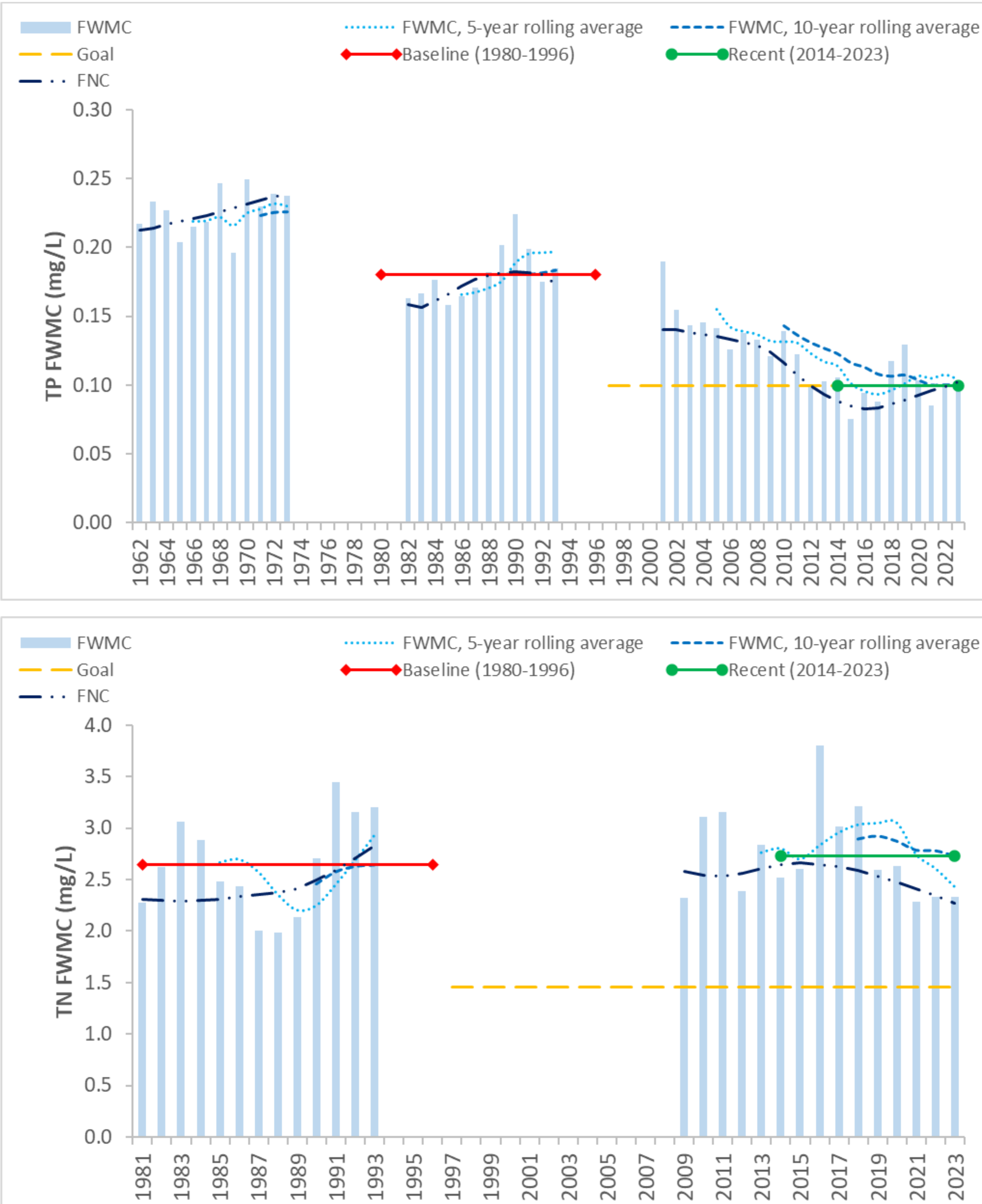


Figure 24. TP (top) and TN (bottom) FWMC trends and goal for the Mississippi River at Winona, MN.

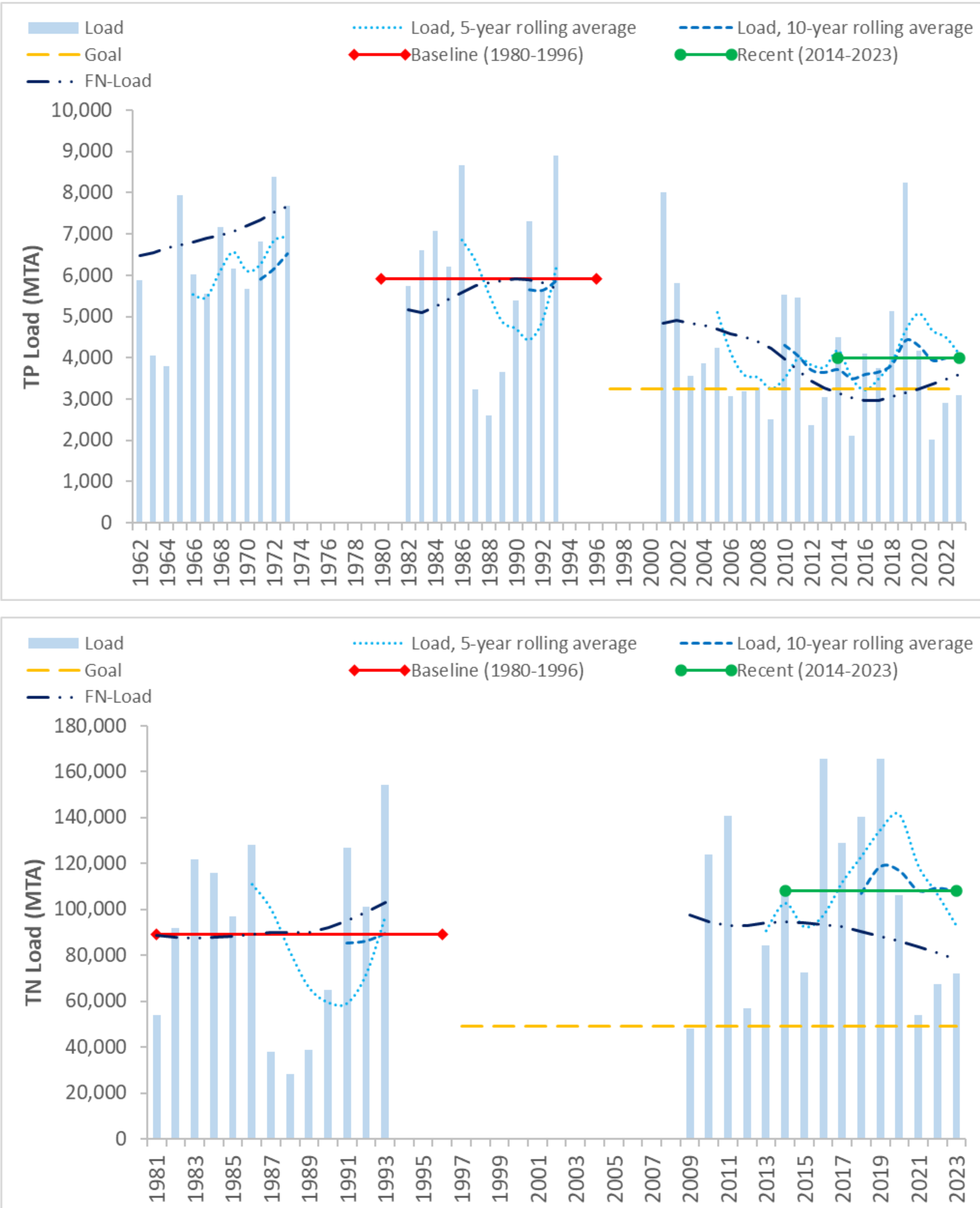
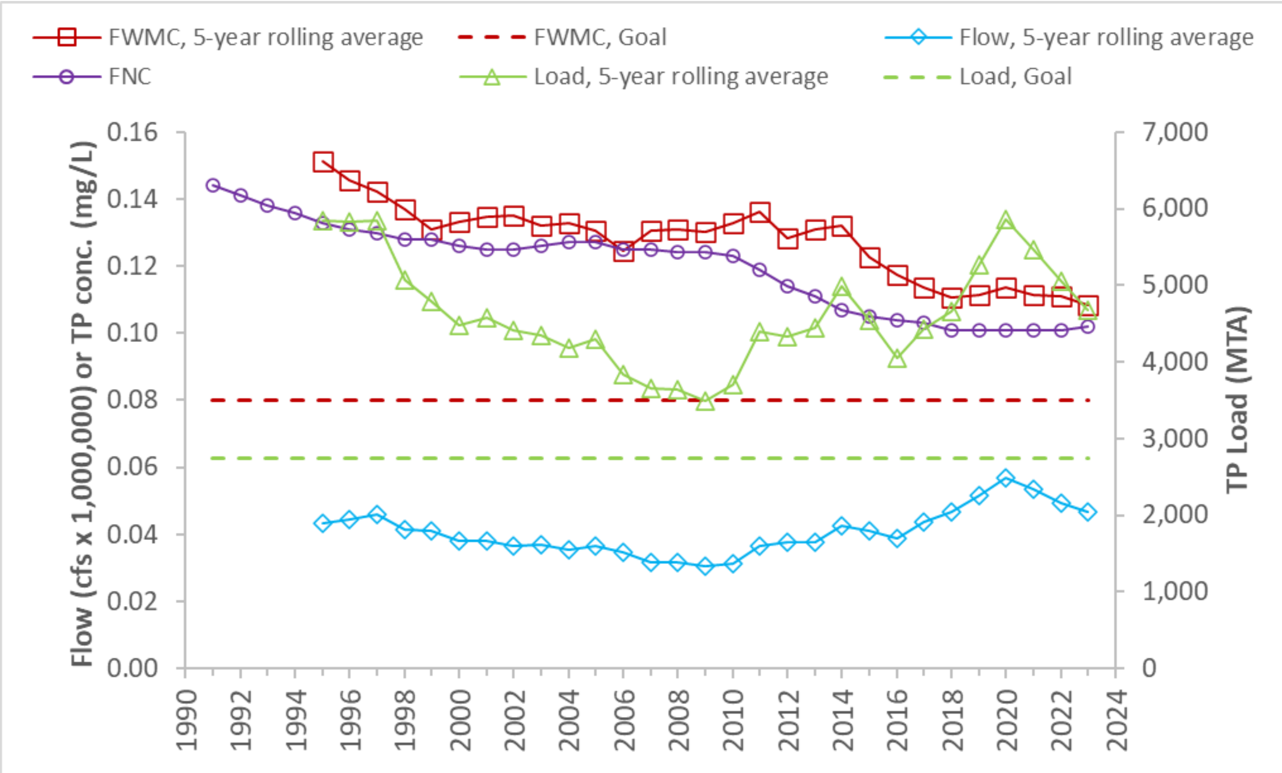


Figure 25. TP (top) and TN (bottom) load trends and goal for the Mississippi River at Red Wing, MN.

Figure 26. TP (top) and TN (bottom) flow-normalized loads for the Mississippi River at Red Wing, MN.

A.8 MISSISSIPPI RIVER AT LA CROSSE, WI (L&D #7) – WRTDS



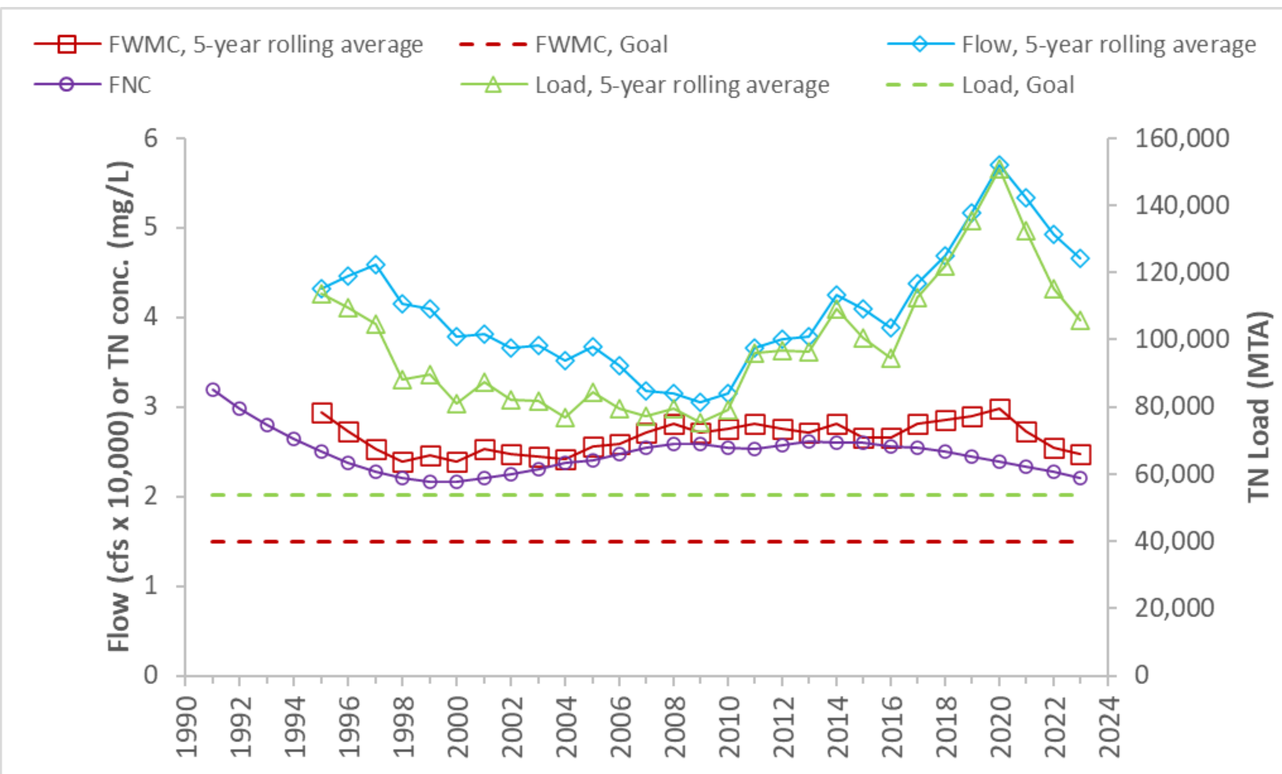


Figure 27. TP (top) and TN (bottom) 5-year rolling averages at the Mississippi River at La Crosse, WI.

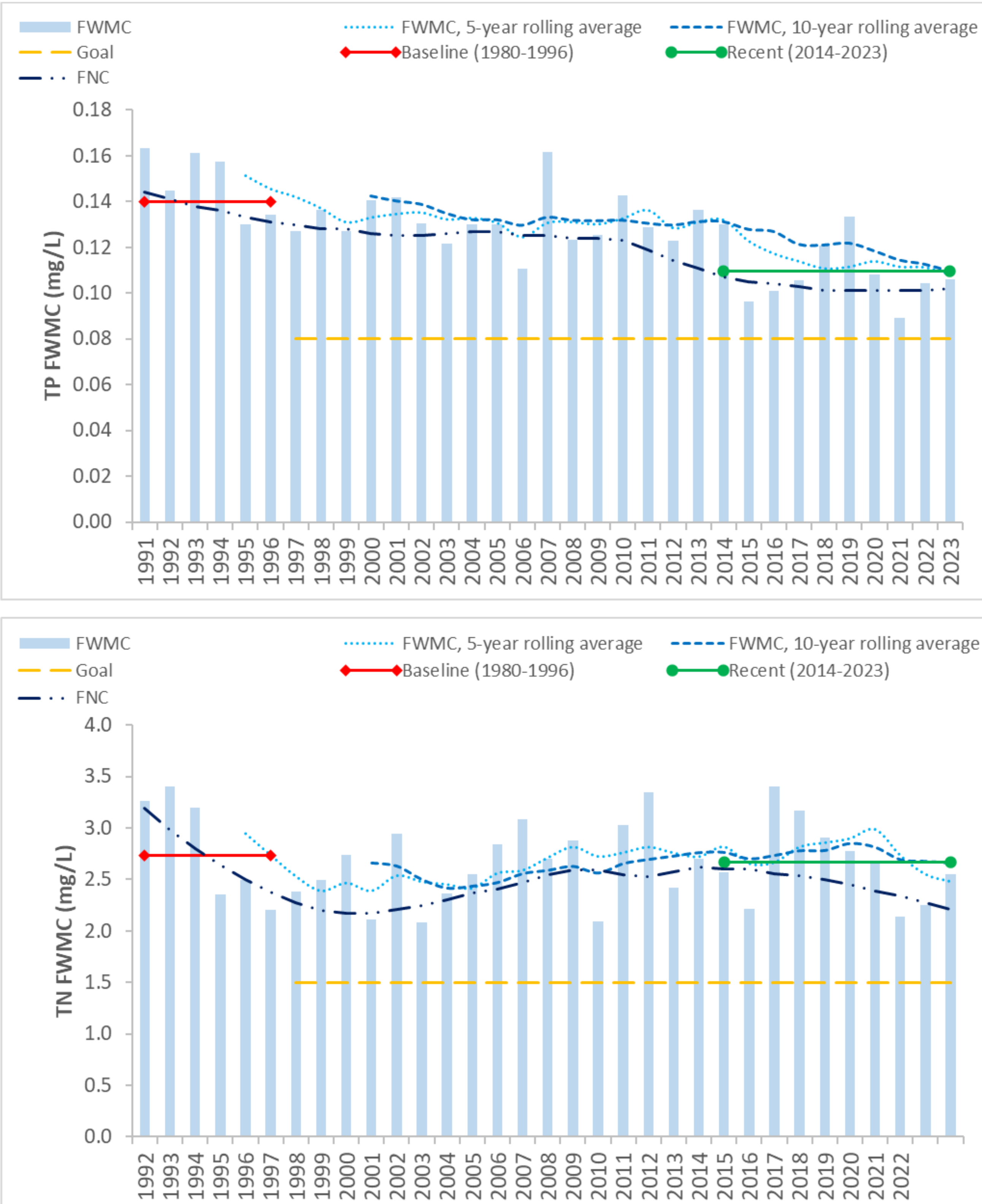


Figure 28. TP (top) and TN (bottom) FWMC trends and goal for the Mississippi River at La Crosse, WI.

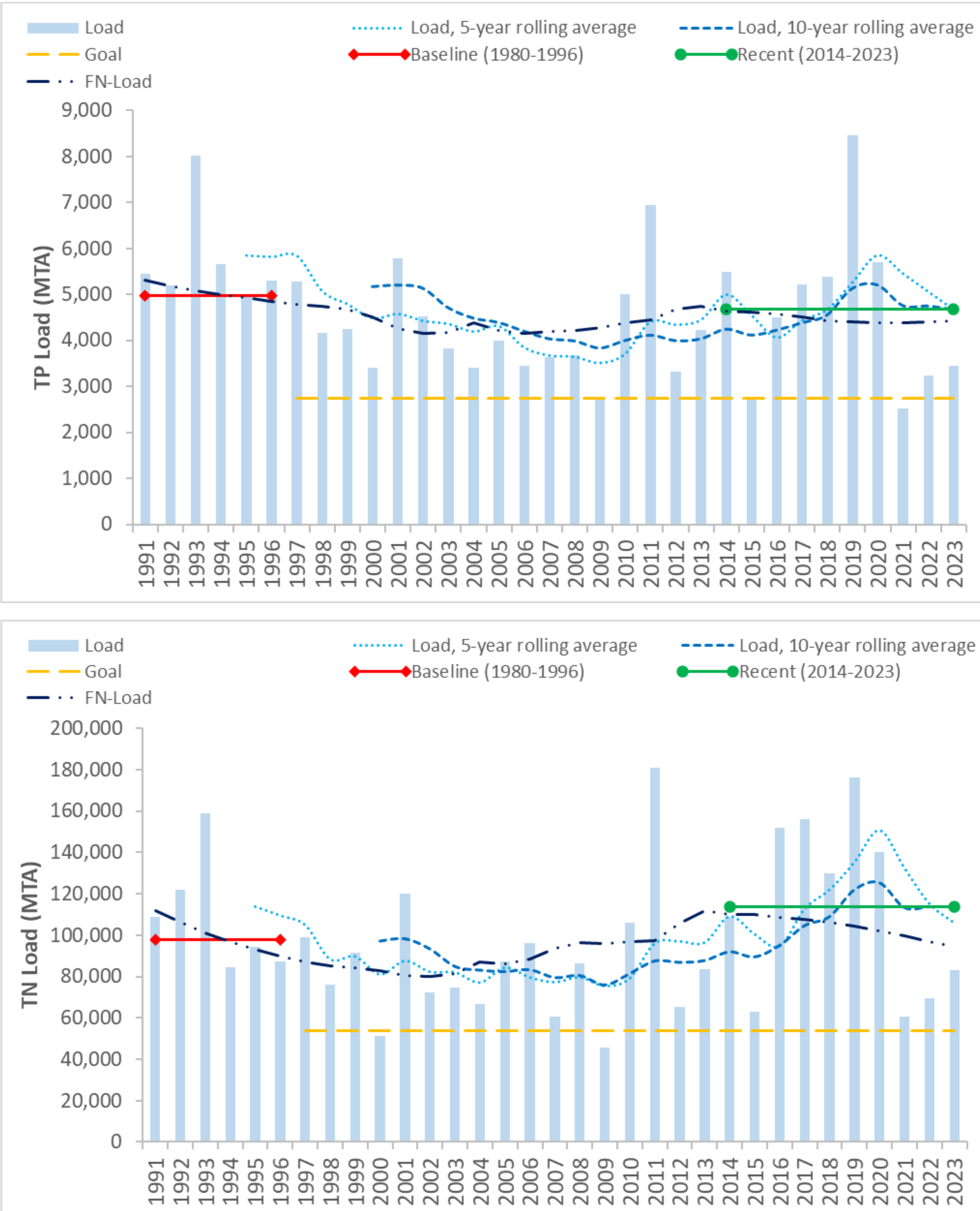


Figure 29. TP (top) and TN (bottom) load trends and goal for the Mississippi River at La Crosse, WI.

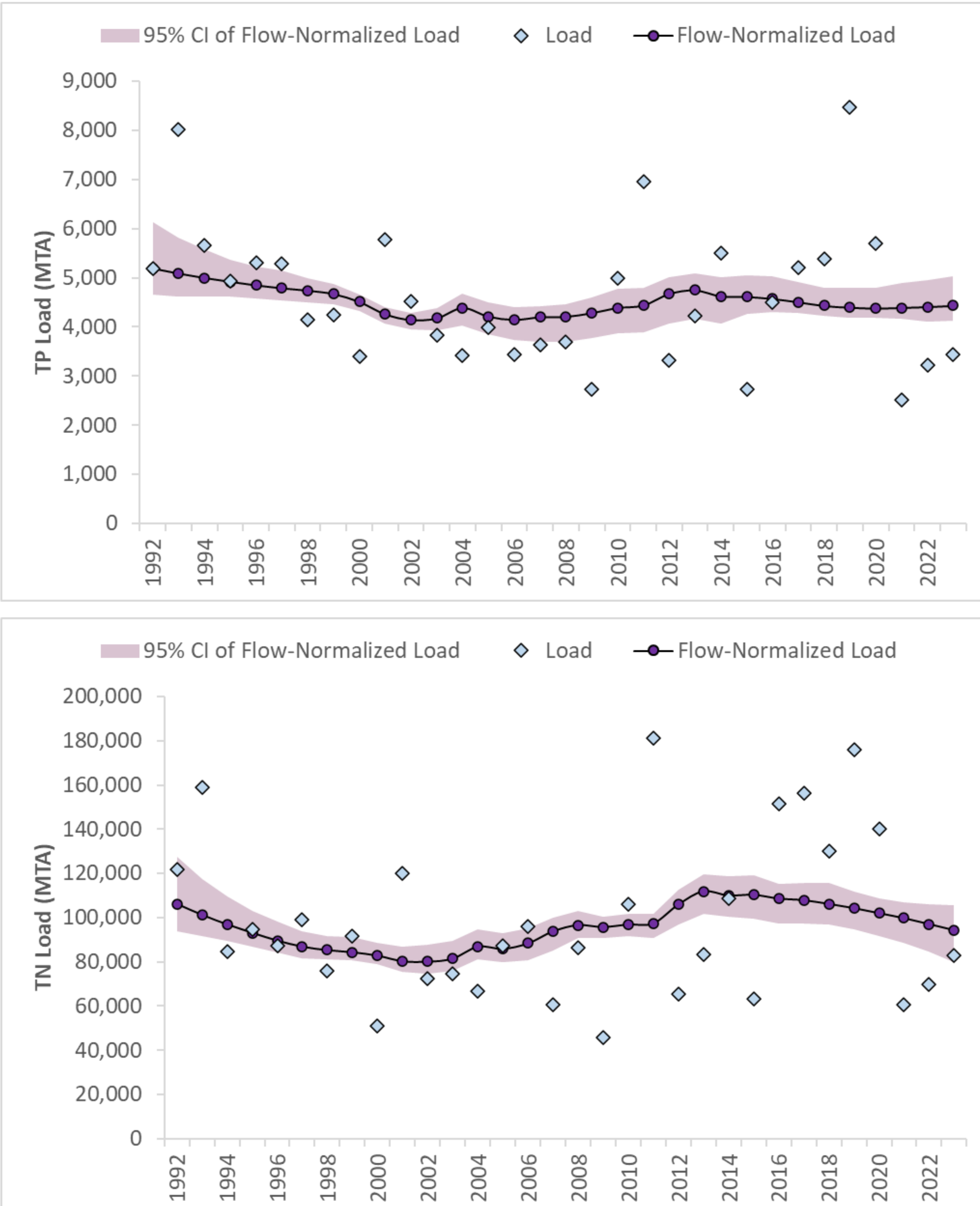
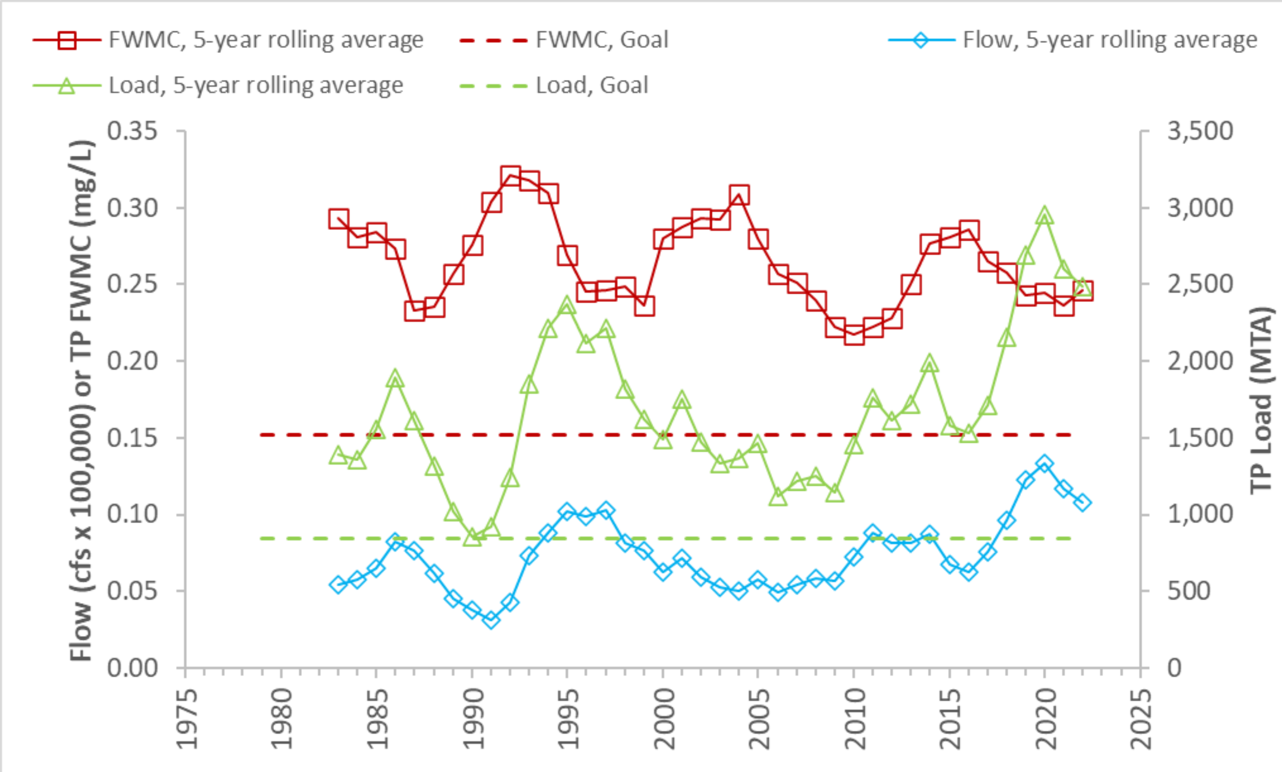


Figure 30. TP (top) and TN (bottom) flow-normalized loads for the Mississippi River at La Crosse, WI.

APPENDIX B. TREND CHARTS FOR MISSISSIPPI RIVER TRIBUTARIES

B.1 MINNESOTA RIVER AT JORDAN, MN – FLUX32



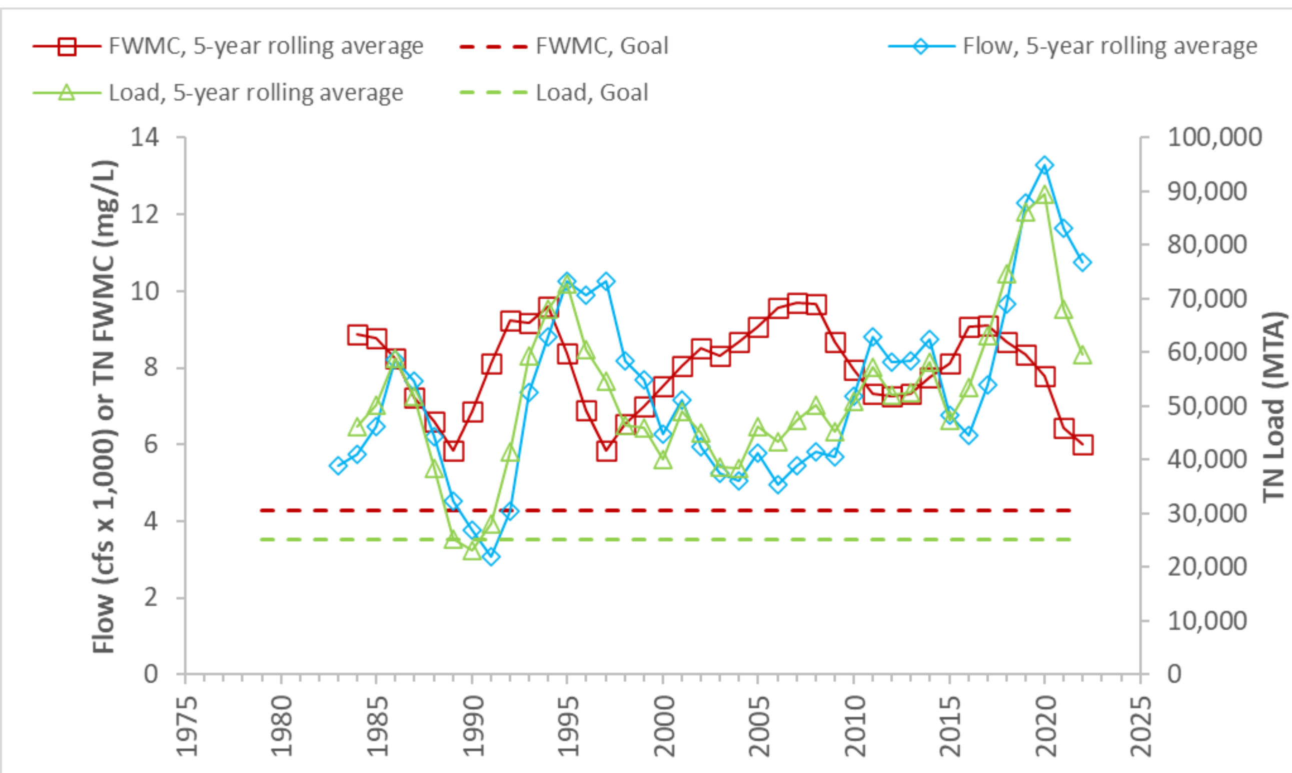
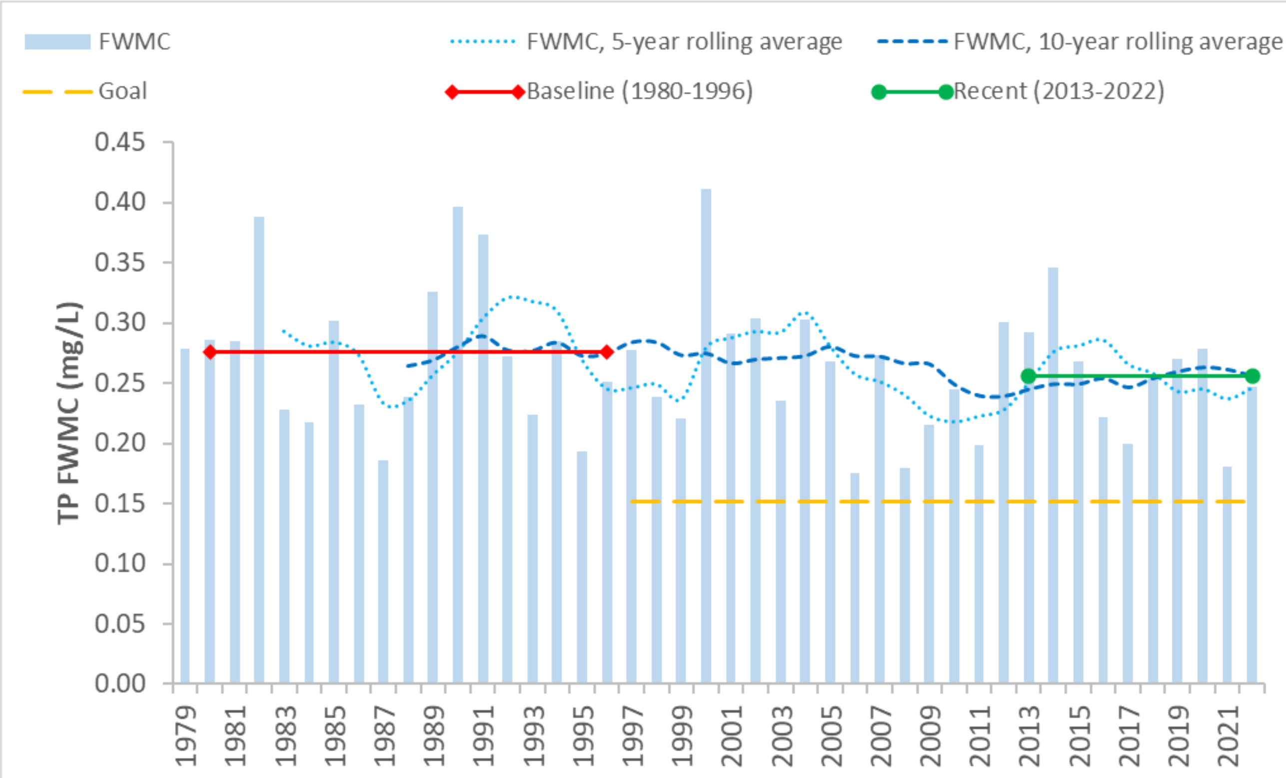


Figure 31. TP (top) and TN (bottom) 5-year rolling averages at the Minnesota River at Jordan, MN.



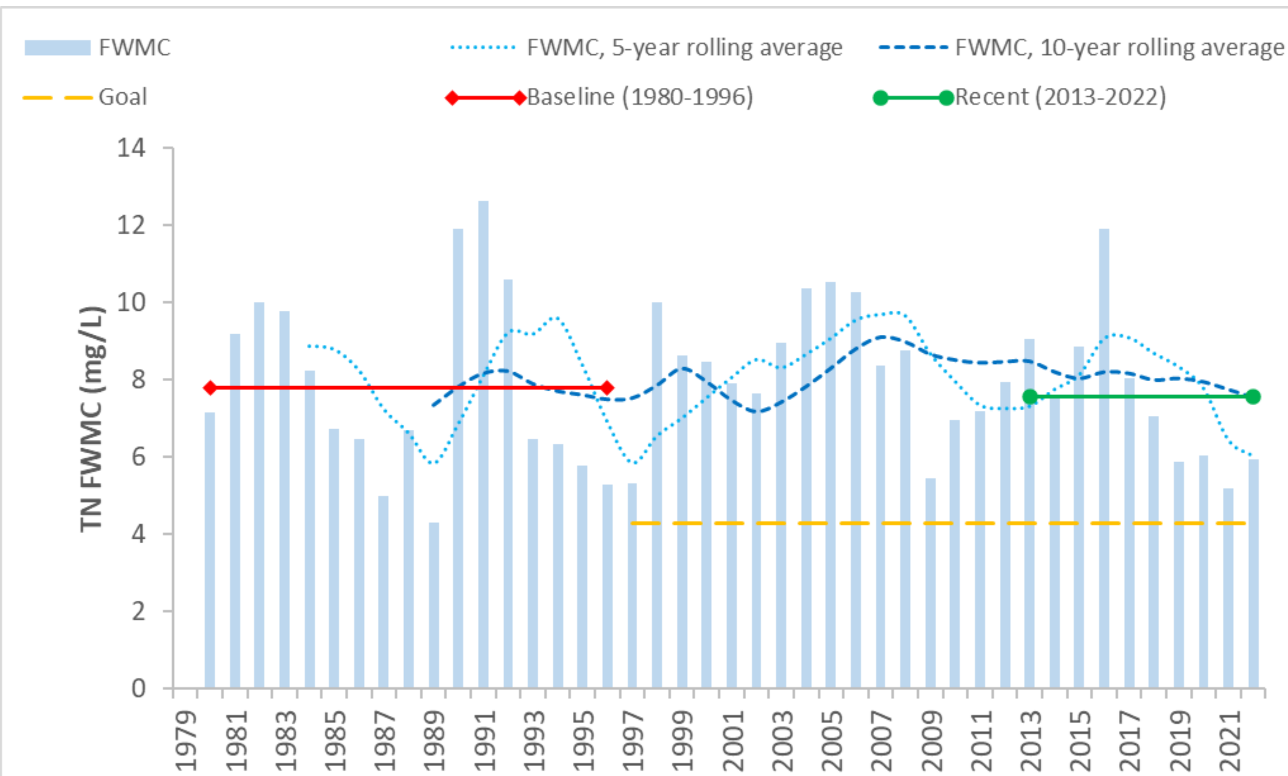


Figure 32. TP (top) and TN (bottom) FWMC trends and goal for the Minnesota River at Jordan, MN.

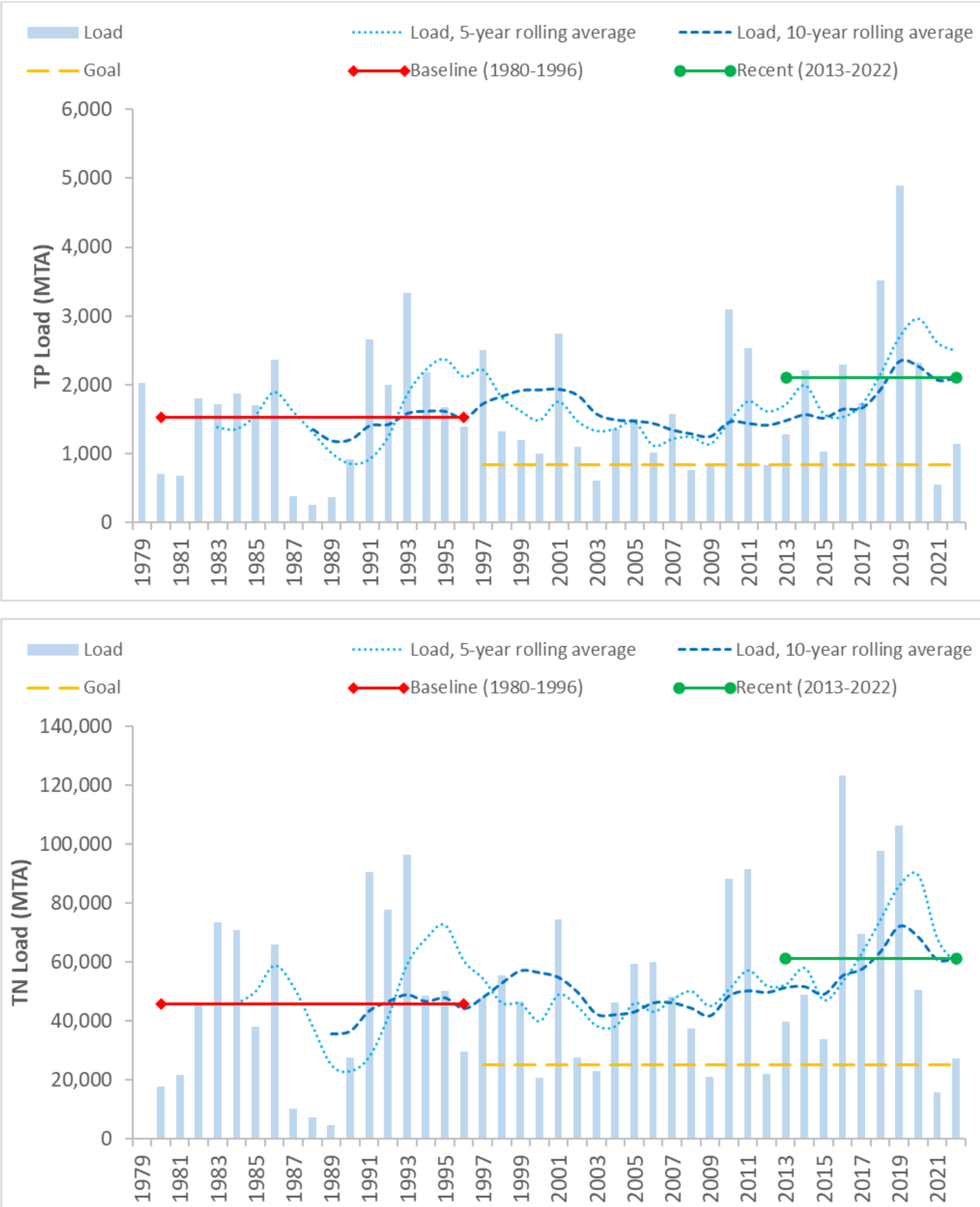
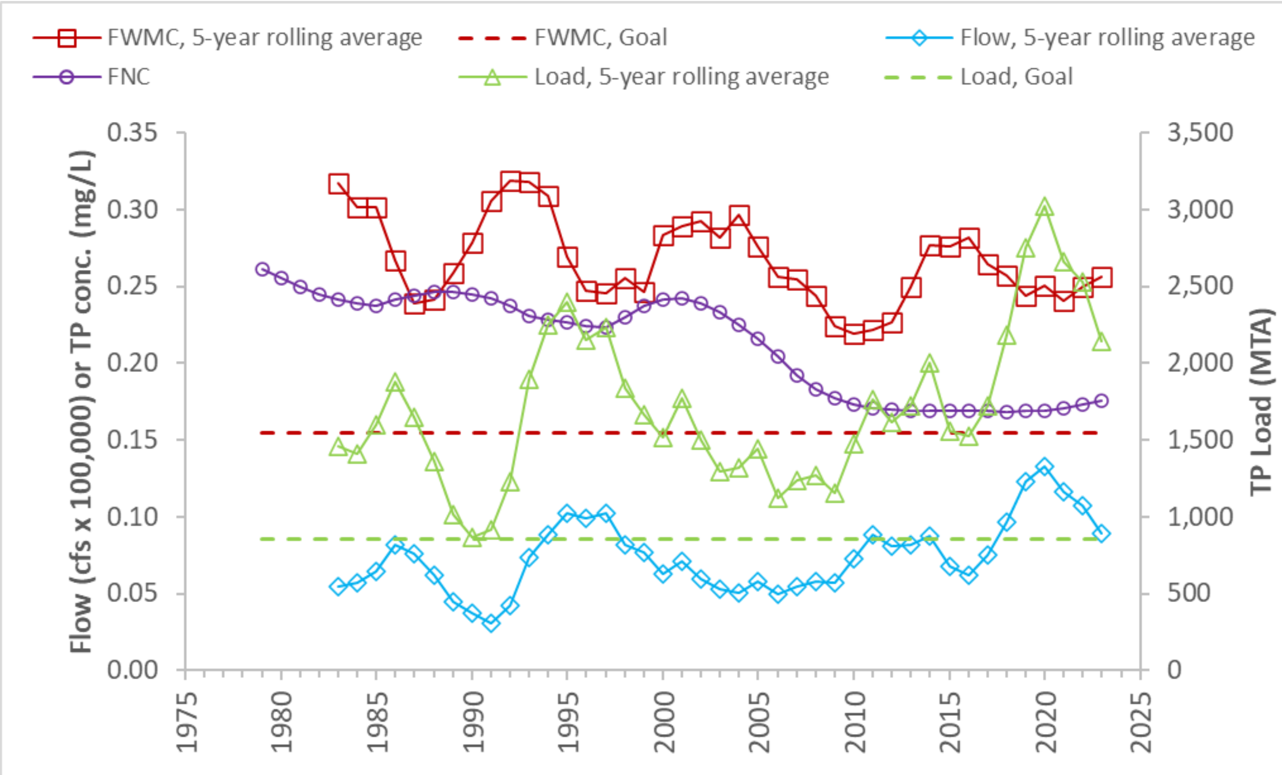


Figure 33. TP (top) and TN (bottom) load trends and goal for the Minnesota River at Jordan, MN.

B.2 MINNESOTA RIVER AT JORDAN, MN – WRTDS



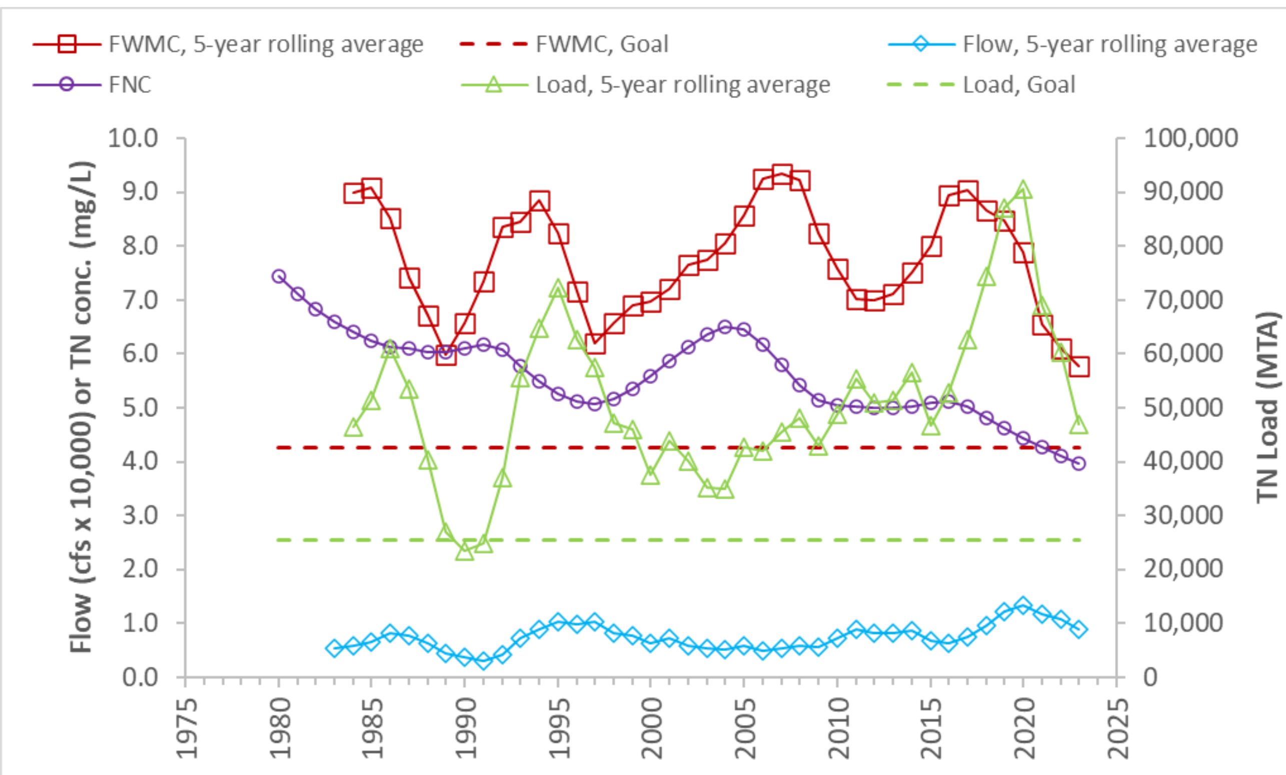


Figure 34. TP (top) and TN (bottom) 5-year rolling averages at the Minnesota River at Jordan, MN.

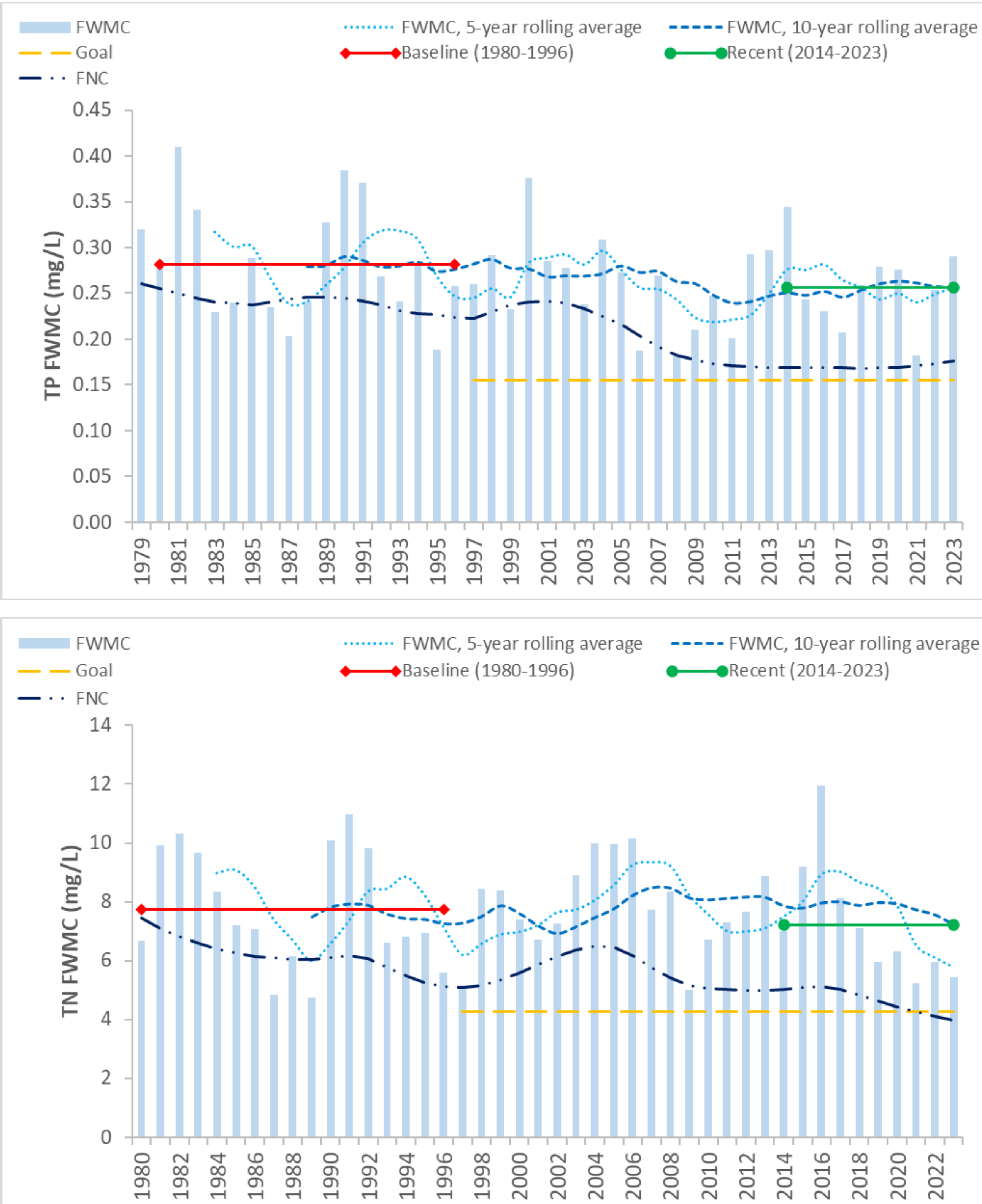


Figure 35. TP (top) and TN (bottom) FWMC trends and goal for the Minnesota River at Jordan, MN.

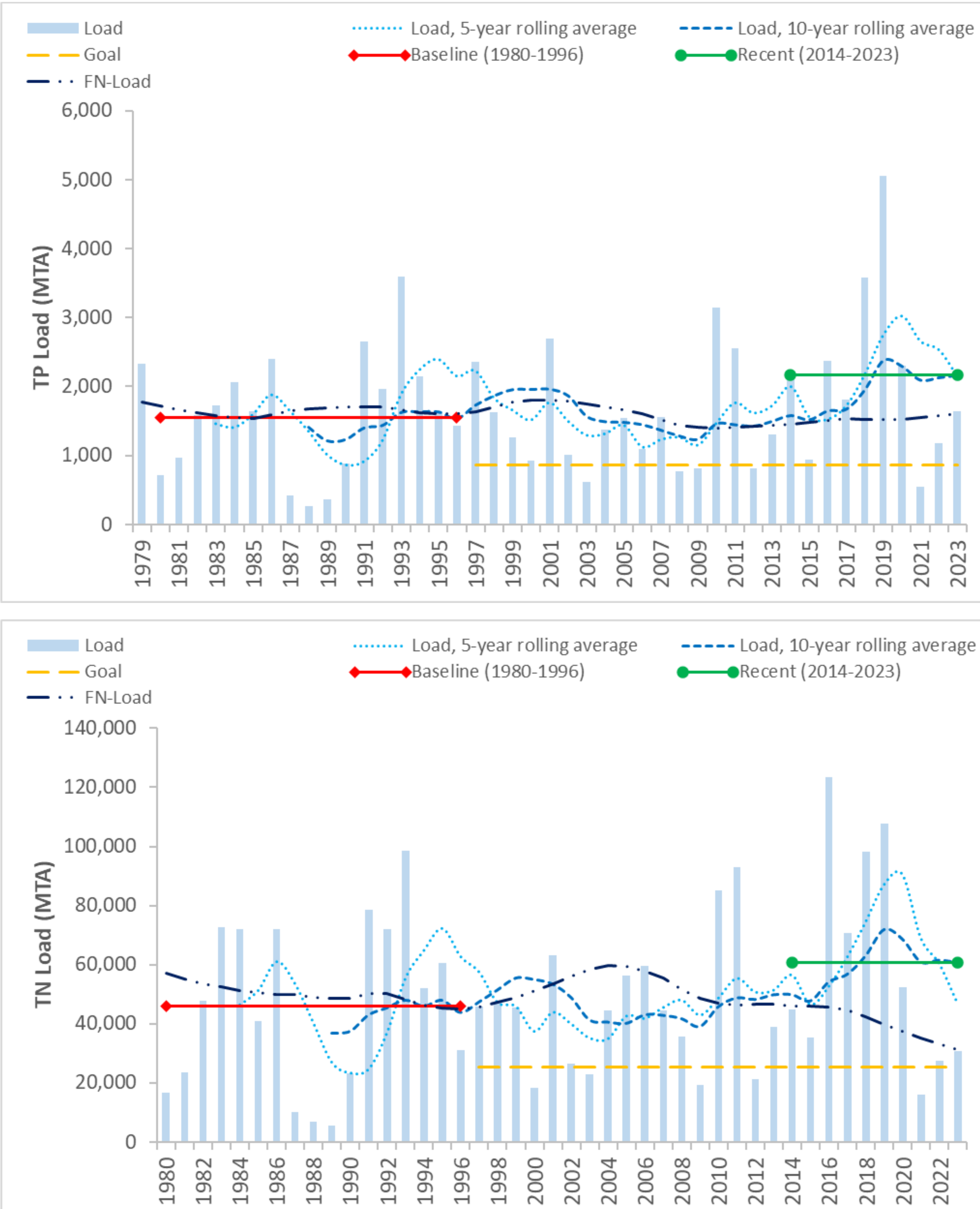
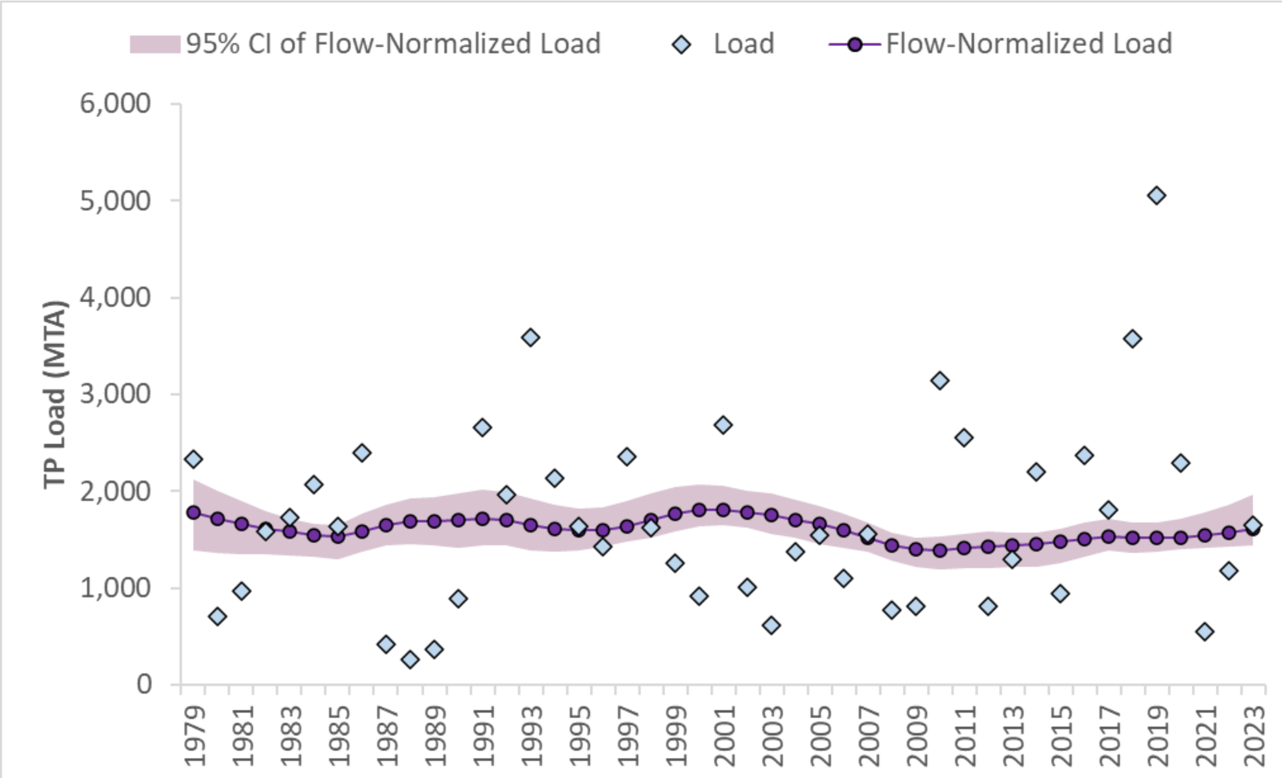


Figure 36. TP (top) and TN (bottom) load trends and goal for the Minnesota River at Jordan, MN.



