Nutrients in water

August 2020

5-year Progress Report on Minnesota's Nutrient Reduction Strategy

MINNESOTA POLLUTION CONTROL AGENCY

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Acronyms and abbreviations

%	percent
1W1P	One Watershed One Plan
AA	Anhydrous ammonia
ac	acre
ACPF	Agricultural Conservation Planning Framework
BMP	best management practices
BWSR	Board of Water and Soil Resources
CFO	concentrated feeding operation
CREP	Conservation Reserve Enhancement Program
CRP	Conservation Reserve Program
CSP	Conservation Stewardship Program
CTIC	Conservation Technology Information Center
DAP	diammonium phosphate
DEP	Daily Erosion Project
DNR	Minnesota Department of Natural Resources
EPA	U.S. Environmental Protection Agency
EQB	Environmental Quality Board
EQIP	Environmental Quality Incentive Program
EWG	Environmental Work Group
GRAPS	groundwater restoration and protection strategies
HSPF	Hydrological Simulation Program – FORTRAN
HSPF-SAM	Hydrological Simulation Program – FORTRAN Scenario Application Manager
HUC	hydrologic unit code
IPNI	International Plant Nutrition Institute
ITPHS	imminent threats to public health and safety
L	liter
lb N	pounds of nitrogen
LiDAR	Light Detection and Ranging
MAP	mono-ammonium phosphate
MDA	Minnesota Department of Agriculture
MDH	Minnesota Department of Health
Met Council	Metropolitan Council
mg	milligram
MG	million gallon
Minn. R. Ch.	Minnesota Rule Chapter
MPCA	Minnesota Pollution Control Agency
MRBI	Mississippi River Basin Healthy Watersheds Initiative
MRTN	Maximum return on total nitrogen
MS4	municipal separate storm sewer system
MT	metric ton
NASS	National Agricultural Statistics Service
NPDES	National pollutant discharge elimination system
NRCS	Natural Resources Conservation Service

NRS	Nutrient Reduction Strategy
NWQI	National Water Quality Initiative
OpTIS	Operational Tillage Information System
ppm	parts per million
PTMApp	Prioritize, Target, and Measure Application
RIM	Re-Invest in Minnesota
SDS	State Discharge System
SPARROW	SPAtially Referenced Regression on Watershed Attributes
SSTS	Subsurface Sewage Treatment Systems
TMDL	total maximum daily load
UAN	Nitrogen solutions
U of MN	University of Minnesota
USDA	United State Department of Agriculture
USGS	U.S. Geological Survey
WLA	wasteload allocation
WLSSD	Western Lake Superior Sanitation District
WRAPS	Watershed Restoration and Protection Strategies
yr	year

1 Introduction

Nutrients are important for all living things. However, too many nutrients in water can produce problems like algae growth, low levels of dissolved oxygen, toxicity to aquatic life, and unhealthy drinking water. Excessive nutrients can diminish water quality, both within Minnesota and in downstream waters, including Lake Winnipeg, the Gulf of Mexico, and Lake Superior.

To address the issue of excessive nutrients, 11 Minnesota organizations finalized a state-level Nutrient Reduction Strategy (NRS) in 2014. Minnesota is one of 12 states on the Gulf of Mexico Hypoxia Task Force that developed such a strategy to reduce nutrients entering in-state waters and to achieve fair-share nutrient reductions for the Gulf of Mexico and other downstream waters. Minnesota's NRS set specific goals for reducing nitrogen and phosphorus and outlined scenarios of changes needed in Minnesota's rural and urban areas to meet those goals. The 2014 NRS is available at https://www.pca.state.mn.us/water/nutrient-reduction-strategy.

Figure 1. Major drainage basins in Minnesota.

1.1 Overview of 2014 NRS goals and milestones

The 2014 NRS set milestones, or interim goals, to assist in tracking Minnesota's statewide nutrient reduction progress. Each major basin has numeric reduction milestones for phosphorus and nitrogen. For example, the nitrogen milestone for the Mississippi River is a 20% reduction by 2025, with a 2040 target date for reaching a 45% final reduction goal. Nitrogen and phosphorus milestones and final goals vary in the three major drainages in Minnesota (Table 1).

Table 1. Timeline for reaching goals and milestones.

Major basin	**Milestone 2014 to 2025**	**Final Goal 2025 to 2040**
1. Mississippi River (Also includes Cedar, Des Moines, and Missouri Rivers)	**12%** reduction in phosphorus (33% reduced prior to 2014)	Achieve **45%** total reduction from 1980-96 baseline and meet in-state lake and river water quality standards
	20% reduction in nitrogen	Achieve **45%** total reduction from 1980-96 baseline
2. Red River (Lake Winnipeg Basin)	**10%** reduction in phosphorus	Achieve final reductions identified through joint efforts with Manitoba (about 50% from 1998 to 2001) [a]
	13% reduction in nitrogen	
3. Lake Superior	Maintain protection goals, no net increase from 1970s	
Groundwater/Source Water	Meet the goals of the 1989 Groundwater Protection Act	

a. The 2014 NRS noted that the International Red River Basin Water Quality Committee had suggested revised Red River nutrient reduction goals as high as 50% reductions from baselines. In September 2019, the International Red River Board agreed to pass along the proposed loading targets for the Red River at the US/Canada Boundary onto the International Joint Commission. The new load targets on the Red River at the Minnesota/Canadian Border are 1,400 MT of total phosphorus and 9,525 MT of total nitrogen. These load targets represent 48% and 52% of phosphorus and nitrogen 5-year rolling average loads during the 1998 to 2001 baseline timeframe, respectively. 5-year rolling average loads during recent years have averaged about 2,200 MT for phosphorus and 13,000 MT for nitrogen.

1.2 Tracking progress toward NRS goals and milestones

Tracking progress toward these nutrient reduction goals and making necessary adjustments is a key component of the 2014 NRS. In the 2014 strategy, Minnesota partner agencies committed to progress reports: a 5-year progress report and a 10-year update and NRS re-publishing.

The 5-year progress report was supposed to include progress on the following:

- Implementation activities and strategies
- Best management practice (BMP) adoption assessment
- Water quality outcomes
- Next steps for the 2020 to 2024 period

The 2024 NRS update will examine progress after 10 years of implementation prior to the 2025 milestone. Depending on the progress found at that time, Minnesota partner agencies could potentially make additional adjustments to NRS implementation efforts.

Overarching goals that the Minnesota NRS and this 5-year progress report address include the following:

- **Ensure nitrogen reductions to water are achieved** in the large parts of Minnesota where specific local drivers do not exist for nitrogen reduction, but where local nitrogen delivery incrementally impacts downstream waters.
- **Ensure local phosphorus reductions are collectively adding up** to address eutrophication in downstream large rivers, regional lakes/reservoirs, and waters further downstream, such as Lake Winnipeg and the Gulf of Mexico.
- **Ensure Minnesota adapts to remain well-positioned for long-term nutrient reduction success**, modifying as necessary the state-level programs, partnerships, priorities, provision to local watersheds, and technical practices to achieve large-scale BMP adoption.
- **Maintain commitments to evaluate and communicate** Minnesota's implementation approaches and progress to both in-state and out-of-state national and international audiences.

1.3 What's in the NRS 5-year progress report

This document is the 5-year progress report intended to fulfill the reporting objectives set forth in the 2014 NRS. This report evaluates and documents Minnesota's progress toward reaching NRS goals and benchmarks at the mid-point of NRS implementation to achieve the 2025 milestones, presented above. This 5-year progress report takes the pulse of water quality trends and provides insights into the implementation activities cited in the 2014 NRS as integral to achieving the 2025 milestones. Evaluation of state-level program advancements, BMP scales of adoption, and nutrient trends in waters provide the needed assessment information to gage progress thus far and recommend next steps.

Key questions that are explored as part of this 5-year progress report include:

Programs – Are the NRS strategies progressing? This section discusses progress on new or expanded programmatic initiatives identified in the 2014 NRS, in addition to continuation and expansion of existing efforts and programs, to achieve nutrient reduction milestones. This section is not intended to be a full accounting of all nutrient reduction programs and activities, but is a comparison of NRS recommended strategies with associated programmatic advancements made since 2014.

In the water – What can we tell so far? This section presents water quality information on nitrogen and phosphorus changes and trends identified from key data sources.

On our cropland – Are we on track for the needed scale of BMP adoption? This section provides information on cropland BMP adoption progress implemented through new and existing programs intended to achieve the NRS milestones.

Wastewater and other sources – Is progress consistent with NRS direction? A summary of progress from wastewater, feedlots, urban stormwater, and septic system sources is provided.

What are the next steps for the NRS (2020 to 2024)? This section outlines high priority steps to

a) increase the potential for successful nutrient reductions prior to the 2025 NRS milestones, and
b) develop the information needed to strengthen the republished NRS in 2024.

Together, answers to these questions help to tell the story of NRS implementation in Minnesota over the past five years and help set the course for successful NRS implementation for the next five years.

This progress report represents a collective effort by the Minnesota partner agencies who developed the 2014 NRS. Each agency contributed readily available data and information to generate this 5-year progress report, minimizing the resources required to assess the NRS progress to date.

2 Programs – Are the NRS strategies progressing?

To make substantial progress in reducing Minnesota's nutrient loads into waters, Minnesota's 2014 NRS Chapter 6 recommended many strategies necessary to achieve NRS reduction goals. These recommended strategies included the creation of new programs and continuation of existing programs for agricultural lands, wastewater, septic systems, feedlots, stormwater, and other overarching activities. These programs and initiatives were intended to help achieve the increased level of effort (implementation of agricultural BMPs, wastewater reductions, etc.) necessary to meet the goals and milestones of the 2014 NRS. In addition, Chapter 7 of the NRS identifies the needed information and tools to track implementation, expected nutrient reductions, and changes in water quality from NRS activities.

The following sections summarize the progress made since 2014 towards NRS recommended strategies and the needed information and tools to track NRS implementation. Sections 4 and 5 in this 5-year progress report provide an update on the adoption levels of the specific activities recommended in the NRS.

Climate change resiliency

While not a specific recommended strategy in the 2014 NRS, climate change resiliency and planning has become a major focus of state agency action in recent years. Several reports and committees have been created to advance programs related to understanding and mitigating the potential effects of climate change. Many NRS practices not only reduce nutrients but help to mitigate the effects of climate change. Reports related to climate change resiliency and planning since 2014 include but are not limited to:

Climate Change Trends and Action Plan (BWSR 2019): https://bwsr.state.mn.us/sites/default/files/2019-09/ClimateChangeTrends%2BActionPlan_Sept2019.pdf

Adapting to Climate Change in Minnesota (Interagency Climate Adaption Team 2017): https://www.pca.state.mn.us/sites/default/files/p-gen4-07c.pdf

Greenhouse gas reduction potential of agricultural BMPs (MPCA 2019): https://www.pca.state.mn.us/air/agriculture-and-climate-change-minnesota

2.1 Progress towards NRS strategies

Minnesota has made substantial progress towards implementation of most of the strategies found in Chapter 6 of the 2014 NRS. Sections 2.1.1 through 2.1.5 summarize the progress made since 2014 towards the NRS recommended strategies by category: overarching, agricultural, wastewater, miscellaneous sources of nutrients, and protection strategies. Some programs created or expanded since 2014 support multiple strategies and are therefore listed multiple times. Major advances for each strategy are further described in Appendix A which includes associated program web links when available.

The programs highlighted in Appendix A and in the tables below are in various stages of development and implementation. Where quantification of program impacts is known for the 2014 to 2018 period, they are provided in the tables and/or Appendix A. However, quantified existing and projected outcomes are not available for each program at this time.

2.1.1 Implementation of overarching recommended strategies

Progressing toward the goals and milestones of the NRS requires a significant amount of coordination and communication at a statewide level. Programmatic infrastructure is necessary to support coordination and communication among the various local, state, and federal partners. The first set of 2014 NRS recommended strategies focus on developing and sustaining the necessary infrastructure to support coordinated implementation and communication on progress over time. Minnesota partner agencies have made substantial progress in implementing these recommendations. Major advances towards the 2014 overarching NRS recommendations are summarized in Table 2. These advances are expanded upon in Appendix A.

Table 2. Progress made towards implementation of overarching strategies.

Strategy	Major Advances since 2014
Develop a Statewide NRS Education/ Outreach Campaign	• Governor's 25% by 2025 initiative resulted in over 3,500 public suggestions from over 2,000 attendees • Interaction between shrimpers and Minnesota farmers • Technical Training and Certification Program established in 2015 • Nitrogen Smart Training Program held 36 educational events from 2016 to 2018 • Annual Statewide Nitrogen and Nutrient Management Conferences reaches approximately 400 attendees each year • Annual Conservation Tillage Conference • Agricultural BMP Guidance, Handbook and updates • Minnesota's Public Drainage Manual updates • Minnesota Department of Natural Resource (DNR) workshops and training to lake associations and local government regarding BMPs to reduce phosphorus inputs to waters • Continued updates to the Minnesota Water Research Digital Library. Over 2,800 articles and reports at the end of 2018
Integrate Basin Reduction Needs with Watershed Planning Goals and Efforts	• Advances in Total Maximum Daily Load (TMDL), Watershed Restoration and Protection Strategies (WRAPS), Groundwater Restoration and Protection Strategies (GRAPS), and One Watershed One Plan (1W1P) development o Over 60% of nutrient impaired waters have approved TMDL plans o 53 WRAPS completed in the state o 14 GRAPS completed by the Minnesota Department of Health (MDH) o Comprehensive watershed plans developed through 1W1P for 12 watersheds, 20 under development • Developed lake and stream protection prioritization guidance for use in WRAPS and 1W1Ps. DNR refined its lake phosphorus sensitivity index and associated cost-benefit analysis. • Watershed Conservation Planning Initiative to increase landowner and producer readiness to implement conservation practices in seven major watersheds • Small watershed activities through Section 319, small watersheds focus program, Mississippi River Basin Healthy Watershed Initiative (MRBI), and National Water Quality Initiative (NWQI) programs • 20 watersheds selected as part of the Section 319 Watersheds Focus Program

2.1.2 Agricultural BMPs

To achieve the goals and milestones of the NRS, strategies were identified to support the increased adoption of the agricultural BMPs identified in Chapter 5 of the NRS. These strategies fall into the following categories: Stepping Up Agricultural BMP Implementation in Key Categories; Support for

Advancing BMP Delivery programs; Economic Strategy Options; Education and Involvement Strategies; Research Strategies; and Demonstration Strategies. Major advances towards the 2014 agricultural BMP NRS recommendations are summarized in Table 3. These advances are expanded upon in Appendix A.

Table 3. Progress made towards agricultural BMP strategies.

Strategy	Major Advances since 2014
Stepping Up Agricultural BMP Implementation in Key Categories	
Work with Private Industry to Support Nutrient Reduction to Water	• Minnesota Agricultural Water Quality Certification Program initiated in 2015 and thus far certified 900+ farmers and over 600,000 acres of land • Nitrogen Smart Training Program held 36 educational events from 2016 to 2018 • Annual Statewide Nutrient Management Conference • Minnesota Corn Growers collaborative efforts • Forever Green Initiative • Discovery Farms efforts • Watershed Partnerships, such as the Cedar River Partnership
Increase and Target Cover Crops and Perennial Vegetation	• Forever Green Initiative • A new Minnesota Conservation Reserve Enhancement Program (CREP) began in 2017 • 12,186 acres received funding during the 2017 to 2018 CREP sign-up period • Working Lands Watershed Restoration Feasibility Study and Program Plan • Red River Conservation Easement Program • Nearly 7,000 easements over the lifetime of the Re-Invest in Minnesota Program
Soil Health	• Minnesota Office for Soil Health initiated in 2018 by University of Minnesota and the Board of Water and Soil Resources (BWSR) • Soil Health Specialist position created and filled
Riparian Buffers	• Minnesota's Buffer Law passed in 2015 • Over 99% compliance with Buffer Law along lakes, rivers and streams, and over 90% for public ditches • DNR developed "Innovative Shoreland Standards Showcase" that emphasizes riparian vegetative management standards
Fertilizer Use Efficiencies	• Nitrogen Smart Training Program held 36 educational events from 2016 to 2018 reaching over 500 farmers and over 100 agronomists • 466 trials covering over 32,000 acres of cropland completed since 2015 through the Nutrient Management Initiative • Nitrogen Fertilizer Management Plan completed in 2015; associated Groundwater Protection Rule passed in 2019
Reduced Tillage and Soil Conservation	• Annual Conservation Tillage Conference • Development of Soil Erosion Prediction Tool
Drainage Water Retention and Treatment	• Minnesota's Public Drainage Manual updated in 2016 • Multi-purpose Drainage Management Grant Program developed by BWSR • Several state-led drainage demonstration sites

Support for Advancing BMP Delivery Programs	
Coordinated Federal/State/Local/ Planning to Increase BMP Implementation for Key Categories of BMPs	• Watershed Based Funding Implementation Program pilot began in 2017 and anticipated program finalization in 2021. • Watershed Conservation Planning Initiative's contribution agreement with the BWSR to increase landowner and producer readiness for implementing BMPs in seven major watersheds • USDA programs including the MRBI and NWQI, RCPP, Conservation Stewardship Program (CSP), EQIP, and Agricultural Conservation Easement Program • Source Water Protection Program for surface waters developed by the MDH in 2017
Increase Delivery of Industry-Led BMP Implementation	• Minnesota Agricultural Water Quality Certification Program • 4R Certification Program for Minnesota led by agricultural industry expected to be launched in 2020
Study Social and Economic Factors Influencing BMP Adoption	• Social science research at the University of Minnesota's Center for Changing Landscapes
Create a Stable Funding Source to Increase Local Capacity to Deliver Agricultural BMPs	• Clean Water Fund provided between $50 and $74 million implementation funding per year over the last 5 years • Watershed Based Funding Implementation Program • Federal 319 Nonpoint Source Pollution Program continuation • A new Minnesota CREP began in 2017
Economic Strategy Options	
Nutrient BMP Crop Insurance Program	• Environmental Initiative is evaluating how cover crops reduce risk to producers and therefore should require less cost for crop insurance
Develop Markets and Technologies for Use of Perennials	• High value commodity crops for conservation being developed through the Forever Green Initiative with the University of Minnesota • The Forever Green Initiative hired a Supply Chain Development Specialist and Market Development Opportunity Specialist in 2019
Quantify Public Environmental Benefits of Reducing Nutrient Levels in Water	• Social science research at the University of Minnesota's Center for Changing Landscapes • 2018 Nitrate Report: Community Public Water Systems by the MDH • New academic research papers including: o The social costs of nitrogen (Keeler et al. 2016) Land-use changes and costs to rural households: a case study in groundwater nitrate contamination (Keeler et al. 2014)
Education and Involvement Strategies	
Targeted Outreach and Education Campaign with Expanded Public-Private Partnerships	• Nitrogen Smart Training Program • (see also Table 2)
Encourage Participation in the Agricultural Water Quality Certification Program	• Minnesota Agricultural Water Quality Certification Program initiated in 2015 and certified 900+ farmers representing over 600,000 acres of land

Focus Education and Technical Assistance to Co-Op Agronomists and Certified Crop Advisors	• Nitrogen Fertilizer and Education Promotion Team led by the Minnesota Department of Agriculture (MDA) • Annual statewide Nitrogen and Nutrient Management Conferences • Nutrient Management Initiative https://www.pca.state.mn.us/sites/default/files/wq-ws1-29.pdf • 4R Certification Program under development in Minnesota by private industry
Involve Agricultural Producers in Identifying Feasible Strategies	• Formation of the Agricultural Water Quality Solutions Workgroup by the MDA and Environmental Initiative • Final recommended framework to establish and fund voluntary Farmer-Led Councils presented to Governor in 2017 • Governor's 25% by 2025 initiative resulted in over 3,500 public suggestions from over 2,000 attendees
Watershed Hero Awards	• Agricultural Water Quality Certification awards 10-year certification to farmers for achieving defined standards of water quality protection
Work with SWCDs, MDA, and University of Minnesota Extension to Increase Education and Involvement	• Annual Statewide Nitrogen and Nutrient Management Conferences • (see also Table 2)
Promote Youth-Based Nutrient Reduction Education	• While this may have advanced, the authors of this report are not aware of major advancements
Research Strategies	
Consolidate and Prioritize Research Objectives **Conduct Research Activities**	• Minnesota Water Research Digital Library • Minnesota's Agricultural BMP Handbook updated with new research in 2017 • University of Minnesota research progress on drainage water management, in-field nitrogen management, benefits of reduced tillage, and living cover practices • Forever Green Initiative • MDA Clean Water Research Program • Met Council/University of Minnesota evaluation of sludge incinerator ash as a phosphorus source for crop production
Demonstration Strategies	
Watershed Scale Nutrient Reduction Demonstration Projects	• Several watershed projects in state including the Root River Field to Stream Partnership
Field Scale BMP Demonstration Projects	• Field and farm scale monitoring of BMP demonstration projects through Minnesota's Discovery Farms Program, Root River Field to Stream Partnership, Red River Valley Drainage Water Management Project, and Clay County Drainage Site • BWSR grant and cover crop demonstration program launched in 2019 • Demonstration practices in public water supply recharge areas

2.1.3 Wastewater

The Phosphorus Strategy and Rule discussed in the NRS has and will continue to address phosphorus reductions in wastewater. To address nitrogen in wastewater, the NRS provided a series of steps. The steps are intended to build the knowledge base and generate the data necessary to support informed decisions and investments and were intended to be completed in order. Major advances towards the 2014 wastewater NRS recommendations are summarized in Table 4. These advances are expanded upon in Appendix A.

Table 4. Progress made towards implementing wastewater strategies.

Strategy	Major Advances since 2014
Continued Implementation of the Current Phosphorus Strategy and Rule	• Phosphorus effluent limit reviews for half of the watersheds in the state • Total phosphorus effluent limits set for 271 facilities • Reductions in phosphorus discharges to all major basins • Regulatory Certainty legislation (for wastewater)
Influent and Effluent Nitrogen Monitoring at Wastewater Treatment Plants (Step 1)	• Minnesota's Nitrogen Monitoring Implementation Plan approved in 2014 • Wastewater nitrogen monitoring required at more than 450 facilities
Nitrogen Management Plans for Wastewater Treatment Facilities (Step 2)	• MPCA identifying steps to provide more direction for implementing Step 2 of the NRS Wastewater Nitrogen Reduction Strategy
Nitrogen Effluent Limits as Necessary (Step 3)	• Regulatory Certainty legislation (for wastewater) • MPCA is in the process of evaluating recently completed national scientific studies of nitrate effects on aquatic life toxicity for furthering nitrate standards development. When completed, these limits will inform wastewater permits, but the process is independent of the National Pollutant Discharge Elimination System (NPDES) program. • Currently nine surface water discharge permits with total nitrogen or nitrate limits
Add Nitrogen Removal Capacity with Facility Upgrades (Step 4)	• This step is contingent on the previous steps
Point Source to Nonpoint Source Trading (Step 5)	• New trading opportunities being considered throughout state, as interest in water quality trading is expressed

2.1.4 Miscellaneous sources

The NRS did not recommend significant new strategies to reduce loads from subsurface sewage treatment systems (SSTS), urban/suburban stormwater, feedlots, and sediment; however, continuation of existing programs was identified as a strategy. Major advances towards the 2014 NRS recommendations for miscellaneous sources are summarized in Table 5. These advances are expanded upon in Appendix A.

Table 5. Progress made towards implementation of strategies to address miscellaneous sources.

Strategy	Major Advances since 2014
SSTS Strategies	• Continued implementation of SSTS inspections • SSTSs with direct outlets to land surface estimated at less than 5% of all systems in the state. Several small community systems also fixed • Education and outreach efforts led by the University of Minnesota Onsite Sewage Treatment Program
Feedlot Strategies	• Continued implementation of feedlot inspection program through state and delegated counties • Increased inspection of land application of manure practices • Improved Feedlot Program inspection checklist and tracking of inspection results • Manure and Water Quality Specialist position created and filled by the University of Minnesota in 2017 • Manure and fertilizer Nutrient use evaluation tool developed by EWG
Nutrient Reduction Associated with Regulated Stormwater Sources	• Minnesota's municipal separate storm sewer system (MS4) general permit to be reissued in 2020 – currently 251 MS4s with stormwater permits • Minnesota's construction general permit reissued in 2018 • Minnesota's industrial stormwater multi-sector general permit reissuance in 2020
Stormwater Technical Assistance	• Continued updates to the Minnesota Stormwater Manual
Stormwater Research and Demonstration	• Minnesota Stormwater Research Council was formed in 2016 • 2018 Stormwater Research Road Map and Framework • Various research activities being conducted by the MPCA and University of Minnesota
Sediment Reduction Strategies	• Minnesota Sediment Reduction Strategy completed in 2015 • DNR standardizing approaches to targeting and prioritizing watershed upland sediment reduction and channel restoration and advancing floodplain culvert technologies at road/river crossings • Multiple TMDLs and sediment modeling efforts completed in the past five years, along with research and monitoring advancements

2.1.5 Protection strategies

The NRS states that protection strategies are needed in watersheds with anticipated changes in agriculture and land use practices, as well as vulnerable groundwater drinking water supplies. In addition, protection strategies for new nitrogen sources, soil phosphorus increases, and the need to be more protective from increasing precipitation are important elements that WRAPS and local water planning (e.g., 1W1P) should address. Major advances towards the 2014 protection NRS recommendations are summarized in Tqable 6. These advances are expanded upon in Appendix A.

Table 6. Progress made towards implementation of protection strategies.

Strategy	Major Advances since 2014
Protecting the Red River from Nitrate Increases	• Flood control and water retention efforts by the Red River Watershed Management Board • Red River Valley Drainage Water Management Project
Lake Superior Nutrient Load	• While this may have advanced, the authors of this report are not aware of major advancements apart from what has been previously noted about progress with misc. sources.
Groundwater Protection Strategies	• Nitrogen Fertilizer Management Plan completed in 2015; associated Groundwater Protection Rule adopted by MDA in 2019 o Fall fertilizer and frozen soil application restrictions set to start Fall 2020 o Development of a vulnerable groundwater area map • Agricultural BMP Practices Booklet for Groundwater

Summary of Progress Made Towards NRS Strategies

Why important

- The NRS identified needs for numerous state, local, private industry, and federal program advances, recognizing that a multi-pronged approach was going to be needed to achieve large-scale progress toward milestones.
- To understand progress with NRS implementation, state-level program advances need to be assessed, in addition to evaluating the actual changes on the land and in the water.

Findings

- Minnesota has advanced almost every major program area identified in the NRS for implementing nutrient reductions. Considerable progress has been made in establishing and/or advancing over 30 programs; described in more detail in Appendix A.
- Some of the programs have documented nutrient progress on hundreds of thousands of acres. The effects of other programs are more difficult to quantify and/or need much more time to reach their full potential to reduce nutrients in water.
- The sufficiency of program advancements to ultimately achieve the large-scale changes needed to meet milestones was not quantified. While program advancements are making a difference, the magnitude of needed change is so high that current program implementation approaches alone may not be enough to reach NRS goals.

Follow-up

- Ongoing improvement and continued implementation of state-level programs is needed for long-term success:
    - The Agricultural Water Quality Certification Program has grown considerably (now with more than a half million acres) and shows much more potential.
    - The Forever Green program has recently received increased funding to further develop marketable cover crops and perennials.
    - Public/private partnerships have recently been initiated and need time to expand and multiply.
    - Private industry 4R certification has been designed for Minnesota but will not begin until later in 2020.
    - WRAPS have now been completed for 53 watersheds and comprehensive local watershed plans completed in multiple watersheds. Time is needed to implement these plans and complete others, with an increasing emphasis on achieving multiple benefits and protecting both local and downstream waters.
- Greater state investment in program implementation is necessary for success with key strategies such as:
    - Building soil health with cover crops, reduced tillage, and perennial crops;
    - Municipal wastewater treatment for total nitrogen reduction; and
    - Programs to promote construction of wetlands and other water storage for tile-drainage water retention and treatment.

2.2 Information needed to track progress

Minnesota has also made significant progress in developing tracking mechanisms that help to account for progress made towards NRS goals and milestones, as provided in Chapter 7 of the NRS. Additional information on advances made in tracking mechanisms is provided in Section 4.2.1.

BMP implementation and evaluation

- Minnesota's Clean Water Legacy Act requires that MPCA report actions taken in Minnesota's watersheds to meet water-quality goals and milestones (Minn. Stat. §114D.26, subd. 2). To meet this requirement the MPCA developed the "Healthier watersheds: Tracking the actions taken" webpage on the MPCA website. Water quality protection and restoration BMP adoption levels implemented through government support programs can be found at the HUC-8 and HUC-12 watershed scales at: https://www.pca.state.mn.us/water/best-management-practices-implemented-watershed. This information is also aggregated and graphed for major river basins and statewide so that it can be used to evaluate progress toward the 2014 NRS goals. The statewide and major drainage basin BMP numbers and graphs can be found at Nutrient Reduction Strategy BMPs - adoption through government programs.
- Satellite aerial imagery analysis projects initiated through a partnership between BWSR and the University of Minnesota within the past five years are beginning to provide a more comprehensive view of soil conservation practices. This project is moving from prototype development into production mode in 2020 and 2021. Information from these projects, integrated with information from other sources such as the U.S. Census of Agriculture, can provide insights into the cumulative progress of living cover and field erosion control adopted through government programs and private adoption.
- Various other sources of information are available to help track activities occurring on private lands, including the U.S. Census of Agriculture and nitrogen fertilizer use farmer surveys, along with fertilizer sales records.

Improved watershed and BMP targeting planning tools

Multiple advancements have been made to aid watershed and conservation planners with identifying priority practices, scales of needed adoption, priority geographic areas and expected effects on nutrient and sediment load reductions to waters. Hydrological Simulation Program – FORTRAN (HSPF) models have been developed for most of the major watersheds in the state. Prioritize, Target, and Measure Application (PTMApp), HSPF Scenario Application Manager (HSPF-SAM), and Agricultural Conservation Planning Framework (ACPF) are three examples of new modeling tools that simulate nutrient and sediment reductions associated with BMP implementation. HSPF-SAM now includes updated BMP nutrient reduction efficiencies, using new information that was not available for the 2014 NRS. These tools and several other watershed planning tools and models are described at https://bwsr.state.mn.us/water-quality-tools-and-models.

Water quality monitoring evaluation

Minnesota dramatically increased its river and stream monitoring programs beginning in 2007. Ongoing nutrient load monitoring through the Watershed Pollutant Load Monitoring Network occurs on every major river throughout the state. The Minnesota Pollution Control Agency (MPCA) began a new monitoring program for large rivers in 2013, starting with the Mississippi River from its headwaters to St. Anthony Falls. Another river was started in each of the following years. The MPCA is working with the other border states to develop uniform monitoring and assessment processes. Trends in river nutrients are discussed in Section 3 of this progress report. More information on MPCA's monitoring programs is available at: https://www.pca.state.mn.us/water/water-monitoring-and-assessment.

Summary of Progress Made on Information Tracking

Why important

- Tracking and gauging progress on the land and in the water is needed so that adjustments can be made over time to improve NRS implementation.
- Time lags exist between program development, watershed planning, BMP adoption and outcomes in water. Tracking each step allows estimation of the potential for success well before observing outcomes in the water.
- Tracking NRS implementation increases Minnesota's accountability to in-state and downstream stakeholders.

Findings

- Significant progress has been made on ways to evaluate BMP adoption, including the development of the Healthier Watersheds tracking system, advances in satellite imagery to map BMPs, along with previously established tracking via surveys, regulatory reports, sales records, and other records.
- Improved watershed BMP targeting and planning tools, including HSPF-SAM and PTMApp, are increasingly used throughout Minnesota.
- Watershed Pollutant Load Monitoring occurs on every major river in Minnesota.

Follow-up

- Continued monitoring and tracking efforts are needed, including continuation and improvement of:
    - Long-term water monitoring programs to assess and re-assess long-term trends.
    - Government program BMP acreages shown in the "Healthier Watersheds" website.
    - Research and expansion of satellite imagery and other techniques to track the combination of BMPs adopted privately and through government programs.

3 In the water – What can we tell so far?

Nutrient water quality trends over time in Minnesota's waters are important metrics used to assess outcomes related to NRS efforts. While nutrient water quality trends provide useful indications of progress toward final outcomes, for a variety of reasons these types of trends are often challenging and complex when trying to associate results with NRS activities. This section presents an analysis of nutrient water quality trends and an overview of other water nutrient monitoring efforts in Minnesota.

3.1 External factors affecting nutrient water quality trends

Many factors affect nutrient water quality trends. External factors, such as land use changes, climate, drainage, and human and livestock population trends can influence nutrient delivery in a watershed or basin. As new BMPs are adopted, these other influences can either increase or decrease the expected nutrient reductions in waters. As a result, these factors might overshadow the effects of adopted BMPs in reducing nutrients.

Understanding external influences on water nutrient trends provides important context for comprehensively and objectively evaluating overall progress toward NRS milestones and goals. A summary of recent changes for key external factors is provided below. Additional information on each factor is provided in Appendix B.

- **Population.** Increases in human population influence domestic wastewater generation, as well as the amount of impervious surface cover and associated surface runoff. Minnesota's population increased 6.1% from 2010 to 2018, totaling 5,629,416 people. Livestock and poultry populations can influence the amount of manure generated. These populations changed slightly between 2012 and 2017, with hogs and pigs seeing the highest increase of 11% (NASS).
- **Precipitation.** The amount and timing of precipitation influences how much water soaks into the ground or runs off directly into lakes, rivers, and wetlands. Annual precipitation has increased at an especially high rate since 2007 in southern Minnesota. In addition, Minnesota experiences more frequent mega rains (over 6 inches of rain across 1,000 or more square miles) in recent years compared to decades past.
- **River flow.** Increases in river flow can cause increased streambank and bluff erosion, which is the largest source of sediment in many rivers. Since soil phosphorus is attached to the eroded sediment, the flow increases can also result in total phosphorus increases. During the past 20 years, streamflow in the Minnesota River increased by 68% at Jordan and 75% near the river's mouth at Fort Snelling. It is particularly challenging to achieve nonpoint source river nutrient load decreases during periods of river flow increases.
- **Land use.** Changes in urban, agricultural, and wetland acreages affect both runoff water quantity and quality. Developed lands, often characterized by an increase in impervious surfaces, increased by 14.3% from 2010 to 2017 (Blann 2019). Total acres of agricultural land use in Minnesota has remained relatively constant over time; however, the type of crops have changed in past decades to fewer acres of small grains and alfalfa and correspondingly more corn and soybean acres.
- **Irrigation and drainage.** Minnesota's irrigated acres increased by 16.7% from 2012 to 2017 and is up 20.8% since 2007; yet the total amount of irrigated lands remains less than 3% of the total cropland in Minnesota. Minnesota gained 6,550 wetland acres (an increase of 0.060%) from 2009 to 2014. Artificial drainage changes the ways that water and nutrients move through the soil and into surface waters, affecting the amount of nitrate and phosphorus delivered to

waters. According to the 2017 U.S. Census of Agriculture, tile-drained lands increased in Minnesota by 25% between 2012 and 2017, with over 8 million acres of Minnesota land tile-drained, equivalent to approximately half of the total statewide corn and soybean lands.

3.2 River nutrient trends

River nitrate and phosphorus trends analysis is one of several ways that Minnesota tracks long-term progress toward the NRS nutrient reduction goals. Measuring ambient nutrient levels in rivers over long periods of time provides information on the combined effects of changing land uses, management practices, and other factors. Improvements made on the land can sometimes take a significant amount of time—in some instances, decades or more—before these changes become observable water quality changes in rivers. This is especially true where dissolved nutrients such as nitrate flow downward through the soil and into groundwater before slowly flowing underground toward streams.

Understanding flow-adjusted versus non-flow-adjusted approaches

Looking at multiple parameters and using more than one statistical approach results in more complex findings, but the results tell a more complete story about river nutrient trends.

Flow-adjusted approaches use statistical analysis techniques to separate the water quality effects caused by human changes on the land and in cities from those caused by short-term variability in precipitation and river flow.

Non flow-adjusted approaches use statistical analysis techniques that do not try to take flow variability into account. Instead, it shows the actual trends which reflect a combination of human changes in urban and rural areas along with variations in precipitation and river flow.

To gain a more complete understanding of river nutrient trends, Minnesota partner agencies compiled and assessed available water quality data at multiple sites, over different time periods, using both flow-adjusted and non-flow-adjusted statistical analyses. The river nutrient water quality trend analysis primarily focuses on approximate 10-year (recent) and 20-year (mid-range) timeframes. The analysis includes a 40-year (long-term) time frame for certain major rivers with longer monitoring records. Mid-range trends indicate changes since the end of baseline periods established for the Mississippi and Red Rivers. Recent trends provide an indication of short-term changes that follow Minnesota's Clean Water Fund establishment. A 5-year trend (since completing the 2014 NRS) would not necessarily yield meaningful results due to limitations in accurately assessing such short periods of time with water trend statistical methods. Therefore, this analysis did not attempt to assess 5-year statistical trends, but instead includes 5-year rolling average nutrient loads.

To make best use of previous and ongoing efforts to statistically assess river nutrient trends, the analysis incorporates trends generated through the work of three partner organizations as follows:

- **U.S. Geological Survey (USGS)**: Red River Basin (mid-range trends).
- **Metropolitan Council (Met Council)**: Major rivers entering and leaving the Twin Cities Metropolitan area (mid-range and long-term trends), based on recent updates to the work reported by Met Council (Met Council 2018). Met Council updated their work reported in www.metrocouncil.org/river-assessment to also include the years 2016 to 2018 and new river nutrient load trend analyses.
- **MPCA**: In-depth analysis of a few major rivers with associated long-term monitoring results, along with a more simplified analysis of all other rivers monitored by the MPCA for the past 10, 20 and 40 years.

Trends from the past 10, 20 and 40 years show that statewide phosphorus concentrations have generally been decreasing and nitrate concentrations have generally been increasing. However, regional differences exist and many of the sites and timeframes have too much variability to show statistically significant trends.

The discussion below summarizes the mid-range (~20-year) trends conducted by all three organizations and the short-term (~10-year) trend work conducted by the MPCA. Appendix C includes a complete discussion of the river nutrient trend analysis results and methods from the USGS, Met Council, and the MPCA.

3.2.1 Mid-range (20-year) river nutrient concentration trend results

This section presents river trend analysis results for phosphorus and nitrate concentrations.

3.2.1.1 *Phosphorus*

Mid-range flow-adjusted phosphorus concentration trends were determined at major river sites and near the outlets of certain tributaries (Figure 2). A majority of the sites (21 of 28) show decreasing trends ranging from 15% to 55%. Six of the 28 sites had no significant trend detected. The only increase (27%) occurred at Emerson, Canada, at a point on the Red River that is immediately downstream of where the Pembina River (North Dakota and Manitoba watershed) enters the Red River. The Pembina River was found to have increasing phosphorus concentrations during this same period of time (Nustad and Vecchia 2020).

Figure 2. River monitoring site locations at sites with enough information to determine mid-range (approximately 20-year) flow-adjusted phosphorus concentration trends. QWTREND was used to assess trends at mapped sites above, except that the flow-adjusted bootstrapped Seasonal Kendall test was used at tributaries to the Minnesota River, the Sauk River and Kettle River.

Phosphorus concentrations in the Red River have decreased since 2000 in the upstream reaches of the River.

The Mississippi River sites near the Twin Cities had flow-adjusted phosphorus concentration decreases of 21% to 26% over the past two decades, with decreases by as much as 50% detected further downstream at Winona, upstream from the state border with Iowa.

The Minnesota River, a high nutrient-loading tributary to the Mississippi River, has had 20-year phosphorus decreases of about 17%. However, at Jordan, Minnesota, this decrease shifted since about 2009 and appears to be increasing, as described in further detail in Appendix C.

Decreasing phosphorus concentrations do not always translate into statistically significant decreasing loads. This is the case in southern Minnesota where increased precipitation and river flows during the past two decades have increased nonpoint source phosphorus runoff amounts, thereby somewhat offsetting the great progress Minnesota has made through changes in urban and rural areas. At most of the Mississippi River sites in Minnesota a statistically significant downward trend in the phosphorus loads during the past 20 years was not found, except when flow-adjusted statistical techniques were used. Near the state border at Winona, the actual phosphorus loads appear to have decreased, but just not enough to be statistically significant.

3.2.1.2 *Nitrogen*

The predominant form of nitrogen added to waters from human activities is nitrate-N, which is typically measured in laboratories in combination with nitrite-N (e.g. nitrite+nitrate-N). Therefore, this report focuses on nitrite+nitrate trend results, typically referred to as “nitrate.” Total nitrogen trend analyses generally showed similar patterns and trend directions as nitrate, although less statistically significant in some instances. Total nitrogen includes all of the nitrite+nitrate-N, organic nitrogen, and ammonium.

Mid-range flow-adjusted nitrate concentration trend determinations showed increasing trends at half of the sites (14 out of 28) and only 3 of 28 sites showed a decreasing trend (Figure 3). Eleven of the 28 sites had too much variability to confidently determine a significant change. Nitrate concentration increases in the major rivers ranged from 21% to 55%, with nitrate concentrations more than doubling in some tributaries. The only decrease in southern Minnesota over the 20-year period was in the Minnesota River at Fort Snelling. A more in-depth analysis of this site showed a 15% nitrate concentration decrease from 2005 to 2018, but with an increase between 1979 and 2004 that caused an overall long term increase of 21% (1979 to 2018).

The Mississippi River sites near the Twin Cities showed 20-year nitrate concentration increases in the range of 25% to 34%. Just downstream of the Twin Cities, at the Mississippi River in Red Wing, nitrate *loads* increased by 62%, which is a much greater increase than the 25% flow-adjusted nitrate *concentration* increase. Increases in both nitrate concentrations and increases in river flow explain the larger load increase as compared to the flow-adjusted concentration increase. Further downstream at Winona, there is too much variability in river flow and nitrate levels for the 20-year nitrate load trends to be statistically significant.

The Minnesota River, a major tributary to the Mississippi and the largest contributor of nitrate, has had mixed 20-year nitrate trends. Nitrate concentration trends (flow-adjusted) at Jordan, Minnesota have shown increases since 2012. The Minnesota River at Fort Snelling has decreasing nitrate concentrations since 2005. The Minnesota River is heavily tile-drained with shorter lag times between practice changes and observed effects in the river. Other tributaries to the Mississippi River are more heavily influenced by groundwater baseflow, which can have a much longer lag time than tile flow. The Minnesota River also has much higher nitrate concentrations than the Mississippi River, therefore requiring much more nitrate additions to the river to cause an increase as compared to the Mississippi River.

With a few exceptions, the Red River Basin has had increasing nitrate trends during the past 20 years in both the Red River main stem and Minnesota tributaries to the Red River. At the state border with Canada, the Red River nitrate trend was not considered statistically significant.

Figure 3. River monitoring site locations at sites with enough information to determine mid-range (20-year) flow-adjusted nitrate concentration trends. QWTREND was used to assess trends at these sites, except that the flow-adjusted bootstrapped Seasonal Kendall test was used at tributaries to the Minnesota River, the Sauk River and Kettle River.

3.2.2 Recent (10-year) nutrient concentration trend results

The MPCA conducted trends analyses from 2008 to 2017 to evaluate trends occurring during more recent years. This period of time is more closely associated with potential NRS effects as compared to the 20-year trend analyses. Another reason to separately focus on the recent, 10-year, timeframe is because many more sites are available for trend analysis. The MPCA greatly increased river monitoring beginning in 2007 to 2008. One drawback of the shorter-term timeframe is that the fewer years of data tends to reduce the likelihood of observing statistically significant trends.

3.2.2.1 *Phosphorus*

Using flow-adjusted approaches, 10-year phosphorus concentrations were found to be decreasing at 48% (24 of 50) of river sites, with all other sites showing no detectable trend (Figure 4). No sites had an increasing phosphorus concentration trend for this 2008 to 2017 period. The majority of the 10-year decreases were found in the eastern part of the state, with the western and northwestern parts of the state showing mostly non-significant trends. Results were similar when the 10-year phosphorus concentration trends were assessed without using a flow-adjusted approach. When not using flow-adjusted techniques, a few decreasing trends shifted to no-trend, and one site showed an increase. In-depth analysis of recent phosphorus trends for major rivers is available in Appendix C.

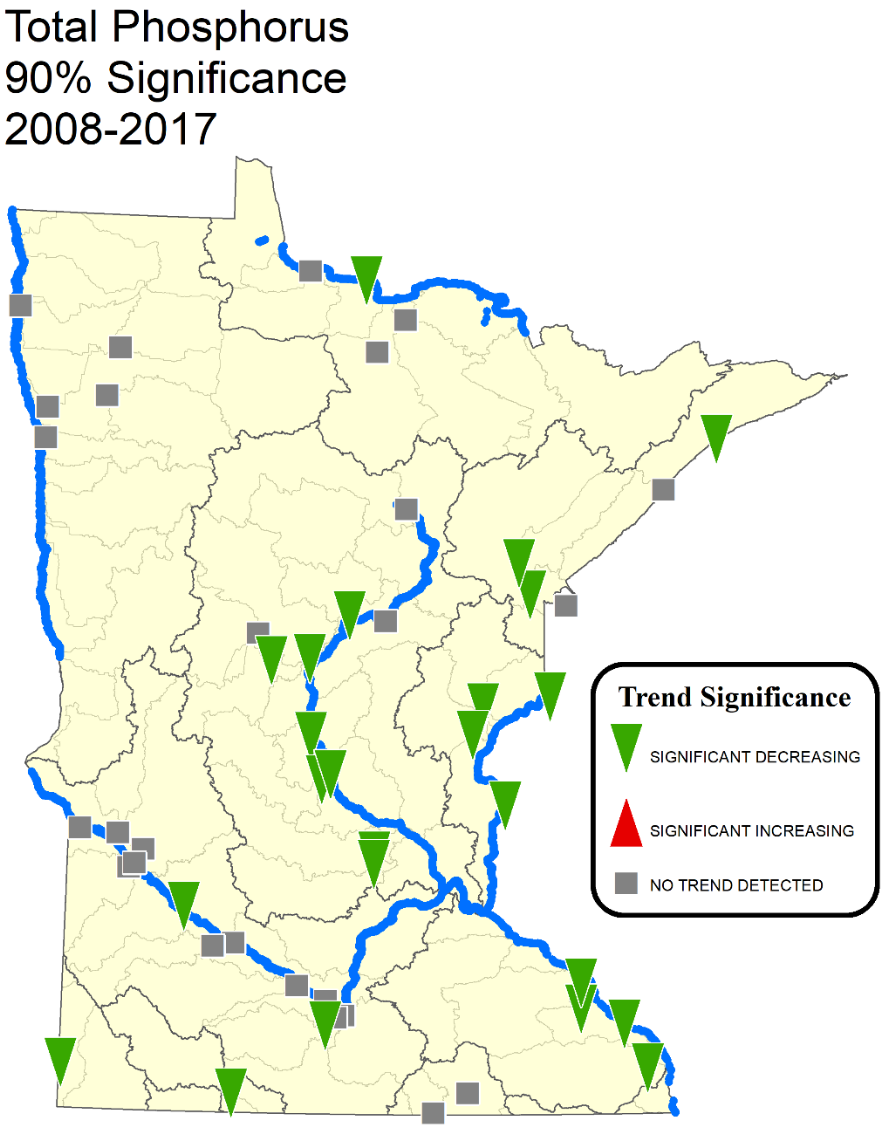


Figure 4. Phosphorus 10-year flow-adjusted concentration trends.

3.2.2.2 *Nitrogen*

Using flow-adjusted techniques for the 10-year period, 37% of sites (14 of 38) that had detectable nitrate levels showed increasing nitrate concentration trends, with the others showing no detectable trend. When using trend analysis techniques that do not adjust for the variability in flow, a higher fraction of sites showed increasing trends (50%), with the others showing non-significant trends. None of the 10-year nitrate trends showed a decrease. The majority of 10-year nitrate concentration trend increases were found in the central and southwestern parts of the state (Figure 5).

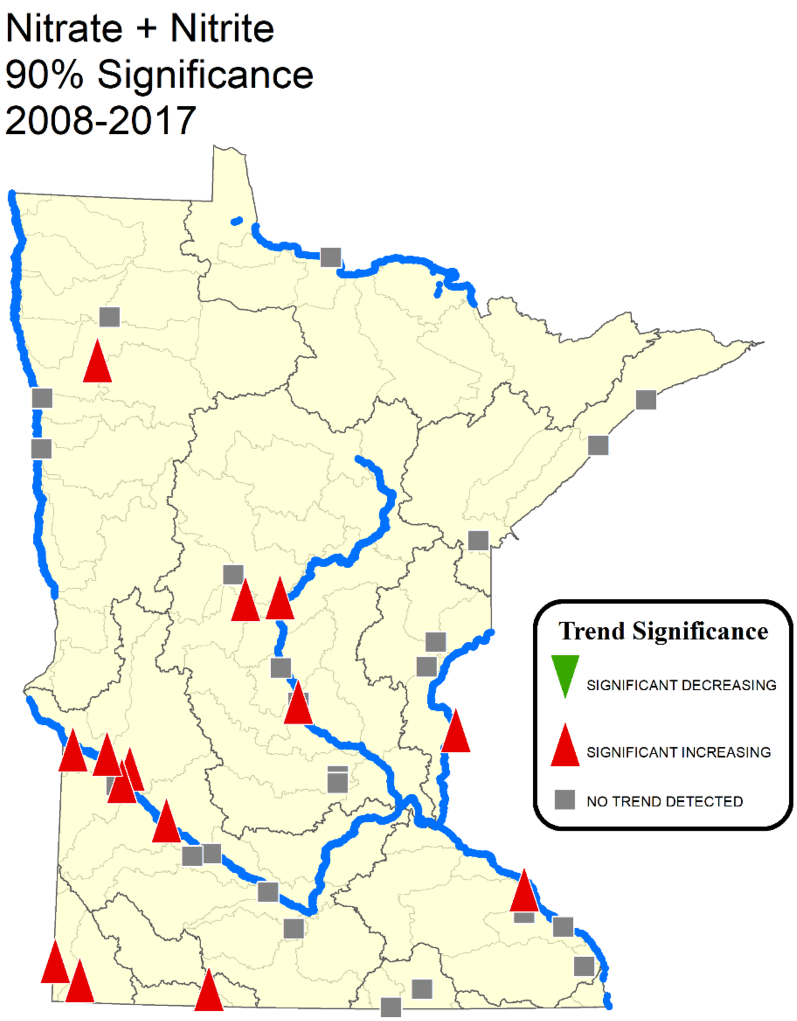


Figure 5. Nitrate plus nitrite 10-year flow-adjusted concentration trends.

3.2.3 Differences between river phosphorus and nitrogen trends

The differences between generally decreasing phosphorus concentration trends and generally increasing nitrogen concentration trends can be explained by differences between nutrient sources, pathways from sources to waters, and Minnesota's progress made toward reductions.

Wastewater discharges, one of the most influential sources of phosphorus in the state (Barr 2004), have decreased by over 70% in the past 20 years. While wastewater nitrogen discharges contribute less than 10% of the nitrogen load to waters, they have increased slightly over the same 20-year timeframe due to both increased population and a limited number of cities that remove total nitrogen from their wastewater.

Row crop agriculture has been the largest source of nitrogen over time. The documented progress in reducing cropland nitrogen losses is not as evident as progress made to reduce cropland phosphorus losses. The substantial adoption of cropland soil and water conservation practices over the years has had a much greater impact on reducing cropland phosphorus than nitrogen. Phosphorus is transported in overland runoff, which can be easier to control, as compared to nitrogen losses that occur largely through subsurface drainage tile lines and groundwater pathways. Since the number of acres that are tile-drained and planted to row-crops in Minnesota has increased over time, those changes may have offset some gains made in improved nitrogen fertilizer and manure management.

Another nutrient source, urban stormwater runoff, is a higher contributor of phosphorus than nitrogen. Minnesota has made significant progress in managing urban stormwater during the past two decades through the state's stormwater permitting program implemented at the municipal level. Additionally, phosphorus fertilizer restrictions have been enacted for lawns and turf.

Lag times are another possible contributing factor for differences in the phosphorus and nitrogen trends. In places where nitrogen is transported to streams and rivers predominantly via groundwater, the lag time between cropland BMP adoption and river improvement can be considerably longer for nitrogen as compared to overland runoff of phosphorus.

Nutrient trends at Mississippi River at Red Wing (Lock and Dam #3)

Minnesota's long-term monitoring site on the Mississippi River at Red Wing (also known as Lock and Dam #3) is important for evaluating nutrient reduction progress throughout much of the state. The location is downstream of the Upper Mississippi River Basin, the Minnesota River Basin, the St. Croix River Basin and the Twin Cities Metropolitan area (Figure 6). This site represents an integrated sample of much of the nutrient pollution that ultimately leaves the state in the Mississippi River. Therefore, nutrient trends at the Red Wing site are key to tracking changes resulting from NRS implementation. It is important to note that not all nutrients reaching this location end up leaving the state; the Red Wing site is upstream of Lake Pepin and other Mississippi River backwaters where some of the nutrients are either temporarily or permanently lost from the river.

Figure 6. Drainage area to Lock and Dam #3.

Met Council results from a statistical analysis in Table 7 shows flow-adjusted phosphorus concentration reductions of 21% and 40% over the past 20 and 40 years, respectively.

Table 7. Statistical trend for total phosphorus concentration in the Mississippi River at Red Wing site (Lock and Dam #3)

Trend Period	Concentration (mg/L)	Change in Conc (%)	Change Rate (mg/L/yr)	*p*	Trend
1976 – 2018	0.17 – 0.10	-41%	-0.0016	< 0.0001	
Overall Trends					
20 years (1999 – 2018)	0.12 – 0.10	-21%	-0.0013	–	
40 years (1979 – 2018)	0.17 – 0.10	-40%	-0.0017	–	

Phosphorus loads at Red Wing show high year-to-year variability (Figure 7). While the 5-year rolling average shows a phosphorus load decrease from 1994 to 2008, a non-flow adjusted analysis of load trends does not show a statistically significant change for either mid-range or long-term periods. This is likely a function of increased average and maximum flow in the river over the past 20 years. While the water has lower phosphorus concentrations, there is more water flow; therefore, the phosphorus load changes are not statistically significant.

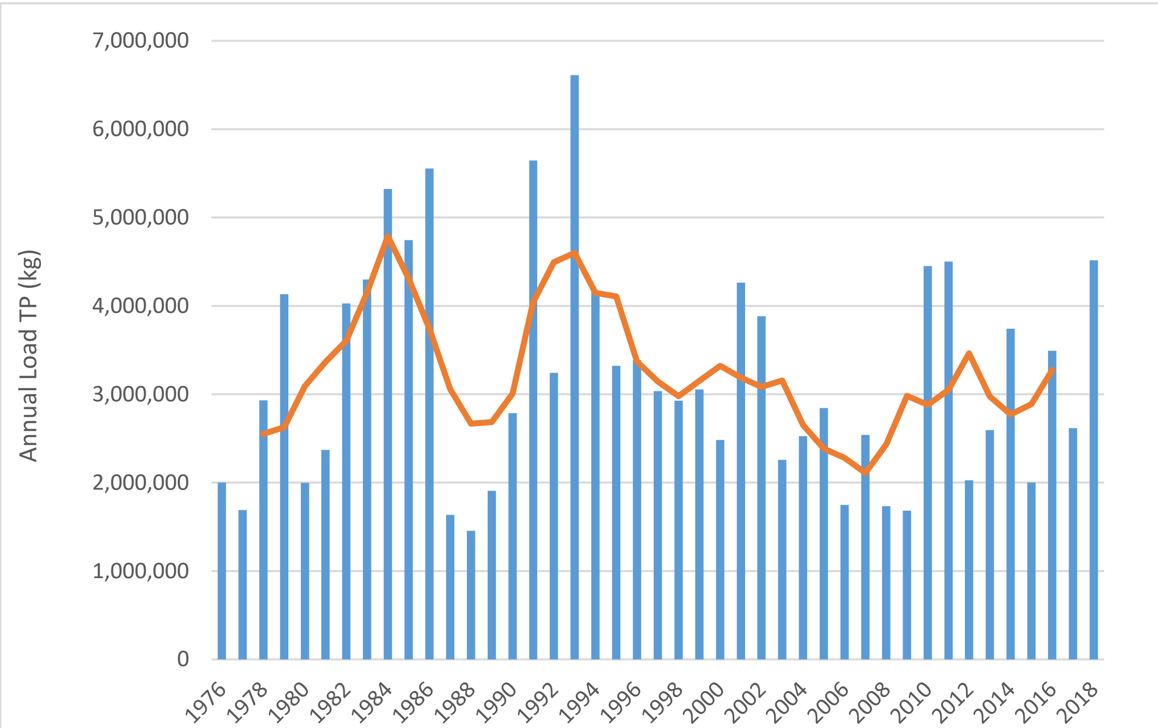


Figure 7. Annual phosphorus loads in the Mississippi River at Red Wing (Lock and Dam 3) and 5-year rolling average load (orange).

Results of the flow-adjusted statistical analysis for nitrate in Table 8 show that flow-adjusted nitrate concentrations in the Mississippi River at Red Wing increased by 25% and 154% over the past 20 and 40 years, respectively. Nitrate concentrations increased markedly from 1976 to 1982, followed by a more gradual increase between 1983 and 2018.

Table 8. Statistical trends for nitrate concentration in the Mississippi River at Red Wing site (Lock and Dam #3)

Trend Period	Concentration (mg/L)	Change in Conc (%)	Change Rate (mg/L/yr)	*p*	Trend
1976 – 1982	0.58 – 1.39	142%	0.12	< 0.0001	⬆
1983 – 2018	1.39 – 2.03	46%	0.018	< 0.0001	⬆
Overall Trends					
20 years (1999 – 2018)	1.62 – 2.03	25%	0.020	–	⬆
40 years (1979 – 2018)	0.80 – 2.02	154%	0.031	–	⬆

Non flow-adjusted loads very greatly from year to year, but overall show increases since 1976 (Figure 8). A statistical analysis of these non-flow-adjusted nitrate load trends showed 62% and 53% increases during the past 20 and 40 years, respectively (Figure 8). This is not surprising since loads reflect the combination of concentrations and river flow, and both have increased. Flows have especially increased during the past 20 years. Both nitrate and total nitrogen loads show a similar pattern over time. More details on the analysis for the Red Wing site, as well as other major river basins, is available in Appendix C.

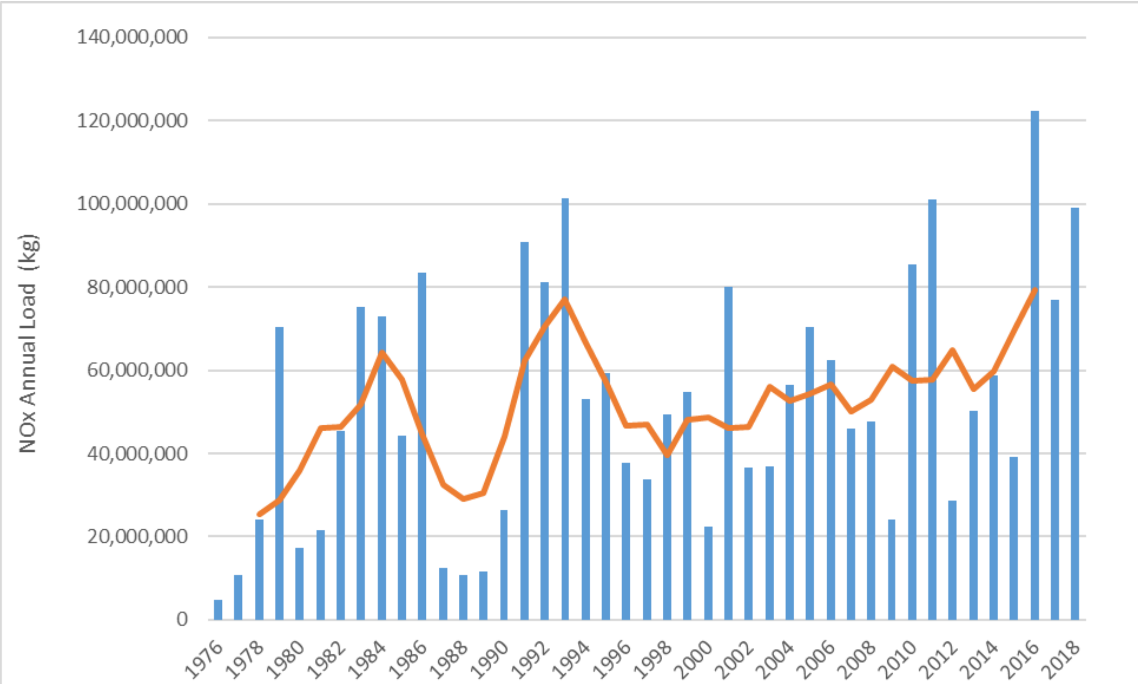


Figure 8. Annual NOx Loads in the Mississippi River at Red Wing (Lock and Dam 3) and 5-year rolling average load (orange).

Summary of Minnesota's Progress in Rivers

Why important

- The NRS aims to achieve measured water nutrient reductions and track our progress toward that outcome.
- Reducing nutrient *concentrations* is important for local water health and drinking water. Reducing nutrient *loads* (total amounts flowing down the river) is important for downstream lakes, reservoirs and the Gulf of Mexico.
- It is important to evaluate water nutrient trends over at least 10 to 20 years because nutrient concentrations and loads are highly variable from year-to-year with changing weather patterns, and because the changes across the landscape can take long periods of time to show observed effects in rivers.
- Changes during the past five years since completion of the NRS (2014-18) have a large effect on the outcomes of the 10 and 20-year trends evaluated for this progress report. However, trends over just a 5-year period is typically too short of time to draw meaningful conclusions about the effects of nutrient-reducing strategies.
- Changes in river nutrients are affected by many factors, in addition to newly adopted BMPs. Flow-adjusted methods are important for assessing trends independent of river flow variability, allowing a more direct evaluation of the effects of human activities.

Findings

- Phosphorus concentrations have generally decreased and nitrate-nitrogen and total nitrogen concentrations have generally increased over the past 10 and 20 years. However, river flow and nutrient concentration variability makes it difficult to confidently show trend directions at many of the monitoring locations.
- *Phosphorus concentration* trends over the past approximate 20 years show mostly decreases (improvements) around the state, with reductions ranging from 15% to 55%. Over the past 10 years, phosphorus concentrations have decreased at nearly half (42%) of 57 monitoring sites evaluated, with all other sites showing no significant trend. This shows that our efforts to reduce phosphorus in recent years have been making a difference.
- *Nitrate concentration* trends over the past approximate 20 years show increases of 20 to 60% in most major rivers. However several sites have no trend detected, and a couple sites showed decreases. Over the past 10 years, nitrate concentrations increased at over one-third of the sites and had no statistically significant trend at the rest. This suggests that efforts to reduce nitrate thus far are either insufficient and/or not enough time has elapsed for the full effects of our efforts to be seen in rivers.
- Increasing precipitation in southern Minnesota over the past two decades has been offsetting the benefits of our phosphorus-reducing activities. As a result, phosphorus load reductions are not statistically significant (i.e. no-trend) in most southern Minnesota rivers, unless statistical methods are used to adjust for river flow variability.

Follow-up

- Continued monitoring will be important to more confidently assess ongoing nutrient changes and the long-term effects of our collective state efforts to reduce river nutrients.
- Follow-up study is needed to help identify the factors contributing to nutrient increases in certain river stretches and decreases in others.

3.3 Small watershed monitoring

The use of small watershed implementation and monitoring programs are very important in Minnesota's NRS approach. The lessons learned from nearly 40 years of nonpoint source pollution management across the nation show the need for long-term, small-scale watershed efforts to increase the likelihood that changes in water quality will occur and be measured. Measured improvements from implementing BMPs in small watersheds can provide other watersheds with information about successful techniques to improve water quality.

While larger-scale (major river basin and hydrologic unit code [HUC-8] major watersheds) monitoring programs provide important overall assessments of water quality conditions and long-term trend analyses, they generally do not provide the data necessary to evaluate changes in water quality attributable to specific sets of management practices. As the watershed size increases, so does the amount of BMP implementation needed to detect changes, the likelihood of undocumented changes occurring, and the length of time required to achieve and measure changes in water quality. A small watershed framework with a strong monitoring component enables Minnesota partner agencies to more clearly connect implementation changes on the land to trends in water quality.

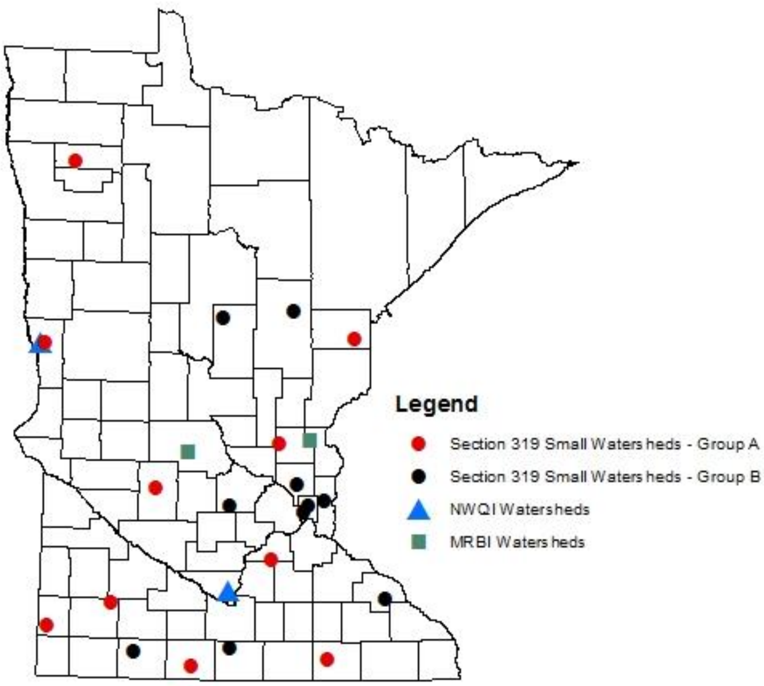


Figure 9. Small watershed monitoring.

The Natural Resources Conservation Service (NRCS) implements both the NWQI and the MRBI in Minnesota. These water quality efforts focus on priority HUC-12 and larger watersheds and have funded efforts such as recent work in the Seven Mile Creek watershed, including effectiveness monitoring. Monitoring and implementation in smaller watersheds are funded through the NWQI, MRBI, and Section 319 Small Watersheds Focus Program (Figure 9). These small watershed programs support small-scale, long-term efforts and provide measurable changes that can be replicated for larger watersheds. Information about these efforts and other small watershed monitoring efforts are described in Appendix A.

3.4 Edge of field monitoring

Edge-of-field monitoring allows us to better understand the factors influencing nutrient delivery to waters. Minnesota is fortunate to have many edge-of-field monitoring programs supported by the agricultural community. The MDA oversees many of these monitoring efforts, which include the Discovery Farms, Root River Field to Stream Partnership, and the Red River Valley Drainage Water Management Project, and others (Figure 10).

Data from on-farm, edge-of-field monitoring sites are used to assess nitrogen, phosphorus and sediment loss at the field scale and to evaluate the effectiveness of conservation practices. Data are also used to support farmer-to-farmer learning and encourage the adoption of conservation practices that protect water resources. In addition, data from edge-of-field projects on small acreages throughout the state are used to improve larger scale models which can show nutrient reduction scenario estimates throughout various watersheds. Example models that have been calibrated with edge-of-field monitoring include: HSPF, Soil and Water Assessment Tool, Agricultural Policy/Environmental eXtender Model, PTMApp, Adapt-N, and the Runoff Risk Advisory Forecast Tool. Without these data, the tools used in the impaired waters process would not be as accurate or refined for conditions in Minnesota.

Key lessons learned across the edge-of-field monitoring locations, as reported by MDA:

- On average, 40-47% of the total surface runoff volume occurs when the soil is frozen.
- Over 50% of the annual phosphorus and sediment losses often occur during 1-2 rain events each year.
- 70-78% of the sediment loss occurs during May and June on fields that lack established crop cover.
- Across the Discovery Farms Minnesota network, nitrogen losses are typically four times higher from subsurface drainage lines compared to surface runoff. Phosphorus losses are typically nine times higher from surface runoff compared to subsurface drainage.

More information on these efforts is provided in Appendix A and https://www.mda.state.mn.us/environment-sustainability/farm-projects.

Small watershed and edge-of-field work should continue during the next five years and results should be carefully studied before making NRS updates.

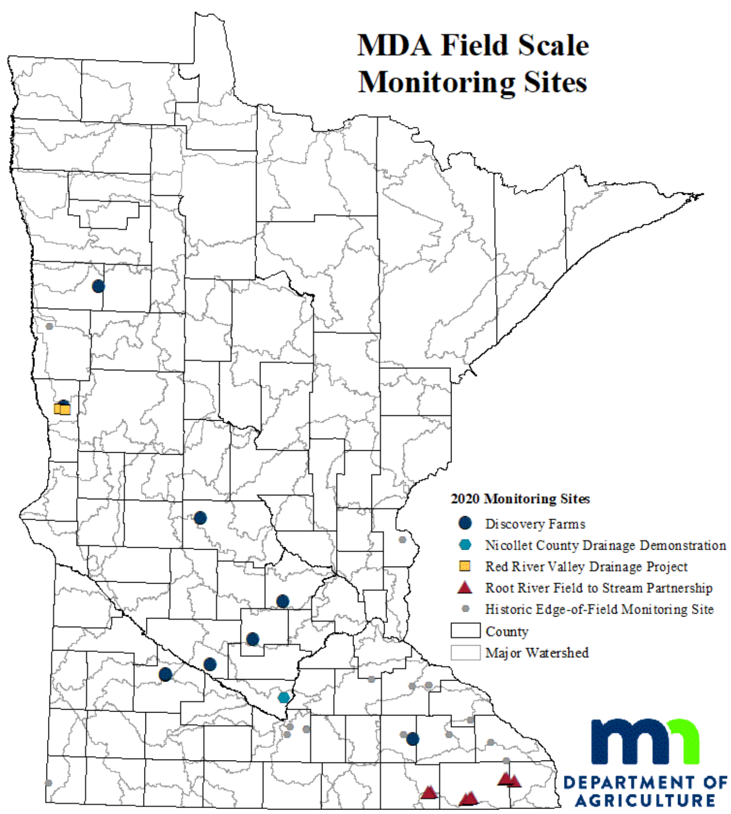


Figure 10. MDA field scale monitoring sites.

3.5 Lake clarity trends

In addition to river nutrient trends, MPCA analyzed lake water clarity trends as one indicator of changes in Minnesota lakes nutrient conditions. While phosphorus can affect lake clarity, it is important to keep in mind that other factors contribute to changes in lake clarity.

Timeframes for this lake clarity trends analysis varies, with the shortest length of monitoring being 2010 to 2018, and the longest 1973 to 2018. A total of 4,796 lakes statewide contained some monitoring data, 1,646 of which met the minimum data requirements and were included in this analysis. Minimum data requirements for lake trend analysis was at least eight years of data and 50 observations.

To be considered an *improving* or *degrading* water clarity trend, a lake must experience a Secchi disk change greater than ½ foot/decade. A lake demonstrating either an improvement or reduction in water clarity that is equal to or less than ½ foot/decade is classified as having *no change* in water clarity trend. A lake that meets the minimum data requirements, but has a non-significant statistical result (i.e., the p value is less than 0.05), is considered to have *no trend* detected at this time.

Of the 1,646 lakes analyzed for trends, 29% were observed to be improving, while 11% saw degrading water quality over the 2010 to 2018 period (Figure 11 and Figure 12). In other words, lakes are getting clearer in nearly three times as many lakes as those showing worsening water clarity. While the larger number of lakes with improving clarity is encouraging, this analysis did not confirm that the improved clarity is the direct result of decreasing phosphorus loads into those lakes. Determining the causes for the improved clarity requires additional study and will vary from one lake to another.

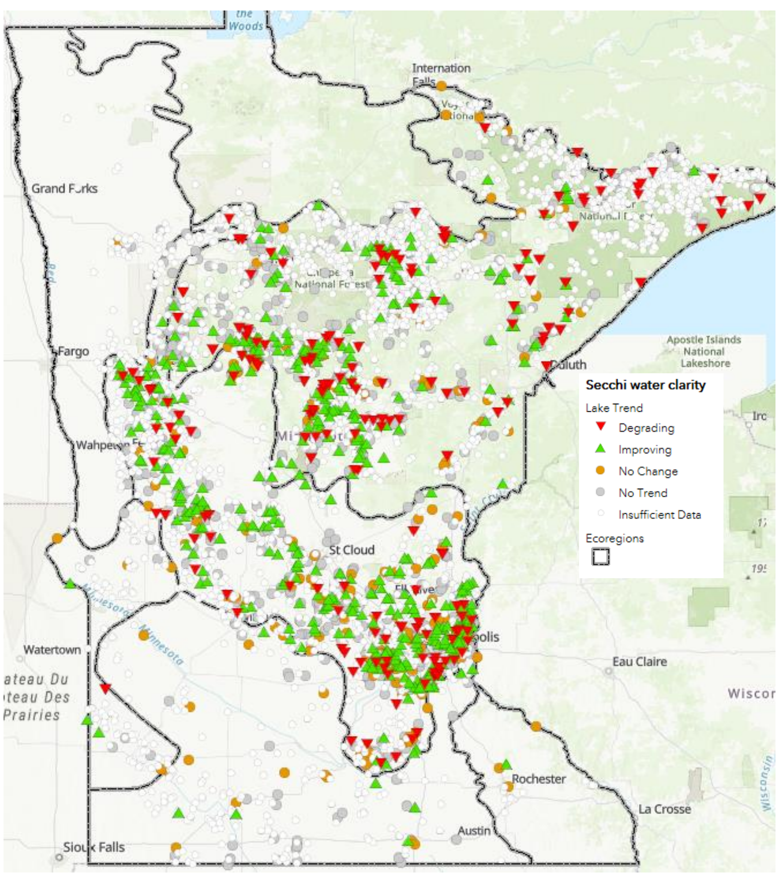


Figure 11. Map of lake clarity trends in Minnesota.
https://www.pca.state.mn.us/water/transparency-trends

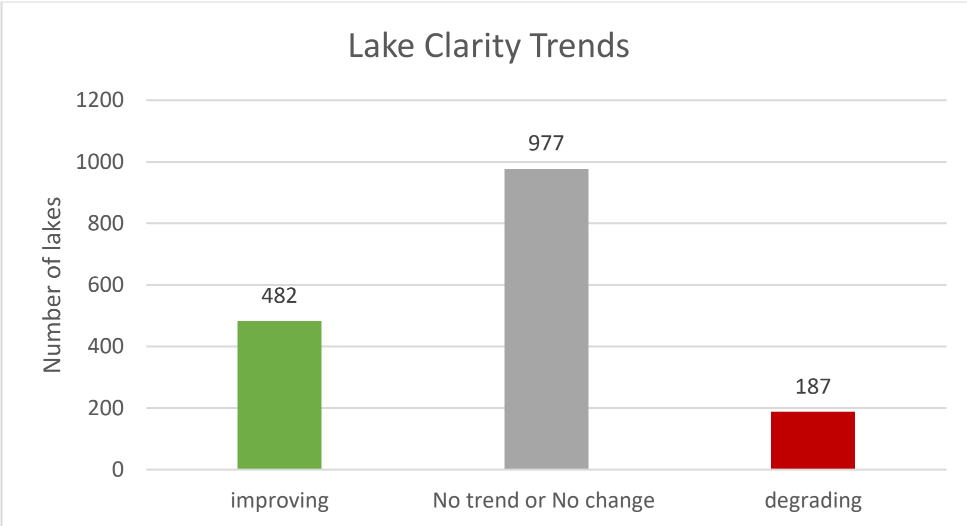


Figure 12. Lake clarity trends in Minnesota.

Lake Pepin phosphorus

Lake Pepin receives nutrients from most of the Mississippi River Basin drainage in Minnesota and has battled eutrophication for many years. Since the mid-1990s, the USGS Long-Term Resource Monitoring Program has served as the principal source of data for Lake Pepin. MPCA used water quality data collected at four USGS sampling stations to characterize average total phosphorus and chlorophyll-*a* concentrations for the most recent 10-year period (2008 to 2017). Chlorophyll-*a* is an indicator of algae growth driven partly by phosphorus. Over the most recent 10-year period, there is a decreasing trend in both phosphorus concentration and chlorophyll-*a* (Figure 13 and Figure 14). The improvement in Lake Pepin water quality coincides with Mississippi River decreases in total phosphorus concentrations.

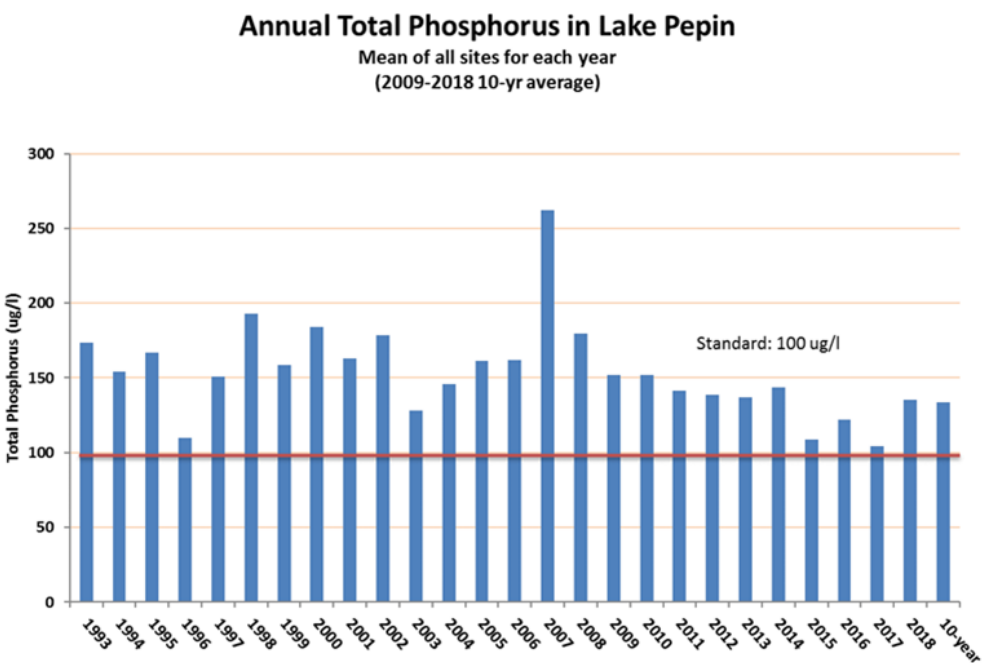


Figure 13. Mean annual total phosphorous in Lake Pepin summarized into a composite concentration from four monitoring stations.

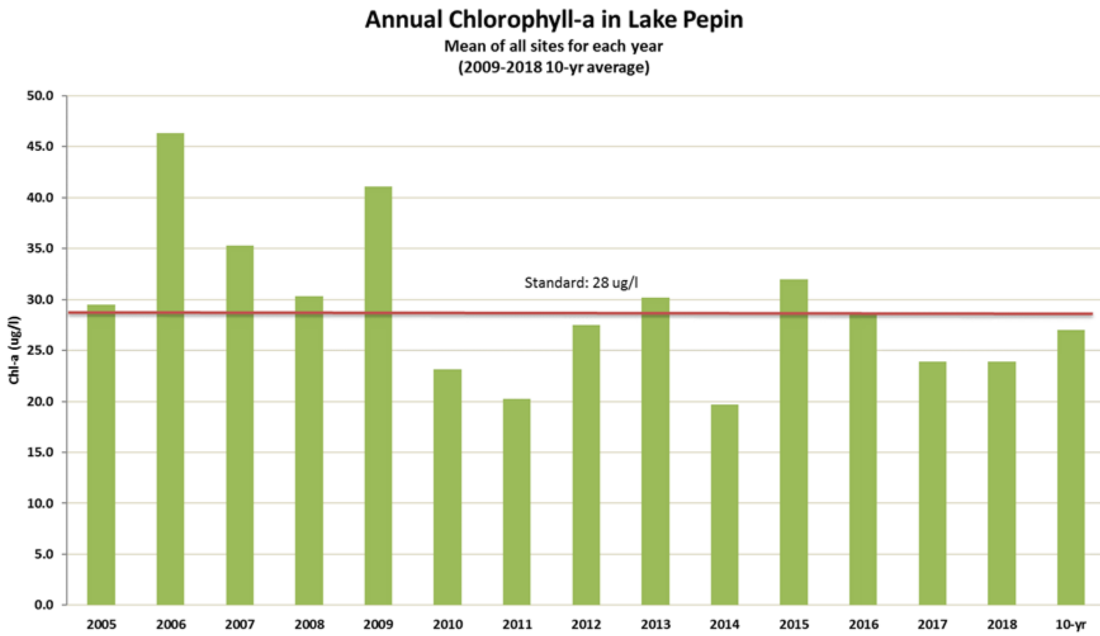


Figure 14. Mean annual chlorophyll-*a* in Lake Pepin summarized into composite concentration from the four monitoring stations (MPCA 2019a).

3.6 Groundwater nitrate trends

Groundwater nitrate is a concern for well water consumption in many parts of Minnesota and as a contributor of nitrate to surface waters. Groundwater baseflow nitrate contributions to rivers depends on the geology, groundwater flow pathways, and time of transport between groundwater recharge area and re-emergence into rivers. River nitrate concentrations and loads often represent a broad-scale mixing of multiple waters, including surface water runoff, groundwater baseflow, and agricultural and urban drainage waters. Some groundwater nitrate can reach surface waters before the nitrate is lost to the atmosphere (as nitrogen gas through denitrification processes). Therefore, studying trends in groundwater nitrate can help inform progress evaluation of river and stream nitrogen goals.

Wells constructed into an aquifer can provide an indication of nitrate concentrations at a discrete point and depth within the groundwater system. Since well water nitrate concentrations often vary greatly within short distances both horizontally and vertically, many wells are often needed to characterize groundwater nitrate concentrations and trends in a given area. The Minnesota Geological Survey recently reported on how greatly hydrogeologic controls affect groundwater nitrate load contributions to surface waters in southeastern Minnesota (https://conservancy.umn.edu/handle/11299/162612). It is important to recognize such limitations and complexities in well-water sampling when evaluating groundwater nitrate trends.

The MPCA and MDA each maintain their own ambient groundwater-monitoring network that, when combined, covers a variety of conditions across the state. The MPCA's ambient groundwater monitoring primarily targets aquifers in urban parts of the state, and most of the MDA's monitoring is performed in agricultural areas. A recently released *Condition of Minnesota's Groundwater Quality* report included a nitrate trend analysis from 117 wells monitored from 2005-2017 by MPCA and MDA (MPCA 2019b).

Statistical analysis of these 117 wells in the upper-most aquifers showed 74 (63%) of the individual wells with no statistically significant change in nitrate concentrations, 19 sites (16%) having significant increases, and 24 sites (21%) having significant decreases in nitrate concentrations (Figure 15**Error! Reference source not found.**). The sites with significant upward or downward trends were scattered throughout the state and generally did not appear to be located within any specific region or land use setting. The report provides some clues about changes in groundwater nitrate levels in recent years but is largely inconclusive about nitrate trends, overall.

Additionally, MDA recently reported on well water nitrate trends results from two Volunteer Nitrate Monitoring Networks in Minnesota (Kaiser et al. 2019). Southeastern Minnesota well water nitrate showed no statistically significant trend between 2008 and 2019 with 5778 samples taken. However, the Central Minnesota Sands private well network showed a slight downward trend between 2011 and 2019 with 3768 samples taken.

MDA also manages a broader domestic well monitoring program and tested 30,769 domestic wells in geologically vulnerable agricultural areas between 2013 and 2018.

4 On our cropland – Are we on track for the needed scale of BMP adoption?

This section examines agricultural BMP adoption from 2014 to 2018 in the same four general categories of practices outlined in the 2014 NRS scenarios. It addresses the example BMP adoption scenarios put forth in the 2014 NRS, the methods and assumptions for assessing BMP adoption, and discussion of BMP adoption for the following categories of practices:

- Crop nutrient management efficiency (fertilizer and manure)
- Living cover
- Field erosion control
- Drainage water treatment and storage

The ongoing township groundwater testing program has provided an increased understanding of the locations and magnitude of high nitrate wells in Minnesota (Figure 16). The results show that 9.2% of the wells in these vulnerable areas had nitrate-N exceeding the 10 mg/l Health Risk Limit. Well water nitrate concentrations are particularly high in southeastern, southwestern and central Minnesota. More info at https://www.mda.state.mn.us/township-testing-program.

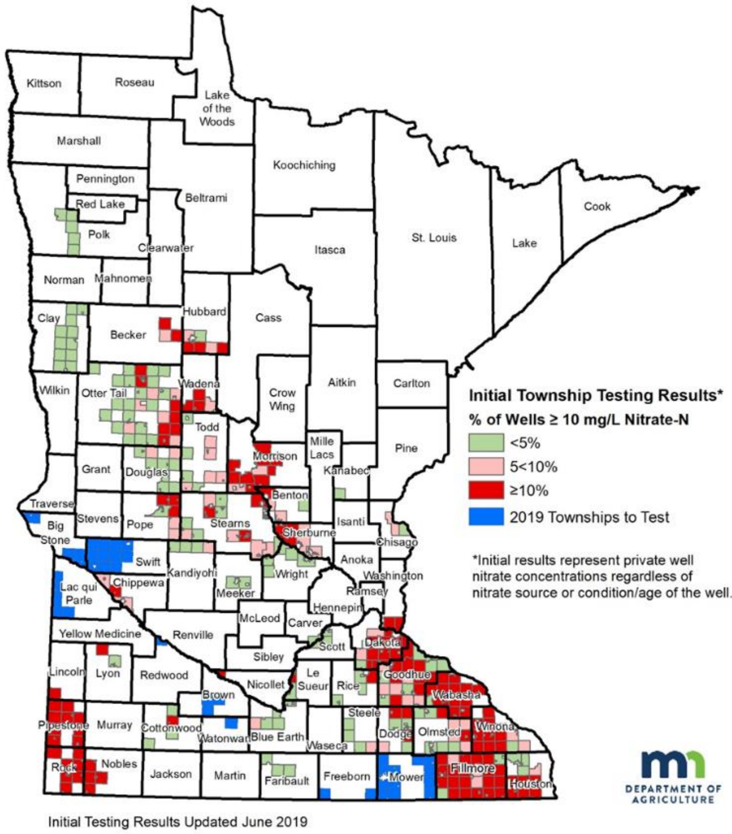


Figure 15. Private well nitrate testing - MDA Township Testing Program results.

5 On our cropland – Are we on track for the needed scale of BMP adoption?

This section examines agricultural BMP adoption from 2014 to 2018 in the same four general categories of practices outlined in the 2014 NRS scenarios. It addresses the example BMP adoption scenarios put forth in the 2014 NRS, the methods and assumptions for assessing BMP adoption, and discussion of BMP adoption for the following categories of practices:

- Crop nutrient management efficiency (fertilizer and manure)
- Living cover
- Field erosion control
- Drainage water treatment and storage

Several sources of data are used as indicators of the general scale of agricultural BMP adoption in the state of Minnesota through a) government supported programs and b) overall BMP adoption reflecting a combination of government-supported and private adoption. These BMPs are just one important factor affecting overall change on the land and in the water. Cropland changes over time (Figure 17, population trends, climate and land use changes, and river flow are additional factors that affect nutrients. Recent changes in these factors are described in Appendix B.

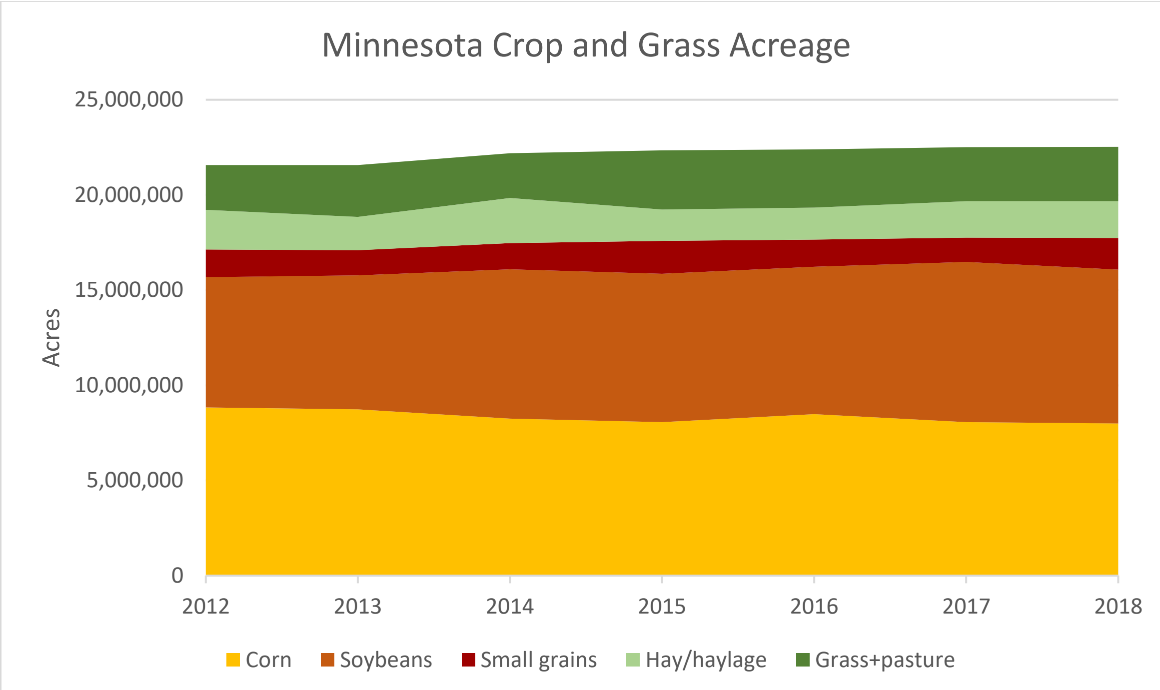


Figure 16. Statewide crop and grass/pasture acreage changes between 2012 and 2018 as identified from Crop Data Layer (CDL).

5.1 Agriculture BMP adoption scenario goals

To guide Minnesota's progress toward the 2014 NRS nutrient reduction goals, the 2014 NRS included example cropland BMP scenarios. These scenarios serve as examples of the level of BMP adoption needed to achieve the nutrient reduction goals and milestones in major river basins, when combined with point source nutrient reductions and other reductions. BMP scenarios included identification of BMPs and adoption rates which were intended to maximize the combination of BMP effectiveness, cost and practice acceptability.

Several million acres of needed BMP additions were identified in the Mississippi River and Red River Basins (Table 9 and Figure 14). For both basins, "total BMP acres" assumes that nitrogen and phosphorus reduction BMPs are on the same lands. For example, cover crop acres to achieve nitrogen reduction are the same cover crop acres that will achieve phosphorus reduction. However, when local watershed prioritization for phosphorus and nitrogen reduction are in different areas, the total needed acreages may be higher than shown in Table 9 and Figure 17. More acres of agricultural BMPs are needed to meet the milestones in the Mississippi River Basin than the Red River Basin (Table 10).

In general, the approach for nitrogen reduction from cropland includes increasing fertilizer and manure use efficiency by optimizing nutrient management, treating tile drainage waters, and implementing living cover BMPs such as cover crops and perennials. Phosphorus reductions from cropland are based largely on optimizing fertilizer and manure application, subsurface banding or injection of fertilizer/manure, reducing soil erosion, and adding riparian buffers and other living cover on the landscape.

Nutrient reduction milestones and final goals for downstream waters

Phosphorus

- 12% reduction for the Mississippi River Basin (thus meeting the overall 45% reduction needed to meet the goal)
- 10% milestone reduction in Minnesota's Red River portion of the Lake Winnipeg Basin on the way to a 50% reduction goal

Nitrogen

- 20% reduction as a milestone on the way to a final 45% reduction goal for the Mississippi River Basin
- 13% milestone reduction for the Red River Basin on the way to a 50% reduction goal

Table 9. Example combined basin scenario from 2014 NRS to achieve milestones.

Agricultural BMP categories	Combined Basin Total (Mississippi River and Red River Basin)		
	Nitrogen BMP acres	Phosphorus BMP acres	Total BMP acres [b]
Field Erosion Control	0	4,900,000	4,900,000
Increasing Fertilizer Use Efficiencies [a]	6,800,000	2,200,000	6,800,000+
Drainage Water Retention and Treatment	620,000	0	620,000
Increase and Target Living Cover			
Perennials	440,000	440,000	440,000
Cover crops	1,900,000	1,400,000	1,900,000

a. Table 5-15 in the 2014 NRS shows a statewide total acreage for nitrogen fertilizer management of 80% of corn acres, or 11,900,000 acres of the 14,875,000 statewide acres of corn/soybean rotations. The BMP used in the 2014 NRS scenario was to decrease the industry average fertilizer rate on those 11,900,000 acres. It is useful to translate the industry average acreages to the actual number of acres that could be more optimally managed for nitrogen fertilizer. A fertilizer use survey report published by the MDA around the time the NRS was finalized showed that 57% of corn following soybean lands could lower rates to align with University of Minnesota recommended economically optimum nitrogen rates (MDA 2014). Using these findings, the total number of acres that could achieve nitrogen fertilizer reductions based on the 2012-2014 timeframe would be 6,783,000 corn/soybean acres (57% of 11,900,000 acres). Note that 2016 and 2019 increases in University of Minnesota recommended nitrogen rates lower this fraction of cropland receiving excess nitrogen fertilizer compared to the 57% reported for 2012. These BMP acreages should be adjusted in future NRS revisions to account for both updated fertilizer use surveys and the changing University of Minnesota recommended rates.

b. The total BMP acres assumes that nitrogen and phosphorus reduction BMPs are on the same lands. In most cases, this is expected to provide a conservative estimate of total acreage. Where local watershed prioritization for phosphorus and nitrogen reducing BMPs are in different areas, the total needed acreages will be higher.

Table 10. Example scenarios from 2014 NRS to achieve milestones in Mississippi River and Red River basins.

BMP categories	Mississippi River			Red River		
	Additional BMP acres needed at the time of NRS (2014)					
	Nitrogen	Phosphorus	Total	Nitrogen	Phosphorus	Total
Field Erosion Control	0	4,500,000	4,500,000	0	400,000	400,000
Increasing Fertilizer Use Efficiencies [a]	6,100,000	2,200,000	6,100,000+	700,000	0	700,000
Drainage Water Retention and Treatment	600,000	--	600,000	20,000	--	20,000
Increase and Target Living Cover						
Perennials	400,000	400,000	400,000+	40,000	40,000	40,000+
Cover crops	1,200,000	800,000	1,200,000+	700,000	600,000	700,000+

a. See footnote "a" in Table 9. Note: The total acres in the Mississippi River Basin that are needed for Increased Fertilizer Use Efficiency BMPs is expected to exceed 6,100,000.

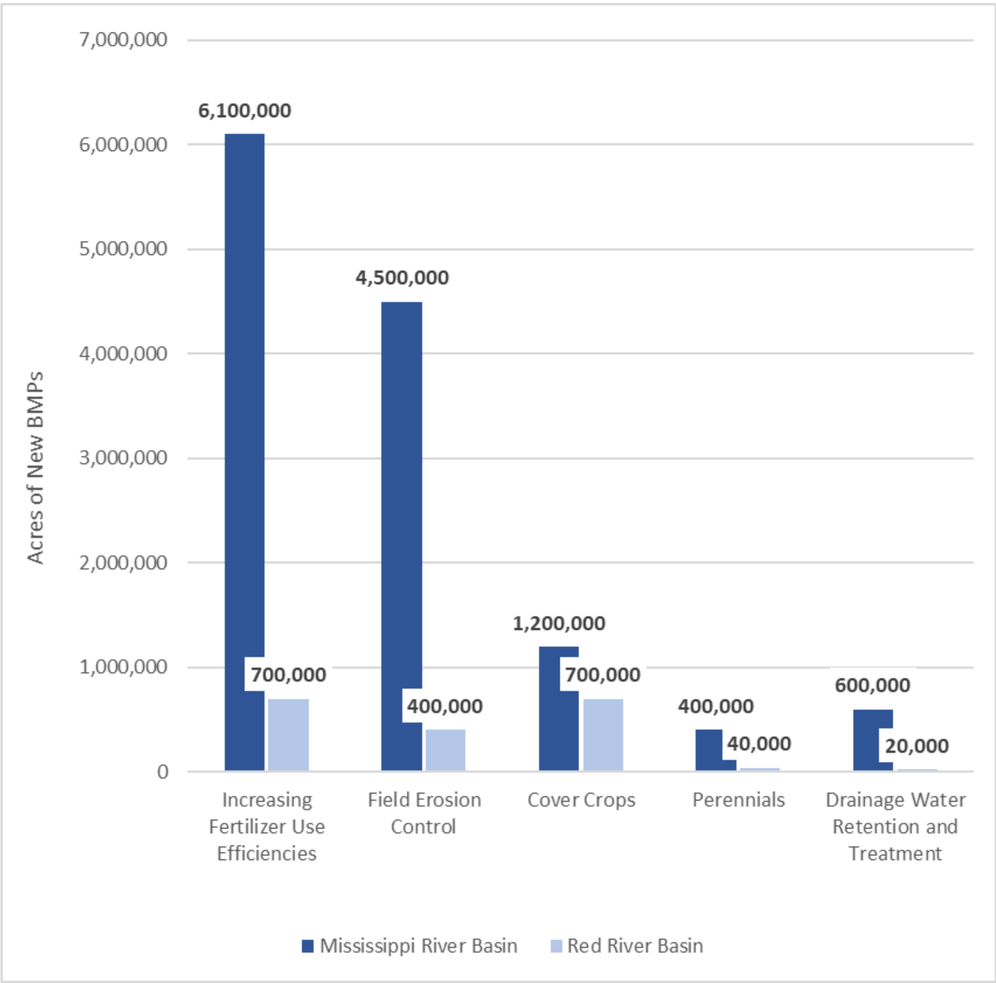


Figure 17. Example agricultural BMP scenario from 2014 NRS to achieve milestones, showing needs for additional acreages of new BMP additions.

The 2014 NRS focused on BMP scenarios to achieve the nitrogen milestones rather than the nitrogen final goals (e.g., 20% reduction in nitrogen in the Mississippi River Basin). The NRS acknowledged that Minnesota did not have a realistic way of showing how the 45% reduction could be achieved using the current state of scientific advancement. However, two hypothetical scenarios were described to indicate what it would potentially take in the future to achieve a 45% reduction in nitrogen from cropland sources in the Mississippi River Basin. Both scenarios assumed that research would advance the success of cover crops in Minnesota, enabling increases in cover crop establishment and success rates. The two hypothetical scenarios included:

Scenario 1 for final goals – Use same adoption rates as for the milestone except that cover crops are established on 80% of corn grain, soybean, dry bean, potato, and sorghum acres and improving the success rate on cover crop establishment from 40% to 80%.

Scenario 2 for final goals – Increase adoption rates of the BMPs used for the milestone to 100% of suitable acreages for those BMPs, and additionally increase cover crops from 10% to 60% of the corn grain, soybean, dry bean, potato, and sorghum acres and improve establishment success from 40% to 60%.

These 45% reduction scenarios indicate that the total amount of land with cover crops or perennials would ultimately need to increase by an estimated 10 to 12 million acres from the current living cover acreages (note: total row crop acres in Minnesota are approximately 16 million acres).

5.2 Agricultural BMP adoption since 2014

Progress toward these hypothetical 2014 NRS scenarios has been evaluated based on trends in the adoption of agricultural BMPs from 2014 to 2018. The following sections describe the data tracking process and provide summaries of key trends for four categories of agricultural BMPs: nutrient management efficiency practices, living cover practices, field erosion control practices, and tile drainage water treatment and storage practices.

5.2.1 Tracking agricultural BMP adoption in Minnesota

Minnesota partner agencies estimate statewide agricultural BMP adoption rates by examining a combination of BMPs adopted through government-supported programs and indicators of overall adoption rates based on satellite imagery, surveys, regulatory inspections, sales data and private industry data.

- **Government programs** that provide BMP-funding assistance have kept records of the new BMPs funded through these programs since approximately 2004. A tracking system managed by the MPCA, referred to as “Healthier Watersheds BMP tracking system,” includes the BMPs tracked by each of the major government programs. In addition, the United States Department of Agriculture (USDA) Farm Service Agency tracks Conservation Reserve Program (CRP) acreages and reports the data annually on a statewide basis.
- **Satellite imagery** provides snapshots in time of certain BMPs used at the time the photos were taken. These images can be used to estimate cover crops, reduced tillage, terraces, water and sediment control basins, grassed waterways, strip-cropping and other structural practices. Satellite imagery can also be used to estimate various land-covers and crops in place, such as hay and grasses.
- **Surveys** by the National Agricultural Statistics Service (NASS) have been used to gauge Minnesota fertilizer use periodically since 2010. Additionally, the U.S. Census of Agriculture surveys taken every five years provide information about cover crops and conservation tillage starting in 2012.

- **Regulatory inspections** of manure spreading practices regulated by the MPCA and delegated counties provide some clues about the adoption of various manure spreading BMPs, but do not provide a statistical representation of statewide manure spreading practices.
- **Sales and private industry records** for fertilizer statewide, when combined with crop harvest data, provide an indication about nutrient use efficiencies at a state scale. Soil phosphorus test results can also be used to inform nutrient management progress but are not currently collected in a manner that provides statistical representation of soil phosphorus trends.

5.2.1.1 *Government programs*

Minnesota's Clean Water Legacy Act requires that MPCA report actions taken in Minnesota's watersheds to meet water-quality goals and milestones (Minn. Stat. § 114D.26, subd. 2). To meet this requirement the MPCA developed the "Healthier watersheds: Tracking the actions taken" webpage. Water quality protection and restoration BMP adoption levels can be found at the HUC-8 and HUC-12 watershed scales at: https://www.pca.state.mn.us/water/best-management-practices-implemented-watershed. For use in evaluating progress toward the 2014 NRS, the Healthier Watersheds information is aggregated into major river drainage basins and four categories of BMPs consistent with the NRS, and can be found at:
https://public.tableau.com/profile/mpca.data.services#!/vizhome/MinnesotaNutrientReductionStrategyBMPSummary/MinnesotaNutrientReductionStrategyBMPSummary .

The programs providing BMP information for the Healthier Watersheds tracking system include:

- USDA– NRCS
    - Environmental Quality Incentives Program (EQIP)
    - CSP
    - Agricultural Conservation Easement Program – Wetland Reserve Easement
    - Emergency Watershed Protection Program – Floodplain Easement
    - Emergency Wetlands Reserve Program
    - Farm and Ranch Lands Protection Program
    - Grassland Reserve Program
    - Wetlands Reserve Program
- Minnesota BWSR
    - Easement Programs
        - CREP
        - RIM
        - Wetland Reserve Program
        - Army Compatible Use Buffer Program
        - Riparian Buffer Conservation Easements
    - Grant Programs
        - Disaster Recovery Assistance Program
        - Clean Water Fund (CWF) Grants
        - State Conservation Cost-Share
        - Native Buffer Grant Program
        - Natural Resources Block Grant
    - Other programs as reported in the eLINK tracking system

Conservation Reserve Enhancement Program (CREP)

The Minnesota CREP began in 2017 with a goal of creating 60,000 acres of buffers, restored wetlands, and protected wellheads for drinking water. CREP is funded through USDA and State of Minnesota funds. Landowner sign-ups began in May 2017 and continued until August 2018. During the landowner sign-up period, a total of 290 applications received funding, representing 12,186 acres. Over 90% of the CREP practice acreages were for wetlands. Due to new federal Farm Bill negotiations and the federal government shutdown, no further sign-ups occurred for the remainder of 2018. More information is available in Appendix A and at: http://www.bwsr.state.mn.us/crep/

MINNESOTA CREP

- MDA
    - Agriculture BMP Loan Program
    - Minnesota Agricultural Water Quality Certification Program
- MPCA
    - Federal Clean Water Act Section 319 Program
    - Clean Water Partnership Program

Specific information provided on the “Healthier watersheds: Tracking the actions taken webpage” is provided below.

Reporting period: The BMP data in this analysis covers the period 2004-2018, except for CSP which goes back to only 2010 and only separates out enhancement BMPs during the past couple years.

Year of BMP: Represents the best available date for BMP installation. When installation dates are not available, the funding year is used.

Joint state/federal cost-share: All BMPs in the BWSR grant tracking system (eLINK) that report federal match (except for the 319 Program) are categorized only with federal program acreages. These practices are not reported under state-funded categories to prevent potential double counting. The majority of the joint state/federal practices are accounted for by the NRCS - EQIP Program. Less than 5% of the eLINK BMPs are associated with federal allocations.

Location of BMP (HUC-12): BMPs that do not have HUC-12 location data associated could not be attributed to a specific drainage area. These BMPs are included in statewide BMP aggregations but are not included with basin or watershed-specific information.

New BMPs: 5-year tallying of acres for this report assumes that once a BMP is installed that it will continue to operate within this 5-year reporting period. In practice, some of the BMPs that are initially funded through government programs will not continue to be implemented after government funding ceases. Therefore, the cumulative BMP elements in this report represent a high-end or overestimate of actual ongoing cumulative practices through government assistance programs.

Multi-year contracts: The EQIP Program funds many BMPs such as reduced tillage, cover crops, and nutrient management under three-year contracts. For such cases, the BMP is attributed to the first year under contract and is assumed to be in operation for the remainder of the reporting period.

Agricultural BMP Loan Program: Acres under this program are assigned to individual loans and may overlap if a borrower has multiple loans for the same BMP within the reporting period. In addition, loan-funded equipment could be used on the same acres that receive federal cost-share under a program like EQIP.

Acres assumptions: When specific adoption acreages were not listed by the government program, estimates of treated acres were derived from statewide averages and literature review related to the practice or closely related practice.

The methods to refine specific acreage estimates of newly adopted practices during any given year may be modified in the future to best meet both state and federal program purposes. While this may result in differences between the acres in this report and future website reported acreages, the general magnitude of government program supported practice adoption acreages over a multi-year period described in this report is not expected to change in a way that would significantly affect this report’s conclusions.

Data from the Healthier Watersheds website (NRS version), in addition to federal tracking of CRP acreage, are used to track BMP adoption categories (Table 11). The government program BMP tracking system developed in Minnesota generally aligns with the Nonpoint Source Workgroup recommendations stemming from the Gulf of Mexico Hypoxia Task Force at: https://www.epa.gov/sites/production/files/2018-05/documents/nps_measures_progress_report_1-_may_2018.pdf.

Table 11. BMPs included in Healthier Watersheds website, reported in the following sections.

Nutrient Management Efficiency	Living Cover	Field Erosion Control	Tile Drainage Water Treatment and Storage
Nutrient management	Conservation Cover Conservation Crop Rotation Conservation Easement Cover Crop Critical Area Planting Filter Strip Forage and Biomass Planting Riparian Forest Buffer Riparian Herbaceous Cover Windbreak/Shelterbelt Establishment	Alternative Tile Intake Contour Buffer Strips Field Border Grassed Waterway Mulching Residue and Tillage Management, No-Till/Strip Till Residue and Tillage Management, Reduced Till Residue and Tillage Management, Ridge Till Sediment Basin Stripcropping Terrace Water and Sediment Control Basins	Denitrifying Bioreactor Drainage Water Management Saturated Buffer Wetland Restoration

5.2.1.2 *Satellite imagery*

Satellite aerial imagery projects initiated by the BWSR within the past five years are beginning to provide a more comprehensive view of soil conservation practices, specifically crop residue and cover crops. The BWSR, the University of Minnesota, and Iowa State University have been working together since 2016 to develop a long-term program to systematically provide cover crop, crop residue, land cover and soil erosion data in Minnesota counties with at least 30% agricultural land use. The goal is to quantify and track this information on multiple scales and to calculate estimated average annual and daily soil loss due to wind and water erosion.

Reduced tillage and cover crop practices are often used without government assistance and are not always tracked through government assistance program databases. The BWSR contracted with the University of Minnesota to provide more comprehensive snapshots of crop residue cover levels and cover crop practices in Minnesota. Data from this project will be important for gauging the statewide NRS goals, as well as measuring changes at the local sub-watershed level. This project is moving from prototype development into production mode in 2020 and 2021.

For collection of spring crop residue levels and fall cover crop adoption, remote sensing techniques utilizing Sentinel 2 and Landsat 8 satellite imagery are used. Data has been collected and analyzed by the University of Minnesota from 2016 through 2019. To provide quality assurance and control of the data, ground truth data is collected in the field to verify and validate the remote sensing model. Digital images of residue are collected to provide precise residue measurements in a limited number of locations. This data is used to calibrate the model and thus improve the accuracy of the model outputs for Minnesota.

One of the major components of Minnesota's crop residue and cover crop satellite imagery project is to deploy the Daily Erosion Project (DEP) web application in Minnesota. The DEP application provides data on the following parameters in an easy to use geospatial interface at https://www.dailyerosion.org/: precipitation, runoff, soil erosion (detachment), soil erosion (hillslope soil loss), along with wind erosion to be added in the future. The DEP will be utilized to help track soil loss by water and wind erosion on an annual basis and Minnesota will have ability to look at trends in the data over time. Data from this project will be useful in looking at regional, county, and watershed scale comparisons. No direct link between erosion and nutrients are provided by this work, however, in the future these connections may be explored.

Similar to Minnesota's satellite imagery project, The Conservation Technology Information Center (CTIC) partnered with Applied GeoSolutions and The Nature Conservancy on the development, testing and application of the Operational Tillage Information System (OpTIS). OpTIS is an automated system to map tillage, residue cover, winter cover, and soil health practices using remote sensing data. OpTIS-based data are currently available for the years 2005 through 2018 for the U.S. Corn Belt, and results can be found at: https://www.ctic.org/optis.

Satellite data can also be used to identify and map the locations of structural practices. Structural BMPs (sediment basins, terraces, waterways, etc.) are being mapped throughout Iowa using Light Detection and Ranging (LiDAR) digital elevation model data and aerial imagery interpretation. Using similar methods to Iowa, the BWSR undertook a pilot project in 2018 to assess the workload that would be needed to conduct such an inventory in Minnesota. A total of 23 HUC-12 watersheds were mapped in this project: 18 in the Blue Earth River Watershed, 2 in the Yellow Medicine Watershed, and 3 in the Buffalo Red Watershed. The Blue Earth Watershed was chosen because of the proximity to Iowa and the ability to compare Minnesota and Iowa information using Iowa's mapping protocol. The Yellow Medicine and Buffalo Red watersheds were selected because of their proximity to glacial ridges and a high density of structural BMPs.

Structural agricultural practices identified from satellite images included:

- Water and sediment control basins
- Grade stabilization structures
- Grassed waterways
- Terraces
- Ponds and dam structures

Figure 18 from the pilot project clearly shows the diversity of adopted structural BMPs. Collecting BMP data from LiDAR provides a more accurate picture of the structural BMPs on the landscape. In the pilot area, the LiDAR BMP mapping project identified 1,420 structural practices, while the BWSR eLINK database identified 226 structural practices. The eLINK data includes practices that have state funding and does not include many practices funded under Federal programs or by landowners directly. In the future, mapping structural practices statewide would allow better tracking of structural BMP adoption. However, the mapping of these practices does not indicate how well the practices are being maintained or their ability to continue providing the intended soil and water protection.

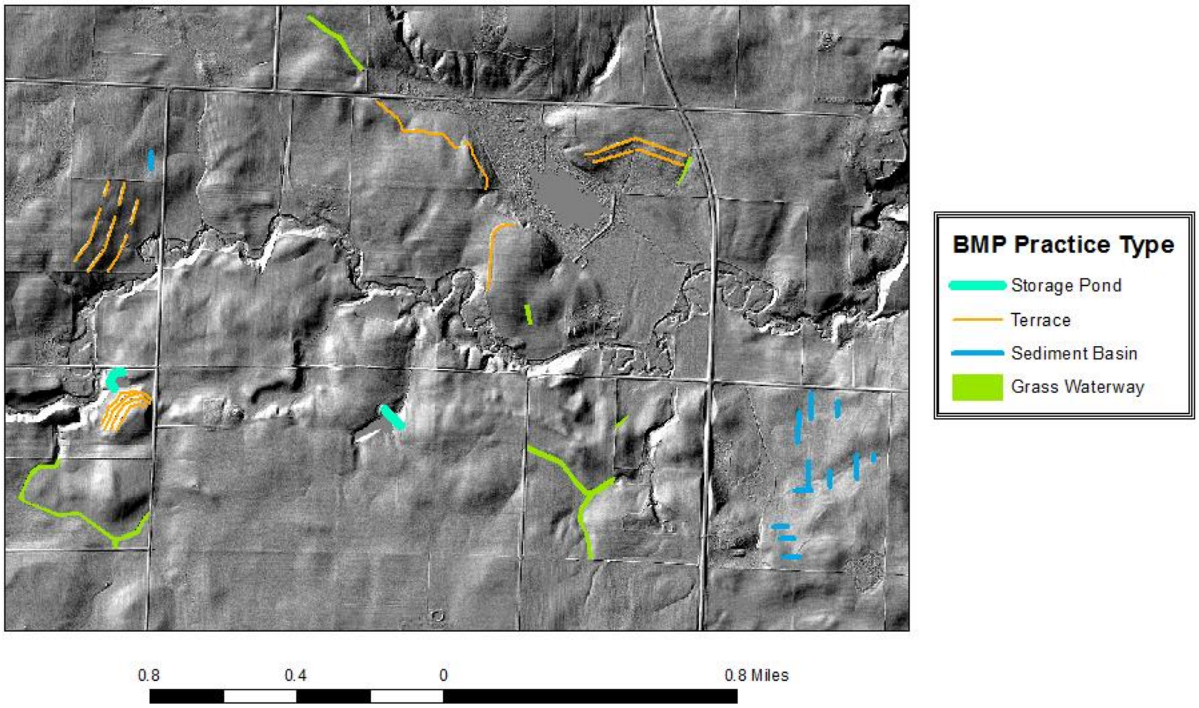


Figure 18. Example image from LiDAR mapping pilot project. (Source: BWSR)

5.2.1.3 *Surveys, regulatory reports and inspections, and sales and private industry records*

In April 2019, the USDA NASS released the 2017 U.S. Census of Agriculture: https://www.nass.usda.gov/Publications/AgCensus/2017/index.php. This Census is taken every five years to look at trends in all aspects of agriculture production for both animal and cropland agriculture. The results most relevant to this assessment of BMP adoption include the 2012 and 2017 census findings on conservation tillage and cover crops in Minnesota.

Nitrogen fertilizer-use farmer surveys are periodically conducted across Minnesota, with findings summarized in reports by the MDA. A survey instrument was developed specifically for the surveys which were conducted over the phone by enumerators from NASS. Reports from the surveys are available at: www.mda.state.mn.us/nutrient-management-surveys.

5.2.2 Nutrient management efficiency (fertilizer and manure) practices

As discussed in the 2014 NRS, increasing the efficient use of fertilizers and manure is a fundamental strategy for reducing nutrient movement to waters.

Nutrient management efficiency practices selected for phosphorus and nitrogen reduction analysis in the 2014 NRS include applying recommended fertilizer rates, proper placement and timing of application, nitrification inhibitors, reducing soil phosphorus levels, and livestock feed management. Adoption levels of fertilizer and manure use-efficiency practices implemented from 2014 to 2018 were assessed using data from government tracking systems as well as overall indicators of adoption derived from fertilizer sales, nitrogen fertilizer use efficiency indices, and farmer fertilizer use survey data. While government programs can help to foster good nutrient management, the NRS suggests that private industry has the largest role to ensure the most efficient fertilizer and manure management practices.

5.2.2.1 *Progress of nutrient management efficiency practice adoption through government programs*

Nutrient management practices under NRCS's conservation practice 590-standard focus on managing the amount (rate), source, placement (method of application), and timing of nutrients and soil amendments; 59,550 new acres of 590-standard nutrient management were newly enrolled through federal and state programs between 2014 and 2018 (Figure 18 and Table 12). Since 2014, annual new acres affected by government-support programs shows a marked decrease when compared to the preceding five years, and has not risen above 15,000 acres since 2013 (Figure 21). Existing data sources do not indicate how many acres continue with nutrient management BMPs after the contracts end (typically after three years). Additionally, the average acreage added annually under contract per year dropped substantially to 13,569 from 2014 to 2018 (compared to 107,640 acres per year during the previous 5-year period), due largely to NRCS EQIP enrollment reductions for this practice (Figure 21).

2014 NRS recommended agricultural BMPs

Increase fertilizer use efficiencies, emphasizing:

a. Nutrient management through reduction of nitrogen losses on corn following soybeans
b. Switch from fall to spring fertilizer applications (or use nitrification inhibitors)
c. Application of phosphorus in accordance with precision fertilizer and manure application techniques, including applications based on soil test results and University of Minnesota recommendations

Manure management on feedlots

When manure is part of the added nutrients to cropland, total manure and fertilizer additions are regulated by the MPCA and delegated county authorities through the Minnesota Feedlot Rules Chapter 7020. State and county inspections of manure spreading practices and records provide some insight into manure spreading BMP use. More information on feedlots and manure management on feedlots is provided in Section 6.

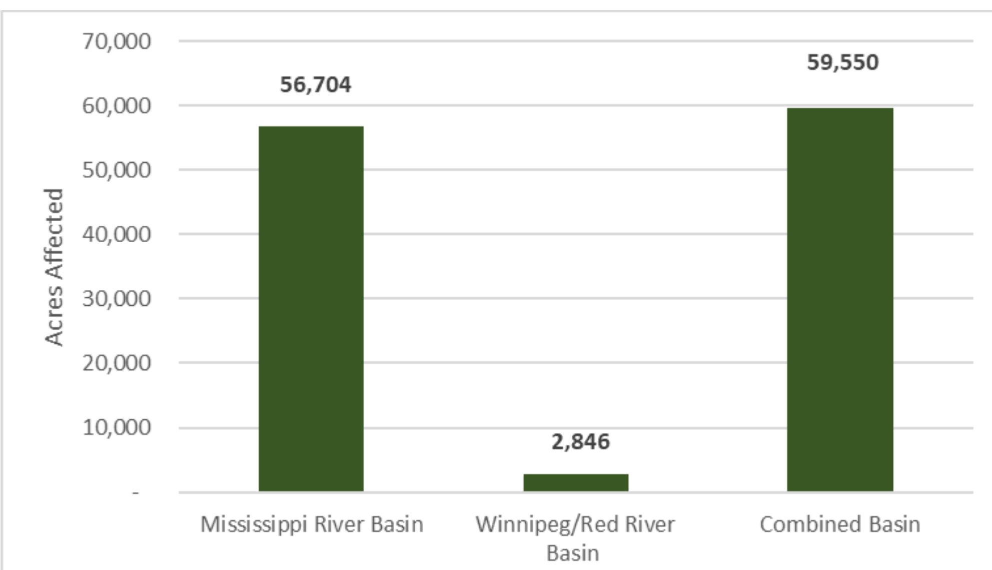


Figure 19. Total new acres for 590 nutrient management efficiency practices enrolled through government support programs from 2014 to 2018 (MPCA's Healthier Watersheds BMP tracking system).

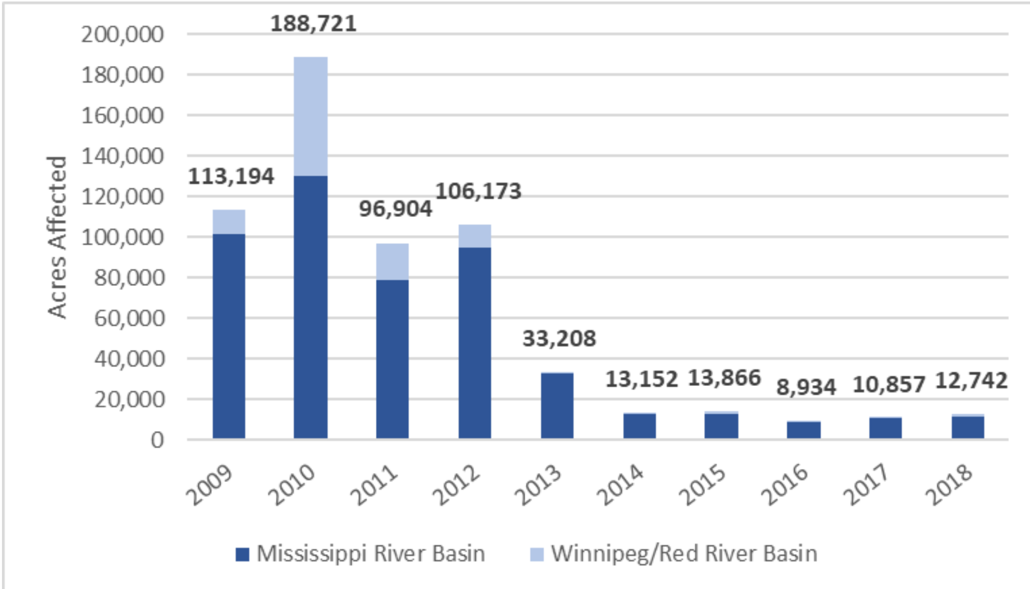


Figure 20. Annual new acres of 590 nutrient management efficiency practices added through government support programs, 2009 to 2018 (MPCA's Healthier Watersheds BMP tracking system - NRS version).

Table 12. Acres of nutrient management efficiency practices enrolled through government support programs, 2014 to 2018 (MPCA's Healthier Watersheds BMP tracking system)

	Nutrient management (CP 590)	Other nutrient management efficiency practices (CP 102 and 104 plans)	Nutrient management efficiency practices – total acreage
Mississippi Basin	56,704	10,300	67,004
Red River Basin	2,846	936	3,782

5.2.2.2 *Additional progress indicators of nitrogen management*

Indicators that help describe nitrogen management on cropland include fertilizer sales, application rates, timing of fertilizer application, and use of nitrification inhibitors. These indicators are described below. Additional detail on changes to University of Minnesota recommended nitrogen fertilizer rates for corn, or the Maximum Return to Nitrogen (MRTN), since 2014 is provided in Appendix D.

Fertilizer sales

Fertilizer sales are tracked by the MDA. The sales data are not tracked in such a way to precisely know the sales in specific watersheds but are more useful at a statewide level. Grain production information when combined with fertilizer sales can provide indications of state-level fertilizer use efficiencies. Statewide, nitrogen fertilizer sales reached a peak in 2012, when grain prices were high and corn acres were elevated. Since 2012, fertilizer sales have trended downward slightly (approximately 1.3% per year) (Figure 21).

The nitrogen sales since 2014 are about 15% higher than the 25-year average. The average decadal sales in the 1990s were 593,000 tons per year, which was comparable to the 2000s at 588,000 tons per year. During the 2010s, sales have hovered near 700,000 tons per year. Fertilizer tonnage reporting prior to 2010 may have underrepresented actual sales during some years and the inter-annual variation may be due to reporting inaccuracies rather than actual variation in sales.

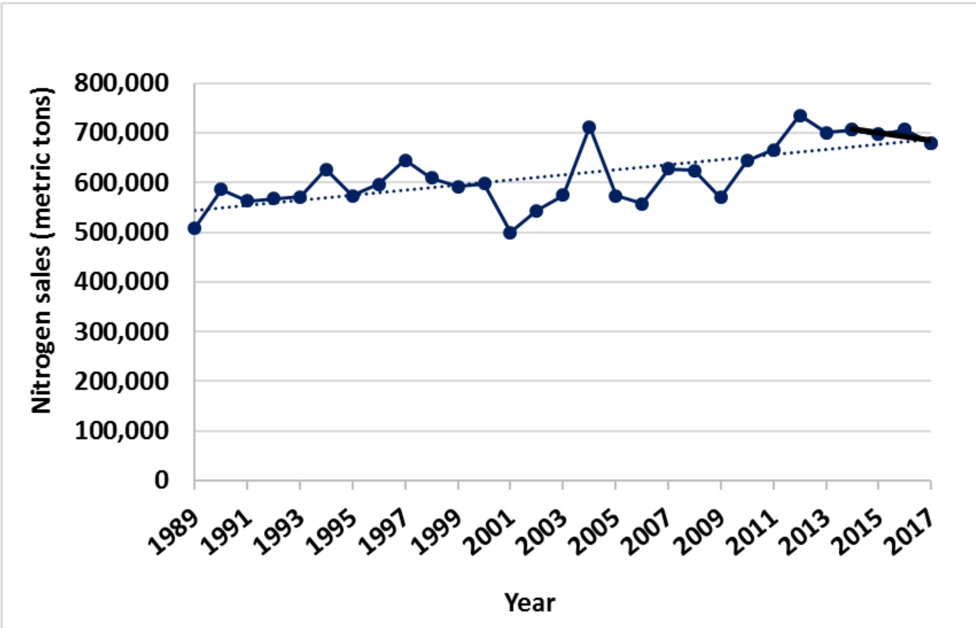


Figure 21. Annual nitrogen sales in fertilizer 1989 – 2017.

An index of nitrogen use efficiency is calculated by dividing total crop harvest yields by fertilizer sales. This index increased from 1992 to 2010, suggesting increased efficiency in nitrogen use, but has recently been lower or equivalent to the 2010 index (Figure 22). Nitrogen use on corn is used in the following example because approximately 75% of the fertilizer tonnage is used on corn acres. Corn yield gains have increased faster than the increase in nitrogen fertilizer application.

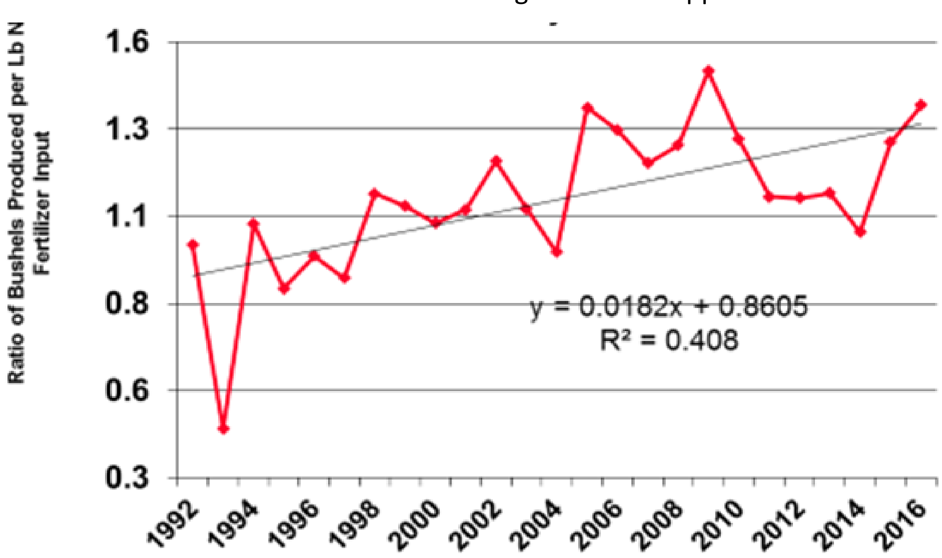


Figure 22. Nitrogen fertilizer use efficiency for corn 1992 – 2016 estimated based on statewide fertilizer sales and corn grain yield.

Application rates

Adherence to University of Minnesota guidelines on nitrogen rates for corn depends on the preceding crop. For example, on corn following corn, approximately 9% of the fields had application rates greater than 25 pounds nitrogen/acre (lb. N/ac) above the MRTN. For corn following soybean, that number is 25%. Excess nitrogen applications above the MRTN are higher yet when corn follows alfalfa in the rotation, or when manure is being applied. The fertilizer use rate information in this section is based on survey data collected by NASS and reported by MDA: https://www.mda.state.mn.us/nutrient-management-surveys.

Corn following corn

The statewide average nitrogen fertilizer application rate for corn following corn was 161, 160 and 153 lb. N/ac based on the 2010, 2012 and 2014 surveys, suggesting a possible slight decreasing trend in application rates. The data are based on 665, 589 and 414 fields for 2010, 2012 and 2014, respectively. A summary of fertilizer rates for corn following corn from the surveys is shown in Figure 23. None of the fields were reported to have received manure for two years or more prior to the cropping year represented by the survey. Also shown in Figure 23 are the approximate University of Minnesota nitrogen fertilizer rate ranges for 2006, 2016 and 2019 (for the 0.10 ratio of fertilizer cost to corn value). Across the three surveys, 55%, 63% and 77% of the fields were at or below the University of Minnesota's recommended rates from 2006, 2016 and 2019, respectively.