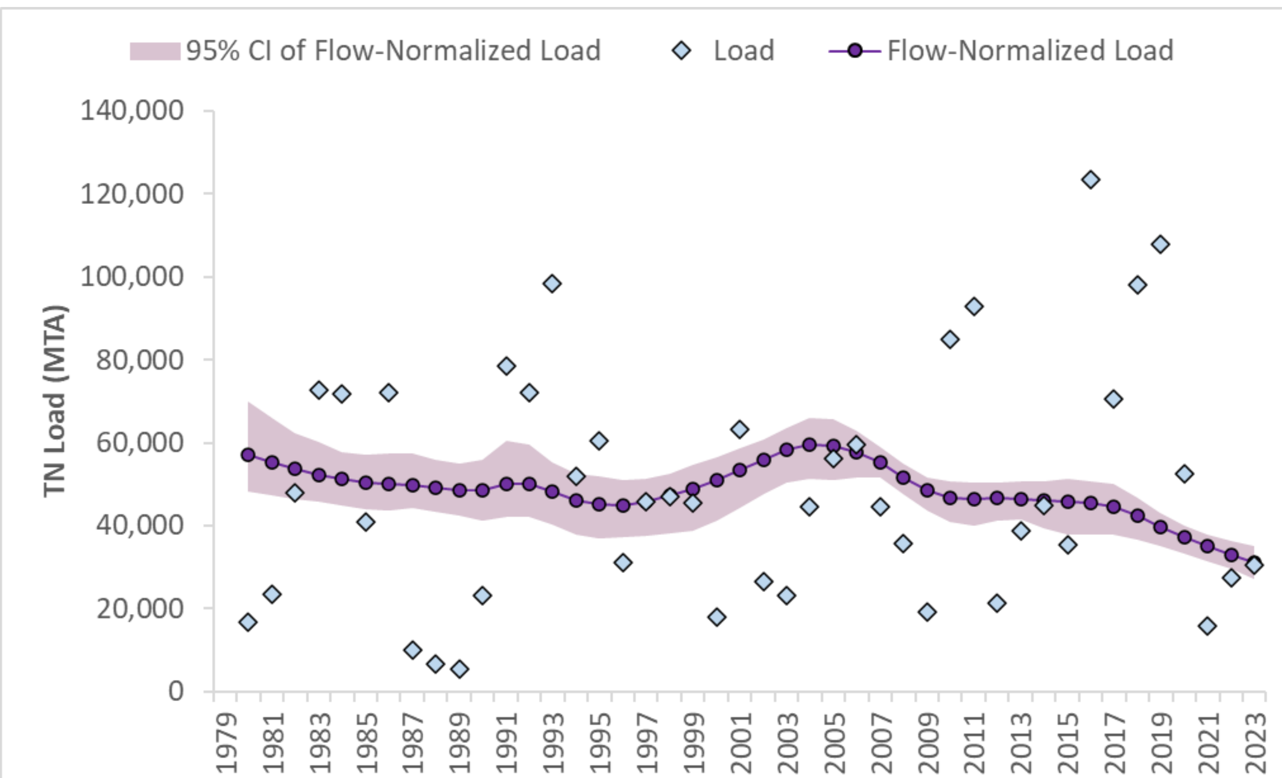


Figure 37. TP (top) and TN (bottom) flow-normalized loads for the Minnesota River at Jordan, MN.

B.3 CANNON RIVER AT WELCH, MN

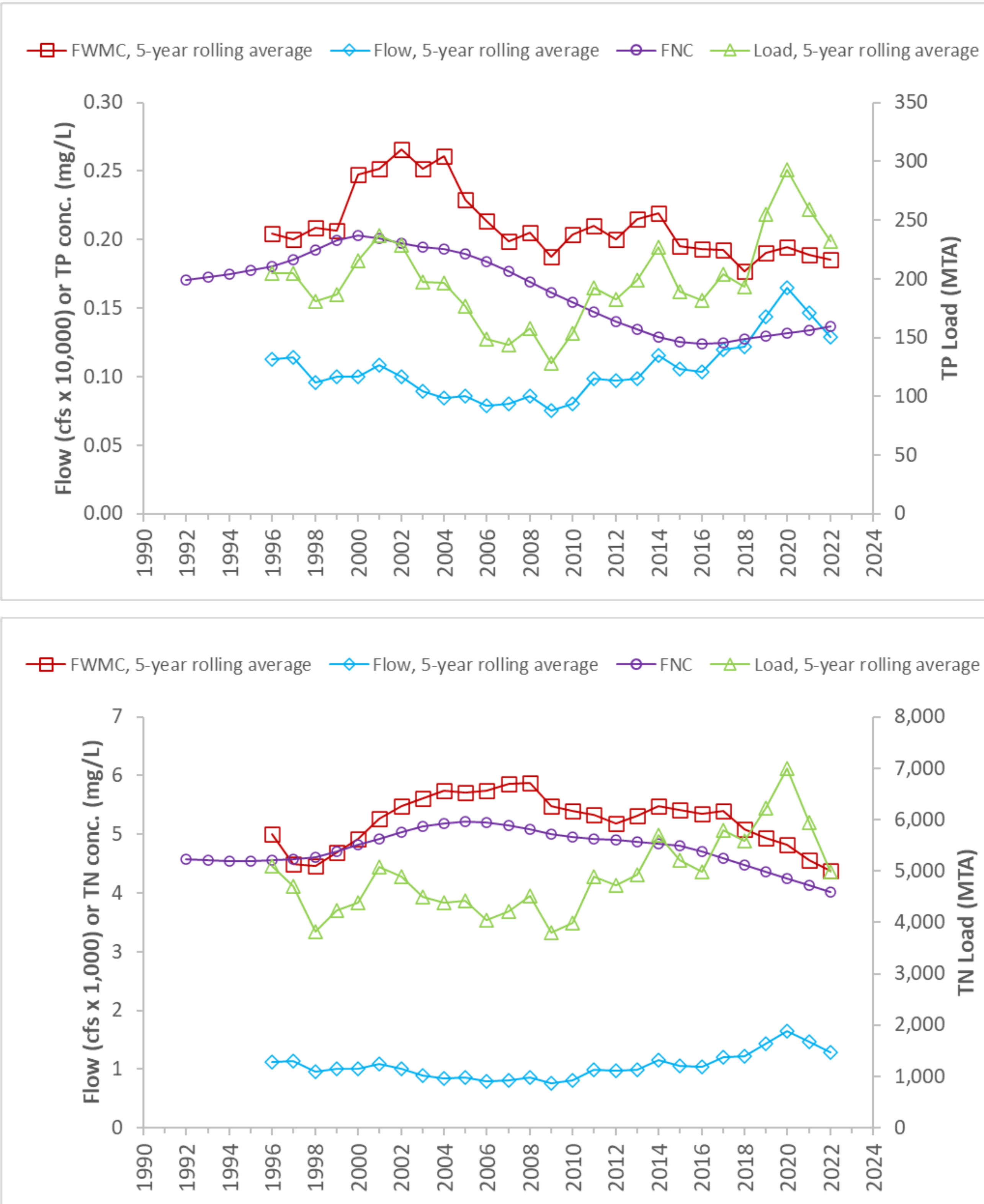
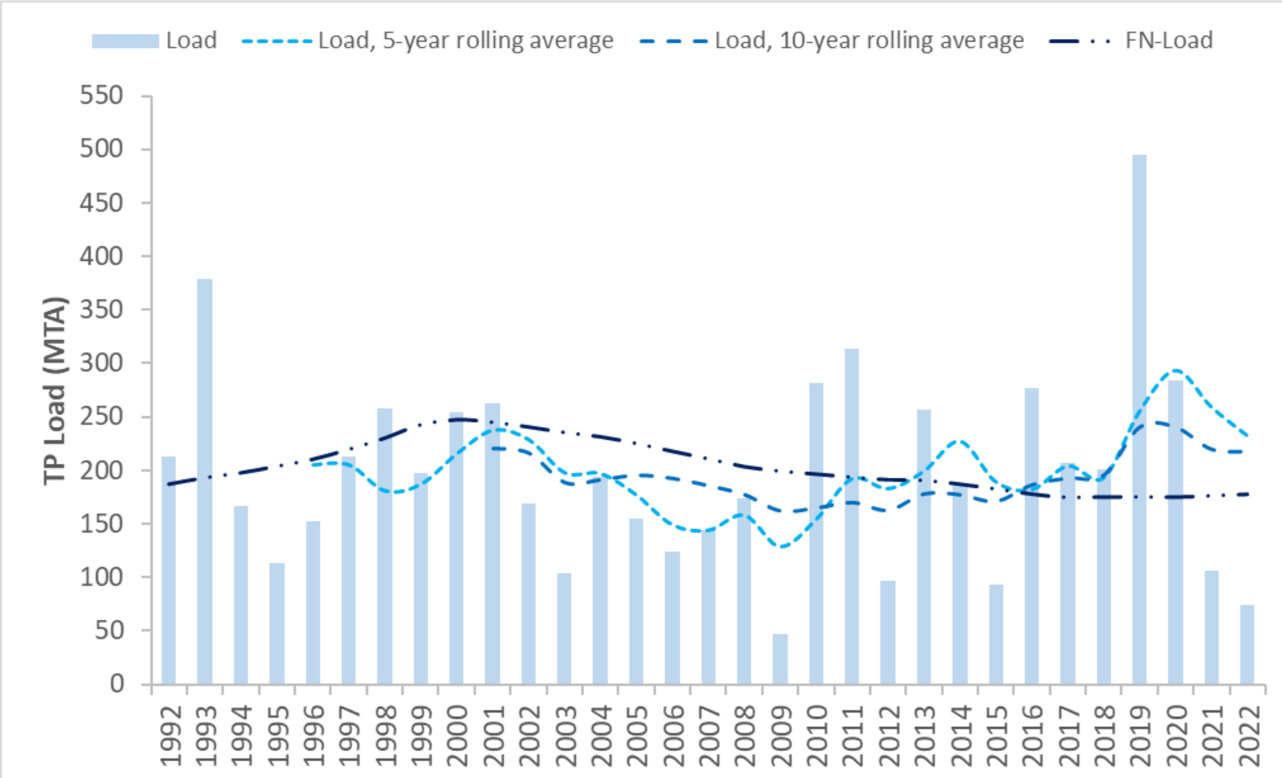


Figure 38. TP (top) and TN (bottom) 5-year rolling averages at the Cannon River at Welch, MN.



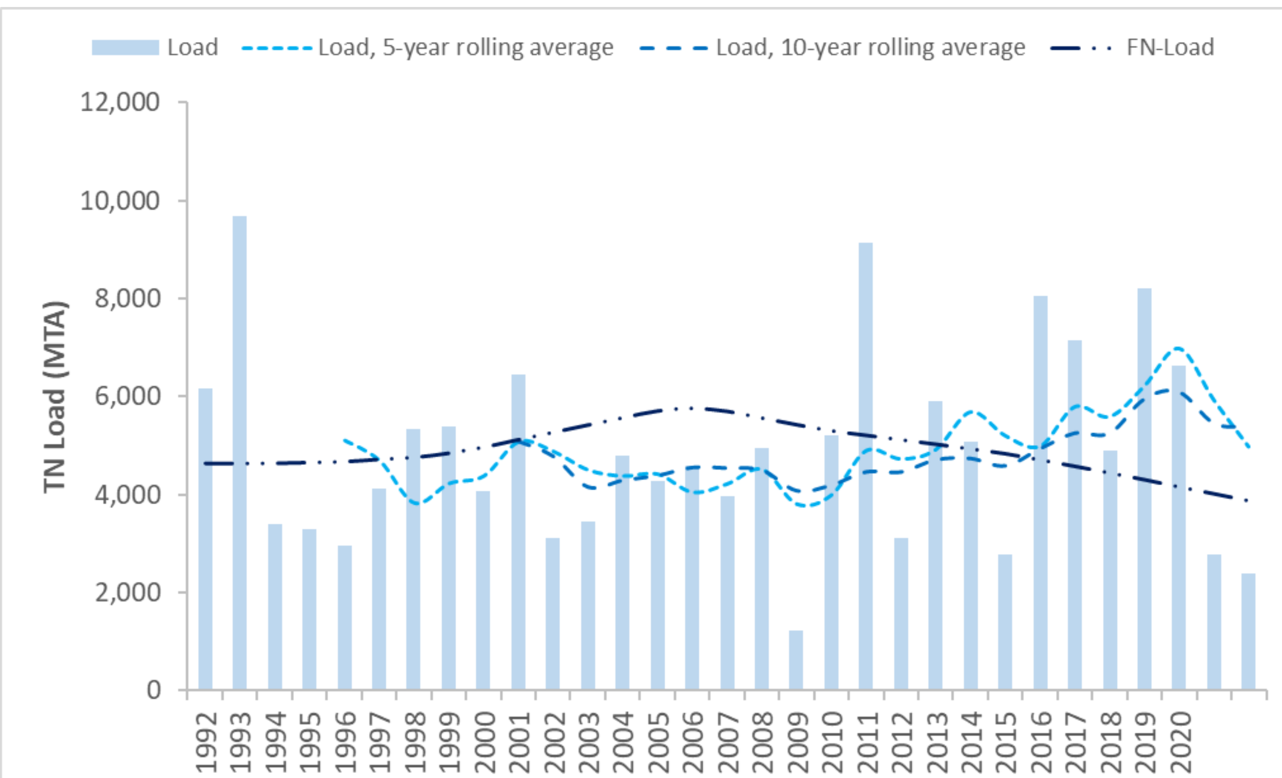
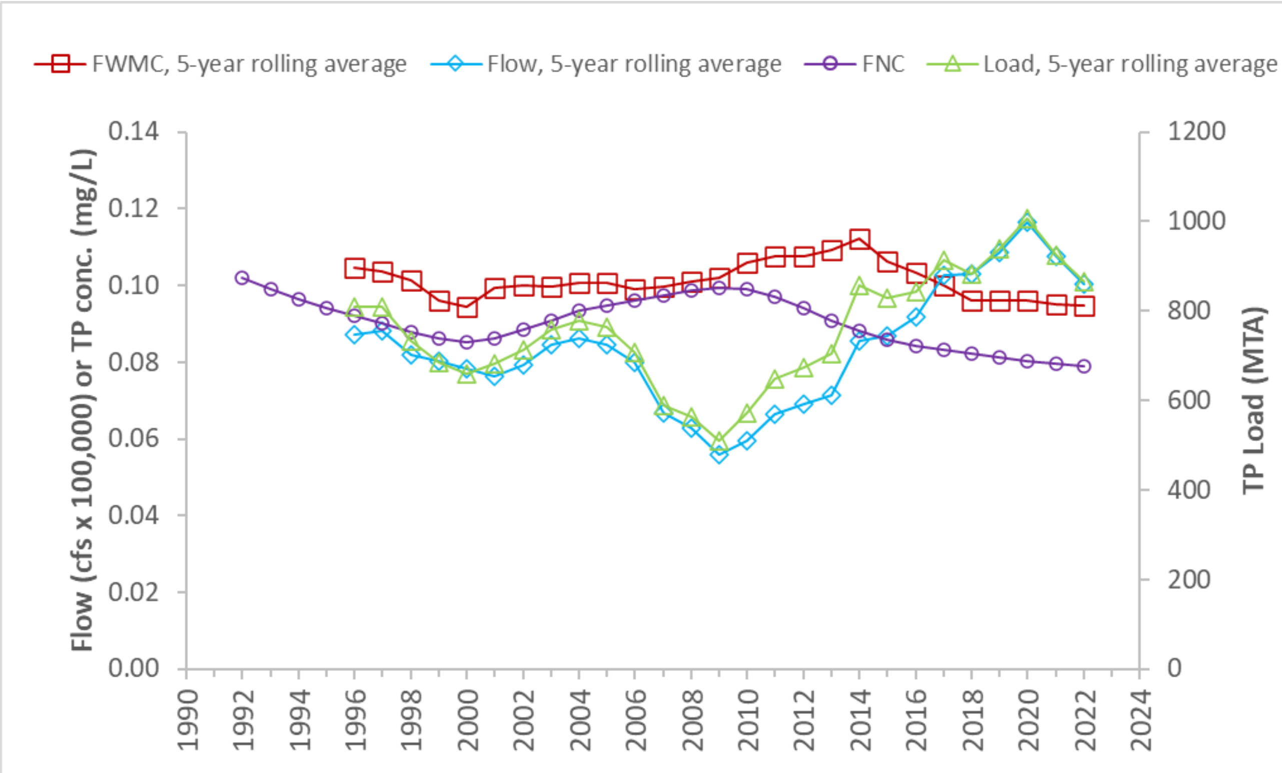


Figure 39. TP (top) and TN (bottom) load trends at the Cannon River at Welch, MN.

B.4 CHIPPEWA RIVER AT DURAND, WI



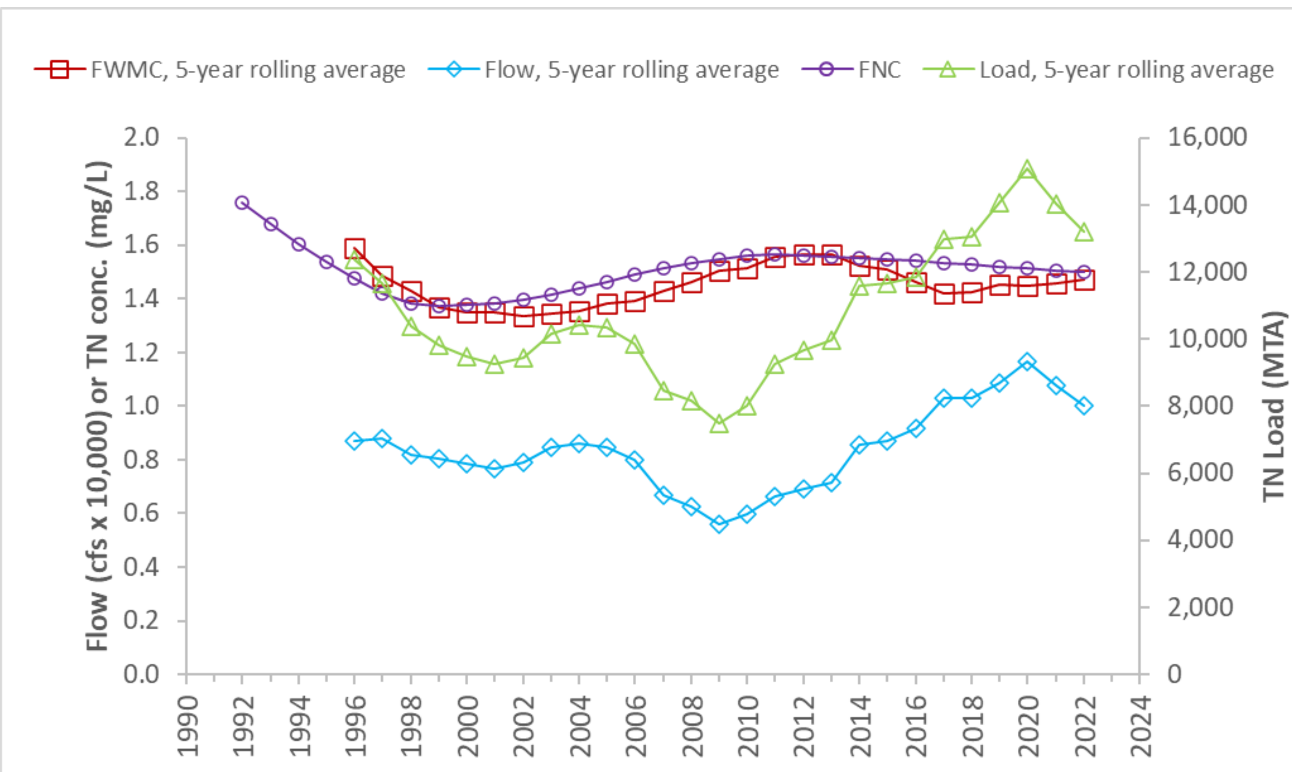


Figure 40. TP (top) and TN (bottom) 5-year rolling averages at the Chippewa River at Durand, WI.

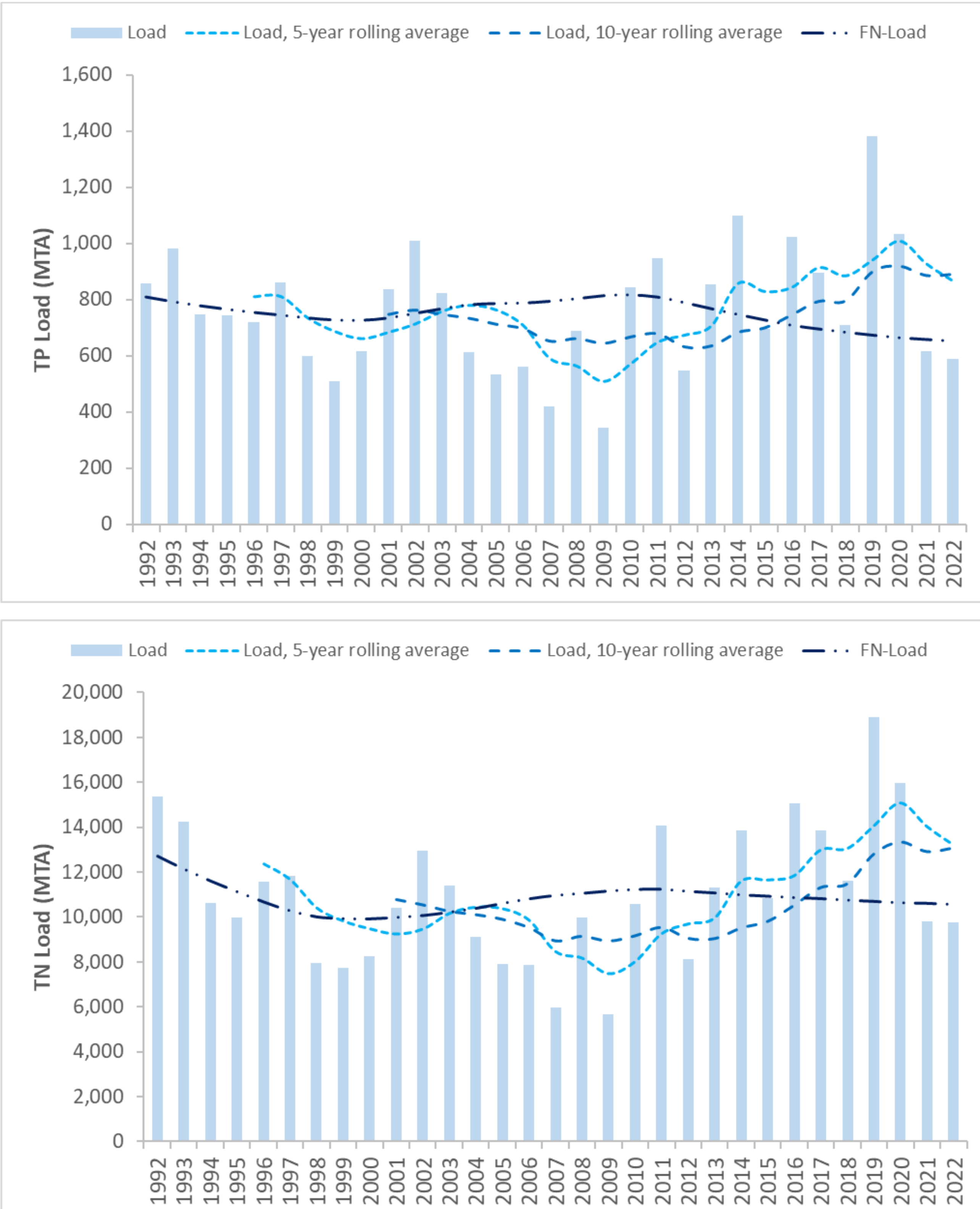
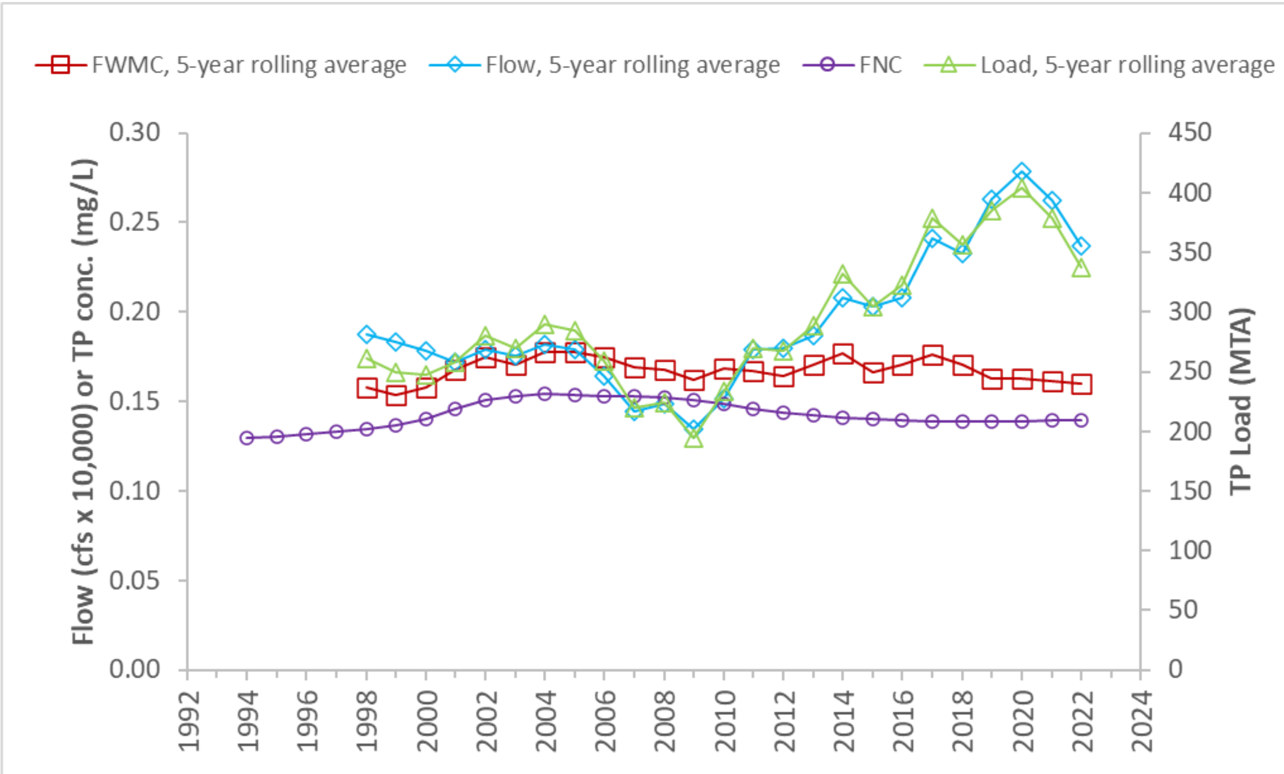


Figure 41. TP (top) and TN (bottom) load trends at the Chippewa River at Durand, WI.

B.5 BLACK RIVER NEAR GALESVILLE, WI



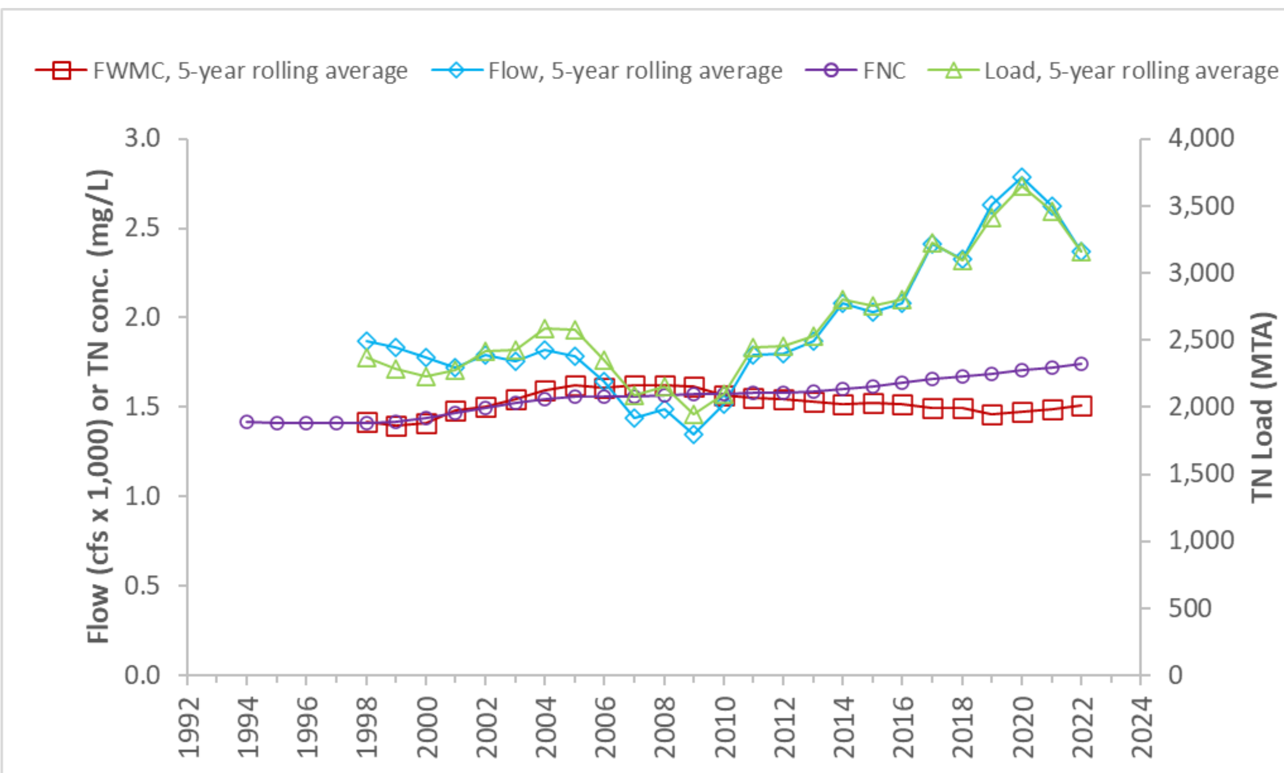
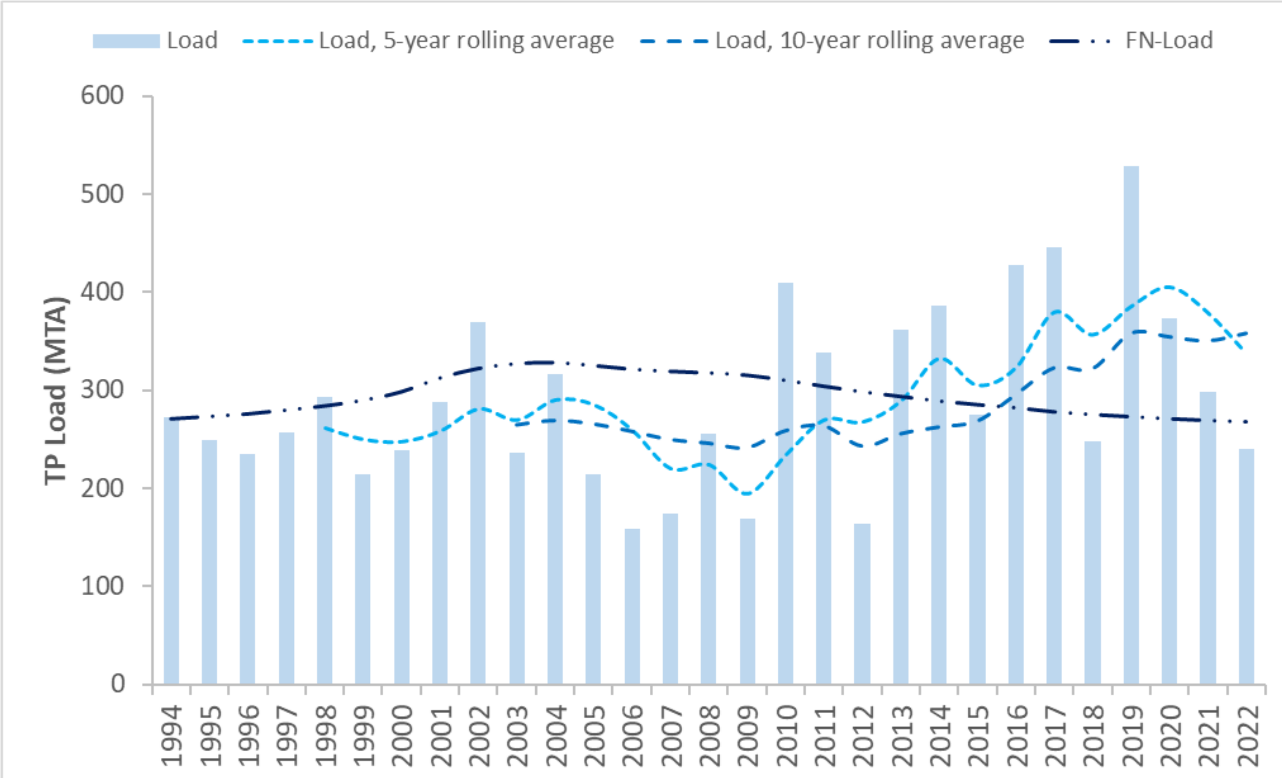


Figure 42. TP (top) and TN (bottom) 5-year rolling averages at the Black River near Galesville, WI.



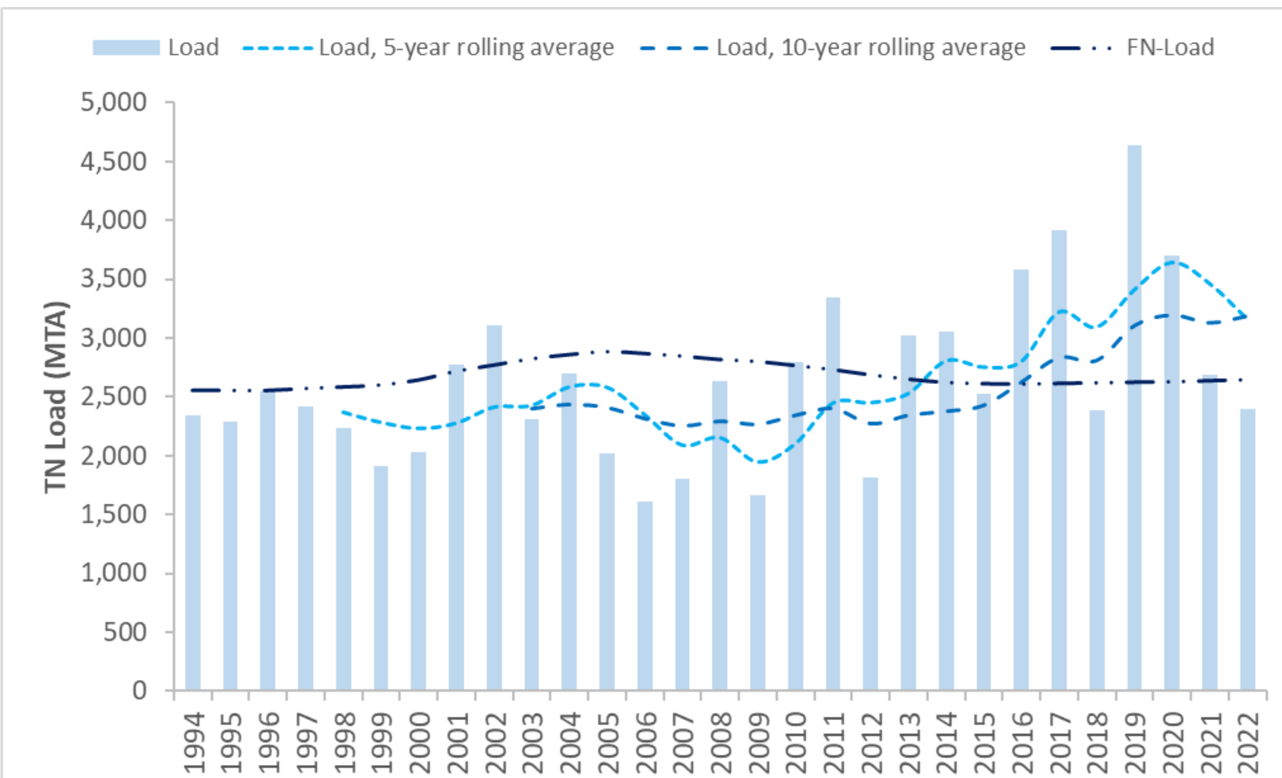
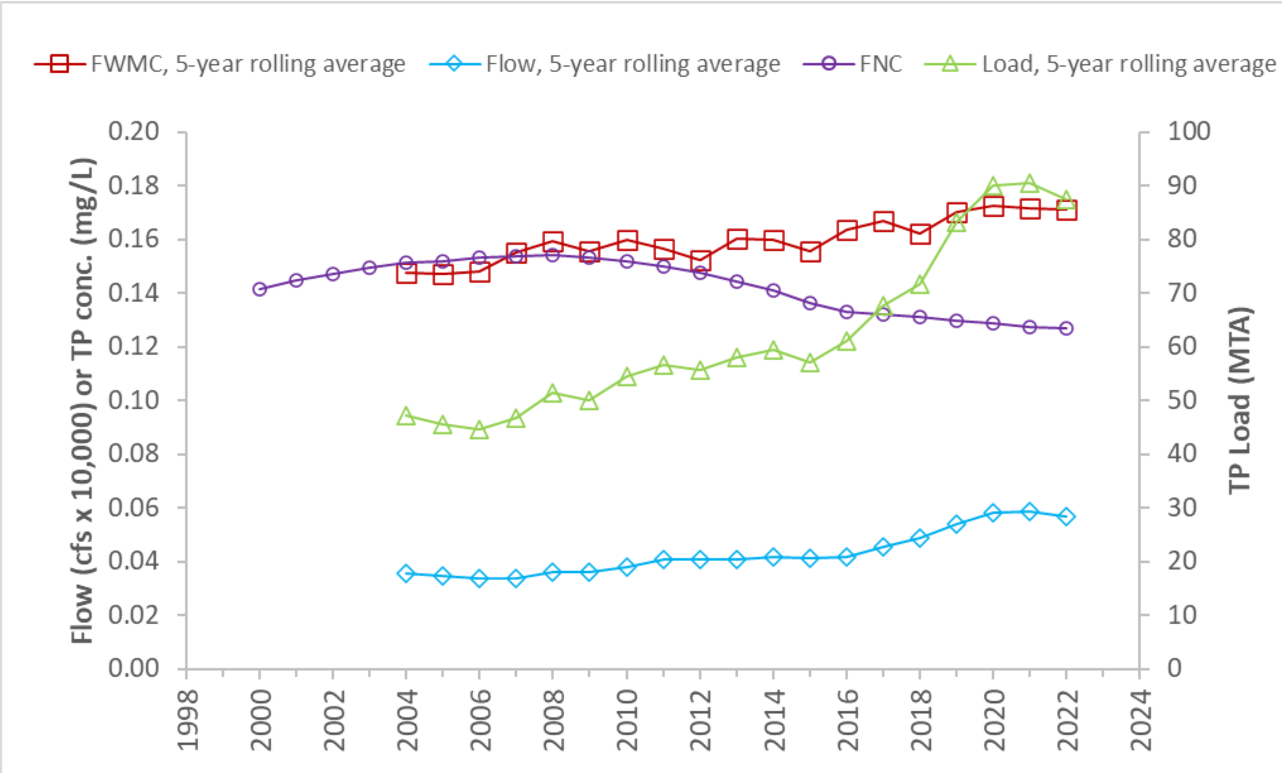


Figure 43. TP (top) and TN (bottom) load trends at the Black River near Galesville, WI.

B.6 LA CROSSE RIVER NEAR LA CROSSE, WI



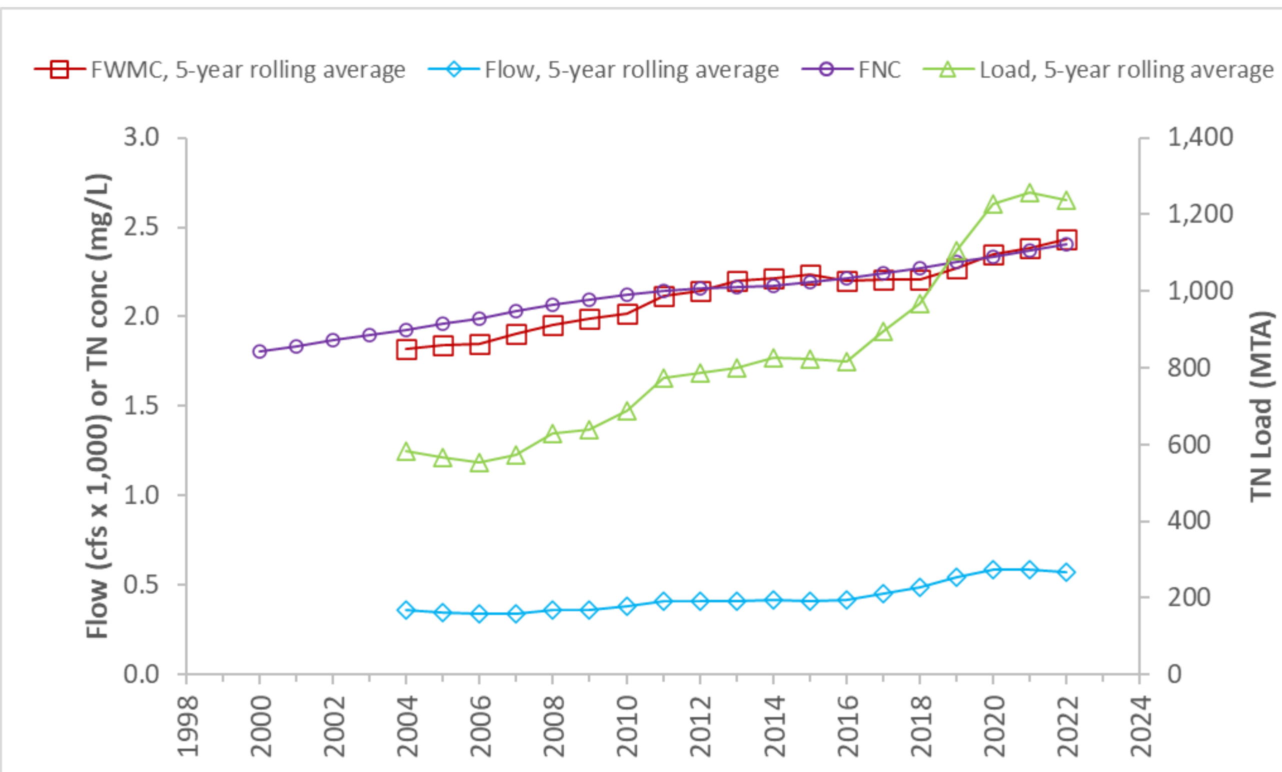


Figure 44. TP (top) and TN (bottom) 5-year rolling averages at the La Crosse River near La Crosse, WI.

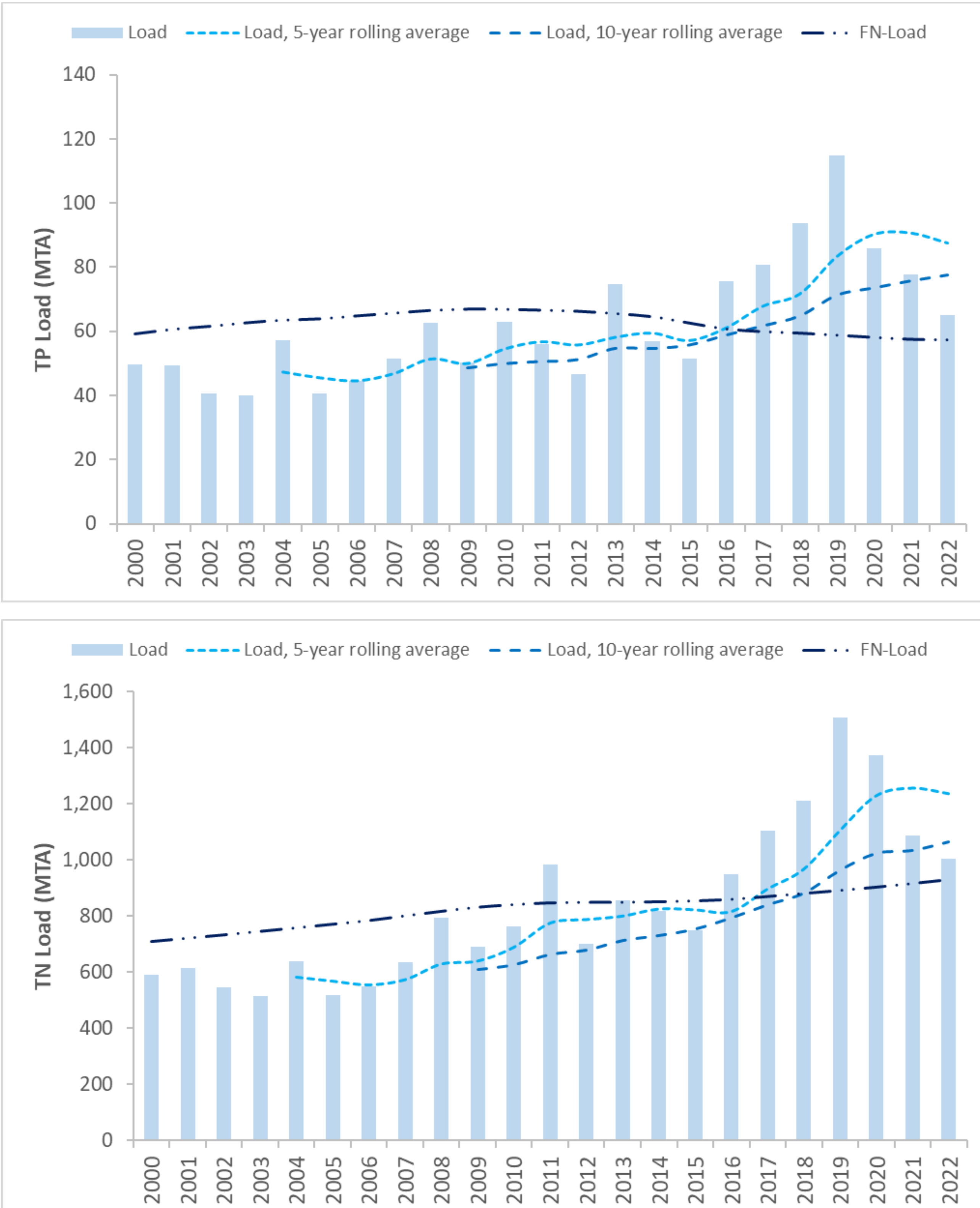
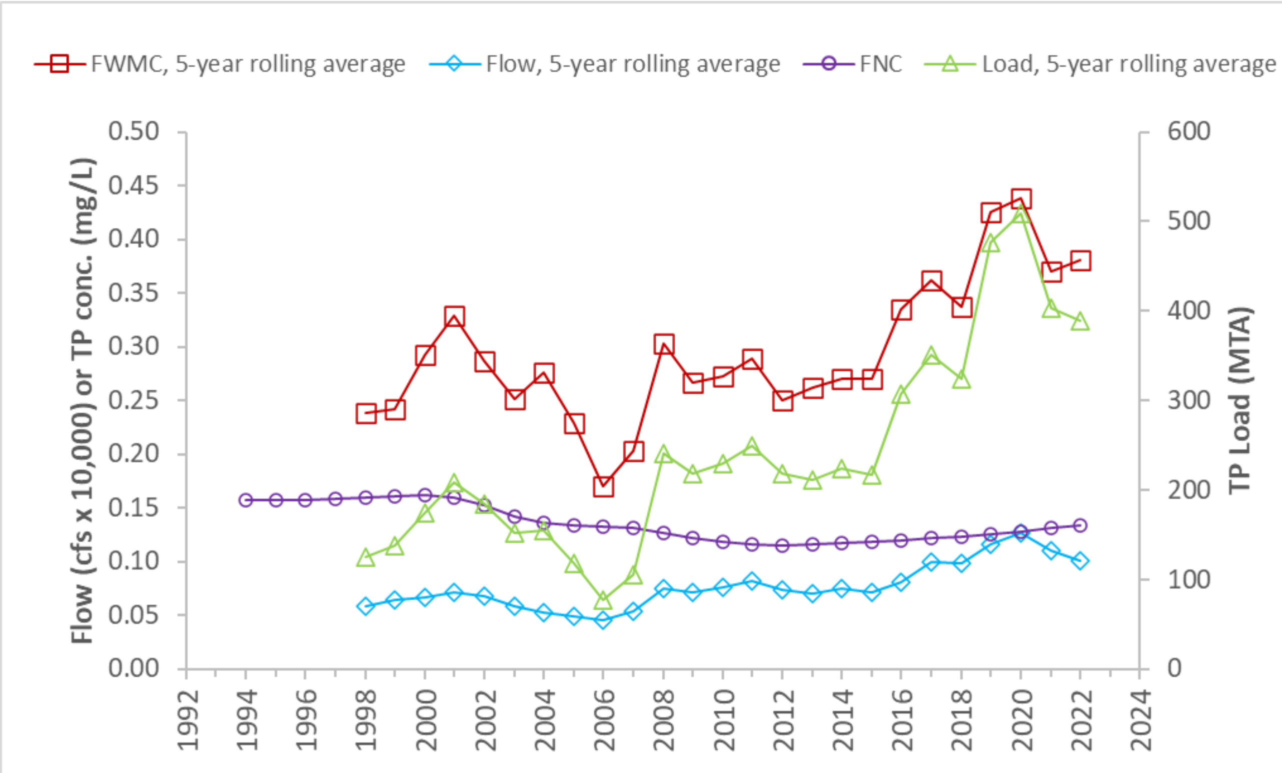


Figure 45. TP (top) and TN (bottom) load trends at the La Crosse River near La Crosse, WI.

B.7 UPPER IOWA RIVER NEAR DORCHESTER, IA



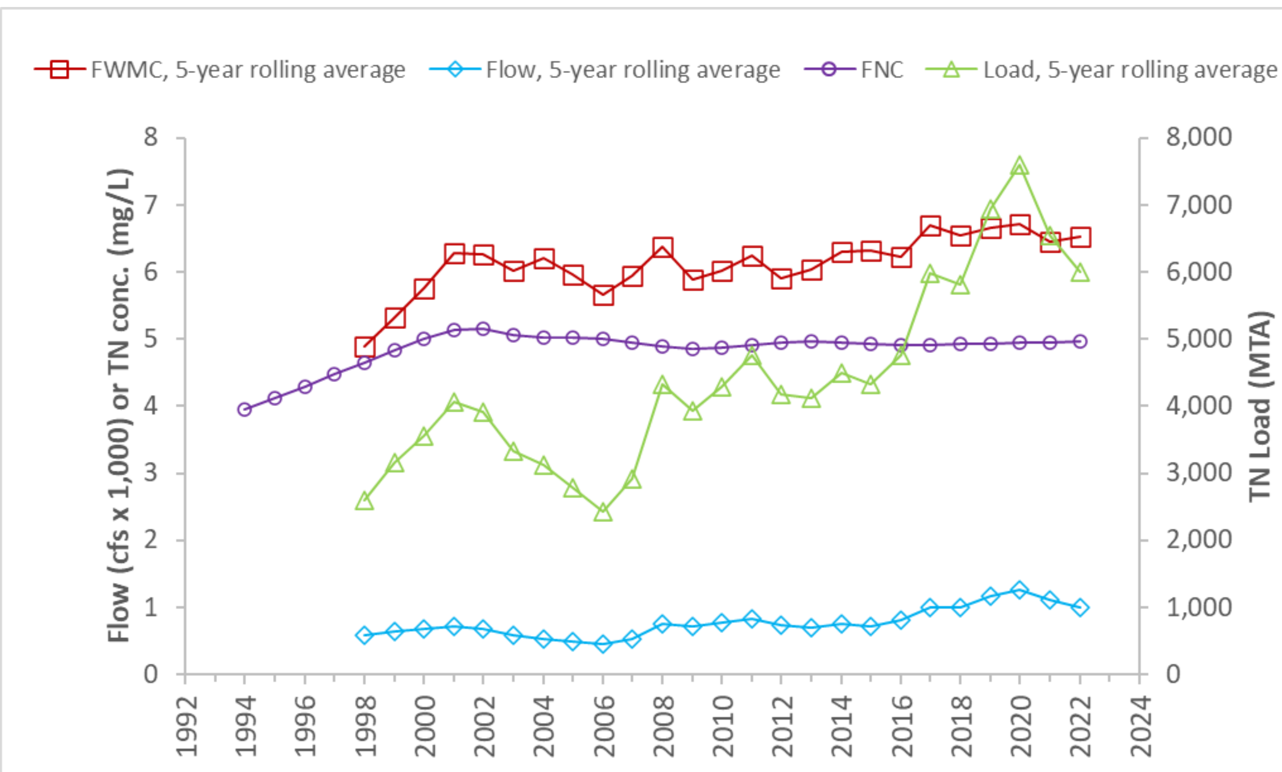
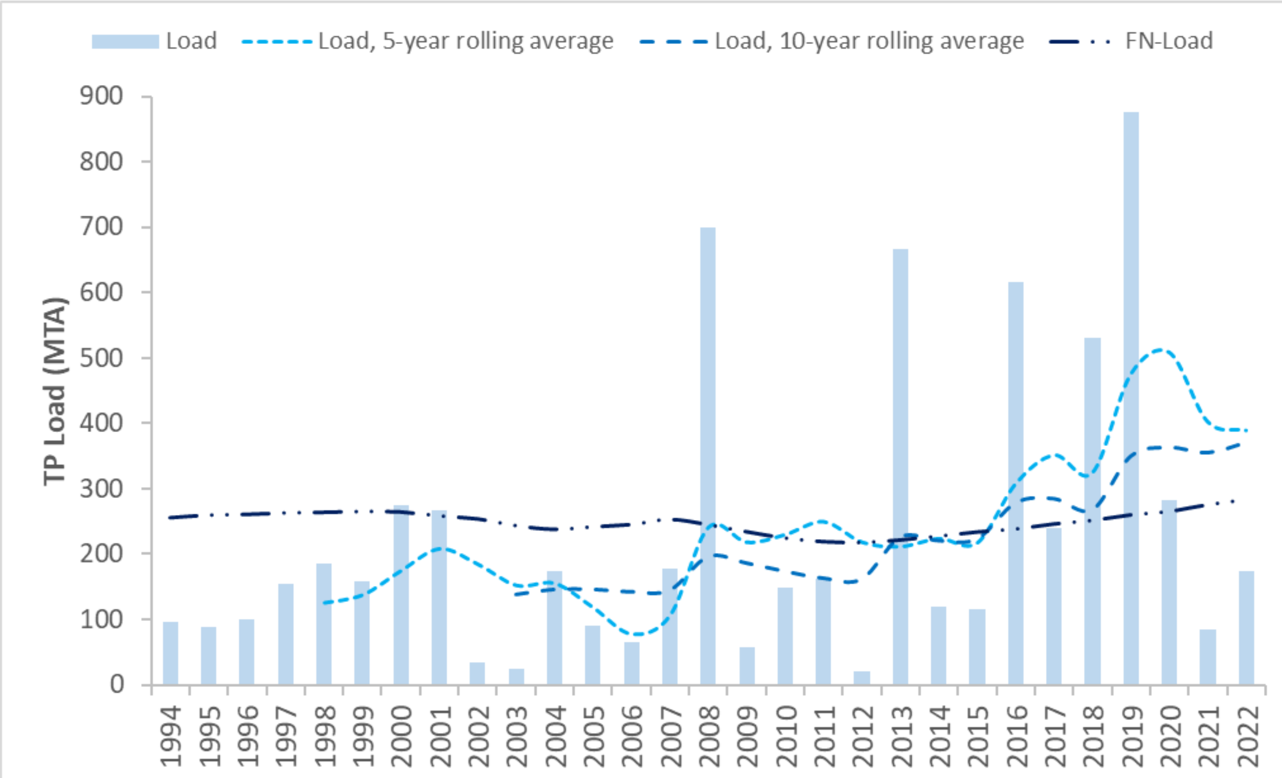


Figure 46. TP (top) and TN (bottom) 5-year rolling averages at the Upper Iowa River near Dorchester, IA.



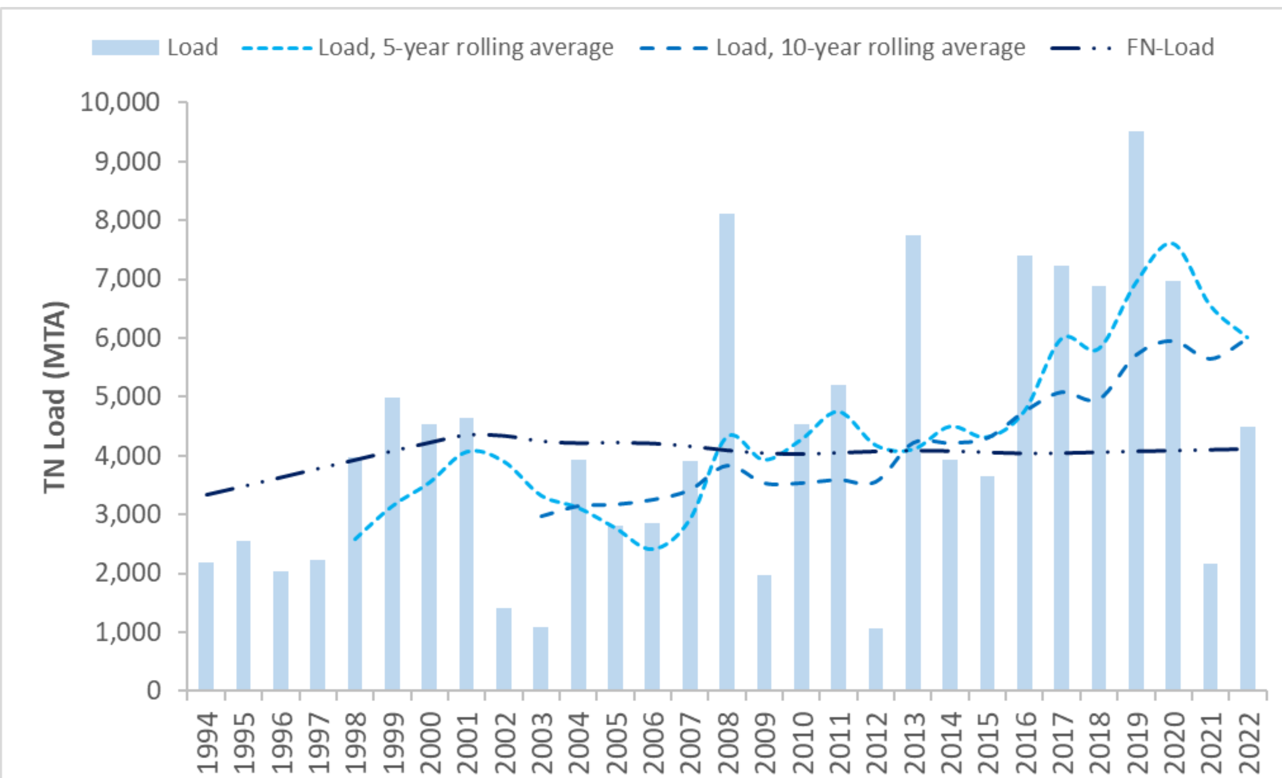


Figure 47. TP (top) and TN (bottom) load trends at the Upper Iowa River near Dorchester, IA.