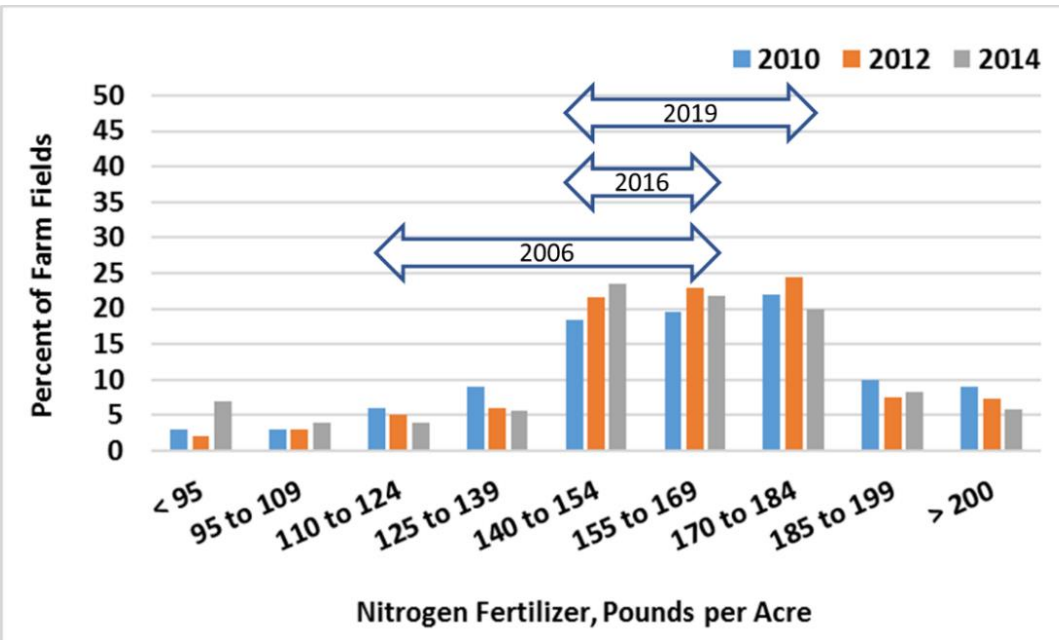


Figure 23. Distribution of nitrogen fertilizer rates from the 2010, 2012 and 2014 surveys for corn after corn. The nitrogen fertilizer rate ranges suggested by the University of Minnesota in 2006, 2016 and 2019 are approximated with the double-arrows.

Corn following soybean

The statewide average nitrogen fertilizer application rate for corn following soybean was 148, 144 and 144 lb. N/ac based on the 2010, 2012 and 2014 surveys (Figure 24). None of the fields were reported to have received manure for two years or more. Across the three surveys, 19%, 22% and 42% of the fields were at or below the University of Minnesota's recommended rates from 2006, 2016 and 2019, respectively. Across the three surveys, 48%, 37% and 15% of the fields had more than 25 lb. N/ac applied in excess of the University of Minnesota's recommended rates from 2006, 2016 and 2019, respectively.

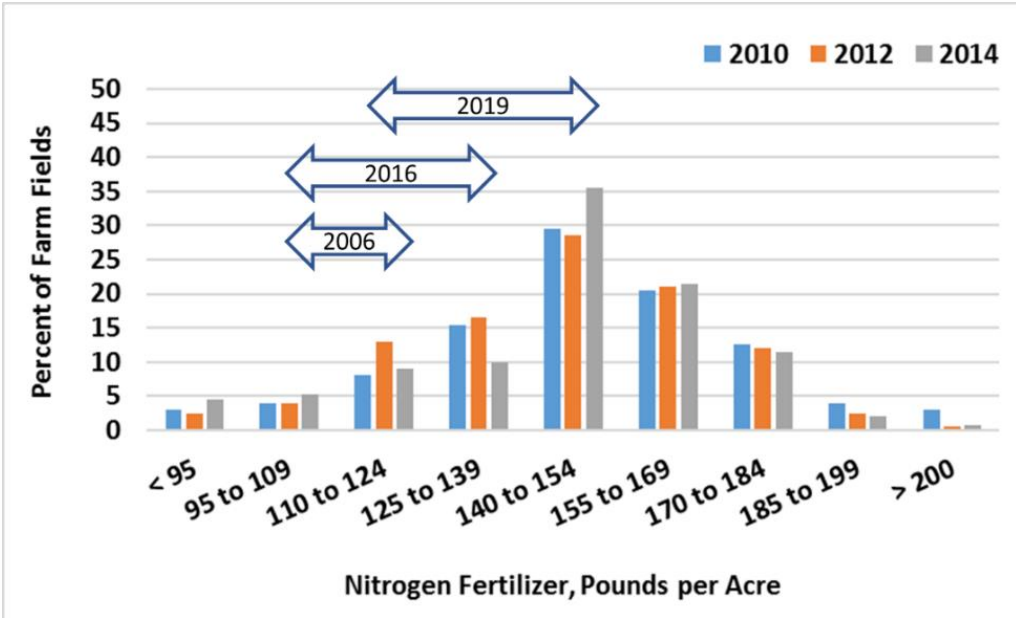


Figure 24. Distribution of nitrogen fertilizer rates from the 2010, 2012 and 2014 surveys for corn after soybean. The nitrogen fertilizer rates suggested by the University of Minnesota in 2006, 2016 and 2019 are approximated with the double-arrows.

Corn following small grain

The statewide average nitrogen fertilizer application rate for corn after small grains (wheat, barley, and rye) was 122, 127 and 119 lb. N/ac based on the 2010, 2012 and 2014 surveys. Across the three surveys, over 90% of the fields were at or below the University of Minnesota's recommended MRTN of 155 lb. N/ac.

Corn following manure

The statewide average nitrogen application rates for corn receiving manure were 173, 196 and 184 lb. N/ac based on the 2010, 2012 and 2014 surveys. This includes nitrogen sources from both manure and commercial fertilizer. The manure was field-applied either the previous fall, in the spring or within the growing season. The distribution of total nitrogen application rates on corn receiving manure from the 2014 survey is shown in Figure 25. The nitrogen inputs include manure and inorganic fertilizer. The average nitrogen inputs were 120 and 67 lb. N/ac from manure and fertilizer, respectively. Nearly half of the fields with manure received total nitrogen additions exceeding 200 lb./ac. The maximum of the range recommended for manured fields with corn following corn is 215 lb./ac (0.05 ratio U of MN published rates in 2019), and the maximum of the recommended range for corn following soybeans is 165 lb./ac. The survey did not determine how the manured-field nitrogen rates were different for these rotations.

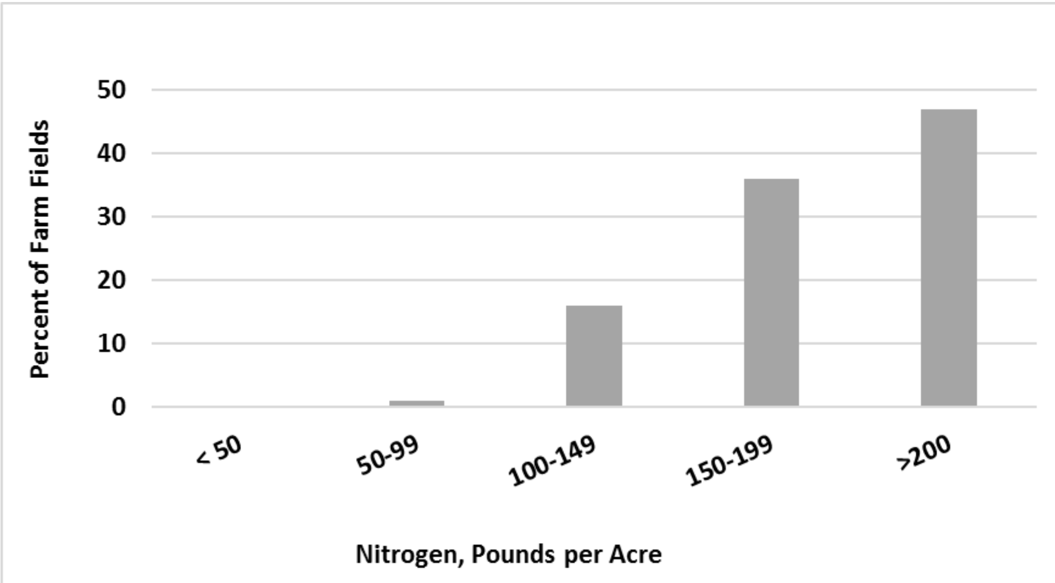


Figure 25. Distribution of total nitrogen application on corn fields receiving manure from 2014. Nitrogen inputs include manure and supplemental nitrogen.

Timing of fertilizer application

The risk of inorganic nitrogen loss typically increases as the time from application to crop uptake increases. For this reason, it is common to use higher nitrogen rates (additional 10-30 lb./ac) for fall application compared to spring applications in the same region. Even under optimal weather conditions, some fall-applied nitrogen will usually be lost either through leaching or denitrification by the time the crop starts uptake.

According to the 2014 survey, approximately 27%, 63% and 10% of nitrogen is applied in the fall, spring (either pre-plant or at planting), or in a split or side-dress application, respectively. The vast majority of the fall-applied acres are in the western and the south-central BMP Regions (Bierman 2011), where fall application of nitrogen fertilizer is a recommended BMP.

Anhydrous ammonia (AA) is considered a good nitrogen source for crop production and is generally the best option for fall application of nitrogen fertilizer. It is less likely to be lost compared to other nitrogen sources since AA immediately after injection converts to ammonium which is retained on the soil cation exchange sites. The injection of AA also causes a temporary inhibition of soil microbes (IPNI 2012). This delays the conversion of ammonium to nitrate which further reduces the risk of leaching losses. Urea is another good nitrogen fertilizer source. In the soil, urea is converted to ammonium, but lacks the nitrification inhibition properties of AA and is more prone to volatilization and leaching losses if not managed properly. Nitrogen solutions (UAN) contain nitrogen in the urea, ammonium and nitrate forms. Because these forms of nitrogen can be readily lost to volatilization or leaching if not managed properly, UAN is frequently banded or injected at planting, used for in-season nitrogen applications or added to irrigation water.

Anhydrous ammonia sales have dropped substantially over the past 25 years (Figure 26). Reasons for the decrease are safety concerns, increasing regulations, and cost. Additionally, it is a difficult product to manage within precision type applications and in no-till systems. Urea sales have steadily increased and have taken up much of the marketplace sales reductions in AA.

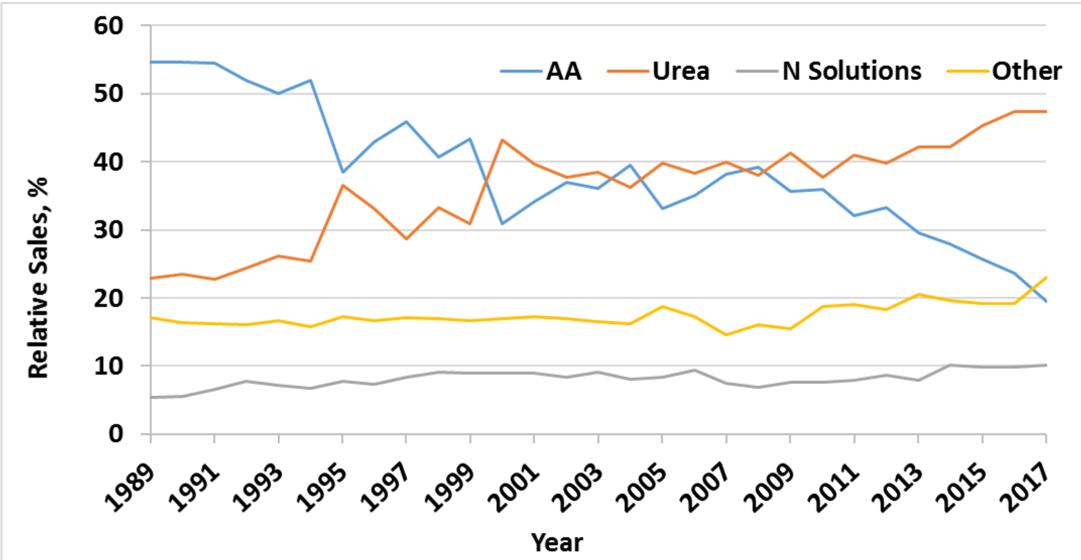


Figure 26. Sales trends for the three major nitrogen fertilizer sources. AA is anhydrous ammonia. Other sources include custom dry blends of fertilizer.

A complicating factor for timing of nitrogen fertilizer application is secondary nitrogen sources. Secondary nitrogen sources typically include ammonium-containing products for phosphorus and sulfur application, such as MAP (mono-ammonium phosphate), DAP (diammonium phosphate) or ammonium sulfate. In 2014 (most recent data), MAP and DAP account for 13% of the nitrogen applied from fertilizer. An additional 7% comes from other sources including sulfur fertilizer products. Approximately one-third of these products are typically applied in the fall, which is consistent with University of Minnesota BMPs. For areas with high loss potential, including areas with coarse textured soils or high rainfall, the University of Minnesota BMPs does not recommend fall nitrogen applications, regardless of source (including MAP and DAP).

Use of nitrification inhibitors

In areas of the state with high nitrogen fertilizer loss potential, it is a University of Minnesota recommended BMP to use nitrification inhibitors to help minimize nitrate losses. Nitrification inhibitors delay the conversion of ammonium to nitrate thereby minimizing the risk of nitrogen leaching losses. There are several nitrification inhibitors available with different modes of action. While many of these products have been rigorously tested and their performance has been verified through independent research, other products lack this testing under neutral research conditions. It continues to be a challenge, therefore, to accurately assess the benefit of some of the products that claim to be nitrification inhibitors.

Currently the state does not have a sales tracking program to collect information about the use of nitrogen enhancement or inhibitor type products in Minnesota. However, because the organic compound nitrapyrin, a commonly used nitrification inhibitor sold under such trade names as "N-Serve" and "Instinct" is considered a restricted use pesticide, its sales numbers are reported (Figure 27). When corn prices were peaking around 2010 to 2012, nitrapyrin sales (statewide) increased dramatically, but have leveled off at around 550,000 pounds per year since 2014. Using the labeled application rate of approximately 0.5 lb. of active ingredient per acre, the MDA estimates around 1,100,000 acres are treated each year with nitrapyrin alone, corresponding to approximately one-eighth of all corn acres.

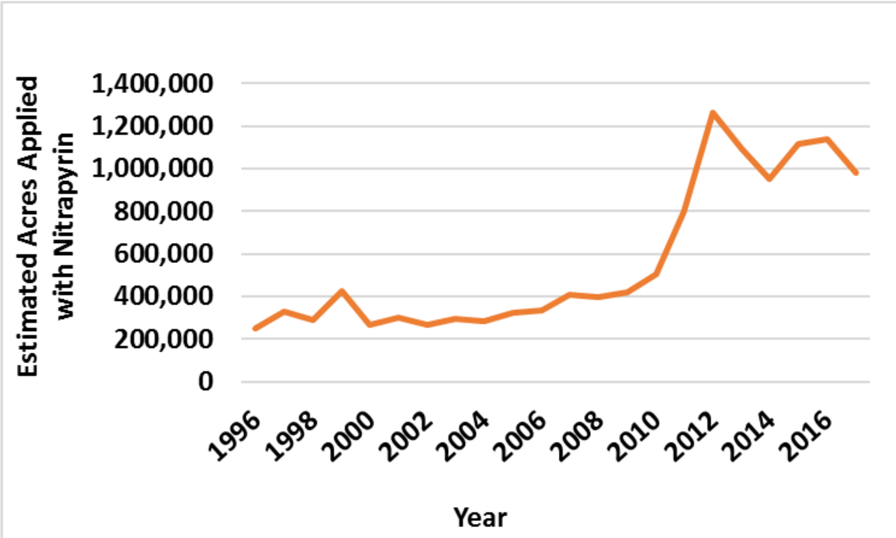


Figure 27. Estimated number of acres treated with the nitrification inhibitor nitrapyrin each year 1996 – 2017. Estimates are based on annual sale reports and the label application rate of one-half pound of active ingredient per acre.

There are regional differences in the use of nitrogen inhibitors. In regions of the state with higher leaching potential such as coarse textured soils or high rainfall amounts, fall application of nitrogen fertilizer is not a recommended BMP. For the southcentral BMP region of the state, which is a transition between the wetter eastern region and the drier western regions, the recommended practice for fall application is using anhydrous ammonia with N-Serve (nitrapyrin). The loss potential in the northwest, southwest and west-central regions is lower compared to the other BMP regions further to the east. For this reason, the BMPs do not suggest nitrification inhibitor use in western Minnesota. For fall applied anhydrous ammonia in 2012 for the 2013 corn crop, 60% and 12% of survey respondents in the south central region indicated all and some of fall-applied AA included nitrapyrin, respectively. Corn acres treated with nitrapyrin were low in the northwest and southwest/west-central regions (Figure 29).

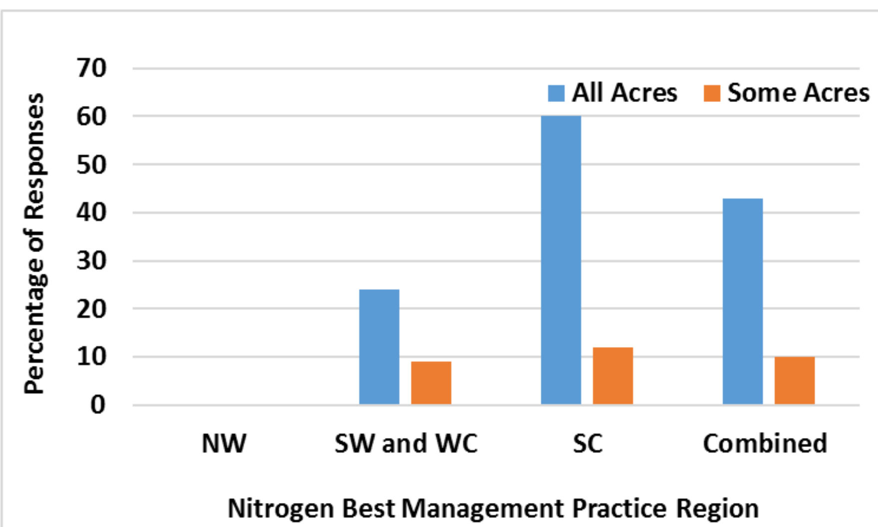


Figure 28. Percent of respondents that used nitrapyrin with fall applied anhydrous ammonia in 2012 for the 2013 corn crop. NW = northwestern MN; SW = southwestern MN; WC = west central; SC = south central MN; Combined = all regions.

5.2.2.3 *Additional progress indicators of phosphorus management*

Phosphorus fertilizer sales and soil phosphorus tests provide indicators of changes in phosphorus management. Phosphorus sales have remained nearly flat since 2014. Sales decreased in 2014 and 2015 and have slowly been rebounding since then (Figure 29). The average annual sale of phosphorus fertilizer increased by approximately 25% between 1989 and 2010.

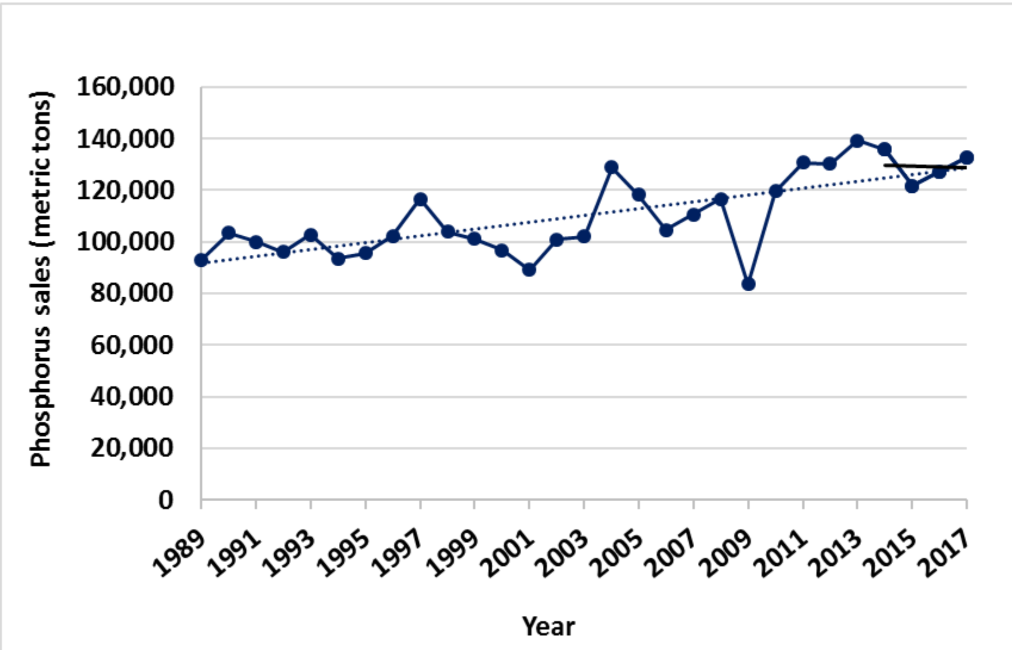


Figure 29. Annual phosphorus sales (as elemental P) during 1989 – 2017.

The phosphorus application rates suggested by the University of Minnesota Extension are based on the expected crop yield and soil phosphorus levels determined through soil sample analysis. Figure 30 shows the distribution of Minnesota phosphorus soil test levels tracked by the International Plant Nutrition Institute (IPNI) for samples collected in 2001, 2005, 2010 and 2015 (IPNI 2019). Soil test levels between 20-25 ppm (Bray P1) are normally considered optimum for corn production. No additional phosphorus application is typically suggested above 25 parts per million (ppm) (University of Minnesota Extension 2019). The change in relative frequency from 2001 to 2015 in Figure 31 shows a trend towards higher soil phosphorus levels. For example, more fields show high levels of phosphorus (above 25 ppm) in 2015, as compared to other earlier years. However, considering that the tested fields are not selected from a random sampling, statistically valid conclusions are not possible.

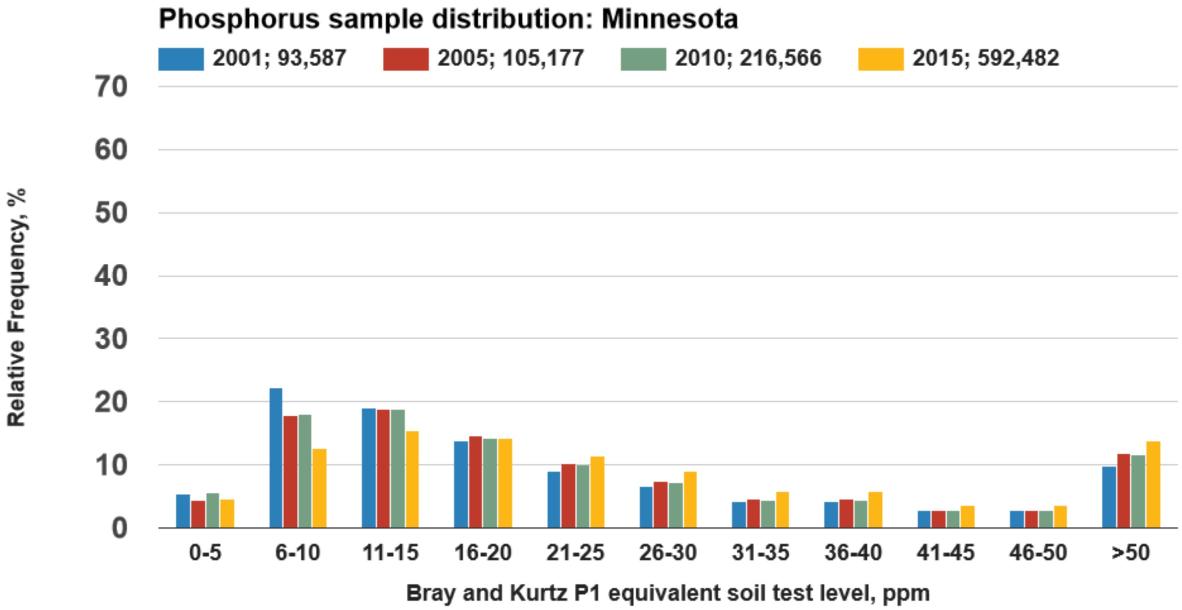


Figure 30. Frequency of phosphorus level in soil samples from Minnesota for 2001, 2005, 2010 and 2015. Soil test levels between 20-25 ppm are normally considered optimum for corn production. Source: IPNI 2019.

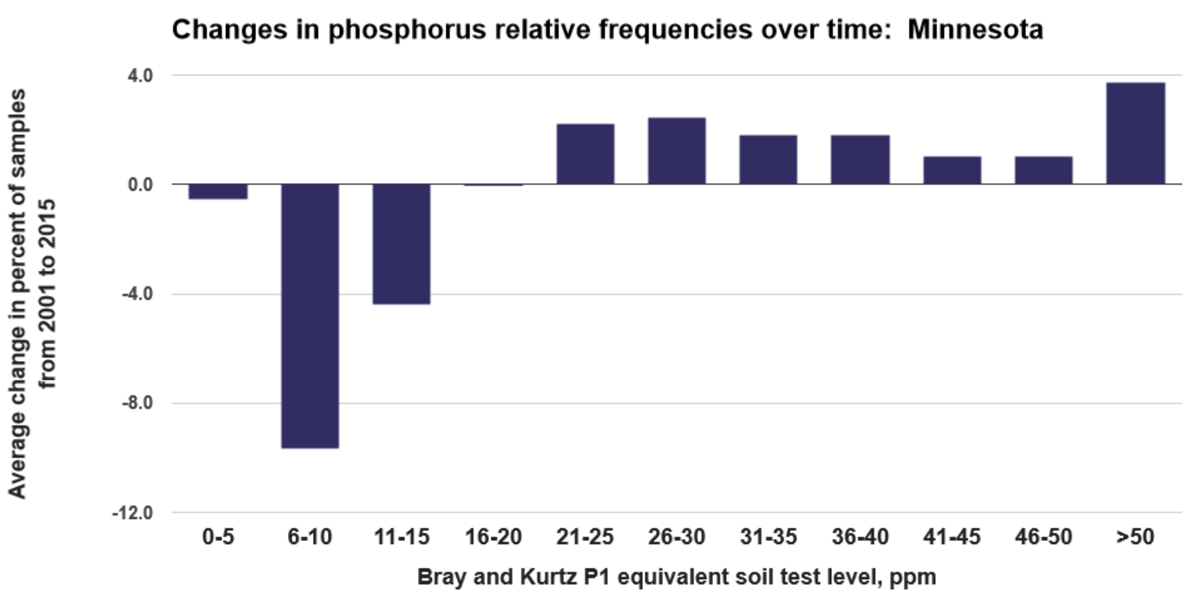


Figure 31. Change in relative frequency of soil phosphorus tests from 2001 to 2015. Source: IPNI 2019.

Summary of Minnesota’s Progress on Nutrient Management Efficiency

Why important

- Nutrient management efficiency gains are among the most economically profitable ways to achieve nutrient reductions. The NRS scenario is to improve nutrient management efficiency on roughly 6.8 million acres.
- This type of change is often accomplished outside of government program funding, and it is important to consider a variety of progress indicators apart from government programs.

Findings

- Government-funded fertilizer/nutrient management practice (i.e., 590 standard) acreages have decreased considerably in recent years.
- Fertilizer use surveys for corn lands showed fairly constant nitrogen rates from 2010 to 2014, with over 35% of corn/soybean rotation fields having received nitrogen rates exceeding the upper end of the recently increased University of Minnesota corn N rate recommendations.
- Statewide, nitrogen and phosphorus fertilizer sales have leveled off during recent years and have started to decrease but remain higher than sales during years prior to 2012. Phosphorus fertilizer sales are 25% higher now than in 1989.
- Nitrogen fertilizer use has shifted in recent years to forms that are more challenging to prevent losses to water, especially when applied during the fall.
- Soil phosphorus test results are showing more fields testing very high. It is unknown if this is an actual increase or otherwise just represents an increasing emphasis to re-test fields previously found to have high soil phosphorus.
- None of the indicators of nutrient management practice adoption show changes during the past five to ten years expected to yield measurable nutrient reductions to surface waters at a large scale.

Follow-up

- More work is needed to identify improved fertilizer and manure use BMP metrics to track progress with such practices as subsurface banding of phosphorus and split application of nitrogen.
- Continue programs that create greater awareness of the connections between nitrogen fertilizer efficiency, farm profitability and water quality protection.
- Gain a better understanding of the current potential for improving nutrient use efficiency and how to overcome barriers for making such improvements.
- Minnesota’s new Groundwater Protection Rule should move the state toward greater nitrogen fertilizer efficiencies in geographic areas with vulnerable groundwater. The lessons learned from these areas can be applied to other geographic areas.

5.2.3 Living cover practices

As discussed in the 2014 NRS, the additional use of vegetative cover during fall and spring months provides protection from soil erosion during times of the year when crops are not in place or of sufficient size. Perennials and cover crop roots capture nitrate that is moving through the soil, preventing it from leaching to tile waters or groundwater. These practices can also improve soil health by increasing soil organic matter, and thereby hold more water in the soil and reduce runoff.

2014 NRS recommended agricultural BMPs

Increase and target living cover, emphasizing**:**

a. Cover crops on fallow and short season crops such as sweet corn, corn silage, peas, small grains, and potatoes
b. Perennials in riparian zones and on marginal cropland
c. Research and development of marketable cover crops to be grown on corn and soybean fields
d. Research and development of perennial energy crop(s)

Living cover practices selected for phosphorus and nitrogen reduction analysis in Chapter 5 of the 2014 NRS include cover crops, perennial buffers, forage and biomass planting, perennial energy crops, and conservation easements and land retirement. Other living cover agricultural BMPs, including conservation cover, conservation crop rotation, critical area planting, and filter strips, can be used to achieve similar benefits. Adoption levels of living cover practices since 2014 were assessed using information tracking systems of practices installed through government program support, along with overall indicators of adoption provided by the U.S. Census of Agriculture and satellite imagery.

5.2.3.1 *Progress of living cover practice adoption through government programs*

Statewide living cover acres tracked by the MPCA's Healthier Watersheds website and those acres enrolled in the CRP, together provide a summary of living cover practices being adopted through government programs.

Estimated non-CRP government program acreages affected by newly funded living cover practices (adopted and tracked through the state and federal government programs) are shown in Figure 32 and Table 13. A marked increase in acreage occurred from 2015 to 2017, coinciding with additional NRCS cover crop funds through EQIP. The recently added cover crop acreages are considerably higher than added acreages of perennials. The total acres of non-CRP living cover practices installed varies greatly from year to year (Figure 34).

Many increases in living cover practices resulted from concerted local watershed efforts. For example, the Cannon River Watershed Partnership contracted with farmers for cover crop planting on 11,870 acres in the Cannon River Watershed. For more information on the cover crop program and for an interactive map of cover crop installations see: https://crwp.net/conservation/cover-crops/

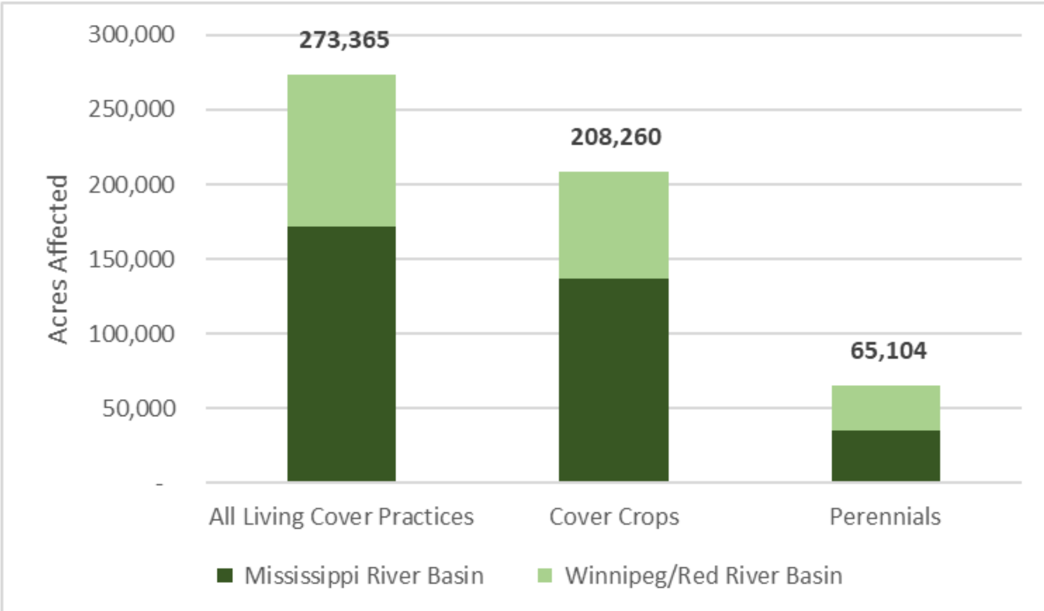


Figure 32. Acres affected by new living cover practices funded by non-CRP government programs from 2014 to 2018 (MPCA's Healthier Watersheds BMP tracking system).

*Perennials include conservation cover, conservation crop rotation, conservation easements, critical area planting, filter strip, forage and biomass planting, riparian herbaceous cover, and windbreak/shelterbelt establishment.

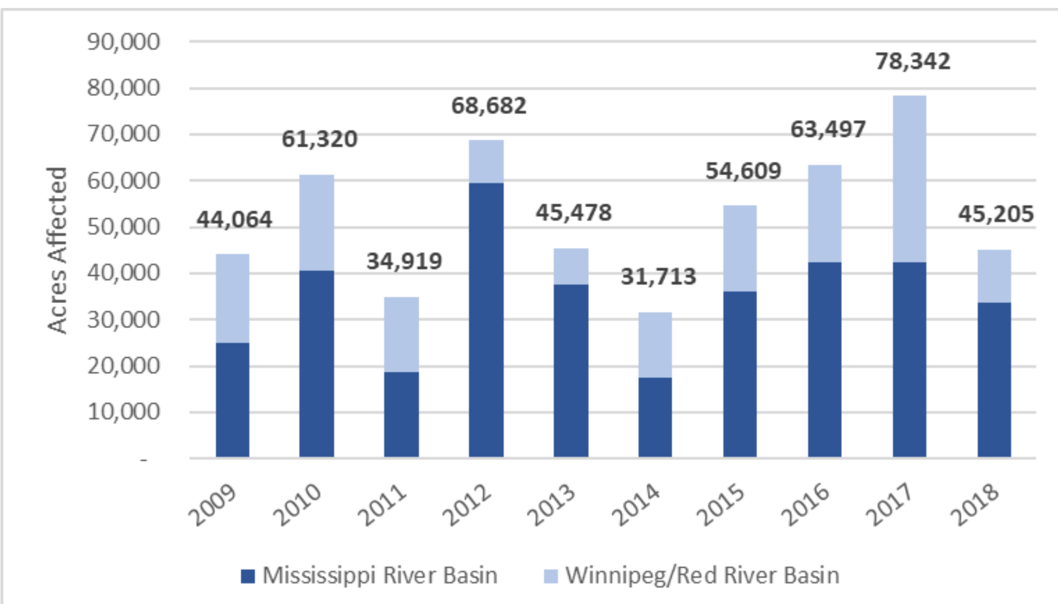


Figure 33. Acres affected by new living cover practices funded by non-CRP government programs from 2009 to 2018 (MPCA's Healthier Watersheds BMP tracking system).

Table 13. Acres of living cover practices 2014 to 2018 funded from non-CRP government programs (MPCA's Healthier Watersheds BMP tracking system).

	2014-2018 Cover crops	2014-2018 Perennials [a]	Living cover practices (non-CRP) – total acreage affected
Mississippi Basin	136,673	35,319	171,992
Red River Basin	71,588	29,785	101,373

a. Perennials include conservation cover, conservation crop rotation, conservation easements, critical area planting, filter strip, riparian forest buffer, riparian herbaceous cover, forage and biomass plantings. This table does not include CRP perennials.

The CRP has historically supported much of the planted perennials in agricultural areas of the state. The CRP is a voluntary program that helps agricultural producers safeguard environmentally sensitive land. CRP participants plant long-term, resource-conserving covers to improve water quality, control soil erosion, and enhance wildlife habitat. In return, Farm Service Agency provides participants with rental payments and cost-share assistance.

Minnesota agricultural land enrolled in USDA's CRP peaked in the 1993 to 1995 and 2007 to 2008 periods, with about 1.8 million acres under contract each year during those timeframes (Figure 34). Minnesota CRP enrolled acreage has dropped from 2008 to 2015 and leveled off with a 2018 enrollment of 1.14 million acres. CRP enrollment during the 2014 to 2018 period averaged 1.17 million acres, 28% lower than the long-term 1987 to 2013 average enrollment. Between 2014 and 2018, the number of CRP acres enrolled decreased by 163,000 acres. Most of this recent drop occurred between 2014 and 2015, with relatively stable CRP total enrollment between 2015 and 2018.

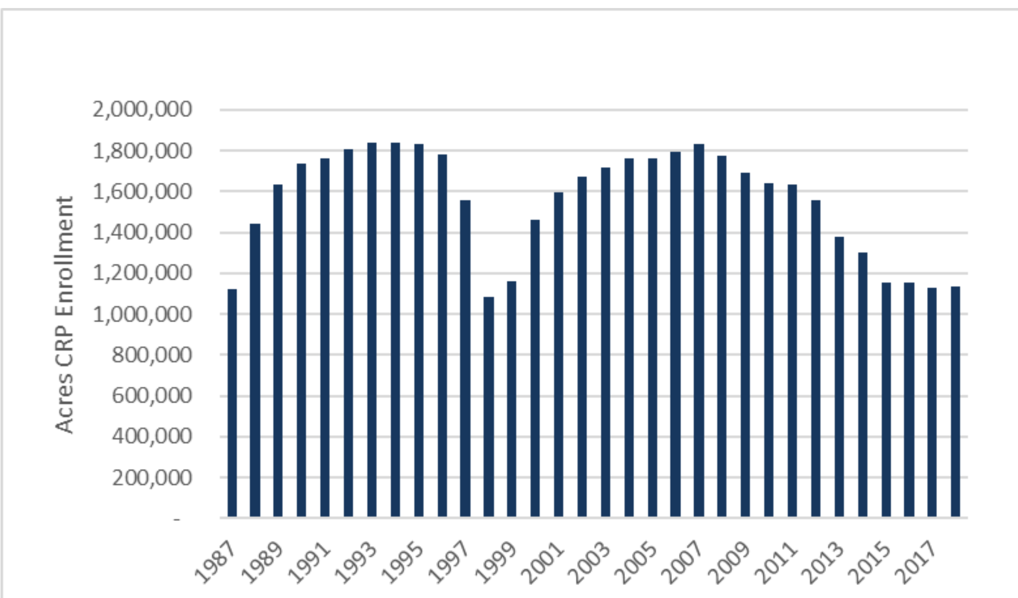


Figure 34. Annual CRP enrollment (1987 to 2018; www.fsa.usda.gov).

5.2.3.2 *Additional progress information on living cover practice adoption*

Information from farmer surveys and satellite imagery can provide additional information on the overall adoption trends for living cover practices.

Cover crops – non-government programs

Two main information sources exist to estimate overall state-level cover crop planting and establishment acreage estimations: the U.S. Census of Agriculture and satellite imagery. The U.S. Census of Agriculture provides survey results of cover crop acreages planted. Both the University of Minnesota (working in partnership with BWSR) and The CTIC OpTIS have been evaluating successful growth of cover crop acreages through satellite imagery. Actual acres of cover crops that emerge or germinate are typically less than the acres planted.

Based on the U.S. Census of Agriculture, between 2012 and 2017, cover crops planted in the state of Minnesota increased by more than 171,000 acres for a total of 579,147 acres in 2017, a 5-year increase of 41%, showing cover crop planting on just under 3% of all cropland in Minnesota. By comparison, government programs supported the addition of 260,954 acres of cover crops over that same 2012 to 2017 timeframe. Some of the cover crop acres tracked through government programs may have dropped out of the program after contract periods ended.

Satellite imagery analysis conducted by the University of Minnesota and BWSR provides an indication of cover crop acreages over southern Minnesota. Example outputs in Figure 35 show cover crops by county growing in fall of 2016, with a total of 214,000 acres. The 2016 outputs can also be viewed for major and minor watersheds. Estimates for cover crop acreage in the fall of 2017 and 2018 were limited because of difficult harvest conditions and early (November) onset of snow cover during those growing years in parts of Minnesota. These conditions made it difficult to get consistent results for cover crops using remote sensing satellite imagery. The University of Minnesota is currently exploring additional techniques to use other satellite-derived data products from synthetic aperture radar, which is less sensitive to cloud cover. This Minnesota-specific assessment with considerable in-state field validation shows promise for assessing long-term cover crop acreage trends.

Figure 35. Cover crop acres estimated using satellite imagery, Fall 2016. (University of Minnesota Soil, Water and Climate Department, and BWSR).

Satellite imagery analysis conducted through the CTIC OpTIS program at the CTIC at Purdue University show that 1.2% of corn and soybeans, on average, had vegetative cover in the winter time between 2005 to 2013 (cover crops, winter annuals or perennials). This percentage has remained about the same in the past five years (2014 to 2018), averaging 1.0%. Cover crops on small grains have been increasing and show up on over 11% of small grains statewide. According to the OpTIS program, established cover crop and winter annual crop acreages between 2014 to 2018 averaged 154,883 acres in Minnesota.

Continued work in the next five years will be undertaken to better understand the differences between these datasets and compare the methodologies and assumptions so that the most accurate and cost-effective way of estimating cover crop changes over time can be used.

The various cover crop measurements in Minnesota are not directly comparable. Based on the combined information, it appears that cover crop acreages are increasing, with total planted acres exceeding a half-million and total established cover crops exceeding 200,000 acres during at least some recent years. Depending on the climate conditions and other factors, not all planted acres of cover crops become well-enough established to be detected through the satellite imagery techniques.

Perennials

Trends in large-scale perennial changes can be approximated using satellite-derived land cover datasets, specifically the Cropland Data Layer (CDL) as well as farmer surveys. The U.S. Census of Agriculture shows a decrease in hay (defined as forage and including hay and all haylage, grass silage, and greenchop) between the years 2012 to 2017, indicating a 3.4% decrease (Table 14). The U.S. Census of Agriculture also summarizes information related to land currently under conservation easements, indicating an 11% decrease.

Land cover data between the years 2012 to 2018 were also summarized to determine trends in grasses, pasture, and hay. The total statewide CDL estimates of grass/pasture plus hay/haylage has gradually increased by 6.7% (300,000 acres) between the years 2014 to 2018 as shown in **Error! Reference source not found.**Figure 37. Hay/haylage acreages decreased and grass/pasture increased, with a net gain in the combination of perennials.

Table 14. Acres of perennial crops based on U.S. Census of Agriculture (2012 to 2017).

Practice	2012 Acres	2017 Acres	Change 2012 to 2017
Hay (forage and including hay and all haylage, grass silage, and greenchop) [a]	1,499,586	1,448,195	Decreased 51,391 acres
Conservation Easements [b]	244,482	218,215	Decreased 26,267 acres

a. Source: USDA NASS U.S. Census of Agriculture, Table 35 – Minnesota Specified Crops by Acres Harvested

b. Source: USDA NASS U.S. Census of Agriculture, Table 47 – Minnesota Land Use Practices

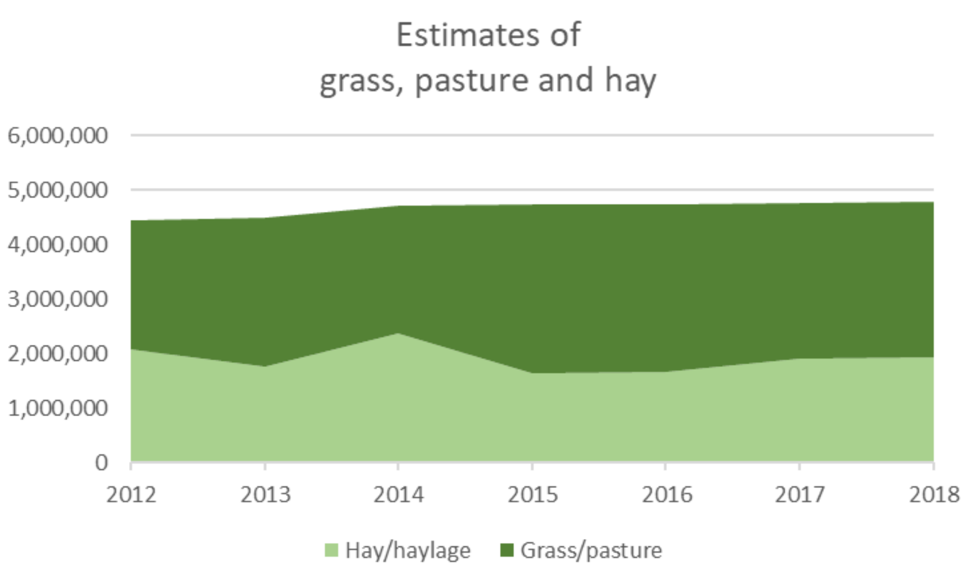


Figure 36. Estimates of grass, pasture, and hay in Minnesota from 2012-18 (Cropland Data Layer).

Summary of Minnesota's Progress on Living Cover Practices

Why important

- The NRS anticipated that the first five years of living cover practices would be largely focused on research and development, and that larger changes would mostly occur after the first five to 10 years.
- Living cover practices are essential for meeting both milestone and long term NRS goals. The NRS set interim targets of 2.2 million acres of new cover crops (largely on early harvest crops) and 440,000 acres of perennial crops and buffers in high priority areas.

Findings

- Some indicators suggest progress with living cover practices; however, adoption rates do not appear to be on track for meeting the needs outlined for 2014 NRS milestone scenario.
    - On average, 40,000 acres of cover crops have been added per year to major basins through government cost-share programs since 2014. Relatively little progress is being made with cover crops on corn/soybean rotations, with an estimated 1 to 1.5% of corn/soybean land currently with cover crops.
    - CRP enrollment remains over 1.1 million acres and has been fairly stable since 2015. However, CRP acreages during the past five years have been lower than most years since 1987.
    - Perennials added through government cost-assistance programs (apart from CRP) affected an average of 13,000 new acres per year between 2014 and 2018.
    - Statewide grass/hay/pasture perennial acreages have been fairly stable since 2014, with indications of slight decreases in hay and increases in grasses/pasture.

Follow-up

- Recent living cover initiatives need to continue while socio-economic information is evaluated to determine how to scale-up adoption rates.
- State water and climate resiliency plans and strategies should be integrated with 2014 NRS goals to work in concert toward new and expanded approaches to vastly increase living cover over the next five years.

5.2.4 Field erosion control practices

As stated in the 2014 NRS, field erosion control is one of the most effective methods for limiting export of cropland total phosphorus, although certain practices in some places can increase losses of the dissolved portion of phosphorus. Field erosion control practices selected for phosphorus reduction analysis in Chapter 5 of the 2014 NRS emphasized conservation tillage and residue management, terraces, grassed waterways, and sediment control basins, while recognizing that many other practices are important and effective for reducing cropland field erosion and associated phosphorus losses.

Adoption levels of field erosion control practices implemented in Minnesota between 2014 and 2018 were assessed using information from government program data bases, along with overall indicators of adoption through satellite imagery and the U.S. Census of Agriculture.

2014 NRS recommended agricultural BMPs

Field erosion control, emphasizing:

a. Tillage practices that leave more than 30% crop residue cover or alternative erosion control practices that provide equivalent protection
b. Grassed waterways and structural practices for runoff control

5.2.4.1 *Progress of field erosion control practice adoption through government programs*

Figure 37 and Table 15 provide a summary of field erosion control practices installed through government programs from 2014 to 2018 by major basin as tracked in the MPCA Healthier Watersheds program (NRS version found at: https://public.tableau.com/profile/mpca.data.services#!/vizhome/MinnesotaNutrientReductionStrategyBMPSummary/MinnesotaNutrientReductionStrategyBMPSummary). Most acres installed were residue and tillage management practices. Annual additions of new acreages of field erosion control practices decreased steadily from 2009 to 2013. In 2014, a slight recovery began, and in 2018 increases in agricultural loans for reduced tillage equipment increased the estimated new acres of adoption (Figure 38).

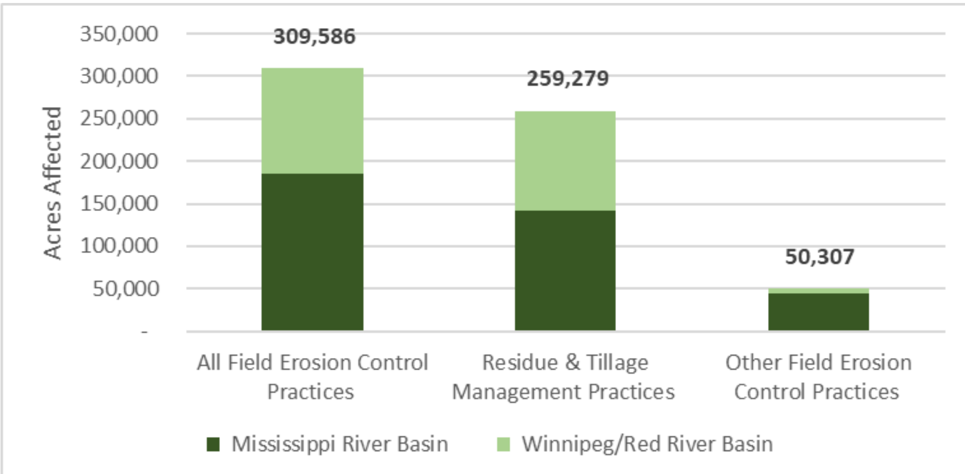


Figure 37. New acres for field erosion control practices enrolled through government programs, 2014 to 2018 (MPCA's Healthier Watersheds BMP tracking system).

*Other erosion control include: alternative tile intakes, contour buffer strips, field borders, grassed waterways, mulching, sediment basins, stripcropping, terraces, water and sediment control basins. Residue and tillage management practices include no-till/strip till, reduced till, and ridge till practices.

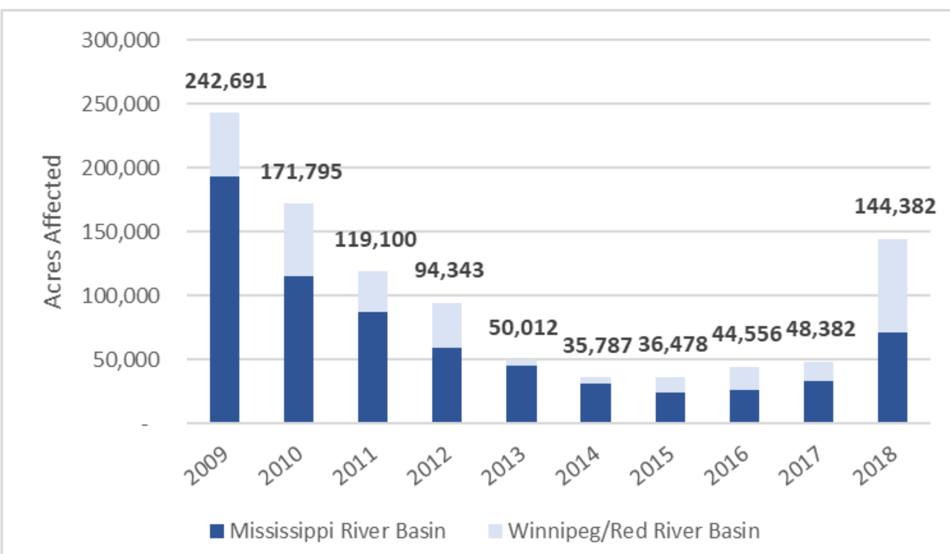


Figure 38. New acres of field erosion control practices added through government support programs 2009 to 2018 (MPCA's Healthier Watersheds BMP tracking system).

Table 15. Acres of field erosion control practices enrolled through government support programs, 2014 to 2018 (MPCA's Healthier Watersheds BMP tracking system).

	2014-2018 Residue and tillage management practices	2014-2018 Other field erosion control practices	Field erosion control – total acreage affected
Mississippi Basin	141,506	44,185	185,691
Red River Basin	117,773	6,122	123,896

5.2.4.2 *Additional progress information on field erosion control practice adoption*

Table 16 provides a comparison of tillage practices in Minnesota using the U.S. Census of Agriculture data from 2012 and 2017. The comparison of data from each census shows an increase in conservation tillage acres and a corresponding decrease of conventional tillage acres.

Table 16. Minnesota tillage practices (2012 and 2017).

Practice	2012 Acres	2017 Acres	Change 2012 to 2017
No-Till Practices Used	818,754	1,091,337	Increased 272,583 acres
Reduced Tillage/Conservation Tillage	6,109,886	8,214,896	Increased 2,105,010 acres
Intensive/Conventional Tillage	11,517,373	9,499,259	Decreased 2,018,114 acres

Source: USDA NASS U.S. Census of Agriculture, Table 47 – Minnesota Land Use Practices
No-till practices used. Using no-till or minimum till is a practice used for weed control and helps reduce weed seed germination by not disturbing the soil.
Reduced tillage. Conserves the soil by reducing erosion and decreasing water pollution. In 2012 this category was labeled conservation tillage. This is a wording change only; data are comparable.
Intensive/conventional tillage. Refers to tillage operations that use standard practices for a specific location and crop to bury crop residues. In 2012, this category was labeled conventional tillage.

Satellite imagery analysis conducted by the BWSR and University of Minnesota shows 2017 crop residue levels between 16 and 50% over most of the cropland regions of the state (Figure 40). The fraction of land with over 30% residue cover varies spatially and is lowest in south-central Minnesota and parts of northwestern Minnesota where land slope is generally lower.

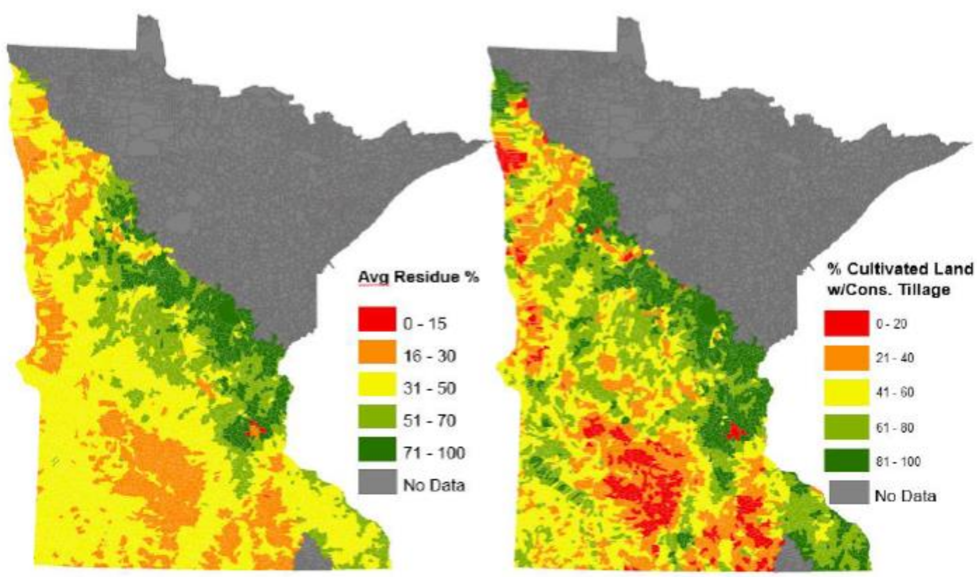


Figure 39. Average crop residue and conservation tillage by subwatershed in 2017 Data source University of Minnesota (Soil, Water and Climate Dept.) and BWSR.

Satellite imagery analysis conducted through the OpTIS program at the CTIC at Purdue University shows historical conservation tillage adoption data over time from 2009 to 2018 (Figure 41). The University of Minnesota compared the outputs of the remote sensing work shown above with the recently released information from the OpTIS program. For this comparison, the University of Minnesota used residue estimates for spring of 2017 based on Landsat 8 and Sentinel 2 imagery. Results between the Tillage and Erosion Survey Project estimates and the OpTIS estimates show relative consistency for cropland percentages falling in the four categories of residue cover, but OpTIS results reported higher acreage of crops grown, as shown in Figure 42. Future analysis will help explain the correlation between the estimates from each of these projects.

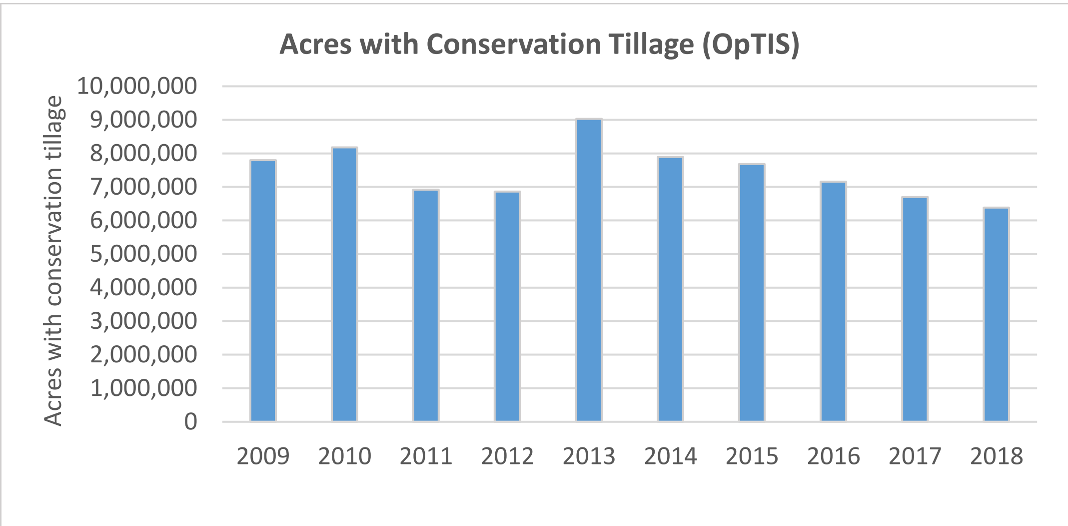


Figure 40. Acres in conservation tillage in Minnesota based on satellite imagery (OpTIS).

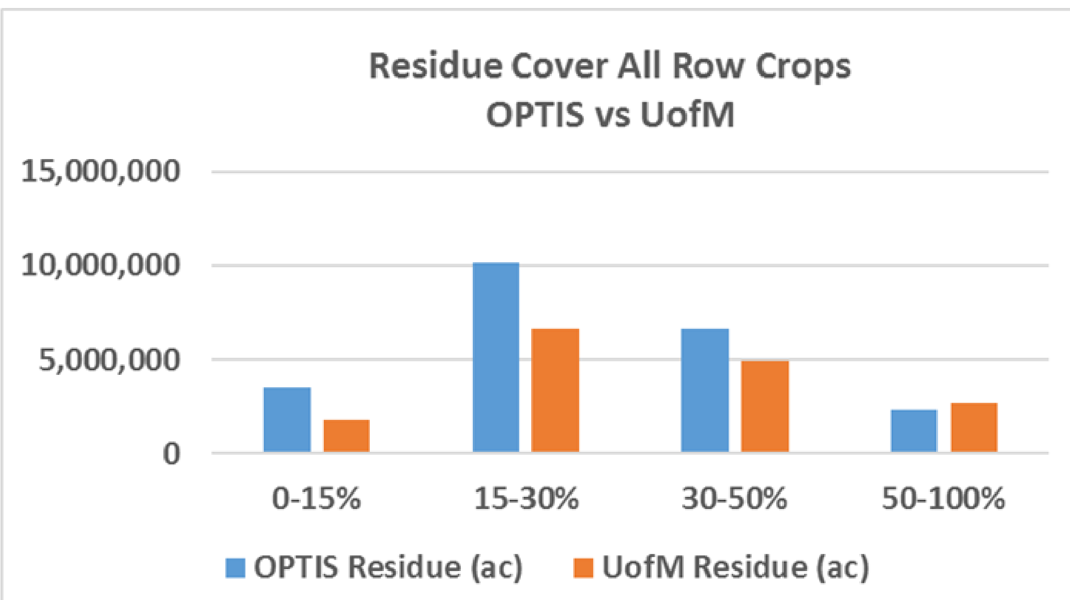


Figure 41. Comparison of residue cover on all row crops for 2016 (y-axis represents acres).

Summary of Minnesota's Progress on Field Erosion Control

Why important

- Conservation tillage, reduced tillage and no-till are common practices throughout Minnesota, with conservation tillage (>30% residue) or no-till on nearly half of cropland acres.
- While considerable progress was achieved with soil erosion control through past decades, crop residue surveys conducted prior to the NRS indicated considerable room for additional progress. An additional 4.9 million acres of erosion control acreage increases was called for in the NRS scenario due to its importance for phosphorus loss reductions, relatively low cost, and multiple benefits for also soil health, carbon storage, and keeping sediment out of waters.
- Tracking progress with soil erosion control practices is important to better plan for future strategy implementation goals and approaches.

Findings

- The rate of new erosion control practice additions appears to have decreased in recent years. An average of 60,000 acres of field erosion practices have been added annually through government cost-share and equipment-funding programs. The vast majority of these affected acres are residue management practices. Not all of these acreages will continue with conservation tillage after the contracted period ends.
- Satellite imagery through OpTIS and University of Minnesota studies shows 8-9 million acres of land with over 30% residue cover. This is generally consistent with the U.S. Census of Agriculture findings in 2017 of 9.3 million acres of conservation tillage plus no-till.
- Satellite imagery suggests about the same acreage of conservation tillage in 2012 and 2017. However, 2017 census information shows a substantial increase in conservation tillage/reduced tillage (on average adding 475,000 acres per year) between 2012 and 2017. If the census information reflects a real increase, it is predominantly outside of government assistance programs, since the total acreage in government programs during that timeframe represents only a small fraction of the census reported increase.

Follow-up

- Minnesota will continue tracking residue cover practices with satellite imagery and reconcile differences between census survey information and aerial imagery techniques.
- Since initial work to map structural conservation BMPs using LiDAR imagery has proven successful in providing a more complete picture of cumulative practices over the years, continuation of this work to statewide levels should be explored.

5.2.5 Tile drainage water treatment and storage practices

As discussed in the 2014 NRS, nitrogen is more mobile in the soil environment compared to phosphorus, and cycles within the air, land, and water. For example, 37% of the statewide nitrogen load to rivers in Minnesota moves through subsurface tile drainage systems on agricultural fields.

Subsurface tile drainage installation has continually increased in Minnesota during the past two decades. The 2017 U.S. Census of Agriculture showed 8,079,994 acres of land drained by tile in Minnesota, over 1.6 million acres more than shown in the 2012 census (Table 17). With approximately 20 million acres of row crops, small grains, and hay grown statewide, Minnesota tile-drains affect approximately 40% of the state's cropland.

2014 NRS recommended agricultural BMPs

Tile drainage water quality treatment and storage, emphasizing:

a. Constructed and restored wetlands
b. Controlled drainage when expanding or retrofitting drainage systems
c. Water control structures
d. Research and development of bioreactors, two-stage ditches, saturated buffers and other ways to store and treat drainage waters

Table 17. Drained land in the state of Minnesota (2012 and 2017) from the U.S. Census of Agriculture.

Practice	2012 Acres	2017 Acres	Change 2012 to 2017
Land Drained by Tile	6,461,173	8,079,984	Increased 1,618,811 acres
Land Drained by Ditches	4,548,977	4,674,449	Increased 125,472 acres

Source: USDA NASS U.S. Census of Agriculture, Table 41 – Minnesota Land Use Practices

Methods for storing and treating agricultural drainage waters for nutrient removal have been researched and demonstrated for many years. Drainage water retention practices selected for nitrogen reduction analysis in Chapter 5 of the 2014 NRS include constructed wetlands, controlled drainage, bioreactors and two stage ditches. Saturated buffers also show promising results for tile-drainage nitrate removal. Reuse of stored drainage waters for surface or subsurface irrigation is another practice being studied; however, reuse is not widely practiced in Minnesota.

Adoption levels for tile drainage water treatment and storage practices since 2014 are determined in this progress report using information from the MPCA's Healthier Watersheds BMP tracking system. Most of the tile drainage water treatment and storage practices are installed through government assistance programs because all require design and construction, and most have limited benefits for agricultural production. As such, the MPCA's Healthier Watersheds BMP tracking system likely captures the majority of existing tile-drainage water treatment and storage practices and no additional tracking methods are used. It is important to note that the MPCA's Healthier Watersheds BMP tracking system does not capture all locally-funded BMPs. Additional information on drainage-water storage practices implemented at the multi-state level in the Red River Basin is provided in Appendix A.

5.2.5.1 *Progress of tile drainage water treatment and storage practice adoption through government programs*

The majority of the government-assistance program BMPs for drainage water treatment were for wetland restoration, with drainage water management also constituting a significant portion of impacted acreages (Figure 42 and Table 18). A total of 15,074 acres were affected by these practices between 2014 and 2018. However, many of the wetland restoration and creation projects were not designed to treat tile drainage waters; therefore, the total acres of drained cropland affected by wetland restoration practices since 2014 is lower than the 9,879 acres noted in Figure 42. Since 2009, annual acreages of new tile drainage water treatment and storage practices has fluctuated (Figure 43). The Red River basin shows a sharp decline in state and federal government program supported implementation starting in 2016. In 2018, the Mississippi River basin experienced its highest rate of implementation since 2009, according to practices recorded in the MPCA Healthier Waters tracking system.