B.8 CEDAR RIVER NEAR AUSTIN, MN

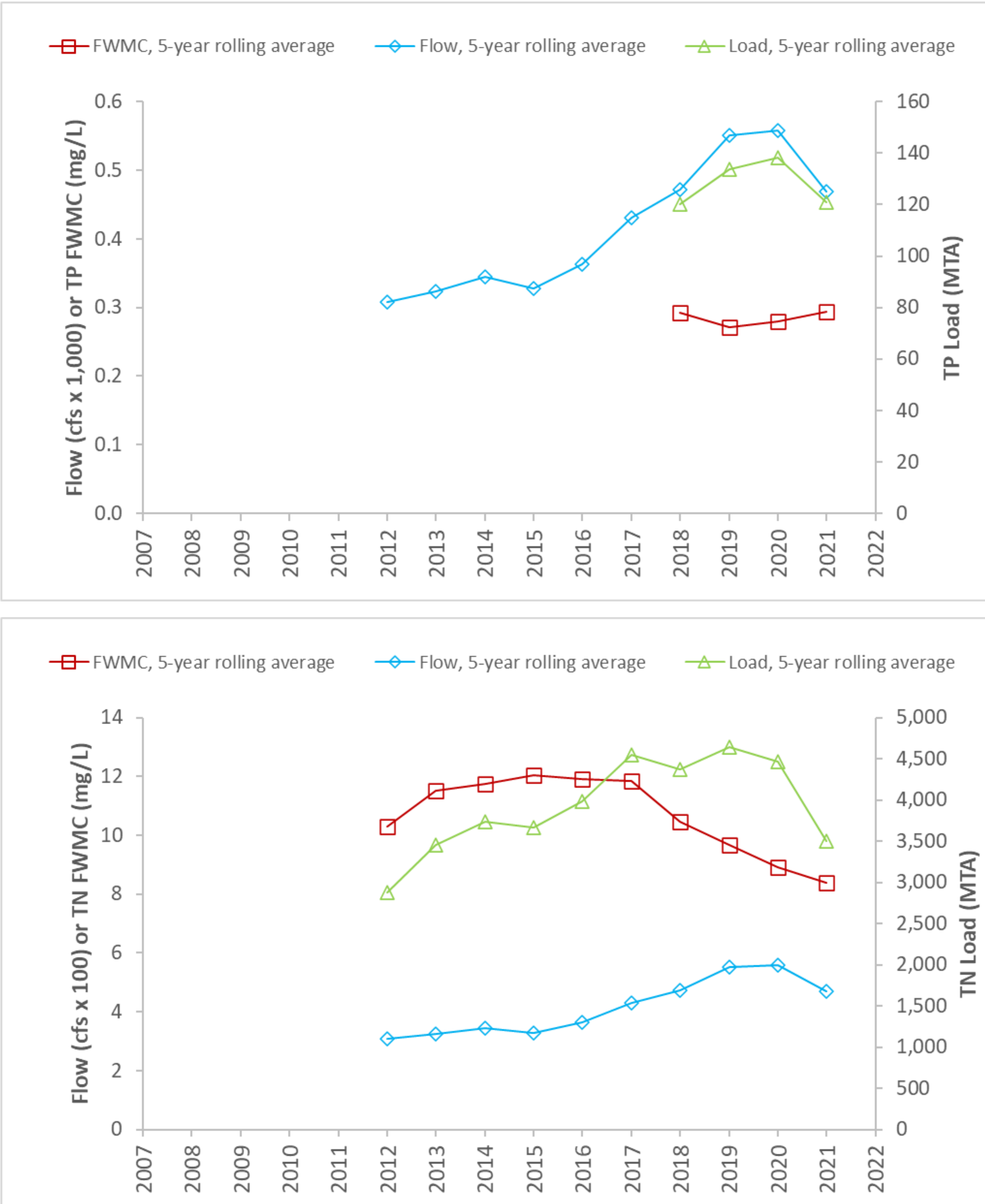


Figure 48. TP (top) and TN (bottom) 5-year rolling averages at the Cedar River near Austin, MN.

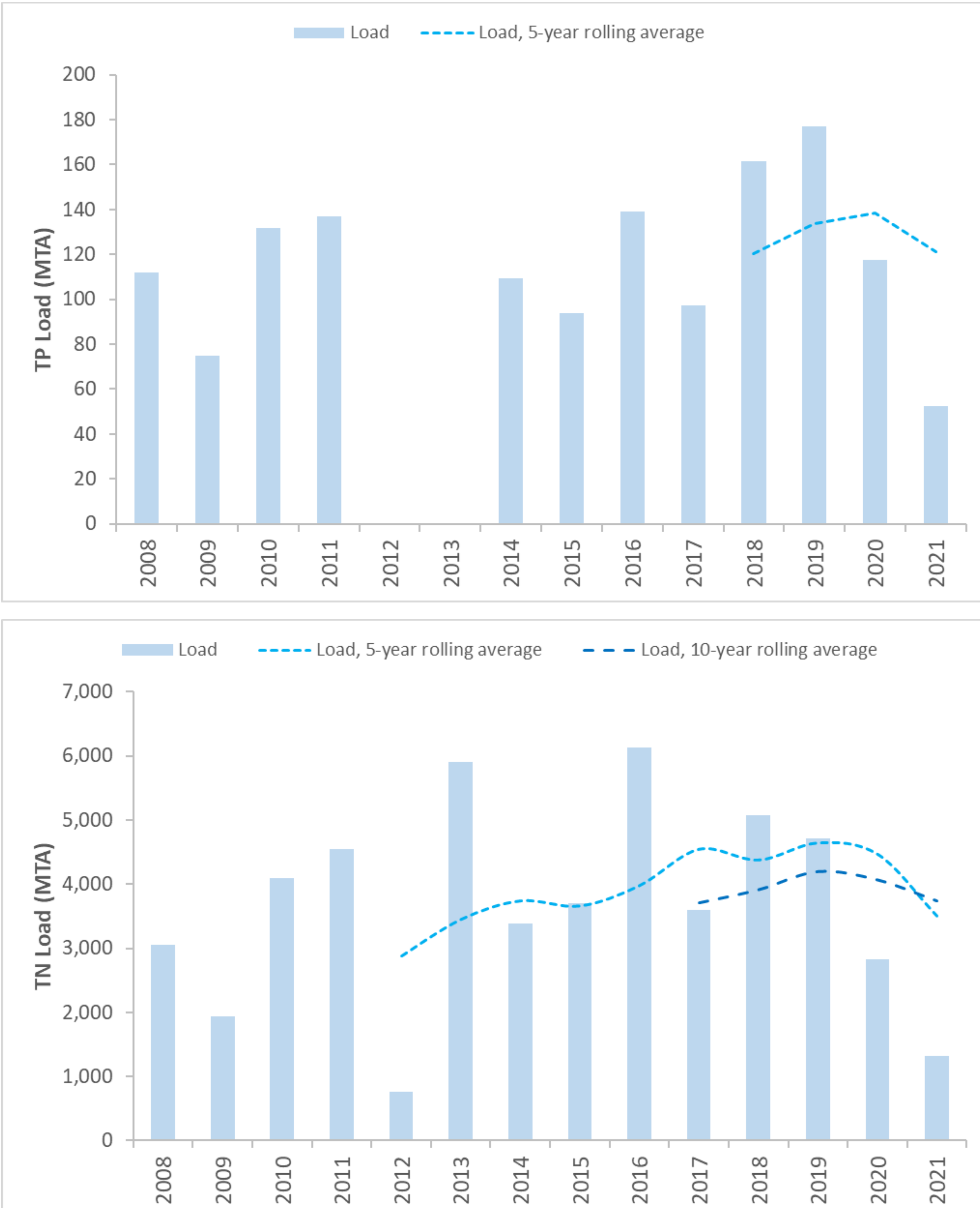


Figure 49. TP (top) and TN (bottom) load trends at the Cedar River near Austin, MN.

B.9 WEST FORK DES MOINES RIVER AT JACKSON, MN

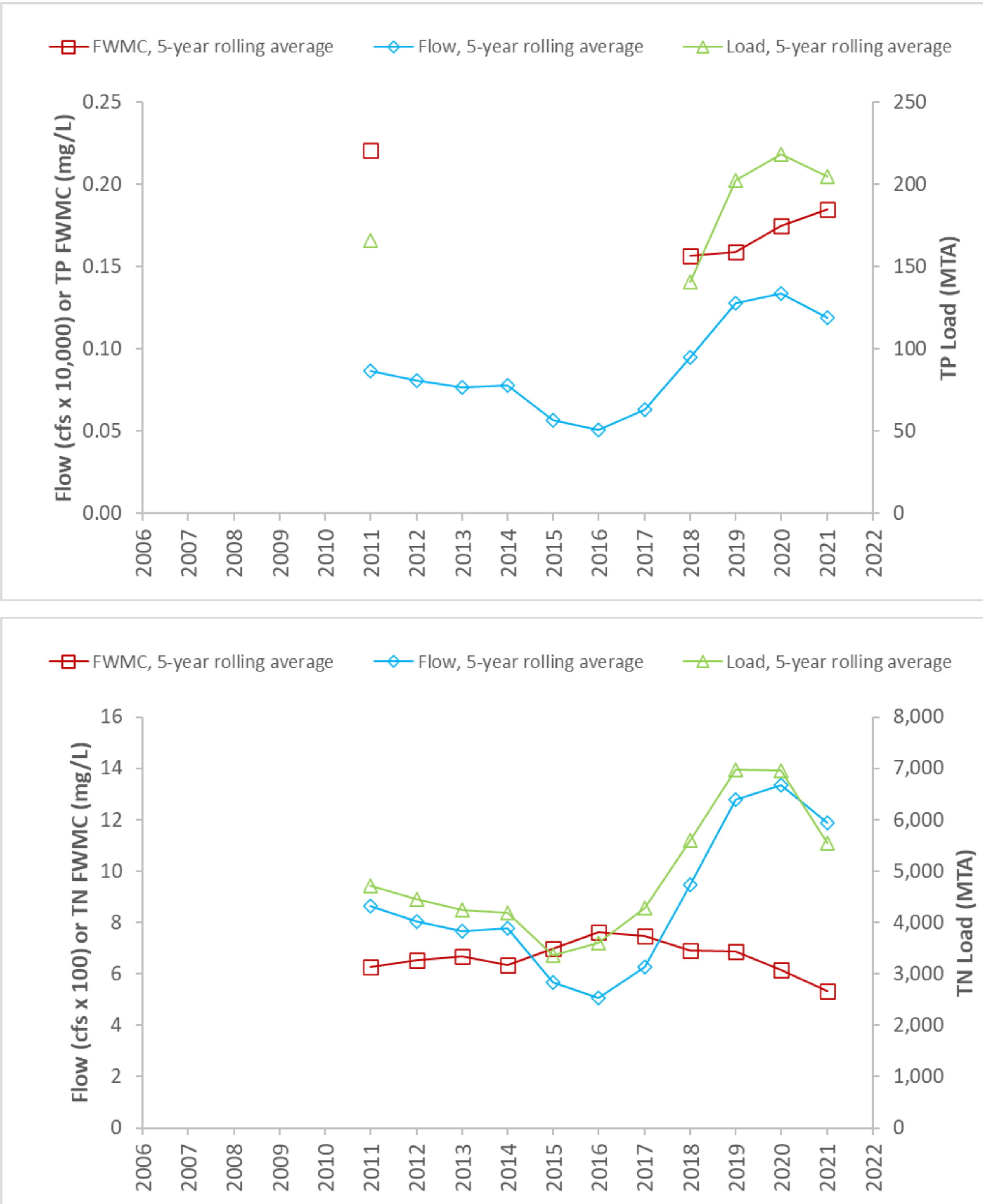


Figure 50. TP (top) and TN (bottom) 5-year rolling averages at the West Fork Des Moines River at Jackson, MN.

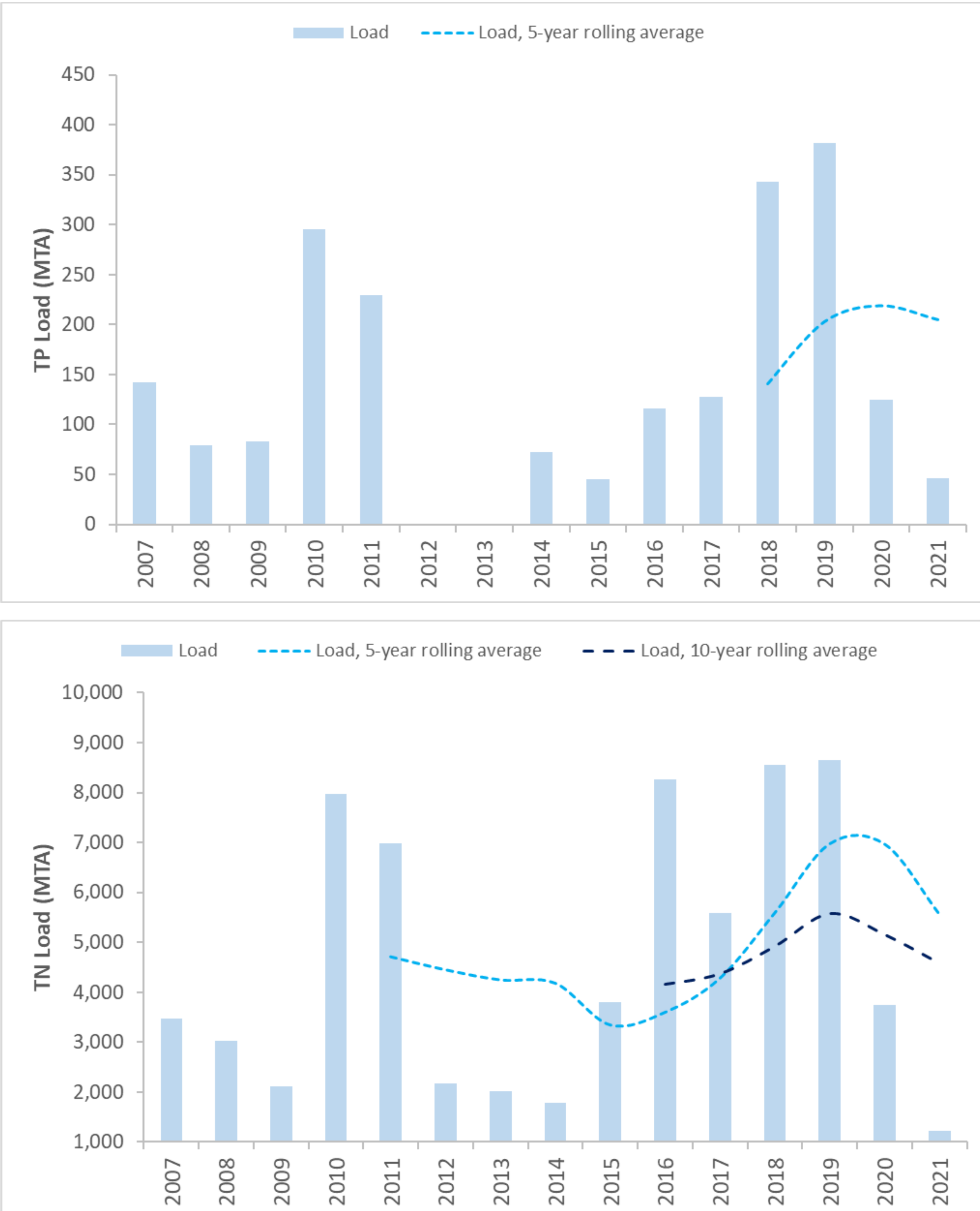
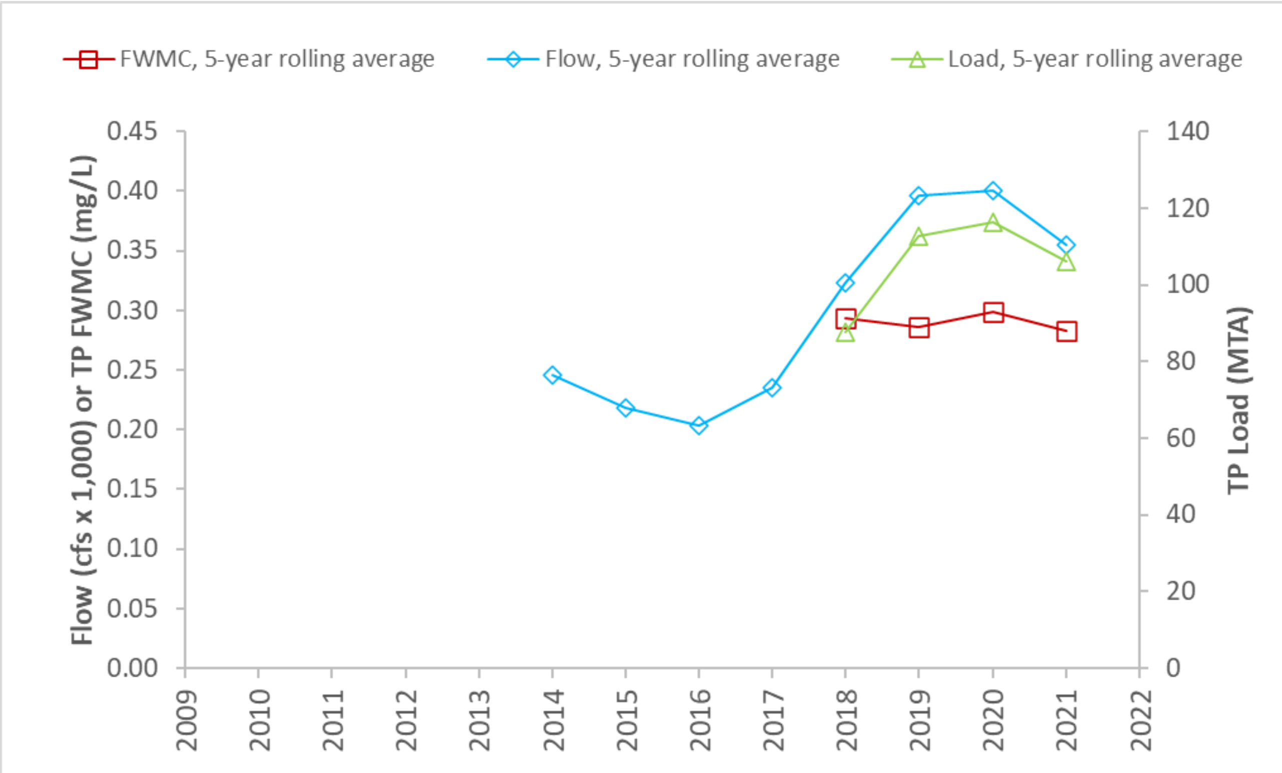


Figure 51. TP (top) and TN (bottom) load trends at the West Fork Des Moines River at Jackson, MN.

B.10 ROCK RIVER AT LUVERNE, MN



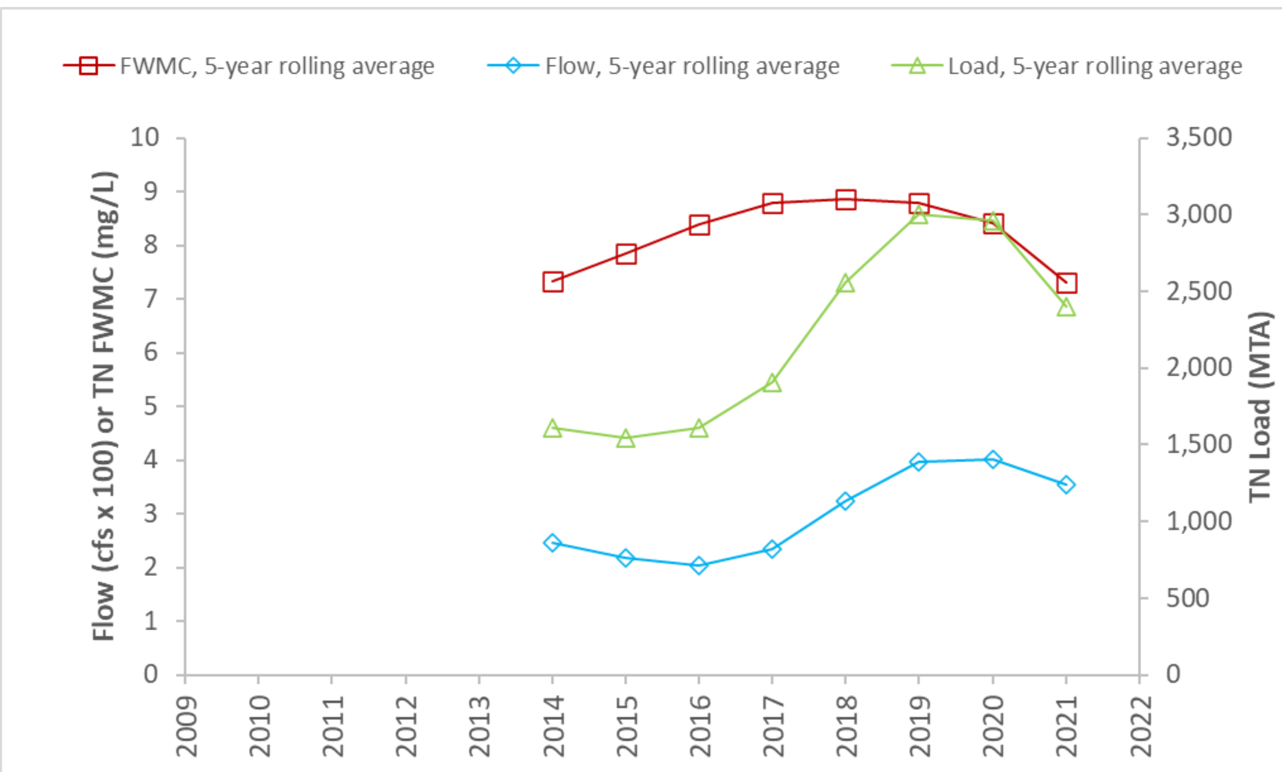


Figure 52. TP (top) and TN (bottom) 5-year rolling averages at the Rock River at Luverne, MN.

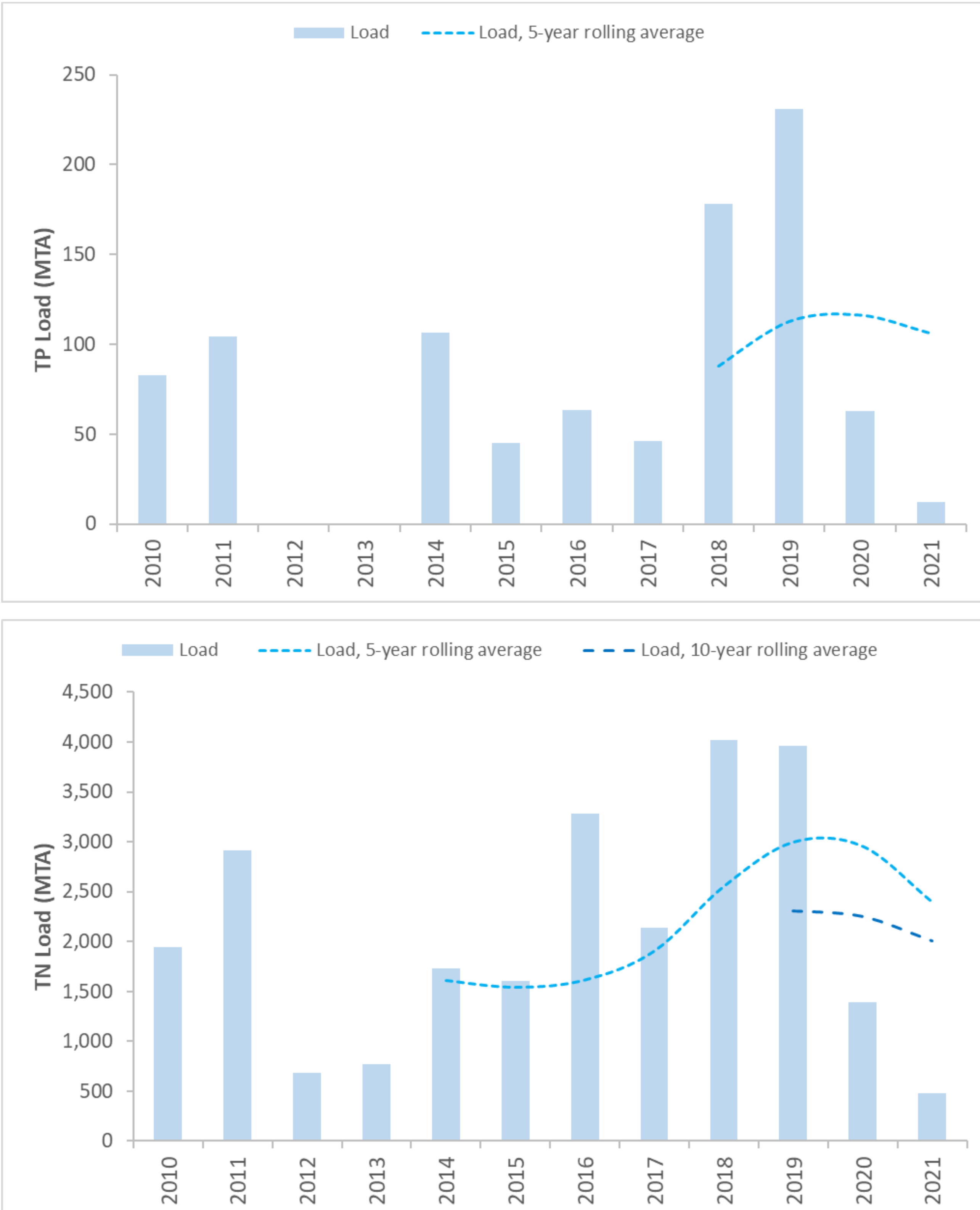
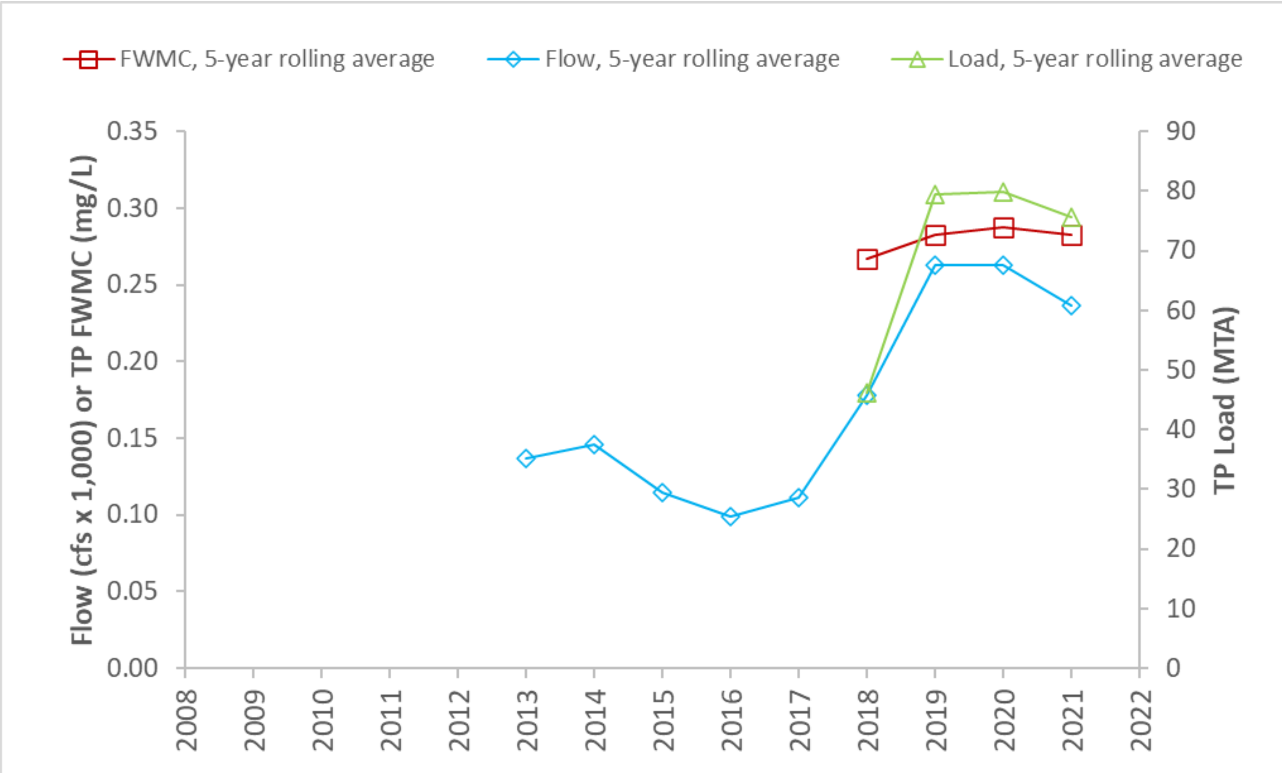


Figure 53. TP (top) and TN (bottom) load trends at the Rock River at Luverne, MN.

B.11 SPLIT ROCK CREEK NEAR JASPER, MN



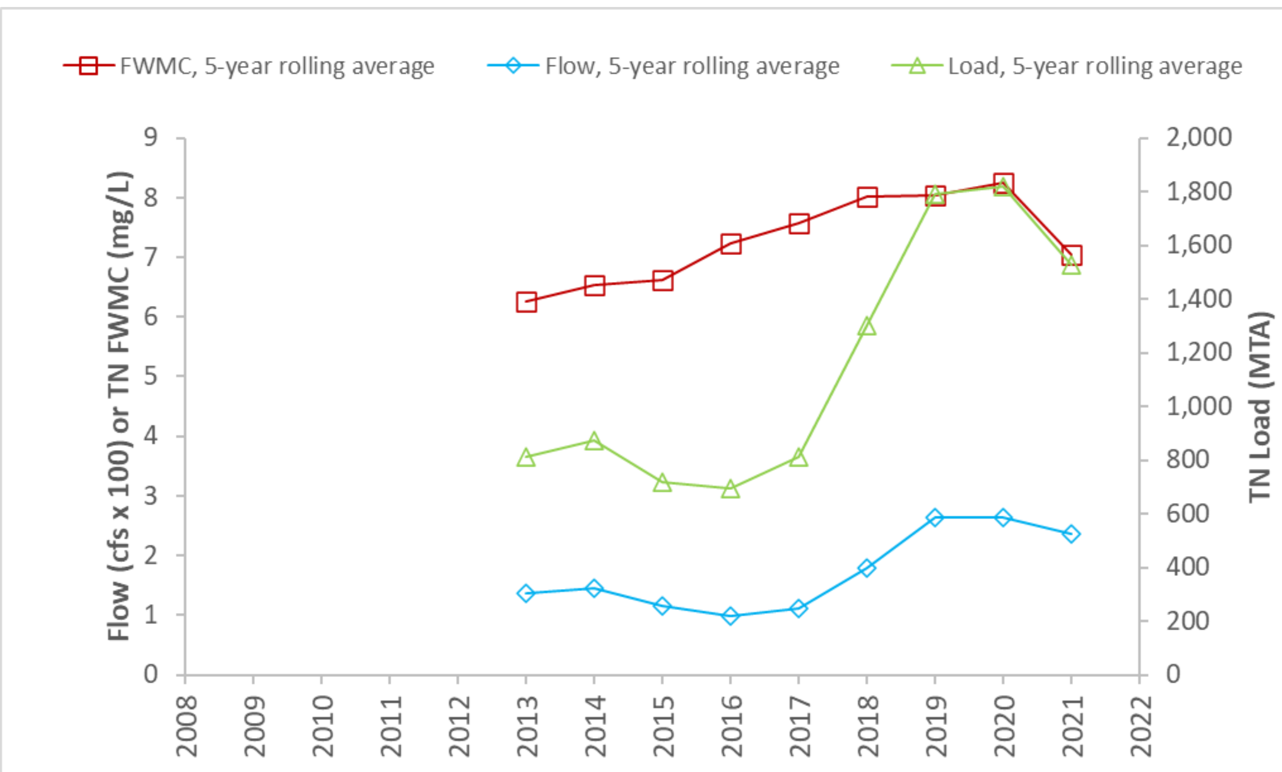


Figure 54. TP (top) and TN (bottom) 5-year rolling averages at Split Rock Creek near Jasper, MN.

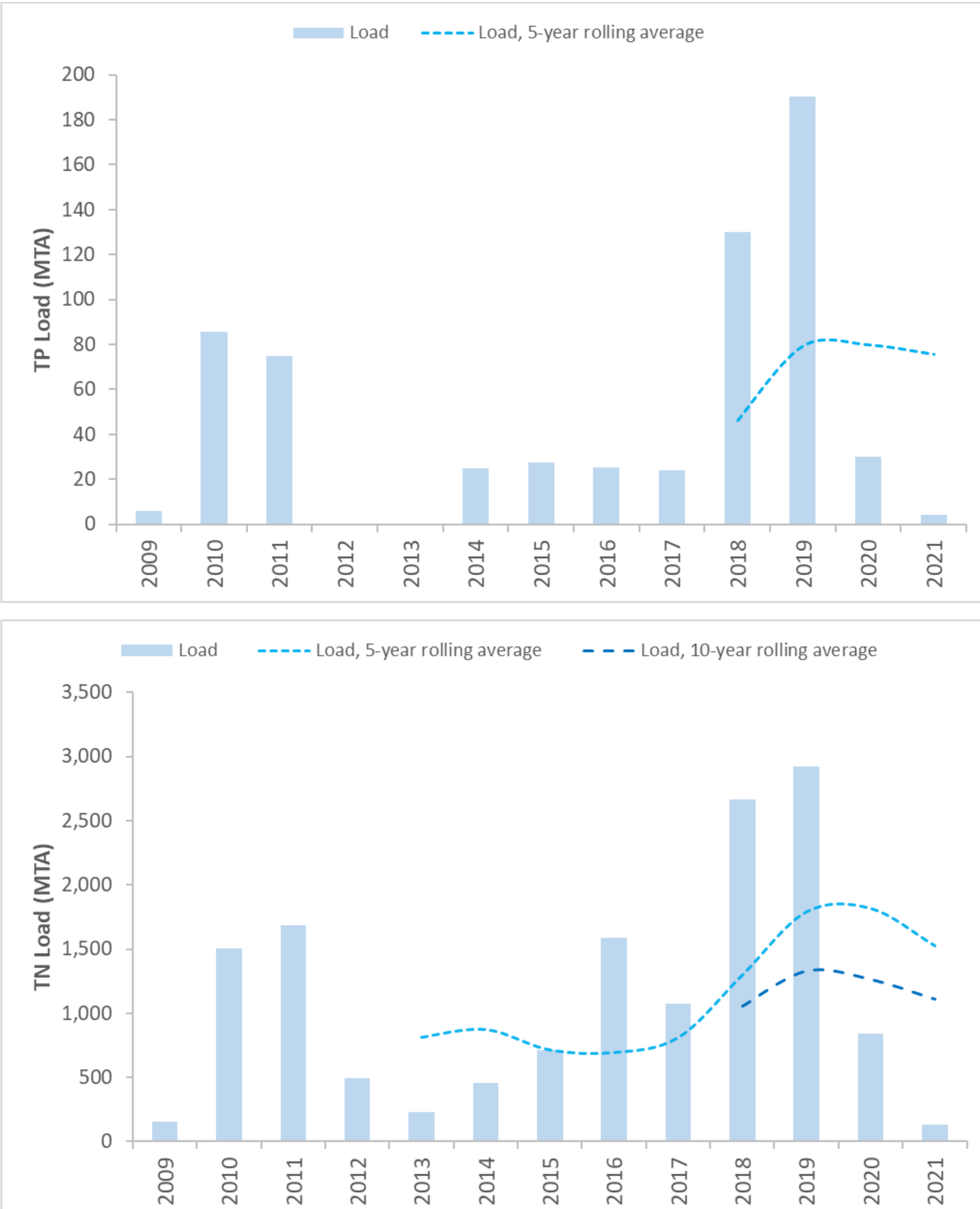
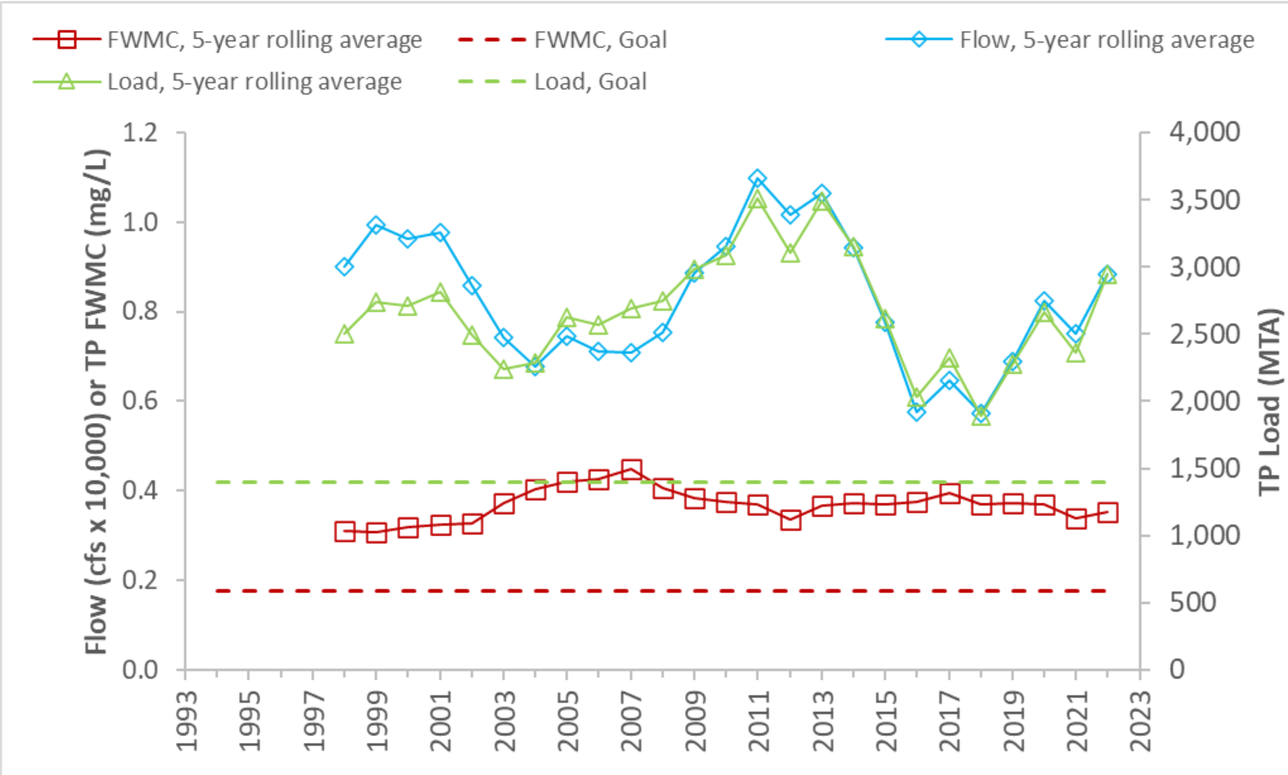


Figure 55. TP (top) and TN (bottom) load trends at Split Rock Creek near Jasper, MN.

APPENDIX C. TREND CHARTS FOR THE LAKE WINNIPEG MAJOR BASIN

C.1 RED RIVER OF THE NORTH AT EMERSON, MANITOBA, CANADA



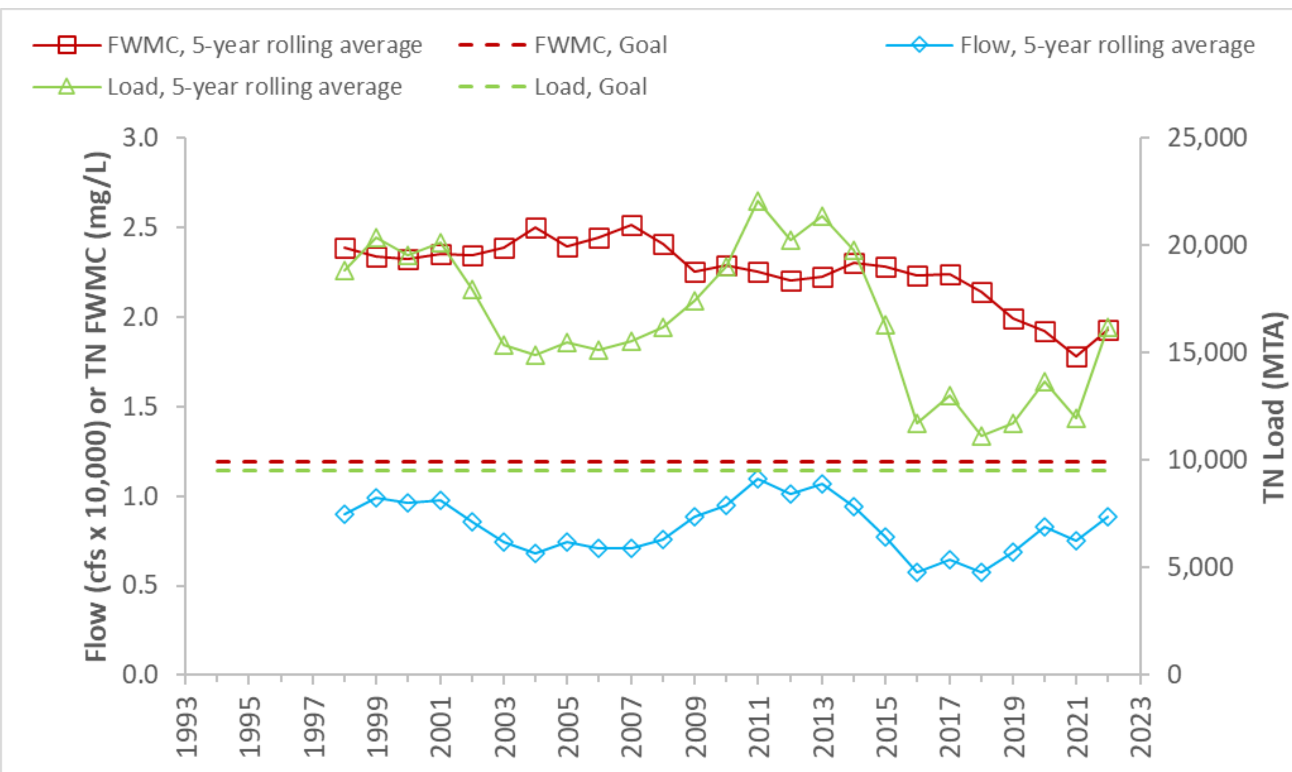
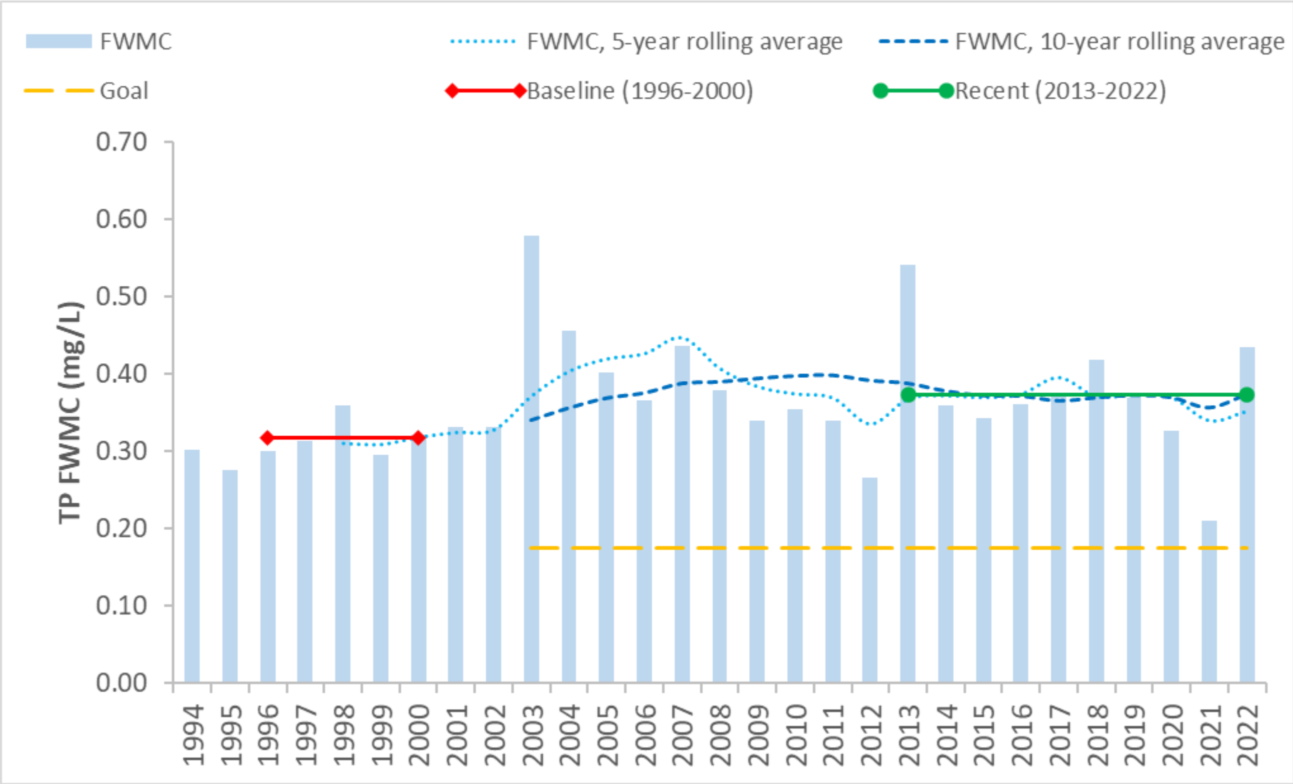


Figure 56. TP (top) and TN (bottom) 5-year rolling averages at the Red River of the North at Emerson.



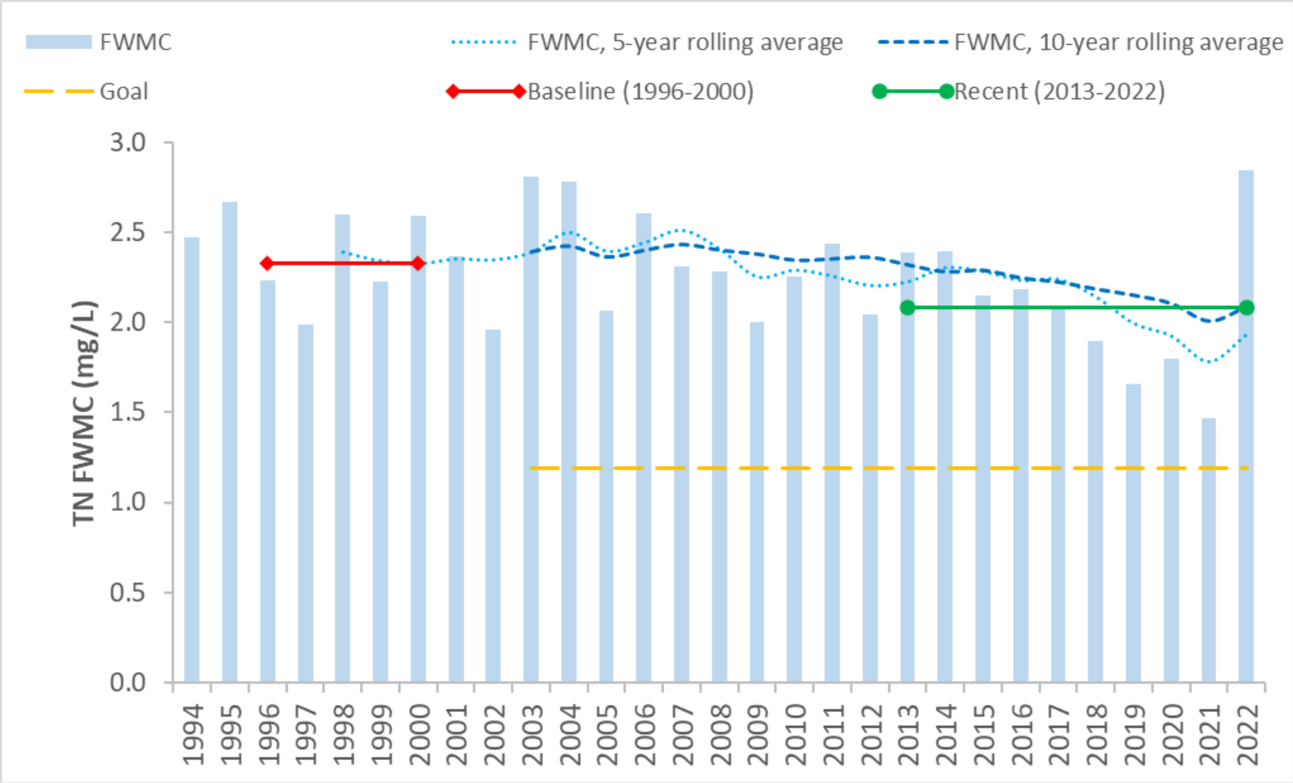


Figure 57. TP (top) and TN (bottom) FWMC trends and goal for the Red River of the North at Emerson.

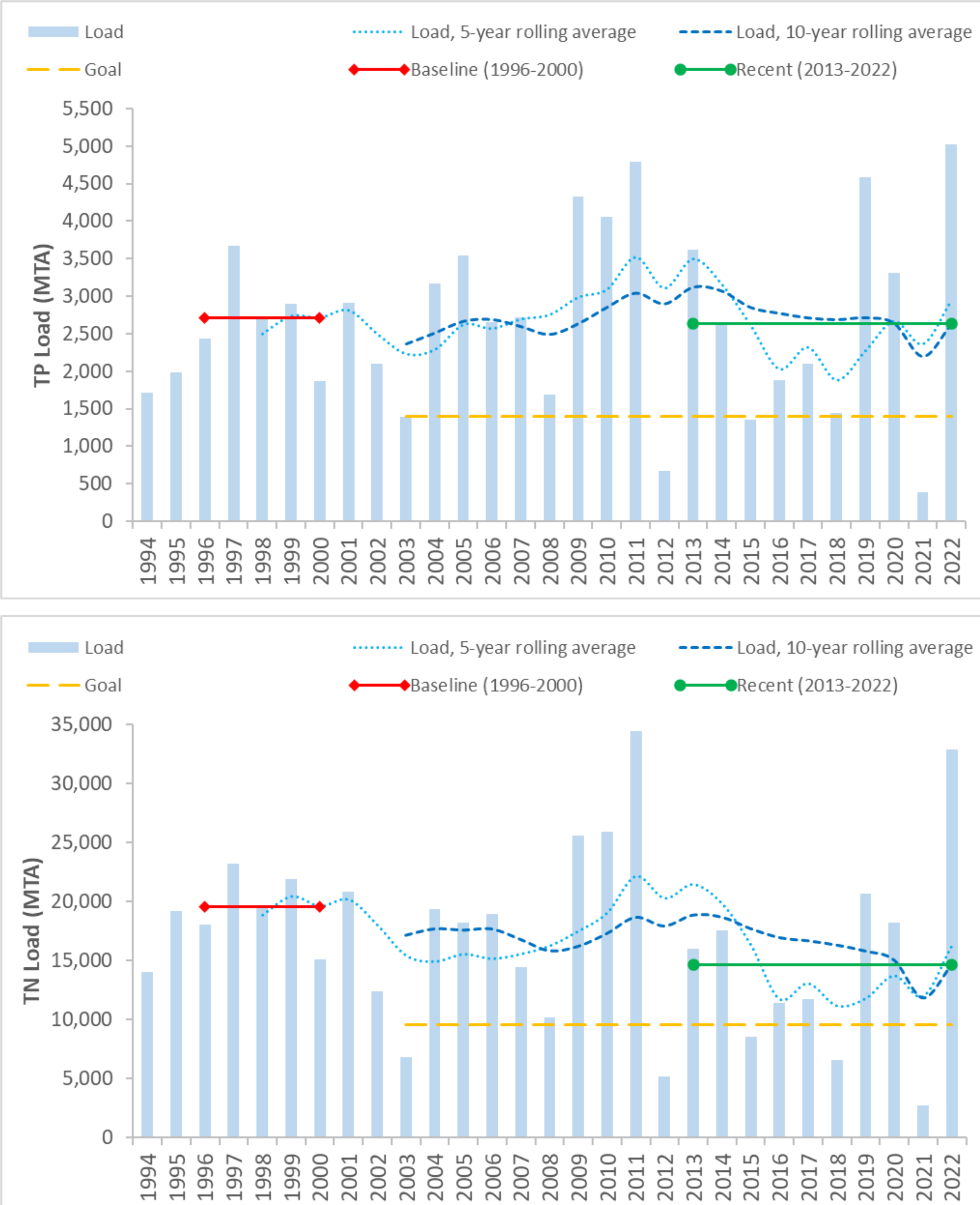


Figure 58. TP (top) and TN (bottom) load trends and goal for the Red River of the North at Emerson.

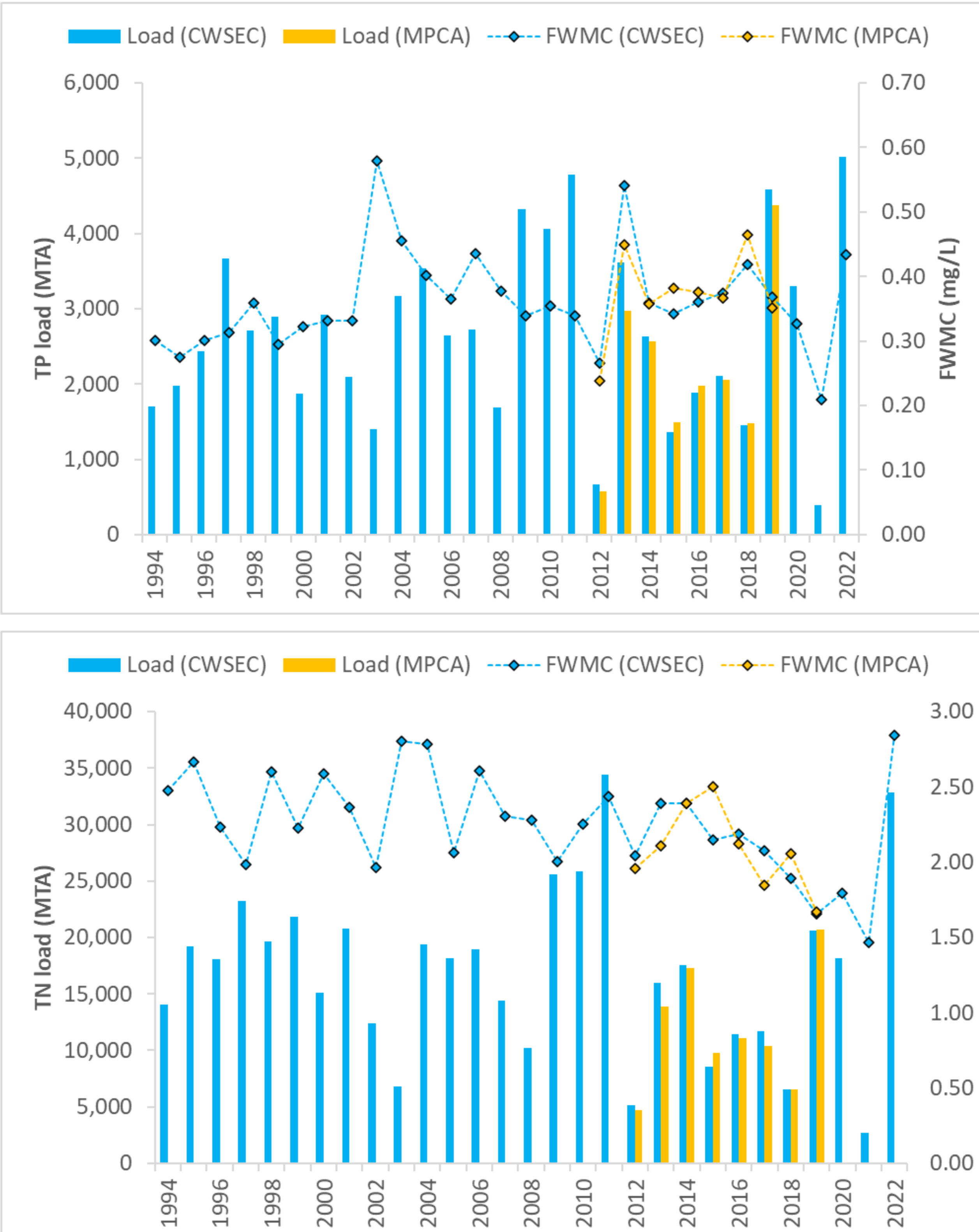
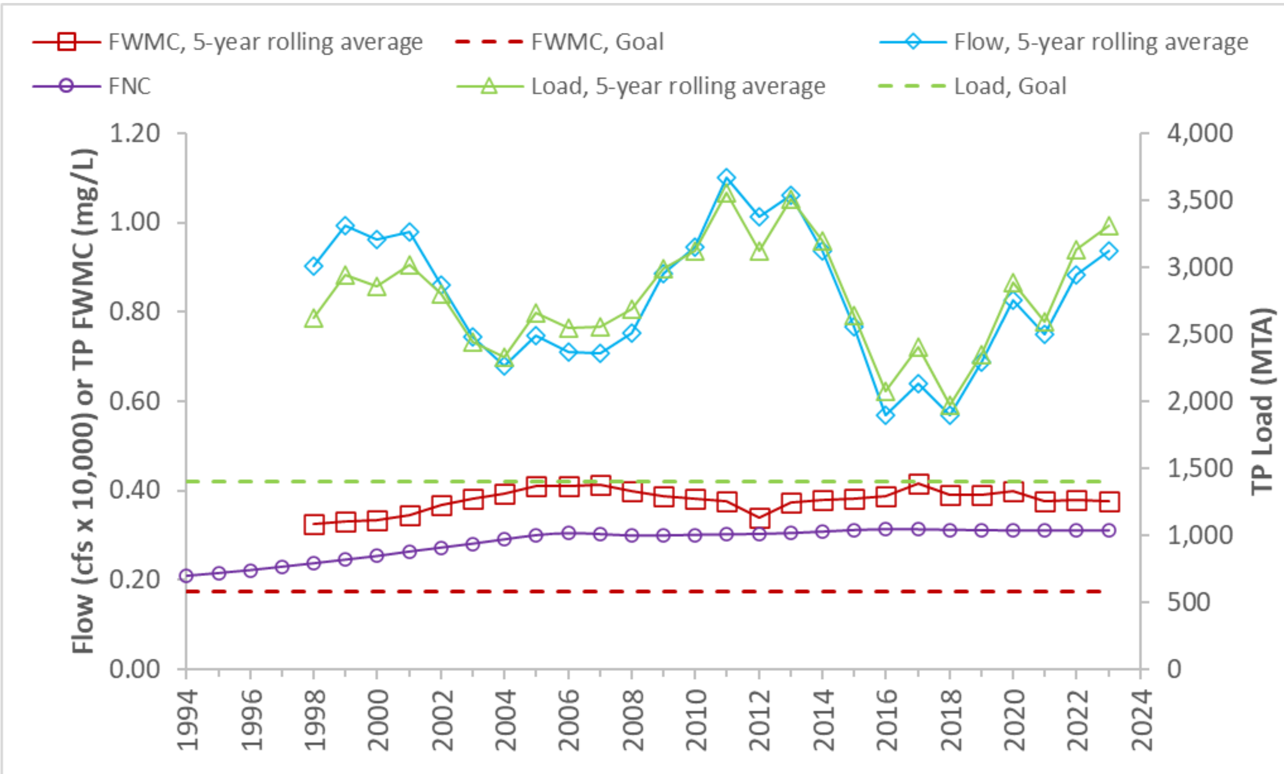


Figure 59. Comparison of TP (top) and TN (bottom) load and FWMC for the CWSEC's and MPCA's monitoring sites on the Red River of the North at Emerson.

C.2 RED RIVER OF THE NORTH AT EMERSON, MANITOBA, CANADA – WRTDS



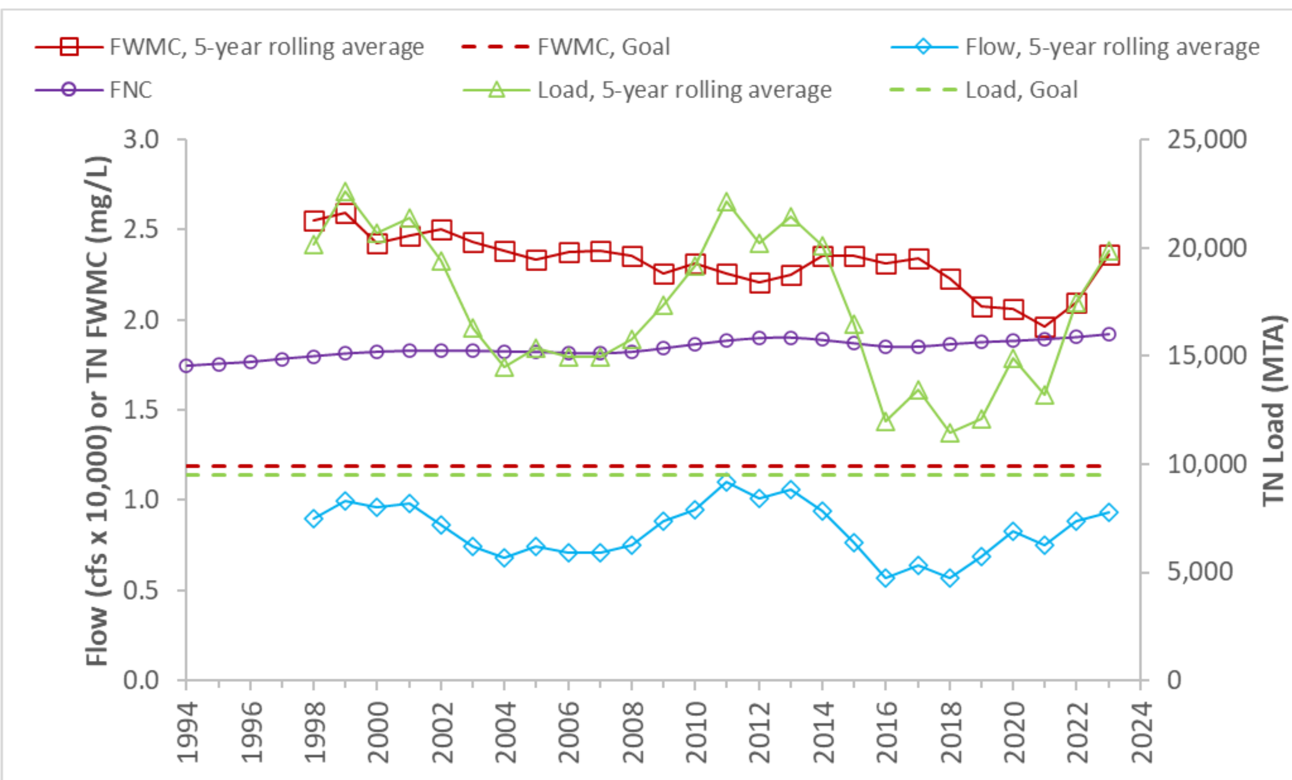
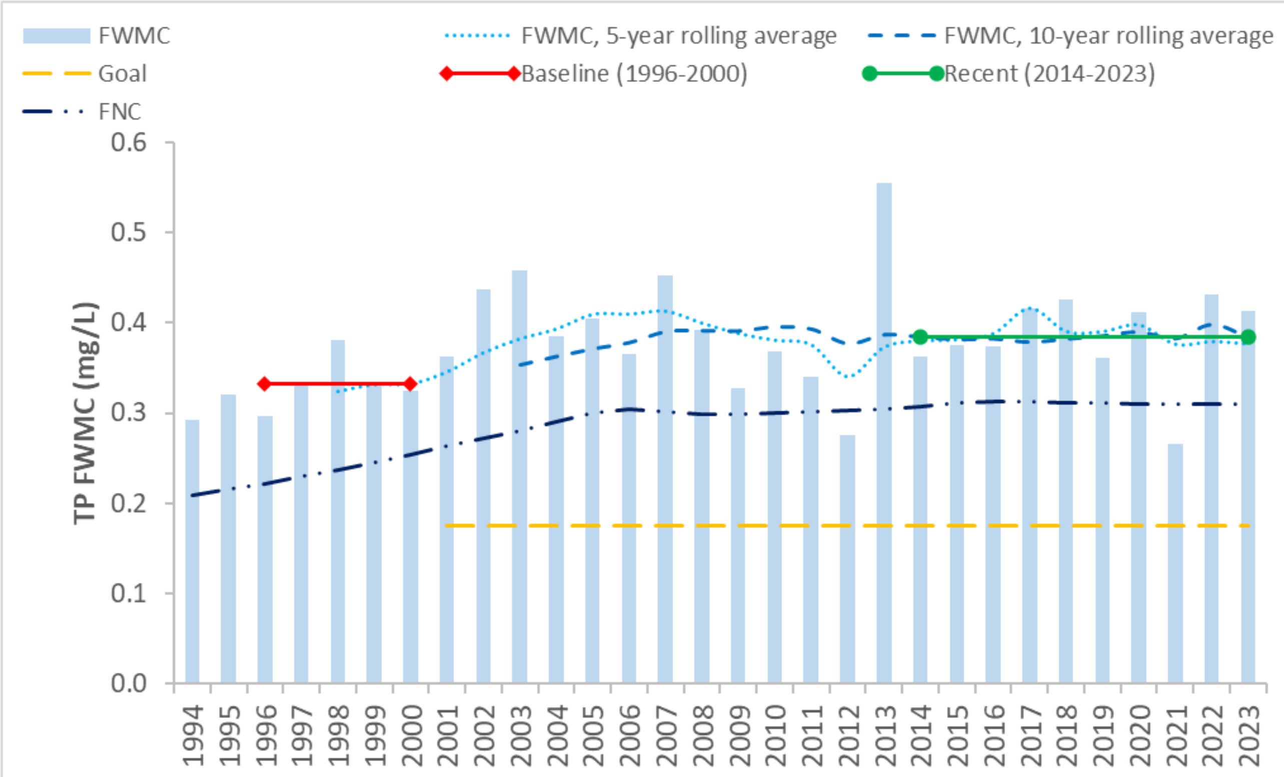


Figure 60. TP (top) and TN (bottom) 5-year rolling averages at the Red River of the North at Emerson.



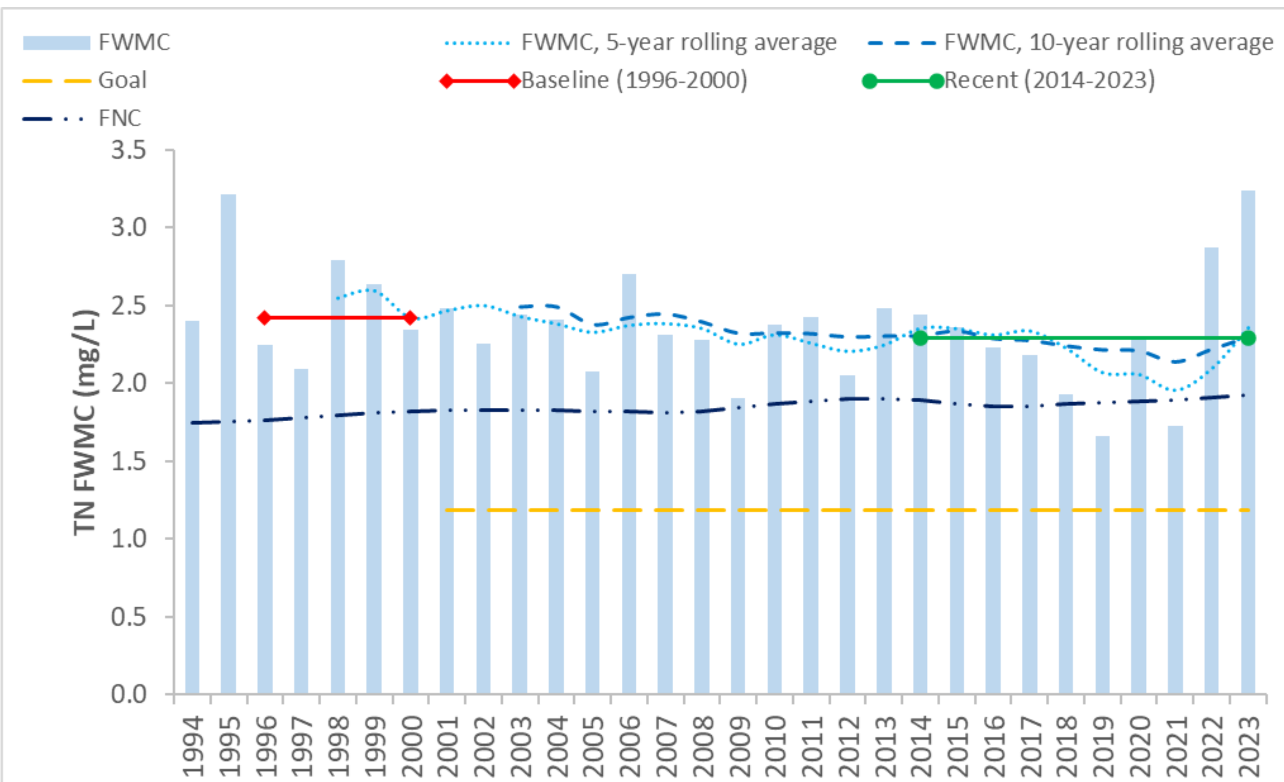
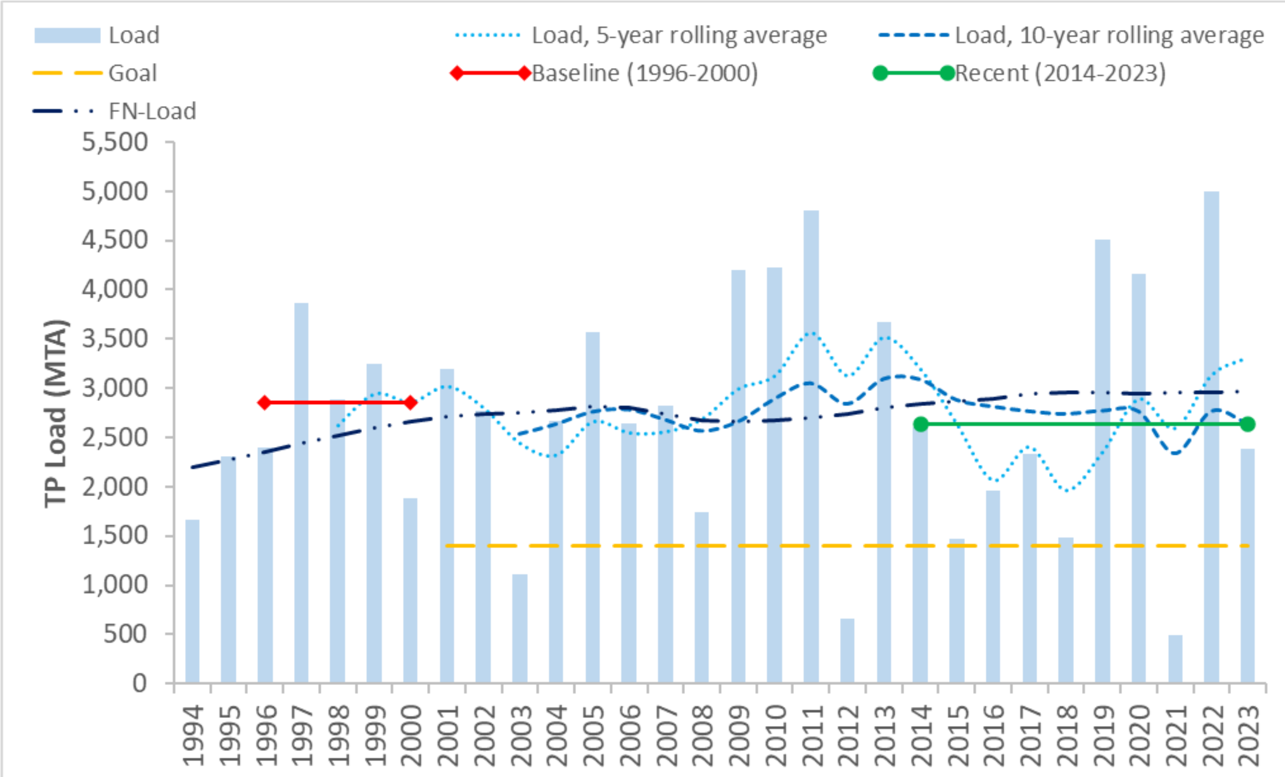


Figure 61. TP (top) and TN (bottom) FWMC trends and goal for the Red River of the North at Emerson.



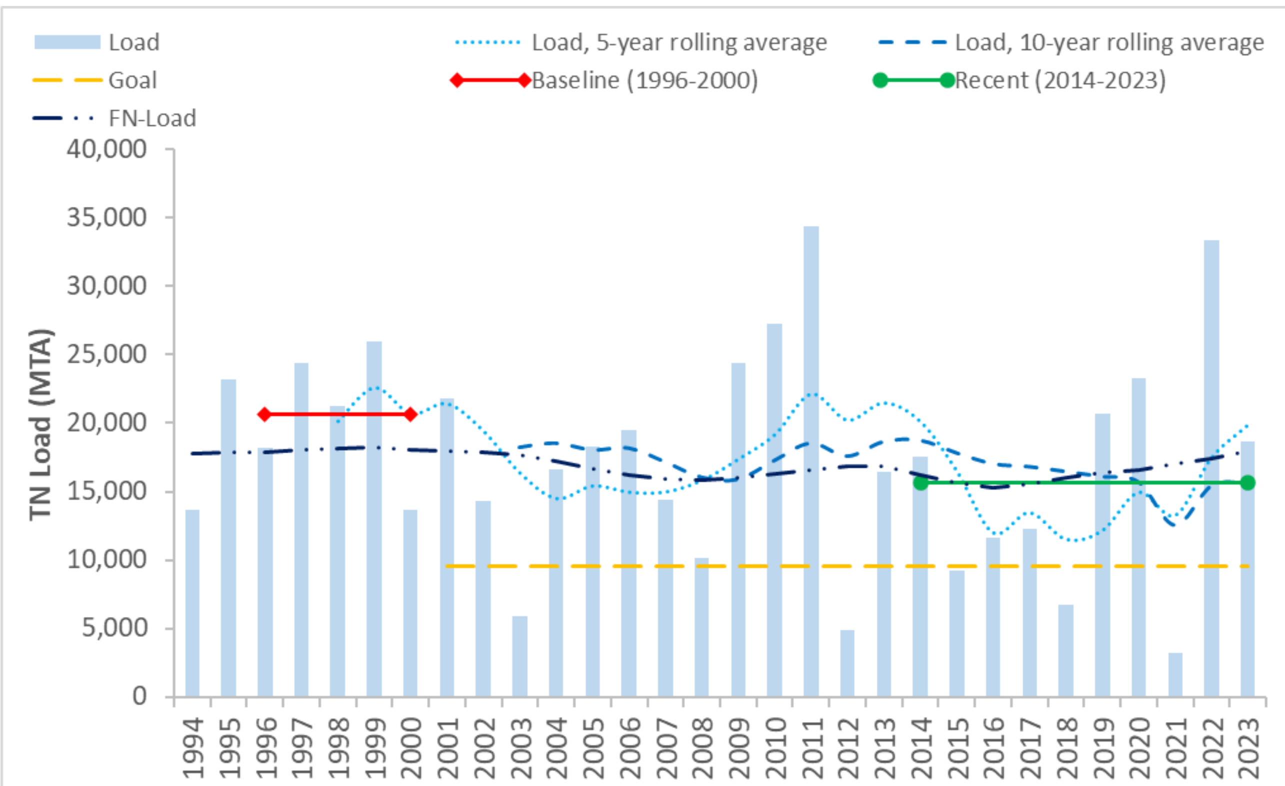


Figure 62. TP (top) and TN (bottom) load trends and goal for the Red River of the North at Emerson.

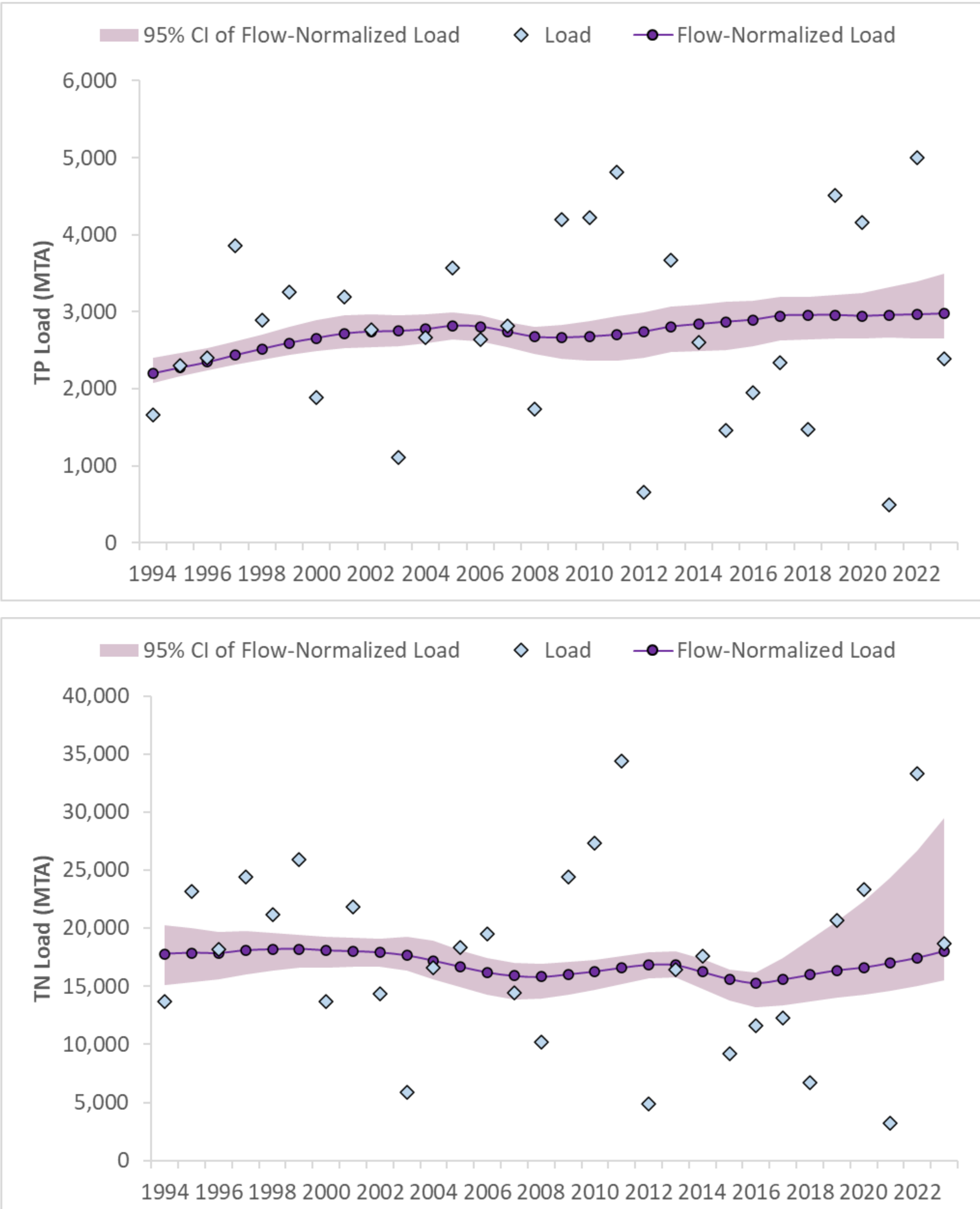


Figure 63. TP (top) and TN (bottom) flow-normalized loads for the Red River of the North at Emerson.

C.3 RED RIVER AT GRAND FORKS, ND

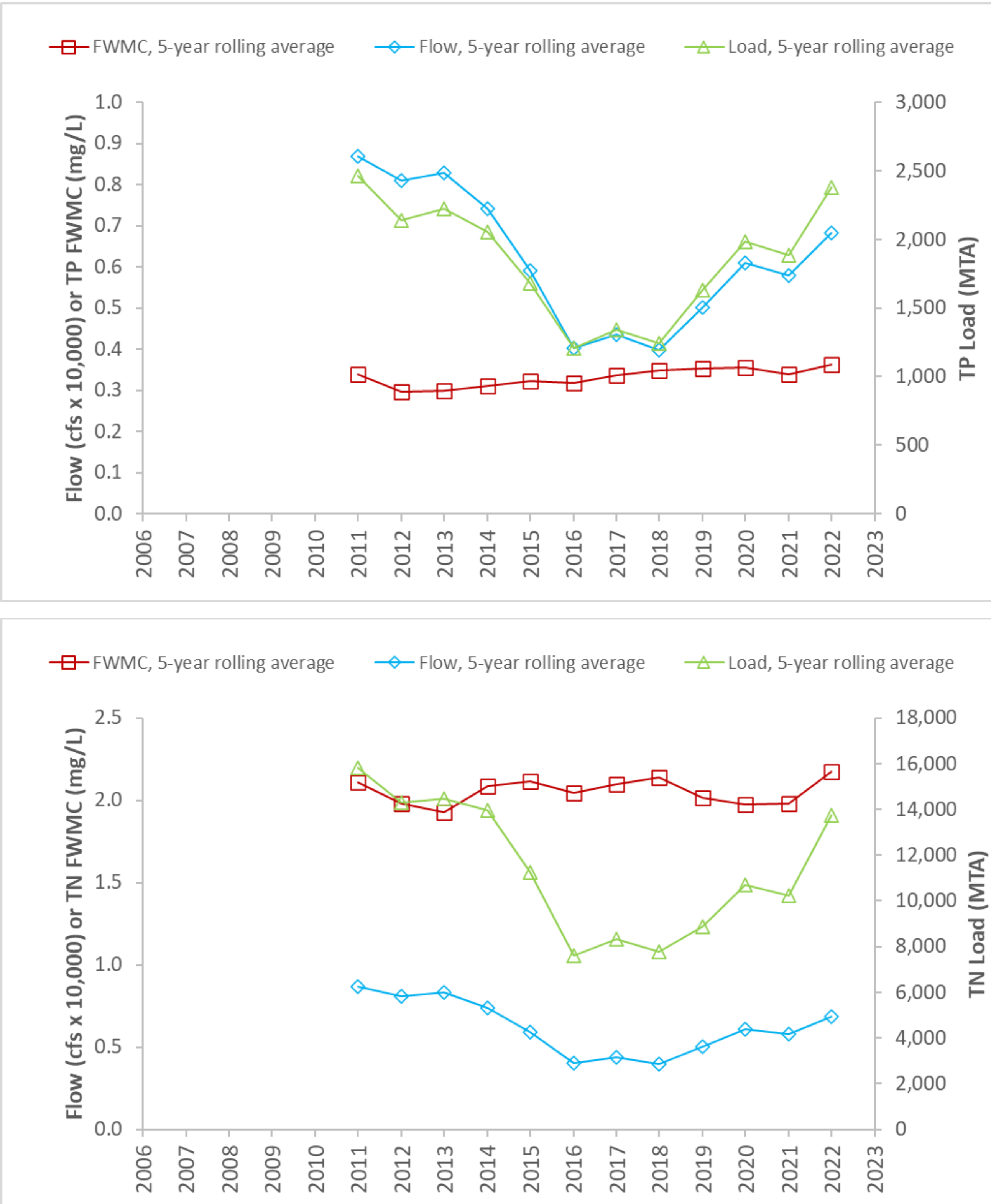


Figure 64. TP (top) and TN (bottom) 5-year rolling averages at the Red River of the North at Grand Forks, ND.

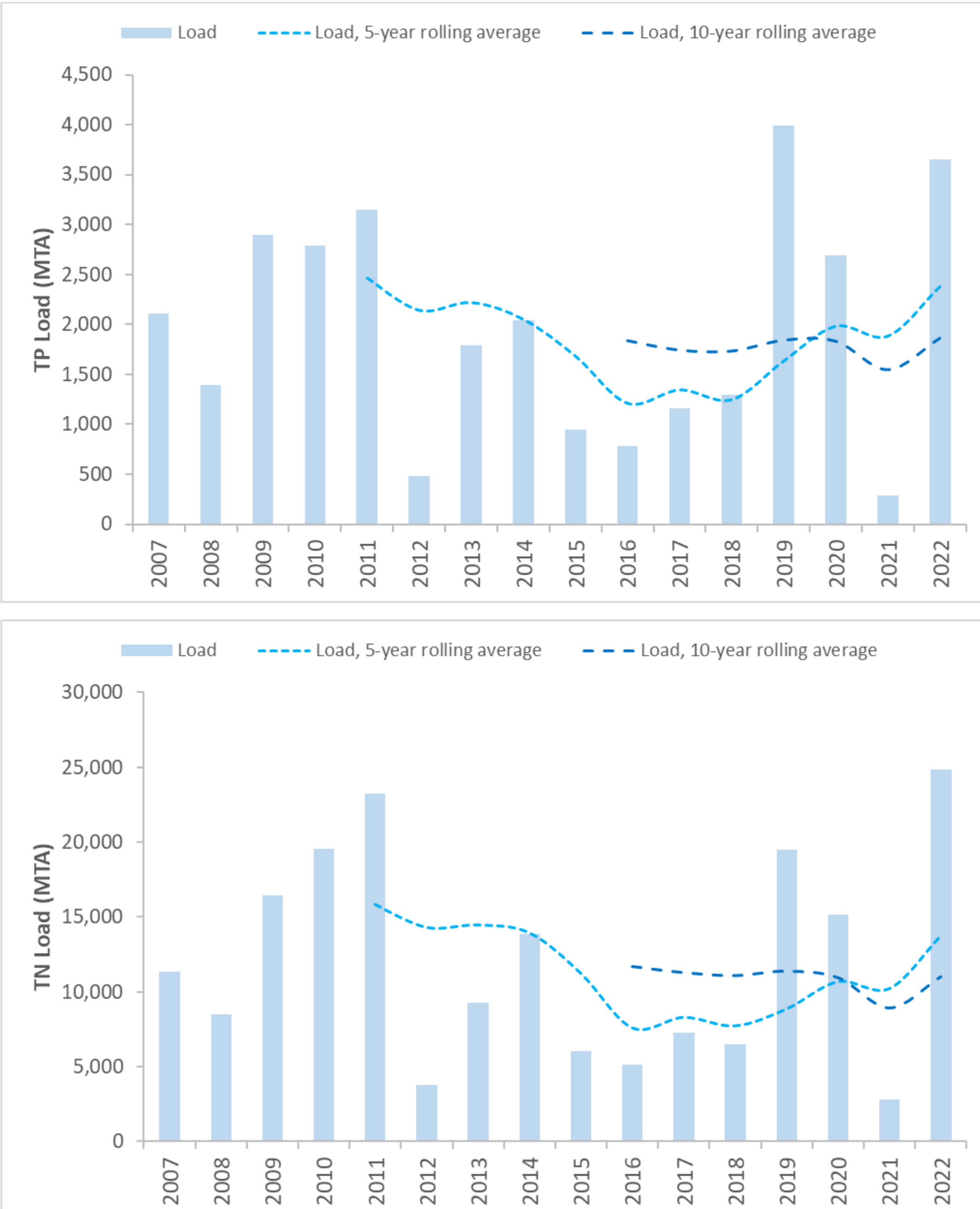
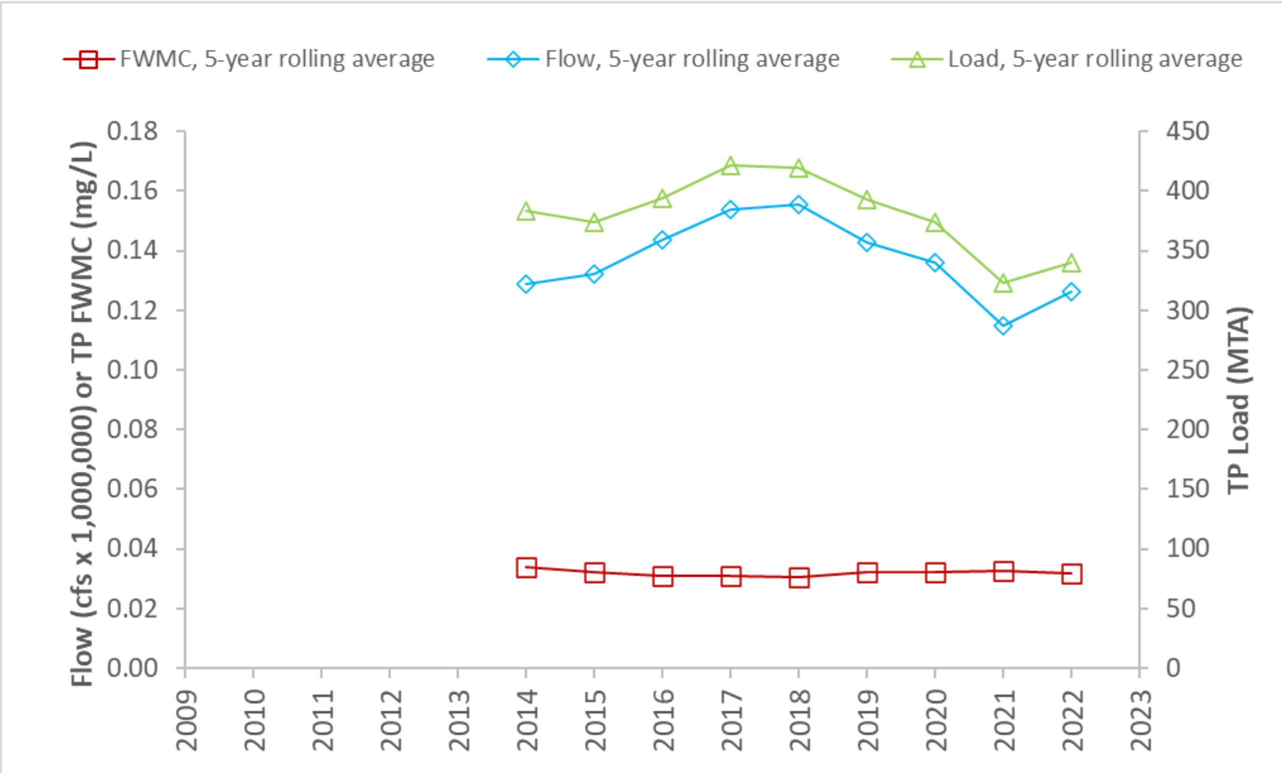


Figure 65. TP (top) and TN (bottom) load trends at the Red River of the North at Grand Forks, ND.

C.4 RAINY RIVER AT MANITOU RAPIDS, MN



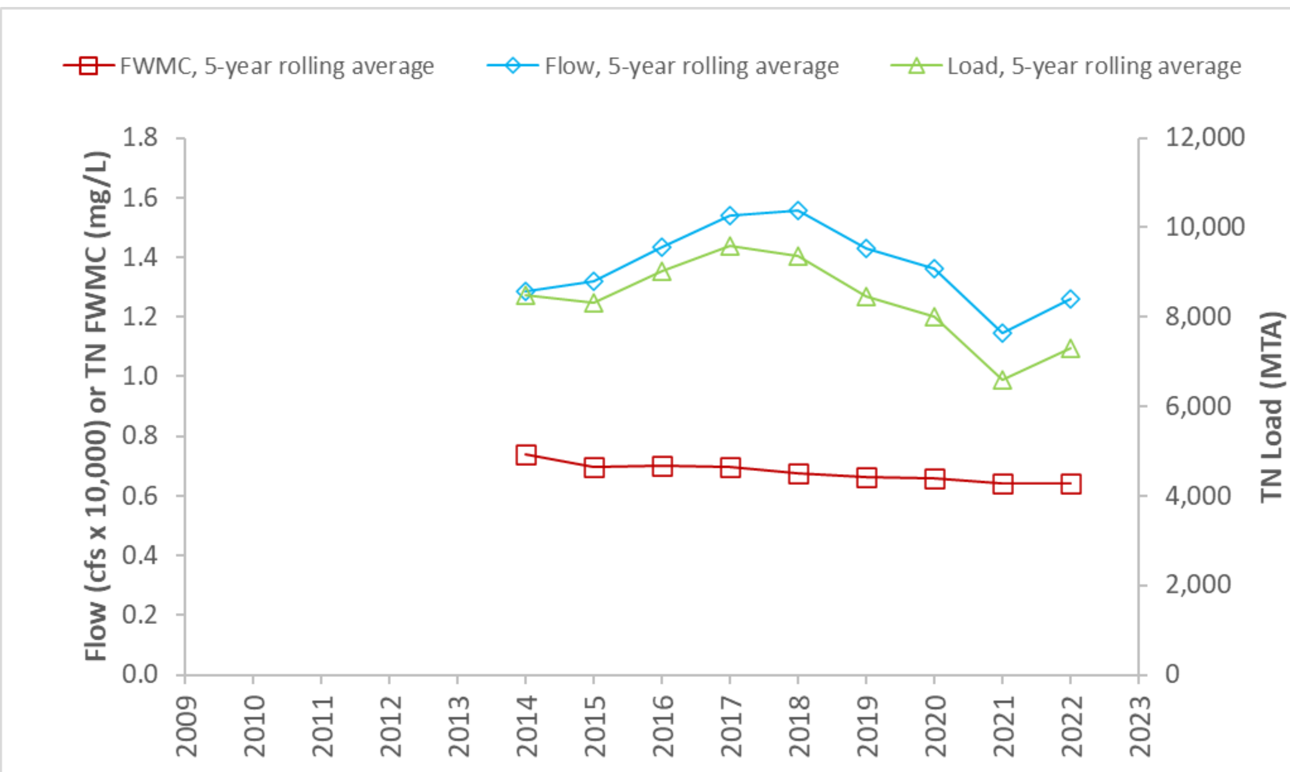


Figure 66. TP (top) and TN (bottom) 5-year rolling averages at the Rainy River at Manitou Rapids, MN.

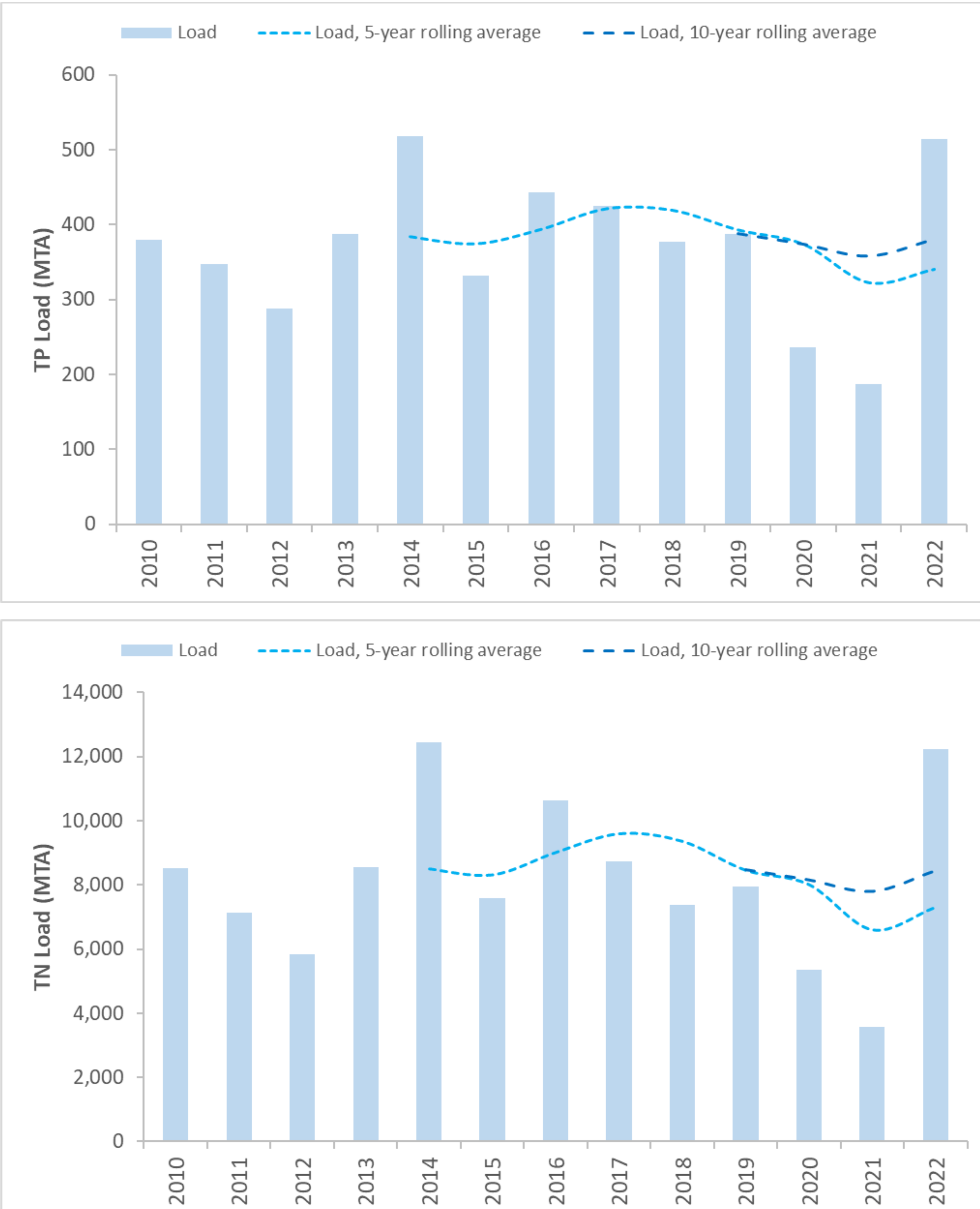
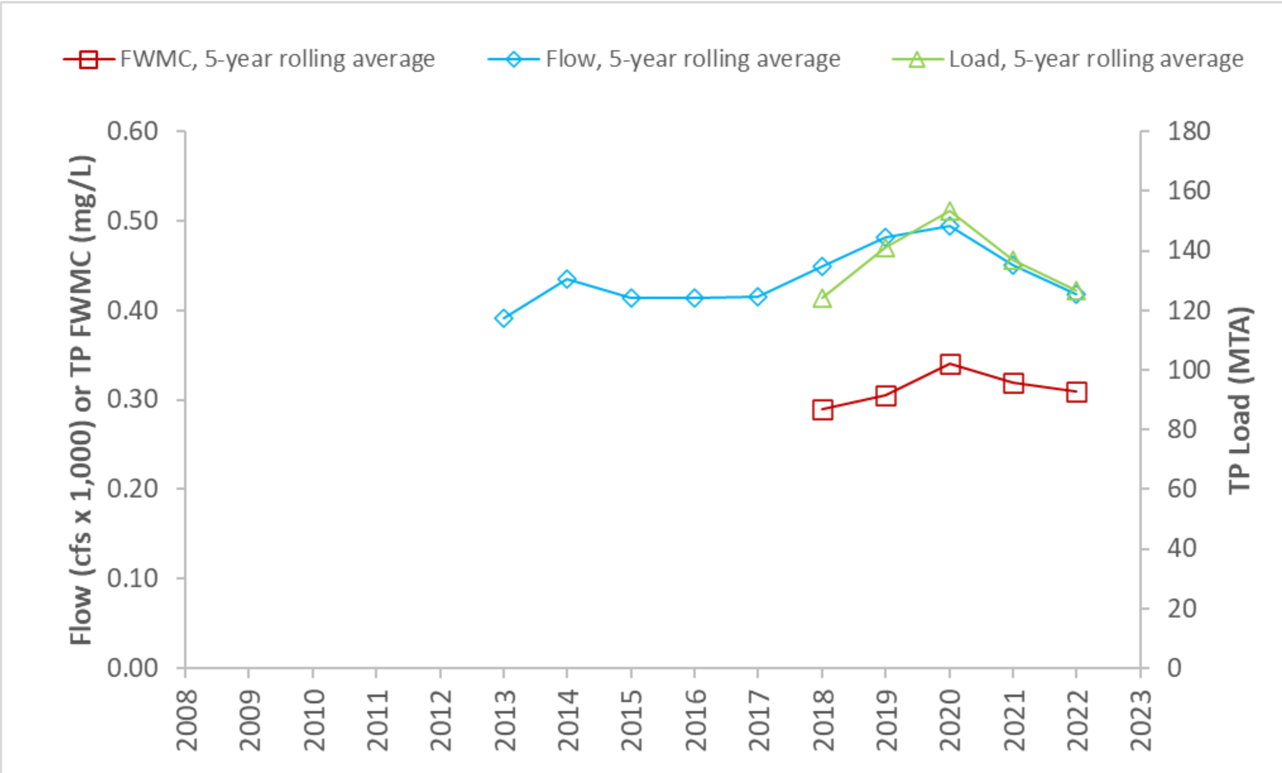


Figure 67. TP (top) and TN (bottom) load trends at the Rainy River at Manitou Rapids, MN.

APPENDIX D. TREND CHARTS FOR THE LAKE SUPERIOR MAJOR BASIN

D.1 NEMADJI RIVER NEAR SOUTH SUPERIOR, WI



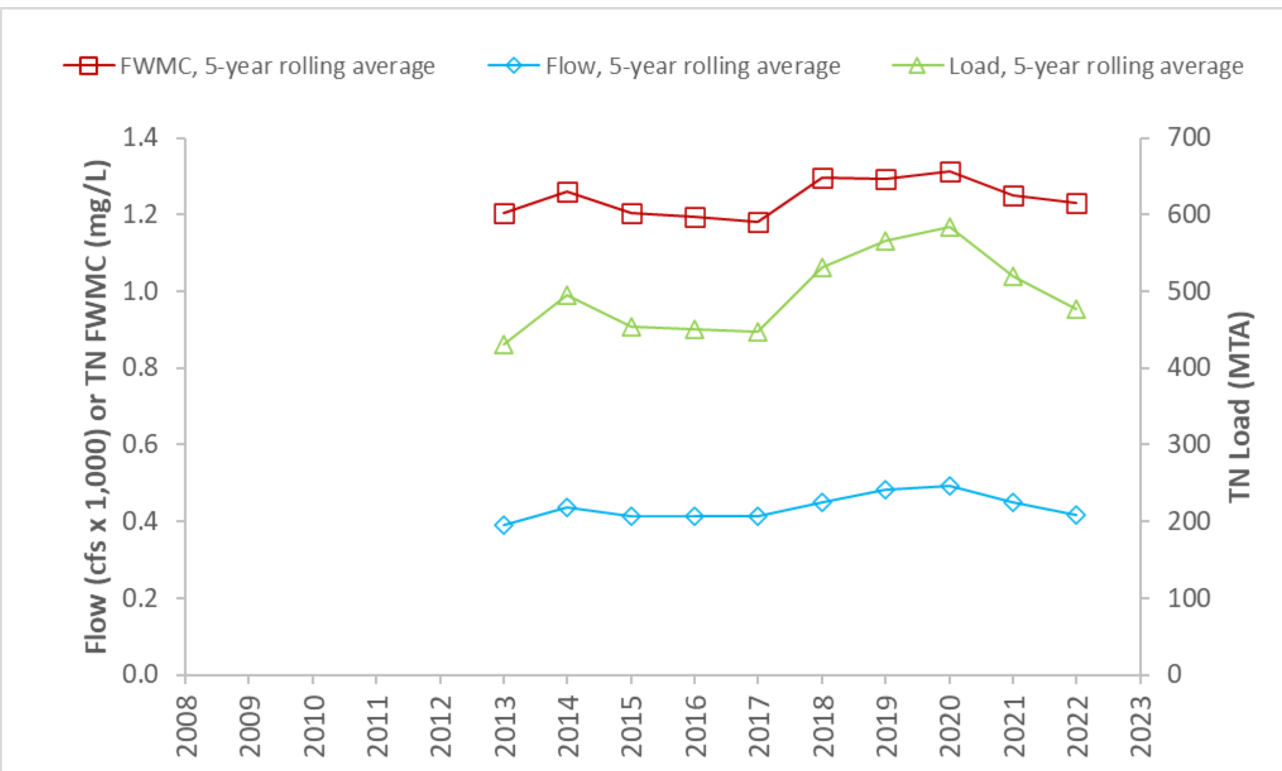
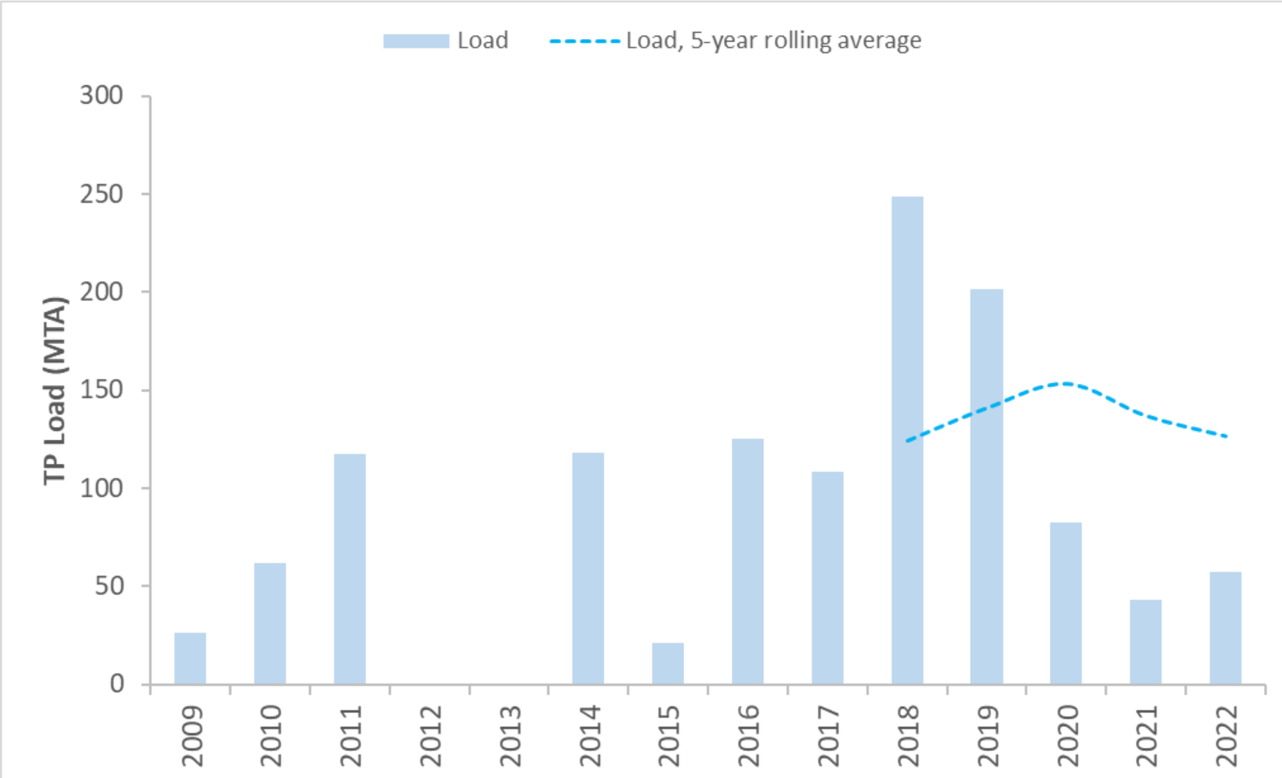


Figure 68. TP (top) and TN (bottom) 5-year rolling averages at the Nemadji River near South Superior, WI.



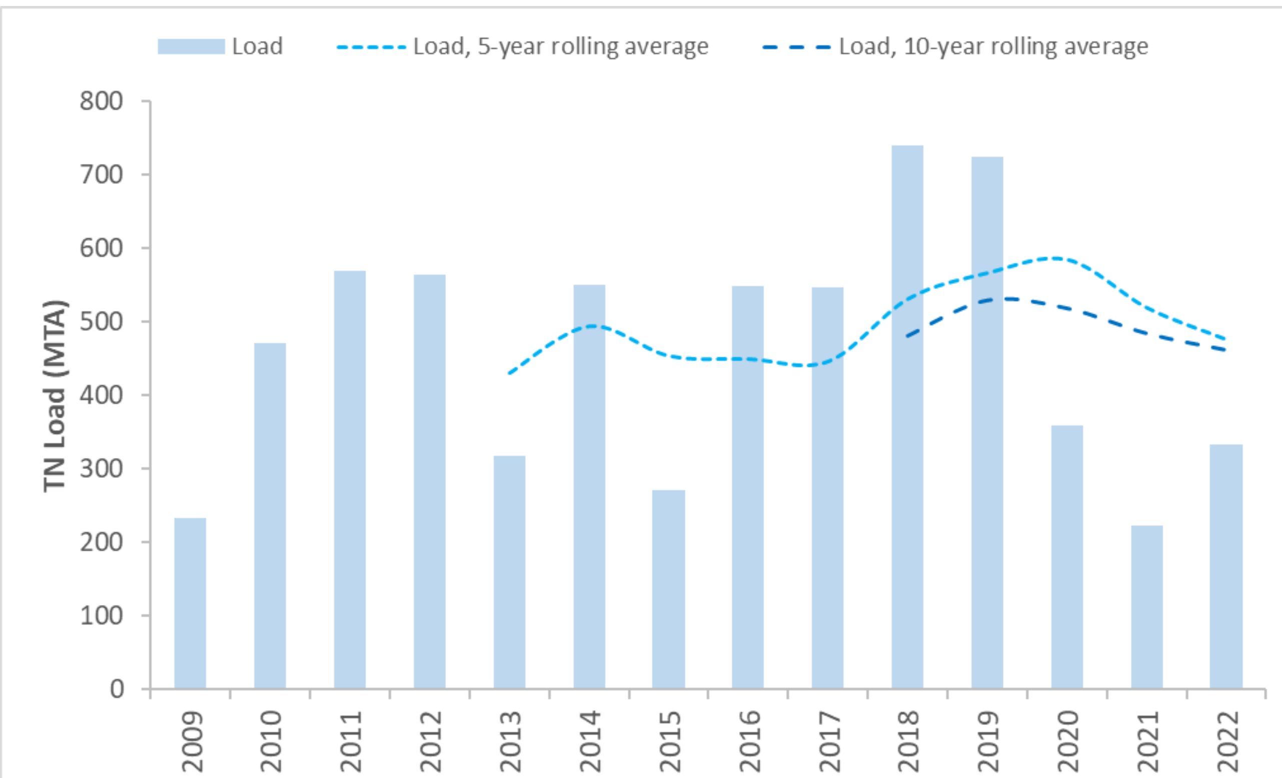
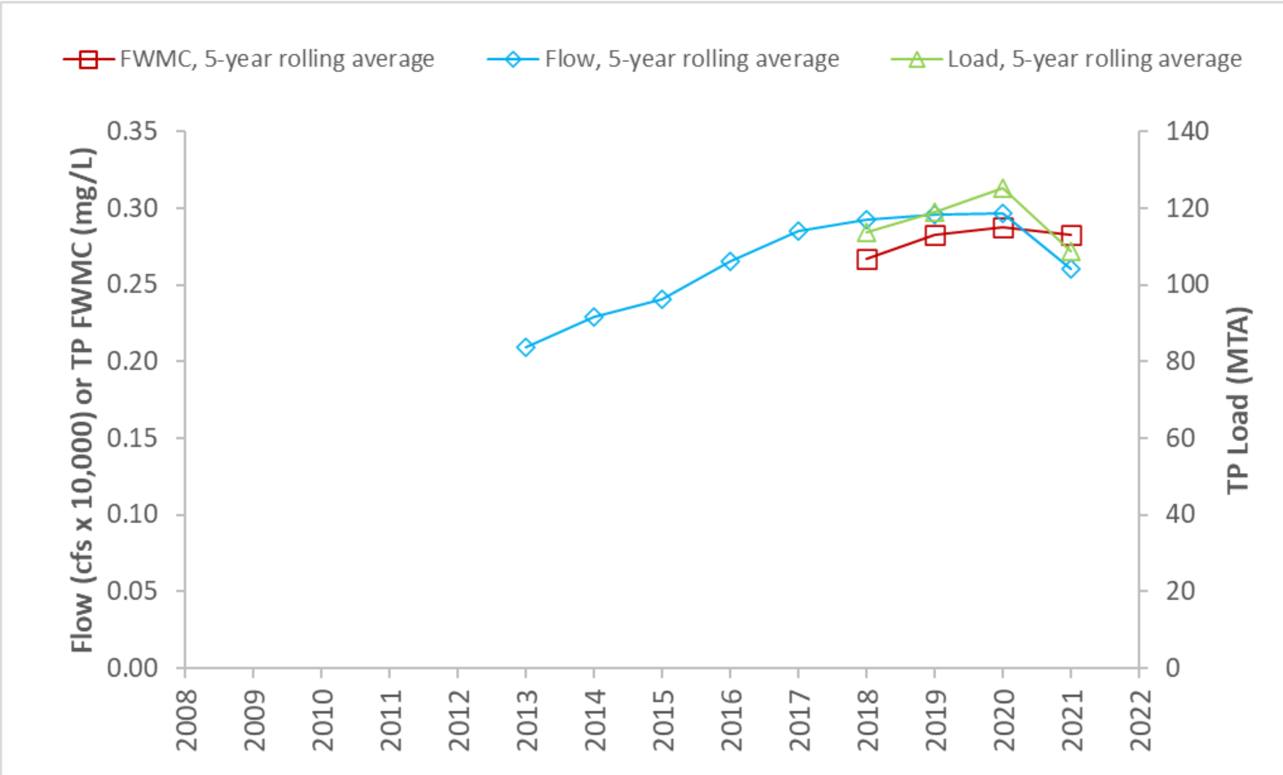


Figure 69. TP (top) and TN (bottom) load trends at the Nemadji River near South Superior, WI.

D.2 ST. LOUIS RIVER AT SCANLON, MN – FLUX32



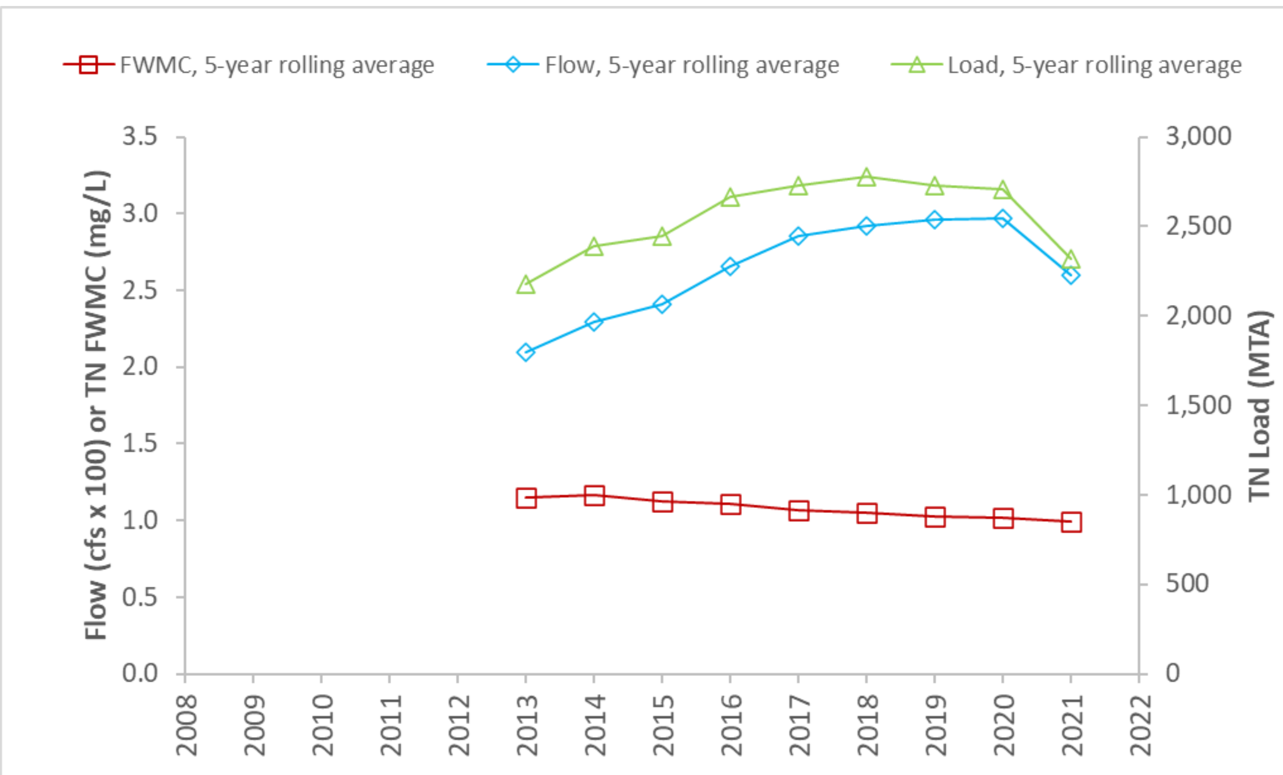


Figure 70. TP (top) and TN (bottom) 5-year rolling averages at the St. Louis River at Scanlon, MN.