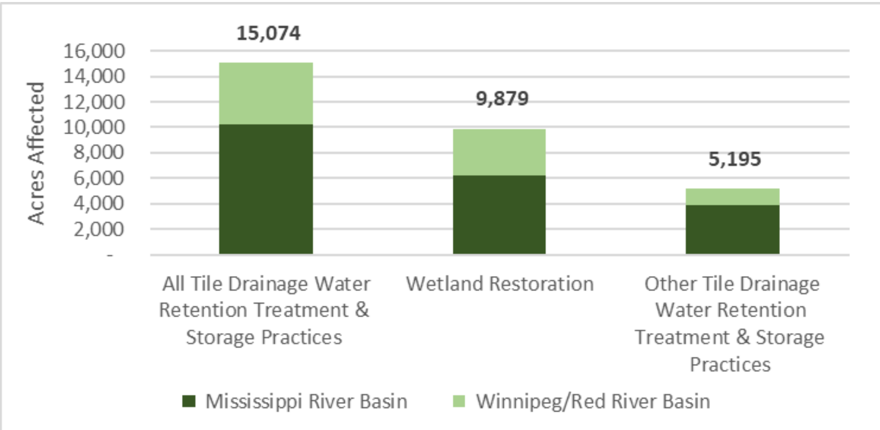


Figure 42. New acres of tile drainage water treatment and storage practices enrolled through government programs, 2014-2018 (MPCA's Healthier Watersheds BMP tracking system).

*Other tile drainage water treatment and storage practices include denitrifying bioreactor, drainage water management, saturated buffers.

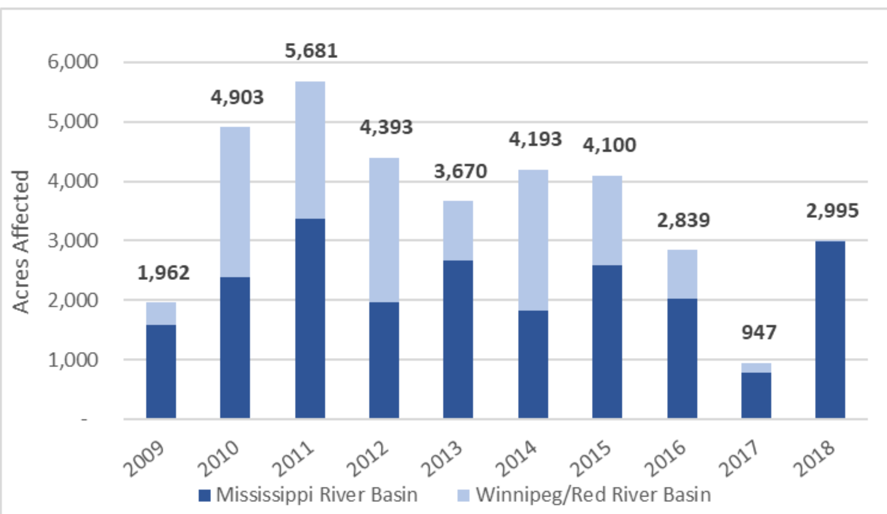


Figure 43. New affected acres of tile drainage water treatment and storage practices added through government support programs 2009 to 2018 (MPCA's Healthier Watersheds BMP tracking system).

Table 18. New affected acres of tile drainage water treatment and storage practices added through government programs, 2014 to 2018 (MPCA's Healthier Watersheds BMP tracking system).

	2014-2018 Wetland Restoration	2014-2018 Other tile drainage treatment practices	Drainage treatment – total acreage affected
Mississippi Basin	6,257	3,926	10,183
Red River Basin	3,622	1,269	4,891

Summary of Minnesota's Progress on Tile Drainage Water Treatment and Storage Practices

Why important

- Tile drainage waters are the largest source pathway of nitrate to rivers in Minnesota. In-field practices such as fertilizer/manure management and cover crops can reduce nitrate leaching to tile-lines. However, to achieve the nitrogen reductions in the NRS, additional measures are needed, including edge-of-field tile water storage and treatment.
- The NRS example milestone scenario calls for 620,000 acres of tile-drainage waters treated through edge-of-field practices (equivalent to 62,000 newly treated acres per year).

Findings

- Tile-drainage water treatment practices have not gained traction in Minnesota. Acreages affected are very low and are still mostly in demonstration mode. Few existing drivers or programs are expected to dramatically increase the use of these practices (i.e., saturated buffers, treatment wetlands, controlled drainage management and bioreactors):
    - The total amount of Minnesota tile-drained lands has increased by over 1.6 million acres between 2012 and 2017, based on the U.S. Census of Agriculture.
    - Tile water treatment for nutrient reduction is increasing by about 3,000 acres per year based on government program records over the past 5 years.

Follow-up

- A better understanding of the socio-economic barriers and opportunities is needed in order to implement more successful strategies for storage and treatment of tile-drainage waters. Emphasizing the multiple benefits of certain practices, such as constructed wetlands and two-stage ditches, may also help boost adoption.

5.3 Are we on track to meet agricultural BMP milestones?

The 2014 NRS includes example cropland BMP scenarios that are predicted to achieve the nutrient reduction goals and milestones, as described in Section 4.1. The short timeframe of this progress report makes it difficult to draw conclusions around actual in-water progress during the past five years. While nitrogen and phosphorus water quality trend monitoring are ideal for long-term evaluation of NRS progress, short-term evaluation through river monitoring is complicated by patterns of climate variability, lag times, margin of error, and other complicating factors. To address these complexities, the 2014 NRS emphasizes the need to track BMP adoption across major basins, and to compare adoption levels with milestone BMP scenarios identified in the 2014 NRS. As was previously noted, considerable cropland acreages were affected by BMPs prior to the beginning of the 2014 NRS, especially reduced tillage and soil erosion control. The focus now is on practices above and beyond the BMP adoption that occurred historically. This section of the 5-year NRS progress report summarizes the progress detailed in section 4.2 concerning 2014 to 2018 changes in BMP adoption compared with NRS-identified benchmark acreages. The government assistance program progress is first summarized, followed by a summary of additional indicators of progress that include efforts outside of government programs.

Considering only BMP adoption tracked through government programs between 2014 and 2018, the recently added BMP acreages are not on a trajectory to meet the 2025 milestone scenario goals, as depicted in Figure 44.

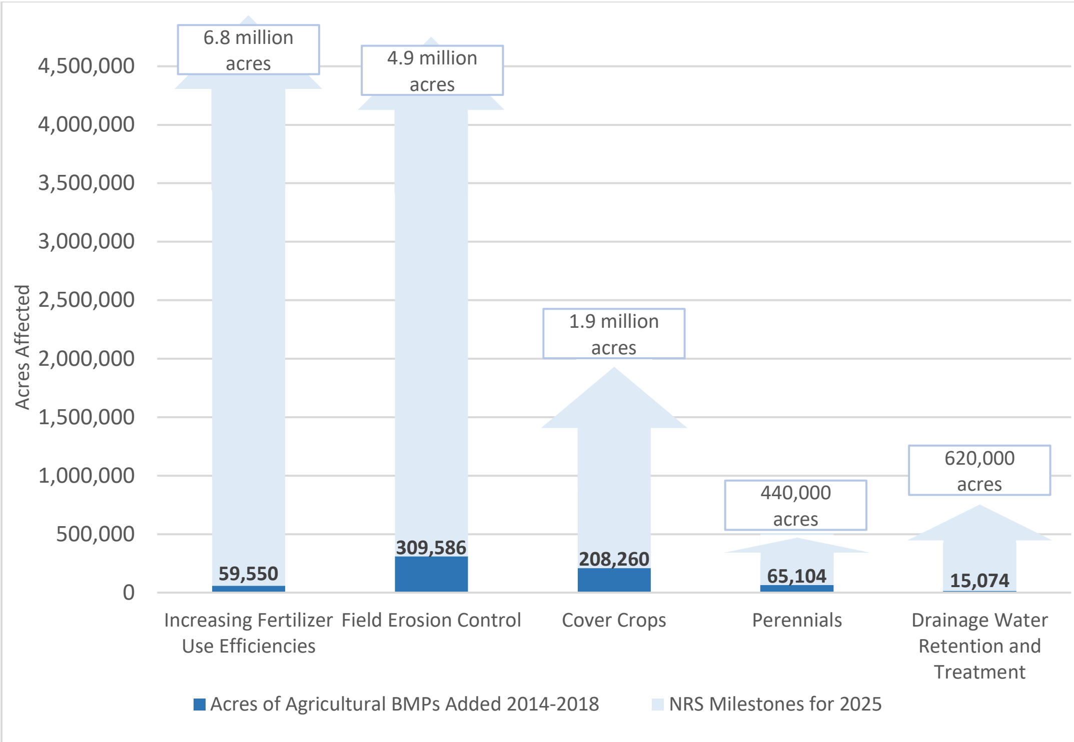


Figure 44. Newly affected acreages of agricultural BMPs (2014-2018) implemented through government programs in the Mississippi River and Lake Winnipeg Basins toward the NRS milestone scenario outlined in the 2014 NRS for completion by 2025. Note: this depiction does not include private adoption of practices outside of government programs.

Progress with government program BMP adoption in the four NRS categories is summarized below.

Nutrient management efficiency practices – From 2014 to 2018, a total of 59,550 new acres of nutrient management efficiency practices were added to the Mississippi River basin under government-tracked programs, representing only 1% of the 6.1 million acres in the milestone scenario. A total of 3,900 acres was added to the Red River basin under government-tracked programs, less than 1% of the 700,000-acre 2024 milestone.

Living cover practices – In the Mississippi River basin, new acres of government program supported cover crops totaled 136,673 acres, 10.5% of the milestone outlined in the 2014 NRS. 71,588 acres of cover crops were added in the Red River basin, representing 10% of the milestone. Perennials in the CRP dropped from 2014 to 2015 and has remained stable since 2015. 65,104 newly affected acres of perennials were added between 2014 and 2018 through other government programs, compared to the milestone scenario 2024 target of 440,000 acres.

Tile drainage water treatment and storage practices – From 2014 to 2018, a total of 10,183 new acres of tile drainage water treatment and storage practices were added to the Mississippi River basin, only 1.6% of the milestone scenario of 600,000 acres. A total of 4,891 acres were added to the Red River basin, or 23% of the 20,000-acre milestone.

Field erosion control practices – 185,691 new acres of government program supported field erosion control practices were added in the Mississippi River basin from 2014 to 2018, representing 4% of the 4.5-million-acre milestone scenario goal by 2024. A total of 123,895 acres were added to the Red River basin, around 31% of the 400,000-acre milestone.

The scale of agricultural BMP adoption through government programs has not been on-pace during recent years to achieve the example NRS milestone BMP scenario. Living cover practices show potential to achieve the milestones, but the rate of adding those practices would need to increase considerably between 2020 and 2025. Two key follow-up questions need to be considered:

(1) Are private industry BMP adoption efforts making up the difference between the government program BMPs and the NRS scenario levels of adoption?
(2) Are the new and advancing programs (see Section 2) ramping-up enough to increase BMP adoption in 2020 to 2025, as compared to 2014 to 2019?

Both private industry efforts and full implementation of recently advancing state programs can potentially make a substantial difference in the rate of BMP adoption.

Indicators of overall BMP adoption rates (including adoption outside of government programs) during the past 5 to 10 years also suggests that Minnesota is likely to fall short of achieving the needed scales of adoption outlined in the NRS scenarios. This assessment is based on a combination of survey information, sales data, satellite imagery findings, soil testing and other sources that reflect the combination of government program and private industry influences. However, the metrics need improvement and further study to gain a greater understanding of overall progress. One area of conflicting information is progress with conservation tillage and residue cover. While the U.S. Census of Agriculture suggests a substantial increase in conservation/reduced tillage acreage, satellite imagery results show decreasing acreages of land with over 30% residue.

Based on the program advancements made during the past five years, it is anticipated that BMP adoption will accelerate in 2020 to 2024, as compared to 2014 to 2018. These program advancements include private/public partnerships, educational programs, watershed plans, BMP funding programs, research findings, rules in place, and other developments reported in Section 2 and Appendix A. While the full effects of these advancing programs won't be apparent for several years, it seems unlikely based on the progress identified in this report that existing program advances alone will achieve the scale of BMP adoption needed to reach nutrient reduction strategy scenario targets.

To increase the likelihood for an improved NRS assessment in 2024, Minnesota should consider what additional information, advancements, and implementation efforts are necessary during 2020 to 2024 to make additional progress toward long-term nutrient reduction success. Section 6 describes recommended next steps for the 2020 to 2024 period.

6 Wastewater and other sources – Is progress consistent with NRS direction?

The implementation strategies outlined in the 2014 NRS provided recommendations and guidance to also reduce phosphorous and nitrogen loading from non-cropland sources. This section examines the progress made in nutrient reduction from wastewater, feedlots, urban stormwater, and septic systems.

6.1 Wastewater

According to the 2014 NRS, wastewater phosphorus and nitrogen loads account for approximately 18% and 11% of the phosphorus loads in the Mississippi and Red Rivers, respectively, and 9% and 6% of the nitrogen loads in the two respective rivers. In the Lake Superior drainages within Minnesota, the overall wastewater nutrient loads are much lower than in the Mississippi, but the fraction of the loads from wastewater is higher (24% for phosphorus and 31% for nitrogen). The 2014 NRS included goals and strategies for nutrient reductions from permitted wastewater sources based on the best available information at the time. Additional phosphorus and nitrogen monitoring data collected since 2014 are now available to refine existing nutrient loads from wastewater. This section presents the updated loading and goals, as well as recent progress on phosphorus and nitrogen reductions.

2014 NRS recommended wastewater strategies

a. Implementation of the Phosphorus Rule and Strategy
b. Implementation of River Eutrophication Standards
c. Influent and effluent nitrogen monitoring at wastewater treatment facilities
d. Nitrogen management plans for wastewater treatment facilities
e. Nitrogen effluent limits
f. Add nitrogen removal capacity with facility upgrade
g. Point source to nonpoint source trading

6.1.1 Updated existing loading and goals

New effluent monitoring and data analysis methods result in a shift in the baseline loads attributed to wastewater compared to the baselines cited in the 2014 NRS. Table 19 summarizes the 2014 NRS loads and new phosphorus information along with the updated current load that represents an average over 2016 to 2018. Overall, using the updated values, there has been an approximate 70% statewide reduction in phosphorus loading from wastewater sources since 2000 to 2002, and a reduction of about 20% since the 2010 to 2012 average.

Baseline nitrogen loads for wastewater in the 2014 NRS were derived from the SPAtially Referenced Regression on Watershed Attributes (SPARROW) model and represent the 2005 to 2006 time period. Table 20 summarizes the new nitrogen information collected through increased monitoring initiated in 2010 and expanded after 2014.

Phosphorus reduction goals for the wastewater sector continue to be based on full implementation of the Phosphorus Strategy (codified as Minn. R. Ch. 7053.0255) and water quality-based effluent limits based on lake and river eutrophication standards. To meet the 2025 milestones for wastewater nitrogen, the reduction goals are based on a 20% reduction in overall nitrogen loading needed in the Mississippi River basin and a 13% reduction in the Red River basin.

Table 19. Revised existing phosphorus loads from permitted wastewater.

Basin	Phosphorus			
	2014 NRS wastewater baseline load (average 2010-2012) (MT/yr)	Updated wastewater baseline load (average 2010-2012) (MT/yr)	Current load (average 2016-2018) (MT/yr)	Change since updated baseline
Statewide	796	737	584	-21% (153 MT/yr)
Mississippi River	Not defined	620	490	-21% (130 MT/yr)
Red River	Not defined	73	54	-26% (19 MT/yr)
Lake Superior	Not defined	43	35	-19% (8 MT/year)

Table 20. Revised existing nitrogen loads from permitted wastewater.

Basin	Nitrogen			
	2014 NRS wastewater baseline load (SPARROW representing the 2005-2006 time period) (MT/yr)	Updated wastewater baseline load (average 2010-2012) (MT/yr)	Current load (average 2016-2018) (MT/yr)	Change since updated baseline
Statewide	10,879	13,824	14,327	+4% (503 MT/yr)
Mississippi River	9,363	11,718	12,593	+7% (875 MT/yr)
Red River	304	487	469	-4% (18 MT/yr)
Lake Superior	1,212	1,645	1,109	-33% (536 MT/yr)

6.1.2 Phosphorus reduction

The total phosphorus load discharged by statewide wastewater sources decreased between 2010 and 2014, maintaining a relatively even trend since 2014, as shown in Figure 45. Statewide, there has been a 71% reduction in phosphorus for wastewater since 2000. Overall, 92% of wastewater phosphorus loads reported here are derived directly from effluent monitoring data, providing a high degree of confidence in these estimates.

Phosphorus limits are required on 89% of the wastewater flow volume in the state. Phosphorus limits are derived from three different standards:

- Lake eutrophication standards – Water quality standards approved in 2008.
- River eutrophication standards – Water quality standards approved in 2015.
- State discharge restriction – Regulation-based effluent limitations that vary with facility size, location, and upgrade timing. These limits are largely the result of implementing the MPCA's Phosphorus Strategy and are gradually being supplemented by limits set to meet lake and river eutrophication standards.

Importance of wastewater phosphorus loads by scale

Wastewater phosphorus loads discharged by industrial facilities are relatively minor on a statewide basis (17% of statewide wastewater phosphorus load totals in 2018) but can be very important on a local watershed scale.

For example, in the Rainy River Basin (HUC-4 0903) the industrial phosphorus load for 2018 is 94% of the total wastewater load.

Table 21 summarizes the number of permits with phosphorus limits. A permit can contain more than one type of phosphorus limit. Table 22 shows the wastewater volume associated with each type of limit. While municipal wastewater facilities discharge the vast majority of statewide effluent phosphorus loads, industrial wastewater is an important local source of nutrient additions in certain areas and are also included in the assessment. Forty-six percent of industrial facilities monitor phosphorus and 9% of the facilities have phosphorus limits.

Table 21. Permits with phosphorus limits (August 2019).

	Permits with phosphorus limits
Lake Eutrophication Standard limits	363
River Eutrophication Standard limits	113
State Discharge Restriction limits	121

Table 22. Permitted flows associated with different phosphorus limits.

Current limit type	2018 Flow (MG)			Municipal	Industrial
	Municipal	Industrial	Total	% of total permitted flow	% of total permitted flow
Lake eutrophication standard	112,943	4,415	117,358	66%	4%
State discharge restriction	39,907	7,432	47,339	23%	6%
River eutrophication standard	578	196	774	0.3%	0.2%
No limit	17,122	105,088	122,210	10%	90%
Total flow	*170,550*	*117,131*	*287,681*	*100%*	*100%*

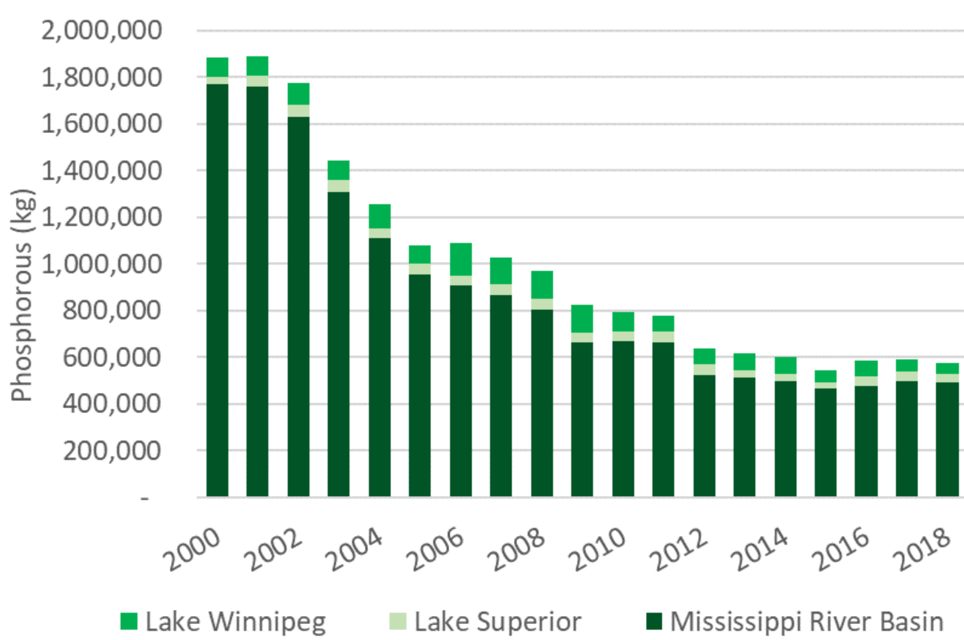


Figure 45. Statewide wastewater phosphorous loads (2000-2018).

Phosphorus loadings by major basin are provided in Figure 47 through Figure 48:

- **Mississippi River** – Between 2014 and 2018, 201 municipal and 82 industrial facilities made reductions. As noted earlier, there was a 21% reduction between the 2010 to 2012 period and the 2016 to 2018 period. From 2014 to 2018, the fraction of decrease was much smaller. The slight increase during the last three years in Figure 47 can be explained by population increases and wet weather, generating greater volumes of wastewater discharge (Figure 47).
- **Lake Winnipeg** –Industrial sources of phosphorus contribute a large fraction of phosphorus discharge. Decreases in phosphorus loading are due in part to actual reductions, and in part to better monitoring of industrial discharges (Figure 47).
- **Lake Superior** – Western Lakes Sanitary Sewer District (WLSSD) in Duluth is the largest wastewater discharger in the Lake Superior Basin and discharged 56% of the total permitted wastewater in this basin in 2018. The WLSSD and the City of Virginia Wastewater Treatment Plant started making phosphorus reductions in 2013, resulting in wastewater phosphorus reductions to Lake Superior between 2012 and 2015. Wastewater phosphorus increased from 2016 to 2018 in part due to increased phosphorus loading from WLSSD, however, total loading is still below the long-term 2000 to 2011 average (Figure 48).

Adoption and implementation of River Eutrophication Standards has generated resistance from some sectors of the wastewater community. This has taken the form of various legal challenges to the adoption of water quality standards (Minn. R. Ch. 7050.022) and implementation at the individual permit level. It is anticipated that RES TMDLs will also face similar legal hurdles. In general, opposition from point sources has centered around challenges to the technical basis for the standards, concern about the costs of implementation and concern that point source investment in further phosphorus reductions will not be effective unless non-point source reductions are also accomplished.

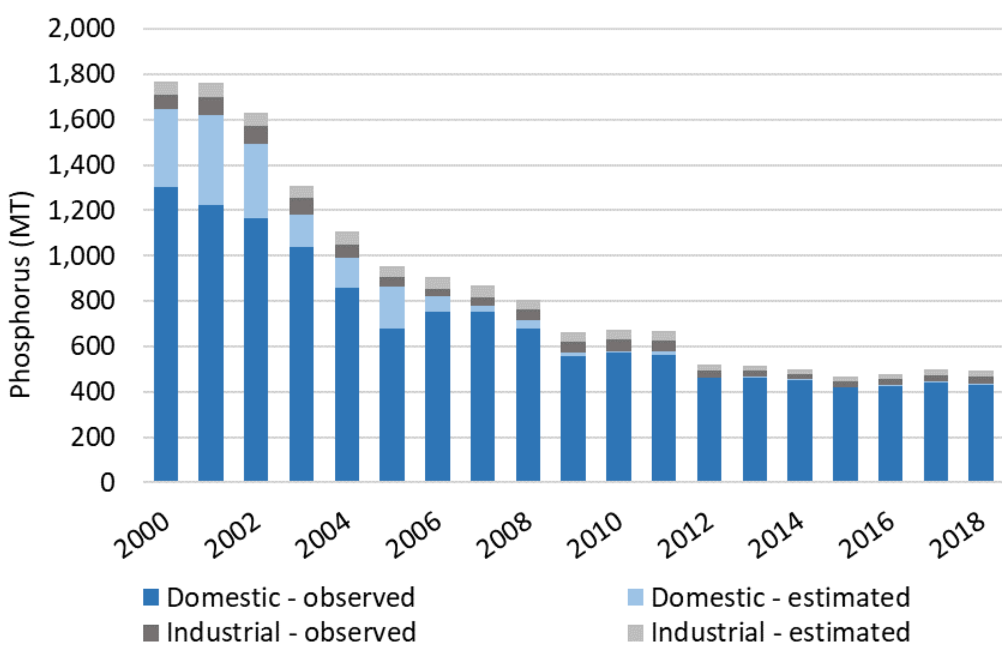


Figure 46. Mississippi River basin phosphorous loading.

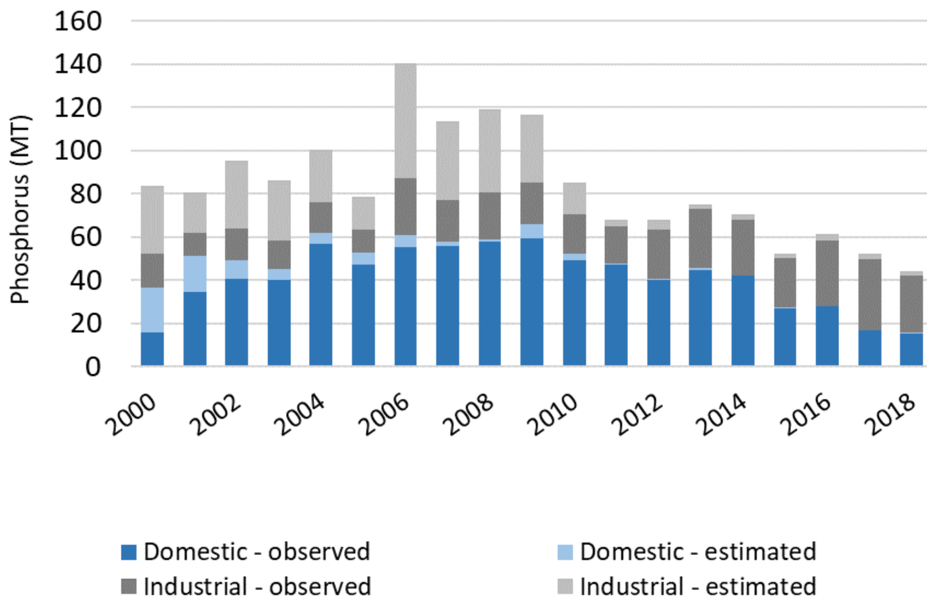


Figure 47. Lake Winnipeg basin phosphorous loading.

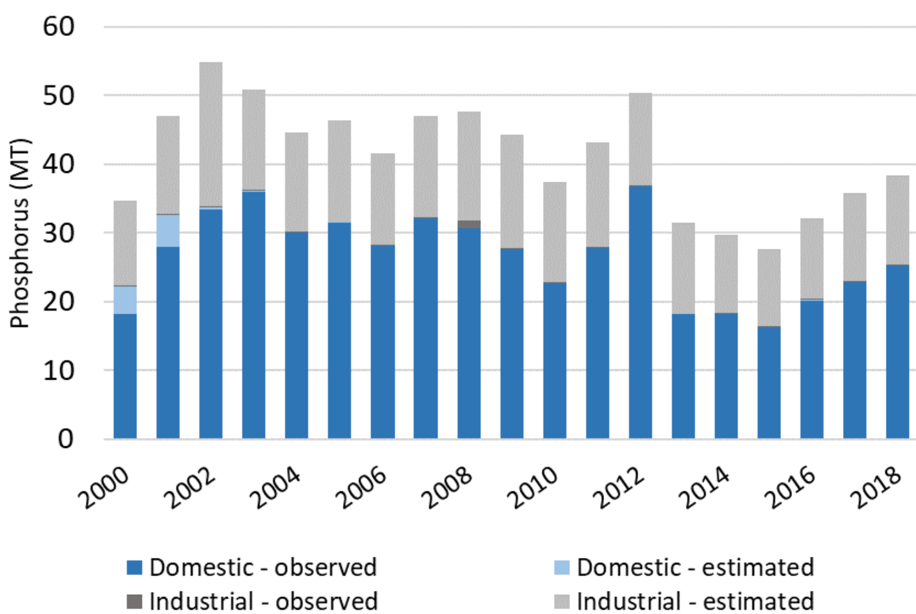


Figure 48. Lake Superior basin phosphorous loading.

6.1.3 Nitrogen reduction

Nitrogen load reductions from wastewater were not expected within the first five years of NRS implementation. Instead, Minnesota focused on collecting new monitoring data from wastewater sources to better determine existing nitrogen loads. Table 23 summarizes updated nitrogen concentrations for treated municipal wastewater based on the new monitoring data. There are 205 facilities with continuous discharge (i.e., mechanical) and 50 facilities with controlled discharge (i.e., stabilization ponds) that monitor nitrogen in their wastewater (Figure 49).

Table 23. Updated average nitrogen concentrations for treated municipal wastewater.

Facility category	Nitrogen concentration assumptions (mg/L)
Class A municipal – large mechanical	21
Class B municipal – medium mechanical	21
Class C municipal – small mechanical/ pond mix	12
Class D municipal – mostly small ponds	6

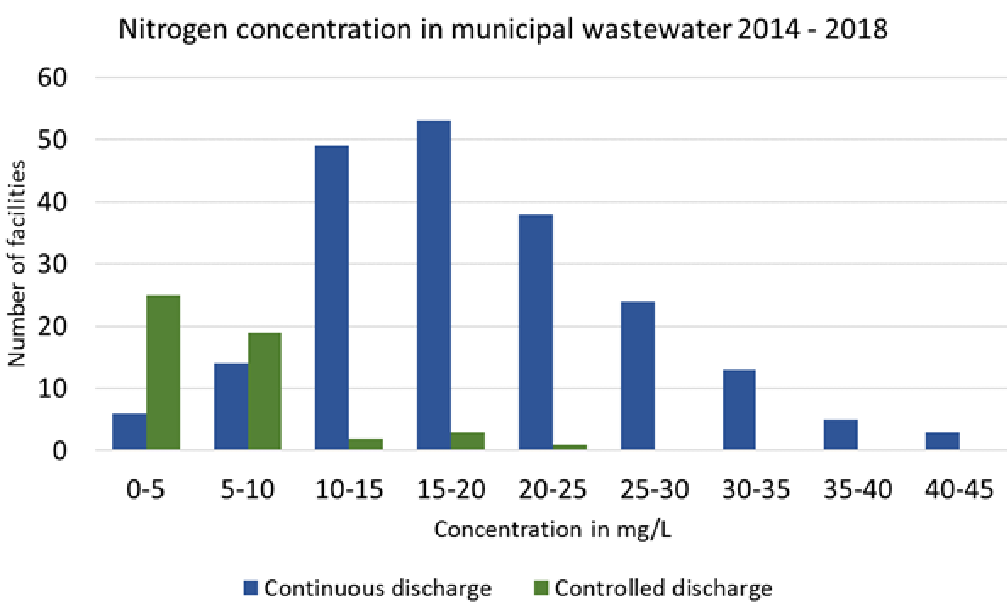


Figure 49. Effluent total nitrogen concentrations for facilities in Minnesota.

Figure 50 provides the best estimate of statewide nitrogen loading from wastewater. Since very few wastewater treatment systems remove nitrate or total nitrogen, statewide load reductions are not evident. Observed trends are due to a combination of improved monitoring information and population increases. The increase in nitrogen monitoring data is evident beginning in 2010 and ramped up considerably in 2016 (Figures 52 to 54). Pre-2016 nitrogen loading estimates are largely based on assumed concentrations; therefore, it is challenging to accurately determine changes in loading. Figure 51 through Figure 54 provide the best estimates of nitrogen loading by major drainage basin.

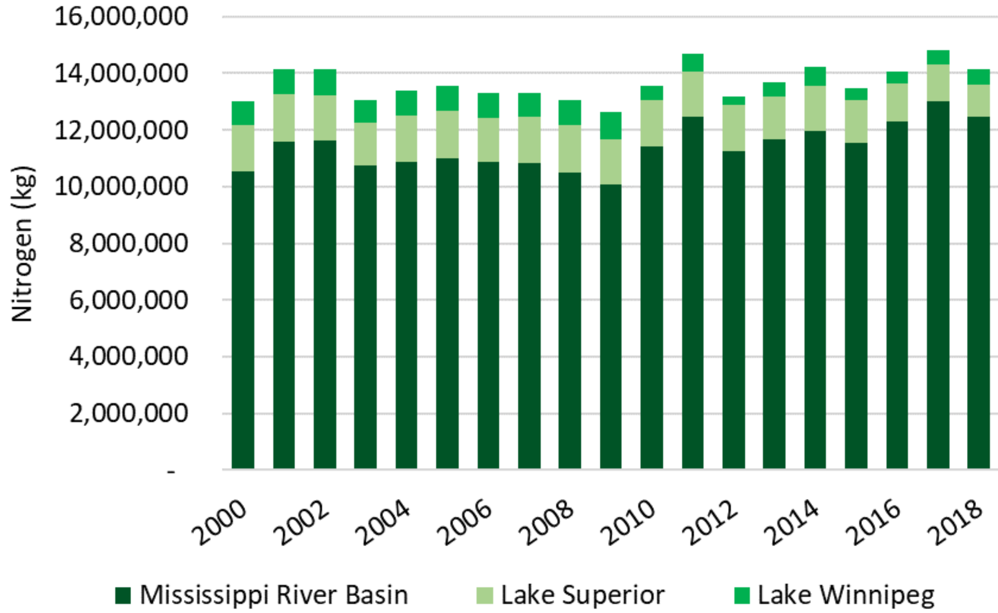


Figure 50. Statewide wastewater nitrogen loads (2000 – 2018).

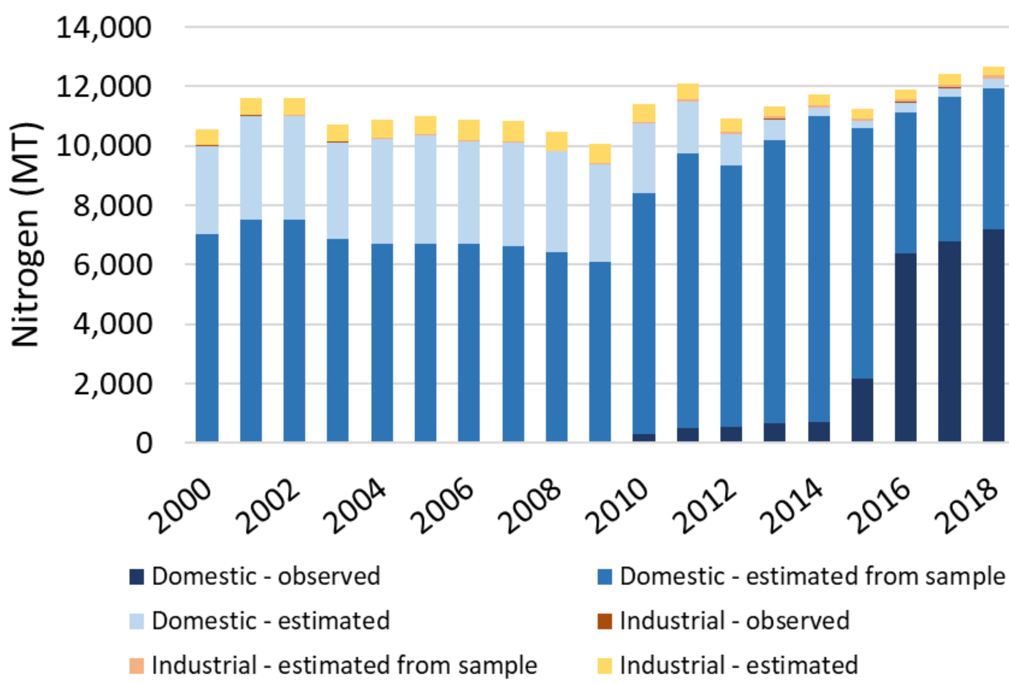


Figure 51. Mississippi River basin nitrogen loading.

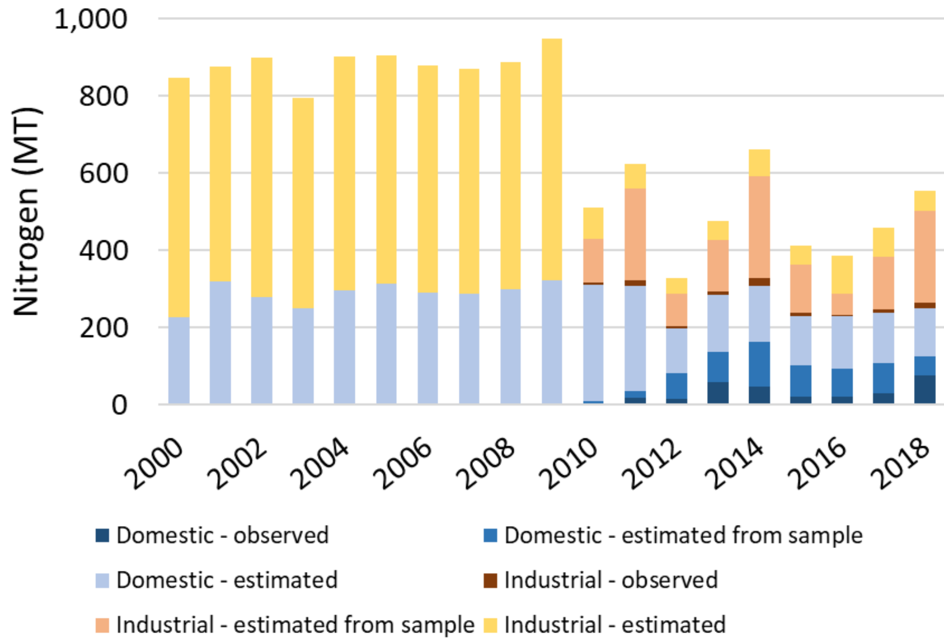


Figure 52. Lake Winnipeg basin nitrogen loading.

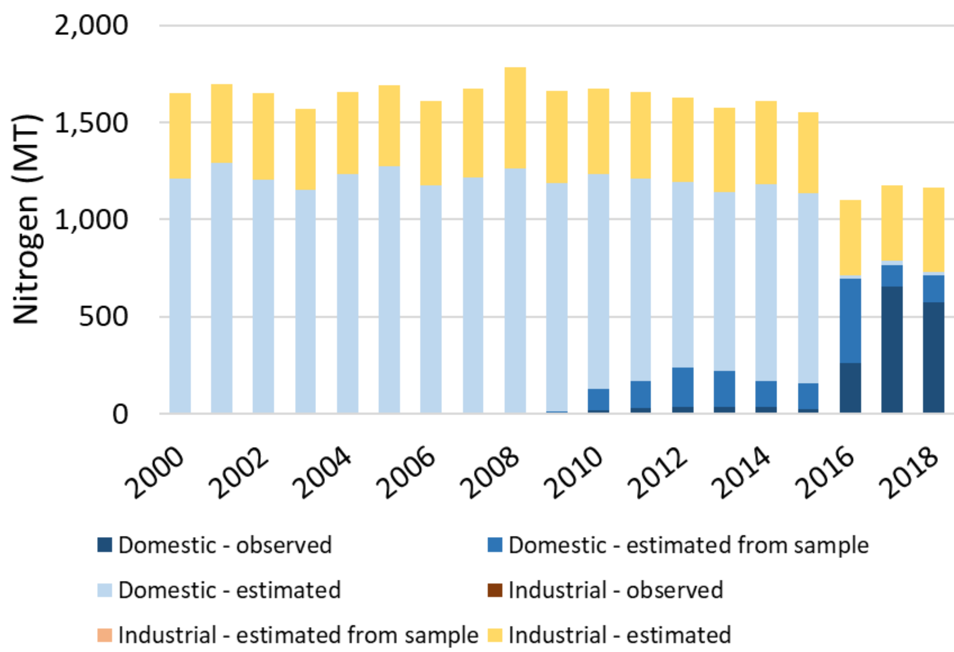


Figure 53. Lake Superior basin nitrogen loading.

Summary of Minnesota's progress on wastewater

Why important

- Municipal and industrial wastewater represent the largest manageable nutrient source category following cropland. The relative proportion of river nutrient loads from wastewater becomes greater during times of low flow, and in areas where agricultural sources are minimal.
- The NRS called for continued phosphorus reductions through wastewater permit limits established to help achieve eutrophication standards, and it also outlines a series of steps to make progress with nitrogen treatment.

Findings

- NPDES phosphorus permit limits apply to approximately 90% of municipal wastewater flows and 10% of industrial wastewater flows (600 wastewater permits), as driven by the Lake Eutrophication Standards, River Eutrophication Standards and/or State Discharge Restriction Limits.
- While much of the 70% reduction in statewide phosphorus wastewater discharges occurred prior to the 2014 NRS, wastewater dischargers have maintained these improvements and achieved additional reductions in alignment with the direction set forth in the NRS.
- One of the first NRS steps for wastewater nitrogen was to increase monitoring. Now, 255 facilities regularly monitor nitrogen in their effluent.
- Estimated statewide nitrogen loads from wastewater have generally remained steady, increasing slightly along with population and precipitation.

Follow-up

- Minnesota will continue taking the steps outlined in the NRS for achieving nitrogen reductions from wastewater, while at the same time maintaining and continuing the progress with phosphorus.

6.2 Miscellaneous sources

The 2014 NRS provides recommended strategies for feedlots, urban stormwater, and septic systems to reduce their runoff and nutrient pollution. The following section outlines each source individually, summarizes the recommended strategies, and summarizes progress made from 2014 to 2018.

6.2.1 Feedlots

Over 20,000 registered feedlots in Minnesota generate manure for land spreading on roughly 4 million acres of cropland. Runoff from feedlot sites (animal holding areas and manure storage systems) and from manure-treated cropland can be an impactful localized source of nutrients. Yet statewide, runoff from feedlot sites represent less than 1% of nitrogen and less than 2% of phosphorus. The 2014 NRS accounts for nutrients directly from feedlot sites in the total phosphorus load "miscellaneous" reductions.

Land application of manure from feedlots to cropland is a more important statewide potential pathway for nutrients than runoff from feedlot animal-holding sites. Proper crediting of nutrients from manure with high organic nitrogen content is challenging compared to inorganic nitrogen sources. Nutrient availability is highly dependent on the type and size of animal, climatic conditions and is influenced by bedding, storage, application method, and other practices. MDA (2014) reported that the average nitrogen rate from manure applied in combination with non-manure sources such as fertilizer is higher than when only non-manure sources are used (MDA 2014). Manure nutrient crediting requires that manure nutrient content be tested, and records shared with the fertilizer dealer so they can accurately adjust commercial inputs.

2014 NRS recommended feedlot strategies

Operational measures through the MPCA Feedlot Program:

- All large concentrated animal feeding operations (CAFOs) and feedlots with greater than or equal to 1,000 animal units should be in compliance with discharge standards at the time of inspection.
- All large CAFOs and feedlots with greater than or equal to 1,000 animal units should be in compliance with nitrogen and phosphorus management requirements at the time of inspection.
- All feedlots not covered by a National Pollutant Discharge Elimination System (NPDES) or State Disposal System (SDS) permit should be in compliance with discharge standards at the time of inspection.
- All feedlots not covered by a NPDES or SDS permit should be in compliance with nitrogen and phosphorus management requirements at the time of inspection, including management of land application of manure activities.

Land application of manure contributes about 25% of the added nitrogen to cropland throughout Minnesota (MPCA 2013), with the other dominant source being cropland fertilizer. The 2014 NRS includes land application of manure to cropland in the "fertilizer use efficiency" reductions for both phosphorus and nitrogen.

An overview of progress made in the feedlot program since 2014 is provided below. Progress since 2014 is determined using information from land application and feedlot inspections and compliance rates.

6.2.1.1 *Land application of manure inspections and compliance*

Feedlot regulation in the State of Minnesota

Feedlot runoff and storage and manure spreading onto cropland are regulated by the MPCA and 50 counties delegated by the State to administer the program for non-CAFOs. In Minnesota, all feedlots (CAFO and non-CAFO) must meet certain feedlot runoff and manure application requirements, including agronomic rates of application and setbacks from waters. As the size of the feedlot increases, additional requirements are added, such as record-keeping, manure and soil testing, manure storage, and nutrient planning.

Inspection records prior to 2018 did not consistently distinguish between non-compliance due to nutrient related regulations and non-nutrient related regulations. Beginning in 2018, the feedlot regulatory program implemented an improved inspection checklist and developed a more rigorous quality assurance/quality control process for compliance rate data (available on MPCA's feedlot website).

The MPCA documented 1,697 land application of manure inspections between 2014 and 2018 (Table 24). In 2018, 97 inspections were of in-field land application of manure and 96 were of nitrogen and phosphorus management records. The inspected sites are not necessarily representative of all feedlots around the state and may depict a different rate of non-compliance than actual statewide averages.

Table 24. Number of land application of manure inspections, 2014-2018.

Year	Total number of land application inspections
2014	656
2015	445
2016	314
2017	89
2018	193
Total	*1,697*

Half of the 2018 land application of manure related inspections were in-field inspections and half were inspections of records documents. The 2018 inspection reports at sites selected for inspection showed the following percentages of inspections that were *non-compliant* with rules and requirements of land application of manure:

In-field inspections of manure spreading practices

- 33% of the 97 *in-field inspections* resulted in non-compliance due to inadequate phosphorus testing and or not complying with state requirements for phosphorus management.
- 10% of the 97 *in-field inspections* resulted in non-compliance due to application of manure within required setback zones to waters or discharging directly to waters.
- 29% of the 97 *in-field inspections* resulted in some level of non-compliance with manure applied at agronomic rates.

Records inspections of manure spreading practices

- 22% of the 96 nitrogen and phosphorus management *record inspections* resulted in non-compliance for one or more of the following: inadequate records, total nitrogen rates exceeding agronomic needs, or manure not incorporated into the soil where and when it is required.

6.2.1.2 *Feedlot inspections and compliance (facility)*

The MPCA and delegated counties documented 9,236 feedlot inspections between 2014 and 2018 (Table 25). Three percent (3%) of all feedlot inspections conducted in 2018 resulted in some level of non-compliance with feedlot facility requirements. These requirements include discharges from open lots, feed storage, process wastewater, stockpiles, mortality management areas, or liquid manure storage areas, and do not include land application of manure.

Table 25. Feedlot inspections (facility), 2014-2018.

	Conducted by Delegated Counties	Conducted by MPCA
2014	1,822	334
2015	1,736	234
2016	1,535	226
2017	1,465	206
2018	1,430	248
Total	*7,988*	*1,248*

Government assistance programs helped to fund construction of 194 manure storage facilities statewide between 2014 to 2018. Many of these storage facilities were constructed to reduce feedlot runoff and/or provide greater management flexibilities for applying manure at more optimal times of the year.

Summary of Minnesota's Progress on Feedlot Program

Why important

- The NRS acknowledges that runoff from feedlot facilities contributes a very small percentage of nutrients on a regional scale, but locally can cause problems. Manure generated at feedlots and applied to cropland, however, is a significant potential source of nitrogen and phosphorus to waters and needs to be carefully and judiciously applied.
- Regulations for land application of manure generated at all Minnesota feedlots increased markedly in 2000.

Findings

- Inspections of land application of manure activities from in-field observations and farm-office records were conducted at 1,697 sites between 2014 and 2018. Inspections during 2018 show that more progress is needed to improve setbacks, rates of nitrogen applied, keeping records, and phosphorus testing and management.
    - Depending on the land-application requirement evaluated, compliance rates were between 67% and 90% at the targeted inspection sites; however, the inspected sites are not necessarily representative of all feedlots.
- The vast majority of feedlot facility sites meet feedlot runoff requirements, with compliance rates at 97% during 2018 inspections.

Follow-up

- Continued and increased emphasis on land application of manure practices is important for reaching NRS goals.
- Cover crops and other conservation and living cover practices should increasingly be used to reduce nutrient leaching and runoff stemming from manure application.

6.2.2 Urban stormwater

2014 NRS recommended urban stormwater strategies

- Regulated stormwater source permitting (MS4, construction, industrial)
- Stormwater technical assistance in the form of the Minimal Impact Design Standards (MIDS) and the Minnesota Stormwater Manual
- Stormwater research and demonstration

Implementation of the MPCA stormwater program serves as the primary strategy to reduce nutrient loads from stormwater. The MPCA stormwater program regulates the discharge of stormwater and snow melt runoff from MS4s, construction activities, and industrial facilities, mainly through the administration of NPDES and SDS permits. For more information go to https://www.pca.state.mn.us/water/stormwater, or search "stormwater" on the MPCA webpage. Nutrients from stormwater (regulated and non-regulated) are accounted for in the "miscellaneous" reductions in total phosphorus load in the 2014 NRS.

An overview of progress made in the stormwater program is provided below. Progress since 2014 is determined using information collected from the stormwater permitting program. Additionally, many watershed organizations, particularly those in the Twin Cities Metropolitan area, have made progress beyond Minnesota's permit requirements.

Three Minnesota general stormwater permits reduce and/or prevent new nutrient additions in stormwater: MS4 Permit, Construction Stormwater Permit (between 2,000 and 2,500 permits issued annually over the past five years), and Industrial Stormwater – Multi-sector General Permit (3,920 permits in 2019).

In addition to the above general permits, other regulatory mechanisms are in place to further protect local waters, such as permitting land-disturbing activities by municipalities or watershed organizations. In addition to regulatory requirements, many volunteer programs exist to encourage and incentivize stormwater treatment. Activities not associated with the MPCA's stormwater program are not tracked at the state level, and therefore are not included in this NRS progress tracking. However, these additional activities do contribute to overall nutrient reduction.

The MPCA only collects and tracks data for regulated (permitted) MS4s. Currently, there are 247 regulated small MS4s in Minnesota, and 2 large permitted MS4s (Minneapolis and St. Paul). Approximately 4% of the land area in the state is covered under a MS4 permit as shown in Figure 55.

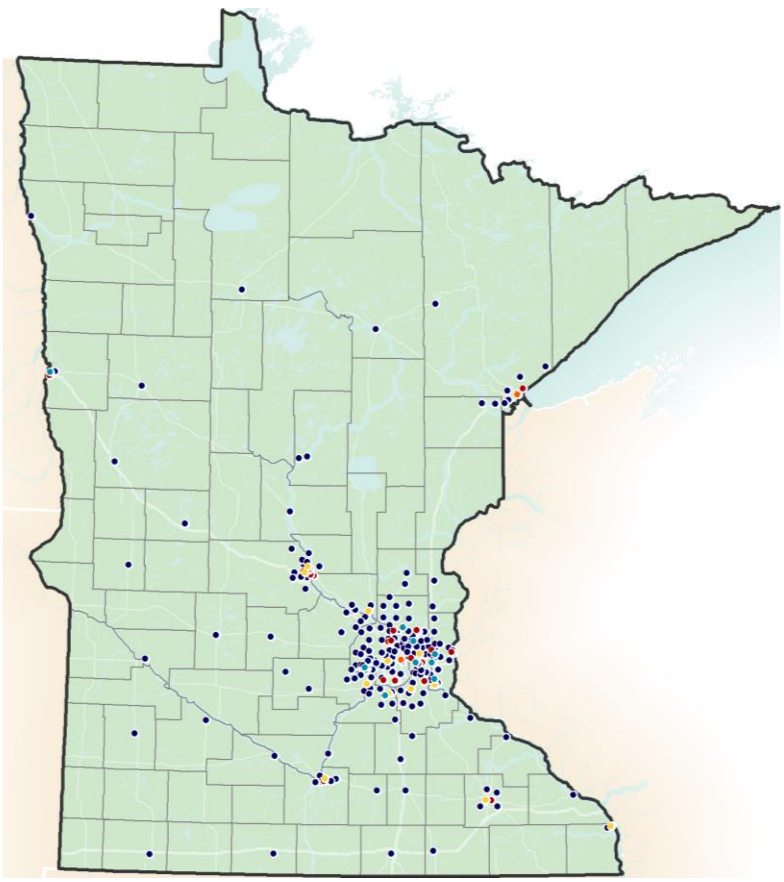


Figure 54. Regulated MS4s.

In addition to making progress towards meeting pollutant load reductions needed to comply with water quality standards and TMDLs, regulated MS4s are also required to meet post-construction volume requirements that will also reduce nutrient loads. The most common method for controlling runoff volume at a site is infiltration or other treatment of the first one inch of runoff from impervious surfaces.

The MPCA collects and tracks data for regulated (permitted) MS4s. Data on structural and non-structural BMPs is provided in required MS4 annual reports. The MS4 permittee must provide a summary of the progress toward achieving TMDL wasteload allocations (WLAs). The summary must include a list of BMPs implemented, the implementation status of BMPs that were included in the permittee's compliance schedule, and an estimate of cumulative total sediment and total phosphorus load reductions.

MS4 permittees with TMDL WLAs were first required to report the BMPs implemented in 2014. Note that the MS4 permittees self-report the data to MPCA and MPCA does not necessarily conduct thorough quality checks of the data reported. The year in which a BMP was reported does not necessarily indicate which year the BMP was implemented.

Structural BMPs

MS4 permittees assigned a WLA in a TMDL approved by the U.S. Environmental Protection Agency (EPA) prior to issuance of the most current MS4 permit (August 1, 2013), and who were not meeting that WLA(s) when they applied for permit coverage, must annually complete a TMDL Report to demonstrate progress toward meeting the WLA(s). Currently, of the 247 regulated small MS4 permittees, 78 permittees are required to complete the TMDL Annual Report under the 2013 MS4 permit. This requirement will continue when the new MS4 permit is re-issued in 2020. When the new MS4 permit is re-issued, 228 regulated MS4s will have a nutrient or sediment WLA and will be required to report progress on meeting these WLAs annually. The data collected from these reports includes the number and type of structural and nonstructural BMPs implemented since the baseline year to make progress towards meeting MS4 WLAs.

From 2015 to 2017, a total of 418 structural BMPs were reported by 78 MS4 permittees (Table 26). The data provided in "pre-2015" represents all BMPs implemented up to and including the year 2014. As of 2017, 1,764 structural BMPs were reported by 78 permittees. The most commonly implemented BMPs include:

- Constructed basin BMPs (e.g., ponds, wetlands) comprised 52% of all BMPs implemented. Wet ponds accounted for 55% of the reported constructed basin BMPs.
- Filter BMPs (e.g., biofiltration, sand filter, permeable pavement, and iron enhanced filter) comprised 10% of all BMPs implemented. Biofiltration (rain garden with an underdrain) accounted for 64% of the reported filter BMPs.
- Infiltrator BMPs (e.g., bio-infiltration, infiltration basins/trench, underground infiltration, tree trench) comprised 33% of all BMPs implemented. Bio-infiltration (rain garden with no underdrain) accounted for 55% of the reported infiltrator BMPs.
- Swale or Strip BMPs (e.g., filter strip, dry swale, and grass channel) comprised 5% of all BMPs implemented. Grass channel/waterway accounted for 69% of the reported swale/strip BMPs.

Table 26. Structural BMPs reported by regulated MS4s

Data provided under "pre-2015" represents all BMPs implemented up to and including the year 2014.

	Reporting Year				
Structural BMP	**pre-2015**	**2015**	**2016**	**2017**	**Grand Total**
Constructed basin	827	25	46	27	925
Filter	88	29	38	21	176
Infiltrator	403	55	63	59	580
Swale or strip	28	4	4	47	83
Grand Total	**1,346**	**113**	**151**	**154**	**1,764**

Non-structural BMPs

In addition to structural practices, MS4 permittees also reported implementing 2,887 non-structural BMPs. Non-structural BMPs include enhanced street sweeping, employee or public education and outreach, establishing ordinances, enhanced road salt management (which can affect phosphorus), improved lawn care practices, etc. Pollutant load reductions associated with non-structural BMPs are difficult to quantify. Properly implemented, however, they will lead to reductions in pollutant loading.

For example, from 2014 to 2017, 42 permittees reported implementing enhanced street sweeping BMPs. These practices included increased frequency of sweeping and implementing vacuum sweeping.

Another example is supplemental public education and outreach, which includes activities such as developing and distributing publications (650), giving presentations (244), and conducting workshops/clinics (126).

Summary of Minnesota's Progress on Urban Stormwater

Why important

- Stormwater runoff contributes relatively little nitrogen to regional surface waters but is a more important source of phosphorus.
- The NRS called for continued attention to phosphorus reduction through the MPCA and local community stormwater program. The MS4 general permit requires reductions in sediment and phosphorus by regulated entities subject to WLAs.

Findings

- Once the 2020 MS4 general permit is issued, 228 regulated MS4s will be required to report progress on sediment and phosphorus reductions annually, compared to 78 permittees reporting under the 2013 general permit.
- Prior to 2015, constructed basins were the most prevalent BMP installed for compliance with MS4 permit requirements. However, since 2015 practices that focus on infiltration, have more commonly been constructed, providing benefits in addition to water quality treatment (e.g., volume control, groundwater recharge, etc.).

Follow-up

- Minnesota will continue improving its tracking of the specific practices implemented to reduce nutrients from urban stormwater runoff.

6.2.3 Septic systems

Implementation of Minnesota's SSTS program serves as the primary strategy in the 2014 NRS to reduce nutrient loads from septic systems. Nutrients from septic systems are accounted for in miscellaneous reductions for total phosphorus in the NRS. Implementation of the SSTS program emphasizes continued progress to reduce the number of failing SSTS and imminent public health threats. An overview of progress made in the SSTS program is provided below. Progress since 2014 is determined using information from SSTS inspections and compliance rates.

2014 NRS recommended Subsurface Sewage Treatment Systems (SSTS) strategies

- Implement existing SSTS Program to reduce the percentage of failing SSTS to less than 5%
- Implement the Large Subsurface Sewage Treatment System Groundwater Nitrogen Policy

SSTS inspections have been occurring at a consistent rate since 2014 (Table 27). Of the reported 575,726 existing systems in Minnesota, 14,923 systems or 2.6 % of existing systems were evaluated for compliance in 2018. Inspections are triggered most commonly during a point of sale of the property. There are currently 166 local government units (80%) that have a point of sale inspection requirements included in their local SSTS ordinance. This includes 61 (71%) county SSTS programs.

Table 27. SSTS compliance inspections.

Year	Number of systems inspected	% of systems inspected
2014	12,805	2.4%
2015	14,543	2.7%
2016	14,847	2.7%
2017	15,250	2.8%
2018	14,923	2.6%

Since 2002, local government units have issued over 96,000 SSTS construction permits for replacement SSTS, or systems that replace an existing sewage system that was identified as non-compliant for either failing to protect groundwater or an imminent threat to public health and safety (ITPHS) through an inspection (Figure 55). While inspection rates have remained fairly steady since 2014, the number of compliant systems has increased and the number and fraction of septic systems that fail to protect groundwater or are otherwise considered ITPHSs has dropped to less than 5% (Figure 57). The number of estimated compliant systems has increased from 424,000 systems in 2014 to roughly 463,500 systems in 2018. Compliance rates in 2018 were estimated at 81%.

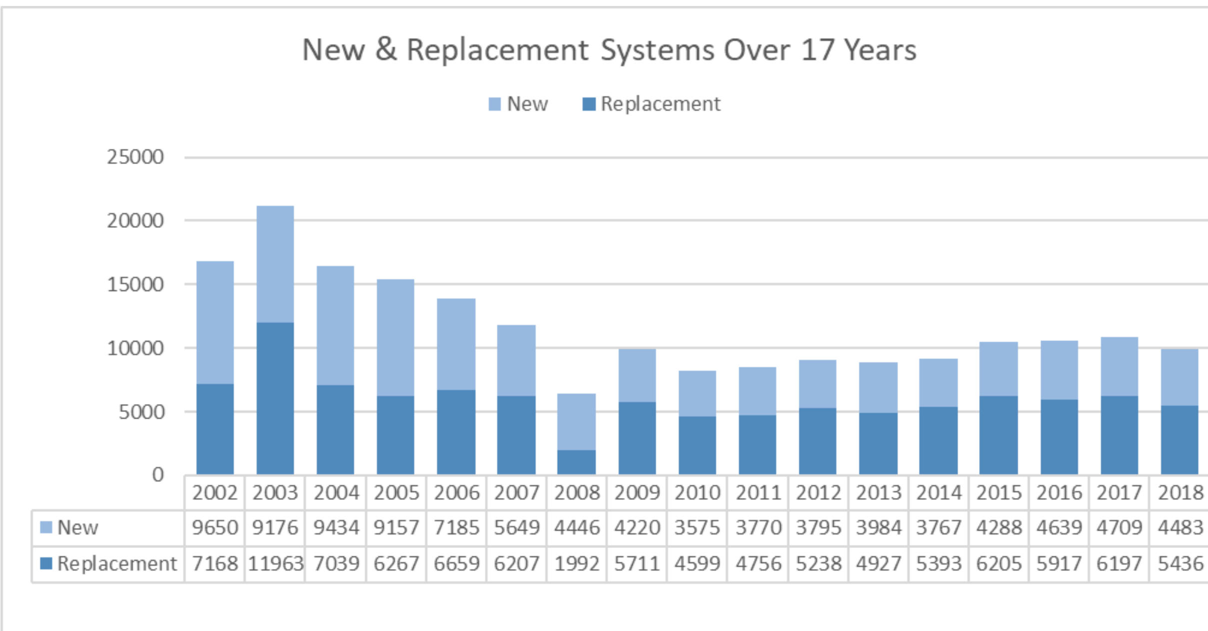
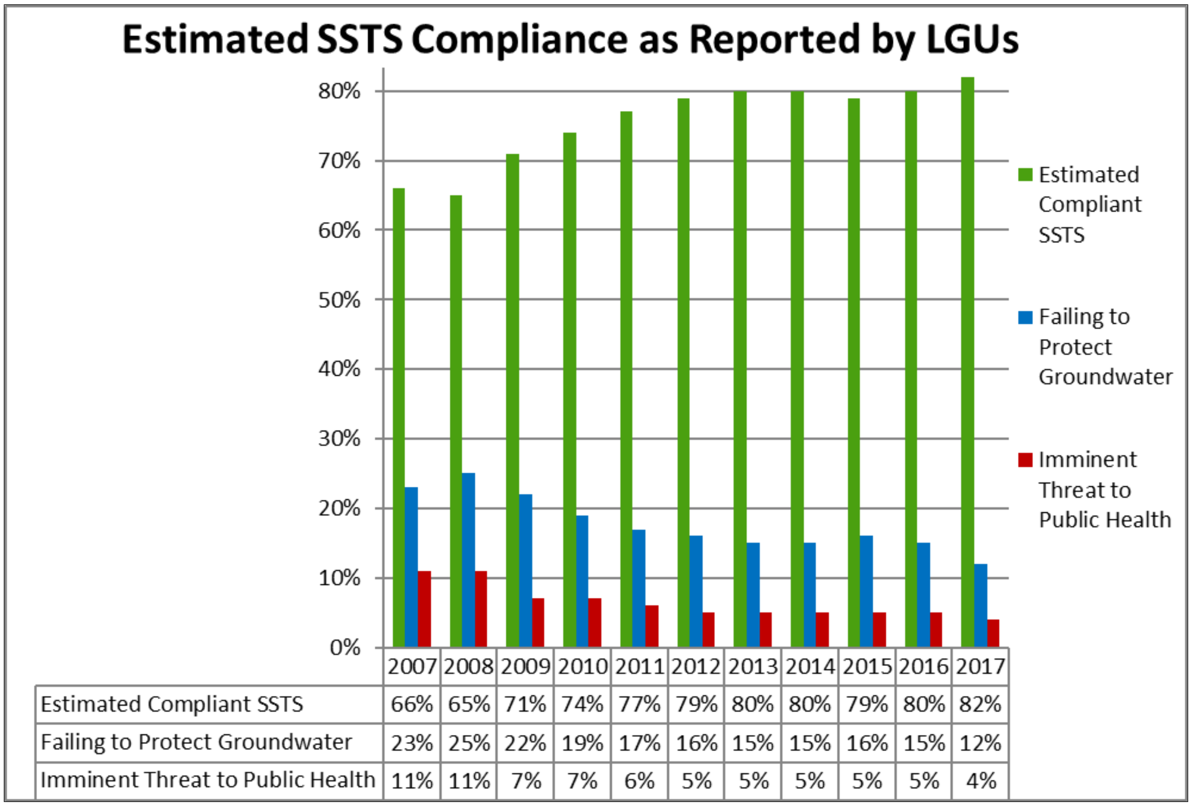


Figure 55. New and replacement SSTSs over time (2002-2018).



	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Estimated Compliant SSTS	66%	65%	71%	74%	77%	79%	80%	80%	79%	80%	82%
Failing to Protect Groundwater	23%	25%	22%	19%	17%	16%	15%	15%	16%	15%	12%
Imminent Threat to Public Health	11%	11%	7%	7%	6%	5%	5%	5%	5%	5%	4%

Figure 56. Estimated compliance (2007-2018).

Summary of Minnesota's Progress on Subsurface Sewage Treatment Systems

Why important

- Septic systems are a small nutrient contributor statewide but can create local groundwater and surface water problems when improperly sited, constructed and maintained.
- The NRS called for continued progress with Minnesota's regulatory program for Septic Systems.

Findings

- Between 2014 and 2018, over 13,000 annual inspections of septic systems occurred each year.
- The number of septic systems considered imminent public health threats has dropped to less than 5%, thus meeting the NRS strategy target.
- During 2014 to 2018, between 12 and 15% of inspected septic systems failed to protect groundwater.

Follow-up

- Continued implementation of the SSTS program to better protect groundwater and surface waters.

7 What are the next steps for the NRS (2020-2024)?

All Minnesotans are part of the nutrient reduction solution. Only with large-scale collaboration at all levels, in all sectors, among all citizens, can Minnesota achieve the scale of change needed to significantly reduce nutrients and meet NRS goals.

Minnesota has advanced most of the numerous program areas identified in the 2014 NRS intended to achieve nutrient reductions. However, as discussed in previous sections, more time is needed for the programs to reach their full potential to significantly reduce nutrients. During the next five years, it is necessary for Minnesota partner agencies to continue developing, advancing and implementing the NRS programs identified in Section 2 and Appendix A. Yet, based on our indicators of progress thus far it is likely that continuation of existing programs alone won't be sufficient to achieve the scale of BMP adoption needed to reach nutrient reduction goals.

Achieving NRS goals depends on large-scale, multi-million acre new adoption of practices such as:

- Cover crops and other continuous living cover vegetation;
- Nitrogen and phosphorus fertilizer (and manure) applied at times, forms, rates and methods that maximize economic efficiencies along with environmental outcomes (i.e., such as split N based on in-field monitoring, sufficient crediting of N from manure and legumes, phosphorus fertilizer banding/incorporation, etc.);
- Increasing crop residue cover through innovative systems, such as strip till, along with other traditional soil conservation practices;
- Treatment-wetland construction and other tile-drainage water storage and treatment systems; and
- Other BMPs proving to be the most promising for *multiple agricultural and ecosystem benefits.*

In addition, wastewater treatment for nitrogen removal is important for meeting the NRS long-term goals.

To further move us toward increased scales of BMP adoption and to set the stage for the 2024 NRS republishing, four next steps are recommended, as follows:

1) Maximize the multiple benefits of NRS practices by coordinating efforts with other plans and strategies that use similar practices to achieve resiliency to climate change and ecosystem improvements. For example, soil health and living cover strategies in the EQB State Water Plan not only help us to become more resilient to precipitation increases but also help us reduce nutrients in water. We need to increase these practices in ways that can best meet both needs.
2) Identify and remove social, economic, and other human-dimension barriers to scaling-up BMP implementation,
3) Use the latest research to continue refining the optimal combination of practices that will achieve the needed nutrient reductions in our waters,
4) Optimize wastewater nitrogen treatment.

Each of these next steps are described in more detail below.

1) Maximize the multiple benefits of NRS practices by coordinating with other plans and strategies that use similar practices to achieve resiliency to climate change and ecosystem improvements.

NRS implementation should be increasingly coordinated and integrated with EQB's State Water Plan, Minnesota Clean Water Council's Strategic Plan, and other water and climate resilience plans and strategies. These plans and strategies can work in harmony to maximize the multiple benefits and increase adoption of practices providing continuous living cover, soil carbon build-up and crop nutrient efficiencies.

Many of the practices identified in the Nutrient Reduction Strategy will result in benefits beyond nutrient reduction. Public agencies and private organizations responsible for administering programs that affect nutrient reductions to waters should integrate planning efforts and prioritize practices and locations to achieve multiple benefits, including:

- Greenhouse gas reduction;
- Sediment reduction in rivers and downstream lakes;
- Resiliency to climate variability;
- Long-term agricultural sustainability and profitability;
- Soil health;
- Wildlife habitat and pollinator increases;
- Lake and river health;
- Nutrient reductions for drinking water source protection (public and private wells), and
- Other ecosystem benefits.

The cost and effort to increase nutrient-related practices to waters can often be further justified when considering the multiple benefits of the practices. For example, if all of the milestone NRS BMPs were implemented, the agricultural cropland portion of greenhouse gas emissions in Minnesota could be expected to be reduced by roughly 10%, and meeting final NRS goals would result in an even greater reduction (based on typical greenhouse gas reductions for BMPs as reported in MPCA, 2019).

Implement soil health and living cover measures in water and climate change plans - The strategy of improving soil health incorporates many of the practices and changes critical to meeting the long-term goals of the NRS, including reduced tillage, cover crops, and perennial crops. Soil health and living cover strategies in Minnesota's 2020 State Water Plan coordinated by EQB and Clean Water Council's (CWC) Strategic Plan are generally consistent with NRS goals and should be a high priority for implementation.

A monumental movement toward building soil health in Minnesota will not only work toward meeting NRS goals, but will also help achieve the other goals outlined above. An important component of building soil health and meeting NRS goals is the addition of cover crops on millions of row crop acres. The CWC's 2020 draft strategic plan sets a goal of adding 5 million acres of cover crops or continuous living cover to row crop agriculture by 2034. This goal is generally consistent with the pace of cover crop additions needed to meet NRS 2025 milestone goals and estimates of what it will likely take to achieve NRS 2040 final goals.

Additionally, Minnesota's Executive Order 19-37 establishes the Climate Change Subcabinet and the Governor's Advisory Council on Climate Change to promote coordinated climate change mitigation and resilience strategies in the state of Minnesota. Strategies for natural and working lands and for resiliency and adaptation to meet the goals are closely related to many of the NRS strategies for increasing living cover, crop residue and overall soil health. Implementing the recommendations of climate action team strategies will have co-benefits to achieving nutrient reductions in waters, along with several other benefits.

Prioritize local watershed efforts to achieve multiple benefits - The NRS emphasized Minnesota's local watershed management approach for implementing state-level programs at the local level, in ways that are prioritized, targeted and measurable. Local watersheds are a scalable unit for planning, priority setting, and implementation, and provide a good place to try approaches that can lead to scaling-up multi-beneficial practices across the landscape.

Minnesota has been developing watershed-scale science-based strategies and plans (i.e. through WRAPS and 1W1P, as shown in the maps below), but has had only a few years to implement the plans. As watershed-scale planning and implementation progresses, it is important to optimize practices and strategies to achieve the multiple benefits identified above. Prioritizing local water planning and implementation efforts to achieve such multiple benefits should increase the probability of success and maximize the use of limited resources.

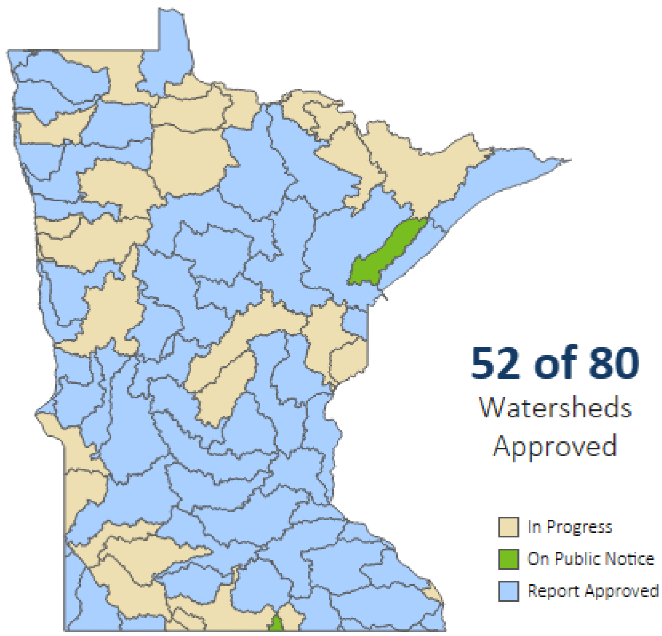


Figure 57. Completion status of Watershed Restoration and Protection Strategies (WRAPS).

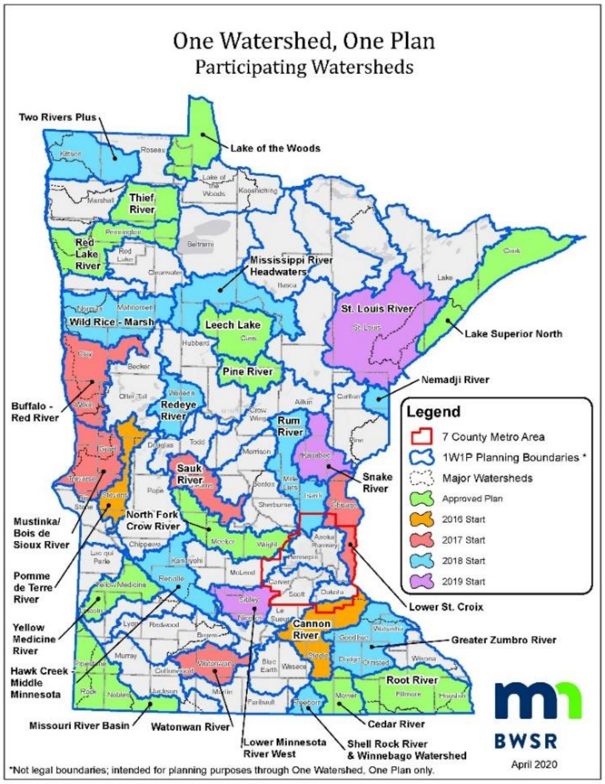


Figure 58. Watersheds participating in the One Watershed, One Plan program.

Specific actions

A. State agencies and partner organizations should seek opportunities to prioritize full implementation of strategies in the CWC Strategic Plan, EQB State Water Plans, NRS, and Climate Change Subcabinet plans that will result in significant increases in living cover and soil health for multi-purpose benefits. The combinations of strategies and plans will work toward:

   - Two million acres by 2025 on our way to over 10 million acres by 2040 of a combination of the following:
     - Cover crops with short-season crops;
     - Cover crops with full-season crops;
     - Expansion of grass-fed meat and dairy;
     - Strategic long-term permanent placement of perennial crops and plants in high-priority areas;
     - Perennial growth and harvesting of perennials for food, livestock feed, biomass and other uses;
     - Combined systems of perennials and annual row crops; and
     - High value winter annuals for incorporation into existing row-crop systems.
   - Increasing soil health practice incentives by adding more market-based funding approaches, carbon market linkages, soil water retention goals, crop insurance rebates, and connections to climate change and agricultural resiliency;
   - Implementing the Nitrogen Fertilizer Management Plan and its associated Alternative Management Tools;

- Supporting private-public partnerships, research and demonstration to promote 4R nutrient management stewardship and increase the adoption of fertilizer and manure BMPs;
- Investing in perennial crop research and development, including sustainable market and supply chain development;
- Multi-million acre enrollment in Minnesota's Agricultural Water Quality Certification Program; and
- Protecting approximately 400,000 acres of vulnerable land surrounding drinking water wellhead areas by investing in living cover and other strategies.

B. State agencies, working in conjunction with the University of Minnesota, should provide guidance and tools to comprehensive local water planners for evaluating and increasing multi-purpose benefits. Supplement or modify tools (i.e. HSPF-SAM, PTMApp) used for nutrient and sediment reduction planning to also include an assessment of other benefits such as resilience to climate change. Additionally, provide guidance on ways to concurrently achieve both downstream and local nutrient reduction goals.

2) Identify and remove social, economic and other human dimension obstacles to scaling-up BMP implementation

Recognizing the challenges of scaling-up practice adoption to the levels needed for NRS nutrient reduction goals, Minnesota should gain more clarity about the factors influencing decisions to adopt BMPs, barriers to adoption, and effective ways to overcome obstacles. At the same time that Minnesota progresses with its many nutrient-related programs that have advanced during recent years, we need to continue developing a better understanding of the human dimension associated with BMP adoption and how that varies across the state.

Specific actions

A. Minnesota should establish a multi-organizational socio-economic team focused on agricultural nutrient BMP adoption. This socio-economic team should build upon existing information from local, regional and national sources and develop recommendations on how to overcome obstacles and barriers to making large-scale changes across the landscape similar to those outlined in the Nutrient Reduction Strategy. The University of Minnesota should work in partnership with state and federal agencies, stakeholders, and national groups such as the Gulf of Mexico Hypoxia Task Force.

B. The above team should develop a report that includes recommendations to state, federal and local organizations on how to overcome identified barriers and achieve large-scale adoption of NRS practices. Where socio-economic information gaps are identified, plans should be made to obtain the needed information, where possible. The findings and recommendations will help Minnesota refine effective, socially acceptable, and financially feasible approaches for programs, policies, and incentives that drive increased BMP adoption. The recommendations and supporting documents from this assessment should be completed by December 2023, so that it can be used for the 2024 NRS revision process.

During the development of this progress report, contributing organizations identified several examples of possible impediments and solutions to increasing practice adoption. The socio-economic evaluation will provide greater insight on how to best resolve potential needs and gaps that might include:

- **Reducing risk when trying new practices** – Increase farmer (and city) protections, assurances and confidences when taking on real or perceived risk to adopt practices (i.e., use a crop insurance supplement for such practices).
- **Building trust and community** – Build stronger relationships, trust and community (landowner to renter, rural to urban, farmer to conservation professional, farmer to financer, etc.).
- **Equipment barriers** – Identify and help provide for equipment needs that include personally-owned, shared, and rented equipment. Also, address the timing of jointly-shared equipment availability.
- **Rented land challenges** – Identify and reconcile rented land obstacles and solutions for making long-term investment in conservation, and develop options for renters to be more involved with increasing conservation and living cover practices.
- **Practice maintenance** – Identify and address management obstacles and solutions related to maintaining practices.
- **Economics** – Understand costs, markets, funding and economic information for short-term (1-5 years) and long-term (over 10 years) practice adoption, including:
    - How to best support practices that have a public benefit but little to no short or long-term economic benefit to farmers;
    - Quantifying benefits of practices such as cover crops and reduced tillage that can lower costs (e.g. fertilizer, fuel, chemicals and labor) and increase resiliency, and include those quantified benefits in farm-profitability decision support tools;
    - Market-based pollutant trading (i.e. urban-rural trading);
    - Market development for crops providing continuous living cover; and
    - Shifting mindsets to longer-term economic planning horizons.
- **Moving beyond crop yields** – Increasingly shift from a crop-yield goal mindset to such things as increasing farmer competitiveness on metrics that focus on return on investment, community building, soil health, and ecosystem gains.
- **Self-assessment tools** – Provide landowners with more affordable tools and on-farm trial approaches to self-assess soil health progress, tile water nitrate, and other ways to independently obtain feedback on how their practices are working for soil and water protection.
- **Farmer Innovation** – Support on-farm innovative farmer-driven practices, tools and technologies for soil and water protection.
- **Farmer-to-farmer learning** – Develop innovative ways to communicate and showcase farm nutrient loss reduction success stories. Communicate stories and narratives of how farmers shifted from long-standing ways of farming and cultural norms to different ways that are good for agriculture, farmers, and ecosystem services.
- **Policy barriers** – Identify and minimize federal and state policy barriers and challenges for farmers, as well as private industry influences. Identify how government and industry programs can offer greater management flexibility. This could involve adjusting current policies to allow more flexibility in conservation practices, such as “working wetlands,” that may be utilized to cut hay or for other profit-generating activities. Also, assess potential differences between fertilizer retailer recommendations and long-term optimization of farmer economic and environmental return.
- **Private/public partnerships** – Initiate additional private/public partnerships that build off past successes and also involve coop and independent crop advisors, and potentially bankers.

- **Confidence in the solutions** – Increase local knowledge of the key practices and confidence in their effectiveness, including an understanding of how well individual practices can resolve multiple environmental issues.
- **Addressing downstream waters** – Identify barriers and solutions for individuals and watershed planners to increase consideration of downstream impacts outside of their jurisdiction.

The identification and resolving of barriers to success should be addressed by processes that welcome and support culturally diverse voices and different ways of knowing and relating to water issues.

3) Use the latest research to continue refining the optimal combination of practices that will achieve the needed nutrient reductions in our waters

The NRS BMP adoption scenarios outline a combination of agricultural and urban practices that will achieve nutrient reduction milestones and goals. While most of this information is still applicable and relevant at this time, our scientific understanding has continued to evolve. The BMP science used to develop the 2014 NRS reflects information generated largely from 2004 to 2012. To maintain the highest level of NRS credibility into the future and to most effectively achieve multi-benefit goals, Minnesota needs to begin working toward updating and improving the BMP adoption scenarios while using the most updated and relevant scientific understanding.

Specific actions

A. An agricultural nutrient water-science team from the University of Minnesota and scientists from agencies and other organizations should be established to evaluate the collective body of recent findings around Minnesota and the upper Midwest to set the stage for an updated strategy in 2024. The team should assess and document the following:

    - **BMP selection** – Identify which BMPs should be central to an updated BMP scenario, especially emphasizing BMPs that provide multiple benefits and that have a relatively low cost to benefit ratios. An updated BMP effectiveness assessment should be included that uses the latest research to update and refine expected water quality improvements afforded by the BMPs.
    - **BMP suitability** – Update GIS-based suitable acreage estimates of potential lands that are well-suited for additional adoption of BMPs, accounting for where BMPs already exist and land limitations for BMP adoption.
    - **BMP combination scenarios** – Use updated tools, models and inputs (such as updated precipitation patterns) to re-assess best combinations of practices and associated adoption acreages to meet nutrient load reduction goals and at the same time achieve other ecosystem and agricultural sustainability benefits.
    - **BMP costs** – Include cost estimates for the BMP scenarios developed, focusing on net cost to landowners with and without existing government cost-share assistance.
    - **BMP progress tracking** – Building from this NRS progress report and recent advancements at the University of Minnesota and elsewhere, recommend the best ways of tracking progress toward adoption of the BMPs outlined in the scenarios, including metrics and measures to assess progress with each BMP category.

    The recommendations and supporting documents from this assessment should be completed by December 2023, so that it can be used for the 2024 NRS revisions and republishing. This effort, along with the socio-economic analysis, should lead to a 2024 NRS update that is most consistent with the latest socio-economic and water-science findings and set the stage for increased scaling-up of highly-effective and feasible BMPs between 2025 and 2035.

B. Where scientific information gaps are found, the team should recommend where to focus future research and data collection efforts so we can develop the most promising technologies for significantly reducing nutrients in waters. Examples of existing research needs identified through this progress report development process include: advanced precision nutrient management for crops; best ways to store and retain water across the landscape; economically sustainable continuous living cover cropping options and building associated markets and supply chains; solutions to in-channel sediment phosphorus sources; and ways to combat detrimental effects of precipitation extremes.

4) Optimize wastewater nitrogen treatment

Minnesota will continue working toward wastewater nitrogen reductions by developing and implementing a detailed strategy consistent with the direction established in the 2014 NRS.

Specific actions

A. MPCA will work with U of MN, Met Council and others to complete more specific steps and considerations for the next five years that will move us further toward increased wastewater nitrogen reduction. Action steps will emphasize pollution prevention and facility optimization of nutrient removal through the use of existing infrastructure.

B. MPCA will analyze and distribute nitrogen monitoring data reported by wastewater dischargers, continue work towards development of a water quality standard for nitrate based on aquatic life toxicity, and work with others to develop nitrogen management plan templates for use by wastewater permittees.

C. U of MN will model and evaluate the potential for optimizing wastewater total nitrogen reductions, while at the same time maintaining phosphorus reduction progress.

D. Depending on the outcome of the above efforts, the MPCA may establish total nitrogen effluent limits in certain locations for attainment of water quality standards and nitrogen reduction goals. Development of nitrate standards and related effluent limits could result in the need to upgrade some wastewater treatment facilities by adding denitrification capacity. Water quality trading and other funding alternatives should continue to be developed.

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Appendices

Appendix A – State-level Nutrient Reduction Program Advancements

Appendix B – External Factors Affecting Nutrients in Waters

Appendix C – River Nutrient Trends in Minnesota

Appendix D – Maximum Return to Nitrogen (MRTN) Values

Nutrient Reduction Strategy

August 2020

Executive Summary

5-year Progress Report on Minnesota's Nutrient Reduction Strategy

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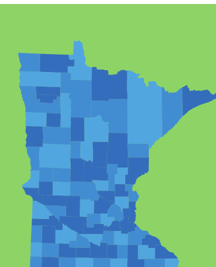

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Executive summary

The Nutrient Reduction Strategy (NRS) outlines how Minnesota will reduce nutrient pollution in its lakes and streams, and reduce the impact downstream. The strategy specifies goals and provides a framework for reducing phosphorus and nitrogen levels.

The NRS, adopted by 11 organizations in 2014, calls for reducing nutrient levels by 10 to 20% over much of the state by 2025, with much larger long-term reductions by 2040.

The NRS calls for a progress report every 5 years to evaluate whether Minnesota is on track for reducing nutrient pollution. The state evaluates progress in three primary ways:

Nutrients cause algal blooms in Minnesota rivers and downstream.

1. Analysis of trends in waters over the past one to two decades: Is water quality improving?
2. Evaluation of state-level program advancements: Are programs making progress?
3. Assessment of change in practices: Are enough practices being added to reduce nutrient pollution?

Analysis of trends in waters over the past one to two decades: Is water quality improving?

In looking at data from intensive river monitoring efforts across Minnesota over the past 10 and 20 years, it's both good and bad news:

- The good news is that phosphorus concentrations - the amount of phosphorus per liter of water - have generally decreased.
- The bad news is that nitrogen concentrations have increased at many locations.
- For both, high year-to-year variability makes it difficult to detect trends at many of the monitoring locations.

Both flow-adjusted and non-flow adjusted evaluation methods were used to create a more complete picture of how nutrients are changing in Minnesota rivers. Flow-adjusted methods are intended to separate the water quality effects caused by human changes on the land and cities from those caused by variability in precipitation and river flow.

Past 10 years

When using the flow-adjusted techniques for the past decade:

- For phosphorus, 24 of 50 (48%) river sites showed decreasing trends, with all other sites showing no detected trend. This indicates that efforts to reduce phosphorus in recent years have been making a difference.
- For nitrate-nitrogen, the dominant form of nitrogen in polluted rivers, 14 of 38 sites (37%) had increases, with the rest having no detected trend. This suggests that efforts to reduce nitrate thus far are either insufficient and/or need more time to be effective.

Past 20 years

Similar patterns were found when looking at flow-adjusted trends over the past two decades:

- The Mississippi River monitoring sites near the Twin Cities showed phosphorus concentration decreases of 21 to 26%. Whereas nitrate had 20-year increases in the range of 25 to 34%.
- Further downstream, closer to the Iowa border, the Mississippi River phosphorus concentrations have dropped by 50%, and nitrate was too variable to detect the trend.
- In the Red River of the North, phosphorus concentrations over the past two decades have decreased in the upstream reaches but increased at the Minnesota-Canada border. With some exceptions, river nitrate concentrations increased in the Red River Basin.

Phosphorus concentrations are decreasing throughout much of Minnesota.

High flows lead to high loads

While reducing nutrient concentrations is important for local water health and drinking water, reducing nutrient loads - the total amount that goes downstream - is important for downstream waters such as the Gulf of Mexico. Nutrient loads are affected by both nutrient concentrations and river flow:

- Because precipitation and associated river flow has markedly increased during the past two decades throughout much of Minnesota, decreasing phosphorus concentrations are not translating into statistically significant decreasing phosphorus loads.

Nitrogen concentrations are increasing throughout much of Minnesota.

Phosphorus loads in the Mississippi River Basin do not have a detectable decreasing trend unless the influence of river flow changes is removed through statistical methods.

- For nitrate, the combination of increasing concentrations and increasing flow has led to load increases of 62% in the Mississippi River near Red Wing.

Smaller monitoring efforts

In addition to intensive river monitoring across the state, Minnesota has dozens of edge-of-field and small watershed monitoring efforts that help scientists understand reasons for water nutrient changes. Evaluating connections between changes on the land and associated trends in water quality is important for demonstrating the effects of changing practices. The MPCA and partners are using results from small-scale monitoring to refine watershed-level nutrient strategies.

Steps for next 5 years – river monitoring

During the next 5 years, river monitoring and associated trends analysis should continue so that nutrient changes occurring between 2014 and 2024 can be used for the 2024 NRS update and republishing.

Evaluation of state-level program advancements: Are programs making progress?

All Minnesotans are part of the nutrient reduction solution. In order to make the wide-scale changes to significantly reduce nutrient pollution, Minnesota needs large-scale collaboration at all levels and in all sectors. The NRS identifies a multi-pronged approach to advance state, local, private industry, and federal programs that can drive nutrient reduction changes.

During the first 5 years of NRS implementation, Minnesota advanced almost every major program area identified in the 2014 Strategy. At the state and regional levels, Minnesota has initiated and/or expanded more than 30 programs associated with Strategy recommendations. The table on the following page outlines many of the programs that advanced between 2014 and 2019. While several programs are prompting changes on hundreds of thousands of acres, effects of other programs are more difficult to quantify or need much more time to reach their full potential.

Steps for next 5 years – Program advancements

During the next 5 years, Minnesota partner agencies need to continue developing, implementing, and expanding the programs that have advanced thus far. If these programs continue to advance, best management practice (BMP) adoption is expected to accelerate in the 2020 to 2024 timeframe, as compared to 2014 to 2018.

Education, Outreach and Research	Voluntary Programs	Regulatory Programs	Watershed Partnerships
• Nitrogen Smart training for farmers and farm-advisers • Annual nutrient management and conservation tillage conferences • Forever Green Initiative • Discovery Farms • Minnesota Office of Soil Health • Guidance manuals for agricultural best management practices, drainage, and urban stormwater management • Conservation professionals training and certification • Nutrient Mgmt. Initiative with on-farm cover crop trials • Center for Changing Landscapes	• Minnesota Agricultural Water Quality Certification • 4R Certification led by private industry (cropland nutrient management) • Red River Basin Initiative and Red River Valley Drainage Water Management • Minnesota Conservation Reserve Enhancement Program • Board of Water and Soil Resources Cover Crop Demonstration Program • Clean Water Fund – increases for BMP implementation • Point – nonpoint trading • Reinvest in Minnesota • Multi-purpose drainage water management	• Municipal and industrial wastewater program • Groundwater Protection Rule (nitrogen fertilizer) • Minnesota Riparian Buffer Law • Feedlot and land application of manure rules and inspections • Urban stormwater runoff program • Subsurface Sewage Treatment Program	• Watershed Restoration and Protection Strategies (WRAPS) • One Watershed, One Plan (1W1P) Program • Groundwater Restoration and Protection Strategies • Watershed Conservation Planning Initiative • Small focus watersheds – Federal Section 319 Program (20 new watersheds) • Guidance on Lake Protection for WRAPS and 1W1P • National Water Quality Initiative and Mississippi River Basin Healthy Watershed Initiative • Watershed-based funding implementation program • Local Field to Stream Partnerships

Assessment of change in practices: Are enough practices being added to reduce nutrient pollution?

Cropland practices

To guide Minnesota's progress toward reducing nutrients, the 2014 NRS included cropland BMP adoption goal scenarios. These scenarios were intended to serve as an example of the level of BMP adoption needed to achieve the nutrient reduction goals and milestones in major river basins.

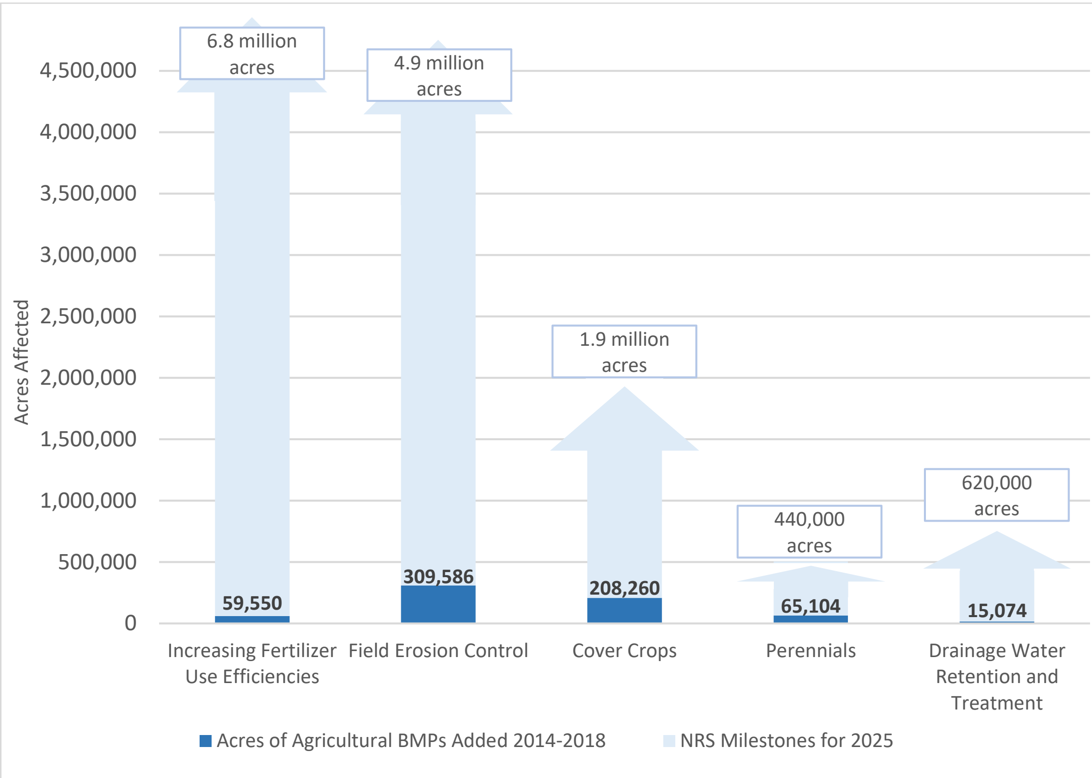
Achieving NRS goals depends on landowners and producers adopting millions more acres of BMPS, such as:

- Cover crops and other continuous living cover vegetation;
- Optimal use of nitrogen fertilizer and manure;
- Cropland erosion control practices; and
- Storing and treating tile drainage waters.

Minnesota has made significant progress during the past 5 years to establish tools to help track BMP adoption progress. BMPs adopted through all major government programs are tracked through a new web-based system entitled, "Healthier watersheds: Tracking the actions taken," which now shows new

BMP adoption at the same scales needed for NRS progress evaluation. Additionally, satellite imagery advancements are beginning to provide useful snapshots on the use of conservation tillage and cover crop practices.

As the figure below shows, between 2014 and 2018 Minnesota has added many BMPs through government assistance programs that reduce nutrient pollution. However, these new practices represent only a small fraction of the NRS scenario goals needed to reach 2025 milestones.



Comparing the actual acres of agricultural BMPs adopted through government programs to the total number of acres needed to meet NRS goals by 2025, showing that Minnesota has a long way to go.

New BMPs adopted through government funding programs achieved the following percentage of acres needed for reaching 2025 NRS milestones:

- 1% of nutrient efficiency acres;
- 10% of cover crops and perennials;
- 6% of conservation tillage and erosion control acres; and
- 2% of the tile drainage treatment acres.

It is clear that the scale of agricultural BMP adoption through government programs alone has not been on-pace to achieve 2025 NRS milestones thus far. Because private adoption of practices outside of government programs are also critical for increasing the rate of BMP adoption, this progress report also considered indicators of overall BMP adoption in the state derived from survey information, sales data, satellite imagery findings, soil testing and other sources of information.

Most of these overall indicators show trends during the past 5 to 10 years also show that Minnesota is not on track to reach the needed scales of change for meeting nutrient reduction goals.

Steps for next 5 years – Cropland practices

During the next 5 years, Minnesota partner agencies and organizations will need to identify and address the primary social, economic, and human dimension barriers impeding the scaling-up of new BMP adoption. Strengthening Minnesota's soil-health building emphasis and new private-public partnerships for 4R nutrient stewardship will also be very important.

Regulatory practices: Wastewater, urban stormwater, rural septic systems and feedlots

In addition to practices on cropland, reducing nutrients from regulated urban and rural sources is also important for meeting NRS goals.

Wastewater

The NRS calls for continued phosphorus reductions through limits in wastewater permits. It also outlined steps to make progress with wastewater nitrogen removal.

Much of the 70% reduction in wastewater phosphorus discharges occurred prior to the 2014 NRS. Statewide, wastewater dischargers have maintained these improvements and achieved additional reductions in alignment with the NRS. Currently, 90% of municipal wastewater flow volumes across the state have phosphorus limits.

One of the first NRS steps for reducing nitrogen from wastewater was to increase monitoring. Minnesota now has 255 facilities regularly monitoring nitrogen in their effluent, which represents the majority of wastewater flow volumes. Estimated statewide nitrogen loads from wastewater have generally remained steady, increasing slightly along with population and precipitation.

Other regulatory programs for urban stormwater, rural septic systems, and feedlots continued to make progress that is in-line with the NRS:

- Regulated stormwater requirements are applying to more urban areas, and there are more requirements for reporting progress on annual phosphorus and sediment reductions.
- For septic systems, more than 13,000 annual inspections show a decrease in imminent public health threats, which is consistent with meeting the NRS milestone. However, continued work is needed to further reduce health threats and to better protect groundwater from untreated septic system discharges.
- Feedlot inspections showed a high rate of compliance (about 97%) related to runoff at the feedlot facility itself. However, inspections of land application of manure showed considerable room for improvement concerning setbacks from waters, rates of nitrogen applied, record-keeping practices, and soil phosphorus testing and management.

Steps for next 5 years – Regulatory programs

During the next 5 years, the MPCA and partner organizations need to continue taking the steps outlined in the NRS for achieving nitrogen reductions from wastewater, while at the same time maintaining and continuing the progress with phosphorus. Continued progress with urban stormwater, septic systems and manure spreading will also be important.

Additional steps to take in the next 5 years

At this mid-way point to the NRS milestones, indicators of progress suggest that existing efforts alone are not likely sufficient for reaching the scale of change needed to achieve nutrient reduction goals. Building on the steps listed above, Minnesota needs to:

1) **Maximize the multiple benefits of NRS practices by coordinating with other plans and strategies that use similar practices to achieve resiliency to climate change and ecosystem improvements.**

NRS implementation should be increasingly coordinated and integrated with other water plans and strategies, at state and local levels, to inspire the needed scale of change for nutrient reduction, while at the same time maximizing multiple benefits such as:

- Greenhouse gas reductions;
- Sediment reduction to waters;
- Resiliency to climate variability;
- Long-term agricultural; sustainability and profitability;
- Wildlife habitat improvement;
- Drinking water source protection (for public and private wells);
- Lake water quality improvement; and
- Other ecosystem benefits.

Reducing nutrient pollution will help keep Minnesota streams healthy for aquatic life and recreation.

2) **Identify and address social, economic and other human dimension obstacles to scaling-up BMP implementation.**

Refine effective, socially-acceptable and financially feasible approaches for programs, policies and incentives that will increase rates of BMP adoption. Plans should be developed and implemented to address hindrances to large-scale adoption. Increase support for private-public partnerships that are achieving success with new practice adoption, including the Agricultural Water Quality Certification Program.

3) **Use the latest research to continue refining the optimal combination of practices that will achieve the needed nutrient reductions in our waters.**

Concurrent with ongoing NRS implementation, evaluate recent scientific findings to set the stage for an updated NRS in 2024. A team of scientists should develop alternative scenarios that ensure Minnesota is moving forward with:

- The most effective BMPs;
- Accurate nutrient reduction potential estimates;
- Optimal combinations of practices to achieve goals; and
- Updated implementation cost estimates.

4) **Optimize wastewater nitrogen treatment**.

Define strategies to reduce wastewater nitrogen discharges through optimization of nitrogen and phosphorus removal, emphasizing use of existing infrastructure.

Nutrient Reduction Strategy

August 2020

Appendix A: State-level Nutrient Reduction Program Advancements

5-year Progress Report on Minnesota's Nutrient Reduction Strategy

MINNESOTA

Appendix A- State-level Nutrient Reduction Program Advancements

Appendix A to Minnesota's Nutrient Reduction Strategy 5-year progress report (2020)

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Minnesota Nutrient Reduction Strategy 5-year Progress Report – Appendix A

Contents

This appendix to the Nutrient Reduction Strategy (NRS) 5-year Progress Report summarizes examples of the most influential programs and initiatives related to nutrient-reduction approaches outlined in Chapter 6 of the 2014 NRS. This document expands on the program progress that is included in section 2 of this progress report: P*rograms – Are the NRS strategies progressing?* It is important to note that many of the programmatic advances listed below influence a broad range of nutrient-reducing activities. While many of the programs listed in this document apply to numerous strategies from the 2014 NRS, each program is listed once.

1 Implementation of overarching recommended actions

1.1 Statewide education and outreach

The NRS recommended a statewide nutrient education/outreach campaign that included several specific educational approaches, such as bringing local watershed staff together with people impacted by nutrients in downstream communities. While a statewide systematic nutrient education and outreach campaign does not currently exist, many nutrient-related educational events and programs have occurred on a statewide basis since 2014 and are noted below. Many of these educational events and programs are applicable to other strategies.

1.1.1 Governor's 25% by 2025 initiative

In 2017, Minnesota's Governor Mark Dayton hosted a series of town hall meetings to promote 25% improvements in Minnesota's water quality by 2025. More than 2,000 people attended these meetings to discuss nutrients and other water pollution issues. The town hall meetings were not only educational, but also provided opportunities to involve stakeholders in identifying solutions (which was also emphasized in the NRS). Attendees provided over 3,500 suggestions on how to improve Minnesota's water quality by 2025. More information is available at: https://www.eqb.state.mn.us/content/25-2025-overview.

1.1.2 Interaction between shrimpers and Minnesota farmers

Downstream shrimpers from Louisiana traveled to Minnesota in 2018 to share stories about how upstream management of lands along the Mississippi River affects their livelihood in the Gulf of Mexico. The event provided an opportunity to exchange ideas and learn from each other. A summary of this event can be found at: https://www.mprnews.org/story/2018/08/28/shrimpers-share-impact-of-dead-zone-in-mississippi-river-in-minnesota-farmers

1.1.3 Technical Training and Certification Program for conservation professionals

Established in 2015, the Technical Training and Certification Program is a collaborative effort between the Board of Water and Soil Resources, the Natural Resources Conservation Service, the Minnesota Association of Conservation District Employees and the Minnesota Association of Soil and Water Conservation Districts. The program efficiently provides training to develop and maintain a highly trained, technically skilled workforce of natural resource professionals capable of meeting the conservation delivery needs of Minnesota.

1.1.4 Nitrogen Smart Training Program

In 2016, the University of Minnesota Extension Service in partnership with the Minnesota Corn Growers Association started a new "Nitrogen Smart" educational program. From 2016 to 2018, 36 nitrogen fertilizer management educational events were conducted. The events reached over 500 farmers and over 100 agronomists. When surveyed several months after the events, 75% of farmers indicated that they intended to make a change in the way they manage nitrogen during the next growing season. Estimated nitrogen fertilizer reductions from these changes exceed 2 million pounds per year. An on-line version of the training is also available. More information is available at: https://extension.umn.edu/courses-and-events/nitrogen-smart.

1.1.5 Formation of the Agricultural (Ag) Water Quality Solutions Workgroup and framework to establish voluntary Farmer-Led Councils

In fall and winter of 2016, the MDA and Environmental Initiative convened 15 Minnesota agricultural organizations, cooperatives, and companies to create a plan that would significantly improve water quality practices related to agriculture. The Ag Water Quality Solutions Workgroup worked with technical experts across academia, private industry, and government to help find strategies and technologies that would both create significant progress in water quality practices based on the best science available and lead to widespread adoption of those practices. The Ag Water Quality Solutions Workgroup unanimously agreed to a single idea that could improve water quality practices and would also be generally accepted by farmers—to establish and fund voluntary Farmer-Led Councils to implement and demonstrate practices in an area. The group presented a final framework capturing this idea to the Governor in 2017. More information is available at: https://environmental-initiative.org/work/agricultural-water-quality-solutions/.

1.1.6 University of Minnesota Nutrient and Nitrogen Management Conferences

The University of Minnesota Extension along with the Minnesota Agricultural Water Resources Center organizes two annual statewide conferences: "The Nutrient Management Conference" started in 2009 and "Nitrogen: Minnesota's Grand Challenge and Compelling Opportunity Conference" started in 2015. These two conferences bring relevant findings from University of Minnesota research and from others on the agronomic management and environmental stewardship of nitrogen and other nutrients in crop production. The events attract over 400 producers, crop advisors, agency staff and other stakeholders annually. Evaluations consistently show a high level of relevance, satisfaction with the quality of information delivered, and impact of the programs. Surveys show that over 2.5 million acres are being influenced by these two educational programs yearly. Minnesota's Nutrient Reduction Strategy was highlighted during the most recent conferences. More information at: https://mawrc.org/events/

1.1.7 Annual Conservation Tillage Conference

For the last several years, the University of Minnesota has held an annual Conservation Tillage Conference, with support from the state's soil and water conservation districts and the Minnesota corn and soybean commodity groups. Although it began with a focus on conservation tillage, the conference has grown to provide farmers, crop advisors, and others in the agriculture community with information on a range of soil health topics, including the use of cover crops, nutrient management, and integrating livestock into cropping systems. The name of the conference was recently changed to "Soil Management Summit." Ninety percent of attendees said they would use the conference information in their work or on their farm during the following year.

1.1.8 Agricultural BMP Guidance and Handbooks

Minnesota's Agricultural BMP Handbook was updated in 2017. The handbook includes updated BMP descriptions and effectiveness information for over 30 different BMPs and can be found at: https://wrl.mnpals.net/islandora/object/WRLrepository:2955.

In addition, MDH and the Minnesota Rural Water Association recently worked with the State NRCS Office to develop an agricultural BMP practices booklet for groundwater *Cropland Conservation Practices for Protecting Groundwater*, which can be found at https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd936806.pdf.

1.1.9 Minnesota Public Drainage Manual (MPDM) Update

The MPDM which was first published in 1991 and updated in 2016, provides detailed information and guidance about Minnesota Statutes, Chapter 103E Drainage law and associated topics. The MPDM is used by a variety of practitioners as a practical guide for navigating Minnesota's public drainage process. The MPDM is an important reference for drainage authorities, attorneys, engineers, viewers, drainage inspectors, and others involved with Chapter 103E drainage systems. The update includes a newly added chapter on BMPs to provide users with a way to identify and consider applicable BMPs for reducing nutrients and sediment into drainage waters. The MPDM provides guidance but is not rule or law. More information is available at: https://drainage.pca.state.mn.us/index.php/Main_Page.

1.1.10 DNR workshops and training to lake associations and local government

The Minnesota Department of Natural Resources (DNR) training program for local government and lake associations concerning lake protection from nutrients was increased. The DNR workshops provided local government staff with specific guidance on phosphorus reduction goals (in pounds per year) for most lakes in their jurisdictions. Workshops also provided training on methods of prioritization for lake protection. In addition, workshops provided strategies to reduce phosphorus loading to lakes through descriptions of successful local government efforts to protect lakes from nutrient pollution.

1.1.11 Minnesota's Water Research Digital Library (MNWRL)

The Minnesota Department of Agriculture began developing the MNWRL in 2011 in consultation with a wide range of stakeholders. This library houses an inventory of current and past water research that supports water protection, restoration, and management activities across the state in one centralized location. At the end 2018, the library includes nearly 2,800 diverse research articles and scientific reports. The library can be accessed at https://wrl.mnpals.net/.

1.2 Integrate basin reduction needs with watershed planning goals and efforts

The state's Coordinated Watershed Management Approach has continued to advance since the NRS was completed in 2014.

1.2.1 Total Maximum Daily Loads (TMDLs)

The Minnesota Pollution Control Agency (MPCA) has intensively monitored water quality conditions in all 80 watersheds (HUC-8 level). Nearly 700 lakes and over 800 river miles have been identified as impaired due to nutrients. Over 60% of the nutrient-impaired waters have approved TMDL plans that identify the needed reductions in nutrient loading from various sources. River eutrophication standards, which were approved in 2015, are also now being used to assess beneficial uses of flowing waters in the state and has led to identifying additional impaired waters. A large-scale TMDL to address phosphorus reductions in the Lake Pepin watershed is currently underway. More info at: https://www.pca.state.mn.us/water/total-maximum-daily-load-tmdl-projects

1.2.2 Watershed Restoration and Protection Strategies (WRAPS)

WRAPS have been developed for 53 of 80 watersheds in the state, with most others approaching completion. Of the 40 WRAPS completed prior to 2019, 16 include HUC-8 level nutrient reduction goals that align with the NRS (Limno Tech 2019). Guidance on nutrient load reduction targets for HUC-8 watershed outlets was recently completed, providing specific anthropogenic fair-share nutrient load reduction for each HUC-8 watershed that would cumulatively achieve NRS goals at state borders. Further information on targets can be found linked at https://www.pca.state.mn.us/water/nutrient-reduction-strategy

Restoration and protection strategies for groundwater (GRAPS) are being developed for watersheds with elevated nitrate. GRAPS help support groundwater and drinking water protection at the watershed scale. Each GRAPS provides local partners with a description of groundwater resources and issues/concerns so that local watershed stakeholders can consider groundwater protection and restoration needs as they begin the One Watershed, One Plan process. The Minnesota Department of Health has thus far completed GRAPS for 14 watersheds, most of which have elevated groundwater nitrate situations. Additional GRAPS are under development. More information is available at: https://www.health.state.mn.us/communities/environment/water/cwf/localimplem.html.

1.2.3 One Watershed, One Plan (1W1P)

Local government partnerships based on watershed boundaries use WRAPS, GRAPS, and other information to develop prioritized, targeted, and measurable comprehensive watershed management plans. These comprehensive watershed management plans have now been completed in 12 watersheds, with another 20 currently under development.

Comprehensive watershed management planning through the 1W1P program is rooted in work initiated by the Local Government Water Roundtable, which has membership from Association of Minnesota Counties, Minnesota Association of Watershed Districts, and Minnesota Association of Soil and Water Conservation Districts). In 2013, the Roundtable developed recommendations to BWSR on how local governments could develop plans on a watershed basis. In 2014, BWSR began implementing the 1W1P program on a pilot basis and the program was formally adopted by the BWSR Board on March 23, 2016.

The 1W1P program is one of the key initiatives for Minnesota to help achieve watershed quality restoration and protection goals, including goals set in the Minnesota Nutrient Reduction Strategy. The purpose of the One Watershed, One Plan program is to develop comprehensive watershed management plans that:

- Align local water planning purposes and procedures under Minnesota Statutes §103C and 103D on watershed boundaries to create a systematic, watershed-wide, science-based approach to watershed management.
- Acknowledge and build off existing local government structure, water plan services, and local capacity.
- Incorporate and make use of data and information, including watershed restoration and protection strategies under Minnesota Statutes §114D.26.
- Solicit input and engage experts from agencies, citizens, and stakeholder groups; focus on implementation of prioritized and targeted actions capable of achieving measurable progress.

- Serve as a substitute for a comprehensive plan, local water management plan, or watershed management plan developed or amended, approved, and adopted, according to Minnesota Statutes §103B, 103C or 103D.

According to Minnesota Statutes §103B.801, one of the nutrient-related items that Comprehensive Watershed Management Plans must address is "Surface water and ground water quality protection, restoration, and improvement, including prevention of erosion and soil transport into surface water systems."

The 1W1P program goals and purpose will help set a planning framework to meet NRS goals and milestones. To learn more about watersheds developing 1W1Ps, go to the interactive map at: https://bwsr.state.mn.us/one-watershed-one-plan-participating-watersheds, https://www.pca.state.mn.us/water/watersheds and for other information go to: https://bwsr.state.mn.us/one-watershed-one-plan.

1.2.4 Watershed Conservation Planning Initiative (WCPI)

The Minnesota NRCS office entered into a contribution agreement with BWSR to increase landowner and producer readiness to implement conservation practices in seven major watersheds. The purpose of WCPI is to establish a partnership framework for cooperation between NRCS, BWSR and SWCDs on activities that involve the planning and implementation of conservation activities in these watersheds. Goals of the program include: 1) increase technical capacity of SWCDs to conduct resources assessments and prepare conservation plans within the selected watersheds; 2) target conservation planning assistance to high priority acres in these watersheds; 3) increase landowner readiness and participation in conservation programs; and 4) accelerate conservation practice implementation along with quantifying the environmental benefits. The program budget totals $3 million and is equally funded by NRCS and BWSR through the Clean Water Fund through December 2021. More info at: https://bwsr.state.mn.us/grant-profile-watershed-conservation-planning-initiative

1.2.5 Section 319 Small Watersheds Focus Program

The MPCA restructured the Section 319 program in 2018 to provide up to 16 years of grant funding to support implementation through multiple grant cycles for selected small watersheds. Twenty watersheds across the state have been selected thus far as Focus Watersheds that support local goals expressed in local water plans along with overall state priorities. Selected small watersheds receive financial and technical support to sustain and build partner and landowner relationships important for addressing water quality restoration and protection needs. Over $2.6 million have been awarded annually in recent years. A detailed plan following the U.S. Environmental Protection Agency (EPA) watershed-based planning guidance including nine key elements is completed for each watershed. Upon approval by EPA, watersheds will be prioritized for Section 319 grant funding. This program is intended to make measurable progress for the targeted waterbodies in Focus Watersheds, ultimately restoring impaired waters and preventing degradation of unimpaired waters. Additional information is available at: https://www.pca.state.mn.us/water/section-319-small-watersheds-focus.

2 Implementation of recommended agricultural strategies

To achieve the goals and milestones of the NRS, strategies were identified to support the increased adoption of the BMPs identified in Chapter 5 of the NRS. These strategies fall into the following categories: Stepping Up Agricultural BMP Implementation in Key Categories; Support for Advancing BMP Delivery Programs; Economic Strategy Options; Education and Involvement Strategies; Research

Strategies; and Demonstration Strategies. Major advancements since 2014 for these categories are described below. Note that the programs and efforts identified below do not include all efforts, but represent prominent examples of efforts with statewide or regional significance.

2.1.1 Minnesota Corn Growers collaborative efforts

Private industry commodity groups, such as the Minnesota Corn Growers Association, invest heavily in research to improve nutrient management, cover cropping, irrigation, bioreactors, and other agronomic practices that benefit water quality: http://www.mncorn.org/research/water-quality/. The Minnesota Corn Growers Association use corn check-off dollars to support research and extension positions at the University of Minnesota who work in several different areas of water quality aspects of corn cropping systems. Minnesota Corn Growers are also involved in several of the collaborative efforts described in this section.

2.1.2 Forever Green Initiative

The Forever Green Initiative brings together researchers from multiple departments at the University of Minnesota, including plant breeding, agronomy, food science and economics, with a goal to develop new high value commodity crops for conservation purposes. Many of these new crops could fit into a corn and soybean rotation thereby providing ground cover from fall to spring where it is otherwise often lacking. Private partners participating in the Forever Green Initiative include General Mills and PepsiCo, amongst others.

The Minnesota Department of Agriculture (MDA) receives Clean Water Funds to support the Forever Green Agricultural Initiative at the University of Minnesota. Research projects are selected through a request for proposal process administered by the University of Minnesota. The MDA oversees the distribution of funds and coordinates reporting on progress results and outcomes. More information is available at: https://www.forevergreen.umn.edu/ and https://www.mda.state.mn.us/protecting/cleanwaterfund/forevergreen.

The Forever Green Initiative hired a Supply Chain Development Specialist and Market Development Opportunity Specialist in 2019.

2.1.3 Discovery Farms

The farmer-led Minnesota Discovery Farms Program is an example of a private-public partnership program within the state of Minnesota. Minnesota Discovery Farms collects field scale water quality information from different types of farming systems across the state. Their mission is to gather water quality information under real-world conditions and engage farmers in “peer to peer” learning to support adoption of key conservation practices. Minnesota Discovery Farms has increased its core farms to eleven farms across different parts of Minnesota. Learning experiences are shared with other farmers through various educational activities. More information is available at: https://discoveryfarmsmn.org/resources/.

2.1.4 Partnerships such as the Cedar River Watershed Partnership

Private Industry has collaborated with public entities in local watershed partnership efforts. The Cedar River Watershed Partnership began in 2018 as a unique public-private-nonprofit collaboration, including leadership from Hormel Foods, Land O’Lakes SUSTAIN, and Central Farm Service. The partnership provides farmers with tools and resources to help them adopt new farm management strategies that improve the soil, water and economic health of their farms and address water quality challenges in the

454,000-acre Cedar River Watershed area. More information is available at: https://environmental-initiative.org/work/cedar-river-watershed-partnership/.

Another example of a private-led partnership includes Fishers and Farmers Partnership for the Upper Mississippi River Basin. More information is available at: https://fishersandfarmers.org/.

2.1.5 Minnesota Agricultural Water Quality Certification Program

Initiated in 2015, the Minnesota Agricultural Water Quality Certification Program (MAWQCP) is a collaborative effort led by the Minnesota Department of Agriculture in partnership with private industry, federal agencies, and other state agencies. The program certifies farmers for their land in a way that protects water quality. If farmers implement and maintain approved farm management practices, the practices are deemed in compliance with new regulation for a period of ten years. Part of the certification process is an evaluation of the nutrient management practices; including a check to ensure that nutrient BMPs are followed. By 2020, the MAWQCP certified more than 900 farmers representing over 600,000 acres of certified land. These producers have installed over 1,800 new practices in the state, resulting in over 46,000 pounds of phosphorus and over 75,000,000 million pounds of sediment from entering waterways and streams. In addition, new nutrient management practices have increased as a result of the MAWQCP in the last few years, with approximately 2,000 acres added in 2018 alone. More information is available at: https://mda.state.mn.us/environment-sustainability/minnesota-agricultural-water-quality-certification-program.

2.1.6 4R Certification led by Private Agricultural Industry

In 2020, the Minnesota Crop Production Retailers Association (MCPR) is launching a 4R Nutrient Stewardship program for agricultural retailers. This voluntary, industry-led certification program consists of 39 science-based best management practices and nutrient standards that will be audited annually by third party auditors. The certification program, which has been in development for the past couple years, will be governed by an eleven-member board called the Minnesota Nutrient Stewardship Council (MNSC) and administered by MCPR. This approach provides a science-based framework for plant nutrition management and sustained crop production, while considering specific individual farms' needs.

2.1.7 Working Lands Watershed Restoration Feasibility Study and Program Plan

In 2018, the Minnesota Board of Water and Soil Resources (BWSR), in collaboration with many others, completed a feasibility study and plan for a future Working Lands Watershed Restoration Program – a program that would provide incentives for landowners to plant perennials and cover crops that improve water quality. The report includes an overview of promising crops and livestock enterprises, including perennial grasses and winter annual cover crops that keep roots in the soil and vegetation on the land throughout the year, improving soil health and wildlife habitat, storing carbon, and capturing excess nitrogen.

The study was directed by the 2016 Minnesota Legislature with the goal of improving water quality by increasing living cover on the landscape at a watershed scale. Since completion of the feasibility study, BWSR staff have focused efforts on encouraging establishment of living cover in vulnerable wellhead protection areas, where change in land cover across relatively small areas can measurably improve drinking water quality. More information is available at: https://bwsr.state.mn.us/planning/WLWRP/wlwrp.html.

2.1.8 Red River Basin Initiative – Landowner Permanent Easements and Storage

The NRCS launched the Red River Basin Initiative (RRBI) in 2011, which covers parts of Minnesota, North Dakota and South Dakota, to reduce the frequency and severity of flooding, reduce erosion, and improve water quality and wildlife habitat through voluntary conservation efforts on private lands. The program aimed to create 30,000 acre-feet of floodwater storage and restore 25,000 acres of wetlands with conservation easements by its completion in 2018.

More information is available:
https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/programs/initiatives/?cid=stelprdb1117397

2.1.9 Re-Invest in Minnesota (RIM)

Landowners have received assistance through the Re-Invest in Minnesota (RIM) Reserve Conservation Easement program for over 30 years. By the end of 2018, nearly 7,000 easements were recorded on almost 300,000 acres statewide during the life of the program (Figure 1).

RIM stand-alone easements have been funded primarily from Capital Funding (bonding), but with the passage of the Clean Water, Land and Legacy Amendment in 2009, funding for RIM has been accelerated primarily due to the Clean Water Fund (water quality) as well as the Outdoor Heritage Fund (habitat).

- *Before Minnesota's Conservation Reserve Program (CREP)*: Wetlands and their associated uplands, as well as buffers, were the primary agricultural RIM easements from 2014 to the start of Minnesota CREP funding. In addition, RIM was used in the forested areas of Northern Minnesota for a variety of protection efforts including wild rice lakes, surface source water, and habitat.
- *During Minnesota's CREP*: In the 54 county Minnesota CREP area, RIM easements have focused solely on agricultural land that are combined with CRP as a part of Minnesota CREP. In addition, RIM grasslands efforts have been utilized in the western half of the state. RIM also continues to be used in the forested areas of Northern Minnesota. Information on Minnesota's CREP is provided in section 2.1.20.

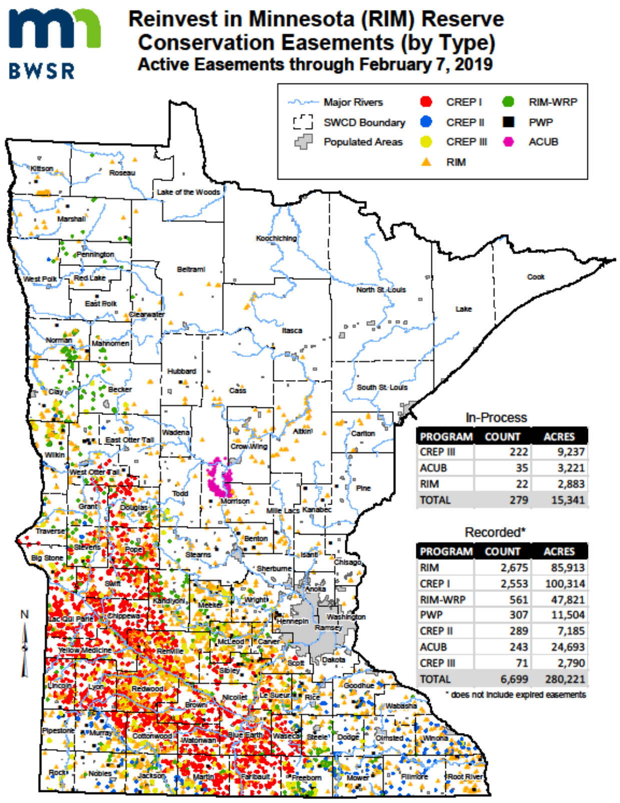


Figure 1. RIM easements through February 2019.

2.1.10 Minnesota Office for Soil Health

In 2018, the Minnesota Board of Water and Soil Resources (BWSR) and the University of Minnesota Water Resources Center (WRC) initiated the Minnesota Office for Soil Health (MOSH). A fulltime State Soil Health Specialist was hired in 2019.

The purpose of MOSH is to support increasing awareness and benefits of soil health and soil conservation through research and outreach that expand the tools and skills of Minnesota's conservation delivery community. The mission of MOSH is to 1) protect and improve soil resources and water quality by developing the knowledge, skill, and ability of local conservationists to more effectively partner with landowners and other stakeholders and 2) to promote sustainable soil and land management. An emphasis is placed on the importance of soil health and identifying the water quality and economic impacts of applied land and water management practices. More information is available at: https://www.wrc.umn.edu/mosh.

2.1.11 Minnesota's Buffer Law

In 2015, a Minnesota Buffer Law was passed, requiring 50-foot perennial vegetative buffers along lakes, rivers, and streams (by November 1, 2017) and 16.5 feet along public ditches (by November 1, 2018). The law provides flexibility for landowners to install alternative practices with equivalent water quality benefits. Grants provided financial assistance that included landowner technical and financial support, equipment purchases and other supportive activities. SWCD progress reports are encouraging, with over

99% compliance with buffers along lakes, rivers and streams, and over 90% compliance with public ditch buffers. More information is available at: https://bwsr.state.mn.us/minnesota-buffer-law.

2.1.12 DNR's "Innovative Shoreland Standards Showcase"

The DNR recently updated their website to promote examples of innovative shoreland practices and ordinance development across the state. The current shoreland rules were last updated in 1989 and do not address emerging problems with declining water quality and habitat loss due to contemporary shoreland development, or the effects of climate change. These examples emphasize that shoreland communities can do more to develop riparian vegetation management standards to protect the water bodies they live on. See the showcase at: https://www.dnr.state.mn.us/waters/watermgmt_section/shoreland/innovative-standards.html.

2.1.13 Nutrient Management Initiative

The Nutrient Management Initiative is a program offered by the Minnesota Department of Agriculture to engage farmers and their crop advisors in evaluating on-farm practices that improve fertilizer efficiency for corn. The program evaluates economic outcomes and offers financial support to the participating farmers and their crop advisors, thereby minimizing the economic risk of trying a new practice. New opportunities have also been added recently for cover crop on-farm trials.

Participants of the nutrient management initiative can select a new fertilizer use practice to compare to their normal practice over three replicated trials. Practices available to select include; changing the nitrogen rate, testing of timing of nitrogen application or nitrogen stabilizer products, or cover crops. Crop and nutrient management information and yield data is collected from each trial plot and the nitrogen use efficiency is estimated. The program also offers an advanced option where six nitrogen rates are replicated three times to enable the estimation of the economic optimum nitrogen rate.

From 2015 to 2018, a total of 466 trials in fields covering over 32,000 acres have helped provide greater producer assurance related to changing nutrient practices for economic and environmental outcomes. An average of 33 crop advisors have participated each year since 2015. More information is available at: https://www.mda.state.mn.us/protecting/cleanwaterfund/onfarmprojects/nmi.

2.1.14 Development of Soil Erosion Prediction Tool

The BWSR, the University of Minnesota, and Iowa State University have been working together since 2016 to develop a long-term program to systematically provide cover crop, crop residue, land cover and soil erosion data in Minnesota counties with at least 30% agricultural land use. The goal is to quantify and track this information on multiple scales and to calculate estimated average annual and daily soil loss due to wind and water erosion. The BWSR contracted with the University of Minnesota to provide more comprehensive snapshots of crop residue cover levels and cover crop practices in Minnesota.

One of the major components of Minnesota's crop residue and cover crop satellite imagery project is to deploy the Daily Erosion Project (DEP) web application in Minnesota. The Daily Erosion Project application provides data on the following parameters in an easy to use geospatial interface (https://www.dailyerosion.org/): precipitation, runoff, soil erosion (detachment), soil erosion (hillslope soil loss), along with wind erosion to be added in the future. The DEP will be utilized to help track soil loss by water and wind erosion on an annual basis and Minnesota will have ability to look at trends in the data over time. Data from this project will be useful in looking at regional, county, and watershed scale comparisons. This project is moving from prototype development into production mode in 2020 and 2021.

2.1.15 Nitrogen Fertilizer Management Plan/Groundwater Protection Rule

Minnesota completed a Nitrogen Fertilizer Management Plan in 2015, which focuses on groundwater nitrate reduction strategies. One part of that plan outlined a phased strategy to mitigate high groundwater nitrate. The plan can be found at: https://www.mda.state.mn.us/pesticide-fertilizer/minnesota-nitrogen-fertilizer-management-plan.

In addition, MDA adopted a groundwater protection rule in 2019 that outlines how an initial voluntary approach can become regulatory in high-nitrate drinking water supply management areas where fertilizer BMPs are not adopted or groundwater nitrate levels increase. The new rule also restricts nitrogen fertilizer applications in the fall and on frozen soils in both vulnerable groundwater areas and drinking water supply management areas with elevated nitrate. More information is available at: https://www.mda.state.mn.us/nfr. An interactive map of vulnerable groundwater is available here: https://mnag.maps.arcgis.com/apps/webappviewer/index.html?id=47a342afe6654640b935c8e76023da92.

2.1.16 Multipurpose Drainage Water Management

Minnesota has approximately 19,150 miles of drainage ditches and extensive untallied miles of subsurface tile installed and maintained under what currently is Minn. Stat. ch. 103E Drainage law. These systems are owned by the benefited property owners and administered by a county, joint county, or watershed district drainage authority.

Minnesota drainage law §103E.015, subd. 1 was amended in 2014 to require drainage authorities to consider multipurpose water management criteria before establishing a drainage project, such that the projects provide adequate drainage capacity while reducing downstream peak flows and flooding, reducing erosion and sedimentation, improving water quality and improving aquatic habitat. The Multipurpose Drainage Management (MDM) program is part of BWSR's competitive Clean Water Fund grants. Examples of MDM practices include, but are not limited to:

- Side inlet controls (NRCS Practice Standard 410 Grade Stabilization Structure)
- Grassed Waterway (NRCS Practice Standard 412 Grassed Waterway)
- Storage and Treatment Wetland Restoration
- Controlled subsurface drainage (NRCS Practice Standard 587 Structure for Water Control)
- Saturated Buffer (NRCS Practice Standard 604 Saturated Buffer)
- Bioreactor (NRCS Practice Standard 605 Denitrifying Bioreactor)
- Water and Sediment Control Basin (NRCS Practice Standard 638 Water and Sediment Control Basin)

More information is available at: https://bwsr.state.mn.us/grant-profile-multipurpose-drainage-management.