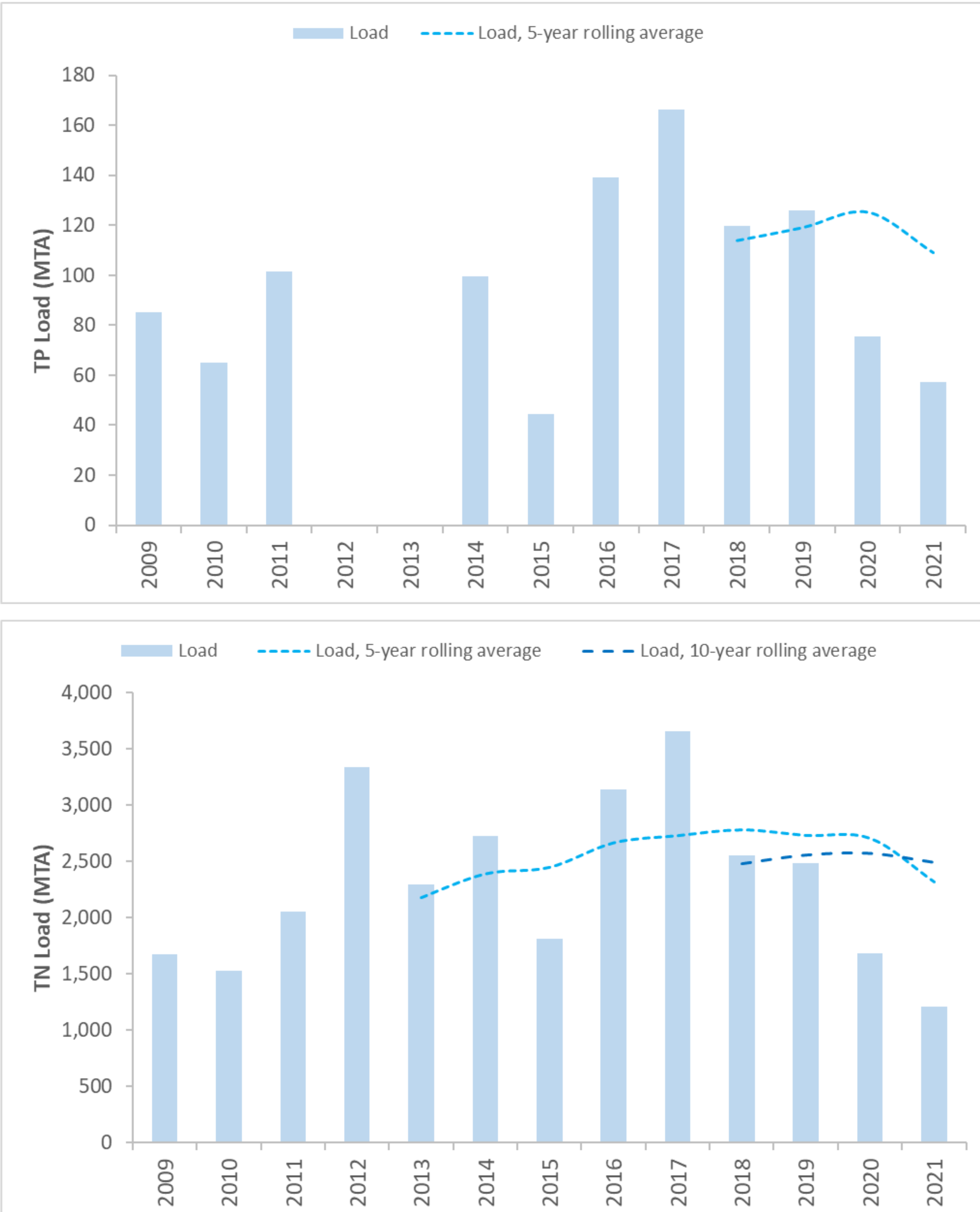


Figure 71. TP (top) and TN (bottom) load trends at the St. Louis River at Scanlon, MN.

D.3 ST. LOUIS RIVER AT SCANLON, MN – WRTDS

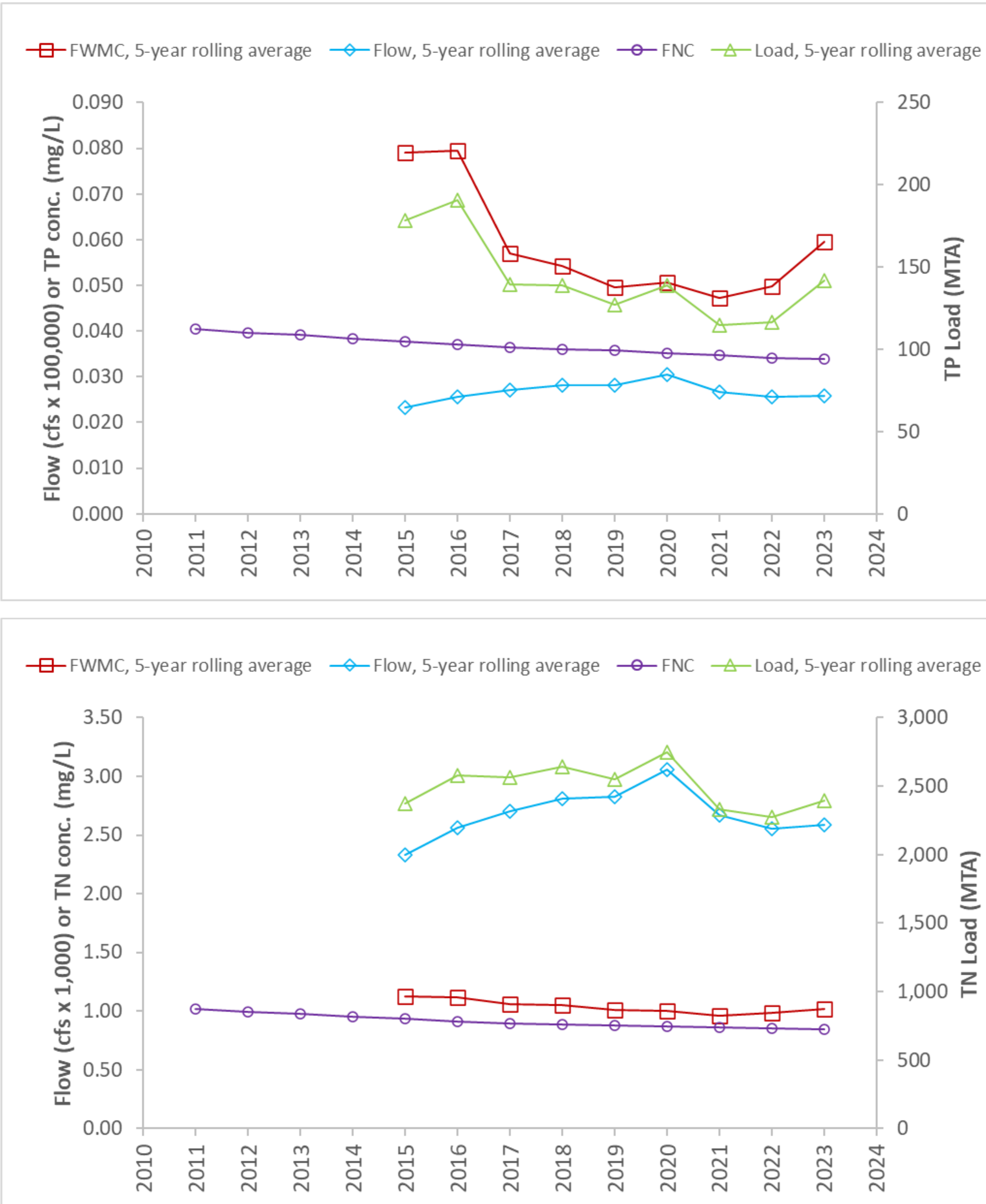


Figure 72. TP (top) and TN (bottom) 5-year rolling averages at the St. Louis River at Scanlon, MN.

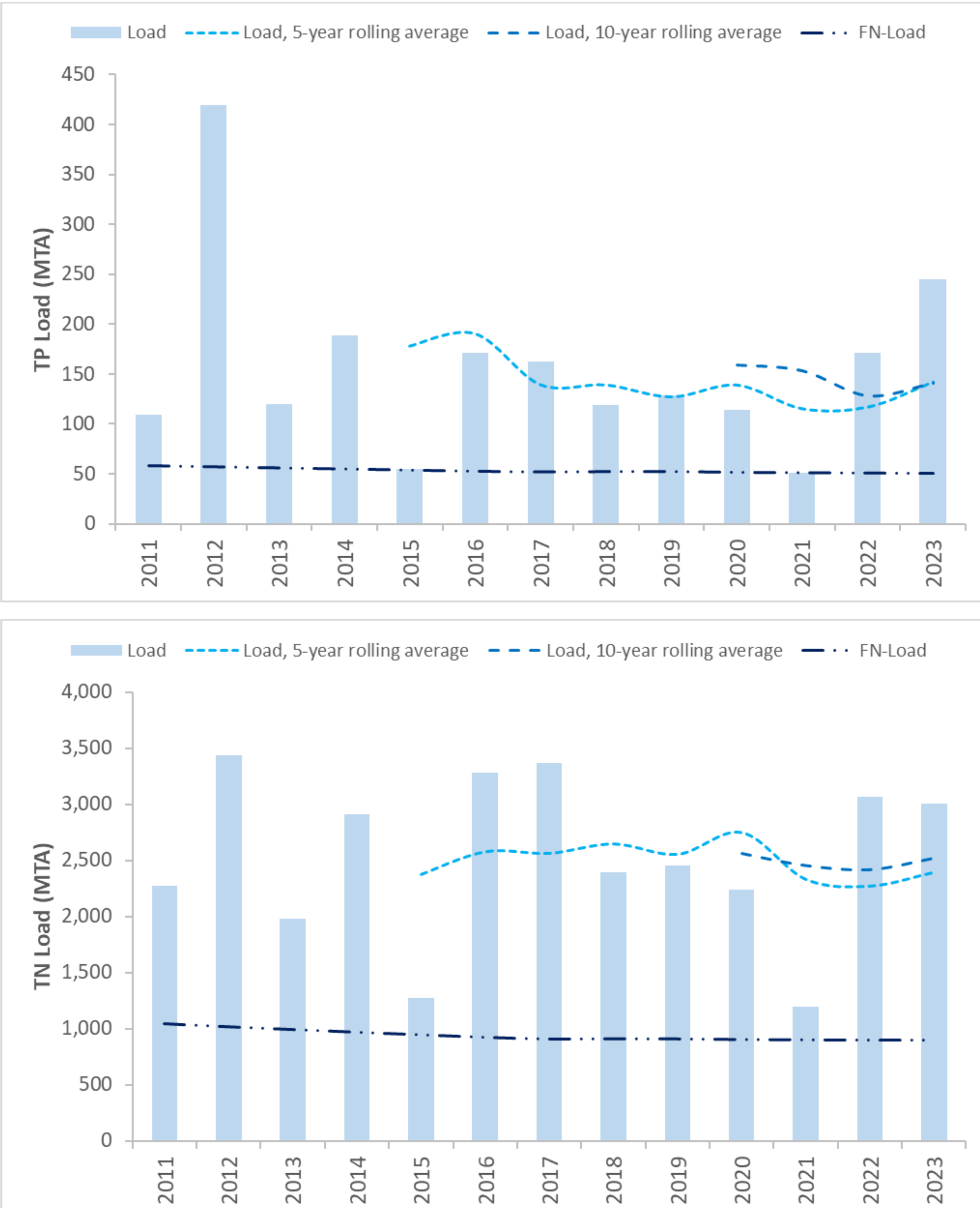


Figure 73. TP (top) and TN (bottom) load trends at the St. Louis River at Scanlon, MN.

APPENDIX E. FLOW-CORRECTED TRENDS

Table 41. Statistically significant, flow-corrected trends for the Mississippi River and tributaries

Monitoring site	Site number	Nitrate plus nitrite	Total phosphorus
Mississippi River			
at Grand Rapids, MN	S003-656	--	None
at Aitkin, MN	S002-010	None	None
near Royalton, MN	S000-150	None	Decreasing
at Winona, MN	S000-096	None	Decreasing
Tributaries to the Upper Mississippi River			
Crow Wing River near Pillager, MN	S001-926	Increasing	Decreasing
Long Prairie River near Philbrook	S002-900	Increasing	Decreasing
Leaf River near Staples, MN	S001-931	Increasing	None
Sauk River at Sauk Rapids	S000-017	Increasing	Decreasing
North Fork Crow River near Rockford	S001-256	None	Decreasing
South Fork Crow River at Delano	S001-255	None	Decreasing
St. Croix River at St. Croix Falls	S000-202	Increasing	Decreasing
St. Croix River near Danbury, WI	S000-056	--	None
Snake River near Pine City, MN	S000-198	None	None
Kettle River near Sandstone	S000-121	Increasing	Decreasing
Tributaries to the Lower Mississippi River			
Zumbro River at Kellogg	S004-384	None	Decreasing
Whitewater River near Beaver	S001-742	Increasing	Decreasing
Root River near Mound Prairie	S004-858	None	Decreasing
Tributaries to the Mississippi River downstream of Minnesota, near the Minnesota-Iowa State Boundary			
Split Rock Creek near Jasper	S004-528	Increasing	Decreasing
Rock Creek at Luverne	S005-381	Increasing	None
West Fork Des Moines River at Jackson	S005-936	None	Decreasing
Shell Rock River near Gordonsville	S000-084	Decreasing	None
Cedar River near Austin	S000-001	None	None

Note: Monitoring sites are sorted from top to bottom as upstream to downstream. Indentation indicates a tributary.

Table 42. Statistically significant, flow-corrected trends for the Minnesota River and tributaries

Monitoring site	Site number	Nitrate plus nitrite	Total phosphorus
Minnesota River			
near Lac qui Parle , MN	S004-469	Increasing	None
at Morton, MN	S000-145	None	Decreasing
at Judson	S001-579	None	None
at St. Peter	S000-41	None	None
Tributaries to the Minnesota River			
Yellow Bank near Odessa	S003-091	Increasing	None
Pomme De Terre River at Appleton, MN	S000-195	Increasing	None
Lac qui Parle River near Lac qui Parle	S003-087	None	None
Chippewa River near Milan	S002-203	None	Decreasing
Hawk Creek near Granite Falls	S002-012	None	Decreasing
Redwood River near Redwood Falls, MN	S001-679	None	Decreasing
Cottonwood River near New Ulm	S001-918	None	None
Blue Earth River near Rapidan	S005-379	None	None
Watonwan River near Garden City	S000-163	None	Decreasing
Le Sueur River near Rapidan	S000-340	None	None

Note: Monitoring sites are sorted from top to bottom as upstream to downstream. Indentation indicates a tributary.

Table 43. Statistically significant, flow-corrected trends for the Red River of the North and tributaries

Monitoring site	Site number	Nitrate plus nitrite	Total phosphorus
Red River of the North			
near Kragnes	S002-097	None	None
at Grand Forks, ND	S000-008	None	None
at Emerson, Manitoba, Canada	S007-127	None	None
Tributaries to the Red River of the North			
Mustinka River near Wheaton	S003-677	None	None
Boix de Sioux River near Doran, MN	S000-553	None	None
Otter Tail River at Breckenridge	S002-000	None	Decreasing
Buffalo River near Georgetown, MN	S002-125	None	None
Wild Rice River at Hendrum, MN	S002-102	None	None
Sand Hill River at Climax, MN	S002-099	None	None
Clearwater River near Red Lake Falls, MN	S002-118	Increasing	None
Thief River near Thief Falls, MN	S002-079	None	None
Snake River near Big Woods, MN	S000-569	None	None
Two Rivers near Hallock	S000-185	None	None

Note: Monitoring sites are sorted from top to bottom as upstream to downstream.

Table 44. Statistically significant, flow-corrected trends for waters in the *Lake Superior* major basin

Monitoring site	Site number	Nitrate plus nitrite	Total phosphorus
Nemadji River near South Superior, WI	S005-115	None	None
St. Louis River near Scanlon, MN	S005-089	None	None
Poplar River near Lutsen, MN	S004-406	None	None
Baptism River near Beaver Bay	S000-250	None	Increasing

APPENDIX F. FWMC AND FLOW LINEAR REGRESSION CHARTS

Table 45. Summary of FWMC and flow linear regressions for the Mississippi River

Monitoring sites	Figure	Total phosphorus			Total nitrogen		
		Stat.	R^2	Slope	Stat.	R^2	Slope
Mississippi River at Anoka, MN (RM 872)	Figure 74	Insig.	<0.01	--	Sig.	0.10	+0.0556
Mississippi River at Red Wing, MN (RM 797; above L&D #3)	Figure 75	Insig.	0.01	--	Sig.	0.20	+0.0437
Mississippi River at Prescott, WI (RM 786)	Figure 76	Insig.	0.02	--	Insig.	0.12	--
Mississippi River at Lake Pepin Outlet (RM 764)	Figure 77	Insig.	0.03	--	Sig.	0.22	+0.2942
Mississippi River at Winona, MN	Figure 78	Insig.	0.13	--	Insig.	0.17	--
Mississippi River at La Crosse, WI (L&D #7)	Figure 79	Insig.	<0.01	--	Sig.	0.25	+0.1804

Note: Insig. = insignificant; L&D = lock and dam; R^2 = coefficient of determination; RM = river mile; Sig. = significant; Stat. = statistical significance.

Table 46. Summary of FWMC and flow linear regressions for tributaries to the Mississippi River

Monitoring sites	Figure	Total phosphorus			Total nitrogen		
		Stat.	R^2	Slope	Stat.	R^2	Slope
Minnesota River at Jordan, MN	Figure 80	Insig.	0.06	--	Insig.	0.01	--
Cannon River at Welch, MN	Figure 81	Insig.	0.01	--	Insig.	<0.01	--
Chippewa River at Durand, WI	Figure 82	Insig.	<0.01	--	Insig.	0.01	--
Black River near Galesville, WI	Figure 83	Insig.	<0.01	--	Sig.	0.22	-0.0725
La Crosse River near La Crosse, WI	Figure 84	Sig.	0.28	+0.0091	Sig.	0.64	+0.1914
Upper Iowa River near Dorchester, IA	Figure 85	Sig.	0.61	+0.0387	Sig.	0.46	+0.2125
Cedar River near Austin, MN	Figure 86	Sig.	0.43	-0.0188	Insig.	<0.01	--
West Fork Des Moines River at Jackson, MN	Figure 87	Insig.	0.01	--	Insig.	0.14	--
Rock River at Luverne, MN	Figure 88	Insig.	0.37	--	Insig.	0.03	--
Split Rock Creek near Jasper, MN	Figure 89	Sig.	0.64	+0.0511	Insig.	0.06	--

Notes

Insig. = insignificant; R^2 = coefficient of determination; Sig. = significant; Stat. = statistical significance.

Tributaries are sorted from top to bottom as upstream to downstream along the Mississippi River.

Table 47. Summary of FWMC and flow linear regressions for the Lake Winnipeg major basin

Monitoring sites	Figure	Total phosphorus			Total nitrogen		
		Stat.	R^2	Slope	Stat.	R^2	Slope
Red River at Emerson, Manitoba, Canada	Figure 90	Insig.	0.01	--	Insig.	<0.01	--
Red River at Grand Forks, ND	Figure 91	Insig.	0.01	--	Insig.	<0.01	--
Rainy River at Manitou Rapids, MN	Figure 92	Insig.	0.06	--	Insig.	0.03	--

Note: Insig. = insignificant; R^2 = coefficient of determination; Stat. = statistical significance.

Table 48. Summary of FWMC and flow linear regressions for the Lake Superior major basin

Monitoring sites	Figure	Total phosphorus			Total nitrogen		
		Stat.	R^2	Slope	Stat.	R^2	Slope
Nemadji River near South Superior, WI	Figure 93	Sig.	0.49	+0.0764	Sig.	0.55	+0.1268
St. Louis River at Scanlon, MN	Figure 94	Insig.	0.22	--	Insig.	0.01	--

Note: Insig. = insignificant; R^2 = coefficient of determination; Sig. = significant; Stat. = statistical significance.

F.1 MISSISSIPPI RIVER

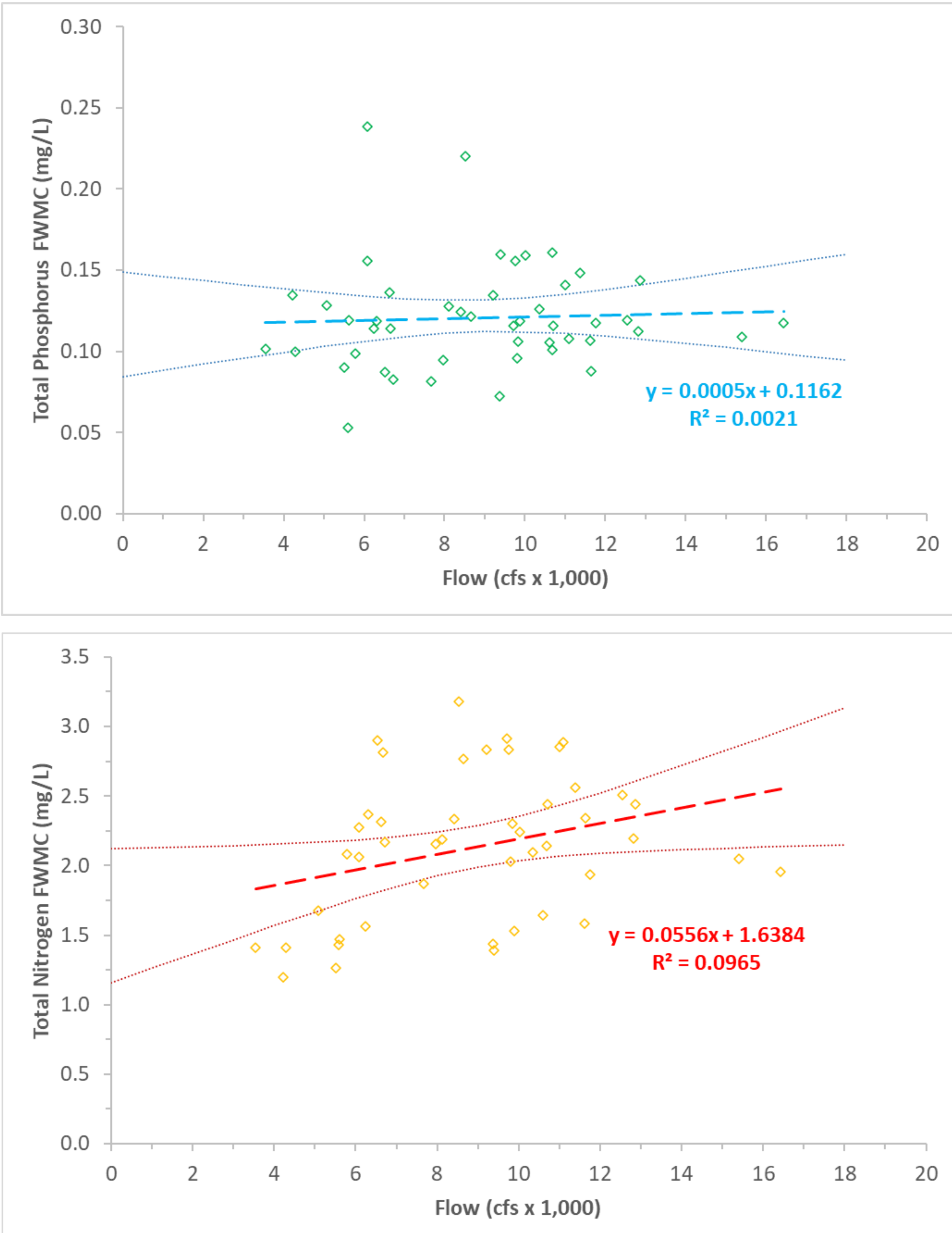


Figure 74. TP (top) and TN (bottom) FWMC and flow linear regressions for the Mississippi River at Anoka, MN.

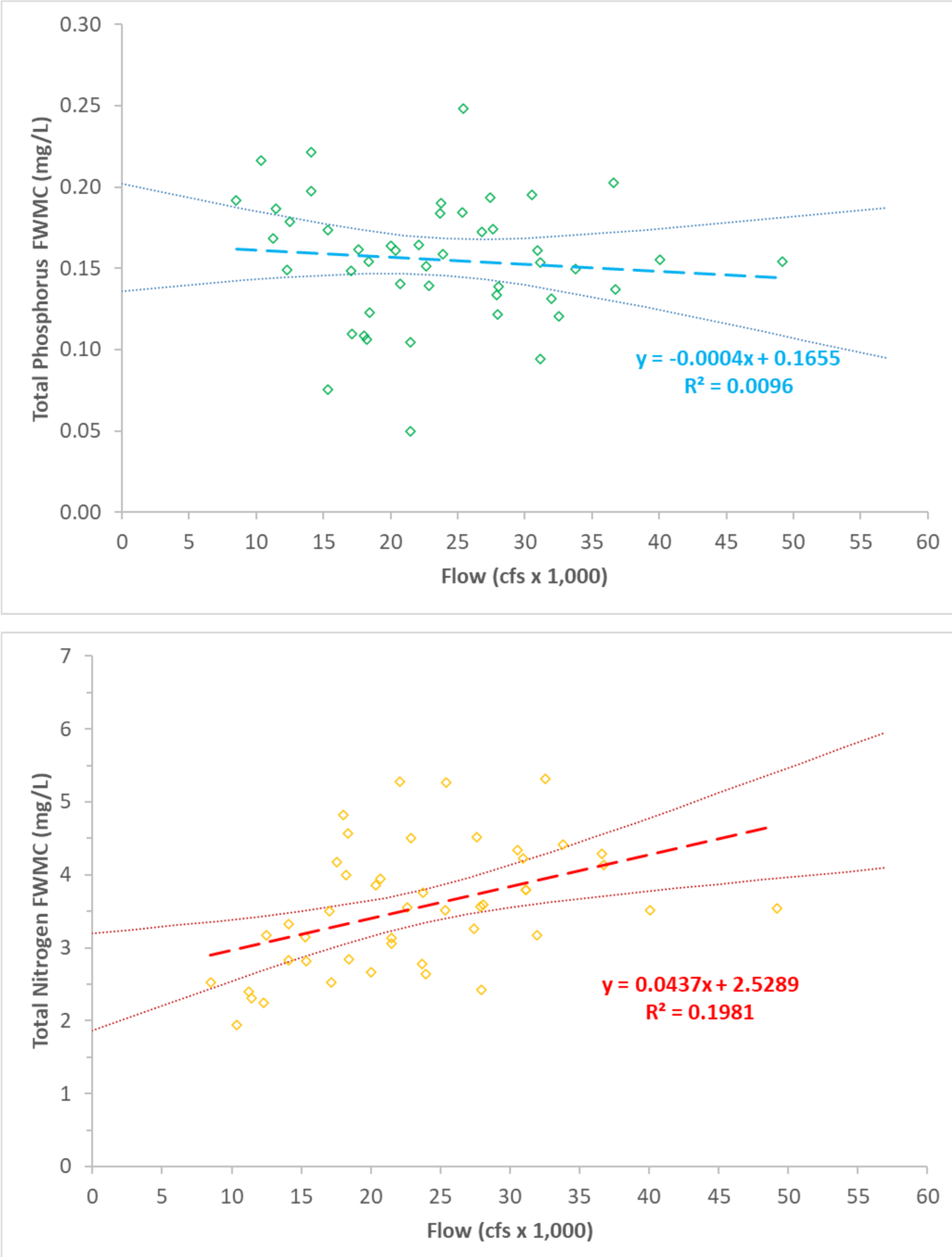


Figure 75. TP (top) and TN (bottom) FWMC and flow linear regression for the Mississippi River at Red Wing, MN.

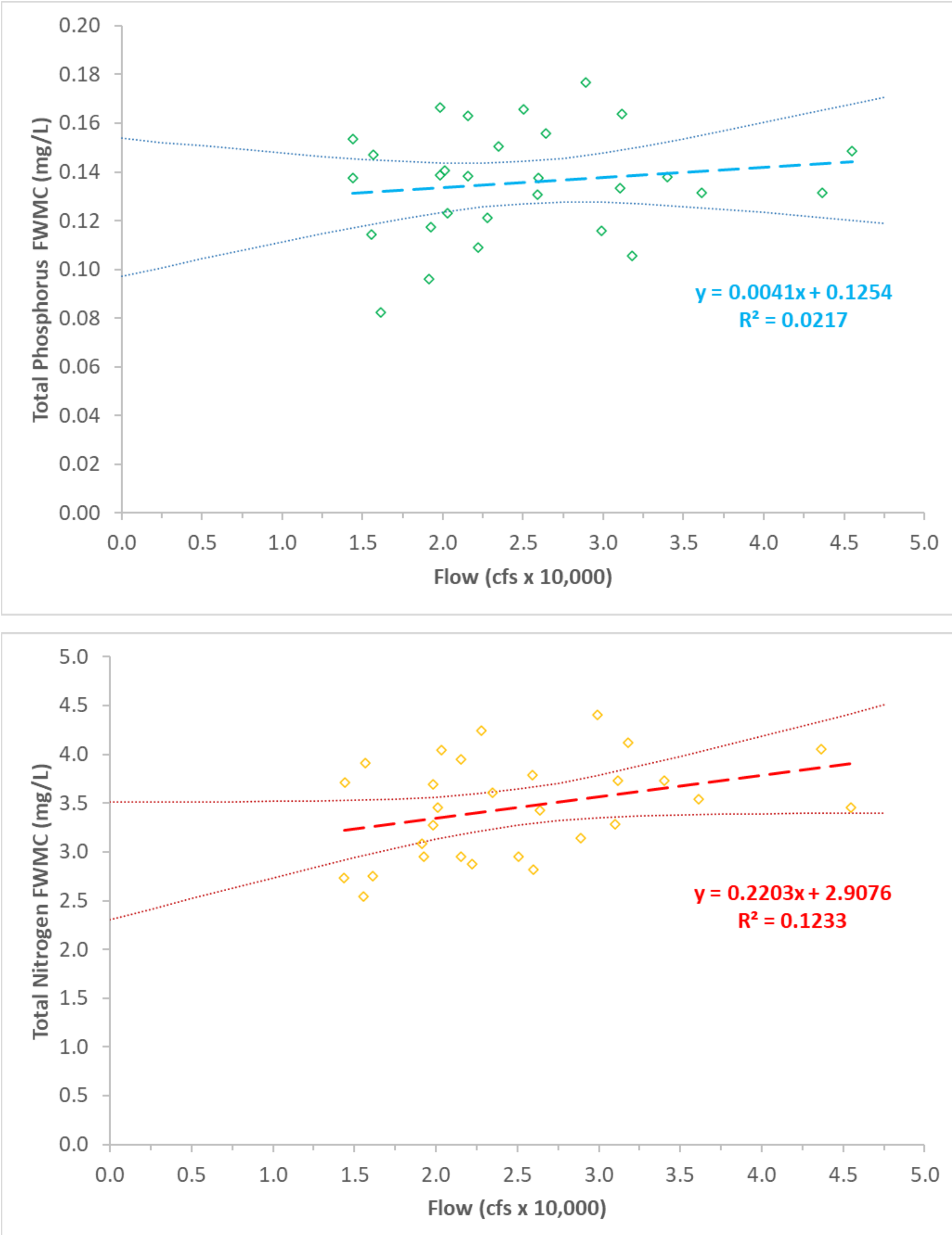
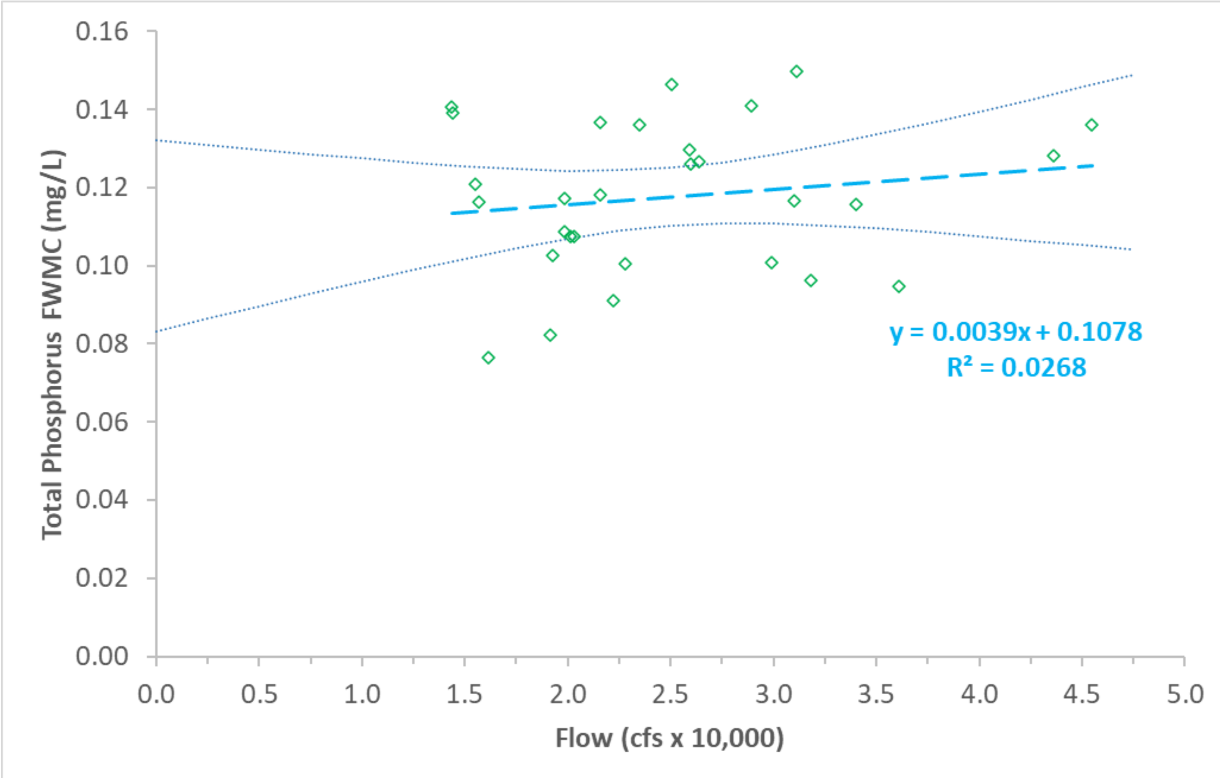


Figure 76. TP (top) and TN (bottom) FWMC and flow linear regressions for the Mississippi River at Prescott, WI.



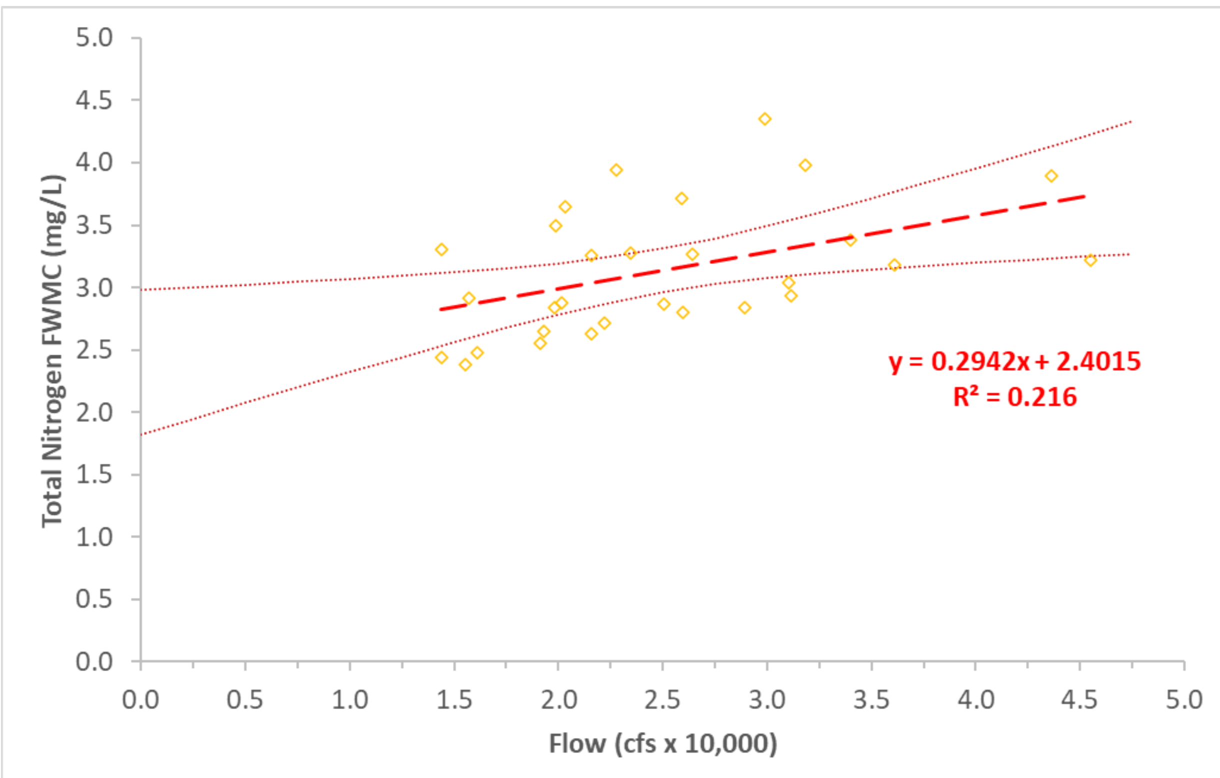


Figure 77. TP (top) and TN (bottom) FWMC and flow linear regressions for the Mississippi River at the Lake Pepin outlet.

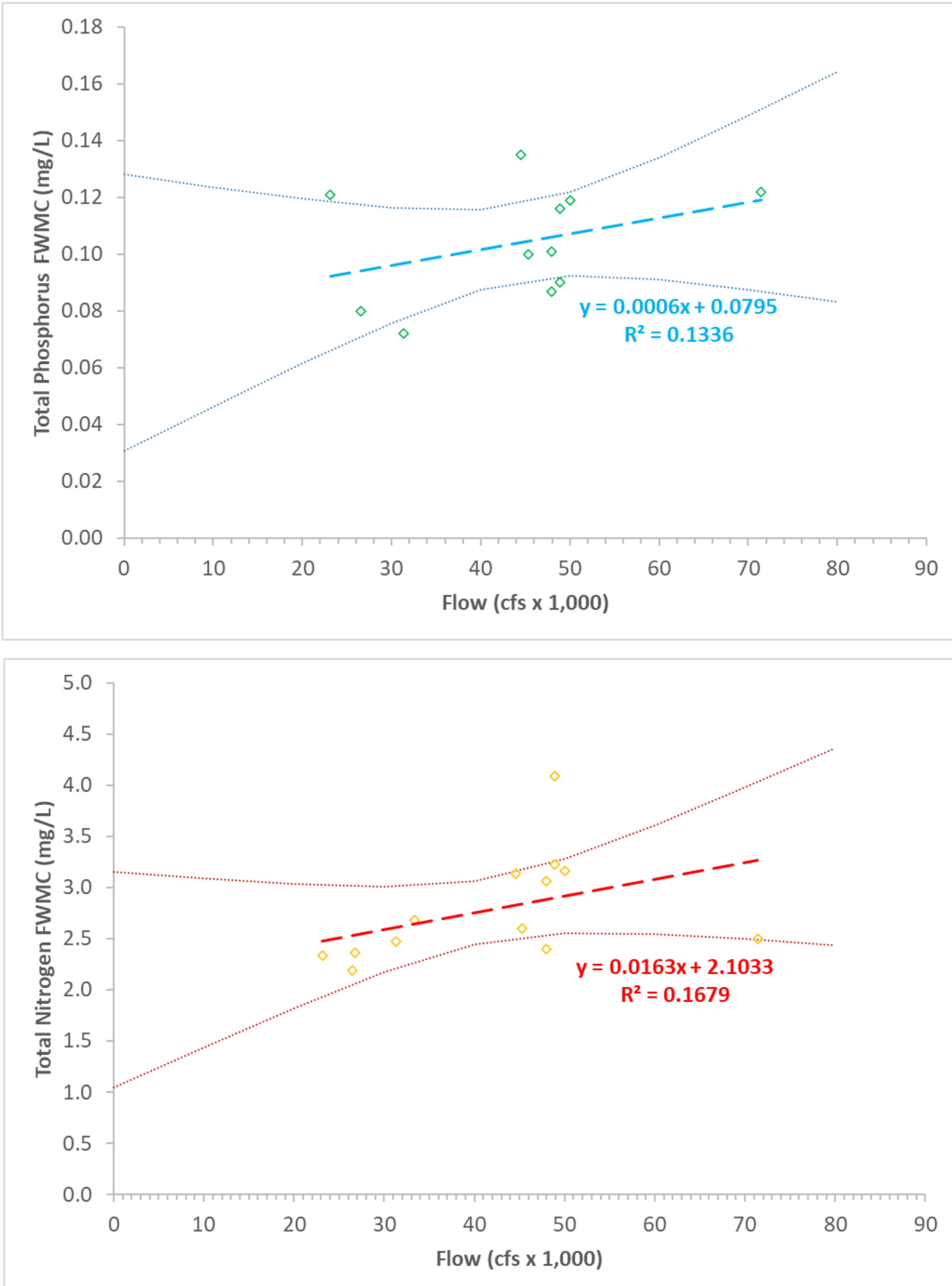


Figure 78. TP (top) and TN (bottom) FWMC and flow linear regressions for the Mississippi River at Winona, MN.

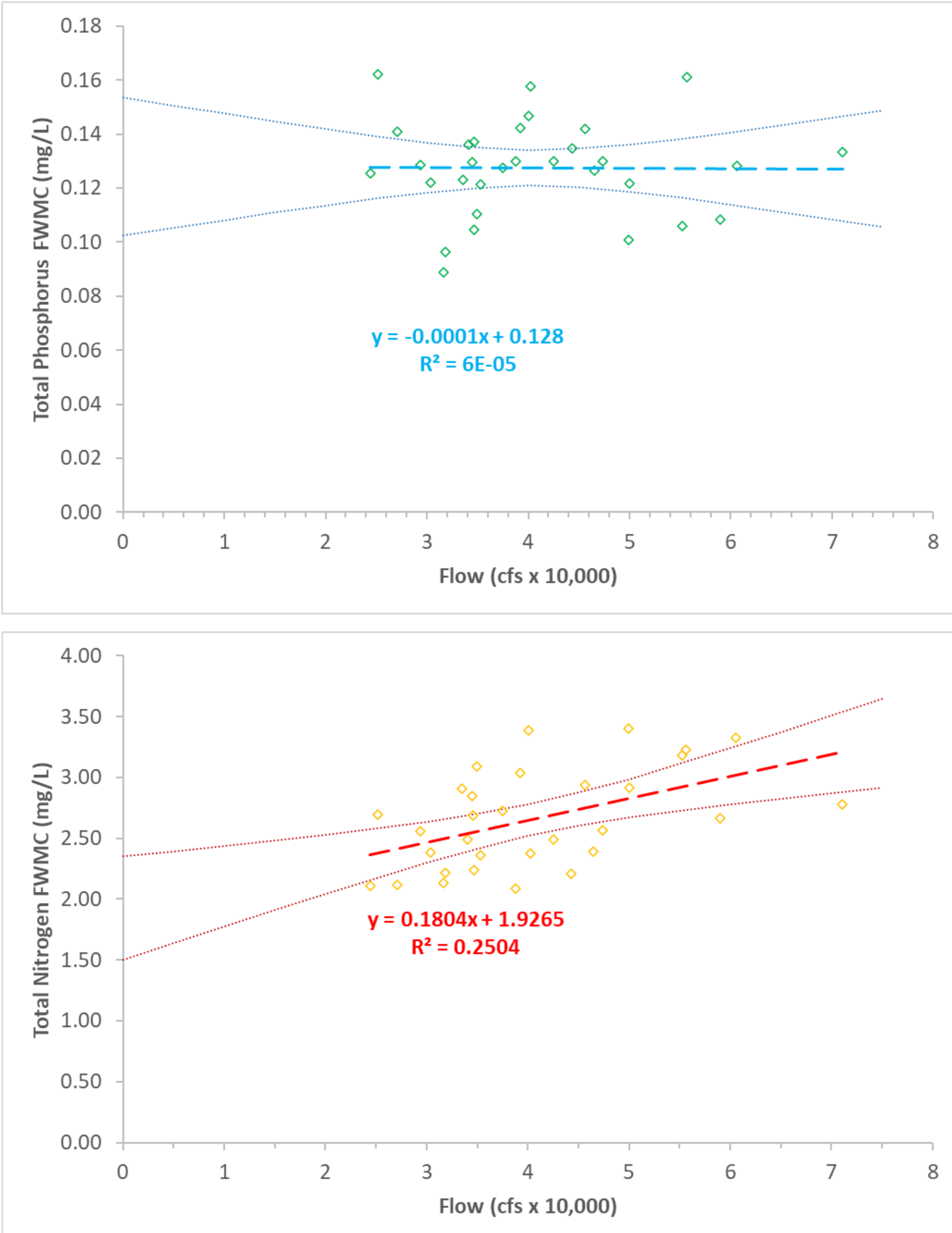


Figure 79. TP (top) and TN (bottom) FWMC and flow linear regressions for the Mississippi River at La Crosse, WI.

F.2 MISSISSIPPI RIVER TRIBUTARIES

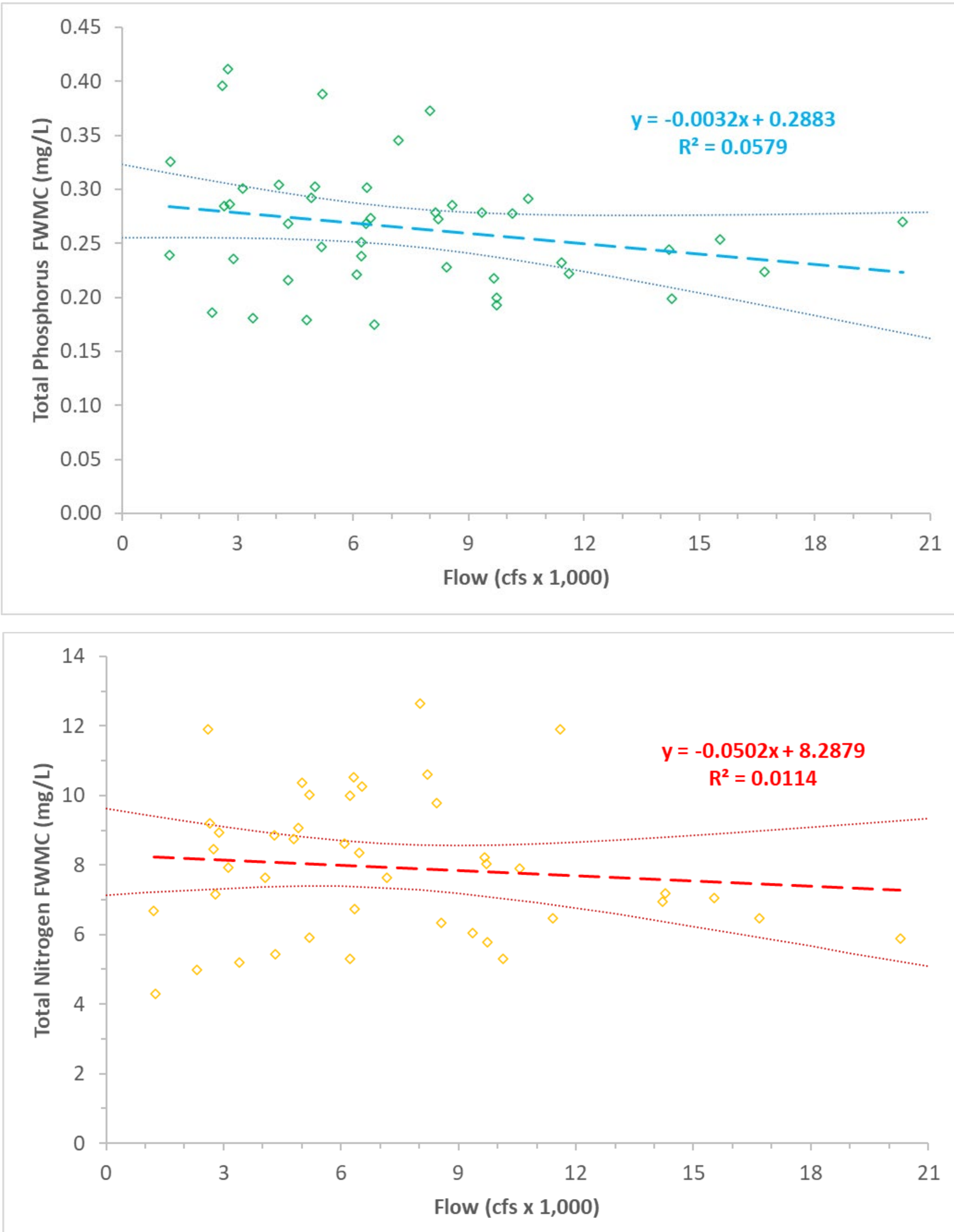


Figure 80. TP (top) and TN (bottom) FWMC and flow linear regressions for the Minnesota River at Jordan, MN.

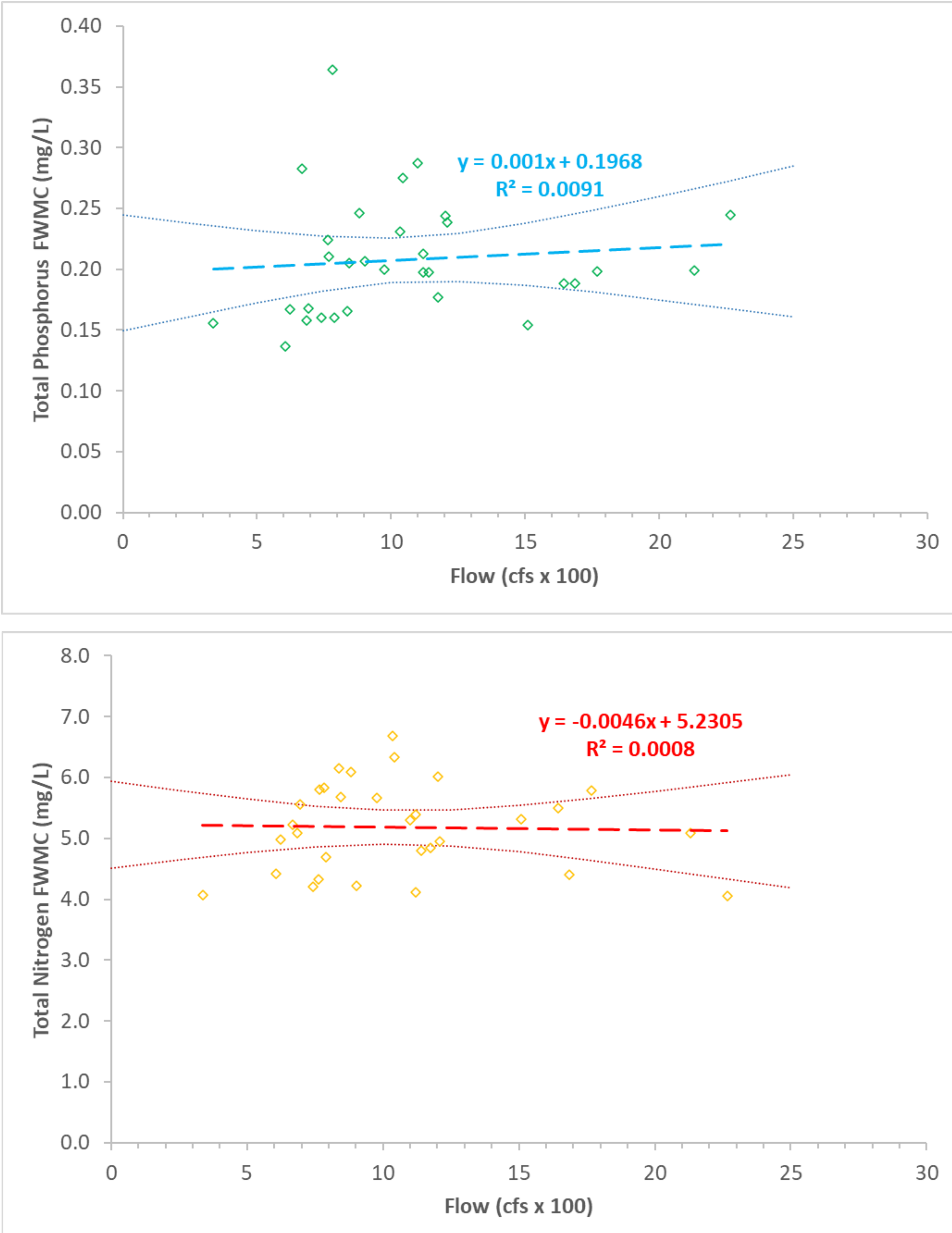
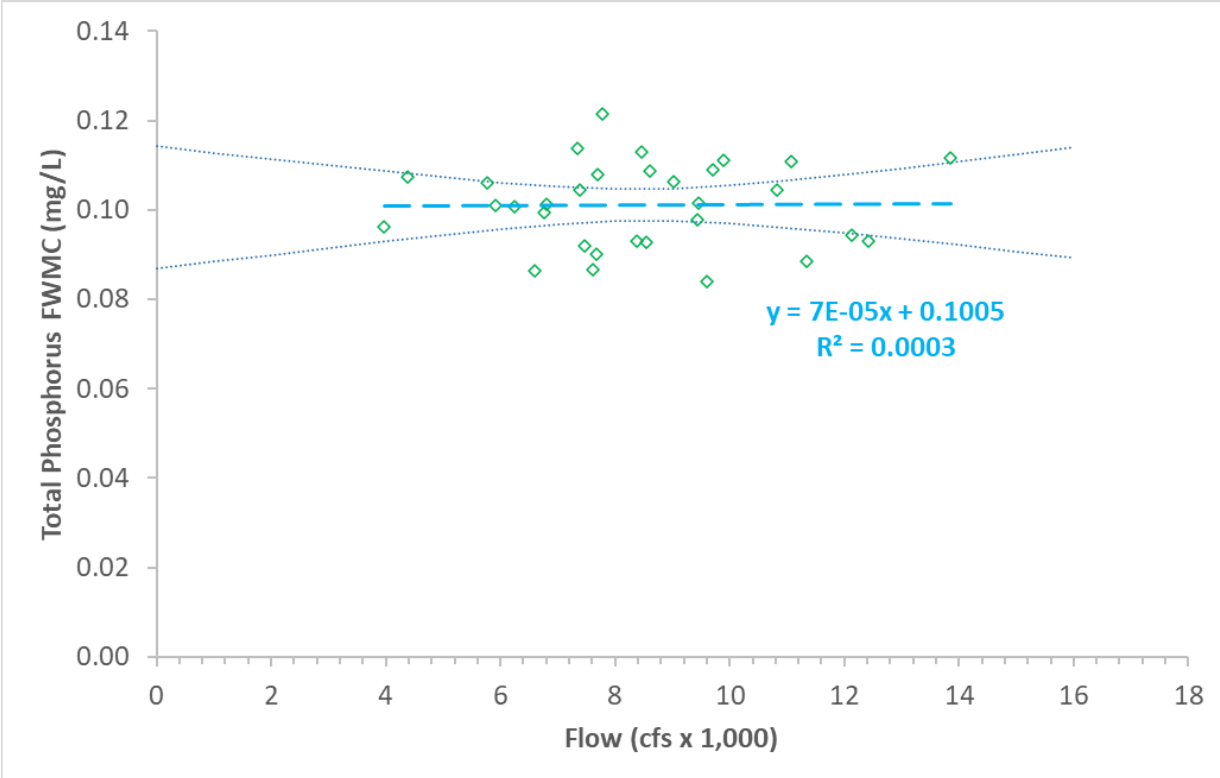


Figure 81. TP (top) and TN (bottom) FWMC and flow linear regressions for the Cannon River at Welch, MN.



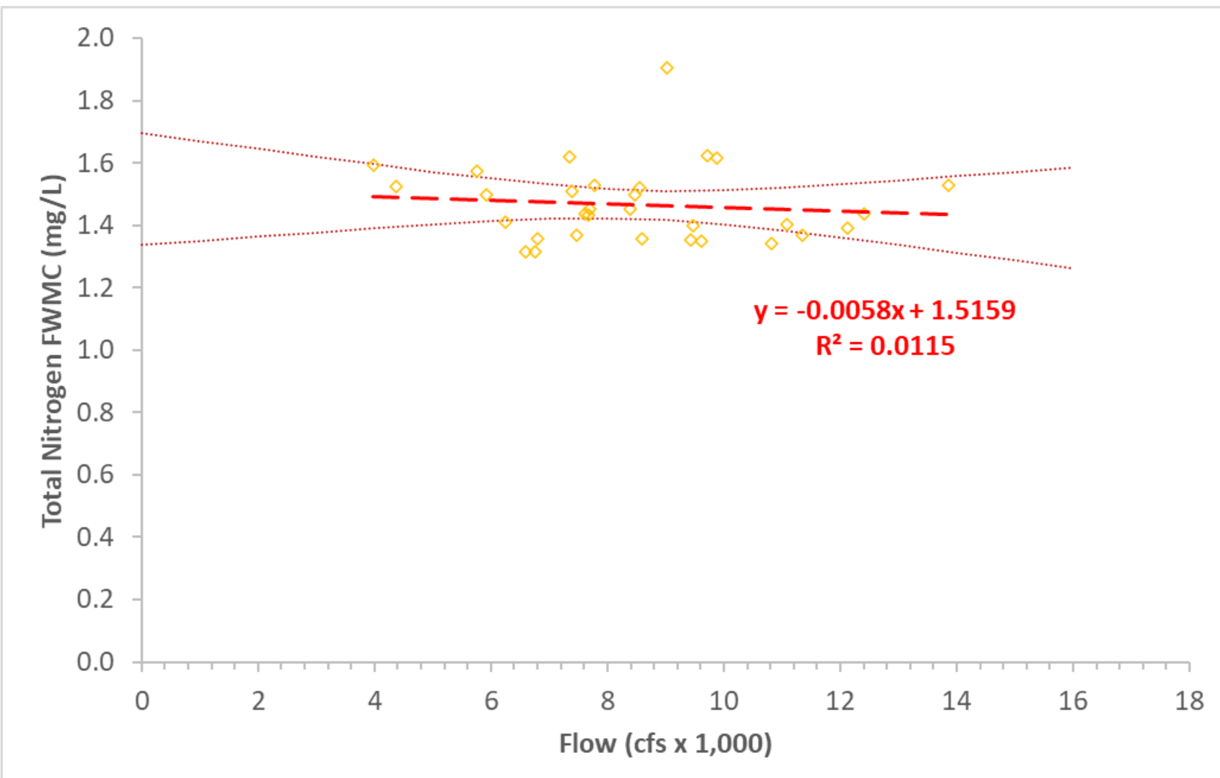


Figure 82. TP (top) and TN (bottom) FWMC and flow linear regressions for the Chippewa River at Durand, WI.