2.1.17 Center for Changing Landscapes

The Center for Changing Landscapes at the University of Minnesota has studied social and economic factors that influence conservation program success. Project findings can be found at: https://umn.maps.arcgis.com/apps/Shortlist/index.html?appid=8ea0c0a8d3b34eb0a68af0b4a71e5d07.

2.1.18 Clean Water Fund

Minnesota citizens committed to a 25-year Clean Water Legacy funding initiative as part of the State's role in that partnership. During the past five years, Minnesota's Clean Water Legacy funding provided $50 to $74 million per year for implementing practices to restore and protect waters. This money helps support local capacity to implement BMPs for nonpoint and point source pollution reductions. Practices extend beyond agriculture and also include BMPs for stormwater, septic systems, stream bank stabilization, etc. Agricultural BMPs funded through the Clean Water Legacy Fund since 2010 are provided in Figure 2.

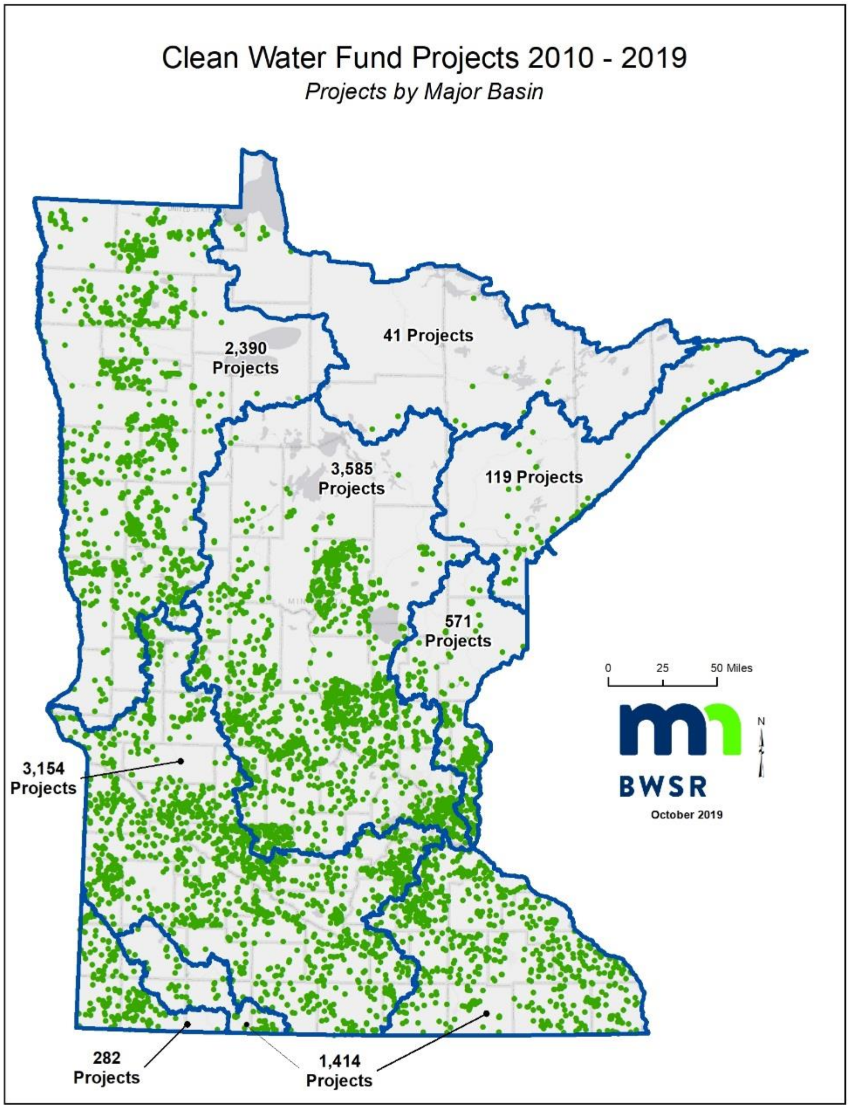


Figure 2. Projects funded by the Clean Water Fund 2010-2019

Beginning in 2015, the Minnesota State Legislature provided Clean Water Funds to the BWSR for grants to invest in building the capacity of local SWCDs. This grant targets four resource concern areas—Soil Erosion, Riparian Zone Management, Water Storage and Treatment, and Excess Nutrients—and supports increased capacity by funding expenses in the following categories: Staffing, Cost Share/Incentives, Technology/Capital Equipment, and Operations. This program has greatly improved the technical capacity of our SWCD staff to meet future needs and to implement critical conservation practices to meet Minnesota's water quality goals. More information on the Clean Water Fund is available at: 2018 Minnesota Clean Water Legacy Report.

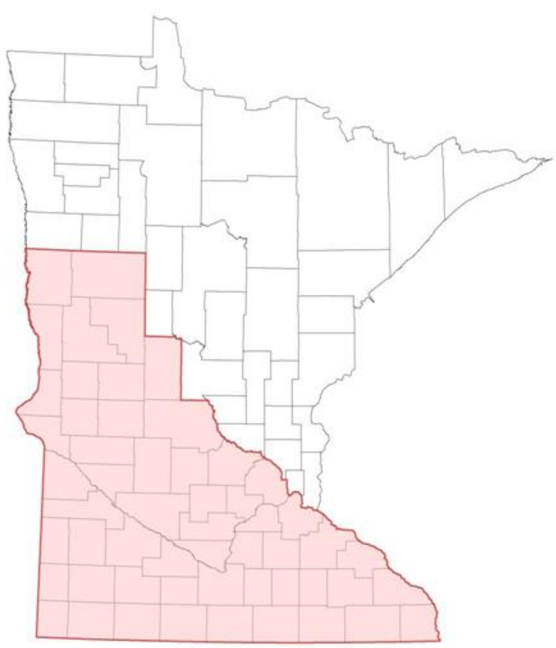
2.1.19 Watershed Based Funding Implementation Program

The BWSR is moving towards providing more systematic Clean Water Funding for local water management authorities on a watershed basis. The watershed-based funding model is intended to provide local governments throughout Minnesota with efficient, transparent and stable funding. To achieve this, BWSR envisions transitioning from project by project competitive grants to a coordinated watershed funding approach designed to increase water management outcomes, enhance accountability, and improve consistency and efficiency across the state. This approach will depend on comprehensive watershed management plans developed under the 1W1P Program or the Metropolitan Surface Water Management Act to provide assurance that actions are prioritized, targeted, and measurable. The efficiencies created by this change will benefit both organizations and landowners by streamlining processes, which will allow more projects to be implemented in a timely manner and ensure limited resources are spent where they are needed most. Watershed-based funding may also provide greater opportunities for local governments to leverage federal and private funding.

This program began as a pilot in 2017 and BWSR will be working with local, State, and Federal partners to finalize this program by 2021. For more information on this program: https://bwsr.state.mn.us/watershed-based-funding-implementation-program.

2.1.20 Minnesota Conservation Reserve Enhancement Program (CREP)

The Minnesota CREP began in 2017 with a goal of creating 60,000 acres of buffers, restored wetlands, and protected wellheads for drinking water. CREP is funded through USDA and State of Minnesota funds: approximately $350 million from USDA and $150 million from the State of Minnesota. Landowner sign-ups began in May 2017. During the landowner sign-up period of May 2017 through August 2018, a total of 290 applications received funding, representing 12,186 acres. Over 90% of the CREP practice acreages were for wetlands. Due to new federal Farm Bill negotiations and the federal government shutdown, no further sign-ups occurred for the remainder of 2018. More information is available below and at: http://www.bwsr.state.mn.us/crep/.



Background: Beginning in early 2014 The Board of Water and Soil Resources (BWSR) started discussions with local, state and federal agencies and organizations about the need to formulate a third Conservation Reserve Enhancement Program (CREP) in Minnesota (CREP I and CREP II protected over 107,000 acres). The discussions led to a two-year effort that ended in Governor Mark Dayton submitting the Minnesota CREP proposal to the USDA Secretary for funding consideration on 100,000 acres in December of 2015. The proposal focused on both water quality and habitat concerns in a 54-county area of southern and west central Minnesota.

The proposal was based on those watershed areas identified in the NRS as high priority for nitrogen and phosphorus load reductions. It also incorporated groundwater protection efforts by targeting land within Drinking Water Supply Management Areas with high and very high vulnerability to drinking water contamination.

The proposal for Minnesota CREP focused on four main Conservation Practices (CPs) that have been identified through the federal CRP:

- Grass Filter Strips (CRP CP 21)
- Wetland Restoration – 100-year Floodplain (CRP CP 23)
- Wetland Restoration – Non-floodplain (CRP CP 23a)
- Wellhead Protection Areas (CRP CP 2)

In January of 2017, the Minnesota CREP Agreement was signed by MN Governor Mark Dayton and U.S. Department of Agriculture Acting Secretary, Mike Scuse.

CREP is:

- Voluntary
- Locally-driven
- Targeted to the most environmentally sensitive acres

The four primary objectives of the Minnesota CREP are to protect 60,000 acres of the highest priority areas across 54 counties. It will:

- Target riparian areas and marginal agricultural land
- Restore hydrology, increase infiltration and provide flood mitigation
- Provide habitat for wildlife, non-game species and pollinators
- Reduce nitrate loading in drinking water supplies

Approximately $140 million of State funding has been appropriated to BWSR for Minnesota CREP. The remaining $10 million to reach the $150 million goal as well as an additional $25 million needed for lands tied to Minnesota CREP that are not eligible for CRP are expected to be secured during the next few years.

The majority of acres funded during the first year (2107-2018) are for floodplain wetlands, especially non-100 year floodplain wetlands.

2.1.21 USDA Programs

- **Mississippi River Basin Healthy Watershed Initiative (MRBI**) – The MRBI uses several Farm Bill programs, including the Environmental Quality Incentives Program (EQIP) and the Agricultural Conservation Easement Program (ACEP), to help landowners sustain America's natural resources through voluntary conservation. The overall goals of MRBI are to improve water quality, restore wetlands and enhance wildlife habitat while ensuring economic viability of agricultural lands. Historically, Minnesota has had several small watersheds in this program.

- **National Water Quality Initiative (NWQI)** – NWQI aims to accelerate voluntary, on-farm conservation investments and focused water quality monitoring and assessment resources where they can deliver the greatest benefits for clean water. Now in its eighth year, the NWQI is a partnership among the National Resources Conservation Service (NRCS), state water quality agencies and the EPA to identify and address impaired water bodies through voluntary conservation. NRCS provides targeted funding for financial and technical assistance in small watersheds most in need and where farmers can use conservation practices to make a difference. In Minnesota, NWQI work has been conducted in Seven Mile Creek in the Minnesota River basin and Whiskey Creek in the Red River basin. More information is available at: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/water/?cid=stelprdb1047761.

- **Regional Conservation Partnership Program (RCPP)** – The Regional Conservation Partnership Program (RCPP) promotes coordination of NRCS conservation activities with partners that offer value-added contributions to expand our collective ability to address on-farm, watershed, and regional natural resource concerns. Through RCPP, NRCS seeks to co-invest with partners to implement projects that demonstrate innovative solutions to conservation challenges and provide measurable improvements and outcomes tied to the resource concerns they seek to address. Minnesota had 10 implementation RCPP projects and 1 technical assistance RCPP in 2019. Several of these projects focused on water quality and nutrient reductions.
- **Conservation Stewardship Program (CSP)** – In 2019, almost $21 million was obligated into CSP contracts in Minnesota. This was a reduction from past years as a result of allocations changes made in the 2018 Farm Bill. The top activities planned on Agricultural lands in CSP for 2019 were associated with nutrient and pest management activities.
- **Environmental Quality Incentives Program (EQIP)** – Through EQIP, NRCS provides agricultural producers with financial resources and one-on-one help to plan and implement conservation practices. Using these practices can lead to cleaner water and air, healthier soil and better wildlife habitat, all while improving agricultural operations. Through EQIP, you can voluntarily implement conservation practices, and NRCS co-invests in these practices with the customer. Minnesota NRCS spent almost $27 million in EQIP in 2019, which was above the five-year funding average of $23 million. The top conservation practices funded in 2019 were Cover Crops, Waste Storage Facilities & Roofs and Covers, Conservation Cover and Residue and Tillage Management, No-Till.
- **Agricultural Conservation Easement Program** – The Agricultural Conservation Easement Program helps landowners, land trusts, and other entities protect, restore, and enhance wetlands, grasslands, and working farms and ranches through conservation easements. Under the Agricultural Land Easements component, NRCS helps American Indian tribes, state and local governments and non-governmental organizations protect working agricultural lands and limit non-agricultural uses of the land. Under the Wetlands Reserve Easements component, NRCS helps to restore, protect and enhance enrolled wetlands.
- **Emphasis on Source Water Protection –** The 2018 Farm Bill emphasized the importance of source water protection by prioritizing ten percent of the conservation title activities for this purpose. A key aim of this effort is to address nutrient issues affecting drinking water sources.

2.1.22 2018 Nitrate Report and Research on the Social Costs of Nitrogen

The 2018 Nitrate Report is updated annually by the Drinking Water Protection Section at the Minnesota Department of Health. The report includes information on Community Public Water Systems with source water nitrate levels of at least 3 milligrams per liter. The report contains information on water quality in drinking water, sources of drinking water, costs to address nitrate in public water systems. More information is available here:
https://www.health.state.mn.us/communities/environment/water/docs/nitrate.pdf

While costs to address nitrate in public water systems is well documented in reports such as the 2018 Nitrate Report, the social costs including damage costs to air, water, and climate, are not very well understood. Examples of recent research into this topic include:

- “The social costs of nitrogen” Keeler et al. 2016[1]. This study proposes a framework to understanding social costs of nitrogen that considers how each form of nitrogen causes damages at specific locations as it cascades through the environment. Results of the framework confirm that the social cost of nitrogen is not universal but depends where the nitrogen moves and the location, vulnerability, and preferences of populations affected by nitrogen. Results demonstrate the potential of integrated biophysical and economic models to better show the costs and benefits of nitrogen and help inform nitrogen management more efficiently.

- “Land-use changes and costs to rural households: a case study in ground water nitrate contamination” Keeler et al. 2014[2]. This study used a groundwater well contamination model to cost estimates for well remediation, replaces, and avoidance behaviors to estimate potential loss of economic value due to nitrate contamination in southeastern Minnesota from recent land use change (grassland to agricultural land). The study estimated a $0.7–12 million cost (present values over a 20-year period) needed to address the increased risk of nitrate contamination of private wells.

2.1.23 Research on Cover Crops to Reduce Producer Risks

The Environmental Initiative is working with Minnesota stakeholders to explore and design a research program to:

- Demonstrate, with sound actuarial data, that cover crops increase resiliency for farmers, at a level that induces the Risk Management Agency to adjust rates favorably for farmers that are using cover crops
- Demonstrate to lenders, crop insurance agents, etc. that cover crops have an economic benefit that can be captured

Through this work, the farm financial system will gain a better understanding of how on-field soil-health practices can mitigate crop insurance risk. The Cover Crop Insurance Incentive Project is undertaken in partnership with NRDC and support from The Walton Family Foundation. More information is available at: https://environmental-initiative.org/work/cover-crop-insurance-incentives/.

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[1] Keeler, B., J. Gourevitch, S. Polasky, Forest Isbell., Chris. Tessum, Jason. Hill, and Julian. Marshall. 2016. The social costs of nitrogen. Published 5 October 2016, Sci. Adv. 2, e1600219 DOI: 10.1126/sciadv.1600219

[2] Bonnie Keeler, B. and Stephen. Polasky. 2014. Land-use change and costs to rural households: a case study in groundwater nitrate contamination. Environ. Res. Lett. 9 (2014) 074002, (10pp).

2.1.24 MDA Clean Water Research Program

Since 2008, MDA has announced nine requests for research proposals. Goals of the Research Program include: (1) Identify underlying processes that affect water quality, (2) Evaluate the effectiveness of agricultural BMPs, and (3) Develop technologies to target BMPs to critical areas of the landscape. Many research projects are funded through this program. See https://www.mda.state.mn.us/environment-sustainability/clean-water-research-program for more information.

A few examples of recent research projects funded by MDA are noted below; however, research at the University of Minnesota includes many additional research projects related to nutrients:

- **Integrated Landscape Management for Agricultural Production and Water Quality.** The objective of this project is to quantify the individual and combined impacts of in-field, edge-of-field, and in-stream management practices on water quantity and quality at the small watershed scale in southern Minnesota. This is accomplished by measuring the individual and cumulative response to cover cropping, bioreactors, constructed wetlands and drainage ditch management on the hydrology, nitrate, phosphorus and sediment. The monitoring data is used in a watershed-scale (HUC-8) computer simulation model to help scale the impact of the practices to identify optimal combinations for water quality improvement. The project started in 2017 and is scheduled to end in 2020. More information is available at: https://www.mda.state.mn.us/integrated-landscape-management-agricultural-production-water-quality.
- **Measuring and modeling watershed phosphorus loss and transport for improved management of agricultural landscapes.** The objective of this project is to evaluate sources and dynamics of phosphorus mobilization within predominantly agricultural small watersheds. The temporal and spatial levels of phosphorus loss was monitored for two years within the Le Sueur Basin. The information is used in computer simulation models to quantify conservation practices' impact on the mobilization of dissolved or particulate phosphorus from agricultural fields within the watershed or remobilization of stored phosphorus in discharge or sediment. The project started in 2015 and ended in 2018.
- **Analyzing and optimizing denitrification in agricultural surface waters.** The objective of this project is to identify and examine areas within a watershed non-floodzone, floodzone, and in-channel that are more effective at denitrification. Denitrification is influenced by many environmental variables and the rate of denitrification varies considerably across the landscape and time of the year. A combination of laboratory and outdoor experiments were used to evaluate different conditions. Findings suggest that denitrification rates at a site that is periodically inundated in a ditch with a constructed floodplain has higher rates of denitrification than at a location that is periodically inundated in a trapezoidal-shaped ditch. An added benefit is to slow the flow to allow sediment to settle and reduce phosphorus loading. Examples of practices to accomplish this include two-stage ditches or ditch level water level control. The project started in 2013 and ended in 2017.

2.1.25 Metropolitan Council/University of Minnesota Evaluation of Sludge Incinerator Ash as a Phosphorus Source for Crop Production

Metropolitan Council Environmental Services is funding a multi-year field study by the University of Minnesota, Department of Soil, Water, and Climate to evaluate sewage sludge incinerator ash as a phosphorus fertilizer. The project is considering impacts on plant growth, soil characteristics, and soil microbial population. The project is collecting data through the 2019 growing season. Results and conclusions will be available the summer of 2020.

2.1.26 Root River Field to Stream Partnership

The Root River Field to Stream (RRFSP) project uses both edge-of-field and in-stream monitoring to characterize water quality in three study areas (sub-watersheds) within the Root River watershed. Sub-watersheds selected for this study are less than 5,000 acres and represent the diversity of farming practices and geologic landscapes in the larger Root River watershed. Flow and water quality monitoring is conducted at the outlet of each sub-watershed. One to two edge-of-field monitoring stations are installed in each sub-watershed to characterize sediment and nutrient loss. While this project has a very limited geographic extent, many of the findings and approaches have a much broader applicability to nutrient reduction work in the state.

Phase I of this project (2010-2016) provided baseline information about water quality, timing, and intensity of runoff, as well as an inventory of existing conservation practices. During Phase II (2017-2020), 100% of the farmers participated in a walkover process to help identify high-risk areas on their farms, and most have installed at least one new conservation practice since then. Farmers and researchers used data gathered throughout the baseline period (Phase I) to identify which practices were best suited for their locale and have the greatest potential to benefit water quality. Monitoring at multiple scales, including cataloging new practices being installed, will continue through at least 2023 to track the performance of prioritized and targeted practices and detect changes in water quality.

Conservation practices installed as a result of the RRFSP field walkover process (2017-2018):

- Over 75,000 feet of grassed waterways
- 14 new water and sediment control basins and catchment ponds
- Rehabilitation of an outdated flood control structure (capacity to store 23 million gallons of runoff at the principal reservoir and nearly 70 million gallons at the emergency spillway)
- Feedlot improvements including an increase in manure storage to reduce manure applications on frozen soil, fixing three milk house wastewater systems, and abandonment of two feedlots in high-risk locations

Over 50% of the highest priority conservation concerns, identified during field walkovers, were addressed by the end of 2017. A local nutrient management specialist is working with 13 producers who apply manure within the study watersheds to ensure application rates are applied at agronomic rates and manure management BMPs are being followed. In collaboration with researchers from the University of Minnesota, on-farm nitrogen rate and timing demonstrations have been conducted since 2015 within two study watersheds to develop nitrogen fertilizer rates that are specific to those landscapes and soil types.

A demonstration field in one study watershed will demonstrate the use of integrating an edge-of-field prairie strip with nitrogen rate and timing BMPs to achieve an estimated 30% reduction in total nitrogen load. This estimate will be validated statistically with additional years of on-farm runoff monitoring data. Since 2010, the RRFSP project manager and collaborators have given over 50 presentations and about the project at local, regional, and national meetings and conferences reaching nearly 3,000 individuals, and hosted over 60 field days. The RRFSP has been featured in 35 articles and 21 publications and reports. More recently, an 8-minute video and two podcasts were developed highlighting project results and walkover approach: https://www.youtube.com/watch?v=QTkMf9joXgA. More information is available at: www.mda.state.mn.us/rrfsp.

2.1.27 The Red River Valley Drainage Water Management Project

The Red River Valley Drainage Water Management Project was established in 2015 to evaluate and demonstrate the benefits of subsurface conservation drainage practices on nitrate-nitrogen and phosphorus exports from agricultural fields and provide educational opportunities for farmers, drainage industry representatives, local and regional technical staff, policy makers and other stakeholders.

To meet these objectives, two controlled drainage systems and one saturated buffer has been installed at two field locations along with edge-of-field monitoring equipment. Monitoring began in 2017 and is scheduled to go through 2023. The controlled drainage systems resulted in a nitrogen loss reduction of 33% based on monitoring data from 2017 and 2018. No reduction in phosphorus losses through the subsurface drains was observed. An 89% nitrate removal efficiency in subsurface drainage was observed in the saturated buffer during the 2018 monitoring season. Phosphorus retention in the saturated buffer was not monitored, but the long-term phosphorus retention capacity is generally considered low.

Education and outreach activities are an important part of the project. Since 2016, project collaborators have given over 30 presentations about the project at local, regional and national meeting and conferences reaching over 1,400 individuals, hosted 12 field days and two U.S. congressional visits. More information is available at: www.mda.state.mn.us/redrivervalleydwm.

2.1.28 Clay County Drainage Site

The Clay County drainage site is designed to evaluate the environmental impact of surface and subsurface drainage from crop production in a cold climate. This site is located at a private farm and includes six subsurface plots and one surface runoff plot, each approximately 22 acres in size. The soils, topography and crop rotation across the demonstration site represents field characteristics common in the most productive agricultural areas of northwest Minnesota. After collecting baseline information from 2011 – 2015, the focus shifted to managing the plots with controlled drainage and quantifying the water quality impacts of this change in management. The monitoring for this demonstration site is ongoing. More information is available at:
www.mda.state.mn.us/protecting/cleanwaterfund/onfarmprojects/claycounty.

2.1.29 BWSR Grant and Cover Crop Demonstration Program

In 2019, during the first Special Session, the Minnesota Legislature, passed Chapter 2, article 2, Sec. 7(b) (Clean Water Fund Appropriations) which provided funding for grants to local government units to protect and restore surface water and drinking water; to keep water on the land; to protect, enhance, and restore water quality in lakes, rivers, and streams and to protect groundwater and drinking water. Based on this legislation, BWSR authorized staff to develop a demonstration program to provide opportunity to increase the establishment of cover crops and related tillage practices in targeted areas on the landscape where there will be water quality benefits to surface and/or ground water.

Priority for this demonstration program was given to new adoption of cover crops and associated reduced tillage practices through identifying and addressing local hurdles to implementation through the following key efforts:

- Building local knowledge
- Facilitating partnerships
- Demonstrating clean water benefits
- Identifying methods to increase long term implementation and sustainability
- Scope and scale of adoption in targeted areas

BWSR had $1 million available for the program and received 18 proposals requesting $3.8 million. Five grants were awarded and will be receiving state funding between $125,000 and $250,000, paying for an estimated 5,000 acres of new cover crop establishment. BWSR will evaluate the effectiveness of this demonstration program before developing a long-term cover crop and soil health implementation program. More info at: https://bwsr.state.mn.us/cover-crop-demonstration-grants-initiative.

2.1.30 Demonstration Practices in Public Water Supply Recharge Areas

The MDA has established a number of local monitoring projects in public water supply recharge areas in Central Sands communities such as the cities of Verndale, Cold Spring, Perham, as well as other communities. These projects aim to create a better understanding of BMPs and their use to improve drinking water quality by local growers. Presently, the Minnesota Department of Health (MDH) and MDA are working with the University of Minnesota to monitor groundwater quality changes where the perennial crop intermediate wheatgrass (Kernza) is being established as a potential alternative to traditional annual row crops in highly vulnerable wellhead protection areas.

3 Implementation of recommended wastewater strategies

The Phosphorus Strategy, Rule, and eutrophication standards discussed in the NRS have and will continue to influence phosphorus reductions in wastewater. To address nitrogen in wastewater, the NRS provided a series of steps. The steps are intended to build the knowledge base and generate the data necessary to support informed decisions and investments. Descriptions of each major advancement follow.

3.1 Wastewater Phosphorus

Eutrophication standards for lakes (2008) and rivers (2015) has continued to be a major driver affecting wastewater facility phosphorus effluent limits. Phosphorus effluent limit reviews have been completed for half of the watersheds throughout Minnesota. Total phosphorus effluent limits have been set for 271 wastewater facilities, which represent 89% of the waste discharge stream. Between 2005 and 2017, wastewater point source phosphorus discharges were reduced 72% in areas draining toward the Mississippi River and 58% in areas draining to the Red River and Lake Winnipeg. More information at: https://www.pca.state.mn.us/water/phosphorus-wastewater and Wastewater phosphorus loads interactive map and 2018 wastewater discharges report to the Legislature. A 2020 report that includes wastewater discharges can be found at https://www.pca.state.mn.us/sites/default/files/lrp-ear-1sy20.pdf Wastewater Nitrogen

For wastewater nitrogen, the NRS established a five-step process that began with requiring wastewater effluent nitrogen monitoring at permitted facilities. In 2014, the MPCA developed a Minnesota NPDES Wastewater Permit Nitrogen Monitoring Implementation Plan. The implementation plan addresses recommended monitoring and data collection and provides the foundation for development and implementation of the remaining wastewater strategies. Minnesota recently added wastewater nitrogen monitoring at more than 450 wastewater facilities, representing 94% of the domestic effluent wastewater flow.

The next step for nitrogen identified in the NRS was to develop nitrogen management plans that could be incorporated into permits based on anticipated nitrate standards for protection of aquatic life. In 2014, these nitrogen standards were awaiting further national scientific studies to support standards development. Those studies have advanced; and as final reports are made available the MPCA anticipates incorporating new information into a nitrate standards development process.

3.1.1 Point-nonpoint Trading

Point-nonpoint trading is a potential cost-effective strategy for reducing nutrient loads to surface waters through a market-based approach. Point-nonpoint trading has advanced in Minnesota during the past five years, and new trading opportunities are currently being considered in several parts of the state. More information is available at: https://www.pca.state.mn.us/water/water-quality-trading

3.1.2 Regulatory Certainty (for Wastewater)

MN Statute §115.426 was signed into law by Minnesota Governor Dayton in 2016. This statute authorizes the MPCA to hold fixed total phosphorus and nitrogen limits for up to 20 years for wastewater facilities that voluntarily accept a total nitrogen effluent limit and employ biological nutrient removal technologies to meet nitrogen and phosphorus effluent limits.

4 Implementation of recommended strategies to address miscellaneous sources

The NRS did not recommend significant *new* strategies to reduce loads from subsurface sewage treatment systems, urban/suburban stormwater, feedlots, and sediment; however, continuation of existing programs was identified as a strategy. Descriptions of each major advancement follow.

4.1 Subsurface sewage treatment systems

Subsurface sewage treatment systems (SSTS) inspections are conducted for a variety of reasons including: point-of-sale, land use permits, building permits, conditional use permits, variances, and complaints. If a SSTS is determined to be an imminent public health threat, the owner has 10 months to upgrade per M.S. 115.55, subd. 5a. An annual report issued by the MPCA describing progress and updates is available by searching for “SSTS annual report” on the MPCA webpage. The 2018 Annual SSTS report was released in August 2019 (MPCA 2019). Since 2014, the fraction of septic systems with direct outlets to the land surface has continued to decrease, and now represents less than 5% of all septic systems (down from 11% in 2008). In addition, several small community sewage treatment systems have been fixed.

The MPCA has recently updated its SSTS program website based on input from local government and other SSTS stakeholders around the state. The website has improved navigation and updated content. In addition, the University of Minnesota Onsite Sewage Treatment Program (OSTP), through support from the Minnesota Department of Health, has offered educational homeowner classes that cover how septic systems function and required maintenance and testing. Over the past two years, more than 700 people attended the course. During that same time period, the OSTP also offered training to more than 3,800 septic system professionals across the state to help them receive and retain their certification to work on these systems.

More information on the septic system program in Minnesota is available at:
https://www.pca.state.mn.us/sites/default/files/wq-wwists1-58.pdf and
https://www.pca.state.mn.us/water/subsurface-sewage-treatment-systems.

4.2 Feedlots and manure

Runoff from feedlots, manure storage and land application of manure are regulated and inspected by the MPCA and 50 counties delegated by the State to administer the program for non-concentrated animal feeding operations (CAFOs), referred to as “delegated counties.” All feedlots must meet feedlot runoff and manure application requirements, including agronomic rates of application and setbacks from waters. As the size of the feedlot and associated manure production increases, additional requirements are added. These additional requirements include record-keeping of manure spreading, manure and soil testing, manure storage requirements, and nutrient planning. Inspections are conducted by MPCA and delegated counties using a risk-based approach that focuses on feedlots in watersheds with impairments for bacteria and nutrients, open-air animal holding and manure storage areas, and feedlots located within vulnerable areas. Inspections are conducted for a variety of reasons, many of which are not related to nutrients. Because proper land-spreading of manure is particularly important for minimizing nutrients in waters, the MN Feedlot Program has continued to advance inspections of land application of manure practices, conducting 1,697 land application inspections during the five-year period, 2014-18. See also: https://www.pca.state.mn.us/quick-links/feedlots.

In addition, beginning in 2018, the feedlot regulatory program implemented an improved inspection checklist and developed a more rigorous QA/QC for compliance rate data (available on MPCA's Feedlot website).

In a separate effort, the Environmental Working Group developed a mapping tool for Minnesota that shows where the potential for over-application of nutrients (combined fertilizer and manure) is most likely. The map can be accessed at https://www.ewg.org/interactive-maps/2020-manure-overload/map-nitrogen/ The associated journal article can be found at https://www.mdpi.com/2073-4395/10/4/480

Lastly, the University of Minnesota hired a manure and water quality specialist in 2017 to further develop education and research in manure management for feedlots and land-application sites. A guide for land application of manure was developed in 2019 by the University of Minnesota. On-going research will provide farmers with better information to plan for available nutrients from manure sources.

4.3 Stormwater

Many advances in the urban stormwater program have been made since the development of the NRS, as summarized below. More information on the urban stormwater program in Minnesota is available at: www.pca.state.mn.us/stormwater.

4.3.1 Municipal Separate Storm Sewer System (MS4) General Permit

The MS4 general permit became effective August 1, 2013; a new permit is expected to be re-issued in 2020.Compliance with a series of minimum control measures as a result of MS4 permit implementation will contribute to nutrient reductions. One of these measures includes requirements for discharges to impaired waters with an EPA-approved TMDL that includes an applicable wasteload allocation (WLA). This permit requirement is currently being implemented in 145 regulated MS4s with TMDLs that address eutrophication, or phosphorus. Of these 145 MS4s, 78 were required to submit annual reports summarizing progress toward meeting WLAs. Reductions in these regulated areas will work towards meeting both local water quality standards and downstream goals. With the 2020 permit reissuance, 230 regulated MS4s will have a nutrient or sediment WLA and will be required to report progress on meeting these WLAs annually. More information is available at: https://www.pca.state.mn.us/water/municipal-stormwater-ms4.

4.3.2 Construction Stormwater General Permit (CGP)

The Minnesota State CGP was reissued and became effective on August 1, 2018. The number of issued construction stormwater permits ranged between 2,000 and 2,500 per year between 2015 and 2019. The CGP applies to new developments and redevelopments that result in one or more acre of land disturbance. From a nutrient reduction perspective, the CGP addresses both construction activities (e.g., erosion control) and post-construction water quality requirements. The permit includes post-construction treatment requirements. The permit states that one inch of stormwater runoff from new impervious areas will be retained on-site via infiltration, harvesting or reuse, unless prohibited. More information is available at: https://www.pca.state.mn.us/water/construction-stormwater.

4.3.3 Industrial Stormwater Multi-Sector General Permit (MSGP)

Minnesota's industrial stormwater MSGP was re-issued in 2020. This permit addresses stormwater generated on industrial properties and requires a series of benchmark and effluent monitoring activities for various pollutants, depending on the type of industrial activity. Effluent limitations are required for certain categories of industrial activity (e.g., sector C1 Phosphate Subcategory of Agricultural Chemicals includes a phosphorus effluent limit for stormwater discharges). There are currently 3,920 industrial stormwater permits in the state. More information is available at: https://www.pca.state.mn.us/water/industrial-stormwater.

4.3.4 Stormwater Technical Assistance

In 2014, the MPCA developed a new Stormwater Manual WIKI website to serve as a user-friendly guide to direct users to more specific information about stormwater BMPs. The Minnesota Stormwater Manual provides detailed information on stormwater management approaches and BMPs recommended for use in Minnesota. The manual also includes newsletters, webinars, training/workshop opportunities, and tools permittees can use to quantify pollutant/volume reductions related to stormwater BMPs, such as the Minimal Impact Design Standards (MIDS) Calculator and MPCA Simple Estimator Tool. The manual is kept up-to-date via a wiki format and includes the most recent and relevant information. The manual is found at https://stormwater.pca.state.mn.us/index.php?title=About_the_Minnesota_Stormwater_Manual.

4.3.5 Stormwater Research and Demonstration

In 2016, the Minnesota Stormwater Research Council (MRSC) non-profit was formed to:

- Facilitate the completion of needed applied research that enables more informed decisions about the use, management and protection of our water resources in urbanized areas.
- Periodically assess the status of research, identify consensus research priorities, and communicate these to Minnesota's public and private research agencies and organizations.
- Promote coordination of research goals, objectives and funding among the research agencies and organizations.

In 2018, the MSRC developed a Stormwater Research Road Map and Framework that includes priority research needs for stormwater: https://www.wrc.umn.edu/stormwaterroadmap.

There are several information gaps with respect to managing phosphorus in urban stormwater runoff that are currently being addressed. The MPCA is currently gathering information and developing guidance on several topics:

- Development of a street sweeping credit
- Phosphorus export from constructed stormwater ponds
- Identifying bioretention media that retains phosphorus
- Identifying amendments that retain phosphorus

The University of Minnesota is currently conducting research related to phosphorus fate and transport in urban stormwater and stormwater management systems:

- Correlating street sweeping material collected by municipalities with phosphorus removal
- Bioretention media
- Alum in ponds
- Understanding the dynamics of phosphorus behavior in constructed stormwater ponds

More information on the Stormwater Research and Technology Transfer Program can be found at: https://www.wrc.umn.edu/projects/stormwater.

4.4 Sediment reduction

Near-channel sources of sediment, such as bluffs, streambanks and ravines, contribute significant amounts of phosphorus to downstream waters, and controlling these sources is important for long term phosphorus reduction needs in many areas of the state.

4.4.1 Sediment Reduction Strategy

The NRS recognized the linkages between sediment and phosphorus reductions and referenced a Sediment Reduction Strategy that was under development in 2014. The Strategy, completed in January 2015, outlines approaches for watersheds to consider when addressing sediment reduction. More information is available at: https://www.pca.state.mn.us/water/sediment-reduction-strategy-minnesota-river-basin-and-south-metro-mississippi-river.

4.4.2 Standardizing Approaches to Targeting and Prioritizing Watershed Upland Sediment Reduction and Channel Restoration and Advancing Floodplain Culvert Technologies at Road and River Crossings

The DNR clean water specialists are in the process of adopting a standardized approach to working with local partners in sediment-impaired major watersheds. The approach involves prioritizing subwatersheds for intensive, multi-year stream stability and sediment supply studies, and conducting these studies where there is local support and staff capacity. Completed studies (such as in the Little Cannon subwatershed) quantify in-channel vs. upland sources of sediment in each catchment in the subwatershed. This information enables DNR to recommend where to begin restoration efforts (which catchments) and which types(s) of restoration to focus on. Where stream channel work is indicated, these studies also provide specific information and cost estimates to aid restoration project planning, design, and execution based on natural channel design principles that improve watershed health and resilience. Effectiveness monitoring protocols for completed projects are being piloted (such as for a completed Cascade Creek restoration project near Rochester).

For more information on DNR's work to evaluate sites for floodplain culverts to capture sediment-laden waters, see the "Designing Resilient Watercourse Infrastructure" tab at: https://www.dnr.state.mn.us/climate/climate_change_info/what-dnr-doing.html, and technical webpage: https://www.dnr.state.mn.us/eco/streamhab/geomorphology/index.html.

4.5 Implementation of protection strategies

The NRS states that protection strategies are needed in watersheds that are subject to changes in agricultural and land use practices, as well as vulnerable groundwater drinking water supplies in Minnesota. In addition, protection strategies for both new nitrogen sources and for soil phosphorus increases from land use changes are both important elements that WRAPS and local water planning (e.g., through One Watershed One Plan) should address.

4.5.1 Red River Watershed Management Board: Red River Basin Water Storage Projects

The Red River Basin Commission (RRBC) Basin-wide Flow Reduction Strategy has a long-term goal of reducing flows by 20% along the Red River. More information on the Basin-wide Flow Reduction Strategy can be found within the Long Term Flood Solutions report developed by the RRBC at: https://www.redriverbasincommission.org/.

Since the formation of the Red River Watershed Management Board (RRWMB) in the late 1970s, the RRWMB has helped fund water storage projects in the Minnesota portion of the Red River Basin. An emphasis has been placed on a portion of the storage being gated, so that longer detention times can be achieved. This allows for flood volume to be reduced along the Red River during the time of peak flow, and for the storage volume to be released at a more opportune time. Projects implemented since 2014, however, have been predominately urban flood control and not storage based. The following impoundments were completed in recent years:

- Buffalo Red River Watershed District (outside of RRWMB) - Manston Slough. This project includes a low-hazard classification dam with more than 4,000 acre-feet of storage and 1,150 acres of wetland restoration.
- Roseau River Watershed District - Roseau Wildlife Management Area. This project includes a mix of upland and wetland habitat and three impoundments. It stores up to 8,000 acre-feet.
- Bois de Sioux Watershed District - North Ottawa Impoundment. This impoundment controls 75 square miles in the Rabbit River Watershed and stores up to 17,200 acre-feet.

Eight new projects are in various stages of design, engineering, permitting, environmental review, and funding. These eight projects will add an expected additional 80,000+ acre-feet of storage (approximately) to the past projects that already added over 180,000 acre-feet of storage.

4.5.2 Source Water Protection Program

The MDH works with public water suppliers, Federal, State and local partners to monitor and evaluate the effectiveness of implementation activities needed to improve drinking water quality. Agricultural best management practices are implemented in the recharge areas of public water system wells with the assistance of the MDA. In 2017, the Minnesota legislature appropriated funds to MDH to develop a surface water Source Water Protection (SWP) program to protect public water supply systems that rely on surface water for their source of drinking water.

The MDH SWP Program for surface waters is currently working with the City of Fairmont as the first pilot community to update their Source Water Assessment and develop a surface water SWP Plan. A main driver for Fairmont is their experience with high nitrate levels in their raw water supply from Budd Lake in 2016. The Cities of Mankato, Moorhead and Virginia are projected to be the next pilot communities to update their SWA and develop a SWP Plan. More information about the MDH SWP Grants Program can be found at: https://www.health.state.mn.us/communities/environment/water/swp/grants.html.

4.5.3 Guidance for Lake and Stream Protection in WRAPS and 1W1P

The Minnesota Pollution Control Agency in collaboration with numerous other state agencies recently developed a guidance document for incorporating lake protection activities into watershed plans. The guidance was developed to provide a uniform starting point in which state and local partners can begin to set lake phosphorus concentration goals and prioritize lakes for protection efforts in the HUC-8 watersheds. Part 1 of this framework describes a five-step process for identifying lakes that are vulnerable to water quality degradation within a HUC-8 watershed, and a process for prioritizing those lakes for immediate action. Part 2 of the guidance includes selected reference materials and an overview of key considerations related to lake protection. The guidance document is available: https://www.pca.state.mn.us/sites/default/files/wq-ws4-03c.pdf.

An additional document was created by the MPCA and other state agencies that outlines protection prioritization of lakes and streams in Minnesota. Stream and lake protection and prioritization tools were developed as part of this process. More information is available: https://www.pca.state.mn.us/sites/default/files/wq-ws1-29.pdf.

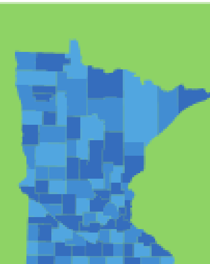
The DNR's lake phosphorus sensitivity index has also been recently refined for watershed use in prioritizing lakes for immediate protection efforts. "Lakes of phosphorus sensitivity significance" can be viewed at https://gisdata.mn.gov/dataset/env-lakes-phosphorus-sensitivity.

August 2020

Appendix B: External Factors Affecting Nutrients in Water

5-year Progress Report on Minnesota's Nutrient Reduction Strategy

MINNESOTA



Appendix B. External Factors Affecting Nutrients in Water

Written by Dave Wall of the MPCA in association with Minnesota's Nutrient Reduction Strategy 5-year Progress Report (2020)

Many external factors outside of management choices influence nutrient delivery to waters over time, including changes in population, climate, land use, river flow, and others. The ability to control these external factors vary. Together these external factors can either increase or decrease the expected nutrient reductions in waters and, as a result, have the potential to overshadow the effectiveness of adopted Best Management Practices (BMPs) in reducing nutrients.

Understanding the influence of external factors on water nutrient trends provides important context for comprehensively and objectively evaluating overall progress toward NRS milestones and goals, and may help inform decisions about future NRS implementation approaches. This section includes a summary of recent changes in certain external factors and how they generally can influence nutrient loads.

Population

Human population influences the amount of wastewater generated and can also have an effect on development that increases impervious surface cover and associated stormwater runoff. According to the Minnesota State Demographic Center[1], Minnesota's population reached 5,629,416 in 2018, an increase of 6.1% since 2010. The Twin Cities Metropolitan area experienced a majority of this population increase; over half of the counties in out-state Minnesota experienced a decrease in population.

In addition to human population, changes in livestock and poultry populations can affect manure generation. More livestock and poultry results in more manure, and depending on how it is managed, has the potential to increase nutrient loads to rivers and lakes. Data from the USDA National Agricultural Statistics Service show slight shifts in livestock and poultry populations between 2012 and 2017[2]. Specific reported changes are as follows:

- Combined milk and beef cow/cattle inventories decreased by approximately 3%
- Hogs and pigs increased by 11%
- All poultry increased by approximately 5%

Based on these changes, we expect that the overall total amount of manure generated at the state level increased slightly.

Precipitation

Precipitation patterns have significant influence on the delivery of nutrient loads to Minnesota's water resources, as well as on strategies that Minnesotans will need to employ to achieve restoration and protection goals. The amount and timing of precipitation influences how much water soaks into the ground or runs off directly into lakes, rivers, and wetlands.

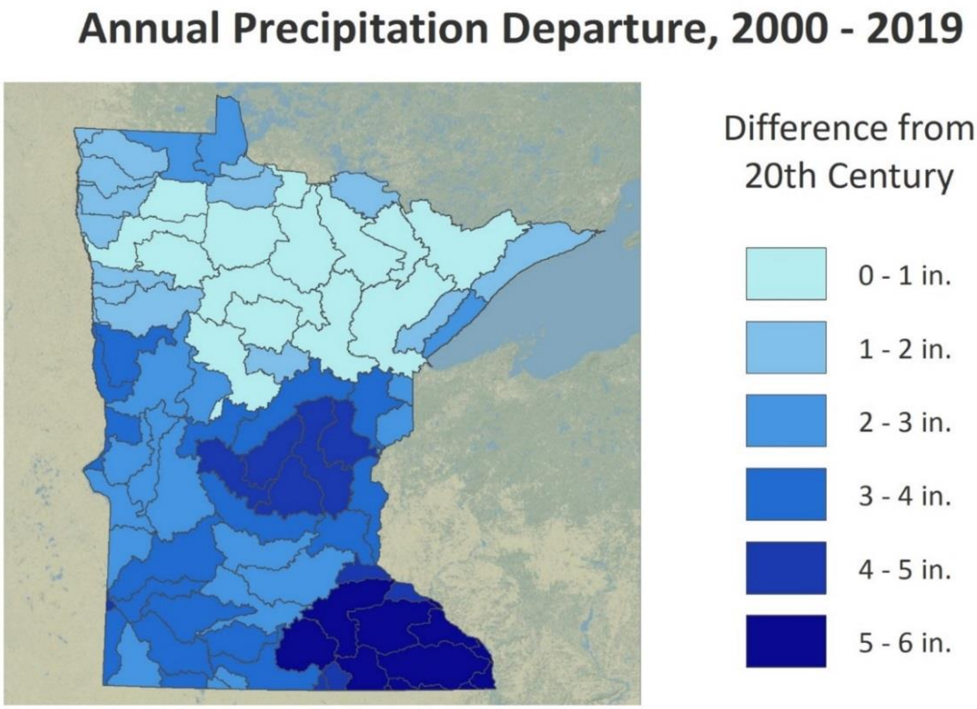
Data show dramatic changes in annual precipitation across the state. Increases in annual precipitation have occurred since 2000 throughout most of the state, with especially high rate of increase in southern

[1] Minnesota State Demographic Center. 2019. Latest annual estimates of Minnesota and its Economic Development Region's population and households. Release August 2019. https://mn.gov/admin/demography/data-by-topic/population-data/our-estimates/

[2] USDA National Agricultural Statistics Services.2012 and 2017. 2012 and 2017 Census of Agriculture. State level data for Minnesota.

wq-s1-84e

Minnesota (see figure below). Southeastern Minnesota precipitation is 5 to 6 inches higher during the past two decades as compared to the entire 20th century average. Such dramatic precipitation increases can cause marked increases in the delivery and concentration of nutrients in our waters.



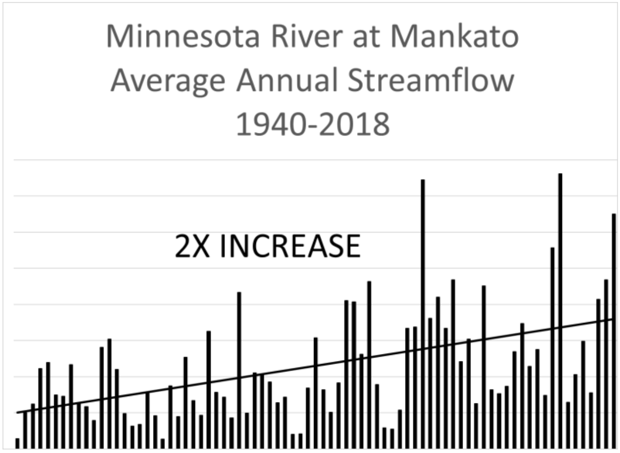
Annual precipitation increases between 20th century averages and 2000-2019 averages in watersheds throughout Minnesota **Source**: DNR State Climatology Office and the DNR Watershed Health Assessment Framework program

In addition, large rain events that produce six inches of rain across 1,000 or more square miles, often referred to as *mega rains*, have increased in frequency. There have been nearly three times as many mega rains in the last 18 years (2000-2017) than the previous 27 years (1973-1999). More information on Minnesota's mega-rain events is available at: https://www.dnr.state.mn.us/climate/summaries_and_publications/mega_rain_events.html.

River Flows

River flow is another key external factor influencing nutrient delivery to Minnesota's rivers and lakes. Changes in river flow are driven by changes in climate, but are also affected by altering hydrology, land uses, soil quality, and other factors. Increases in river flow can cause increased streambank and bluff erosion which constitutes the largest source of sediment in many of our high sediment rivers. Since soil phosphorus is attached to the eroded sediment, flow increases can also result in total phosphorus increases.

During the past 20 years (1999 to 2018), data collected by the Metropolitan Council Environmental Services show that annual average streamflow in the Minnesota River has increased by 68% at the Jordan monitoring site and 75% near the river's mouth at Fort Snelling. The recent decades are part of a long-term Minnesota River flow increase that started prior to 1940 (see figure below).



Average annual streamflow trends in the Minnesota River at Mankato (1940-2018).

The Mississippi River flows have also increased during the 1999 to 2018 timeframe. Minimum flows at Anoka increased by 64%. Average and maximum flows at Red Wing have increased by 40% and 38%, respectively. It is challenging to achieve nonpoint source nutrient load decreases during periods of such significant river flow increases.

Land-use

Changes in and wetland acreages affect how much precipitation reaches lakes, rivers, and wetlands, or percolates into aquifers. Land use also has a major influence on the quantity and quality of runoff and nutrient losses to groundwater. A summary of major land use changes in Minnesota is presented below.

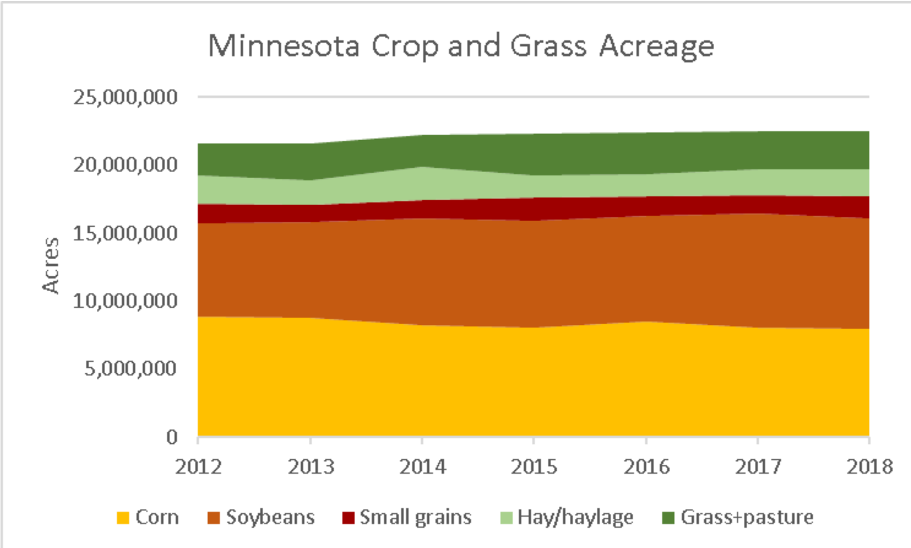
Urban

Developed lands, often characterized by an increase in impervious surfaces, increased by 14.3% from 2010 to 2017[3]. As previously discussed, increases in impervious surfaces contribute to increases in nutrient loads from surface runoff.

Cropland

Total acres of agricultural land use in Minnesota has remained relatively constant over time. However, the type of crops has changed in past decades to fewer small grains and alfalfa acres and more corn and soybeans. Between 2012 and 2018, most of the major crop acreages remained fairly stable. Soybean acreages surpassed corn in 2017 and 2018 (see figure below).

[3] Blann, K. 2019. Personal communications. The Nature Conservancy, Minnesota.



Statewide crop and grass/pasture acreage changes between 2012 and 2018 as identified from Crop Data Layer (CDL).

Wetlands

In 1991, Minnesota adopted a no-net-loss wetland policy because of the benefits associated with wetlands. Then in 2006, Minnesota initiated a rigorous, long-term monitoring program to track changes in wetland quality and quantity over time. Between 2006 and 2008, the monitoring effort assessed wetland abundance in almost 5,000 plots across Minnesota to serve as a baseline. Those same sites are reassessed every three years to track the amount of change that is occurring. Results showed a net wetland gain of 6,550 acres (0.06%) from 2009 to 2014. While historical patterns of wetland loss appear to have leveled off, more recent efforts have focused on restoring and maintaining wetland functional quality.

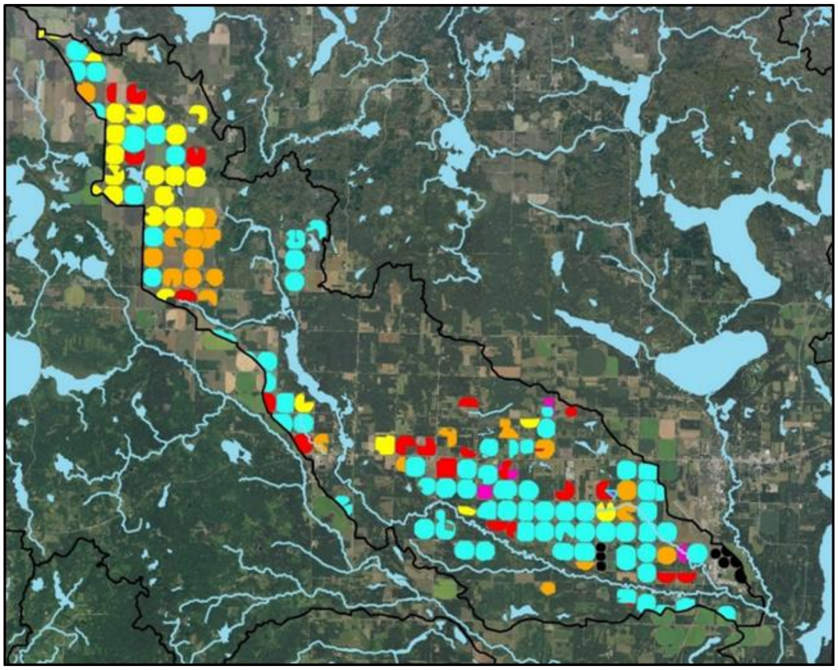
Irrigation and Drainage

Cropland irrigation and artificial drainage changes how water and nutrients move through the soil and into surface waters. These activities can affect the amount of nitrate and phosphorus delivered to waters.

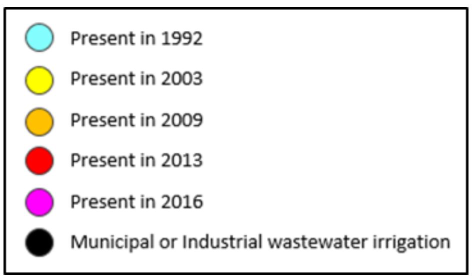
Less than 3% of the total cropland in Minnesota is currently irrigated, using approximately 103 billion gallons of water. There has been a slight increase in irrigation in Minnesota according to the U.S. Census of Agriculture. Acres of irrigated land increased by 21% during 2007-2017 and by 17% from 2012 to 2017.

While the statewide increase in irrigated agriculture is relatively small, increases can have large impacts in local watersheds. For example, the amount of irrigated lands within the Straight River watershed, which drains to the Crow Wing River in north central Minnesota, nearly doubled between 1992 to 2016.

Grassland and forested areas with very low nitrate leaching potential were converted into irrigated row crops with much higher potential for nitrate leaching.



Added irrigation between 1992 and 2016 in the Straight River Watershed, and subwatershed of the Crow Wing River Watershed (Information provided by MPCA).



Subsurface tile drainage has the potential to transport nutrients out of the root zone to surface waters, especially nitrate. During the past two decades, subsurface tile drainage installation has continually increased in Minnesota. A substantial increase in the installation rate occurred when a combination of wetter climate coincided with higher corn and soybean prices, particularly following 2008.

The 2017 U.S. Census of Agriculture indicated that tile drained lands increased in Minnesota by 25% during the five-year period between 2012 and 2017 (see table below). The Census report also indicated that over eight million acres of land is tile-drained, which is approximately half of the total statewide corn and soybean lands. The Cropland Data Layer (CDL) published by USDA indicates there are about 20 million acres of cropland (i.e., corn, soybean, sugar beets, wheat, oats, potatoes, barley) in Minnesota. Therefore, the 2017 Census data indicates that tile-drained land represents approximately 40% of Minnesota's cropland.

Minnesota Land Use Data Practices (2012 to 2017).

Practice	2012 Acres	2017 Acres	Increase 2012-17
Land Drained by Tile	6,461,173	8,079,984	+ 1,618,811 (+25%)
Land Drained by Ditches	4,548,977	4,674,449	+ 125,472 (+3%)

Source: USDA NASS US Census of Agriculture, Table 41 – Minnesota Land Use Practices

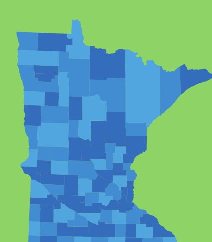
Nutrient Reduction Strategy

August 2020

Appendix C: River Nutrient Trends in Minnesota

5-year Progress Report on Minnesota’s Nutrient Reduction Strategy

MINNESOTA



River Nutrient Trends in Minnesota

Appendix C of the Minnesota Nutrient Reduction Strategy 5-year Progress Report

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Appendix C to the Minnesota Nutrient Reduction Strategy 5-year Progress Report

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1. Introduction

Analyzing river nitrate and phosphorus trends is one of the many ways that Minnesota tracks long-term progress toward nutrient reduction goals. To gain a more complete understanding of river nutrient trends, Minnesota partner agencies assessed available data from multiple river locations over different time periods using a variety of approaches. This analysis builds upon existing and ongoing trends assessment work by the U.S. Geological Survey (USGS), Minnesota Pollution Control Agency (MPCA), and Metropolitan Council Environmental Services (Met Council).

River nutrient trends indicate how collective actions to improve the water, coupled with the influence of other external changes, are reflected in our river monitoring data. These analyses, when conducted over long periods of time, provide an understanding of the combined outcomes of land use changes, management practices, and other key factors affecting water quality. Long-term assessments are important to better distinguish between real changes in the water as opposed to temporary influences in climate and other year-to-year variability. Improvements made on the land can sometimes take decades or more before changes are observed in the ambient river water quality.

Many of the river trends assessment methods use statistical analysis techniques that largely separate the effects caused by human changes on the land from those caused by variability in precipitation and river flow. These "flow-adjusted" techniques (sometimes called "flow-corrected," "flow-normalized," or "flow-averaged") can better indicate the combined effects of best management practice (BMP) adoption and other changes made by people in the watersheds—effects that are otherwise often overshadowed by the changes in precipitation and corresponding river flows. Trends developed using flow-adjusted methods can be interpreted as changes that would occur if flow had been the same year after year.

It is possible, however, that the climate in portions of Minnesota will continue to be wetter over the long-term. For that reason, MPCA and Met Council additionally assessed nutrient load trends without adjusting for year-to-year variability in flow. The term "non flow-adjusted" in this report indicates the use of statistical techniques that do not remove the influence of year-to-year flow variability.

Each way of assessing river nutrient trends provides information about a specific aspect of the trends. A look at multiple chemical parameter concentrations and loads, different timeframes, and more than one statistical technique and model, provides a more comprehensive understanding of Minnesota's nutrient trends in rivers. The multiple combinations of trends assessments in this report make the findings more complex, but tells a more complete story.

This analysis included trends from several different timeframes. Five-year trends (since completing the 2014 Nutrient Reduction Strategy) would not generally yield meaningful conclusions about trends due to limitations in accurately assessing such short periods with statistical methods. Therefore, five-year trend analyses were not performed. This analysis focused mostly on river trends from the 10-year (recent) and 20-year (mid-range) timeframes. Analyses for *recent* timeframes represent the past 10 years, providing an indication of changes following Minnesota's Clean Water Fund establishment. Analyses for *mid-range* timeframes represent the past approximate two decades, indicating changes near the end of baseline periods established for the Mississippi and Red Rivers. For certain major rivers with lengthy monitoring records, some analysis was performed on approximately 40-year (long-term) timeframes.

To make best use of previous and ongoing efforts to statistically assess river nutrient trends, the work of three different organizations contributed to this analysis as follows:

- **USGS**: Red River Basin mid-range trends
- **Met Council**: Major rivers entering and leaving the Twin Cities Metropolitan area (mid-range and long-term trends), based on recent updates to the work reported in Metropolitan Council (2018). Met Council updated their work reported in www.metrocouncil.org/river-assessment to also include the years 2016-2018 and new river nutrient load trend analyses
- **MPCA**: In-depth analysis of certain major rivers with long-term monitoring results, along with a more streamlined analysis of all other rivers monitored by the MPCA for at least the past ten years (recent, mid-range and long-term trends)

The availability and duration of monitoring data influenced the selection of sites for this report, as did the emphasis on larger rivers. Trends were determined for flow-adjusted and non flow-adjusted concentrations and loads, highlighting both nitrite+nitrate-N (referred to often as “nitrate” or “NOx”) and total phosphorus (referred to often as “phosphorus” or “TP”).

The difference between concentration and load is worth noting. Concentrations are direct measures of water quality that define such things as the probability of algae blooms, the health of the water for fish and other aquatic life, and the suitability for drinking. Loads describe the amount of nutrients moving downstream over a period of time and are affected by watershed conditions, weather, and climate. Loads are a combination of concentrations and river flow.

This analysis includes an evaluation of both concentration and load trends for major river sites near state borders or confluences with other major rivers. For most HUC-8 watershed outlets and secondary sites, the analyses evaluated only concentration trends. The statistical methods and timeframes selected for assessment varied by the organization conducting the analysis, data availability, and the relative importance of the river to downstream waters (Table 1).

A description of the methods, as well as additional site and sampling details for the Met Council analyses can be found in Met Council (2018) www.metrocouncil.org/river-assessment. The methods described in Met Council (2018) are the same as used for the QWTREND analyses in this report, with the exception of an expanded timeframe for the years 2016-2018 included in this report.The USGS analysis methods are described in Nustad and Vecchia (2020) with further details about the use of R-QWTREND at https://pubs.er.usgs.gov/publication/ofr20201014. MPCA methods are included as Attachment A to this report.

Unless otherwise noted, a 90% statistical confidence ($p<0.1$) denotes a statistically significant trend. A trend described as *not significant* or *non-significant* can mean there is no trend, but these terms can also mean that the data set was not conducive to demonstrating a significant change. In some cases, there are not enough data or enough years to have high confidence in a real change given the year-to-year variability. For that reason, the analyses show a particularly high number of non-significant trends when assessing the recent time period (i.e., 10 years).

Table 1. Metadata for river nutrient concentration and load trend data used in this report.

Flow Statistical Method	Concentration Trends Metadata	Load Trends Metadata
Flow-adjusted	**Region:** Red River Valley **Organization:** USGS **Timeframe:** 2000-2015 (incorporating additional years between 1995-2017 as data were available) **Method:** **R-**QWTREND **Region:** Twin Cities Metro **Organization:** Met Council **Timeframe(s):** approximately 20- and 40-year periods ending in 2018 **Method:** QWTREND **Region:** Statewide **Organization:** MPCA **Timeframe(s):** approximately 10-, 20- and 40-year periods ending in 2017-18 **Methods:** Bootstrapped seasonal Kendall w/flow adjustment; QWTREND for Mississippi River Winona and St. Louis River Scanlon	**Region:** Mississippi River at Winona and Red Wing, St. Louis River at Scanlon, **Organization:** MPCA **Timeframe(s):** 36-, 43- and 20-year periods ending in 2017-18 **Method**: EGRETci WRTDS
Not-flow-adjusted	**Region:** Statewide **Organization(s):** MPCA **Timeframe(s):** 10-, 20-, 40-year periods ending in 2017 **Method:** Bootstrapped Seasonal Kendall	**Region:** Metro Area Major Rivers **Organization:** Met Council **Timeframe(s):** 43 years ending in 2018 **Method:** Mann Kendall on annual loads calculated with FLUX32

Trend results for phosphorus and nitrate are presented separately due to differences between the nutrients related to sources, transport pathways from source to river, and practices to reduce sources. For nitrogen, the analysis focuses on nitrate results rather than total nitrogen, since nitrate is the most dominant form of nitrogen in most polluted waters and it has important environmental and human health effects. Total nitrogen trends were assessed at most of the same sites and had similar trend directions, with only a few exceptions which are noted.