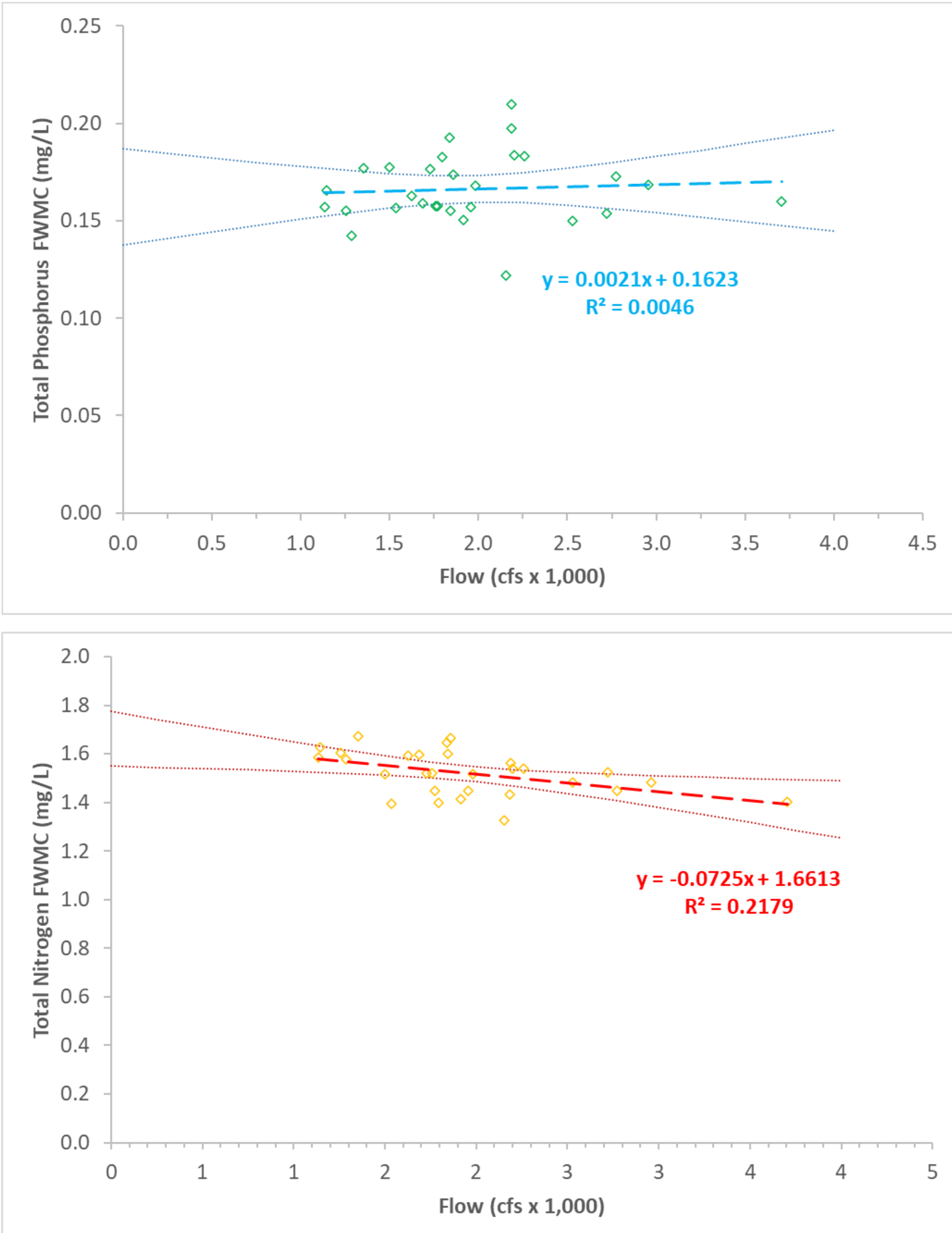


Figure 83. TP (top) and TN (bottom) FWMC and flow linear regressions for the Black River near Galesville, WI.

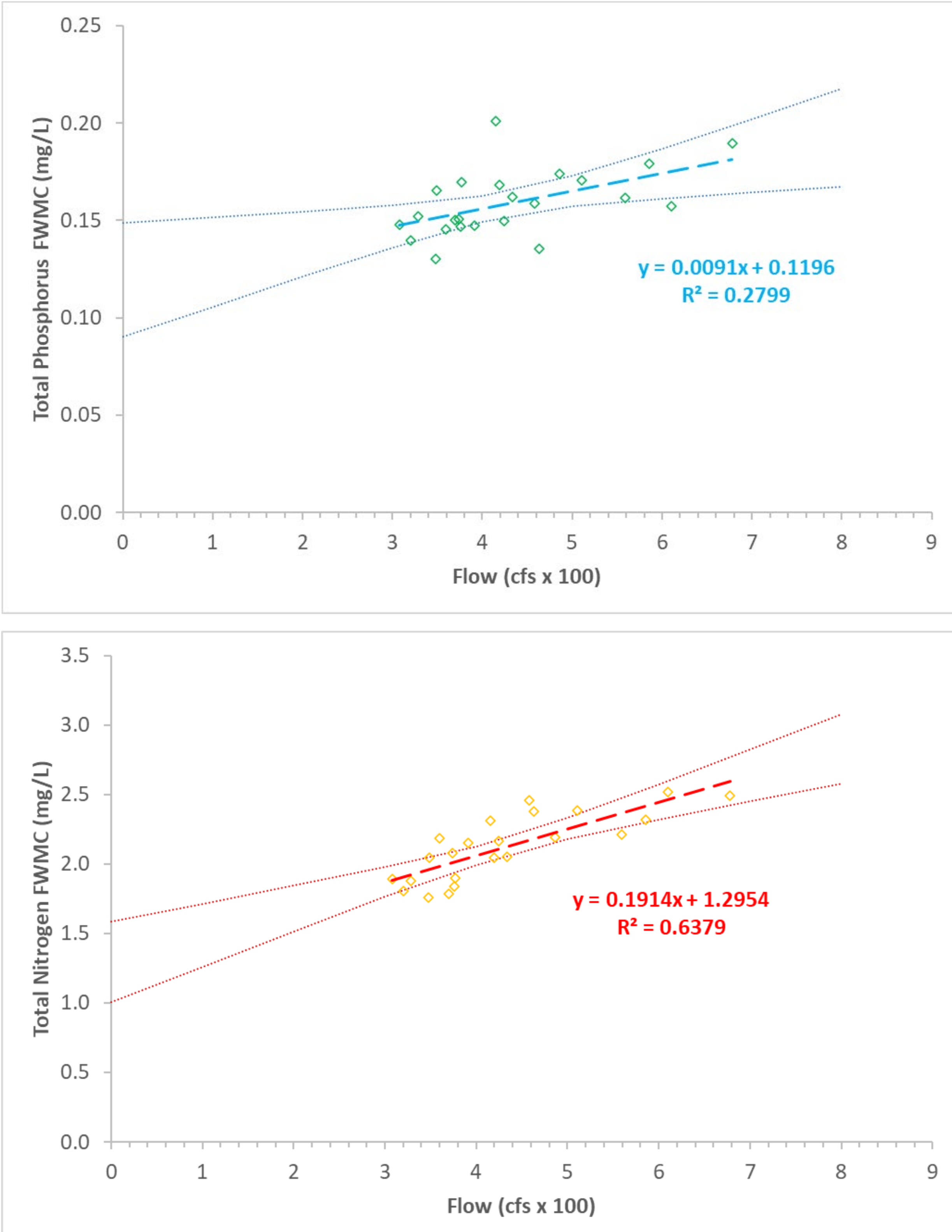
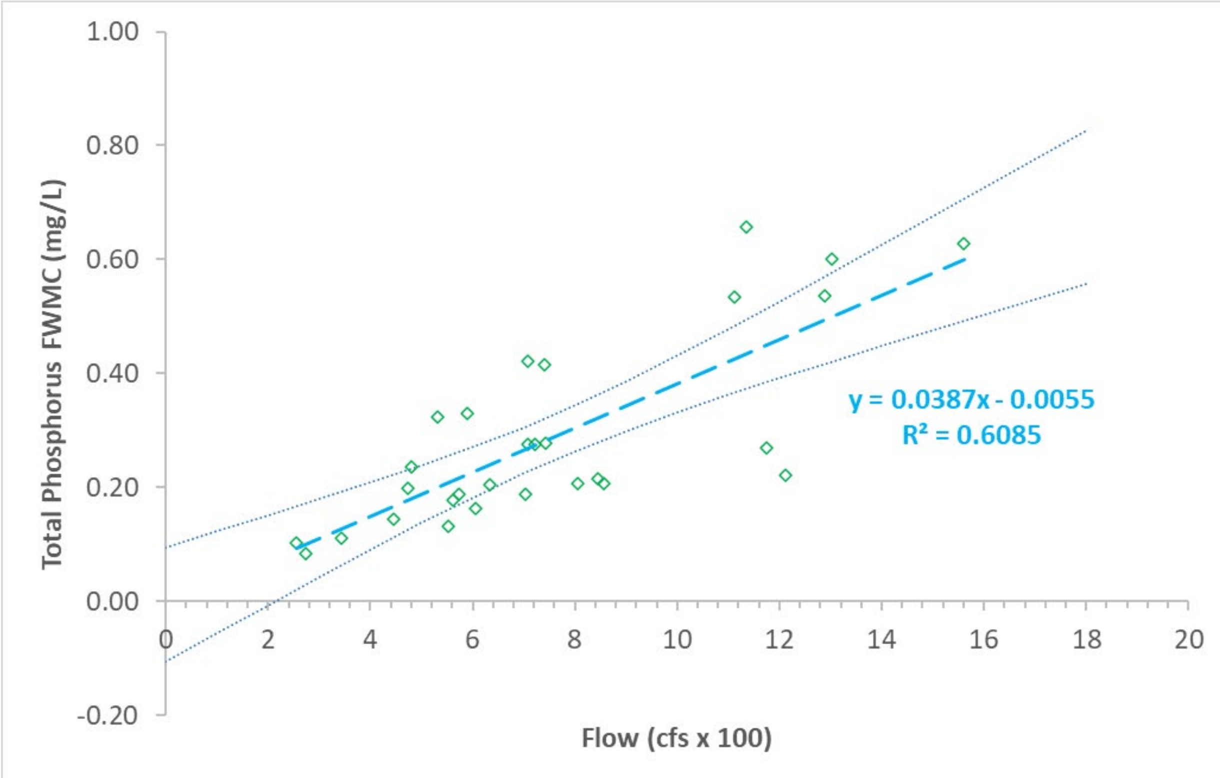


Figure 84. TP (top) and TN (bottom) FWMC and flow linear regressions for the La Crosse River near La Crosse, WI.



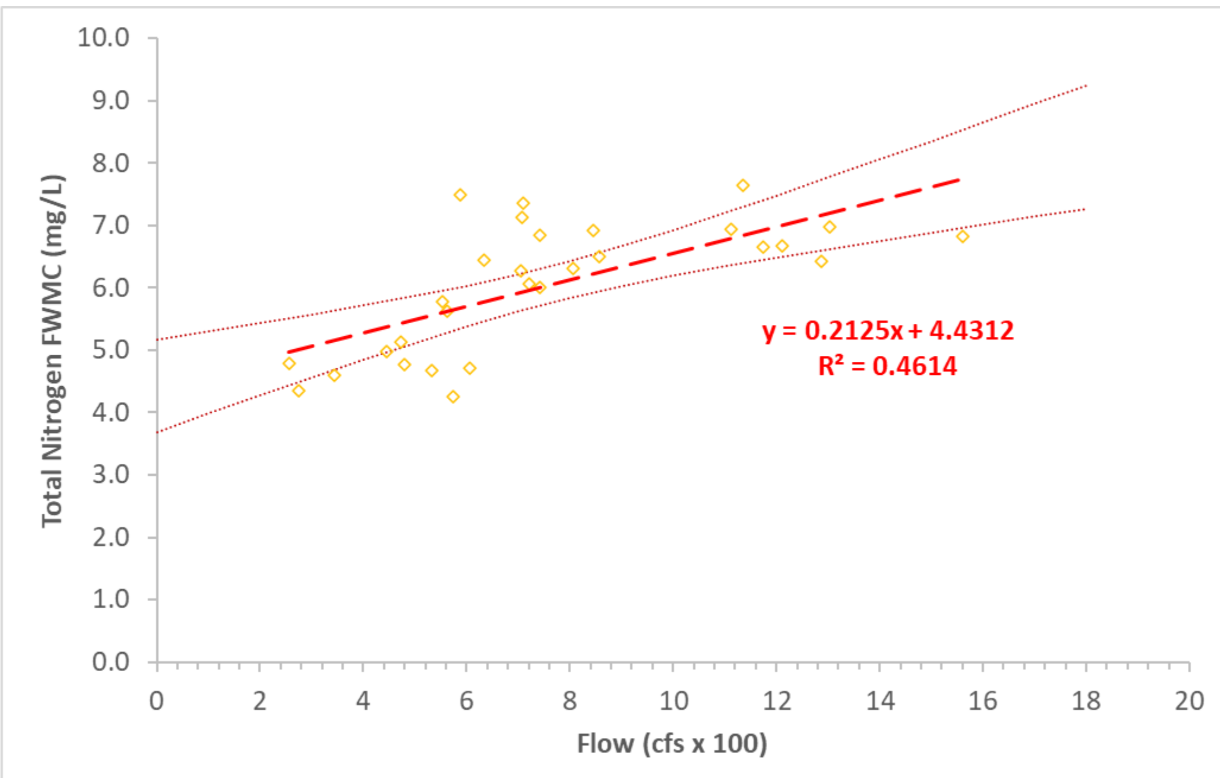
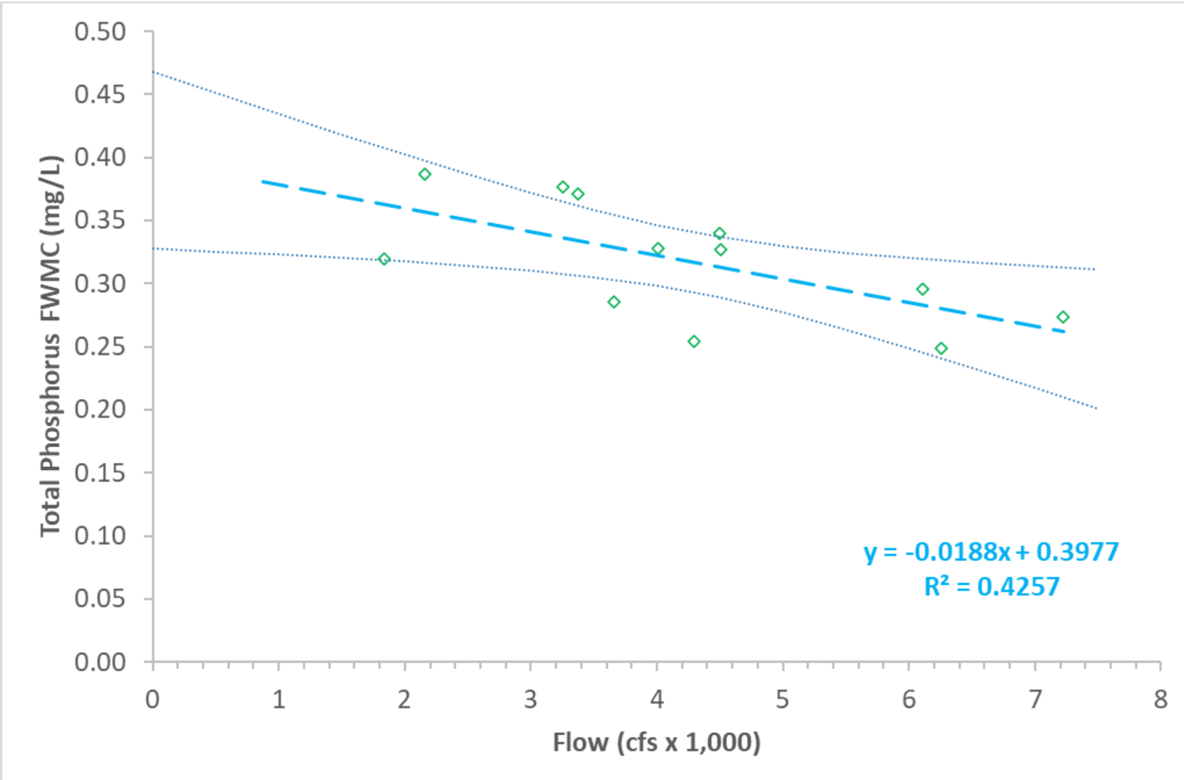


Figure 85. TP (top) and TN (bottom) FWMC and flow linear regressions for the Upper Iowa River near Dorchester, IA.



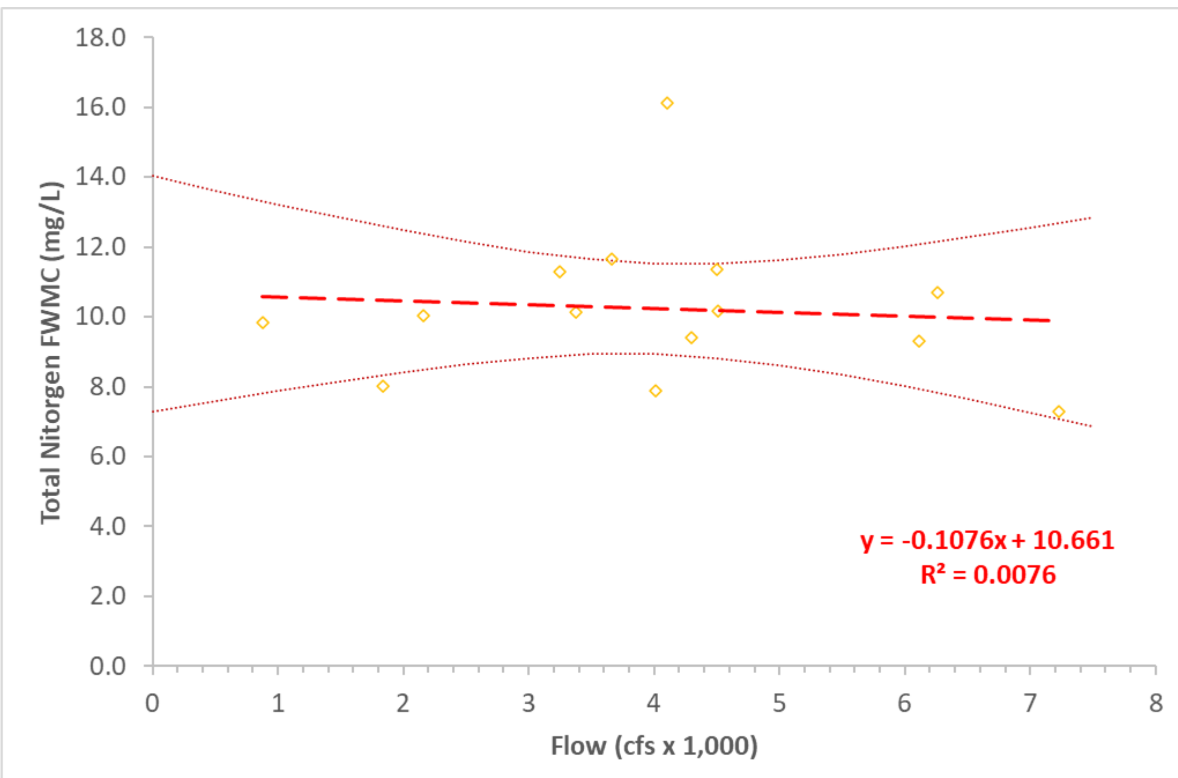


Figure 86. TP (top) and TN (bottom) FWMC and flow linear regressions for the Cedar River near Austin, MN.

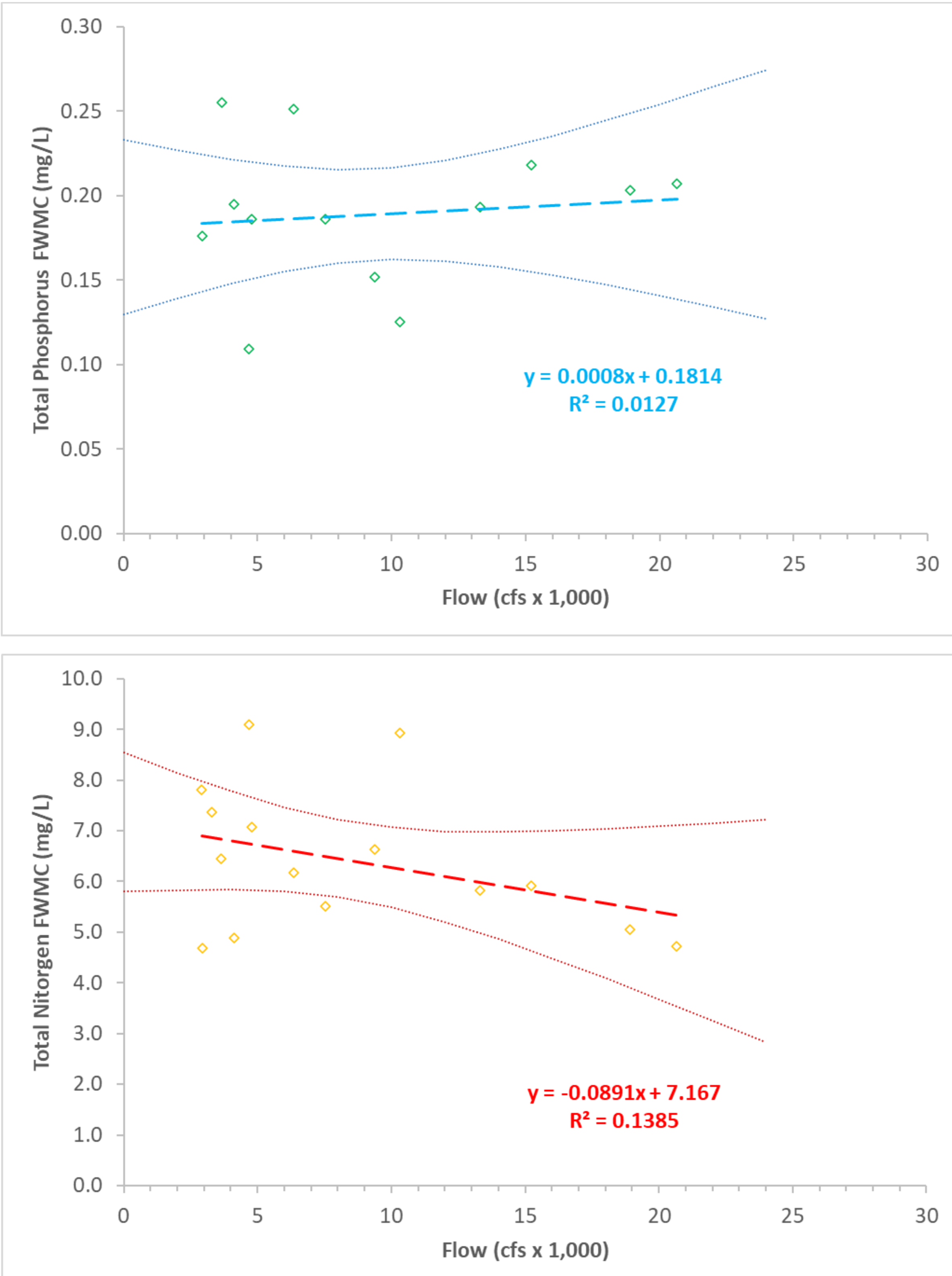
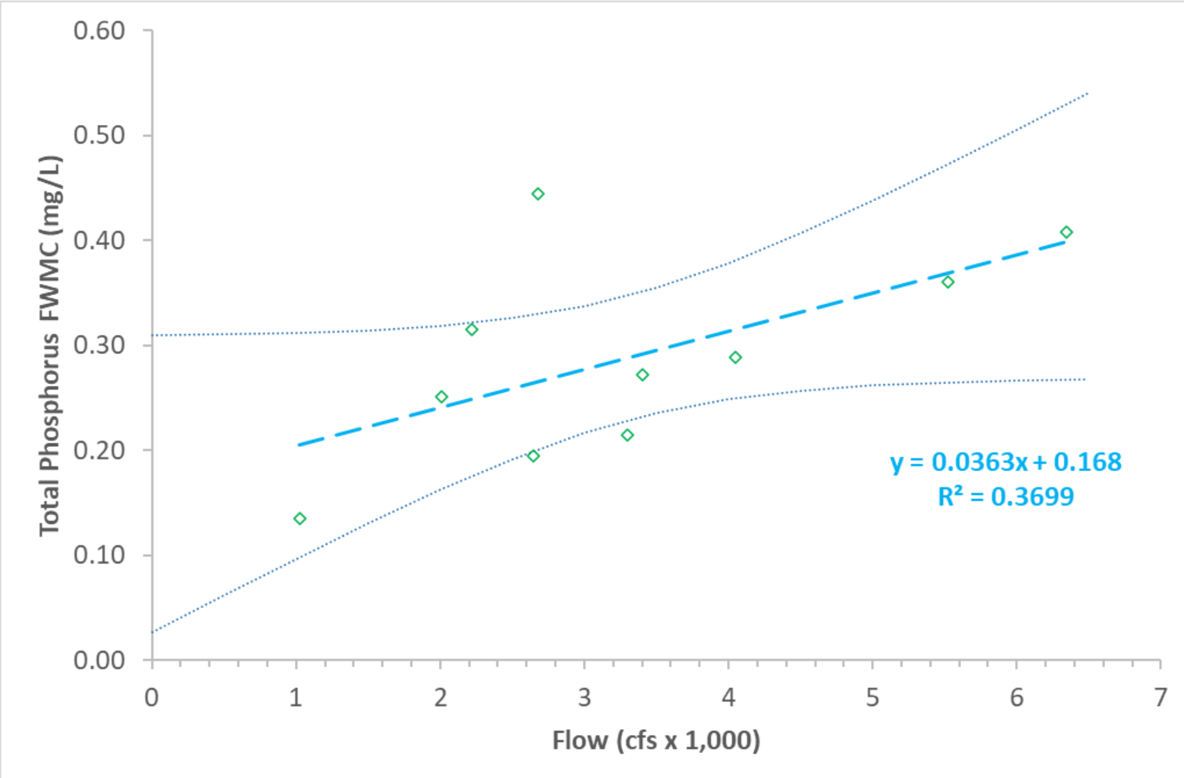


Figure 87. TP (top) and TN (bottom) FWMC and flow linear regressions for the West Fork Des Moines River at Jackson, MN.



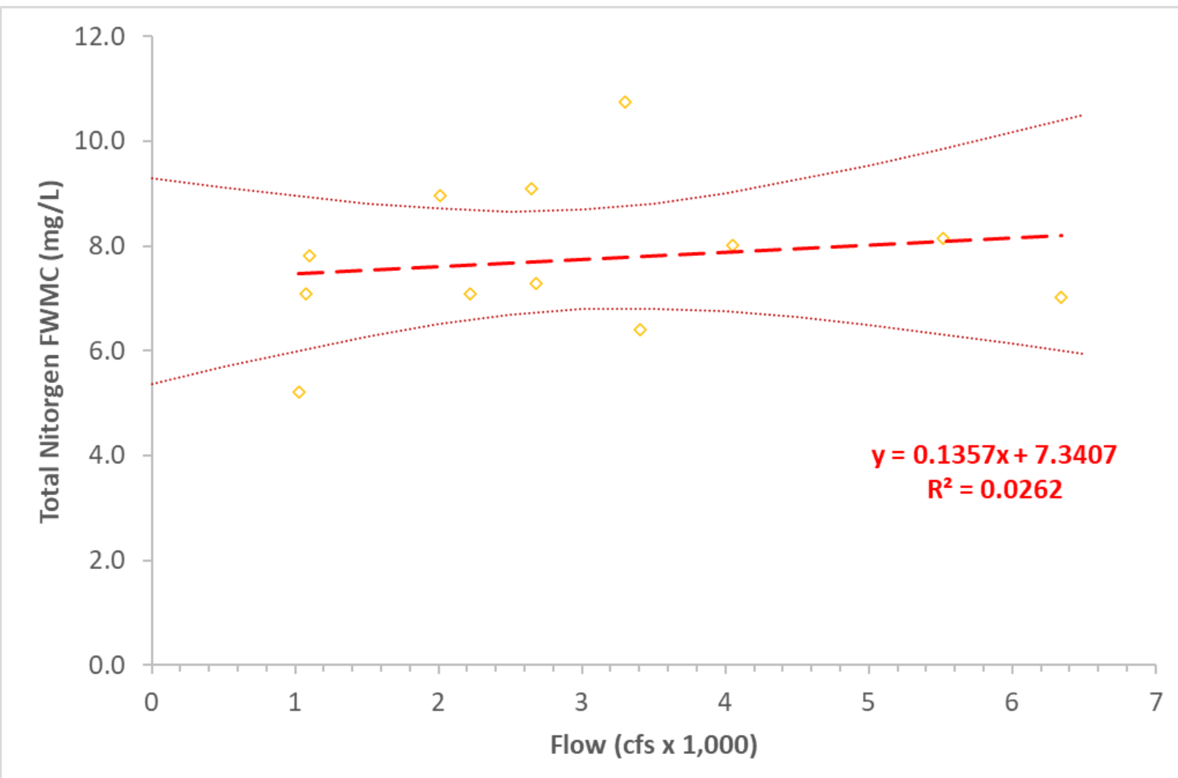


Figure 88. TP (top) and TN (bottom) FWMC and flow linear regressions for the Rock River at Luverne, MN.

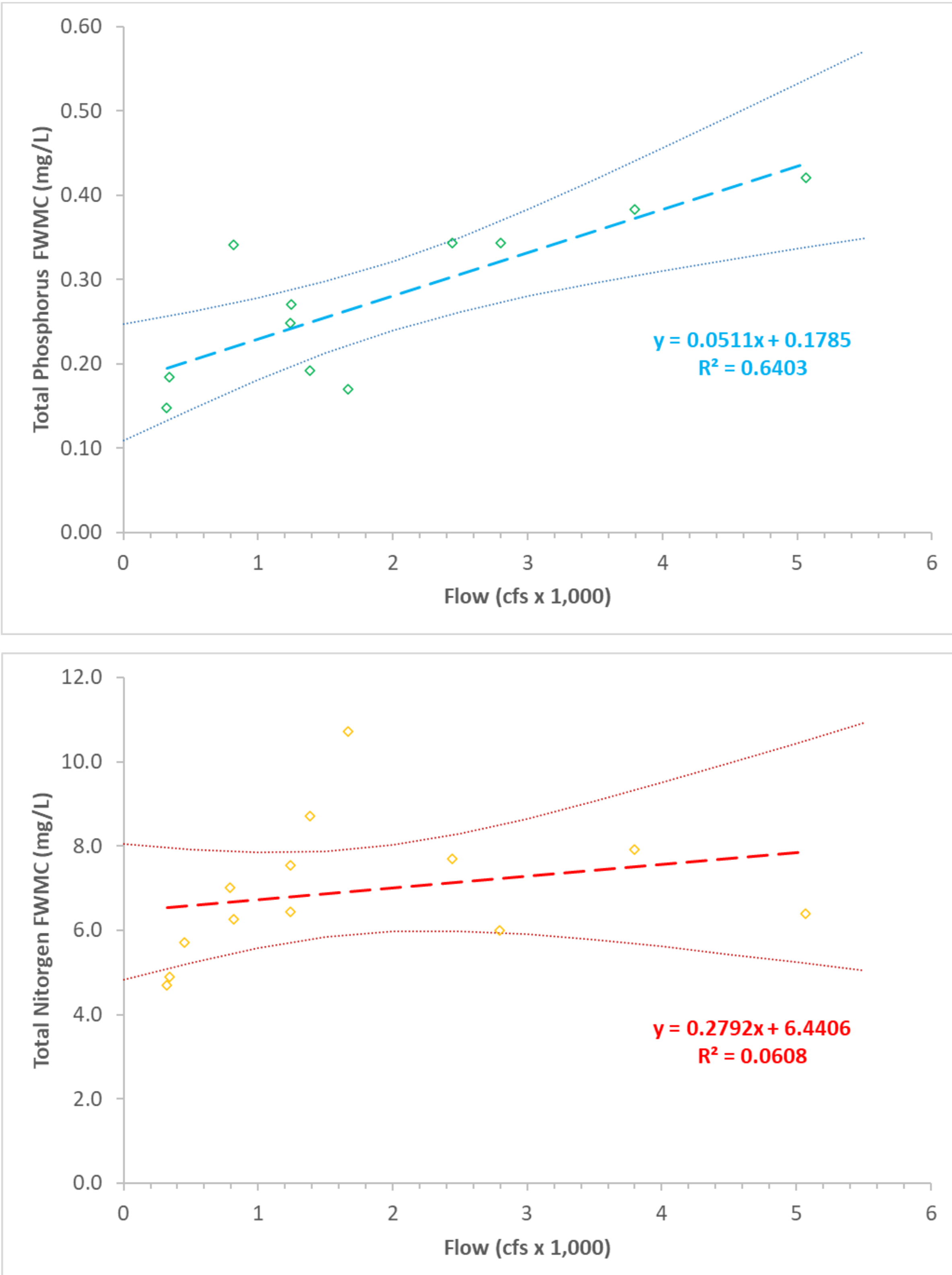
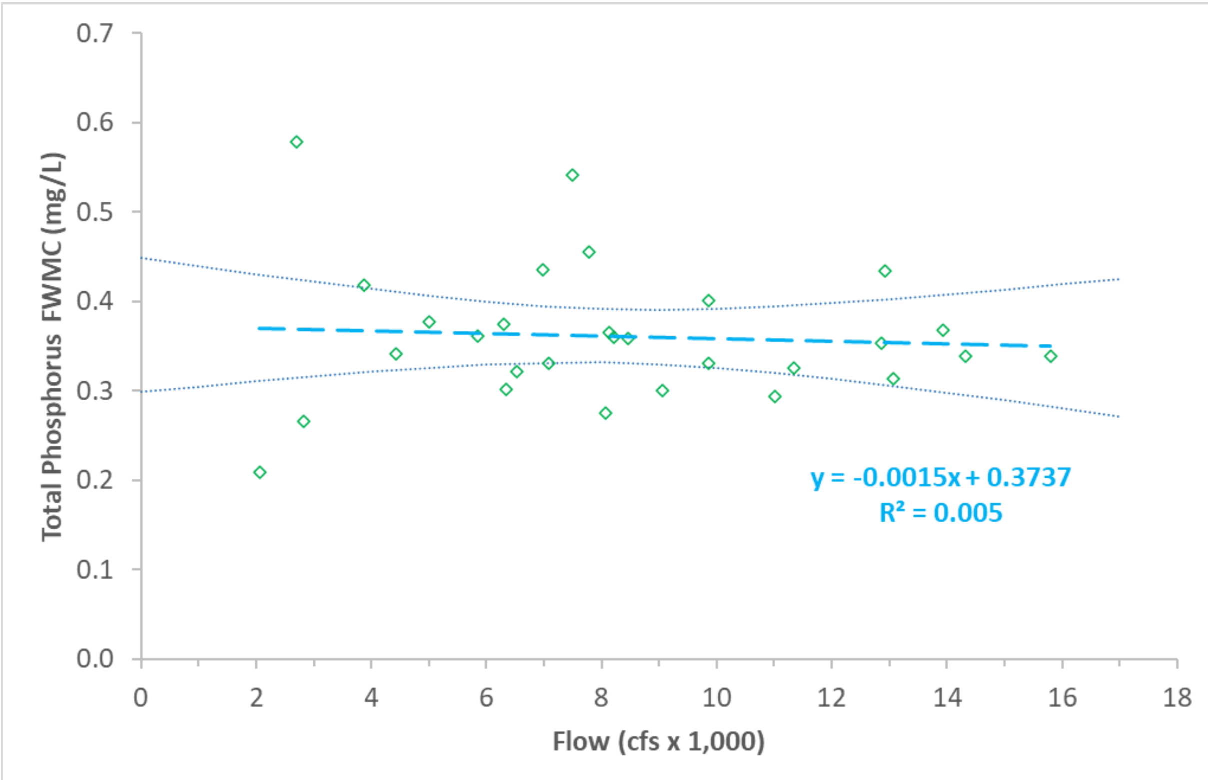


Figure 89. TP (top) and TN (bottom) FWMC and flow linear regressions for Split Rock Creek near Jasper, MN.

F.3 LAKE WINIPEG MAJOR BASIN



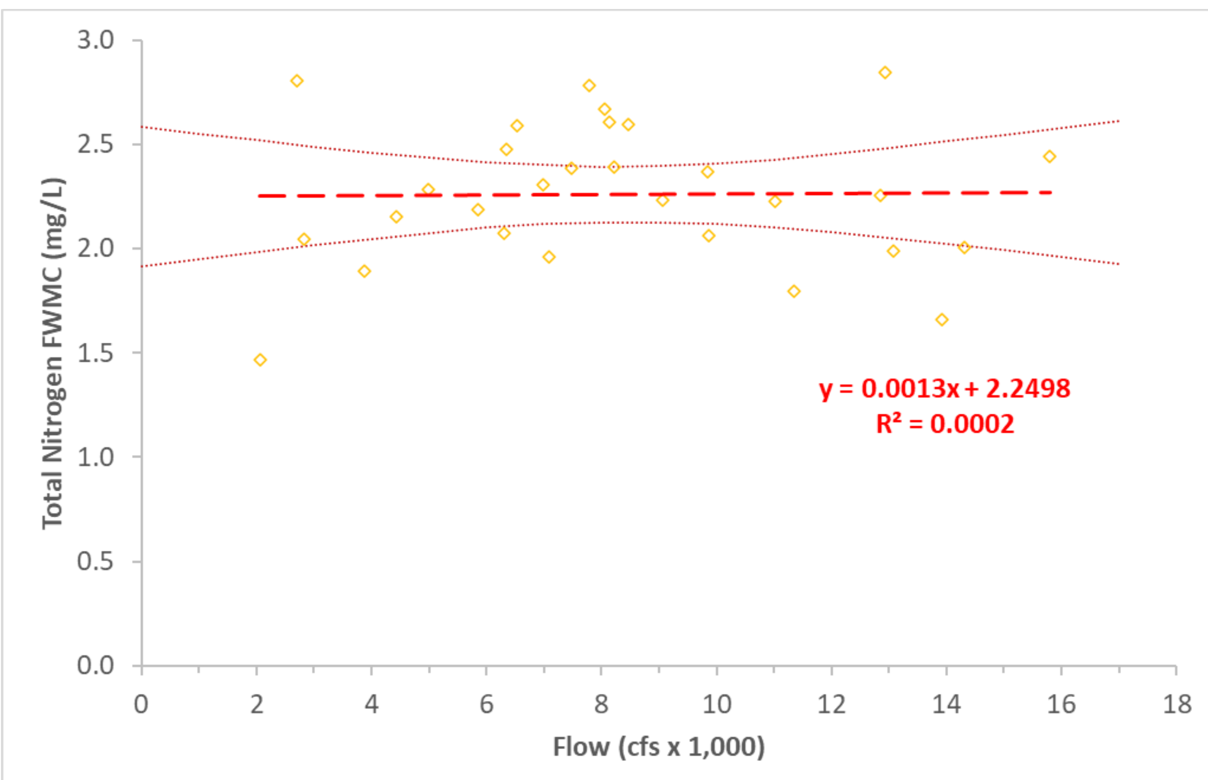


Figure 90. TP (top) and TN (bottom) FWMC and flow linear regressions for the Red River of the North at Emerson.

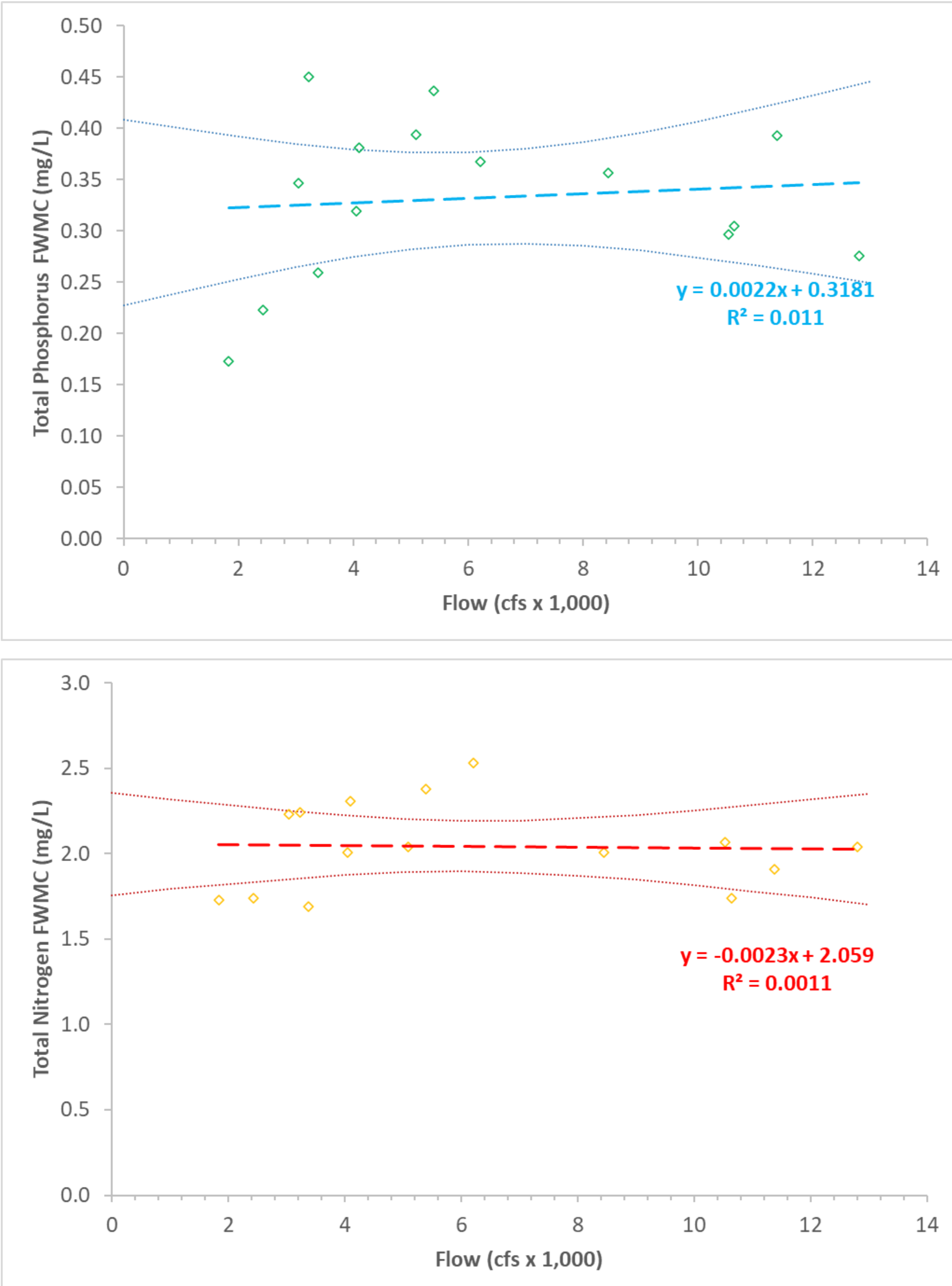


Figure 91. TP (top) and TN (bottom) FWMC and flow linear regressions for the Red River at Grand Forks, ND.

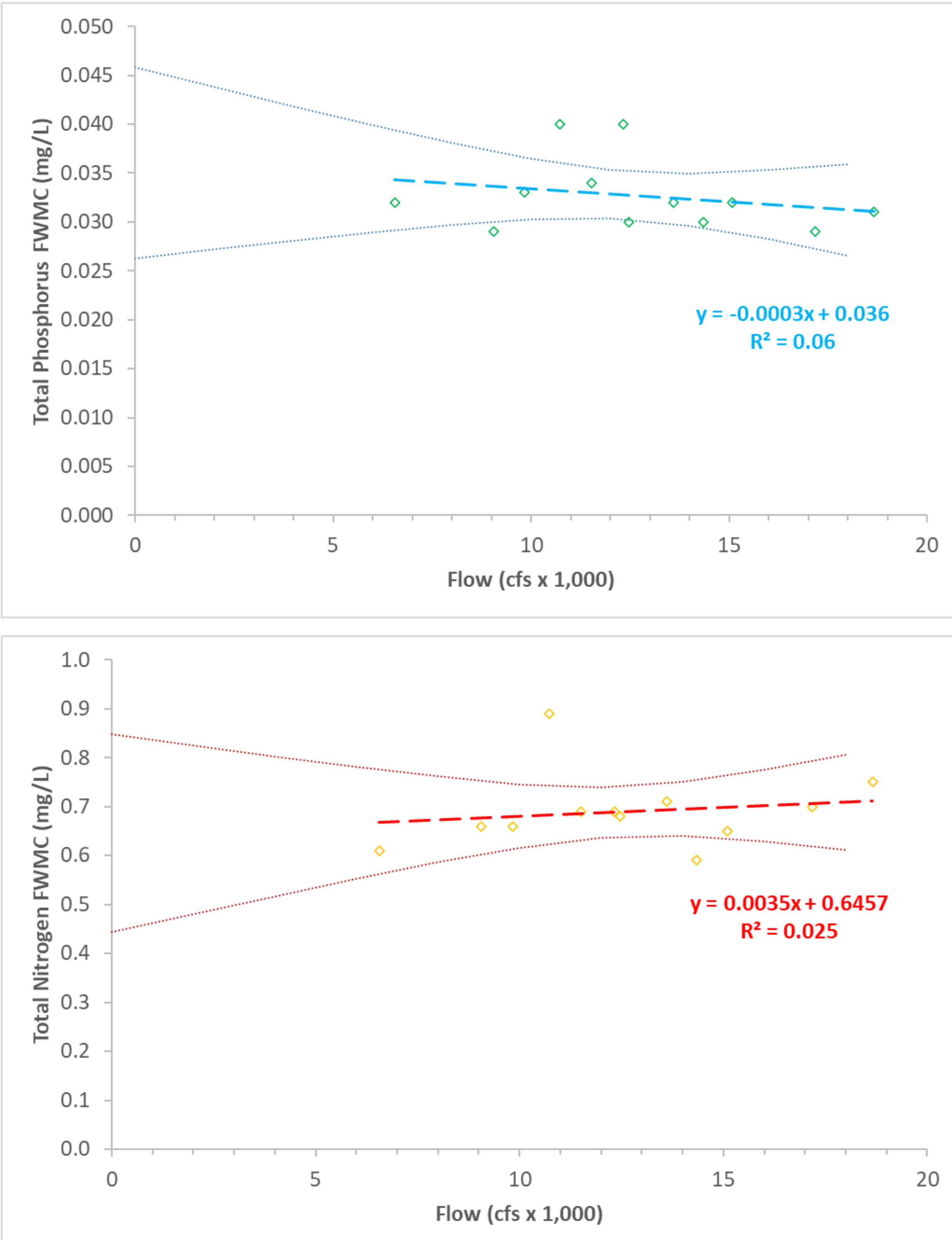
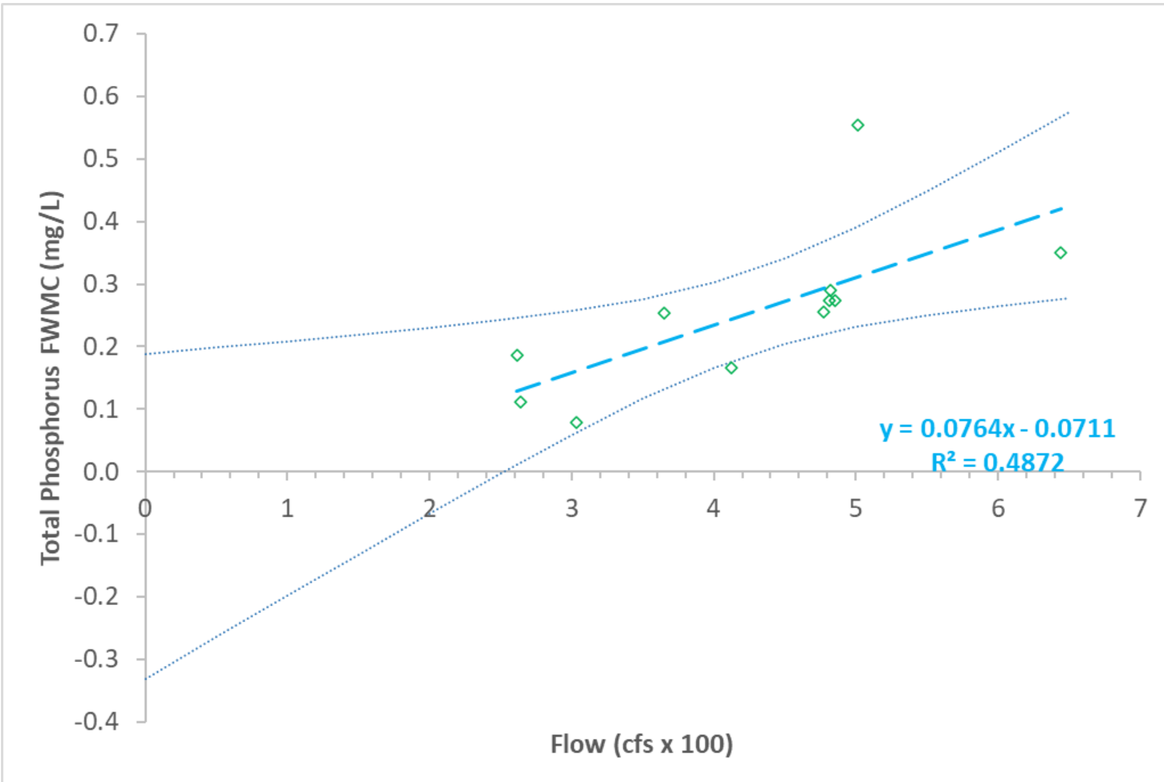


Figure 92. TP (top) and TN (bottom) FWMC and flow linear regressions for the Rainy River at Manitou Rapids, MN.

F.4 LAKE SUPERIOR MAJOR BASIN



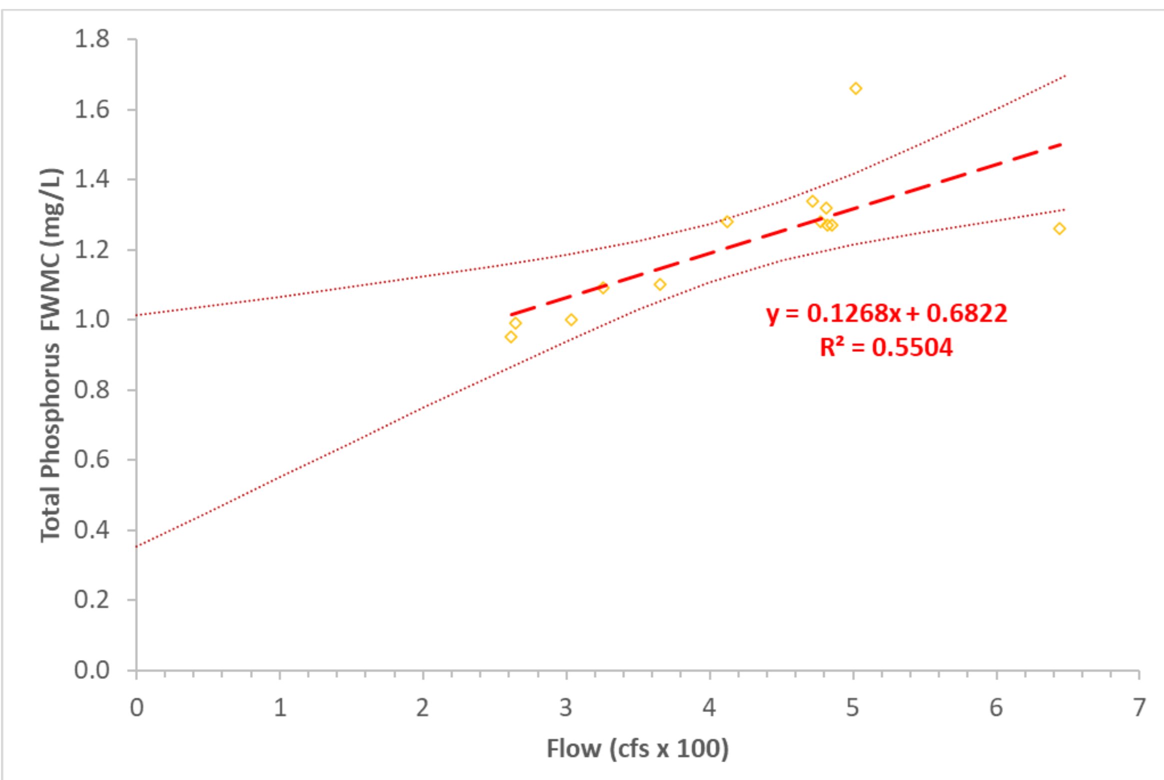


Figure 93. TP (top) and TN (bottom) FWMC and flow linear regressions for the Nemadji River near South Superior, WI.

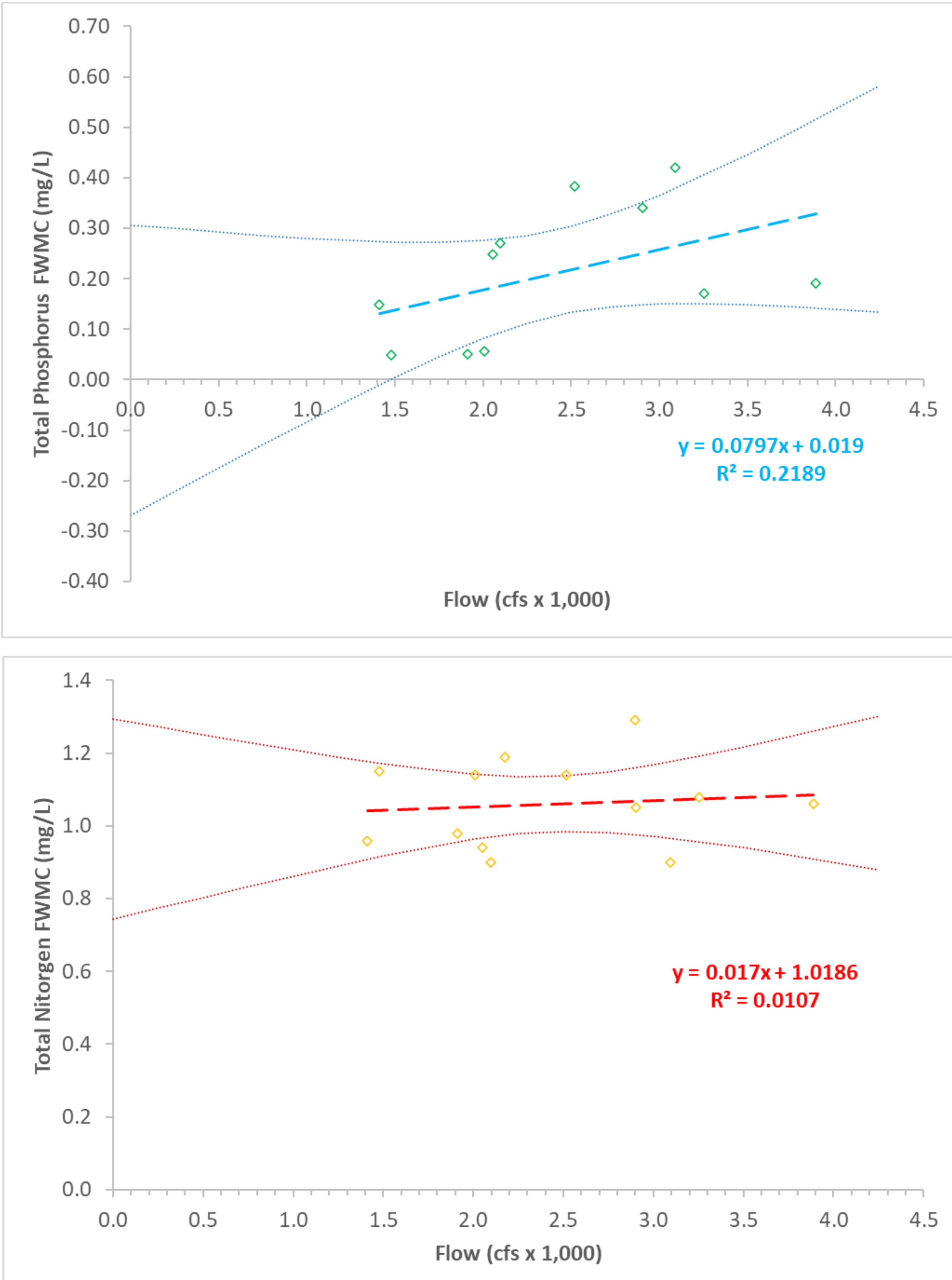


Figure 94. TP (top) and TN (bottom) FWMC and flow linear regressions for the St. Louis River at Scanlon, MN.