2. Phosphorus Results

The analysis for phosphorus begins with a statewide MPCA assessment using a less labor-intensive statistical approach, followed by the more in-depth analyses at certain key river monitoring sites in the (1) Mississippi River Basin, (2) Red River Basin, and (3) Lake Superior Basin.

2.1 Statewide Phosphorus (MPCA)

Statewide phosphorus concentration trends include data from MPCA monitoring sites assessed using the bootstrapped seasonal Kendall approach for three different timeframes Additionally, 20-year mid-range trend analyses were conducted by MPCA, Met Council and USGS using WRTDS EGRETci, QWTREND and R-QWTREND, respectively, at select monitoring sites across Minnesota.

2.1.1 All MPCA Sites - Seasonal Kendall Test

Using the bootstrapped seasonal Kendall approach at MPCA-monitored sites statewide, phosphorus concentrations have generally either decreased or had no statistically significant trend during recent decades (Figure 1). When adjusting for flow variability, no sites had an increasing concentration trend. Even when not adjusting for flow, only one site out of 50 was found to have increasing phosphorus concentrations over the past 10- and 20-year periods.

Using the flow-corrected seasonal-Kendall test, over half of the sites had non-significant 10-year phosphorus concentration trends ($p<0.1$). The fraction of non-significant trends decreased as the length of monitoring period increased, such that 11 of 13 sites had significant 20-year trends and all of the 10 sites evaluated for 40-year records had significant trends.

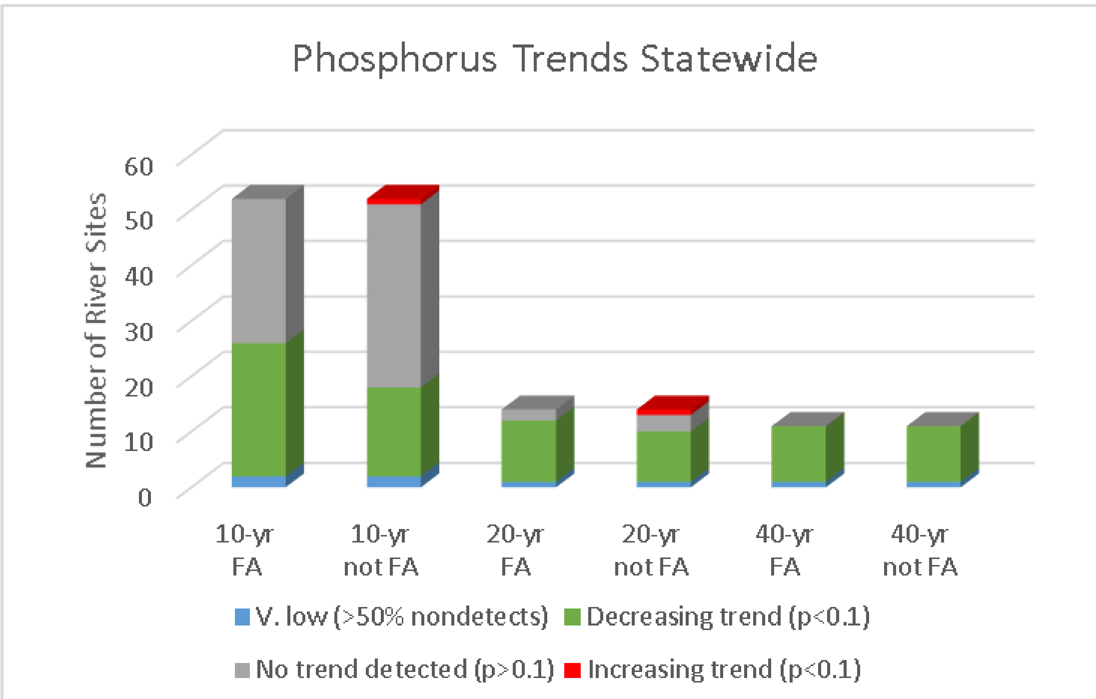

Figure 1. Bootstrapped Seasonal Kendall phosphorus concentration trend results using both flow-adjusted (FA) and non flow-adjusted (not FA) techniques at MPCA-monitored river sites across the state.

The majority of the 10-year decreasing phosphorus concentration trends were found in the eastern part of the state, with the western and northwestern parts of the state showing largely no detectable trends (Figure 2). Through this analysis, the only area of the state with non-significant phosphorus concentration trends over the past 20 years is in the upstream stretches of the Minnesota River Basin (Figure 3).

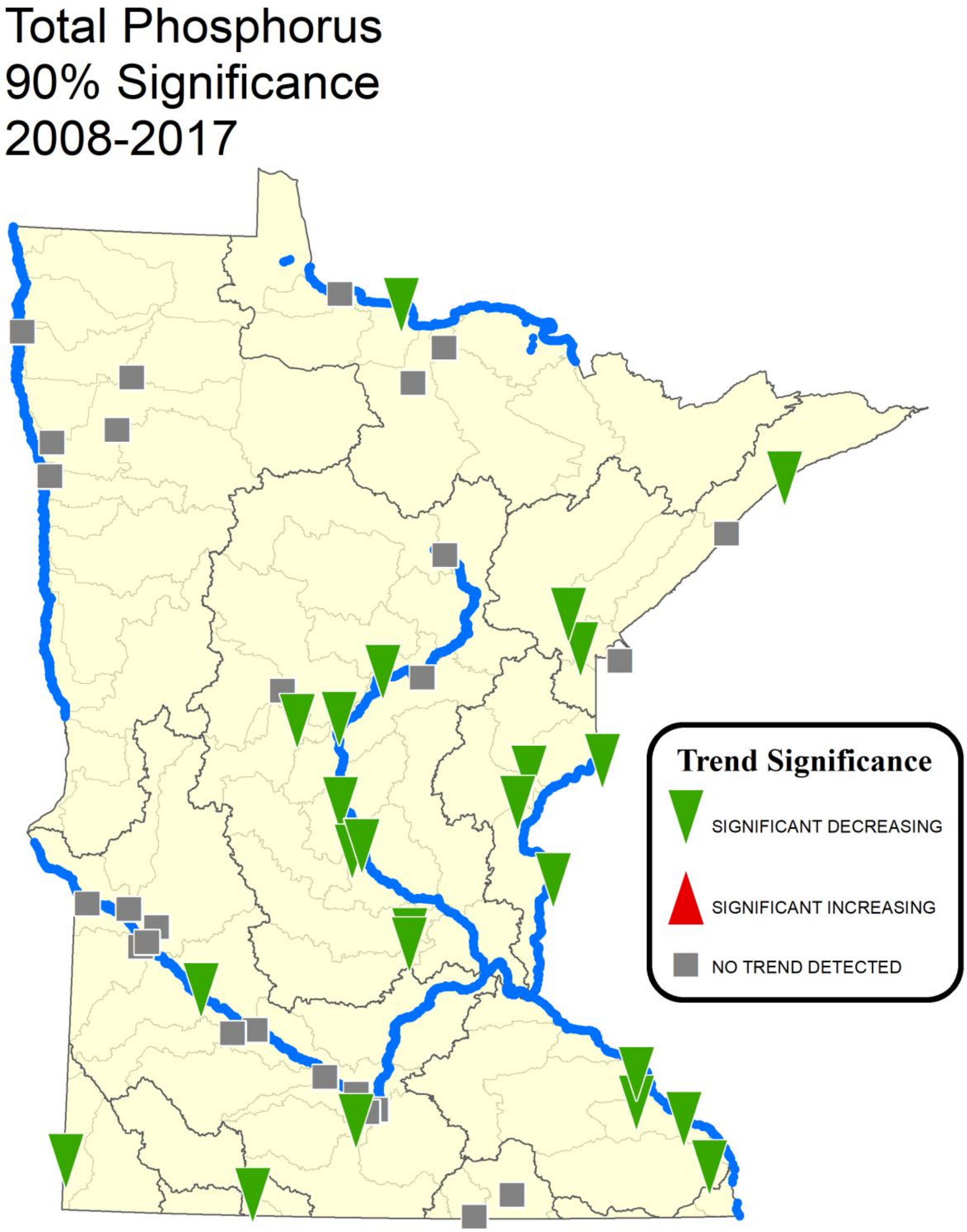

Figure 2. Recent (2008-17) phosphorus trends at MPCA sites assessed using a flow-adjusted bootstrapped Seasonal Kendall method.

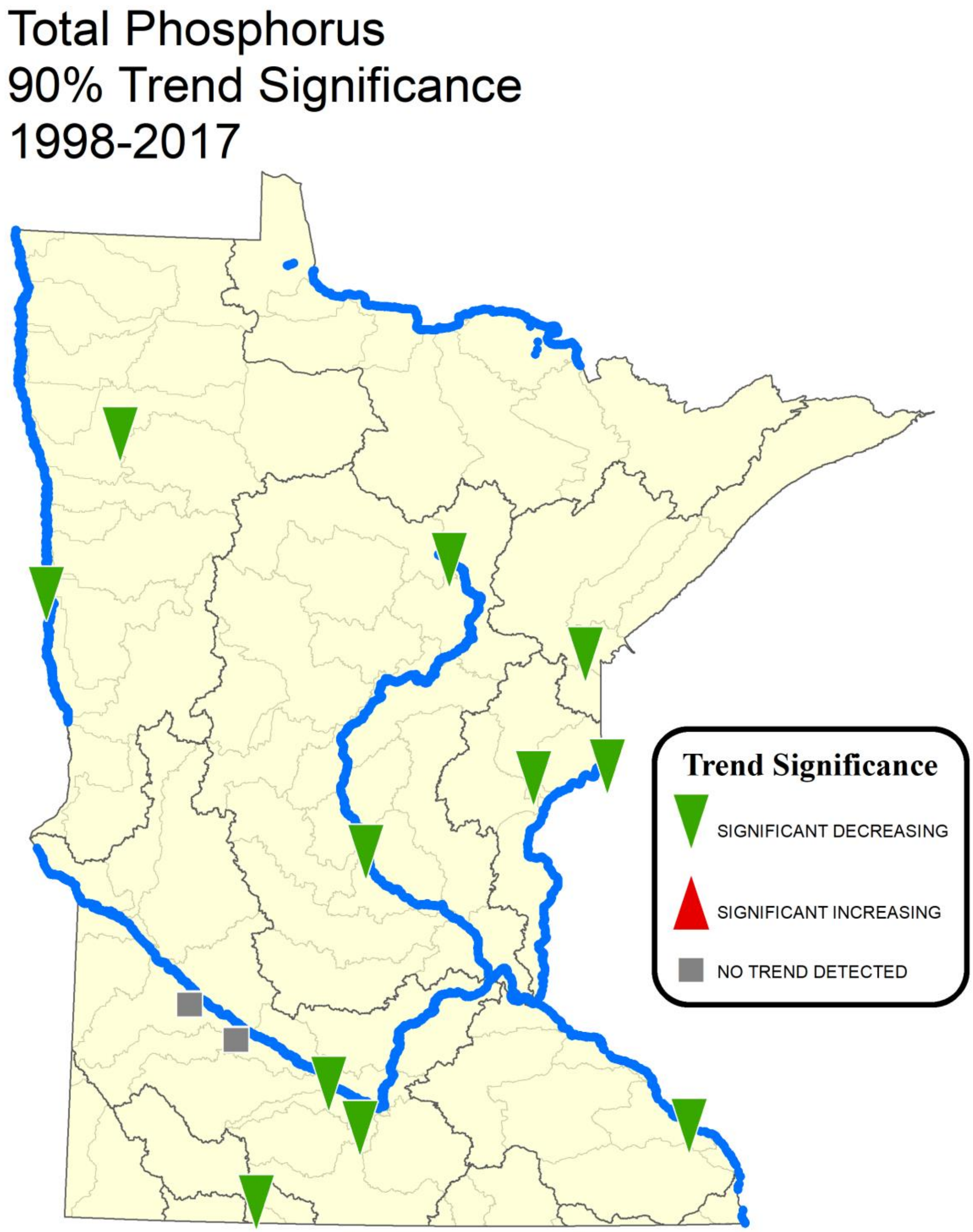

Figure 3. Mid-range (1998-2017) phosphorus trends at MPCA sites assessed using a flow-adjusted Seasonal Kendall approach.

2.1.2 Statewide Mid-range Phosphorus Trends from Met Council, USGS, and MPCA

Rigorous statistical analysis techniques using QWTREND and R-QWTREND (concentration) and/or WRTDS EGRETci (loads) were performed at major river sites and certain other tributaries to major rivers, as described below. Associated site locations and the organizations conducting trends analyses are shown in Figure 4.

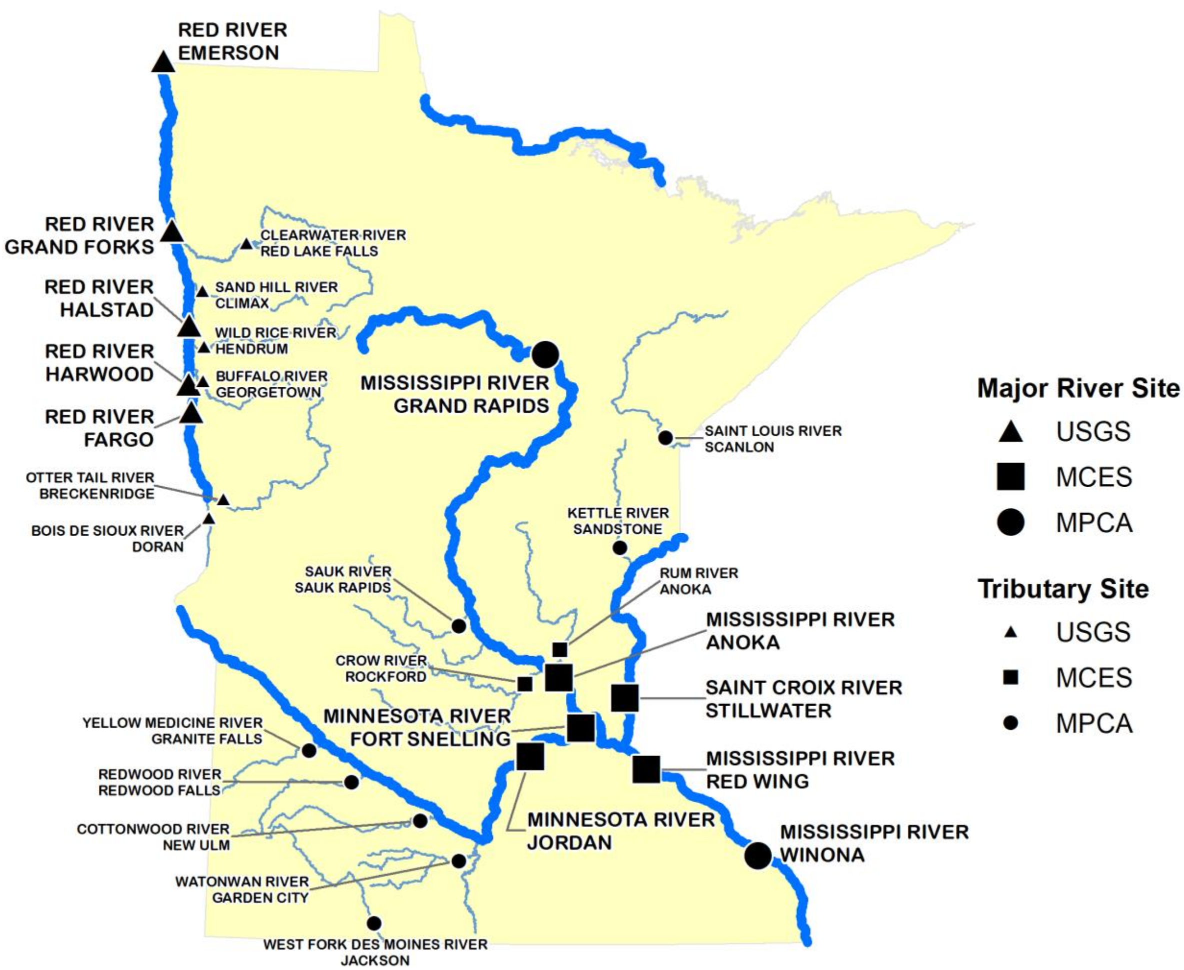

Figure 4. River monitoring site locations for major river and tributary sites where trends were evaluated for about the past two decades.

Mid-range (approximately 20-year) flow-adjusted phosphorus concentration trends were conducted using QWTREND and R-QWTREND (Red River Basin) at major river sites around the state (Figure 5). QWTREND and R-QWTREND was used to assess trends at all mapped sites, except that the flow-adjusted Seasonal Kendall test was used at tributaries to the Minnesota River, along with the Sauk River and Kettle River.

A majority of the sites (21 of 28) show decreasing phosphorus concentration trends. Six of the 28 sites had no significant trend detected. Only the Red River at the Emerson site had an increasing trend. The

Emerson site is a point on the Red River that has upstream nutrient additions from North Dakota and Manitoba, in addition to Minnesota's contributions.

In general, phosphorus concentration trend directions for mid-range trends in figure 5 are generally similar to the mid-range trends in figure 3. However, figure 5 also includes additional sites assessed by Met Council and the USGS. The method of statistical trend analysis is also different for most of the sites on figure 5 as compared to figure 3, as previously described.

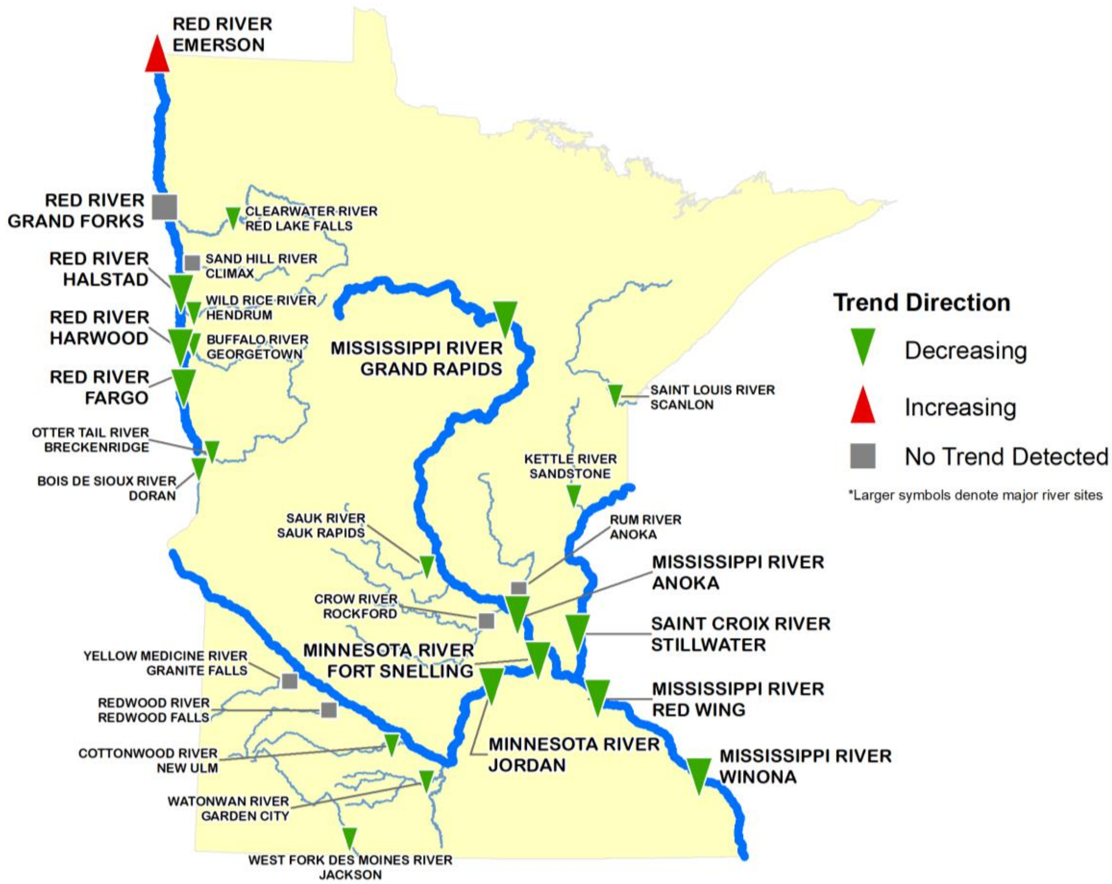

Figure 5. River monitoring site locations at sites with enough information to determine mid-range (approximately 20-year) flow-adjusted phosphorus concentration trends. Large symbols represent major river sites and small symbols represent tributary river sites.

More details about phosphorus concentration trend results are described below for sites where the QWTREND and R-QWTREND methods were used.

2.2 Mississippi River Basin

An overview of phosphorus trends in the Mississippi River and its major tributaries is shown in Table 2. Trends over the past approximate 20 and 40 years consistently show decreasing flow-adjusted concentration trends in the range of 15-53%.

At the two Mississippi River sites evaluated for load trends (Red Wing and Winona), flow-adjusted loads also show decreases. The magnitude of these decreasing flow-adjusted phosphorus loads range from 37% in Red Wing to 54% at Winona.

A more simplified Mann Kendall analysis of annual loads (not flow-adjusted) shows non-significant trends (p<0.1 is our criteria for statistical significance) at all evaluated sites. Increasing precipitation during the past 20 years is likely one important reason that the loads, when assessed without any flow adjustment, show a non-significant trend as compared to the significant decreases in flow-adjusted loads. The calculated p-value for each non-significant load trend analysis is included in Table 2. The 20-year non flow-adjusted load trends in the Minnesota River had p-values just over 0.1 and, therefore, were close to being statistically significant. More detailed results and analysis for each site are described below.

Table 2. Overview of Mississippi River Basin phosphorus trend results for both concentration and load at long-term major river monitoring sites.

A decreasing trend is denoted by "-." Non-significant trends (p<0.1) is denoted by "NS." P-value indicates the significance level of trends that are not statistically significant.

Monitoring site	Parameter and method (phosphorus)	Recent (~ 10 yr)	Mid-range (~ 20 yr)	Long-Term (~ 40 yr)
Mississippi River Winona	Concentration (QWTREND flow-adjusted)	**-41%**	**-50%**	**-53%**
	Load flow-adjusted (EGRETci WRTDS-WRTDS)	**-50%**	**-54%**	**-52%**
Mississippi River Red Wing	Concentration (QWTREND flow-adjusted)		**-21%**	**-40%**
	Load flow-adjusted (EGRETci WRTDS-WRTDS)	**-27%**	**-37%**	**-36%**
	Load (Mann Kendall of annual loads, not flow-adjusted)		**NS** P=0.36	**NS** P=0.67
Mississippi River Anoka	Concentration (QWTREND flow-adjusted)		**-26%**	**-41%**
	Load (Mann Kendall of annual loads, not flow-adjusted)		**NS** P=0.87	**NS** P=0.14
Minnesota River Jordan	Concentration (QWTREND flow-adjusted)	**See narrative**	**-17%**	**-30%**
	Load (Mann Kendall of annual loads, not flow-adjusted)		**NS** P=0.11	**NS** P=0.48
Minnesota River Fort Snelling	Concentration (QWTREND flow-adjusted)		**-18%**	**-51%**
	Load (Mann Kendall of annual loads, not flow-adjusted)		**NS** P=0.18	**NS** P=0.92
St. Croix River Stillwater	Concentration (QWTREND flow-adjusted)		**-15%**	**-27%**
	Load (Mann Kendall of annual loads, not flow-adjusted)		**NS** P=0.77	**NS** P=0.58

In addition to the results in Table 2, Met Council used the QWTREND analysis to assess phosphorus trends in the Crow River, a major tributary delivering nutrients in the Upper Mississippi River Basin. The Crow River at Rockford did not have statistically significant phosphorus concentration trends from 1999-2018. The MPCA assessed trends on many other HUC-8 tributaries in the Mississippi Basin using the Seasonal Kendall method, as previously discussed.

2.2.1 Mississippi River at Winona - Phosphorus

The Mississippi River at Winona site provides short- and long-term monitoring records enabling statistical analysis of trends near the state border with Iowa. While this site includes some flow from Wisconsin rivers, it is mostly influenced by waters flowing from the Minnesota River, Upper Mississippi River, St. Croix River, along with the Zumbro and Cannon Rivers (Figure 6). Therefore, this site represents an integrated sample of much of the nutrient pollution that ultimately leaves the state via the Mississippi River.

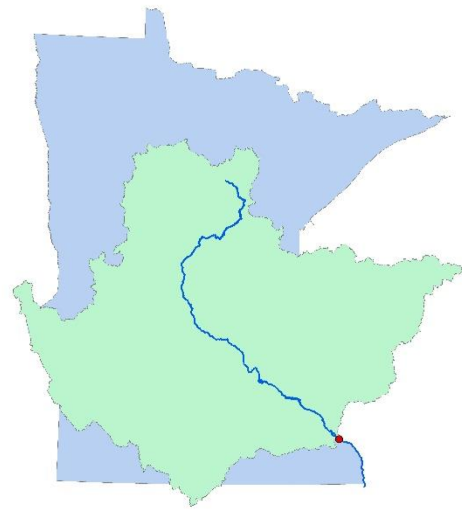

Figure 6. Watershed draining to Mississippi River at Winona monitoring site.

It should be noted that Winona phosphorus concentration data set has a data gap in the middle of the record between 1994 and 2000. The models estimate loads based on river flows and the river flow and concentration relationships. While the long-term and short-term trends are less affected by this gap, the mid-range period is more greatly influenced.

Using the QWTREND model, the MPCA assessed flow-adjusted phosphorus concentration trends over three time periods, representing the past 11 (2007-2017), 21 (1997-2017) and 36 years (1982-2017). For all three periods, the phosphorus concentration decreased by approximately 50% (Table 2).

The MPCA used EGRETci WRTDS to evaluate the flow-adjusted phosphorus load trends for the short-term (2008-2018), mid-range (2001-2018) and long-term (1982-2018) timeframes. All three periods showed major load reductions of a similar magnitude (2.7 to 2.9 million pounds per year). Based on the graph of modeled load (flux) trends (Figure 7), it appears that flow-adjusted phosphorus loads were increasing during the 1980s and then shifted to a decreasing trend in the early 1990s.

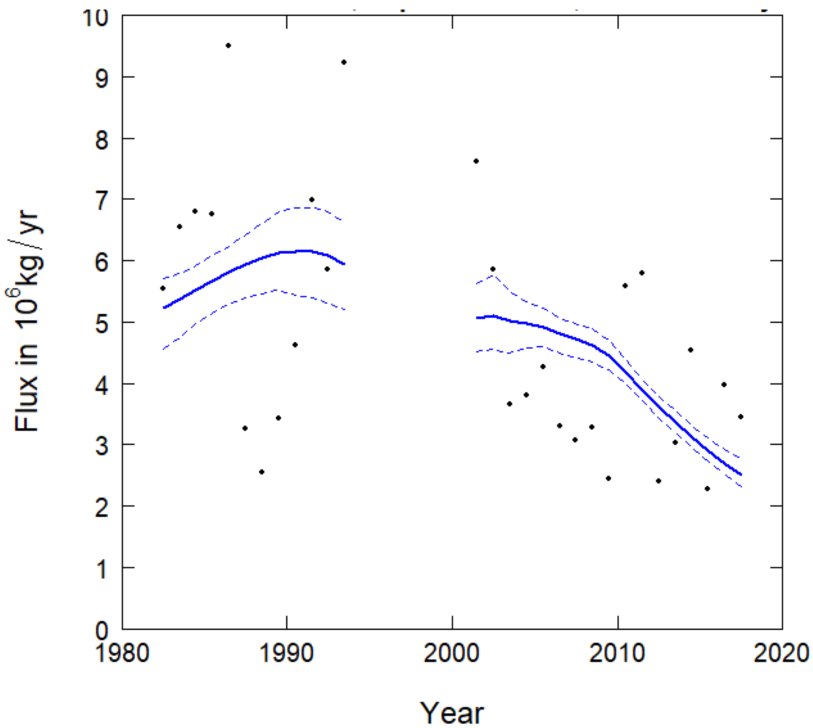

Figure 7. Flow-adjusted phosphorus load trends modeled with EGRETci WRTDS at the Mississippi River Winona site.

The non flow-adjusted total phosphorus loads (Figure 8) show a decreasing trend, but suggest no trend between 2003 and 2017. River flow greatly affects the view of non flow-adjusted loads. It appears that precipitation increases in the recent years have increased flow and offset much of the progress made with flow-adjusted phosphorus concentrations.

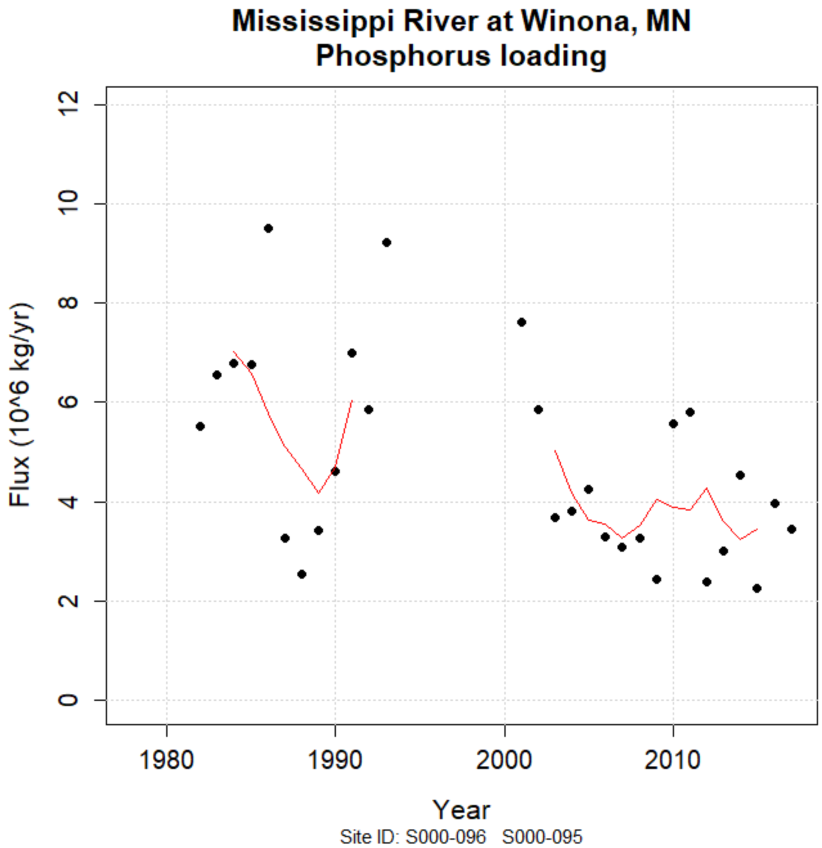

Figure 8. Mississippi River at Winona five-year rolling average loads (non flow-adjusted). Loads calculated with EGRETci WRTDS.

2.2.2 Mississippi River at Red Wing (Lock and Dam #3) Phosphorus

The Red Wing site (also known as Lock and Dam #3) in Minnesota is an important long-term continuously monitored site for evaluating nutrient reduction progress throughout much of the state. The location is downstream of the Upper Mississippi River Basin, the Minnesota River Basin, the St. Croix River Basin, and the Twin Cities Metropolitan area (Figure 9). The portion of nutrients at this site that do not leave the state are either temporarily or permanently lost from the river in the downstream Lake Pepin and Mississippi River backwaters.

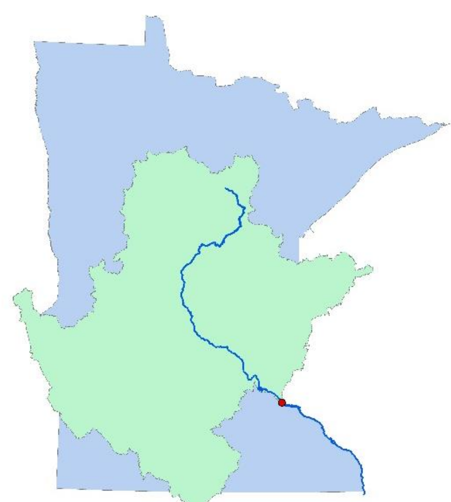

Figure 9. Watershed draining to Mississippi River at Red Wing monitoring site.

The Met Council analysis using the QWTREND program showed flow-adjusted phosphorus concentration reductions of 21% and 40% over the past 20 and 40 years, respectively. Phosphorus concentration trends were best represented by a one-trend model (Table 3 and Figure 10), showing that TP concentrations decreased gradually over the entire assessment period (1976 to 2018).

Table 3. Statistical Trend for TP Concentration in the Mississippi River at Lock and Dam 3.

Trend Period	Concentration (mg/L)	Change in Concentration (%)	Change Rate (mg/L/yr)	*p*	Trend
1976 – 2018	0.17 – 0.10	-41%	-0.0016	< 0.0001	⬇
Overall Trends					
20 years (1999 – 2018)	0.12 – 0.10	-21%	-0.0013	–	⬇
40 years (1979 – 2018)	0.17 – 0.10	-40%	-0.0017	–	⬇

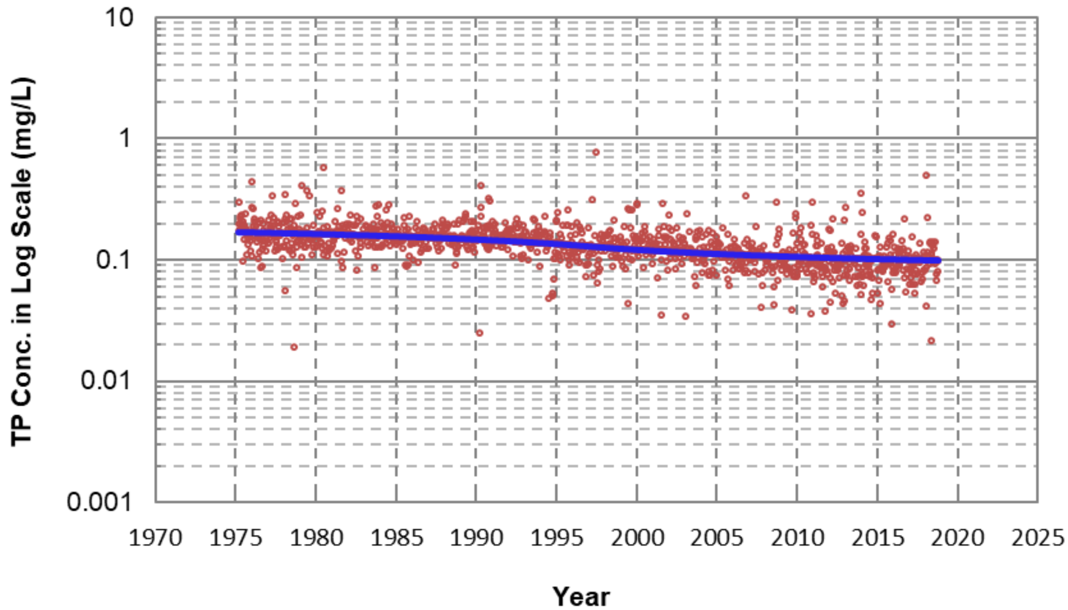

Figure 10. Statistical Trend for Flow-Adjusted TP Concentration in the Mississippi River at Lock and Dam 3.

Annual phosphorus loads at Red Wing show a very high year-to-year variability (Figure 11). While the five-year rolling average shows a general load decrease from 1994-2008, a separate analysis of load trends (non flow-adjusted) did not show a significant change for either mid-range or long-term periods. The lack of certainty about a trend is likely attributed to increased average and maximum flow in the river over the past 20 years (Table 4 and Figure 12). While the water has lower flow-adjusted phosphorus concentrations, there is more water flowing in the river and thus more delivery of nonpoint source phosphorus. The net effect is no significant trend in phosphorus load.

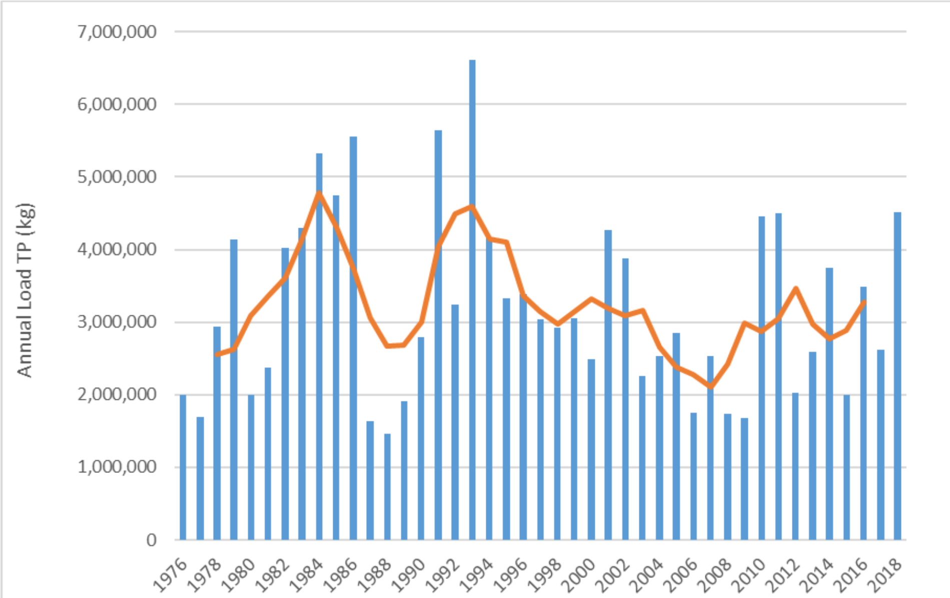

Figure 11. Annual phosphorus Loads (Non Flow-Adjusted) in the Mississippi River at Red Wing (Lock and Dam 3) and five-year rolling average load (orange).

Table 4. Statistical Trends for River Flow Volume in the Mississippi River at Lock and Dam 3 near Red Wing. "No trend" means no trend detected with the trend analysis methods.

Trend Period		**Change Rate (CFS)**	**Change Rate (%)**	***p***	**Trend**
20 years (1999 – 2018)	Minimum	–	–	0.12	No trend
	Average	479	40%	0.03	⬆
	Maximum	1,560	38%	0.07	⬆
40 years (1979 – 2018)	Minimum	–	–	0.58	No trend
	Average	–	–	0.20	No trend
	Maximum	–	–	0.23	No trend

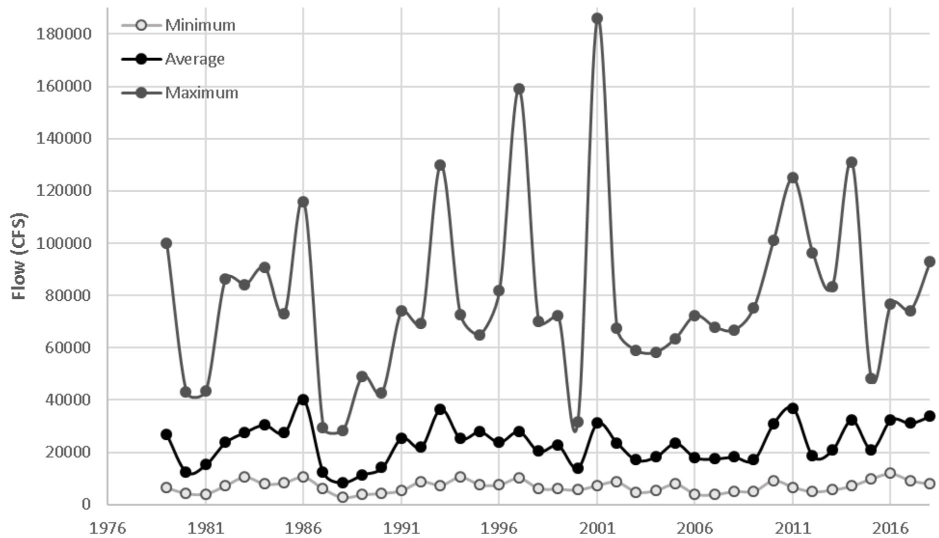

Figure 12. Annual minimum, maximum, and average daily flow in the Mississippi River at Lock and Dam 3 near Red Wing (1979-2018).

In a separate analysis of the data, the MPCA evaluated flow-adjusted loads at Red Wing using EGRETci WRTDS. Significant downward phosphorus loading trends were found for 12-year (2007-2018), 22-year (1997 to 2018) and 42-year (1977-2018) timeframes, resulting in an estimated phosphorus decrease of 0.87 million pounds (27% reduction), 1.3 million pounds (37% reduction), and 1.4 million pounds (36% reduction) over those three periods, respectively.

2.2.3 Mississippi River at Anoka – Phosphorus

The Mississippi River at Anoka site represents flow coming from areas mostly to the north and upstream of the Twin Cities (Figure 13). This part of the river has much lower nutrient concentrations than downstream of the confluence with the Minnesota River. The Met Council analysis using the QWTREND program shows flow-adjusted total phosphorus concentration reductions of 26% and 41% over the past 20 and 40 years, respectively, in the Mississippi River at Anoka. The decreases were particularly rapid during the 2006 to 2018 period (Table 5 and Figure 14).

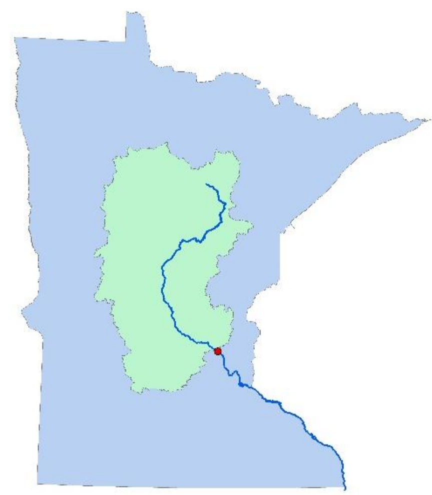

Figure 13. Watershed draining to Mississippi River at Anoka monitoring site.

Table 5. Statistical Trends for TP Concentration in the Mississippi River at Anoka.

Trend Period	Concentration (mg/L)	Change in Concentration (%)	Change Rate (mg/L/yr)	*p*	Trend
1976 – 2005	0.10 – 0.08	-26%	-0.00089	< 0.0001	↓
2006 – 2018	0.08 – 0.06	-22%	-0.0013	0.0004	↓
Overall Trends					
20 years (1999 – 2018)	0.08 – 0.06	-26%	-0.0010	–	↓
40 years (1979 – 2018)	0.10 – 0.06	-41%	-0.0010	–	↓

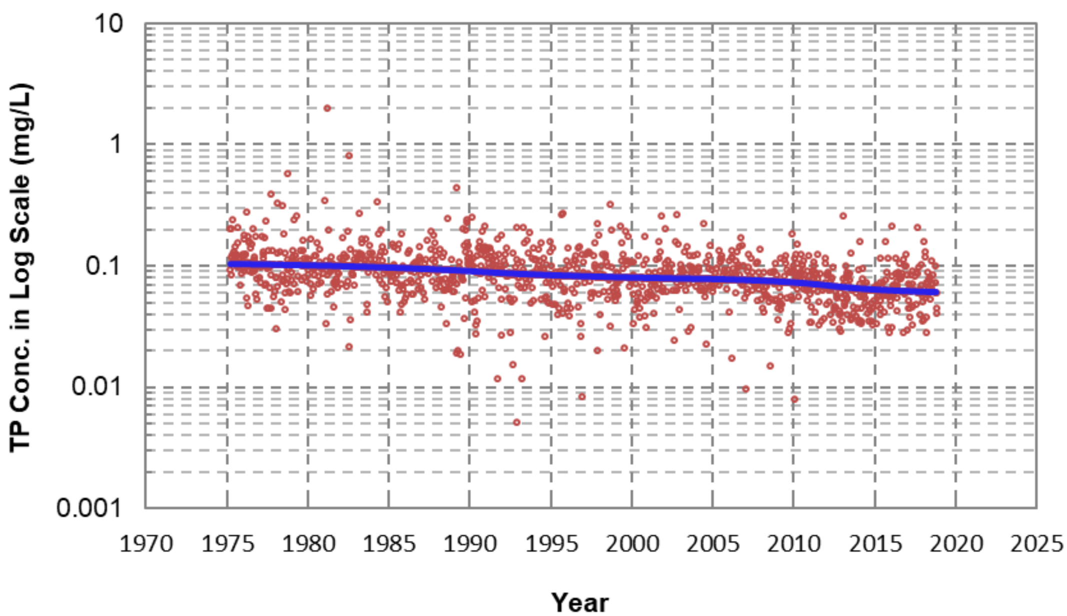

Figure 14. Statistical Trends for Flow-Adjusted TP Concentration in the Mississippi River at Anoka.

A separate analysis of non flow-adjusted load trends did not show a significant change for either time period. Trends in river flow at this site were mostly non-significant, except that low-flow conditions were significantly increasing over the past 20 years. Flow variability may be one factor affecting the lack of significance in the non flow-adjusted load trends (Table 6 and Figure 15).

Table 6. Statistical Trends for TP Loads in the Mississippi River at Anoka (not flow-adjusted). "No trend" means no trend detected with the trend analysis methods.

Trend Period	Change Rate (kg/yr)	Change Rate (%)	*p*	Trend
20 years (1999 – 2018)	–	–	0.87	No trend
40 years (1979 – 2018)	–	–	0.14	No trend

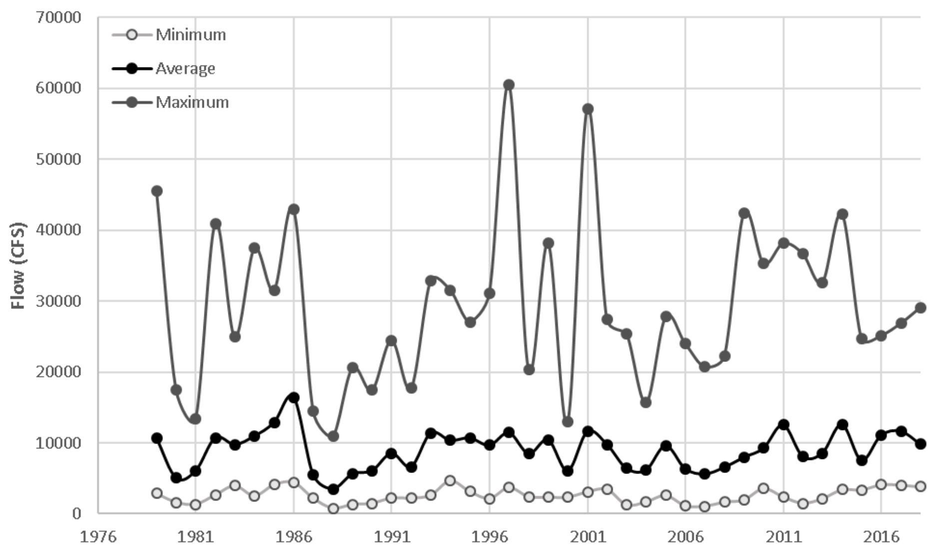

Figure 15. Annual minimum, maximum, and average daily flow in the Mississippi River at Anoka (1979-2018).

2.2.4 Minnesota River, Jordan – Phosphorus

The Minnesota River at Jordan is one of two long-term sites on the Minnesota River monitored by Met Council, with the other located near the mouth of the river at Fort Snelling (Figure 16 and Figure 20). The Jordan location receives over 90% of the same flow that pours into the Mississippi River site near Fort Snelling, where high amounts of nitrogen and phosphorus enter the Mississippi River.

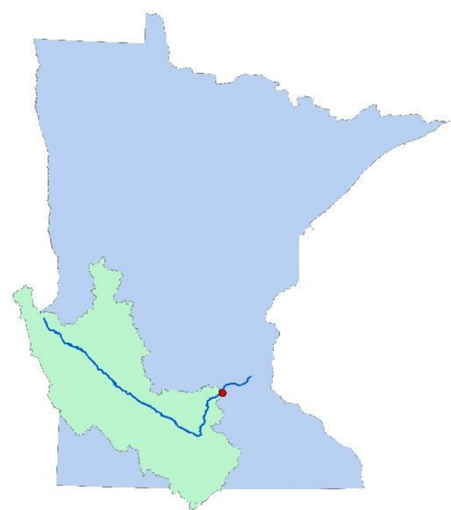

Figure 16. Watershed draining to Minnesota River at Jordan monitoring site.

The Met Council analysis with QWTREND showed three different periods of change over the course of the assessment period from 1979 to 2018 (Table 7 and Figure 17). The trend results show that TP concentration decreased slowly from 1979 to 2005, followed by a quick drop from 2005 to 2008, then increased slightly over the next 10 years from 2009 to 2018.

Overall, TP concentrations decreased by 17 and 30%, respectively, during the past 20 years (1999 to 2018) and 40 years (1979 to 2018), indicating an overall long-term improvement in flow-adjusted phosphorus concentrations. However, it appears that these long-term trends may be reversing as indicated by the significant increase from 2009-2018. Additional years of monitoring will provide the information necessary to evaluate if the more recent increasing trends continue.

Table 7. Statistical Trends for flow-adjusted TP Concentration in the Minnesota River at Jordan.

Trend Period	Concentration (mg/L)	Change in Concentration (%)	Change Rate (mg/L/yr)	*p*	Trend
1979 – 2004	0.23 – 0.19	-18%	-0.0016	0.0001	⬇
2005 – 2008	0.19 – 0.14	-25%	-0.012	< 0.0001	⬇
2009 – 2018	0.14 – 0.16	14%	0.0020	0.04	⬆
Overall Trends					
20 years (1999 – 2018)	0.19 – 0.16	-17%	-0.0017	–	⬇
40 years (1979 – 2018)	0.23 – 0.16	-30%	-0.0017	–	⬇

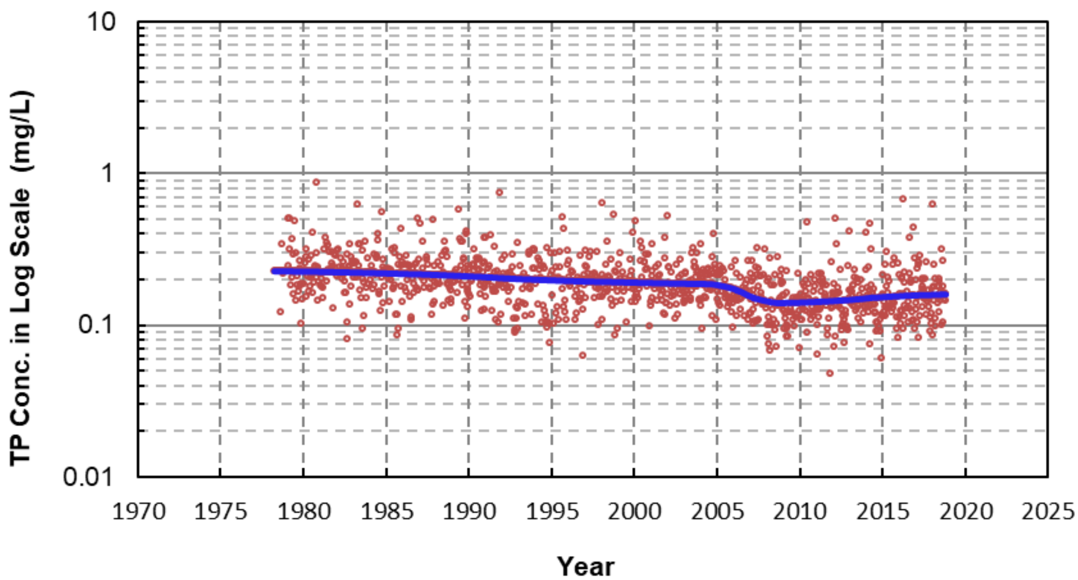

Figure 17. Statistical Trends for Flow-Adjusted TP Concentration in the Minnesota River at Jordan.

Phosphorus loads at Jordan show that the five-year rolling average has generally increased since about 2004 (Figure 18). Using a non flow-adjusted approach, Met Council did not find a statistically significant phosphorus load trend for the past 20 and 40 years (Table 8). While the non flow-adjusted load trend has increased during the past 20 years, the increase has been just over the threshold for considering it a statistically significant trend (p=0.11). A 68% increase in average river flow volume at this site during the past 20 years has increased phosphorus loads, even though flow-adjusted concentrations have been decreasing during the same timeframe (Table 9 and Figure 19).

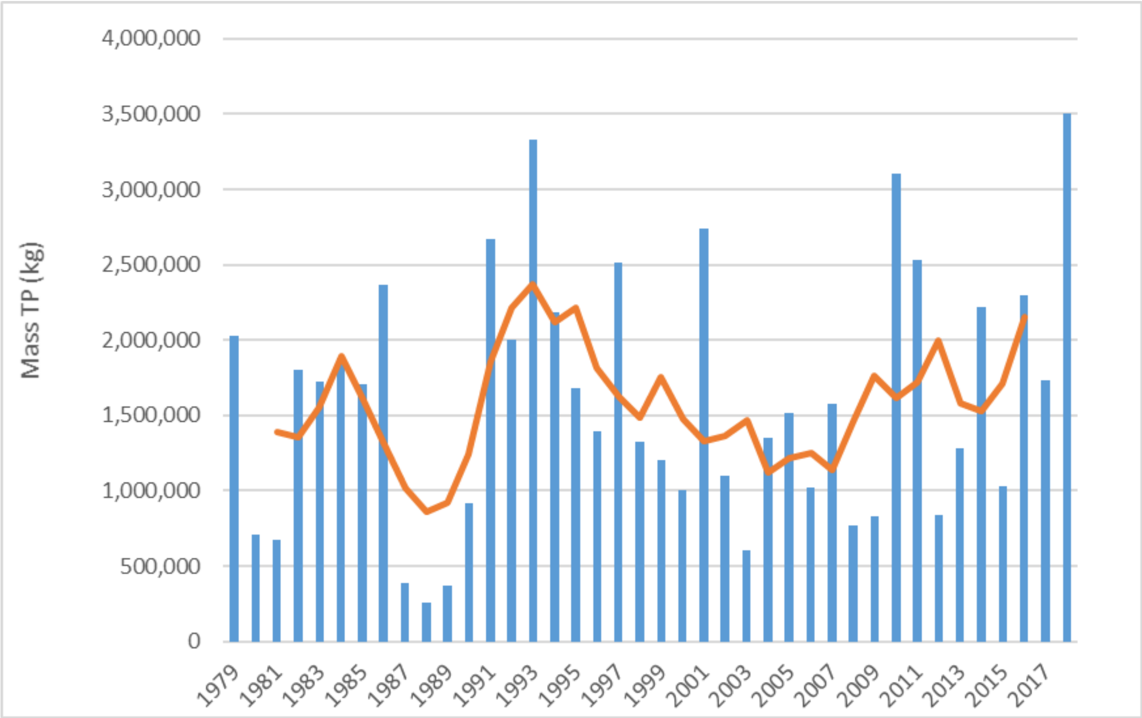

Figure 18. Annual TP Loads (non flow-adjusted) in the Minnesota River at Jordan (1979-2018), also showing the 5-year moving average (orange line).

Table 8. Statistical Trends for Non Flow-Adjusted TP Loads in the Minnesota River at Jordan. "No trend" means no trend detected with the trend analysis methods.

Trend Period	Change Rate (kg/yr)	Change Rate (%)	*p*	Trend
20 years (1999 – 2018)	–	–	0.11	No trend
40 years (1979 – 2018)	–	–	0.48	No trend

Table 9. Statistical Trends for River Flow Volume in the Minnesota River at Jordan. "No trend" means no trend detected with the trend analysis methods.

Trend Period		Change Rate (CFS)	Change Rate (%)	*p*	Trend
20 years (1999 – 2018)	Minimum	27.7	61%	0.10	⬆
	Average	247	68%	0.06	⬆
	Maximum	–	–	0.21	No trend
40 years (1979 – 2018)	Minimum	–	–	0.23	No trend
	Average	–	–	0.17	No trend
	Maximum	–	–	0.11	No trend

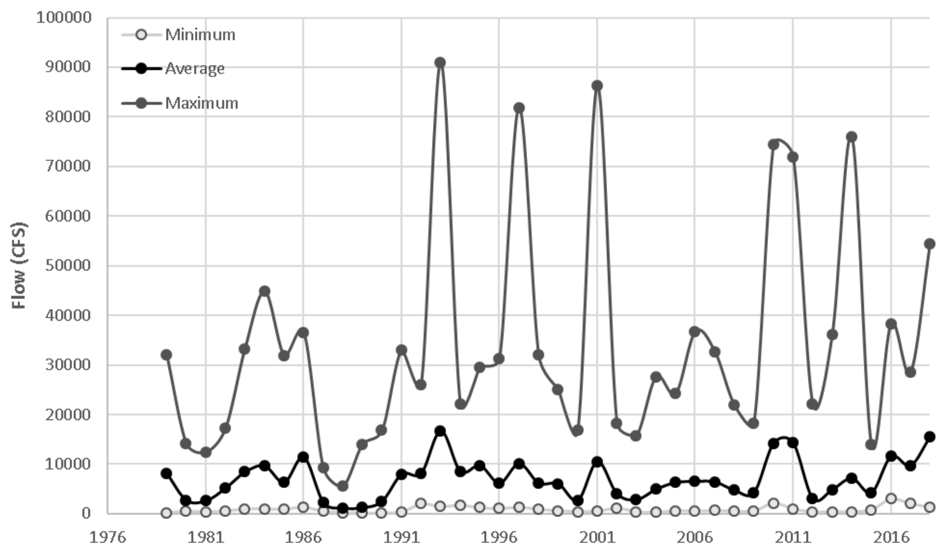

Figure 19. Annual minimum, maximum, and average daily flow in the Minnesota River at Jordan (1979-2018).

2.2.5 Minnesota River, Fort Snelling – Phosphorus

The Fort Snelling location on the Minnesota River is immediately upstream of the river mouth and its confluence with the Mississippi River (Figure 20). The QWTREND analysis showed a phosphorus concentration decrease from 1976 to 2000, followed by a more gradual decrease from 2001 to 2018. Overall, TP concentrations decreased by 18 and 51%, during the past 20 and 40 years, respectively (Table 10 and Figure 21).

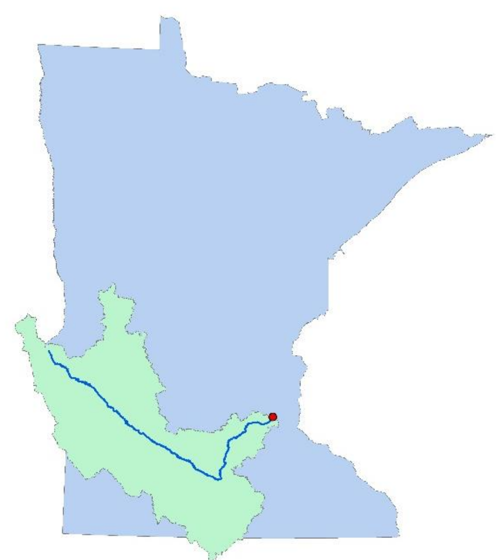

Figure 20. Minnesota River at Fort Snelling drainage area.

Table 10. Statistical Trends for TP Concentration in the Minnesota River at Fort Snelling.

Trend Period	Concentration (mg/L)	Change in Concentration (%)	Change Rate (mg/L/yr)	*p*	Trend
1976 – 2000	0.33 – 0.19	-44%	-0.0057	< 0.0001	⬇
2001 – 2018	0.19 – 0.16	-16%	-0.0017	0.005	⬇
Overall Trends					
20 years (1999 – 2018)	0.19 – 0.16	-18%	-0.0018	–	⬇
40 years (1979 – 2018)	0.32 – 0.16	-51%	-0.0040	–	⬇

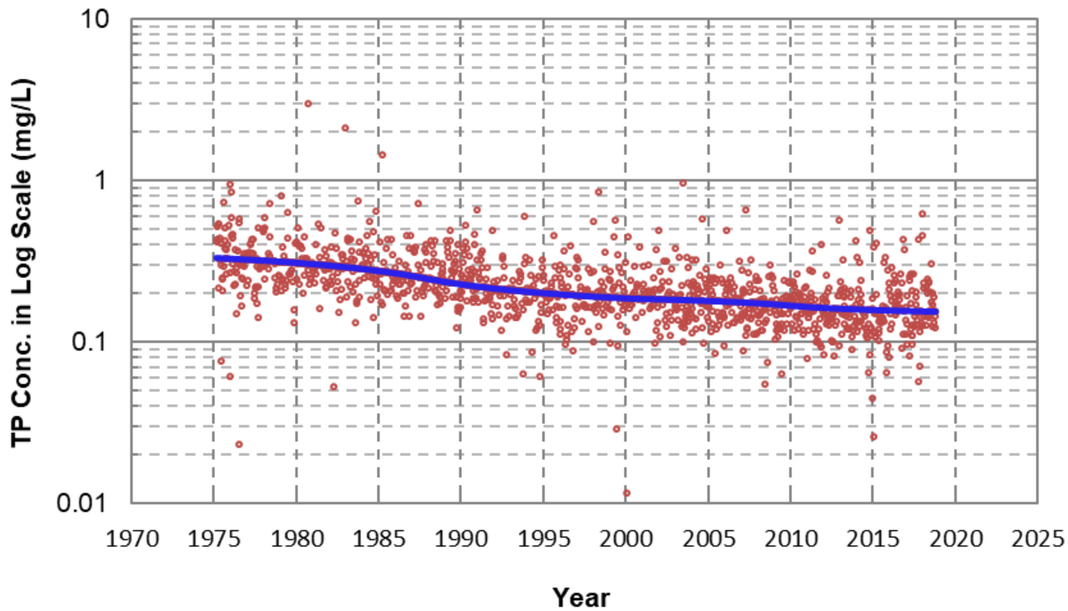

Figure 21. Statistical Trends for Flow-Adjusted TP Concentration in the Minnesota River at Fort Snelling.

Met Council did not find a statistically significant phosphorus load trend (non flow-adjusted) for the past 20 and 40 years (Table 11) at Fort Snelling. A 75% increase in flow during the past 20 years is a factor explaining why phosphorus concentrations have dropped in the past 20 years, but loads have not correspondingly decreased (Table 12).

Table 11. Statistical Trends for Non Flow-Adjusted TP Loads in the Minnesota River at Fort Snelling. "No trend" means no trend detected with the trend analysis methods.

Trend Period	Change Rate (kg/yr)	Change Rate (%)	*p*	Trend
20 years (1999 – 2018)	–	–	0.18	No trend
40 years (1979 – 2018)	–	–	0.92	No trend

Table 12. Statistical Trends for River Flow Volume in the Minnesota River at Fort Snelling. "No trend" means no trend detected with the trend analysis methods.

Trend Period		Change Rate (CFS)	Change Rate (%)	*p*	Trend
20 years (1999 – 2018)	Minimum	65.0	118%	0.01	↑
	Average	285	75%	0.05	↑
	Maximum	–	–	0.23	No trend
40 years (1979 – 2018)	Minimum	16.1	64%	0.04	↑
	Average	–	–	0.15	No trend
	Maximum	–	–	0.13	No trend

2.2.6 St. Croix River, Stillwater – Phosphorus

Flow-adjusted total phosphorus concentrations in the St. Croix River at Stillwater (Figure 22) have gradually declined since 1976, based on the Met Council analysis using QWTREND (Table 13 and Figure 23). Overall, total phosphorus concentrations have decreased by 13 and 27%, respectively, during the past 20 years (1999 to 2018) and 40 years (1979 to 2018).

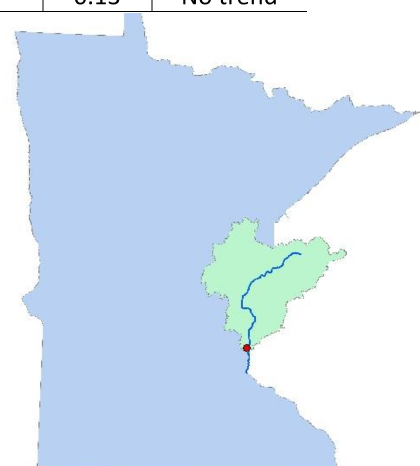

Figure 22. Watershed draining to St. Croix River at Stillwater monitoring site.

Table 13. Statistical Trend for Flow-Adjusted TP Concentration in the St. Croix River at Stillwater.