APPENDIX G. LOAD AND FLOW LINAR REGRESSION CHARTS

G.1 MISSISSIPPI RIVER AT ANOKA, MN (RM 872)

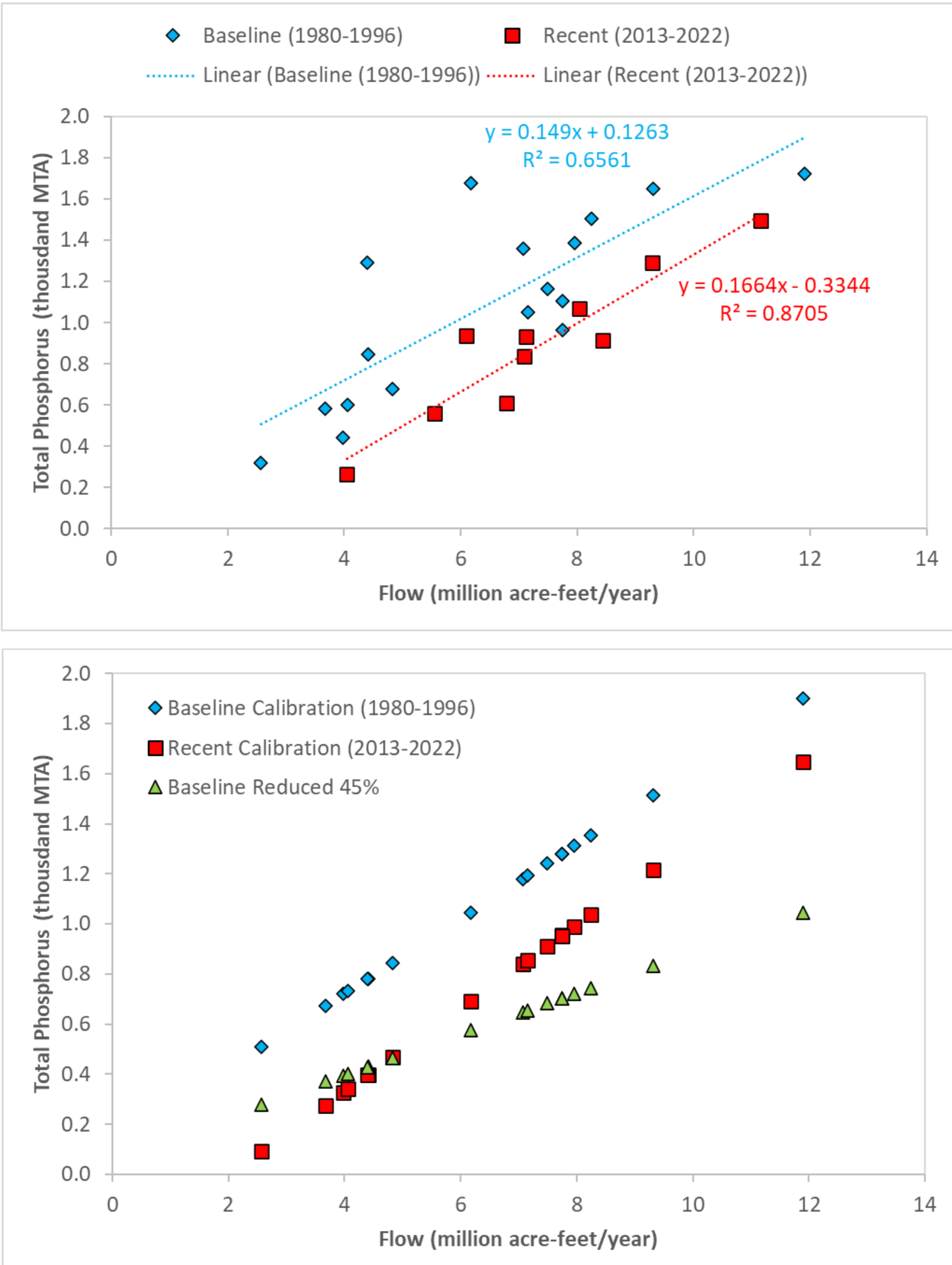


Figure 95. TP load and flow relationships in the baseline and current periods (top) and predicted loads using baseline flows (bottom) in the Mississippi River at Anoka, MN.

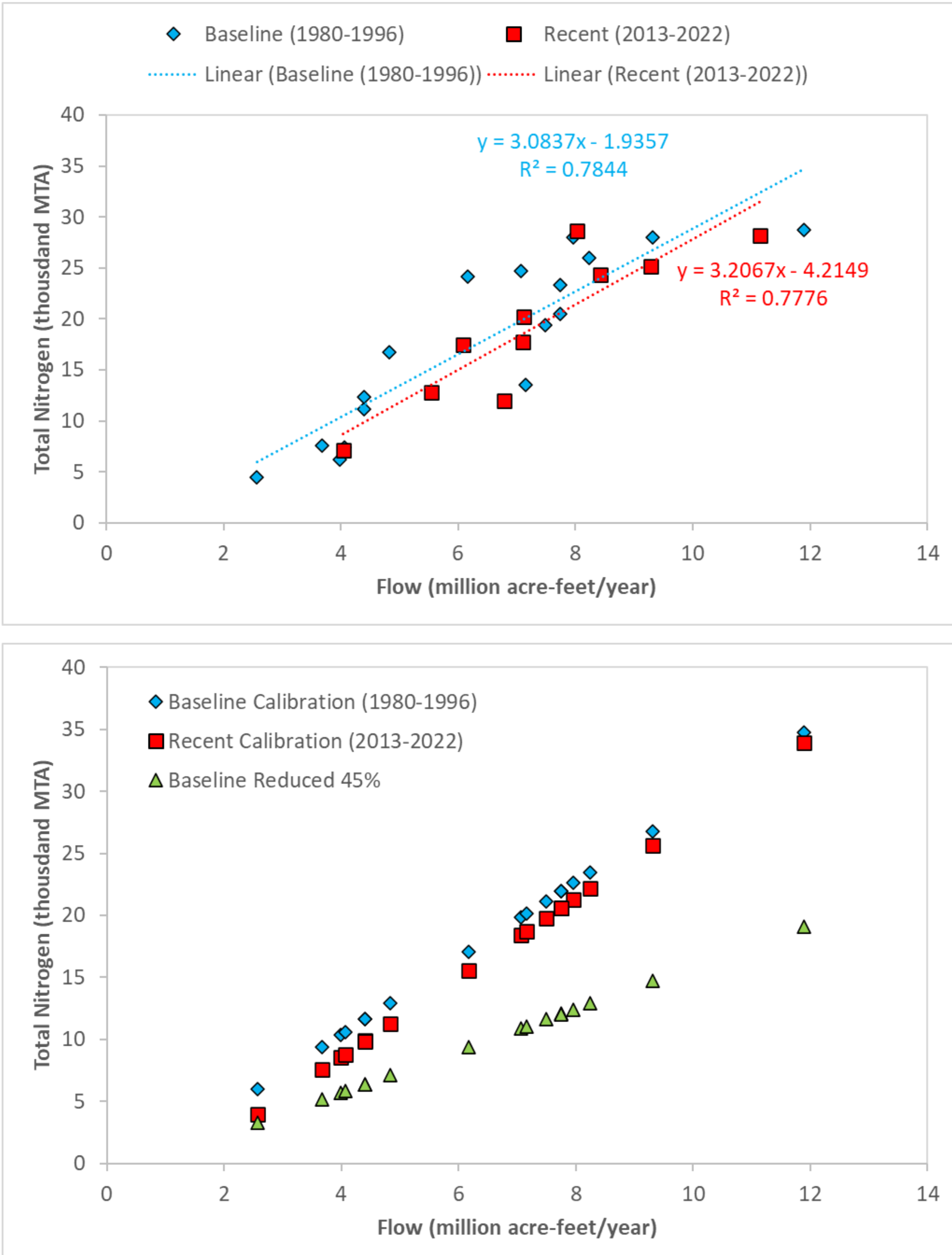


Figure 96. TN load and flow relationships in the baseline and current periods (top) and predicted loads using baseline flows (bottom) in the Mississippi River at Anoka, MN.

G.2 MISSISSIPPI RIVER AT RED WING, MN (RM 797; L&D #3)

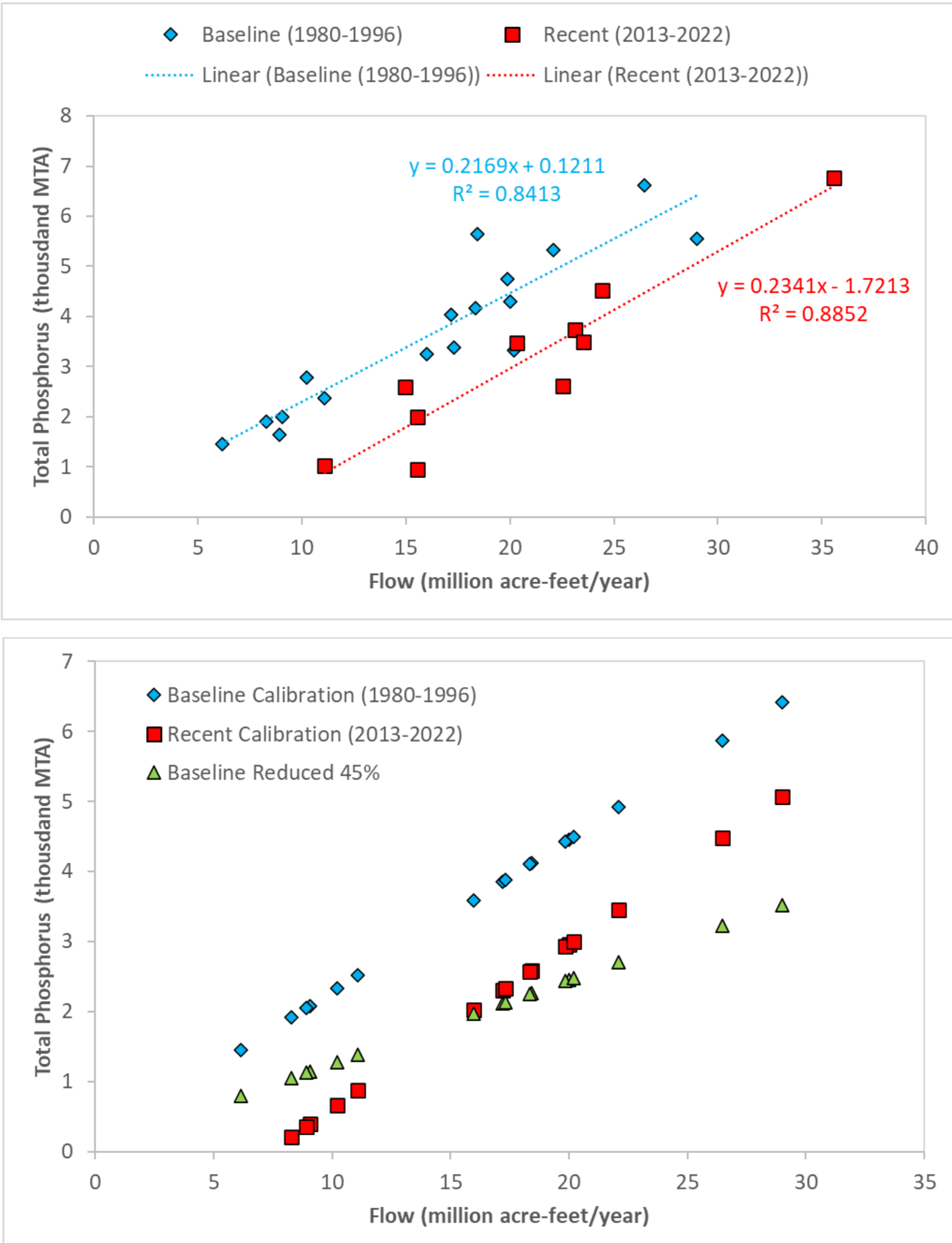


Figure 97. TP load and flow relationships in the baseline and current periods (top) and predicted loads using baseline flows (bottom) in the Mississippi River at Red Wing, MN.

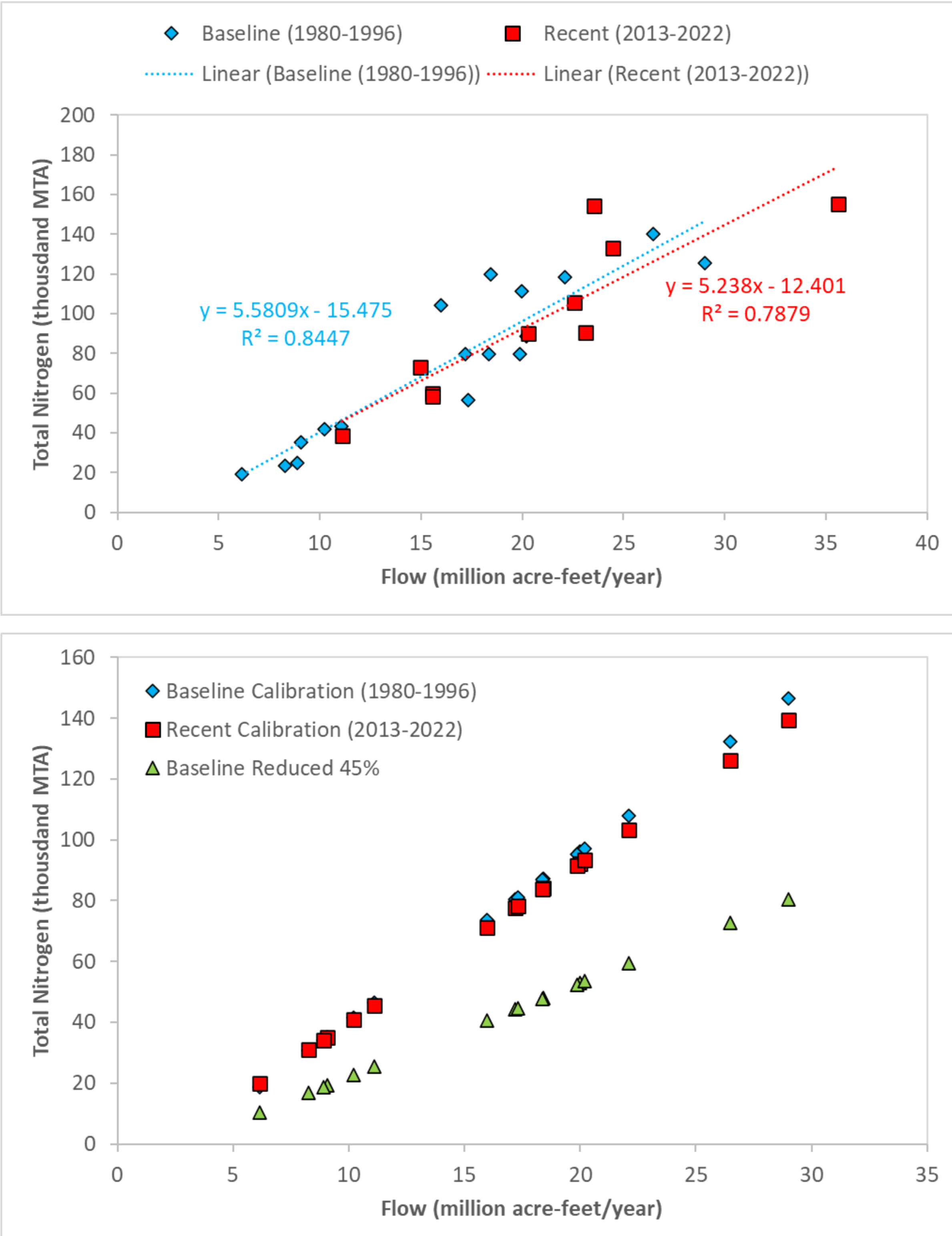


Figure 98. TN load and flow relationships in the baseline and current periods (top) and predicted loads using baseline flows (bottom) in the Mississippi River at Red Wing, MN.

G.3 MINNESOTA RIVER AT JORDAN, MN

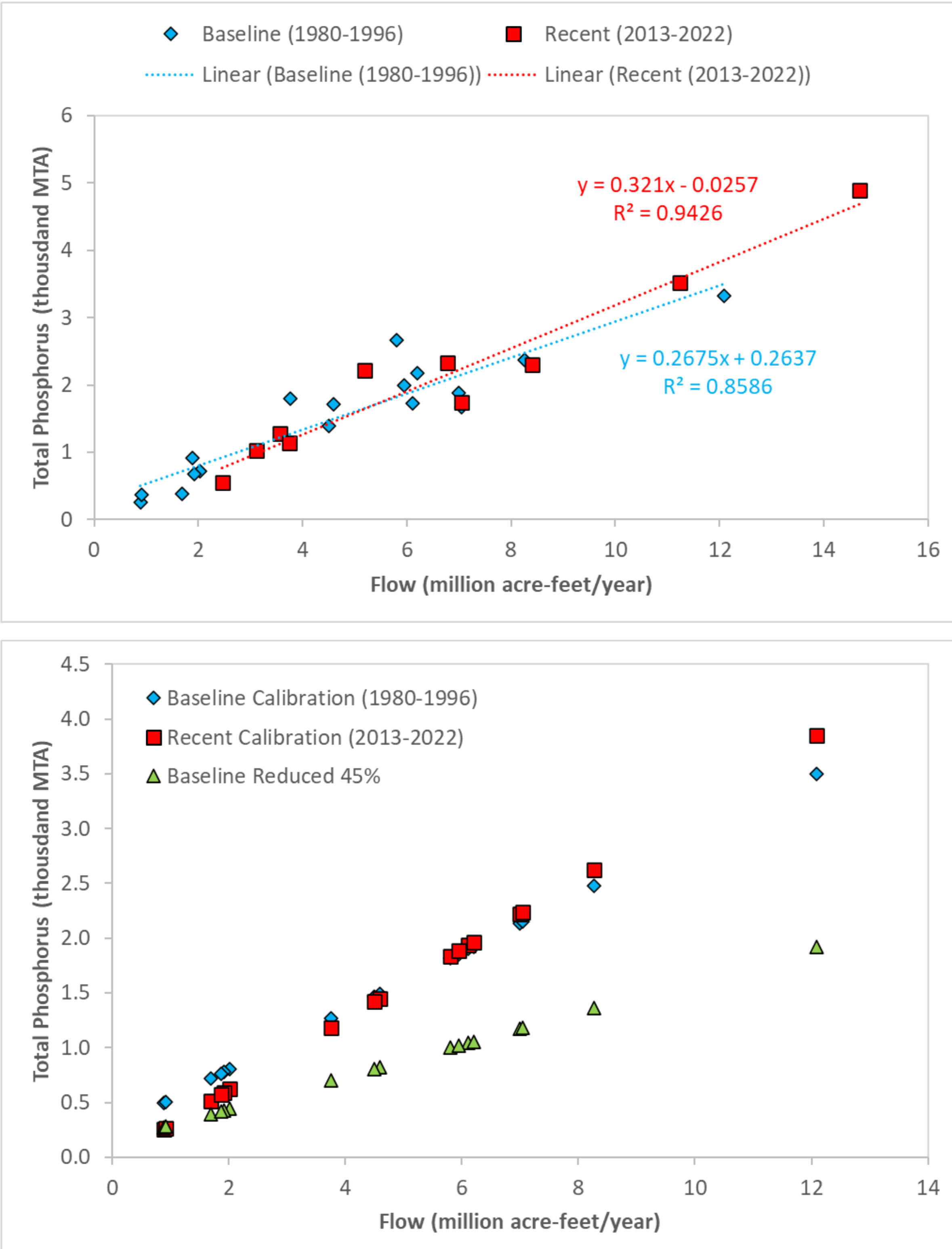


Figure 99. TP load and flow relationships in the baseline and current periods (top) and predicted loads using baseline flows (bottom) in the Minnesota River at Jordan, MN.

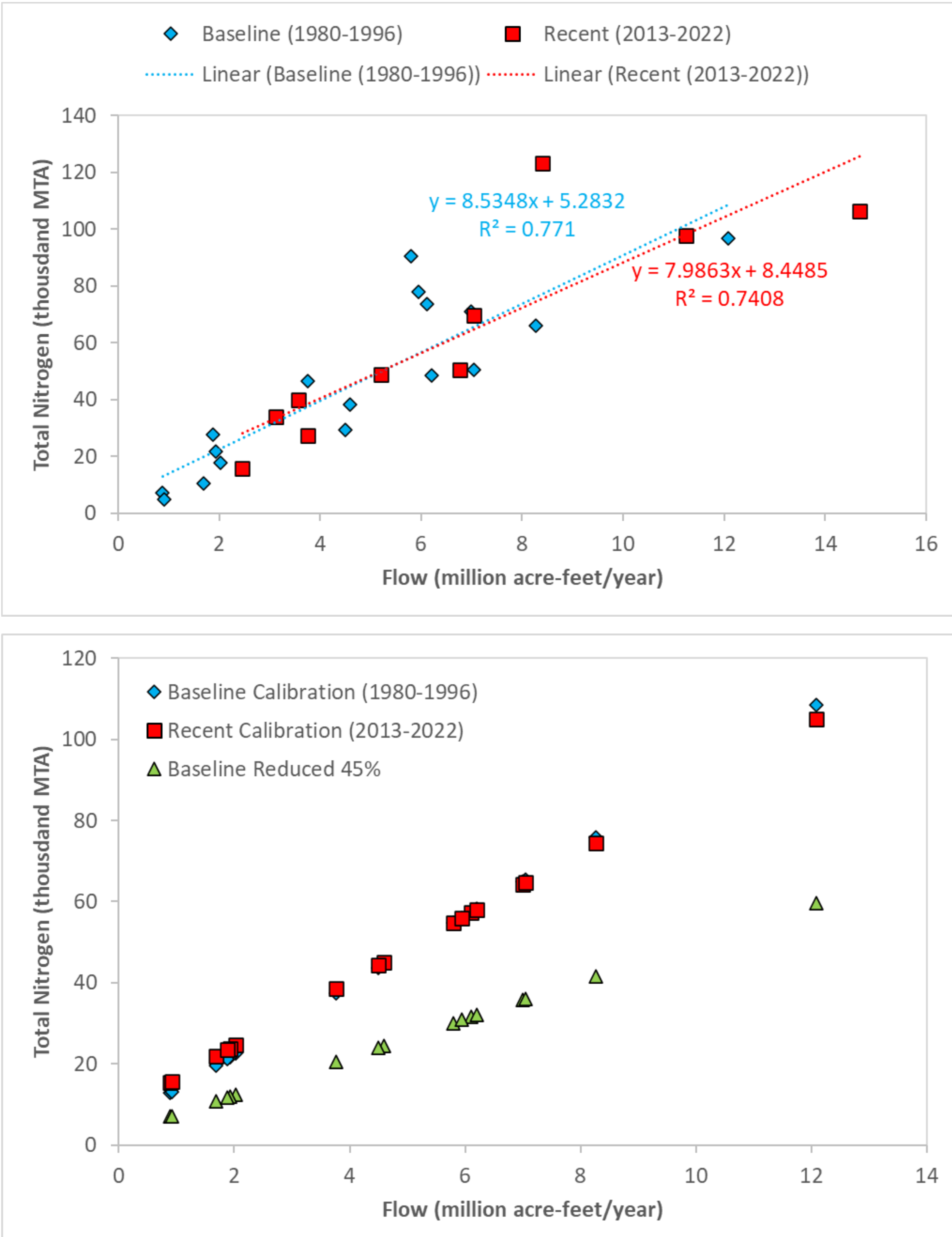
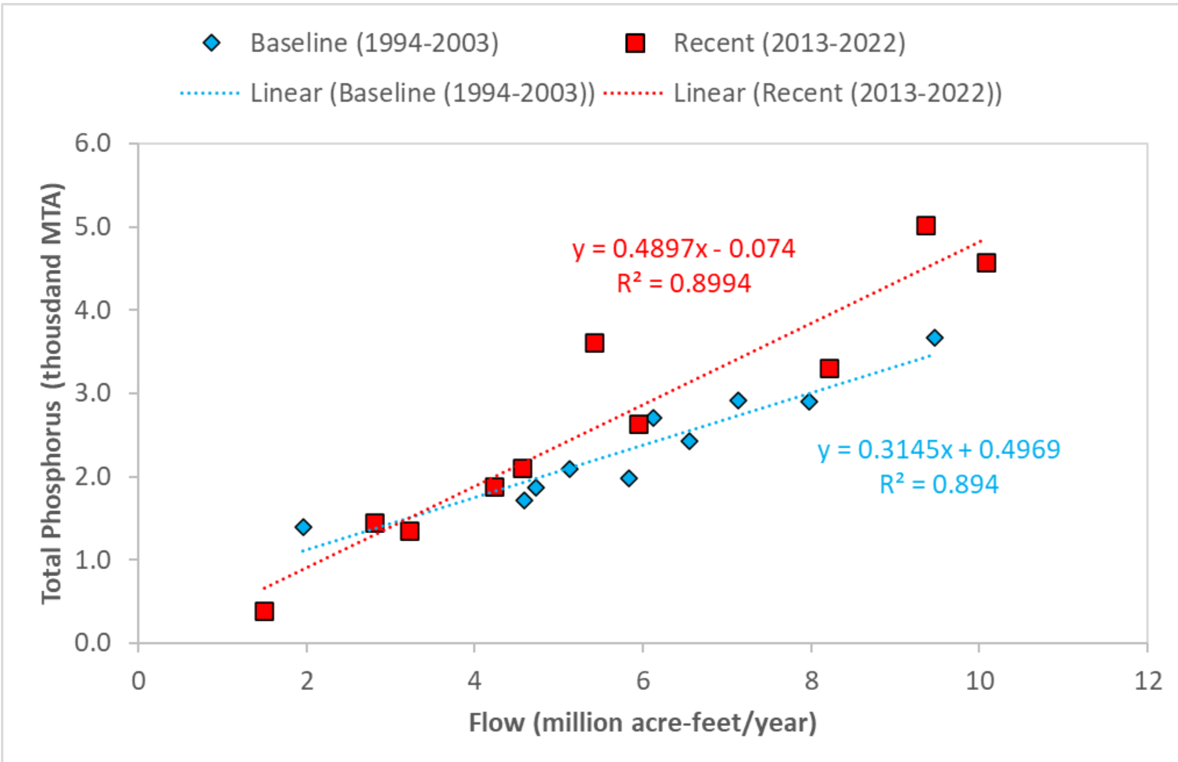


Figure 100. TN load and flow relationships in the baseline and current periods (top) and predicted loads using baseline flows (bottom) in the Minnesota River at Jordan, MN.

G.4 RED RIVER OF THE NORTH AT EMERSON, MANITOBA, CANADA



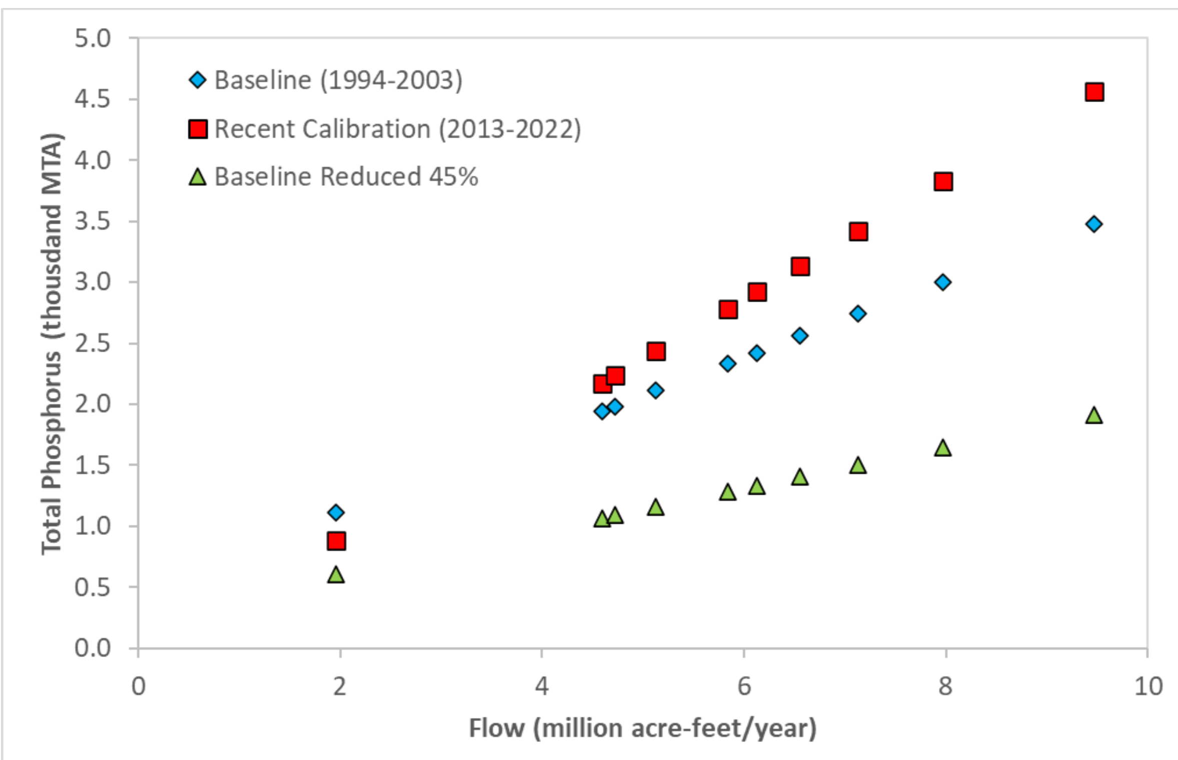
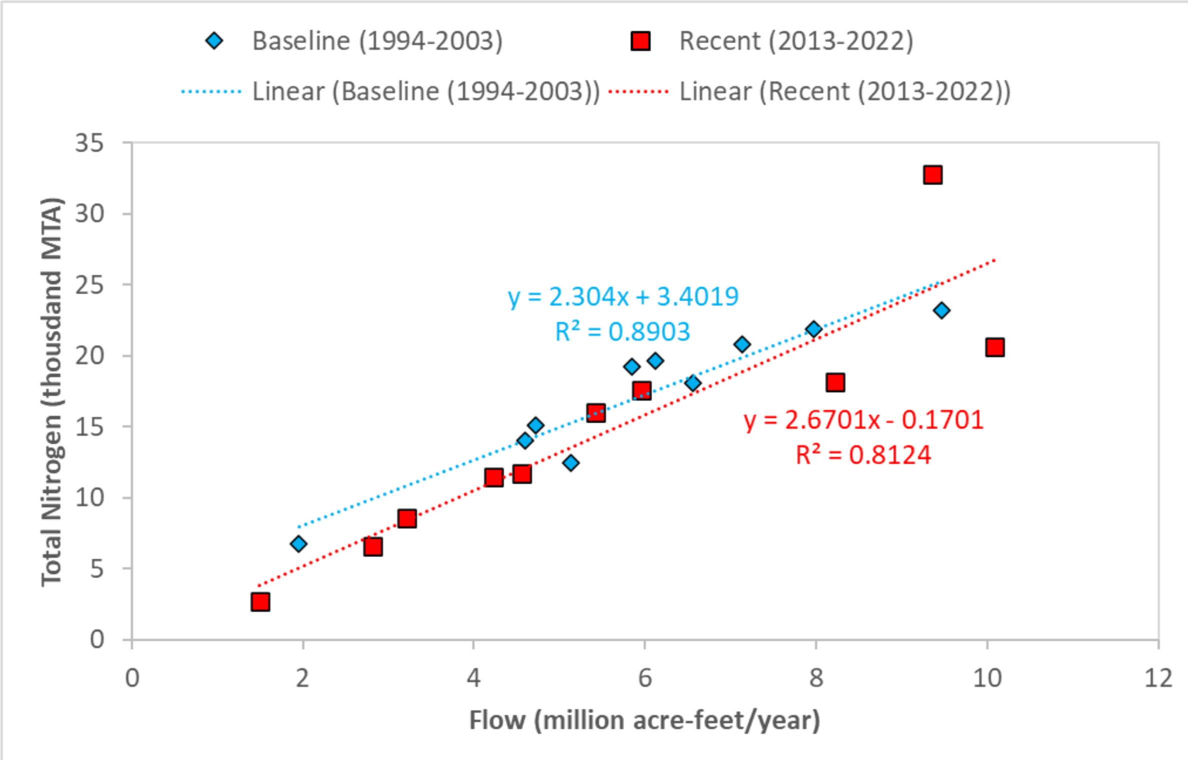


Figure 101. TP load and flow relationships in the baseline and current periods (top) and predicted loads using baseline flows (bottom) in the Red River of the North at Emerson, Manitoba, Canada.



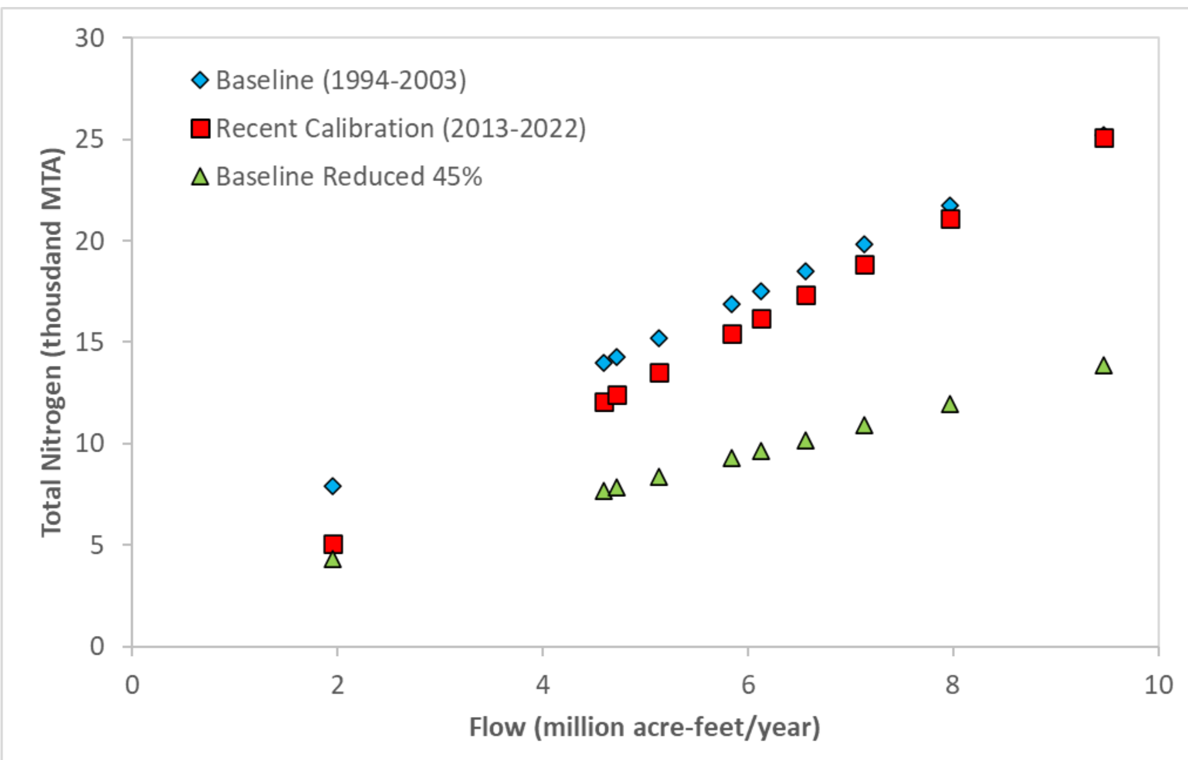


Figure 102. TN load and flow relationships in the baseline and current periods (top) and predicted loads using baseline flows (bottom) in the Red River of the North at Emerson, Manitoba, Canada.

APPENDIX H. IN-STATE AND OUT-OF-STATE TP AND TN LOADS

H.1 IN-STATE AND OUT-OF-STATE TP AND TN LOAD FRACTIONS

Table 49. Calculated TP and TN fractions at key monitoring sites for the Mississippi and Minnesota rivers

Monitoring sites	Relative TP loads (%)		Relative TN loads (%)	
	Minnesota	Out of state	Minnesota	Out of state
Mississippi River				
at Anoka, MN (RM 872)	100%	--	100%	--
at Red Wing, MN (RM 797; above L&D #3)	97.5%	2.5%	95.5%	4.5%
at La Crosse, WI (L&D #7)	81.4%	18.6%	77.7%	22.3%
Minnesota River				
at Jordan, MN	96.7%	3.3%	96.6%	3.4%

Notes

L&D = lock and dam; RM = river mile; TN = total nitrogen; TP = total phosphorus.

Percentages are rounded to the nearest one-tenth percentage point.

Table 50. Calculated TP and TN fractions at key monitoring sites for the *Lake Winnipeg* major basin

Monitoring sites	Relative TP loads (%)		Relative TN loads (%)	
	Minnesota	Out of state	Minnesota	Out of state
Red River at Emerson, Manitoba, Canada	34.1%	65.9%	38.9%	61.1%
Red River at Grand Forks, ND	43.6%	56.4%	46.9%	53.1%
Rainy River at Manitou Rapids, MN	53.4%	46.6%	26.8%	73.2%

Notes

TN = total nitrogen; TP = total phosphorus.

Percentages are rounded to the nearest one-tenth percentage point.

Table 51. Calculated TP and TN fractions at key monitoring sites for the *Lake Superior* major basin

Monitoring sites	Relative TP loads (%)		Relative TN loads (%)	
	Minnesota	Out of state	Minnesota	Out of state
Nemadji River near South Superior, WI	53.5%	46.5%	63.8%	36.2%
St. Louis River at Scanlon, MN	100%	--	100%	--

Notes

TN = total nitrogen; TP = total phosphorus.

Percentages are rounded to the nearest one-tenth percentage point.

H.2 IN-STATE AND OUT-OF-STATE BASELINE AND RECENT TP AND TN LOADS

Table 52. In-state and out-of-state TP loads at key sites in the Mississippi and Minnesota rivers

Monitoring sites	Load estimation method	1980-1996			2013-2022		
		In-stream (MTA)	Minnesota (MTA)	Out of state (MTA)	In-stream (MTA)	Minnesota (MTA)	Out of state (MTA)
Mississippi River							
at Anoka, MN	FLUX32	1,079	1,079	--	890	890	--
at Red Wing, MN	FLUX32	3,676	3,584	92	3,119	3,041	78
	WRTDS	4,082	3,980	102	3,512	3,424	88
	WRTDS flow-normalized	4,207	4,102	105	2,697	2,629	67
at La Crosse, WI	WRTDS	4,976 [a]	4,050	926	4,670	3,801	869
	WRTDS flow-normalized	--	--	--	4,475	3,643	832
Minnesota River							
at Jordan, MN	FLUX32	1,532	1,482	51	2,100	2,030	69
	WRTDS	1,801	1,741	59	2,119	2,049	70
	WRTDS flow-normalized	1,725	1,668	57	1,558	1,506	51

Notes

MTA = metric ton annually; TP = total phosphorus.

Refer to Table 6 and Table 7 for the full monitoring site names.

Refer to Table 49 for the in-state and out-of-state TP load fractions at each monitoring site.

a. This load is for the *Mississippi River near State Border* in the 2014 NRS (MPCA 2014, Table 3-7, p. 3-27) and was not calculated using WRTDS.

Table 53. In-state and out-of-state TN loads at key sties in the Mississippi and Minnesota rivers

Monitoring sites	Load estimation method	1980-1996			2013-2022		
		In-stream (MTA)	Minnesota (MTA)	Out of state (MTA)	In-stream (MTA)	Minnesota (MTA)	Out of state (MTA)
Mississippi River							
at Anoka, MN	FLUX32	17,778	17,778	--	19,378	19,378	--
at Red Wing, MN	FLUX32	75,982	72,563	3,419	95,890	91,575	4,315
	WRTDS	79,899	76,304	3,595	105,410	100,667	4,743
	WRTDS flow-normalized	82,473	78,762	3,711	82,138	78,442	3,696
at La Crosse, WI	WRTDS	97,996	76,143	21,853	113,887	88,490	25,397
	WRTDS flow-normalized	--	--	--	103,995	80,804	23,191
Minnesota River							
at Jordan, MN	FLUX32	45,752	44,196	1,556	61,333	59,248	2,085
	WRTDS	52,033	50,264	1,769	63,173	61,025	2,148
	WRTDS flow-normalized	52,638	50,848	1,790	43,495	42,016	1,479

Notes

MTA = metric ton annually; TN = total nitrogen.

Refer to Table 6 and Table 7 for the full monitoring site names and the baseline and recent periods.

Refer to Table 49 for the in-state and out-of-state TP load fractions at each monitoring site.

Table 54. In-state and out-of-state TP loads in the Red River of the North at Emerson, Manitoba, Canada

Monitoring entity	Load estimation method	1998-2001			2013-2022		
		In-stream (MTA)	Minnesota (MTA)	Out of state (MTA)	In-stream (MTA)	Minnesota (MTA)	Out of state (MTA)
CWSEC	FLUX32	2,599	985	1,614	2,635	999	1,636
CSWEC (by MPCA)	WRTDS	2,828	1,072	1,756	2,765	1,048	1,717
	WRTDS flow-normalized	2,643	1,002	1,641	2,925	1,109	1,816

Notes

MTA = metric ton annually; TP = total phosphorus.

Refer to Table 14 for the full monitoring site names and the baseline and current periods.

Refer to Table 50 for the in-state and out-of-state TP load fractions at each monitoring site.

Table 55. In-state and out-of-state TN loads in the *Lake Winnipeg* major basin

Monitoring entity	Load estimation method	1998-2001			2013-2022		
		In-stream (MTA)	Minnesota (MTA)	Out of state (MTA)	In-stream (MTA)	Minnesota (MTA)	Out of state (MTA)
CWSEC	FLUX32	19,352	7,528	11,824	14,603	5,681	8,922
CSWEC (by MPCA)	WRTDS	20,880	9,229	11,651	15,396	6,805	6,501
	WRTDS flow-normalized	18,261	8,071	10,190	16,288	7,199	9,089

Notes

MTA = metric ton annually; TN = total nitrogen.

Refer to Table 14 for the full monitoring site names and the baseline and current periods.

Refer to Table 50 for the in-state and out-of-state TP load fractions at each monitoring site.

APPENDIX I. SUBWATERSHED BISECTED BY THE MINNESOTA STATE BOUNDARY

Table 56. Subwatershed bisected by the Minnesota state boundary

Subbasin	HUC12	Name	Total area (sq. mi.)	Area in MN (sq. mi.)	Area in MN (%)	Included in an HSPF model
Lake Superior North (HUC 04010101)	040101010101	Rose Lake–Arrow River	45.8	29.0	63%	Yes
	040101010203	Fowl Lake–Pigeon River	41.1	11.9	29%	Yes
	040101010207	Prout Lake–Pigeon River	41.1	14.6	36%	Yes
	040101010208	Outlet Pigeon River	26.2	14.5	55%	Yes
St. Louis River (HUC 04010201)	040102011601	Red River–Saint Louis River	34.3	23.8	69%	Yes
	040102011602	Pokegama River	31.9	2.2	7%	Yes
	040102011603	Spirit Lake-Saint Louis River	51.1	30.5	60%	Yes
	040102011604	Saint Louis River	37.8	22.8	60%	Yes
Nemadji River (HUC 04010301)	040103010103	Lower South Fork Nemadji River	16.1	12.7	79%	Yes
	040103010301	Upper Black River	27.6	16.6	60%	Yes
	040103010401	Clear Creek	16.4	14.6	89%	Yes
	040103010402	Balsam Creek	31.1	0.3	1%	Yes
	040103010403	Mud Creek-Nemadji River	27.7	15.3	55%	Yes
Minnesota River – Headwaters (HUC 07020001)	070200010305	Little Minnesota River	22.1	2.0	9%	Yes
	070200010408	Big Stone Lake	113.3	56.6	50%	Yes
	070200010706	Outlet Whetstone River	24.6	0.1	0%	Yes
	070200010907	Lake Albert–North Fork Yellow Bank River	41.6	7.4	18%	Yes
	070200011004	Middle South Fork Yellow Bank River	23.3	5.8	25%	Yes
	070200011005	LaBolt Lake	49.1	2.4	5%	Yes
	070200011006	Kaufman Slough	17.2	0.5	3%	Yes
	070200011007	Lower South Fork Yellow Bank River	32.9	29.6	90%	Yes
	070200011009	Yellow Bank River	14.5	12.2	85%	Yes
	070200011101	Big Stone NWR–Minnesota River	42.9	41.9	98%	Yes

Subbasin	HUC12	Name	Total area (sq. mi.)	Area in MN (sq. mi.)	Area in MN (%)	Included in an HSPF model
Lac qui Parle River (HUC 07020003)	070200030101	Lake Hendricks	38.9	8.8	23%	Yes
	070200030102	JD No. 19–Lac qui Parle River	38.8	35.4	91%	Yes
	070200030105	Twin Lake	27.2	25.2	93%	Yes
	070200030201	Upper Lazarus Creek	18.0	3.2	18%	Yes
	070200030202	Middle Lazarus Creek	32.3	28.0	87%	Yes
	070200030203	Canby Creek	36.3	35.7	98%	Yes
	070200030301	Headwaters West Branch Lac qui Parle River	17.7	0.8	5%	Yes
	070200030302	Monighan Creek	40.1	0.4	1%	Yes
	070200030303	Crow Creek	42.4	8.5	20%	Yes
	070200030304	Lost Creek	34.9	5.7	16%	Yes
	070200030305	Upper CD No. 5	39.0	12.5	32%	Yes
	070200030306	Lower CD No. 5	20.1	16.5	82%	Yes
	070200030307	Bolland Slough-West Branch Lac qui Parle River	25.8	17.5	68%	Yes
	070200030403	Sweetwater SWMA–Cobb Creek	27.7	26.9	97%	Yes
	070200030404	Florida Creek-Cobb Creek	60.7	49.0	81%	Yes
MR-YMR (HUC 07020004)	070200040303	Upper North Branch Yellow Medicine River	42.8	42.6	100%	Yes
Blue Earth (HUC 07020009)	070200090201	Ditch Number 60	25.5	0.9	4%	Yes
	070200090202	JD No. 7	30.9	25.6	83%	Yes
	070200090203	West Branch Blue Earth River	45.8	8.5	19%	Yes
	070200090303	Middle Branch Blue Earth River	49.7	13.4	27%	Yes
	070200090401	Drainage Ditch Number 21	27.9	0.4	1%	Yes
	070200090402	JD No. 13	20.7	11.5	56%	Yes
	070200090403	CD No. 78–JD No. 12	30.8	28.7	93%	Yes

Subbasin	HUC12	Name	Total area (sq. mi.)	Area in MN (sq. mi.)	Area in MN (%)	Included in an HSPF model
	070200090404	CD No. 31–Coon Creek	20.4	20.0	98%	Yes
	070200090504	Brush Creek	47.6	41.3	87%	Yes
	070200090601	Iowa Lake	15.3	9.5	62%	Yes
	070200090602	Upper South Creek	39.1	18.5	47%	Yes
Upper St. Croix River (HUC 07030001)	070300010301	Spruce River	41.8	0.4	1%	Yes
	070300010303	Upper Tamarack River	18.9	10.4	55%	Yes
	070300010604	Bjorks Creek–Hay Creek	51.9	42.1	81%	Yes
	070300011202	Hay Creek-Saint Croix River	50.1	8.7	17%	Yes
	070300011203	City of Danbury–Saint Croix River	35.0	13.7	39%	Yes
	070300011205	Barrett Creek-Saint Croix River	43.4	4.4	10%	Yes
Lower St. Croix River (HUC 07030005)	070300050201	Long Meadows Lake–Saint Croix River	41.5	23.3	56%	No
	070300050207	Lagoo Creek–Saint Croix River	36.8	12.0	33%	No
	070300050602	Nevers Dam–Saint Croix River	19.4	7.1	36%	No
	070300050605	Big Rock Creek–Saint Croix River	50.8	17.8	35%	No
	070300050902	Osceola Creek–Saint Croix River	40.1	7.4	18%	No
	070300050903	McLeods Slough–Saint Croix River	50.4	31.3	62%	No
	070300050905	Square Lake–Saint Croix River	25.5	19.5	76%	No
	070300050908	Silver Creek–Saint Croix River	41.5	16.4	40%	No
	070300051201	City of Stillwater–Lake Saint Croix	22.1	11.9	54%	No
	070300051205	Trout Brook–Lake Saint Croix	52.3	22.1	42%	No
	070300051206	Saint Croix River	29.4	21.0	71%	No
Mississippi River – Lake Pepin (HUC 07040001)	070400010102	L&D No. 3–Mississippi River	62.7	15.8	25%	No
	070400010403	City of Red Wing–Mississippi River	22.5	9.0	40%	Yes
	070400010705	Lake Pepin	121.4	47.3	39%	Yes

Subbasin	HUC12	Name	Total area (sq. mi.)	Area in MN (sq. mi.)	Area in MN (%)	Included in an HSPF model
Mississippi River – Winona (HUC 07040003)	070400030601	City of Wabasha–Mississippi River	56.0	26.8	48%	No
	070400030604	City of Buffalo City–Mississippi River	44.5	25.3	57%	No
	070400030606	Fountain City–Mississippi River	40.3	18.9	47%	No
	070400030608	Cedar Creek	17.9	17.9	100%	No
	070400030609	Big Trout Creek	21.0	21.0	100%	No
	070400030610	City of Winona–Mississippi River	45.4	20.9	46%	No
Mississippi River – La Crescent (HUC 07040006)	070400060101	Shingle Creek–Mississippi River	33.8	8.3	25%	No
	070400060103	Lake Onalaska–Mississippi River	52.6	15.5	29%	No
	070400060502	City of La Crosse–Mississippi River	37.7	12.4	33%	No
Root River (HUC 07040008)	070400080804	Riceford Creek	64.7	60.2	93%	Yes
Mississippi River – Reno (HUC 07060001)	070600010504	L&D No.8–Mississippi River	59.8	16.1	27%	Yes
	070600010505	Town of New Albin–Mississippi River	40.3	20.7	51%	Yes
Upper Iowa River (HUC 07060002)	070600020101	NBUIR–Upper Iowa River	36.5	34.9	96%	Yes
	070600020106	City of Le Roy–Upper Iowa River	41.2	20.7	50%	Yes
	070600020107	Town of Granger–Upper Iowa River	43.9	14.3	33%	Yes
	070600020203	Daisy Valley–Upper Iowa River	45.5	22.7	50%	Yes
	070600020204	Cold Water Creek	25.0	10.7	43%	Yes
	070600020205	Pine Creek	35.4	14.9	42%	Yes
	070600020208	Silver Creek–Upper Iowa River	32.2	0.2	1%	Yes
	070600020302	Canoe Creek	47.7	0.1	0%	No
	070600020501	North Bear Creek	31.9	16.0	50%	Yes
	070600020502	Waterloo Creek	48.0	27.3	57%	Yes
	070600020605	Clear Creek–Upper Iowa River	27.3	0.8	3%	Yes

Subbasin	HUC12	Name	Total area (sq. mi.)	Area in MN (sq. mi.)	Area in MN (%)	Included in an HSPF model
	070600020606	Outlet Upper Iowa River	34.9	0.7	2%	Yes
UWR (HUC 07080102)	070801020201	Headwaters Wapsipinicon River	42.5	13.0	30%	No
Cedar River (HUC 07080201)	070802010402	Headwaters Deer Creek	34.7	25.0	72%	Yes
	070802010504	Otter Creek	62.6	33.3	53%	Yes
	070802010505	Town of Otranto–Cedar River	35.9	6.9	19%	Yes
	070802010702	Town of Meyer–Little Cedar River	35.7	21.5	60%	Yes
	070802010703	City of Stacyville–Little Cedar River	45.7	8.2	18%	Yes
Shell Rock River (HUC 07080202)	070802020106	Goose Creek	62.8	51.0	81%	Yes
	070802020107	Goose Creek-Shell Rock River	21.7	4.0	18%	Yes
Winnebago River (HUC 07080203)	070802030102	State Line Lake–Lime Creek	45.2	32.5	72%	Yes
Lower Des Moines River (HUC 07100002)	071000020101	Stony Brook	31.1	28.6	92%	Yes
	071000020102	Swan Lake	23.8	3.1	13%	Yes
	071000020105	Brown Creek	35.2	13.3	38%	Yes
	071000020106	School Creek–Des Moines River	56.5	2.8	5%	Yes
EFDMR (HUC 07100003)	071000030107	Soldier Creek	29.0	14.2	49%	Yes
	071000030108	Okamanpeedan Lake-EFDMR	39.8	19.9	50%	Yes
Bois de Sioux River (HUC 09020101)	090201010201	Upper Lake Traverse	42.6	24.3	57%	Yes
	090201010203	Lower Lake Traverse	39.5	22.4	57%	No
	090201010205	Mud Lake	50.0	24.8	50%	Yes
	090201010305	Outlet Big Slough	40.0	0.0	0%	Yes
	090201010502	Clubhouse Lake–Bois de Sioux River	56.9	25.3	45%	Yes
	090201010505	CD No. 26–Bois de Sioux River	43.2	15.2	35%	Yes

Subbasin	HUC12	Name	Total area (sq. mi.)	Area in MN (sq. mi.)	Area in MN (%)	Included in an HSPF model
	090201010507	Bois de Sioux River	56.6	26.9	47%	Yes
Upper Red River of the North (HUC 09020104)	090201040401	CD No. 1–Red River	43.0	18.2	42%	Yes
	090201040402	City of Wolverton–Red River	34.5	18.1	52%	Yes
	090201040403	City of Hickson–Red River	40.4	22.0	55%	Yes
	090201040501	Town of Briarwood–Red River	42.9	40.4	94%	Yes
	090201040504	City of Fargo–Red River	54.9	26.2	48%	Yes
	090201040506	Town of Oakport–Red River	38.6	26.4	68%	Yes
Red River of the North – Marsh River (HUC 08020107)	090201070101	CD No. 6–Red River	30.7	27.5	90%	Yes
	090201070103	Rose Valley Cemetery	54.7	0.0	0%	No
	090201070104	CD No. 49–Red River	21.3	5.1	24%	No
	090201070106	CD No. 13–Red River	29.3	6.5	22%	No
	090201070601	Love Lake-Red River	12.7	8.5	67%	No
	090201070603	Grandin Lake-Red River	36.3	17.5	48%	Yes
	090201070605	Augustana Church–Red River	22.3	11.0	49%	No
Red River of the North – Sandhill River (HUC 09020301)	090203010401	JD No. 54–Red River	32.3	5.5	17%	Yes
	090203010402	Salem Cemetery–Red River	33.1	3.0	9%	Yes
	090203010403	CD No. 77–Red River	33.0	17.0	51%	No
	090203010404	CD No. 19–Red River	40.4	25.2	62%	No
	090203010704	Ost Valle Church–Red River	31.2	12.6	40%	No
	090203010705	City of Grand Forks–Red River	23.7	12.0	51%	Yes
Red River of the North – Grand Marais Creek (HUC 09020306)	090203060501	Town of North Grand Forks–Red River	15.3	8.6	56%	No
	090203060504	JD No. 69–Red River	16.6	10.6	64%	Yes
	090203060601	City of Oslo–Red River	52.1	40.0	77%	Yes
	090203060602	Horseshoe Lake–Red River	20.8	4.2	20%	No

Subbasin	HUC12	Name	Total area (sq. mi.)	Area in MN (sq. mi.)	Area in MN (%)	Included in an HSPF model
	090203060603	JD No. 9–Red River	30.6	28.3	93%	Yes
Red River of the North – Tamarac Creek (HUC 09020311)	090203110502	CD No. 55–Red River	41.1	7.8	19%	Yes
	090203110503	City of Drayton–Red River	31.8	22.7	71%	Yes
	090203110505	Town of Mattson–Red River	28.2	21.1	75%	Yes
	090203110703	Joe River	48.5	38.6	79%	Yes
	090203110801	CD No. 39–Red River	57.8	13.2	23%	Yes
	090203110802	Lake Stella–Red River	48.5	24.0	50%	Yes
	090203110803	Bradley Coulee	16.3	13.7	84%	Yes
	090203110804	City of Pembina–Red River	26.1	1.4	5%	No
Two River (HUC 09020312)	090203120501	090203120501	39.5	35.8	91%	Yes
Roseau River (HUC 09020314)	090203140405	Town of Hickey	17.7	1.4	8%	Yes
	090203140406	Cat Hills–Sprague Creek	47.9	0.7	1%	Yes
	090203140407	JD No. 61	40.0	26.5	66%	Yes
	090203140409	Popple Creek–Sprague Creek	36.2	28.5	79%	Yes
	090203140504	090203140504–Roseau River	29.1	28.2	97%	Yes
	090203140507	Pine Creek	53.6	15.1	28%	Yes
	090203140508	Roseau Lakebed–Roseau River	35.2	33.6	95%	Yes
	090203140602	Pool Number Two–Sundown Bog	122.6	36.3	30%	Yes
	090203140603	Pool Number Three	21.3	16.2	76%	Yes
	090203140606	Town of Caribou–Roseau River	35.6	30.6	86%	Yes
	090203140607	Arbakka Drain	14.5	0.5	4%	No
	090203140608	Gardenton Floodway–Roseau River	54.3	0.0	0%	No
	090203140801	90203140801	49.9	28.0	56%	Yes

Subbasin	HUC12	Name	Total area (sq. mi.)	Area in MN (sq. mi.)	Area in MN (%)	Included in an HSPF model
	090203140806	Stewart Drain	36.2	1.1	3%	No
	090203140808	Upper Main Drain	21.6	3.8	17%	No
	090203140809	Lower Main Drain	62.0	4.9	8%	No
Rainy River Headwaters (HUC 09030001)	090300010301	North Lake	33.8	3.3	10%	Yes
	090300010304	Gunflint Lake	40.4	26.2	65%	Yes
	090300010305	Upper Granite River	53.8	11.7	22%	Yes
	090300010306	Lower Granite River	18.5	6.7	36%	Yes
	090300010405	Saganaga Lake	76.2	32.6	43%	Yes
	090300010502	Knife Lake	62.9	44.9	71%	Yes
	090300010507	Prairie Portage–Sucker Lake	50.7	4.9	10%	Yes
	090300011104	Basswood Lake	161.2	102.0	63%	Yes
	090300011206	Crooked Lake	80.2	48.4	60%	Yes
	090300011208	Iron Lake	13.4	11.5	86%	Yes
	090300012007	Lac La Croix	137.4	65.9	48%	Yes
	090300012103	Loon Lake	35.8	33.0	92%	Yes
	090300012104	Loon River–Little Vermilion Lake	64.3	35.5	55%	Yes
	090300012602	Sand Point Lake	62.1	32.7	53%	Yes
	090300012605	Namakan Lake	110.3	65.0	59%	Yes
RR-RL (HUC 09030003)	090300031804	Rainy Lake	425.3	180.0	42%	Yes
Rainy River – Baudette (HUC 09030008)	090300080501	City of International Falls–Rainy River	57.1	23.1	40%	Yes
	090300080502	Watrous Island–Rainy River	22.5	9.0	40%	Yes
	090300080504	Smoot Island–Rainy River	56.8	15.5	27%	Yes
	090300080507	Manitou Rapids–Rainy River	55.7	25.0	45%	Yes

Subbasin	HUC12	Name	Total area (sq. mi.)	Area in MN (sq. mi.)	Area in MN (%)	Included in an HSPF model
	090300080508	McCloud Creek–Rainy River	37.5	18.3	49%	Yes
	090300080509	Whitefish Creek–Rainy River	66.3	30.3	46%	Yes
	090300080704	Gormley Creek–Rainy River	21.4	7.6	35%	Yes
	090300080708	Rainy River	35.9	17.6	49%	Yes
Lake of the Woods (HUC 09030009)	090300091403	Stony Creek	71.9	28.1	39%	Yes
	090300091405	Harrison Creek	54.5	0.4	1%	No
	090300091406	Poplar Creek	30.2	5.2	17%	No
	090300091423	Lake of the Woods	2256.3	665.2	29%	Yes
Upper Big Sioux River (HUC 10170202)	101702020901	Upper Deer Creek	46.2	9.1	20%	Yes
	101702021001	Upper Medary Creek	44.4	32.2	73%	Yes
	101702021002	Middle Medary Creek	48.8	0.0	0%	Yes
Lower Big Sioux River (HUC 10170203)	101702030101	Upper Spring Creek	33.3	13.4	40%	Yes
	101702030303	Town of Verdi-Willow Creek	29.1	27.2	94%	Yes
	101702030304	Lower Flandreau Creek	33.8	15.3	45%	Yes
	101702031304	SBPC–Pipestone Creek	63.0	34.3	54%	Yes
	101702031305	Pipestone Creek	49.2	8.8	18%	Yes
	101702031504	Springwater Creek	16.3	15.9	98%	Yes
	101702031505	Fourmile Creek	20.2	6.9	34%	Yes
	101702031506	Lower Beaver Creek	37.9	6.0	16%	Yes
	101702031602	City of Jasper-Split Rock Creek	44.6	44.4	99%	Yes
	101702031605	The Palisades-Split Rock Creek	49.9	17.0	34%	Yes
	101702031702	Blood Run	31.7	7.7	24%	Yes
Rock River (HUC 10170204)	101702040205	Kanaranzi Creek	23.9	13.7	57%	Yes
	101702040306	Ash Creek-Rock River	45.8	32.0	70%	Yes

Subbasin	HUC12	Name	Total area (sq. mi.)	Area in MN (sq. mi.)	Area in MN (%)	Included in an HSPF model
	101702040401	Upper Mud Creek	57.3	40.6	71%	Yes
	101702040502	Hawkeye Point–Otter Creek	55.0	7.6	14%	Yes
	101702040603	Argo Slough–Little Rock River	62.4	15.6	25%	Yes
	101702040701	Tom Creek	61.6	9.5	15%	Yes
Little Sioux River (HUC 10230003)	102300030102	JD No. 24	36.1	28.6	79%	Yes
	102300030104	West Branch Little Sioux River	31.6	0.3	1%	Yes
	102300030105	Rush Lake–West Fork Little Sioux River	23.9	12.8	53%	Yes
	102300030203	East Okoboji Lake	58.9	7.5	13%	Yes
	102300030304	Diamond Lake–Little Sioux River	37.1	17.0	46%	Yes
	102300030503	Osterman Creek–Ocheyedan River	54.3	17.1	32%	Yes

Note: CD = County Ditch; EFDMR = East Fork Des Moines River; JD = Judicial Ditch; L&D = lock and dam; NBUIR = North Branch Upper Iowa River; No. = Number; MR-YMR = Minnesota River-Yellow Medicine River; NWR = National Wildlife Refuge; RR-RL = Rainy River- Rainy Lake; SBPC = South Branch Pipestone Creek; SWMA = State Wildlife Management Area; UWR = Upper Wapsipinicon River.

APPENDIX J. MODEL RESULTS

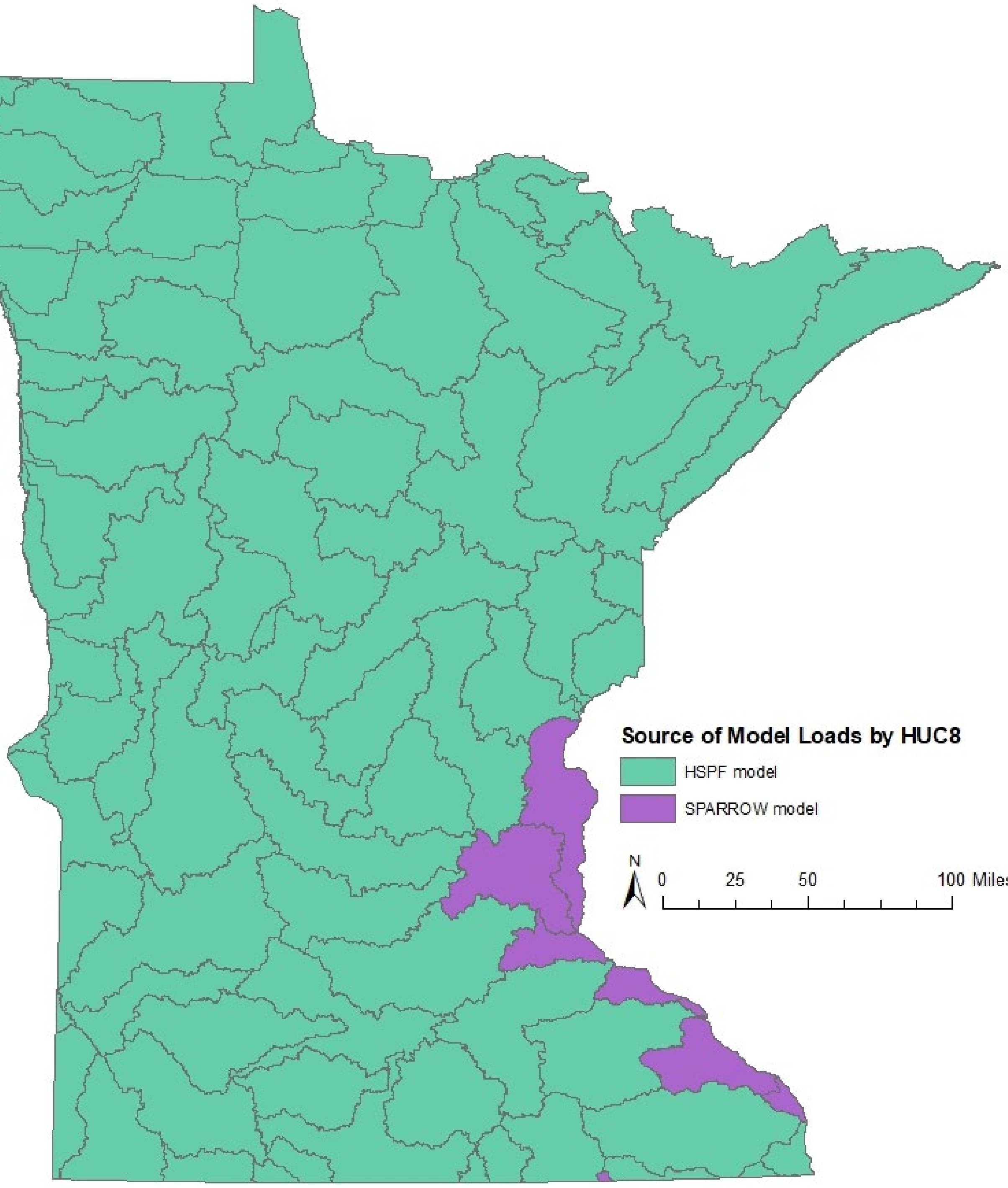


Figure 103. Subbasins simulated by HSPF and SPARROW models

Table 57. Summary of updated HSPF models

Model name	HUC8	No. of reaches [a]	No. of outlets	No. of source IDs	Simulated years
BigFork_2014	09030006	124	1	14	2005 – 2014
BigSioux_2009	10170202 10170203	6 (0)(6) 65 (7)(31)	2 5	15	2000 - 2009
BlueEarth_2017	07020009	124 (6)(14)	1	20	2008 – 2017
Buffalo_2022	09020106	100	1	13	2013 – 2022
Cannon_2012	07040002	219	1	18	2003 – 2012
Cedar_2012	07080201	128 (4)(17)	2	17	2003 – 2012
Chippewa_2022	07020005	66	1	23	2013 – 2022
Clearwater_2016	09020305	141	1	15	2007 – 2016
Cottonwood_2017	07020008	108	1	19	2008 – 2017
CrowWing_2020	07010106	103	1	20	2011 – 2020
DesMoines_2014	07100001 07100002 07100003	155 12 (0)(8) 27 (0)(5)	1 2 2	23	2005 – 2014
GrandMarais_2009	09020301 09020306 09020309	1 (0)(1) 93 (0)(13) 2	1 18 2	15	2000 – 2009
HawkYellowMedicine_2022	07020004	78 (0)(1)	2	23	2013 – 2022
Kettle_2009	07030001 07030003	57 (1)(12) 123	3 1	20	2000 – 2009
LacQuiParle_2017	07020001 07020003	90 (43)(17) 54 (6)(25)	2 1	25	2008 – 2017
LeechLake_2015	07010102	83	1	19	2006 – 2015
LeSueur_2017	07020011	93	1	19	2008 – 2017
LittleFork_2014	09030005	114	2	14	2005 – 2014
LittleSioux_2009	10230003	88 (35)(20)	1	13	2000 – 2009
LongPrairie_2020	07010108	47	1	18	2011 – 2020
LOWCan_2014	09030009	82 (75)(7)	2	11	2005 – 2014
LowerMN_2012	07020012	106	1	20	2003 – 2012
LowerRed_2009	09020311 09020312	114 (0)(16) 3	12 3	16	2000 – 2009
LOWUS_2014	09030009	36 (0)(15)	1	16	2005 – 2014

Model name	HUC8	No. of reaches [a]	No. of outlets	No. of source IDs	Simulated years
MetroMN_2012	07020012	146	1	20	2003 – 2012
MiddleMN_2012	07020007	129	1	20	2003 – 2012
MissBrainerd_2015	07010104	152	1	19	2006 – 2015
MissGrandRapids_2015	07010103	158	4	20	2006 – 2015
MissHeadwaters_2015	07010101	134	1	20	2006 – 2015
MissSartell_2015	07010201	83	1	19	2006 – 2015
MissStCloud_2015	07010203	125	1	19	2006 – 2015
MustinkaBDS_2022	09020101 09020102	38 (13)(8) 44	1	15	2006 – 2015
Nemadji_2014	04010301	26 (8)(7)	1	28	2005 – 2014
NFCrow_2015	07010204	134	1	18	2006 – 2015
OtterTail_2014	09020103	148	1	33	2005 – 2014
PepinTribs_2016	07040001	42 (0)(9)	17	14	2007 – 2016
Pine_2015	07010105	79	1	18	2006 – 2015
PommeDeTerre_2017	07020002	53	1	13	2008 – 2017
RainyHeadwaters_2014	09030001 09030003	274 (108)(26) 1 (1)(0)	3	15	2005 – 2014
RainyLake_2014	09030001 09030003	23 (0)(3) 67 (52)(3)	1 1	17	2005 – 2014
RainyRiver_2014	09030007 09030008 [b]	30 51 (5)(12)	1 1	17	2005 – 2014
Redeye_2020	07010107	33	1	18	2011 – 2020
RedLake_2016	09020303 09020306	137 1	1 1	16	2007 – 2016
RedLakes_2016	09020302	113	1	16	2007 – 2016
Redwood_2017	07020006	80	1	19	2008 – 2017
RenoUpperIA_2015	07060001 07060002	17 (0)(4) 40 (5)(28)	4 9	18	2005 – 2015
Rock_2009	10170204	102 (15)(17)	1	13	2000 – 2009
Root_2021	07040008	92 (0)(2)	1	18	2011 – 2021
Roseau_2014	09020314	105 (9)(35)	2	15	2005 – 2014
Rum_2015	07010207	131	1	19	2006 – 2015
Sandhill_2016	09020301	73	1	13	2007 – 2016

Model name	HUC8	No. of reaches [a]	No. of outlets	No. of source IDs	Simulated years
Sauk_2019	07010202	97	1	17	2010 – 2019
SFCrow_2015	07010205	118	1	17	2006 – 2015
ShellRock_2018	07080202	59 (0)(14)	1	16	2009 – 2018
SnakeNW_2015	09020309	106	1	15	2006 – 2015
SnakeSE_2018	07030004	108	1	20	2009 – 2018
StLouisCloquet_2014 [c]	04010201 04010202	111 (0)(5) 23	3 1	26	2005 – 2014
SuperiorNorth_2016	04010101	130 (0)(16)	47	23	2007 – 2016
SuperiorSouth_2012	04010102	60	27	23	2003 – 2012
Thief_2016	09020304	123	2	17	2007 – 2016
TwoRivers_2017	09020312 09020314	86 (0)(2) 3 (0)(2)	1 1	15	2008 – 2017
UpperRed_2022	09020104 09020107	141 (7)(109) 1 (0)(1)	1 1	20	2006 – 2022
Vermilion_2014	09030002	71	1	16	2005 – 2014
Watonwan_2017	07020010	80	1	19	2008 – 2017
WildRiceMarsh_2009	09020107 09020108 09020301	25 (0)(1) 144 3 (0)(2)	3 1 3	14	2000 – 2009
Winnebago_2018	07080203	13 (0)(8)	2	16	2009 – 2018
Zumbro_2018	07040004	109	1	21	2009 – 2018

Notes

a. Number of reaches in the model. In parentheses, first, the number of reaches in HUC12 subwatersheds fully outside of Minnesota, and second, the number of reaches in HUC12 subwatersheds bisected by the state border.

b. The former *Upper Rainy River* (HUC 09030004) is included in the current *Lower Rainy River* (HUC 09030008).

c. Tetra Tech recently updated and extended (through 2021) the St. Louis and Cloquet rivers HSPF model. However, the updated model was not used to provide loads for this study.

Table 58. Model results delivered to subbasin outlets and at state boundaries

Subbasin	Delivery factor		Load delivered to subbasin outlet (metric tons/year) [a]		Load delivered to state boundary (metric tons/year)	
	TP	TN	TP	TN	TP	TN
Lake Superior basin						
04010101	100%	100%	50	1,482	50	1,482
04010102	100%	100%	34	503	34	503
04010201	100%	100%	91	2,218	91	2,218
04010202	86%	90%	14	362	12	327
04010301	100%	100%	59	140	59	140
Upper Mississippi River basin						
07010101	45%	56%	13	267	6	149
07010102	35%	46%	6	122	2	56
07010103	52%	63%	45	1,265	24	793
07010104	59%	69%	148	744	88	509
07010105	54%	65%	7	214	4	138
07010106	56%	66%	47	729	26	483
07010107	56%	65%	31	682	17	442
07010108	55%	65%	36	628	20	409
07010201	61%	69%	130	1,390	80	959
07010202	61%	69%	74	1,373	45	947
07010203	62%	70%	72	1,217	45	853
07010204	62%	70%	91	1,073	57	752
07010205	60%	69%	144	3,322	87	2,285
07010206 [a]	63%	71%	1,365 [a]	3,576 [a]	854 [a]	2,524 [a]
07010207	62%	70%	67	1,161	42	814
Minnesota River basin						
07020001	46%	57%	57	449	26	256
07020002	37%	38%	54	623	20	235
07020003	46%	57%	74	946	35	540
07020004	52%	64%	266	4,906	137	3,127
07020005	46%	57%	68	1,369	31	782
07020006	52%	64%	91	3,107	47	1,980

Subbasin	Delivery factor		Load delivered to subbasin outlet (metric tons/year) [a]		Load delivered to state boundary (metric tons/year)	
	TP	TN	TP	TN	TP	TN
07020007	61%	70%	188	4,975	115	3,458
07020008	58%	67%	308	10,989	180	7,416
07020009	59%	69%	235	14,825	138	10,167
07020010	57%	59%	134	6,903	77	4,085
07020011	59%	69%	292	9,095	172	6,237
07020012	63%	71%	342	8,086	214	5,707
St. Croix River basin						
07030001	60%	65%	17	153	10	100
07030003	60%	65%	32	280	19	183
07030004	60%	65%	62	875	37	572
07030005 [a]	64%	72%	86 [a]	1,060 [a]	54 [a]	767 [a]
Lower Mississippi River basin						
07040001 [a]	66%	76%	155 [a]	1,274 [a]	102 [a]	968 [a]
07040002	64%	73%	311	4,400	198	3,212
07040003 [a]	82%	92%	110	1,443	91	1,330
07040004	73%	85%	383	7,764	281	6,621
07040006 [a]	82%	92%	11 [a]	150 [a]	9 [a]	138 [a]
07040008	82%	92%	412	8,254	339	7,610
07060001	100%	100%	79	858	79	858
07060002	100%	100%	79	1,816	79	1,816
Cedar River basin						
07080102 [a]	100%	100%	2 [a]	77 [a]	2 [a]	77 [a]
07080201	100%	100%	78	5,306	78	5,306
07080202	100%	100%	54	1,746	54	1,746
07080203	100%	100%	9	527	9	527
Des Moines River basin						
07100001	96%	97%	77	978	74	951
07100002	100%	100%	5	146	5	146
07100003	100%	100%	8	157	8	157
Red River of the North basin						

Subbasin	Delivery factor		Load delivered to subbasin outlet (metric tons/year) [a]		Load delivered to state boundary (metric tons/year)	
	TP	TN	TP	TN	TP	TN
09020101	79%	90%	69	677	54	609
09020102	36%	41%	50	433	18	178
09020103	79%	90%	64	862	50	776
09020104	95%	98%	258	1,061	246	1,041
09020106	95%	98%	85	769	81	755
09020107	95%	98%	25	147	24	144
09020108	95%	98%	84	411	80	403
09020301	95%	98%	24	263	23	258
09020302	59%	45%	5	97	3	43
09020303	95%	98%	85	764	81	751
09020304	94%	85%	43	653	40	552
09020305	94%	90%	36	520	34	465
09020306	96%	99%	78	473	75	468
09020309	100%	100%	87	675	87	675
09020311	100%	100%	69	527	69	527
09020312	100%	100%	79	765	79	765
09020314	100%	100%	41	262	41	262
Rainy River basin						
09030001	62%	56%	26	646	16	363
09030002	49%	47%	14	367	7	172
09030003	82%	87%	21	561	17	491
09030005	86%	87%	76	1,213	65	1,055
09030006	87%	88%	49	1,107	43	976
09030007	95%	95%	20	391	19	373
09030008 [b]	100%	100%	51	790	51	790
09030009	100%	100%	10	56	10	56
Missouri River basin						
10170202	100%	100%	2	46	2	46
10170203	100%	100%	38	885	38	885
10170204	100%	100%	70	2,844	70	2,844

Subbasin	Delivery factor		Load delivered to subbasin outlet (metric tons/year) [a]		Load delivered to state boundary (metric tons/year)	
	TP	TN	TP	TN	TP	TN
10230003	100%	100%	46	1,202	46	1,202

Notes

All percentages are rounded to the nearest percentage point, and all loads are rounded to the nearest integer.

a. An HSPF model has not been developed for this subbasin. The loads delivered to subbasin outlets were derived from SPARROW model results.

b. The former *Upper Rainy River* (HUC 09030004) is included in the current *Lower Rainy River* (HUC 09030008).

Table 59. Annual yields delivered to subbasin outlets

Subbasin	TN yield (pounds/acre/year)	TP yield (pounds/acre/year)
Lake Superior basin		
04010101	3.39	0.114
04010102	2.78	0.189
04010201	2.76	0.113
04010202	1.62	0.0642
04010301	1.40	0.730
Upper Mississippi River basin		
07010101	0.542	0.0255
07010102	0.378	0.0199
07010103	2.15	0.0766
07010104	1.56	0.310
07010105	1.01	0.0351
07010106	1.32	0.0844
07010107	2.65	0.121
07010108	2.59	0.149
07010201	4.73	0.443
07010202	4.70	0.252
07010203	3.81	0.227
07010204	2.63	0.223
07010205	9.20	0.399
07010206 [a]	12.7 [a]	4.44 [a]

Subbasin	TN yield (pounds/acre/year)	TP yield (pounds/acre/year)
07010207	2.93	0.170
Minnesota River basin		
07020001	1.97	0.250
07020002	2.56	0.223
07020003	4.28	0.337
07020004	8.21	0.444
07020005	2.31	0.115
07020006	15.9	0.463
07020007	13.2	0.499
07020008	29.3	0.821
07020009	42.4	0.672
07020010	28.1	0.544
07020011	28.7	0.921
07020012	15.5	0.656
St. Croix River basin		
07030001	0.992	0.112
07030003	0.943	0.109
07030004	3.05	0.216
07030005 [a]	4.42 [a]	0.254 [a]
Lower Mississippi River basin		
07040001 [b]	7.33 [b]	0.889 [b]
07040002	10.6	0.750
07040003 [a]	7.71 [a]	0.579 [a]
07040004	19.0	0.935
07040006 [a]	5.60 [a]	0.404 [a]
07040008	17.1	0.854
07060001	17.5	1.62
07060002	31.9	1.39
Cedar River basin		
07080102 [a]	20.5 [a]	0.521 [a]
07080201	25.9	0.381

Subbasin	TN yield (pounds/acre/year)	TP yield (pounds/acre/year)
07080202	25.1	0.778
07080203	26.2	0.423
Des Moines River basin		
07100001	2.75	0.215
07100002	5.78	0.206
07100003	2.68	0.137
Red River of the North basin		
09020101	4.40	0.449
09020102	1.85	0.212
09020103	1.71	0.126
09020104	7.30	1.77
09020106	2.40	0.265
09020107	1.50	0.255
09020108	0.932	0.189
09020301	1.89	0.175
09020302	0.236	0.0114
09020303	2.00	0.222
09020304	2.16	0.142
09020305	1.37	0.0944
09020306	2.97	0.491
09020309	3.00	0.385
09020311	2.25	0.295
09020312	2.40	0.248
09020314	0.856	0.134
Rainy River basin		
09030001	0.822	0.0326
09030002	1.36	0.0528
09030003	3.33	0.125
09030005	2.25	0.140
09030006	1.90	0.0841
09030007	1.43	0.0740

Subbasin	TN yield (pounds/acre/year)	TP yield (pounds/acre/year)
09030008 [c]	3.24	0.211
09030009	0.218	0.037
Missouri River basin		
10170202	3.83	0.144
10170203	5.95	0.258
10170204	10.7	0.262
10230003	13.6	0.519

Notes

All yields are rounded to three significant digits.

Yields are based on loading within Minnesota. Loading from outside of Minnesota is excluded.

a. An HSPF model has not been developed for this subbasin. The yields delivered to subbasin outlets were derived from SPARROW model results.

b. An HSPF model was developed for a portion of this subbasin. The yields delivered to subbasin outlets were derived from SPARROW model results.

c. The former *Upper Rainy River* (HUC 09030004) is included in the current *Lower Rainy River* (HUC 09030008).

Table 60. Annual yields delivered to state boundaries

Subbasin	TN yield (pounds/acre/year)			TP yield (pounds/acre/year)		
	HSPF	SPARROW	Average	HSPF	SPARROW	Average
Lake Superior basin						
04010101	0.11	0.09	0.10	3.31	1.20	2.25
04010102	0.19	0.19	0.19	2.78	2.29	2.54
04010201	0.11	0.17	0.14	2.69	2.25	2.47
04010202	0.06	0.06	0.06	1.47	1.29	1.38
04010301	0.43	0.16	0.29	1.02	2.66	1.84
Upper Mississippi River basin						
07010101	0.01	0.02	0.01	0.30	0.43	0.37
07010102	0.01	0.01	0.01	0.17	0.29	0.23
07010103	0.04	0.10	0.07	1.36	1.41	1.39
07010104	0.18	0.18	0.18	1.07	2.51	1.79
07010105	0.02	0.03	0.02	0.65	0.77	0.71
07010106	0.05	0.10	0.08	0.88	1.86	1.37

Subbasin	TN yield (pounds/acre/year)			TP yield (pounds/acre/year)		
	HSPF	SPARROW	Average	HSPF	SPARROW	Average
07010107	0.07	0.18	0.12	1.71	2.98	2.35
07010108	0.08	0.17	0.13	1.69	2.36	2.02
07010201	0.27	0.28	0.27	3.26	5.15	4.20
07010202	0.15	0.31	0.23	3.24	5.43	4.34
07010203	0.14	0.40	0.27	2.67	5.44	4.06
07010204	0.14	0.35	0.24	1.85	4.72	3.28
07010205	0.24	0.61	0.43	6.33	8.57	7.45
07010206 [a]	-- [a]	4.44	4.44	-- [a]	12.23	12.23
07010207	0.11	0.18	0.14	2.06	2.72	2.39
Minnesota River basin						
07020001	0.04	0.16	0.10	0.41	1.49	0.95
07020002	0.08	0.23	0.15	0.96	1.96	1.46
07020003	0.11	0.45	0.28	1.69	3.77	2.73
07020004	0.23	0.60	0.42	5.23	6.59	5.91
07020005	0.05	0.31	0.18	1.32	3.35	2.33
07020006	0.24	0.76	0.50	10.13	7.42	8.77
07020007	0.30	0.84	0.57	9.18	14.28	11.73
07020008	0.48	0.65	0.57	19.76	11.04	15.40
07020009	0.31	0.81	0.56	22.50	15.41	18.95
07020010	0.31	0.81	0.56	16.61	14.98	15.79
07020011	0.54	0.82	0.68	19.67	20.17	19.92
07020012	0.41	0.72	0.57	10.95	11.29	11.12
St. Croix River basin						
07030001	0.05	0.13	0.09	0.49	2.53	1.51
07030003	0.07	0.16	0.11	0.62	2.54	1.58
07030004	0.13	0.25	0.19	2.00	4.00	3.00
07030005 [a]	-- [a]	0.17	0.17	-- [a]	3.18	3.18
Lower Mississippi River basin						
07040001 [b]	1.65	0.89	1.27	15.70	7.33	11.51
07040002	0.48	0.63	0.56	7.75	11.30	9.53

Subbasin	TN yield (pounds/acre/year)			TP yield (pounds/acre/year)		
	HSPF	SPARROW	Average	HSPF	SPARROW	Average
07040003 [a]	-- [a]	0.58	0.58	-- [a]	7.58	7.58
07040004	0.69	0.67	0.68	16.17	11.12	13.65
07040006 [a]	-- [a]	0.40	0.40	-- [a]	5.45	5.45
07040008	0.70	0.56	0.63	15.76	10.27	13.02
07060001	1.40	0.34	0.87	15.14	7.08	11.11
07060002	0.61	0.70	0.65	13.96	16.43	15.19
Cedar River basin						
07080102 [a]	-- [a]	0.52	0.52	-- [a]	20.46	20.46
07080201	0.28	0.83	0.55	18.77	18.98	18.87
07080202	0.69	1.17	0.93	22.37	12.51	17.44
07080203	0.36	0.54	0.45	22.21	12.19	17.20
Des Moines River basin						
07100001	0.21	0.42	0.31	2.67	8.89	5.78
07100002	0.10	0.88	0.49	2.71	12.60	7.65
07100003	0.12	0.40	0.26	2.29	19.93	11.11
Red River of the North basin						
09020101	0.19	0.43	0.31	2.19	1.43	1.81
09020102	0.08	0.14	0.11	0.76	1.22	0.99
09020103	0.10	0.10	0.10	1.54	0.69	1.11
09020104	1.27	0.67	0.97	5.37	2.09	3.73
09020106	0.25	0.29	0.27	2.33	1.47	1.90
09020107	0.23	0.44	0.33	1.39	1.46	1.42
09020108	0.18	0.27	0.23	0.92	1.29	1.10
09020301	0.16	0.32	0.24	1.82	1.56	1.69
09020302	0.01	0.00	0.00	0.11	0.11	0.11
09020303	0.21	0.39	0.30	1.97	1.29	1.63
09020304	0.13	0.16	0.15	1.82	0.80	1.31
09020305	0.09	0.16	0.12	1.23	1.26	1.24
09020306	0.46	0.38	0.42	2.89	1.76	2.32
09020309	0.39	0.26	0.32	3.00	1.18	2.09

Subbasin	TN yield (pounds/acre/year)			TP yield (pounds/acre/year)		
	HSPF	SPARROW	Average	HSPF	SPARROW	Average
09020311	0.28	0.42	0.35	2.17	1.06	1.62
09020312	0.25	0.18	0.22	2.40	1.06	1.73
09020314	0.09	0.19	0.14	0.60	1.05	0.82
Rainy River basin						
09030001	0.01	0.01	0.01	0.22	0.51	0.37
09030002	0.03	0.02	0.02	0.64	0.55	0.59
09030003	0.01	0.03	0.02	0.38	0.46	0.42
09030005	0.12	0.11	0.12	1.96	0.81	1.38
09030006	0.07	0.09	0.08	1.68	0.70	1.19
09030007	0.07	0.08	0.08	1.36	0.55	0.95
09030008 [c]	0.12	0.12	0.12	1.82	0.79	1.30
09030009	0.01	0.00	0.01	0.05	0.13	0.09
Missouri River basin						
10170202	0.04	-- [b]	0.04	1.13	-- [b]	1.13
10170203	0.16	-- [b]	0.16	3.68	-- [b]	3.68
10170204	0.15	-- [b]	0.15	6.12	-- [b]	6.12
10230003	0.10	-- [b]	0.10	2.71	-- [b]	2.71

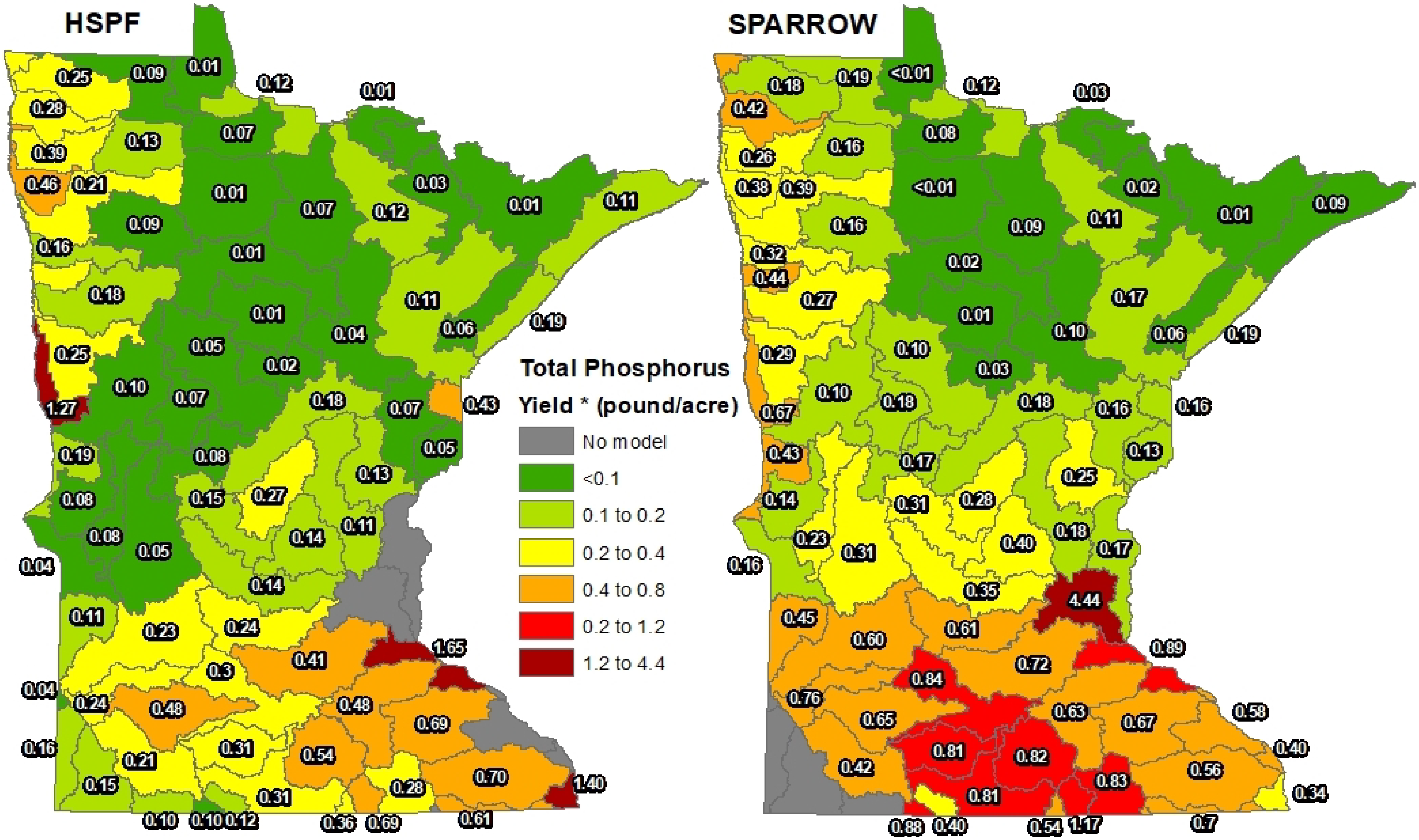
Notes

All yields are rounded to one-hundredth of a pound per acre per year.

Yields are based on loading within Minnesota. Loading from outside of Minnesota is excluded.

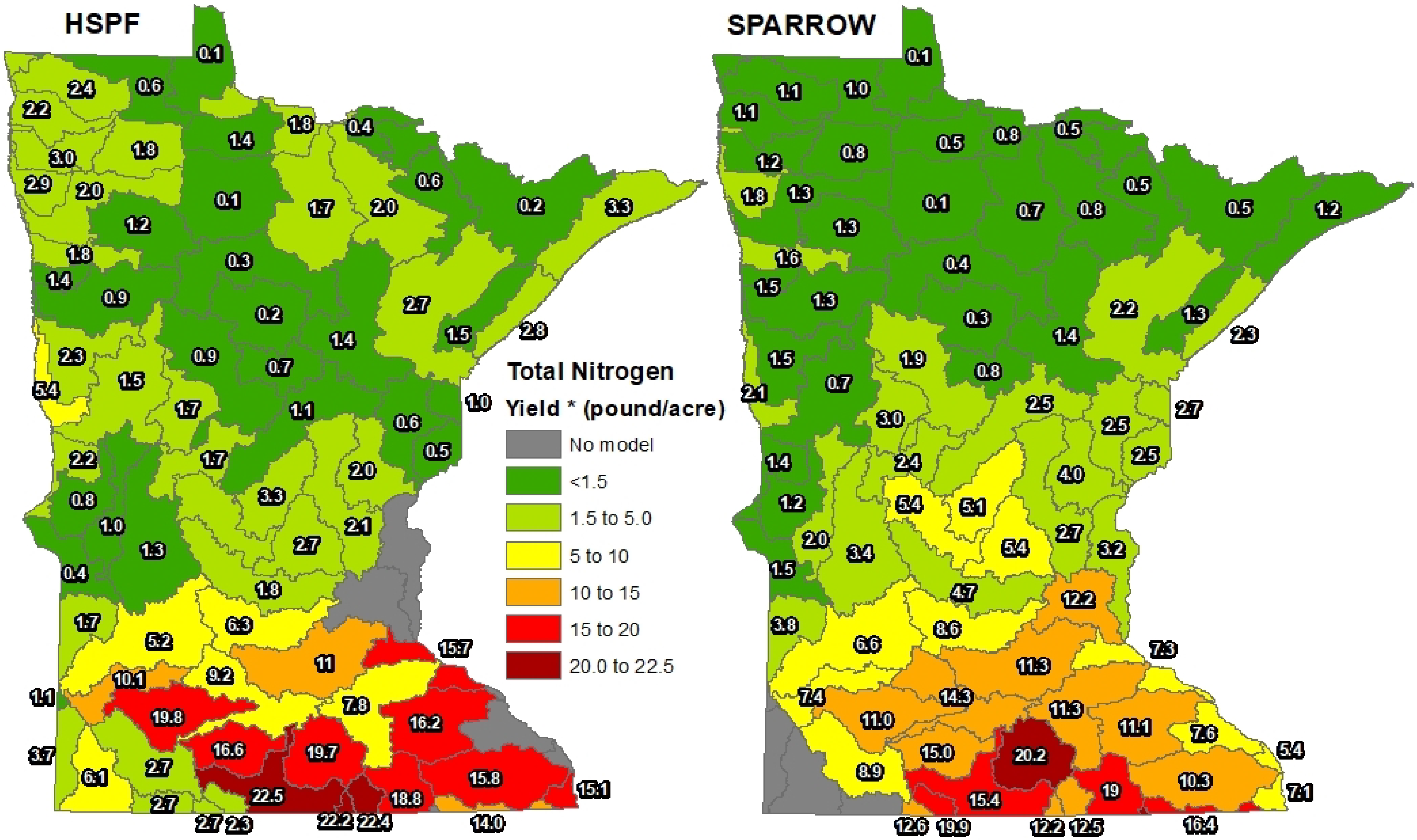
a. An HSPF model has not been developed for this subbasin.

b. SPARROW modeling for this subbasin is not available in the Mid-Continental SPARROW dataset (USGS 2019b) but may be available elsewhere.



* Yields are delivered to Minnesota's state boundaries.

Figure 104. Annual total phosphorus yields delivered to state boundaries.



* Yields are delivered to Minnesota's state boundaries.

Figure 105. Annual total nitrogen yields delivered to state boundaries.

APPENDIX K. MONITORED VERSUS MODELED LOADS

K.1 *MISSISSIPPI RIVER* MAJOR BASIN

Recent monitored and modeled loads were compared at one key location on the Mississippi River and one key location on the Minnesota River in the *Mississippi River* major basin (Table 61 on page 197). The methods for this analysis are summarized by monitoring site:

- **Mississippi River delivered to the IA-MN-WI boundary**: The monitored loads represent the 10-year average (2013-2022) in-stream loads for the Mississippi River at Lock & Dam #7. The monitored loads were reduced by the delivery factors described in Section 3.3 to calculate monitored loads delivered to the Mississippi River at the Iowa-Minnesota-Wisconsin state boundary, which are comparable to the modeled loads delivered to that location. The Mississippi River at Lock and Dam #7 is in the *Mississippi River – La Crescent* subbasin (HUC 07040006) with a TP delivery factor of 82% and a TN delivery factor of 92% (Appendix J).

  The modeled loads represent the loads delivered to the Mississippi River at the Iowa-Minnesota-Wisconsin state boundary from 38 subbasins across all or portions of four subregions: *Upper Mississippi River* (HUC 0701), *Minnesota River* subregion (HUC 0702), *St. Croix River* (HUC 0703), and *Lower Mississippi River* (HUCs 0704 and 0706). The HSPF model simulation periods[7] varied considerably across 34 subbasins[8], and the SPARROW model simulation period was 2002-2014 for four subbasins[9].

  The monitored loads do not account for a few tributaries to the Mississippi River between the monitoring site at Lock and Dam #7, and the Iowa-Minnesota-Wisconsin state boundary that are accounted for in the HSPF model (e.g., Root River, Coon Creek, Crooked Creek).

- **Minnesota River at Jordan, MN**: The monitored loads represent the 10-year average (2013-2022) in-stream loads. The monitored loads were reduced by the delivery factors described in Section 3.3 to calculate monitored loads delivered to the Mississippi River at the Iowa-Minnesota-Wisconsin state boundary, which are comparable to the modeled loads delivered to that location. The Minnesota River at Jordan, MN, is in the *Lower Minnesota River* subbasin (HUC 07020012) with a TP delivery factor of 63% and a TN delivery factor of 71% (Appendix G).

  The modeled loads represent the loads delivered to the state boundary (the Mississippi River at the Iowa-Minnesota-Wisconsin state boundary) from all 12 subbasins in the *Minnesota River* subregion (HUC 0702). The model simulation periods varied considerably across the 12 subbasins[10].

  The monitored loads do not account for several tributaries to the Minnesota River between the monitoring site at Jordan, MN, and outlet of the subbasin that are accounted for in the HSPF model (e.g., Carver Creek, Credit River, Ninemile Creek, Sand Creek).

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[7] The HSPF model simulation periods for the 31 subbasins 2000-2009 (n=2), 2003-2012 (n=4), 2003-2017 (n=2), 2006-2015 (n=10), 2007-2016 (n=1), 2008-2019 (n=6), 2009-2018 (n=2), 2010-2019 (n=1), 2011-2020 (n=3), and 2013-2022 (n=2).

[8] The subbasins in HSPF models are 14 of the 15 subbasins in the *Upper Minnesota River* subregion (HUC 0701), all 12 subbasins in the *Minnesota River* subregion (HUC 0702), *Upper St. Croix River* (HUC 07030001), *Kettle River* (HUC 0703003), *Snake River* (HUC 07030004), *Mississippi River – Lake Pepin* (HUC 07040001), *Cannon River* (HUC 07040002), *Zumbro River* (HUC 07040004), *Root River* (HUC 07040008), and *Mississippi River – Reno* (HUC 07060001).

[9] The four subbasins are the *Mississippi River – Twin Cities* (HUC 07010206), *Lower St. Croix River* (HUC 07030005), *Mississippi River – Winona* (HUC 07040003), and *Mississippi River – La Crescent* (HUC 07040006).

[10] The model simulation periods for the 12 subbasins are 2003-2012 (n=1), 2003-2017 (n=2), and 2008-2017 (n=6), 2013-2022 (n=3).

- **Mississippi River tributaries at state boundaries**: The monitored loads represent the 10-year average (2012-2021) in-stream loads for the Cedar River near Austin, MN, Rock River near Luvern, MN, Split Rock Creek near Jasper, MN, and West Fork Des Moines River at Jackson, MN. As these monitoring stations are near the state boundaries, the delivery factors are 100%.

  The modeled loads represent the loads delivered to the Minnesota-Iowa and Minnesota-South Dakota state boundaries from 11 subbasins. The HSPF model simulation periods[11] varied considerably across 10 subbasins[12], and the SPARROW model simulation period was 2002-2014 for one subbasins[13].

  The monitored loads do not account for a few small tributaries to the Cedar, Rock, and West Fork Des Moines rivers and Split Rock Creek between the monitoring site and the state boundaries that are accounted for in the HSPF model.

The monitored loads presented in this analysis are non-flow-normalized because the modeled loads were non-flow-normalized.

Generally, monitored and model loads are similar. The simulated TP loads were between 11% smaller and 18% larger than the monitored TP loads, while the simulated TN loads were between 4% smaller and 44% larger than the monitored loads. A combination of factors likely explains the discrepancies: (1) the monitoring and simulation periods were different, (2) HSPF and SPARROW model results were combined, and (3) the monitoring sites were sometimes upstream of one or more tributaries (i.e., not included in monitored data) that the models included.

Table 61. Comparison of current monitored and modeled Minnesota-only loads delivered to the state line in the *Mississippi River* major basin

Location	Total phosphorus (metric tons annually)		Total nitrogen (metric tons annually)	
	Monitored	Modeled	Monitored	Modeled
Mississippi River delivered to the IA-MN-WI boundary	3,117	3,888	81,411	80,280
Minnesota River delivered to the IA-MN-WI boundary	*1,279*	*1,192*	*42,066*	*43,989*
Mississippi River tributaries at state boundaries [a]	426	385	7,816	13,889

Note a: The Mississippi River tributaries are the Cedar, Rock, and West Fork Des Moines rivers and Split Rock Creek.

[11] The HSPF model simulation periods for the 10 subbasins 2000-2009 (n=4), 2003-2012 (n=1), 2005-2014 (n=3), and 2009-2018 (n=2).

[12] The subbasins in HSPF models are *Cedar River* (HUC 07080201), *Shell Rock River* (HUC 07080202), *Winnebago River* (HUC 07080203), *Des Moines River Headwaters* (HUC 07100001), *Upper Des Moines River* (HUC 07100002), *East Fork Des Moines River* (HUC 07100003), *Upper Big Sioux River* (HUC 10170202), *Lower Big Sioux River* (HUC 10170203), *Rock River* (HUC 10170204), and *Little Sioux River* (HUC 10230003).

[13] The one subbasin is *Upper Wapsipinicon River* (HUC 07080102).

K.2 *LAKE WINNIPEG* MAJOR BASIN

Recent monitored (non-flow-normalized) and modeled loads were compared at two key locations in the *Lake Winnipeg* major basin (Table 62 on page 201). The methods for this analysis are summarized by monitoring site:

- **Red River at Emerson, Manitoba**: The monitored loads represent the 10-year average (2013-2022) in-stream loads reduced to the proportion of loading within Minnesota. The modeled loads represent the loads delivered to the state/international boundary at Emerson from 17 subbasins[14] in the *Red* subregion (HUC 0902). The model simulation periods varied considerably across the 17 subbasins[15].
- **Rainy River at Manitou Rapids, MN**: The monitored loads represent the 10-year average (2012-2021) in-stream loads reduced to the proportion of loading within Minnesota. The monitored loads were not reduced by a delivery factor because the monitoring station is within the Lake-of-the-Woods subbasin (HUC 09030009) that has TP and TN delivery factors of 100%. The modeled loads represent the loads delivered to the Lake-of-the-Woods at the state/international boundary from eight subbasins[16] in the *Rainy* subregion (HUC 0903). The modeled loads were reduced by the delivery factors (Appendix J). The model simulation periods are 2005-2014.

Generally, monitored and model loads are similar. The simulated TP loads for the Red River of the North (+8%) and Rainy River (+16%) were larger than the monitored loads. The simulated TN loads for the Red River of the North (+35%) and Rainy River (+51%) were considerably larger than the monitored loads.

The larger discrepancy with the TN loads may be due to the application of the Minnesota-fraction to the in-stream loads. The in-state and out-of-state distribution analysis (Section 2.7 and Appendix H) found TN loads in the Rainy River at Manitou Rapids to be 26.8% in-state and 73.2% out-of-state. This monitoring site was not evaluated in this manner in the 2014 NRS, and as such, no data are immediately available to verify this distribution.

Table 62. Comparison of current monitored and modeled Minnesota-only loads in the *Lake Winnipeg* major basin

Monitoring sites	Total phosphorus (metric tons annually)		Total nitrogen (metric tons annually)	
	Monitored	Modeled	Monitored	Modeled
Red River at Emerson, Manitoba	999	1,084	5,681	8,674
Rainy River at Manitou Rapids, MN	191	228	2,092	4,275

[14] The 17 subbasins are *Boix de Sioux River* (HUC 09020101), *Mustinka River* (HUC 09020102), *Otter Tail River* (HUC 09020103), *Upper Red River of the North* (HUC 09020104), *Buffalo River* (HUC 09020106), *Red River of the North – Marsh River* (HUC 09020107), *Wild Rice River* (HUC 09020108), Red River of the North – Sandhill River (HUC 09020301), *Upper/Lower Red Lake* (HUC 09020302), *Red Lake River* (HUC 09020303), *Thief River* (HUC 09020304), *Clearwater River* (HUC 09020305), *Red River of the North – Grand Marais Creek* (HUC 09020306), *Snake River* (HUC 09020309), *Red River of the North – Tamarac River* (HUC 09020311), *Two River* (HUC 09020312), and *Roseau River* (HUC 09020314).

[15] The model simulation periods for the 17 subbasins are 2000-2009 (n=4), 2005-2014 (n=2), 2006-2015 (n=3), 2006-2022 (n=1), 2007-2016 (n=5), 2008-2017 (n=1), and 2013-2022 (n=1).

[16] The five subbasins are *Rainy River Headwaters* (HUC 09030001), *Vermilion River* (HUC 09030002), *Rainy River – Rainy Lake* (HUC 09030003), *Little Fork River* (HUC 09030005), *Big Fork River* (HUC 09030006), *Rapid River* (HUC 09030007), *Rainy – Baudette* (HUC 09030008), and *Lake-of-the-Woods* (HUC 09030009).

K.4 *LAKE SUPERIOR* MAJOR BASIN

Monitored and modeled loads were compared at two key locations in the *Lake Superior* major basin (Table 63). The methods for this analysis are summarized by monitoring site:

- **Nemadji River near South Superior, WI**: The monitored loads represent the 10-year average (2014-2021 for TP[17] and 2012-2021 for TN) in-stream loads delivered to Lake Superior . The modeled loads represent the 10-year average (2005-2014) load delivered to Lake Superior from one subbasin: *Nemadji River* (HUC 04010301). As the delivery factors for the *Nemadji River* subbasin (HUC 04010301) are 100%, neither the monitored nor modeled loads were further modified. While the monitoring site is more than 10-miles east of the state border, the monitored load was reduced by the out-of-state fraction, which means that the geographic representation of the monitored and modeled loads is approximately equal.
- **St. Louis River at Scanlon, MN**: The monitored loads represent the 10-year average (2014-2021 for TP[18] and 2012-2021 for TN) in-stream loads delivered to Lake Superior. The delivery factor for the St. Louis River subbasin (HUC 04010201) is 100%. The modeled loads represent the 10-year average (2005-2014) loads delivered to Lake Superior from two subbasins: *St. Louis River* (HUC 04010201) and *Cloquet River* (04010202). The monitoring site is about 12-miles upstream of the Fond du Lac dam.

  The monitored loads do not account for several tributaries to the St Louis River between the monitoring site at Scanlon, MN, and the Fond du Lac dam on the St. Louis River that are accounted for in the HSPF (e.g., Midway River, Otter Creek). Additionally, tributaries in the greater Duluth area discharge to the St. Louis River Estuary and Bay that are all downstream of the monitoring site.

Generally, monitored and model loads are similar. For the Nemadji River, the simulated TP load was 7% less than the monitored TP load and the simulated TN load was 121% less than the monitored TN load. For the St. Louis River, the monitored and modeled TP loads were nearly identical and the simulated TN load was 2% larger than the monitored TN load. Besides the differences between simulated and monitored periods, the differences in geography may also contribute to the discrepancies.

Table 63. Comparison of current monitored and modeled Minnesota-only loads in the *Lake Superior* major basin

Monitoring sites	Total phosphorus (metric tons annually)		Total nitrogen (metric tons annually)	
	Monitored	Modeled	Monitored	Modeled
Nemadji River near South Superior, WI	63	59	309	140
St. Louis River at Scanlon, MN	103	103	2,491	2,545

[17] Annual TP loads were not available for 2012 or 2013.
[18] Annual TP loads were not available for 2012 or 2013.

APPENDIX L. SUMMARIES OF PERTINENT CLIMATE CHANGE STUDIES

L.1 SUMMARIES OF STUDIES

A sample of literature pertinent to climate change and how climate change may affect flow conditions in Minnesota is briefly summarized in this appendix.

***Agricultural Best Management Practice Sensitivity to Changing Air Temperature and Precipitation* (Schmidt et al. 2015)**

BMPs and potential climate change scenarios were quantified for the Ichawaynochaway Creek watershed in Georgia and the Little Cobb River watershed in Minnesota using the Soil and Water Assessment Tool (SWAT). BMPs were simulated in three hydroclimatic settings: recent conditions (1950-2005), future mid-century (2030-2059), and late century (2070-2099). Results suggest future increases in agricultural source loads of sediment, nitrogen, and phosphorous. Most BMPs continue to reduce loads, but removal efficiencies generally decline due to more intense runoff events, biological responses to changes in soil moisture and temperature, and exacerbated upland loading. The coupled effects of higher upland loading and reduced BMP efficiencies suggest that wider adoption, resizing, and combining practices may be needed in the future to meet water quality goals for agricultural lands.

***Climate Change Adaptation Modeling in the Chippewa River Watershed, MN* (Tetra Tech 2015)**

Several climate scenarios (e.g., MIROC-ESM, immcm4) were simulated in an HSPF model for the agricultural *Chippewa River* subbasin (HUC 07020005) in the *Minnesota River* subregion (HUC 0702). Although climate models agree that average temperatures will increase, the models are not in consensus regarding precipitation and evapotranspiration. Even as extreme runoff events are likely to increase, one of the models suggests that the decline in total precipitation volume is likely to overwhelm any increases in precipitation intensity. Therefore, the general trend is for increases in total flow, pollutant loads, and peak runoff, with a decrease in soil moisture. However, the suite of model projections for 2040 conditions covers the zero line of no change from historical conditions.

***Modeling Streamflow and Water Quality Sensitivity to Climate Change and Uban Development in 20 U.S. Watersheds* (Johnson et al. 2015)**

A literature review suggests that changes in precipitation and evapotranspiration will affect hydrology such that runoff may increase in higher latitudes and wet tropical areas, while runoff may decrease in mid-latitudes and dry and semiarid regions (IPCC 2014; Melillo et al. 2014). In northern and mountainous areas, a shift is anticipated toward more rain-dominated systems with less snowpack storage, resulting in greater winter and early spring runoff. The effects of climate change on hydrology will vary across the United States due to regional differences in climate change, watershed physiography, land use, water management, and other factors.

Twenty large watersheds in the United States were simulated in SWAT models to assess the sensitivity of streamflow, nutrient, and sediment loading to mid-21st Century climate change and urban/residential development scenarios. The climate change scenarios were created through dynamically downscaling climate model output from the North American Regional Climate Change Assessment Program.

Ensemble mean results suggest that by the mid-21st Century, statistically significant changes in streamflow TSS loads (relative to baseline conditions) are possible in roughly 30-40% of study watersheds. These proportions increase to around 60% for TP and TN loads. It is important to note that these results are descriptive only of scenario simulations in this study, and do not imply future probabilities of occurrence.

Simulations suggest potential streamflow volume decreases in the Rockies and interior Southwest and increases in the East and Southeast Coasts. Wetter winters and earlier snowmelt are likely in many of the northern and higher elevation watersheds. In general, simulated changes in pollutant loads follow a similar pattern to streamflow, but with additional variability associated with watershed differences in nutrient and sediment sources and pathways.

Simulation of Watershed Response to Climate Change for the Duluth Urban Area and Lake Superior South Watersheds, MN **(Tetra Tech 2017)**

According to the IPCC's 2013 Global Climate Model simulations from the CIMP5 (as well as NASA and USGS models), there will be a steady increase in maximum and minimum air temperature throughout the 21st Century, although trends diverge after about 2050 depending on the greenhouse gas concentration trajectory. There is less agreement as to future trends in precipitation, although most models tend to predict some increase in winter and spring precipitation and a decrease in summer precipitation in the watershed. Rising temperatures will cause winter snowpack to decrease while summer evaporation rates will increase, likely leading to declining soil water storage based on the simple water balance accounting method of McCabe and Wolock (2011). Resulting impacts on runoff, which integrates the effects of precipitation and evaporation are uncertain in the McCabe and Wolock (2011) analysis, although total runoff volume appears likely to not change greatly.

Potential changes in flow, sediment, and nutrient loading in the Duluth Urban Area and Lake Superior South subbasin (HUC 04010102) that may be associated with climate change were studied using the Lake Superior South HSPF model. Simulations indicate that the water balances for the Duluth Urban Area and Lake Superior South subbasin will change under future climate scenarios. Evapotranspiration is expected to increase significantly, more so for the end-century time-frame. Increase in evapotranspiration appears to occur at the expense of reduced groundwater flows. Reduced baseflow in streams may have serious implications on aquatic life. Despite decreases in total flow volume for some GCMs, the peak flows are expected to generally increase. Increased peak flows results in increases in stream sediment scour for several streams in the study area. The simulations suggest that sediment outflow for some major streams increase more than 30% under future climate (mid-century) scenarios. The simulation results for the mid-century time-frame are also more conclusive than end-century for nutrient loads delivered to Lake Superior and major streams, which may lead to issues such as eutrophication and changes to the food web. Stream temperatures are expected to increase universally with larger increases expected for the later time-period.

Adaptation strategies should include strategies to reduce peak flows and incorporate strategies to maintain baseflow in streams. Some such strategies could include limiting increases in impervious areas and implementing practices that increase infiltration. To mitigate the predicted increase in stream water temperature, an important strategy would be increase or at least maintain current levels of shading over streams.

Winter/Spring Runoff Is Earlier, More Protracted, and Increasing in Volume in the Laurentian Great Lakes Basin **(Hrycik 2024)**

Climate change has altered the timing of when snowmelt occurs in the spring and how long it takes for the snowpack to melt. Such changes in snowmelt are caused by warming temperatures, and potentially, changes in winter and spring precipitation that includes a greater proportion of rain. One way to measure the effects of melting and precipitation is to examine the amount and timing of streamflow, which includes water from snowmelt and precipitation. Streamflow data from the Great Lakes Basin since 1950 were examined and the authors found that the timing of streamflow in the winter and spring has become earlier and is stretched out over a longer period of time. This means that the Great Lakes region is shifting away from "spring floods" toward smaller, more spread out melting events that now begin earlier during the winter. The amount of streamflow during the winter and spring has also increased over time. Because streamflow can transport particulate and dissolved nutrients, shallower areas of the Great Lakes may be affected by changes in the seasonality of nutrient inputs.

Overall, winter/spring runoff became earlier, more protracted, and had higher volume in the Great Lakes Basin over the period 1950–2019. Runoff timing was significantly earlier in Lakes Michigan and Ontario, and nonsignificant in Lakes Superior and Huron, despite strong trends toward becoming earlier. Lake Erie was the only Great Lake that showed only weak evidence of earlier runoff. Results indicate that the fastest change toward earlier runoff occurred in the Lake Ontario watershed. The duration of winter ‐ spring runoff became significantly longer in Lakes Erie, Ontario, and Michigan, and similar but non ‐ significant trends were found in Lakes Superior and Huron. The amount of winter ‐ spring runoff increased in all the lakes except Lake Superior. Increased runoff was significant in Lakes Huron, Michigan, and Erie, but also showed an increasing trend in Lake Ontario. Changes in runoff have implications for mixing patterns, nutrient dynamics, water balance, and potentially nearshore primary production in the Great Lakes.

Little difference was evident between impacted and natural streams, indicating that results are likely due to broad changes associated with climate change rather than local alterations to subwatersheds. The timing and magnitude of snowmelt may also have implications for how inflow impacts flushing rates and mixing in the Great Lake nearshore zones. The interaction of the timing of runoff entering a lake and the lake's antecedent conditions are critical for the fate of the external nutrient load, particularly in nearshore areas that are ice-covered in winter. Earlier runoff events during winter ice cover may travel under the ice as a plume during winter inverse stratification or be mixed into the water column when the runoff occurs during isothermal spring mixing, as we often expect with a "typical" spring flood. These differences in the flow paths of runoff, depending on hydrothermal condition of the lake, may impact phytoplankton growth later in the year if the uptake or sequestration of nutrient is altered.

Contrasting expectations of the role of early-season runoff entering ice covered lakes versus that occurring during the open-water season make interpretation and prediction of primary production trajectories with climate change difficult, and the effects of runoff timing on lake productivity may also differ by region. Precipitation analysis indicated that January–May precipitation increased through the period of study, and other research indicates that this trend will continue into the future with climate change. Runoff timing for Lake Erie became more protracted and Lake Erie had the most dramatic increase in volume of runoff of all the Great Lakes, but the timing of the center of winter/spring runoff did not change as much in Lake Erie as the other lakes. Some outliers were evident in runoff indices, included in the analysis except for some runoff depth values that were suspiciously high. As a result, runoff indices were extremely variable. Some outliers, but not all, came from shorter data sets where trends were strongly affected by one or a few extreme points. Shorter time series were kept despite this variability to have the most complete dataset possible to elucidate broad trends. Additionally, the analysis of impacted and natural sites did not reveal many differences between streams with high and low human impact, suggesting that trends were consistent among subwatersheds with different land use changes.

Runoff changed dramatically in the Great Lakes Basin over the past 70 years: the majority of winter-spring runoff occurs earlier in the year, runoff is more protracted throughout the winter and spring, and runoff is occurring at higher volume over time. findings suggest that changes in timing, duration, and amount of nutrient loading occurring during the Winter-Spring period may also need to be considered to understand the ongoing changes to Great Lake primary productivity.

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