Trend Period	Concentration (mg/L)	Change in Concentration (%)	Change Rate (mg/L/yr)	*p*	Trend
1976 – 2018	0.05 – 0.04	-28%	-0.00032	< 0.0001	↓
Overall Trends					
20 years (1999 – 2018)	0.04 – 0.036	-13%	-0.00028	–	↓
40 years (1979 – 2018)	0.05 – 0.04	-27%	-0.00033	–	↓

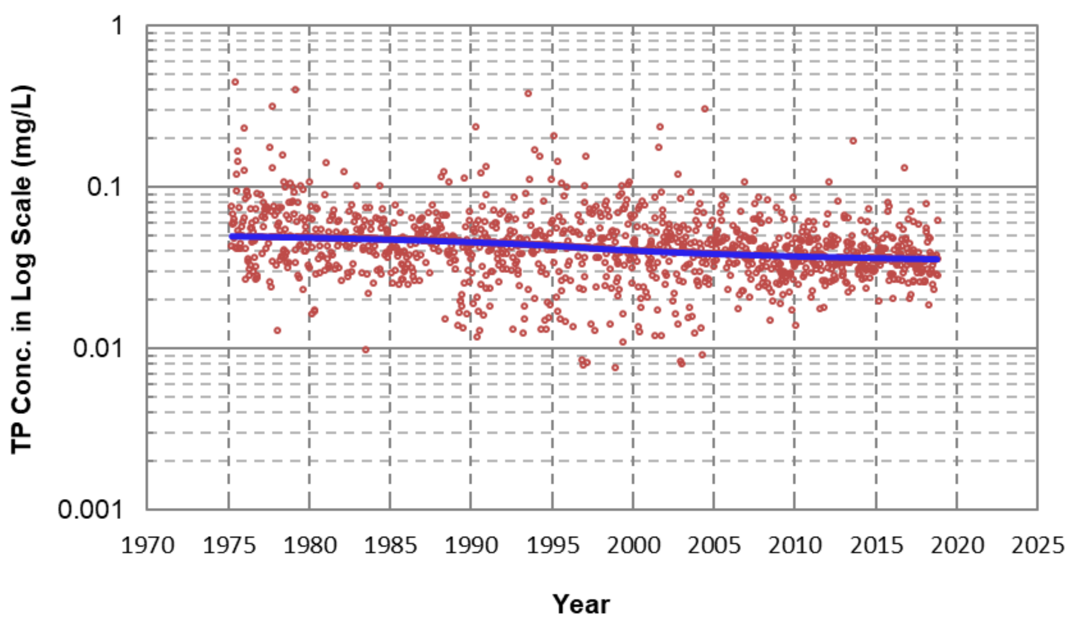

Figure 23. Statistical Trend for flow-adjusted TP Concentration in the St. Croix River at Stillwater.

Met Council did not find a statistically significant phosphorus load trend (non flow-adjusted) for the past 20 and 40 years at Stillwater (Table 14). Flows have increased in the past 20 years (Figure 24), but these increases are not statistically significant (p>0.1). The river flow changes may be offsetting at least some of the progress made in phosphorus concentration decreases.

Table 14. Statistical Trends for non flow-adjusted TP Loads in the St. Croix River at Stillwater. "No trend" means no trend detected with the trend analysis methods.

Trend Period	Change Rate (kg/yr)	Change Rate (%)	*p*	Trend
20 years (1999 – 2018)	–	–	0.77	No trend
40 years (1979 – 2018)	–	–	0.58	No trend

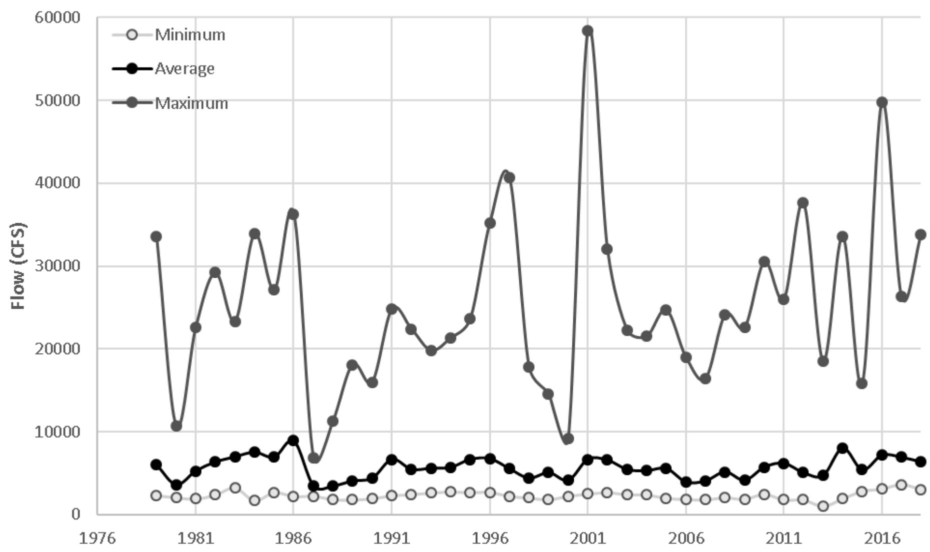

Figure 24. Annual minimum, maximum, and average daily flow in the St. Croix River at Stillwater (1979-2018).

2.3 Red River of the North

The USGS statistical trends focused on QWTREND analyses in the Red River and its tributaries for the period 2000 to 2015. While the modeling used available data also from 1995-1999 and 2016-2017 to help establish the 2000-2015 trend, the reported findings are only evaluated for statistical significance within the 2000-2015 period.

This report uses a Minnesota-specific subset of the sites in the full USGS report (Nustad and Vecchia, 2020) that also includes North Dakota and Manitoba. Additionally, this report uses different notation for indicating statistically significant trends than used by Nustad and Vecchia (2020). The USGS report uses lower p-value thresholds for denoting a significant trend, and also shows the direction of non-significant trends with high p-values. Refer to the complete USGS report for a more detailed breakdown of the trend findings in the Red River of the North Basin.

The USGS results show Red River flow-adjusted phosphorus concentrations decreased by 24% since 2000 in the three upstream locations (Table 15). Further downstream in Grand Forks the river phosphorus concentration trends become non-significant ($p>0.1$). Further downstream yet, an increasing trend was found at the U.S. – Canada border in Emerson. The Emerson site is located just downstream from where the Pembina River flows in from Manitoba and North Dakota (Figure 25). The Pembina River shows increasing trends and is likely one reason for the increasing trend at Emerson. Other tributaries between Grand Forks and Emerson may also contribute to the increase as well;

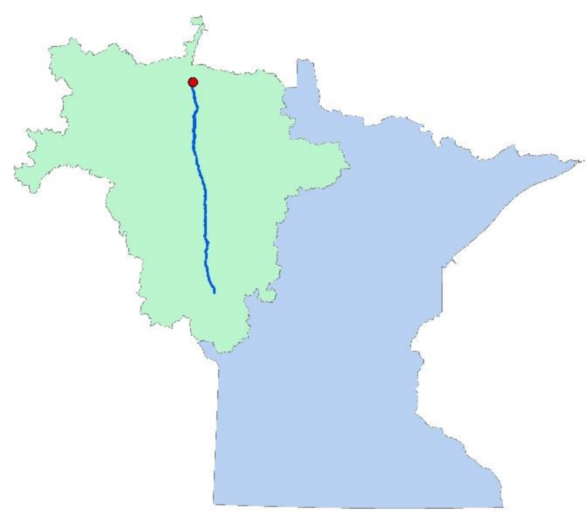

Figure 25. Approximate watershed draining to Red River at Emerson monitoring site.

however, a lack of data for those tributaries prevented inclusion in this analysis. It is possible that localized changes along the mainstem Red River may also contribute to the phosphorus increase at the Emerson site.

The Minnesota Red River tributaries evaluated by the USGS all show flow-adjusted phosphorus concentration decreases (13-51%), with the exception of Sand Hill River at Climax, which did not show a statistically significant trend (p>0.1). Flow-adjusted phosphorus load trends in the Red River Basin included in this report are identical to the concentration trends because of model assumptions and the approach used for trend calculation.

Table 15. Overview of Red River Basin phosphorus trends results at long-term Red River and Minnesota tributary monitoring sites. An increasing trend is denoted by "+" and a decreasing trend is "-." Non-significant trends (p<0.1) is denoted by "NS."

Red River and HUC-8 Tributaries	**Parameter and Method (phosphorus)**	**Mid-range (2000-15)**
Red River Emerson	Concentration and load (QWTREND flow-adjusted)	**+27%**
Red River Grand Forks	Concentration and load (R-QWTREND flow-adjusted)	**NS**
Red River Halstad	Concentration and load (R-QWTREND flow-adjusted)	**-24%**
Red River Harwood	Concentration and load (R-QWTREND flow-adjusted)	**-24%**
Red River Fargo	Concentration and load (R-QWTREND flow-adjusted)	**-24%**
Tributaries (MN)		
Wild Rice River Hendrum	Concentration (R-QWTREND flow-adjusted)	**-33%**
Sand Hill River Climax	Concentration (R-QWTREND flow-adjusted)	**NS**
Ottertail River Breckenridge	Concentration (R-QWTREND flow-adjusted)	**-56%**
Clearwater River Red Lake Falls	Concentration (R-QWTREND flow-adjusted)	**-21%**
Boix de Sioux River Doran	Concentration (R-QWTREND flow-adjusted)	**-13%**
Buffalo River Georgetown	Concentration (R-QWTREND flow-adjusted)	**-27%**

2.4 Lake Superior Basin

The St. Louis River contributes the most flow of any of Minnesota's rivers draining into Lake Superior (Figure 26). One site is included in the analysis: St. Louis River at Scanlon. The monitoring site is located just downstream from the town of Cloquet and several miles upstream from Duluth. The site is also upstream of where the river widens at Spirit Lake. Phosphorus concentrations are quite low in this river compared to the Mississippi and Red Rivers near the state borders.

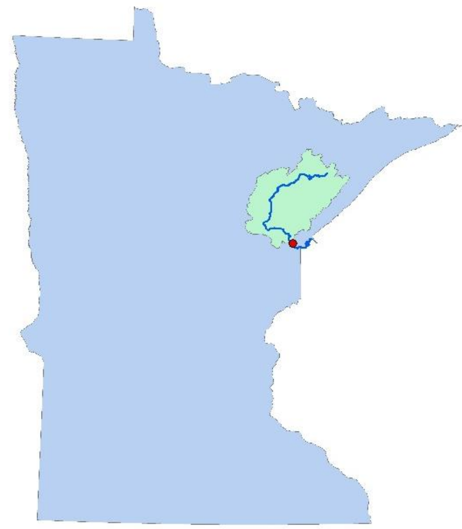

Figure 26. St. Louis River watershed.

Using the QWTREND model, the MPCA found flow-adjusted phosphorus concentrations decreased by 0.013 mg/l (30%) over a 43-year period from 1976 to 2018 (Table 16). Phosphorus concentrations decreased by 53% over the past 10 years (2009 to 2018). The mid-range concentration trend was not evaluated due to a data gap that affects that timeframe.

Table 16. Overview of St. Louis River at Scanlon Phosphorus concentration and load trend results.

Tributary	Parameter and Method (phosphorus)	Recent (2009-18)	Mid-range (1998-17)	Long-Term (1976-2018)
St. Louis River	Concentration (QWTREND flow-adjusted)	**-53%**		**-30%**
	Load flow-adjusted (EGRETci WRTDS)	**NS**	**NS**	**-44%**

The MPCA evaluated flow-adjusted phosphorus loads at the St. Louis River at Scanlon site using EGRETci WRTDS and found significant downward trends for the 43-year timeframe, with an estimated 44% decrease (73,360 pounds of phosphorus reduced). Flow-adjusted load decreases of about 40% during the 10- and 20-year timeframes were not significant (p=0.11, p=0.20), just over the significance threshold of p=0.1. The non flow-adjusted phosphorus loads show an increasing five-year rolling average since 2003 (Figure 27), coinciding with precipitation increases in this part of the state over that time period.

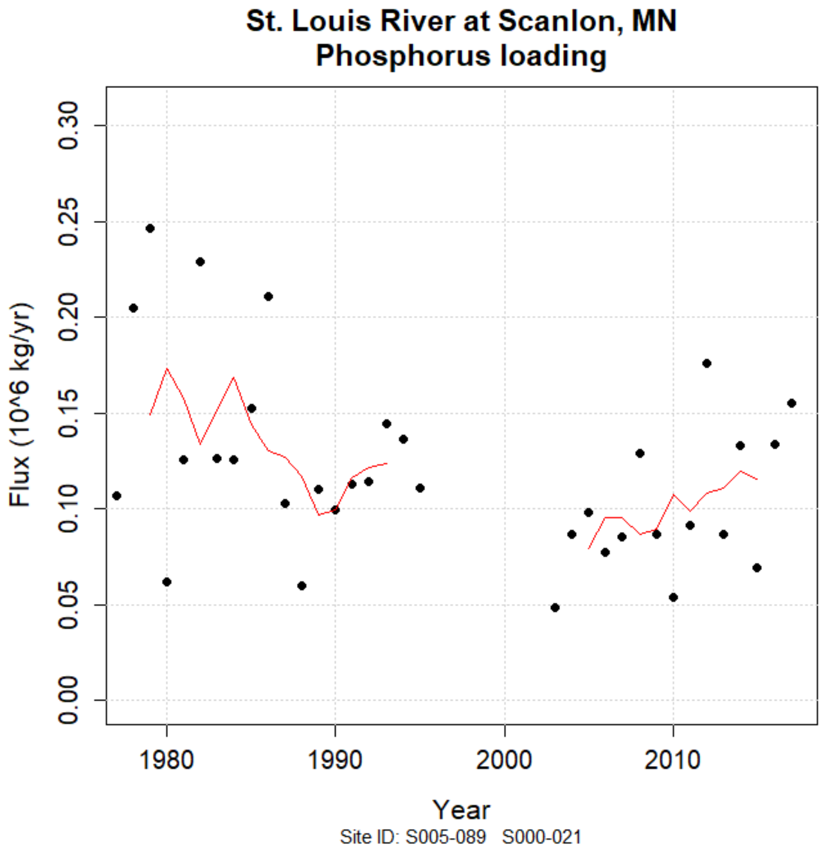

Figure 27. St. Louis River at Scanlon loads (not flow-adjusted) along with the five-year moving average.

3. Nitrate Results

The analysis for nitrate trends first uses a less rigorous statistical approach across the state, and then is followed by more in-depth analyses at certain key river monitoring sites in the (1) Mississippi River Basin, (2) Red River Basin, and (3) Lake Superior Basin.

3.1 Statewide Nitrate (MPCA)

Similar to phosphorus, the nitrate trend analyses include two levels: 1) data from MPCA monitoring sites assessed using the bootstrapped seasonal Kendall approach for 10, 20, and 40 year timeframes, and 2) 20-year mid-range trend analyses from Met Council, USGS and MPCA using QWTREND, R-QWTREND, and/or WRTDS EGRETci at long-term monitoring sites across Minnesota. Note that Met Council and USGS include additional river sites that are not included in the MPCA-assessed data sets.

3.1.1 MPCA Sites - Seasonal Kendall Test – 10, 20, and 40 Year Trends

The MPCA used the bootstrapped seasonal-Kendall statistical test for data collected at each of its monitoring sites during the past ten years or more to evaluate nitrate concentration trends. The vast majority of river nitrite+nitrate-N is nitrate (rather than the nitrite); therefore, this section refers to nitrite+nitrate as *nitrate*. The nitrate trend assessments included methods adjusting for year-to-year river flow variability, along with some analysis that did not adjust for flow. See the methods section at the beginning of this report for more information about the difference between flow-adjusted and non flow-adjusted techniques.

The analyses show that river nitrate concentrations have increased throughout much of Minnesota during recent decades. No sites had a decreasing nitrate concentration trend, although many sites have had no statistically significant trend. Other sites had nitrate levels below laboratory detection limits so often that trends analyses could not be performed. Using the flow-corrected seasonal-Kendall method, 14 of 38 sites (37%) with detectable nitrate showed increasing 10-year trends, with the other 63% showing non-significant trends. River monitoring results showed increasing 20-year nitrate trends at 5 out of 11 sites (45%). Statistically significant increasing trends were found at 75% (6 out of 8) of sites with 40-year records (Figure 28).

The non flow-adjusted trends showed 50% of sites with increasing trends, as compared to 37% of sites with increases using the flow-adjusted methods (Figure 28). At the same time that nitrate concentrations were increasing, river flows throughout most of southern and northeastern Minnesota were also increasing, causing even more sites to have statistically significant nitrate increases when not adjusting for flow.

The majority of the 10-year nitrate increases were found in the central and southwestern part of the state (Figure 29). The 20-year increases were more scattered at the five sites with increases (Figure 30).

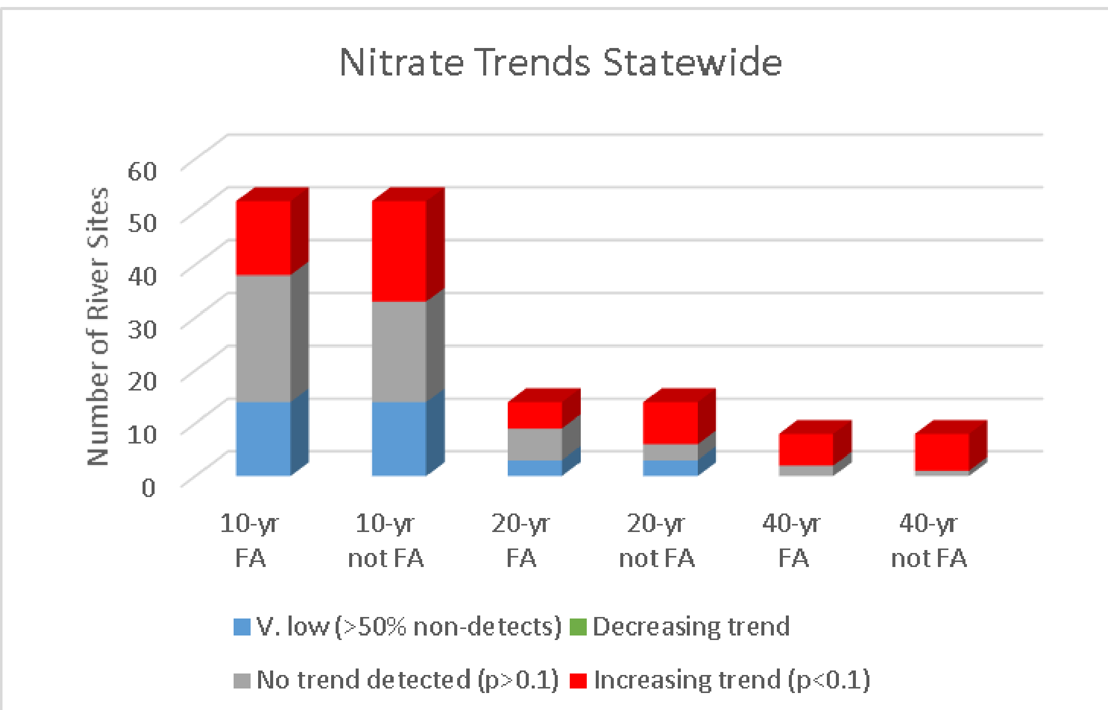

Figure 28. Bootstrapped Seasonal Kendall nitrate concentration trend results using both flow-adjusted (FA) and non flow-adjusted (not FA) techniques at MPCA monitored river sites across Minnesota.

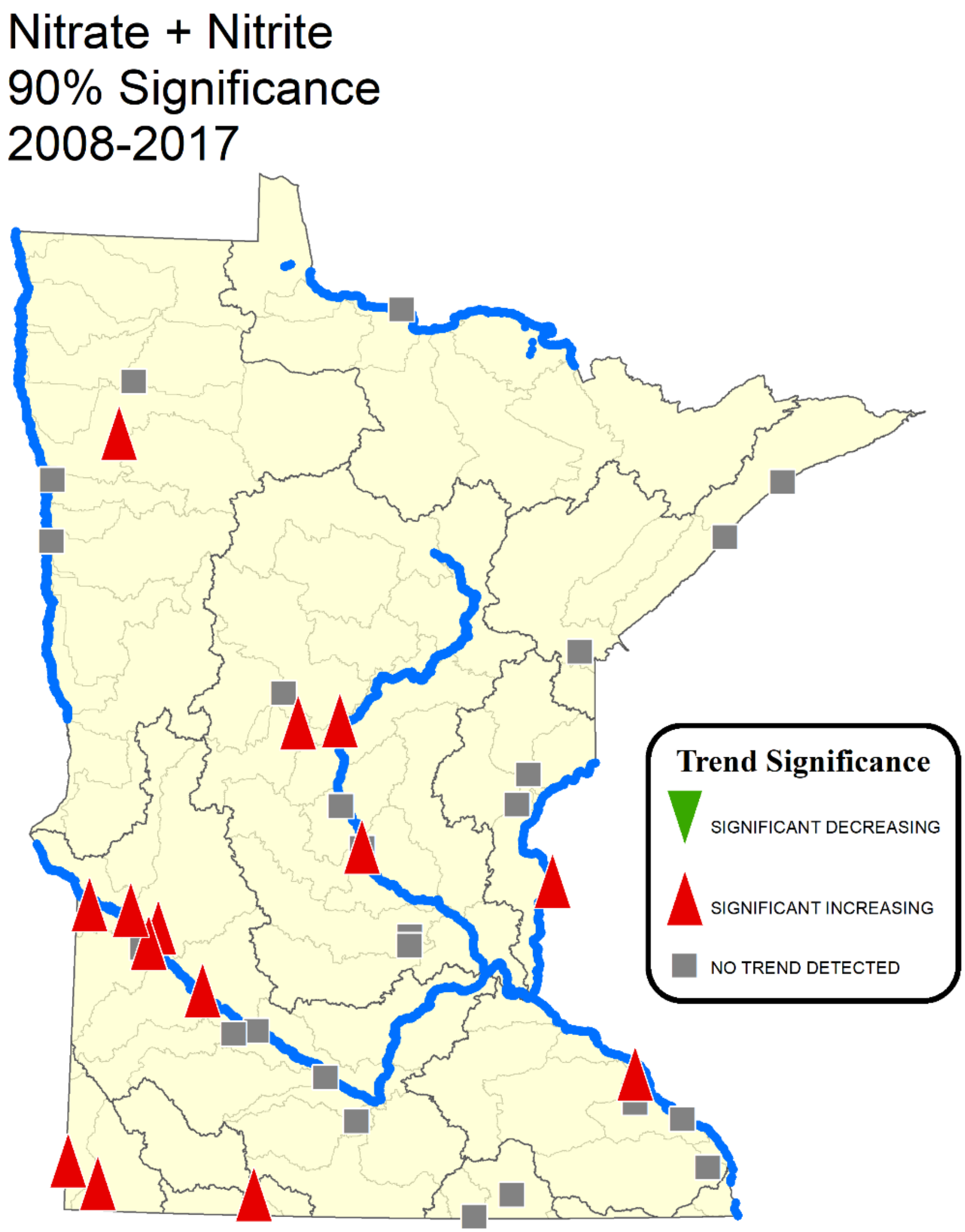

Figure 29. Recent (2008-2017) nitrate trends at MPCA sites assessed using a flow-adjusted Seasonal Kendall approach.

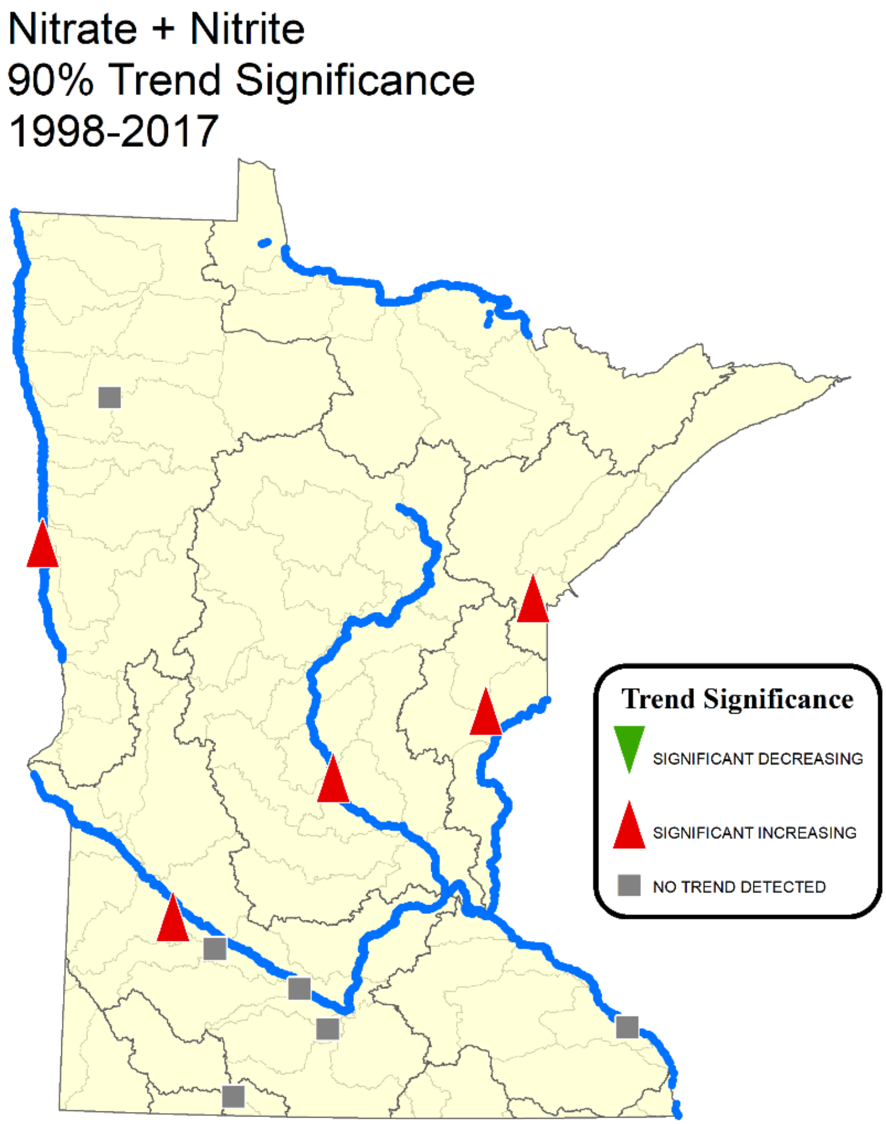

Figure 30. Mid-range (1998-2017) nitrate+nitrite trends at MPCA sites assessed using a flow-adjusted Seasonal Kendall approach.

3.1.2 Statewide Mid-range Nitrate Trends from Met Council, USGS, and MPCA

Rigorous statistical analyses using QWTREND and R-QWTREND (concentration trends) and/or EGRETci WRTDS (load trends) were also performed for nitrate statewide.

Mid-range (approximately 20-year) flow-adjusted nitrate concentration trends were conducted using QWTREND and/or EGRETci WRTDS at the same key major river sites as previously described for phosphorus and shown in Figure 31. QWTREND was used to assess trends at all mapped sites in Figure 31, except that the flow-adjusted Seasonal Kendall test used at tributaries to the Minnesota River, along with the Sauk River and Kettle River.

Half of the mid-range sites show increasing trends (14 of 28) and only 3 of 28 (11%) sites showed a decreasing trend. Eleven of the 28 sites had no significant trend detected. More details about nitrate trend results are described below for each site where the QWTREND or R-QWTREND method was used by either the USGS, Met Council or MPCA.

In general, nitrate concentration trend directions for mid-range trends in figure 30 are similar to the mid-range trends in Figure 31, which includes several different sites and different statistical methods.

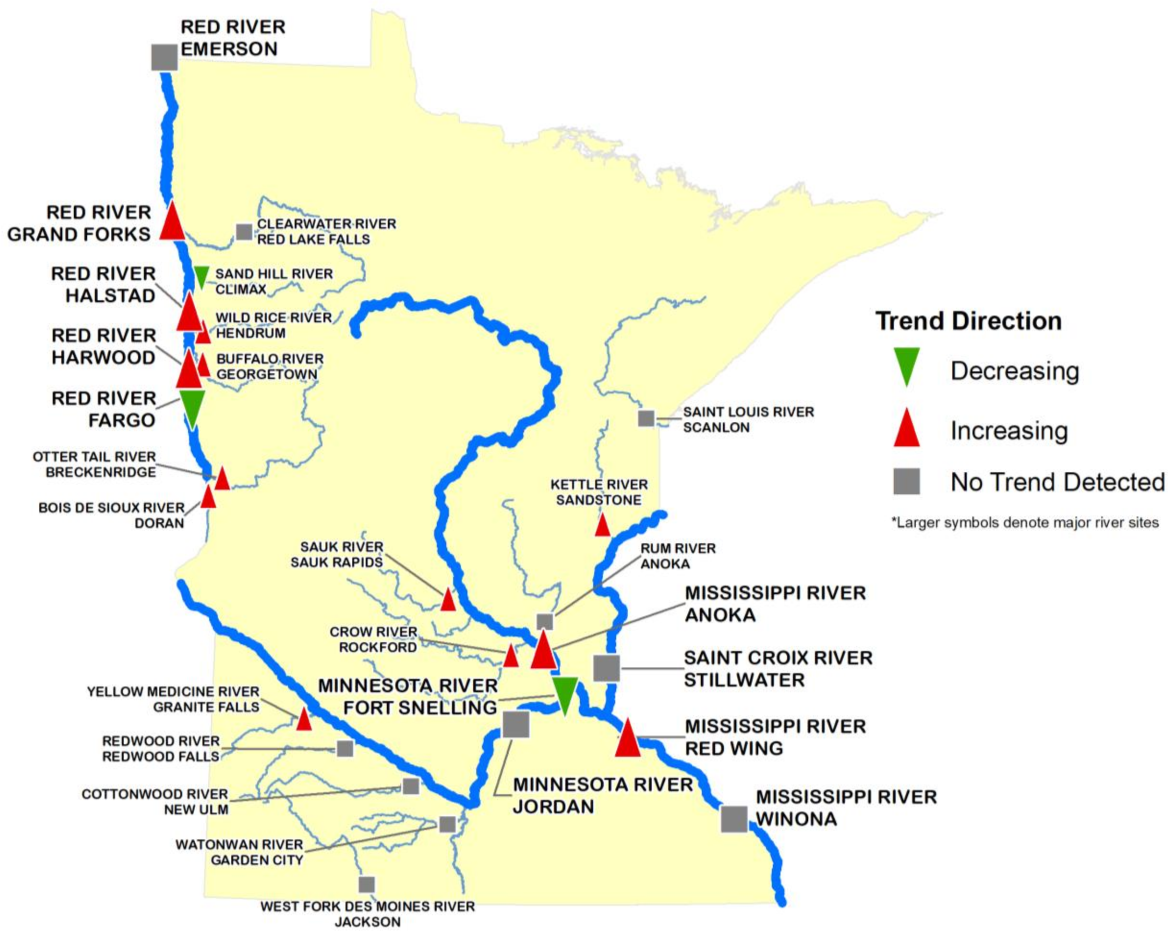

Figure 31. River monitoring site locations at sites with enough information to determine mid-range (approximately 20-year) flow-adjusted nitrate concentration trends. Large symbols represent major river sites and small symbols represent tributary river sites.

3.2 Mississippi River Basin

An overview of nitrate trends in the Mississippi River and its major tributaries is shown in Table 17. Trends over the long-term (37-43 years) show increasing flow-adjusted concentration trends in the Mississippi River (68% to 162%) and Minnesota River at Fort Snelling (21%). Long-term nitrate concentration increases were non-significant in the St. Croix River Stillwater and Minnesota River

Jordan. The mid-range (approximately 20-year) flow-adjusted nitrate concentration trends were more varied, with two increases of 25 and 34%, one decrease by 15%, and three non-significant increases.

Nitrate flow-adjusted load increases were not significant at the Mississippi River Winona site, but were significant for the 40-year trends at the Mississippi River Red Wing site (53-54% increases in both flow-adjusted and non flow-adjusted loads). Further upstream at the Minnesota River sites and the Mississippi River Anoka site, the non flow-adjusted load increases were fairly close to being significant, with p-values between 0.11 and 0.22 in.

Table 17. Overview of Mississippi River Basin nitrate trends results for concentration and load at long-term major river monitoring sites.

An increasing trend is denoted by "+" and a decreasing trend is "-." Non-significant trends at a p<0.1 is denoted by "NS."

Mississippi River and Major Tributaries	Parameter and Method	Recent (~ 10 yr)	Mid-range (~ 20 yr)	Long-Term (~ 40 yr)
Mississippi River Winona	Concentration (QWTREND flow-adjusted)	**NS**	**NS**	**+68%**
	Load flow-adjusted (EGRETci-WRTDS flow- adjusted)	**NS**	**NS**	**NS**
Mississippi River Red Wing	Concentration (QWTREND flow-adjusted)		**+25%**	**+154%**
	Load flow-adjusted (EGRETci-WRTDS)	**NS**	**NS**	**+54%**
	Load (Mann Kendall of annual loads, not flow-adjusted)		**+62%**	**+53%**
Mississippi River Anoka	Concentration (QWTREND flow-adjusted)		**+34%**	**+162%**
	Load (Mann Kendall of annual loads, not flow-adjusted)		**NS** P=0.14	**NS** P=0.16
Minnesota River Jordan	Concentration (QWTREND flow-adjusted)		**NS**	**NS**
	Load (Mann Kendall of annual loads, not flow-adjusted)		**NS** P=0.16	**NS** P=0.13
Minnesota River Fort Snelling	Concentration (QWTREND flow-adjusted)		**-15%**	**+21%**
	Load (Mann Kendall of annual loads, not flow-adjusted)		**NS** P=0.11	**NS** P=0.22
St. Croix River Stillwater	Concentration (QWTREND flow-adjusted)		**NS** P=0.	**NS** P=0.
	Load (Mann Kendall of annual loads, not flow-adjusted)		**NS** P=0.63	**NS** P=0.97
Crow River Rockford	Concentration (QWTREND flow-adjusted)		**+55%**	

The Crow River, a major tributary delivering nutrients to the Upper Mississippi River, showed a 55% nitrate concentration increase from 1999-2018. Trends on many other different HUC-8 tributaries in the Mississippi Basin were calculated by the MPCA using the seasonal Kendall method, as previously discussed.

3.2.1 Mississippi River at Winona - Nitrate

For the Mississippi River Winona site near the state border with Iowa (Figure 32), this analysis assessed flow-adjusted nitrate concentration trends over three time periods representing the past 11, 21 and 36 years. The long-term (36-year) trends show a 68% increase using the QWTREND model. However, the recent (11-year) and mid-range (21-year) increases were not statistically significant.

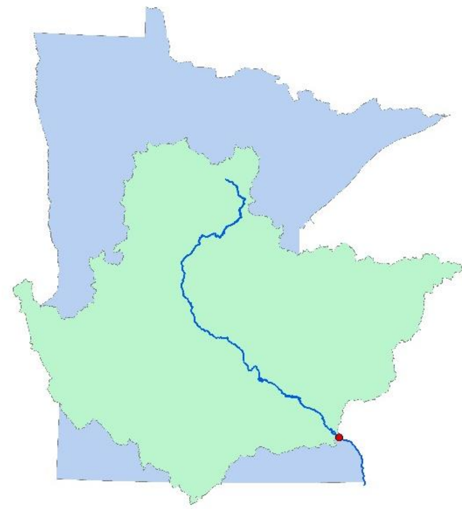

Figure 32. Watershed draining to Mississippi River at Winona monitoring site.

Using EGRETci WRTDS, we also evaluated the flow-adjusted nitrate load trends for the short-term (2008-2018), mid-range (2001-2018) and long-term (1982-2018) timeframes. The load results show non-significant flow-adjusted nitrate load increases for these periods.

The non flow-adjusted nitrate loads viewed as a five-year rolling average (Figure 33) show inconsistent trends over the decades, but shows an increasing trend since 2007.

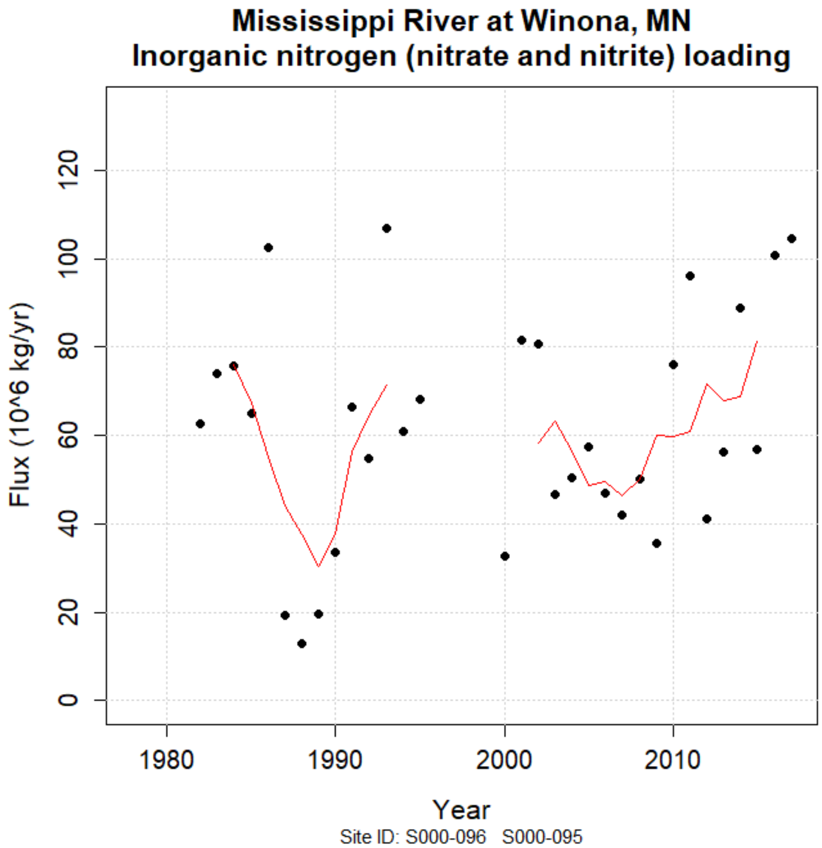

Figure 33. Mississippi River at Winona five-year rolling average nitrate loads (non flow-adjusted). Loads were calculated with the EGRETci WRTDS model.

3.2.2 Mississippi River at Red Wing (Lock and Dam #3) – Nitrate

The Met Council analysis using the QWTREND program shows that nitrate flow-adjusted concentrations increased in the Mississippi River at Red Wing (Figure 34) by 25 and 154% over the past 20 and 40 years, respectively. Nitrate concentration changes at this site are best represented by a two-trend model ($p < 0.0001$) over the assessment period of 1976 to 2018 (Table 18 and Figure 35). Nitrate concentrations increased markedly from 1976 to 1982, followed by a more gradual increase between 1983 and 2018.

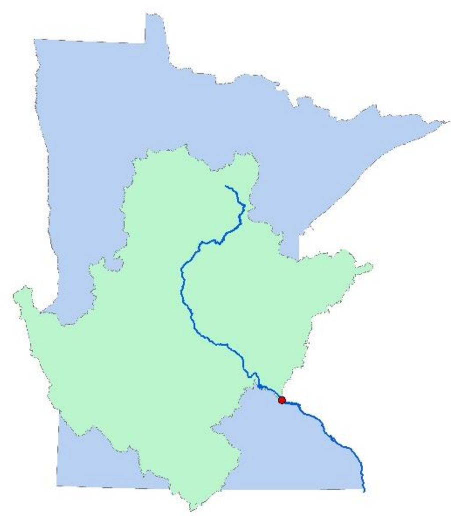

Figure 34. Watershed draining to Mississippi River at Red Wing monitoring site.

Table 18. Statistical Trends for NOx Concentration in the Mississippi River at Lock and Dam 3.

Trend Period	Concentration (mg/L)	Change in Concentration (%)	Change Rate (mg/L/yr)	*p*	Trend
1976 – 1982	0.58 – 1.39	142%	0.12	< 0.0001	⬆
1983 – 2018	1.39 – 2.03	46%	0.018	< 0.0001	⬆
Overall Trends					
20 years (1999 – 2018)	1.62 – 2.03	25%	0.020	–	⬆
40 years (1979 – 2018)	0.80 – 2.02	154%	0.031	–	⬆

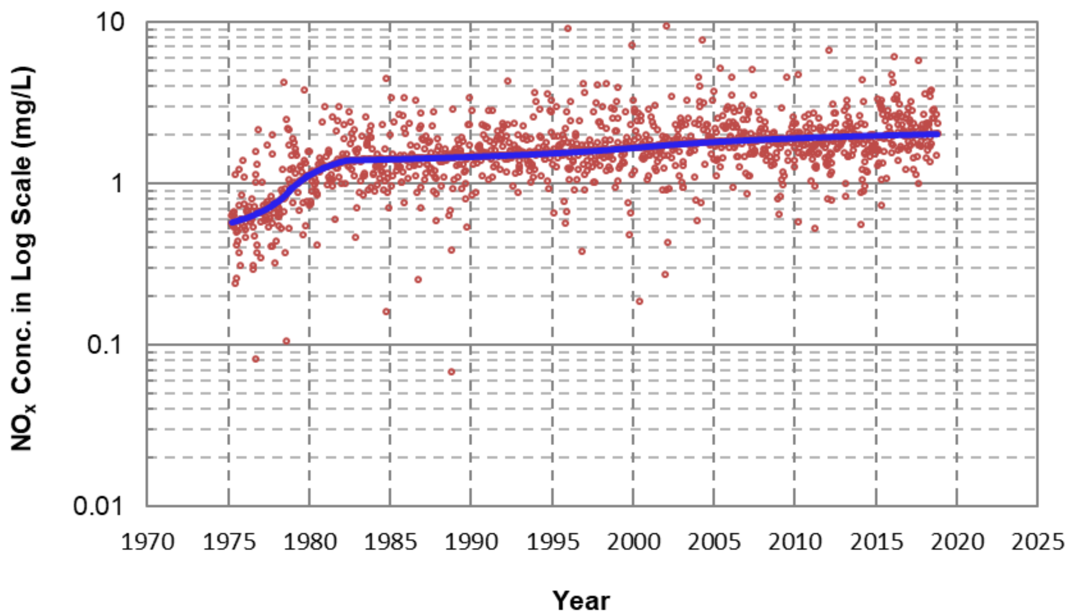

Figure 35. Statistical Trends for NOx Concentration in the Mississippi River at Lock and Dam 3.

A separate analysis of non flow-adjusted load trends showed 62% and 53% nitrate load increases during the past 20 and 40 years, respectively (Table 19 and Figure 36). This is not surprising since loads reflect the combination of concentrations and river flow, and both have increased. Flows have especially increased during the past 20 years. Total nitrogen loads show a similar pattern over time as nitrate.

Table 19. Statistical Trends for NOx Loads in the Mississippi River at Lock and Dam 3.

Trend Period	Change Rate (kg/yr)	Change Rate (%)	*p*	Trend
20 years (1999 – 2018)	1,850,000	62%	0.09	⬆
40 years (1979 – 2018)	723,000	53%	0.09	⬆

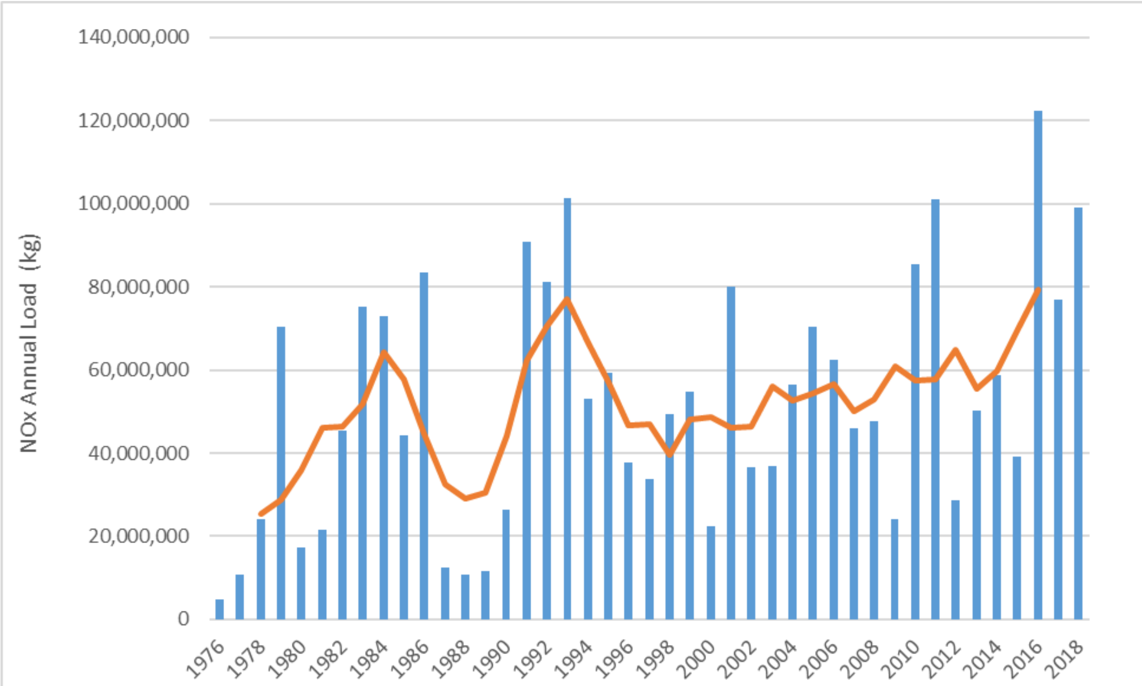

Figure 36. Annual NOx Loads in the Mississippi River Red Wing along with the five-year rolling average (orange line).

The MPCA evaluated flow-adjusted nitrate load trends for the recent, mid-range and long-term periods of 2007-2018, 1997-2018, and 1977-2018. The EGRETci WRTDS trend results show nitrate annual flow-adjusted load increases of 10.2, 16.6 and 21.7 million pounds per year for the 12-, 22- and 42-year periods. However, the load trends were only significant ($p<0.1$) for the long-term period.

3.2.3 Mississippi River at Anoka – Nitrate

Met Council found flow-adjusted nitrate concentration increases of 34% and 162% over the past 20 and 40 years, respectively, in the Mississippi River at Anoka (Figure 37). Similar to the Mississippi River at Red Wing, the increases were greatest during the 1976 to 1983 timeframe and more gradual from 1984 to 2018 (Table 20 and Figure 38).

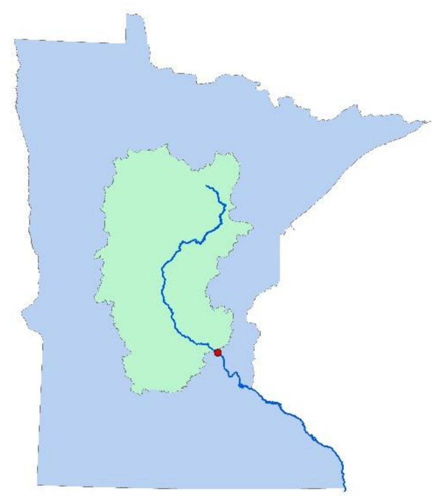

Figure 37. Watershed draining to Mississippi River at Anoka monitoring site.

Table 20. Statistical Trends for NOx Concentration in the Mississippi River at Anoka.

Trend Period	Concentration (mg/L)	Change in Concentration (%)	Change Rate (mg/L/yr)	*p*	Trend
1976 – 1983	0.28 – 0.57	103%	0.036	< 0.0001	⬆
1984 – 2018	0.57 – 0.90	59%	0.0095	< 0.0001	⬆
Overall Trends					
20 years (1999 – 2018)	0.67 – 0.90	34%	0.011	–	⬆
40 years (1979 – 2018)	0.34 – 0.90	162%	0.014	–	⬆

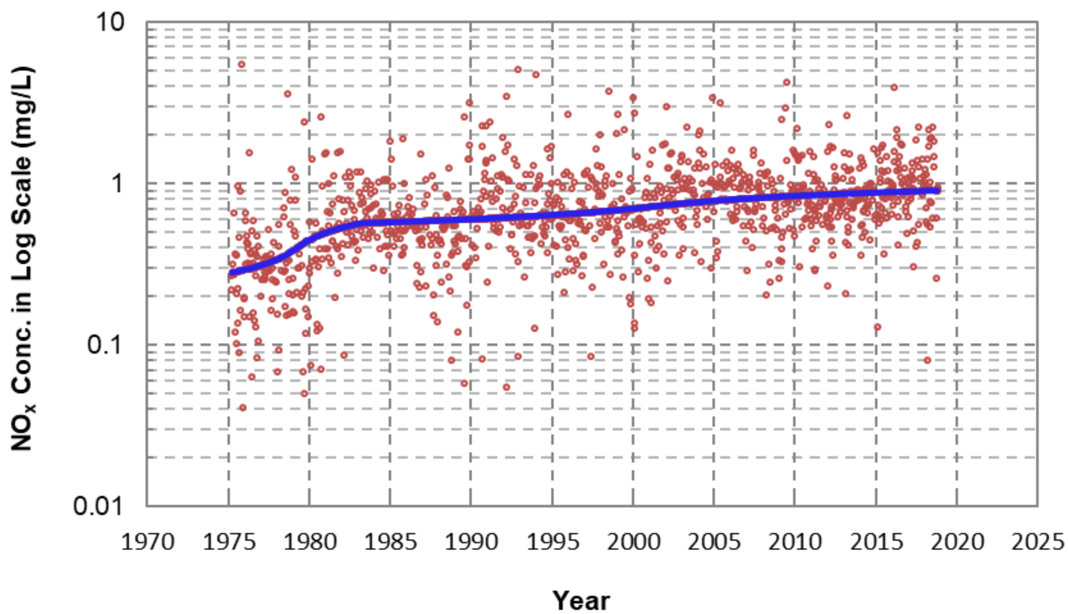

Figure 38. Statistical Trends for flow-adjusted nitrate (NOx) Concentration in the Mississippi River at Anoka

A separate analysis of non flow-adjusted load trends showed an increase at Anoka, but was not statistically significant for either the 20- or 40-year periods (p= 0.14 and 0.16; Table 21). The river flow trends at this site were not statistically significant. The year-to-year flow variability reduce the likelihood of showing statistically significant load trends.

Table 21. Statistical Trends for Non Flow-Adjusted Nitrate Loads in the Mississippi River at Anoka. "No trend" means no trend detected with the trend analysis methods.

Trend Period	Change Rate (kg/yr)	Change Rate (%)	*p*	Trend
20 years (1999 – 2018)	–	–	0.14	No trend
40 years (1979 – 2018)	–	–	0.16	No trend

3.2.4 Minnesota River, Jordan – Nitrate

Flow-adjusted nitrate concentrations in the Minnesota River at Jordan (Figure 39) had three significant trend periods (p = 0.01) between 1979 and 2018 (Table 22 and Figure 40). The trend identified for the 1979 to 2004 period was not statistically significant. However, the high nitrate concentrations at Jordan started to decrease by 32% from 2005 to 2011, followed by an increase of 40% from 2012 to 2018.

Even though significant trends were found in the periods noted above, when assessing the pre-defined 20-year and 40-year periods, no overall changes were provided for the past 20 and 40 years because one of the sub-trends during these time frames (1979-2004) is not statistically significant.

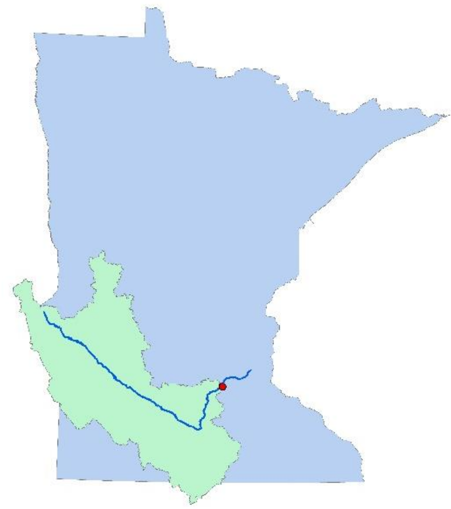

Figure 39. Watershed draining to Minnesota River at Jordan monitoring site.

Table 22. Statistical Trends for Nitrate Concentration in the Minnesota River at Jordan.

Trend Period	Concentration (mg/L)	Change in Concentration (%)	Change Rate (mg/L/yr)	*p*	Trend
1979 – 2004	–	–	–	0.19	No trend
2005 – 2011	2.92 – 1.98	-32%	-0.14	0.0004	
2012 – 2018	1.98 – 2.77	40%	0.11	0.05	
Overall Trends					
20 years (1999 – 2018)	–	–	–	–	NA
40 years (1979 – 2018)	–	–	–	–	NA

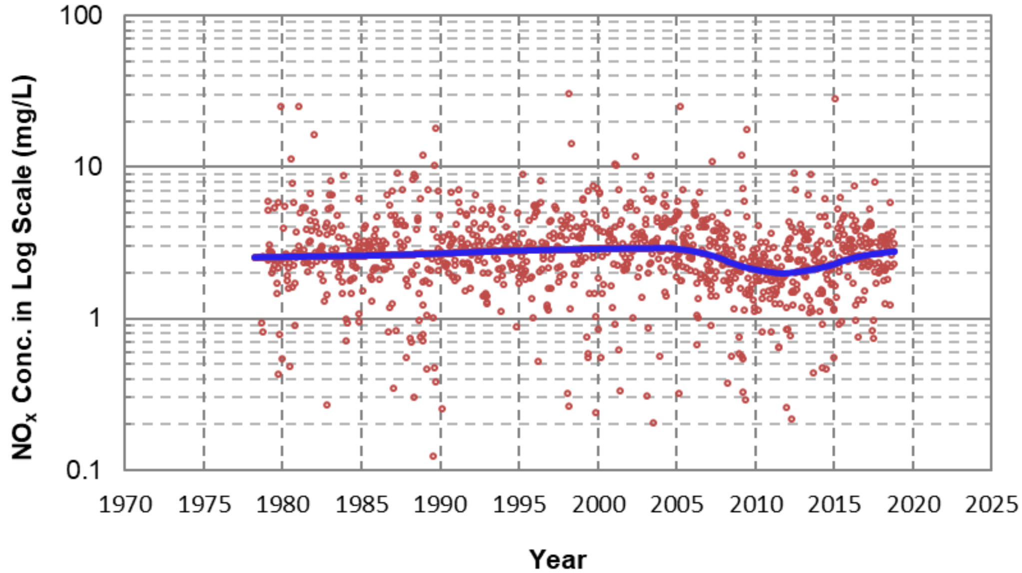

Figure 40. Statistical Trends for Flow-Adjusted Nitrate (NOx) Concentration in the Minnesota River at Jordan.

The highest nitrate load on record through 2018 at Jordan occurred in 2016. Nitrate load increases were relatively close to being significant, but did not meet the 90% confidence criteria for the past 20 and 40 years in the Minnesota River at Jordan (Table 23). Even though flows increased by 68% during the past 20 years, the annual variability in loads was quite high and thus the load trends were not significant.

The non flow-adjusted nitrate loads viewed as a five-year rolling average (Figure 41) shows what appears to be a nitrate load increase between 1998 and 2016.

Table 23. Statistical Trends for Non Flow-adjusted Nitrate (NOx) Loads in the Minnesota River at Jordan. "No trend" means no trend detected with the trend analysis methods.

Trend Period	Change Rate (kg/yr)	Change Rate (%)	*p*	Trend
20 years (1999 – 2018)	–	–	0.16	No trend
40 years (1979 – 2018)	–	–	0.13	No trend

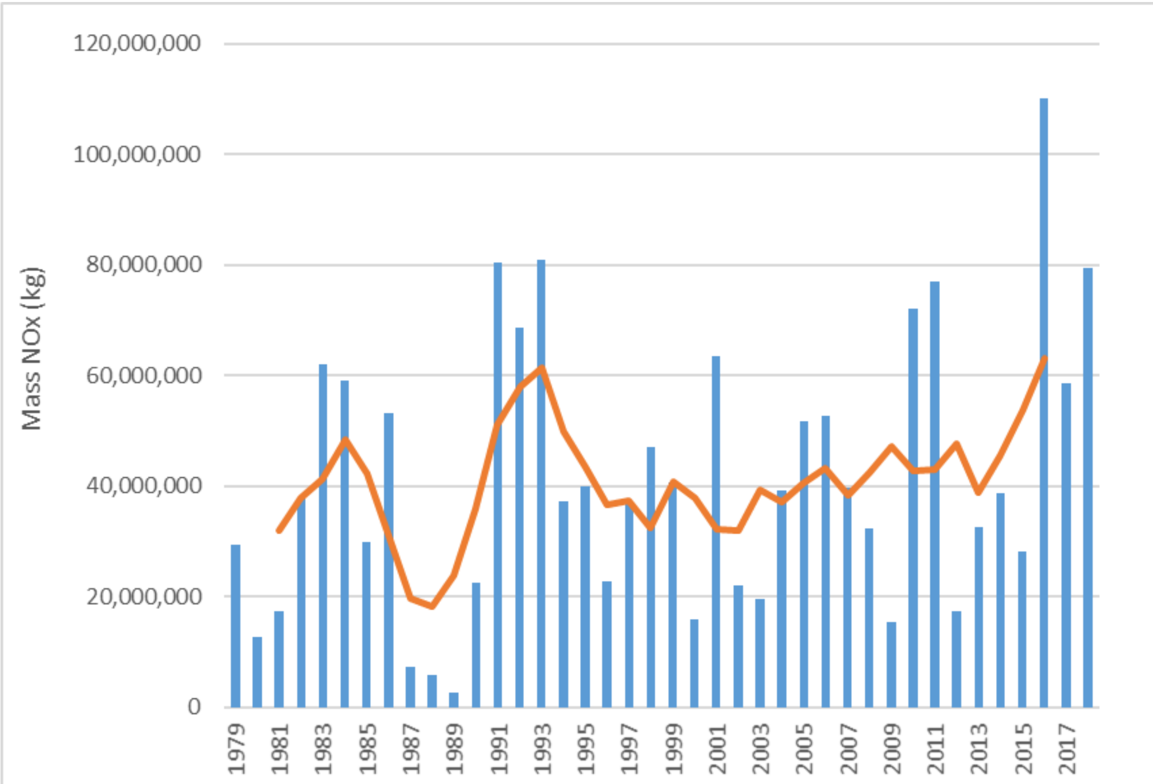

Figure 41. Annual Non Flow-Adjusted Nitrate (NOx) Loads in the Minnesota River at Jordan (1979-2018).

3.2.5 Minnesota River, Fort Snelling – Nitrate

Based on the Met Council QWTREND analysis, nitrate concentration changes in the Minnesota River at Fort Snelling are best represented by an increase from 1976 to 2004 followed by a decrease from 2005 to 2018 (Table 24 and Figure 43).

Overall, nitrate concentrations decreased by 15% from 2005 to 2018 but increased by 21% from 1979 to 2018. While the specific periods of change are different between the Minnesota River Jordan site and the nearby Minnesota River Fort Snelling site, data from both sites indicate that there has not been a clear and consistent concentration trend direction over the past 20 and 40 years at these downstream reaches of the Minnesota River.

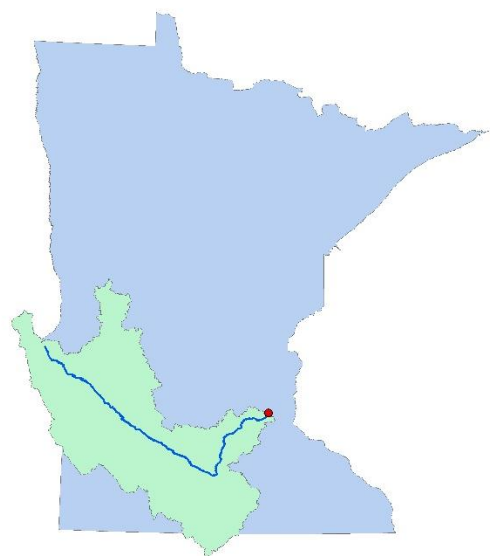

Figure 42. Minnesota River at Fort Snelling drainage area.

Table 24. Statistical Trends for Nitrate Concentration in the Minnesota River at Fort Snelling.

Trend Period	Concentration (mg/L)	Change in Concentration (%)	Change Rate (mg/L/yr)	*p*	Trend
1976 – 2004	2.15– 3.32	54%	0.040	< 0.0001	⬆
2005 – 2018	3.32 – 2.66	-20%	-0.047	0.05	⬇
Overall Trends					
20 years (1999 – 2018)	3.1 – 2.7	-15%	-0.024	–	⬇
40 years (1979 – 2018)	2.2 – 2.7	21%	0.011	–	⬆

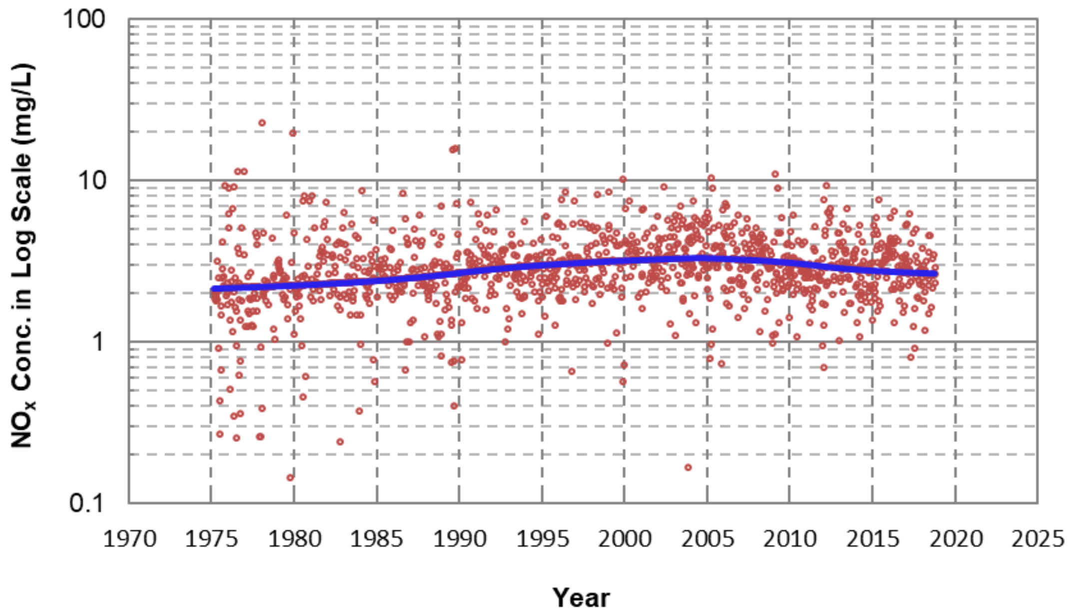

Figure 43. Statistical Trends for Flow-Adjusted Nitrate (NOx) Concentration in the Minnesota River at Fort Snelling.

Met Council did not find a statistically significant non flow-adjusted nitrate load increase for the past 20 and 40 years at Fort Snelling. Similar to the Minnesota River Jordan site, the p-values slightly exceeded the 90% confidence threshold, especially for the 20-year period (Table 25).

Table 25. Statistical Trends for Non Flow-Adjusted Nitrate Loads in the Minnesota River at Fort Snelling. "No trend" means no trend detected with the trend analysis methods.

Trend Period	Change Rate (kg/yr)	Change Rate (%)	*p*	Trend
20 years (1999 – 2018)	–	–	0.11	No trend
40 years (1979 – 2018)	–	–	0.22	No trend

3.2.6 St. Croix River, Stillwater – Nitrate

Nitrate flow-adjusted concentrations in the St. Croix River at Stillwater (Figure 44) gradually increased between 1976 and 2003, with a total change in concentration of 49%. No statistically significant trends were reported for the 20-and 40-year periods because one of the subtrends was not statistically significant (Table 26 and Figure 45).

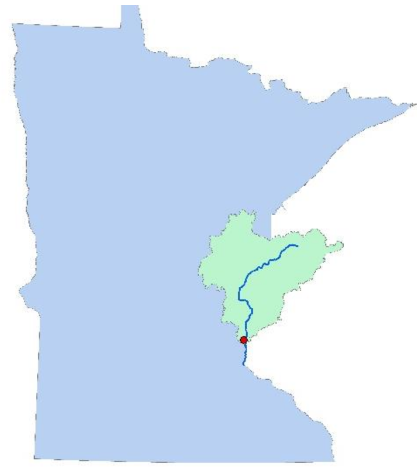

Figure 44. Watershed draining to St. Croix River at Stillwater monitoring site.

The St. Croix River at Stillwater is one location where total nitrogen concentration trends differed from nitrate. Total nitrogen decreased slightly over 20 years (-3%) and 40 years (-6%). Both nitrate and total nitrogen are relatively low at this site, and the organic forms of nitrogen constitute a higher fraction of the total nitrogen as compared to most other rivers evaluated, helping explain why nitrate and total nitrogen trends differ.

Table 26. Statistical Trends for Flow-Adjusted Nitrate (NOx) Concentration in the St. Croix River at Stillwater.

Trend Period	Concentration (mg/L)	Change in Concentration (%)	Change Rate (mg/L/yr)	*p*	Trend
1976 – 2003	0.22 – 0.32	49%	0.0038	< 0.0001	⬆
2004 – 2018	–	–	–	0.24	No trend
Overall Trends					
20 years (1999 – 2018)	–	–	–	–	–
40 years (1979 – 2018)	–	–	–	–	–

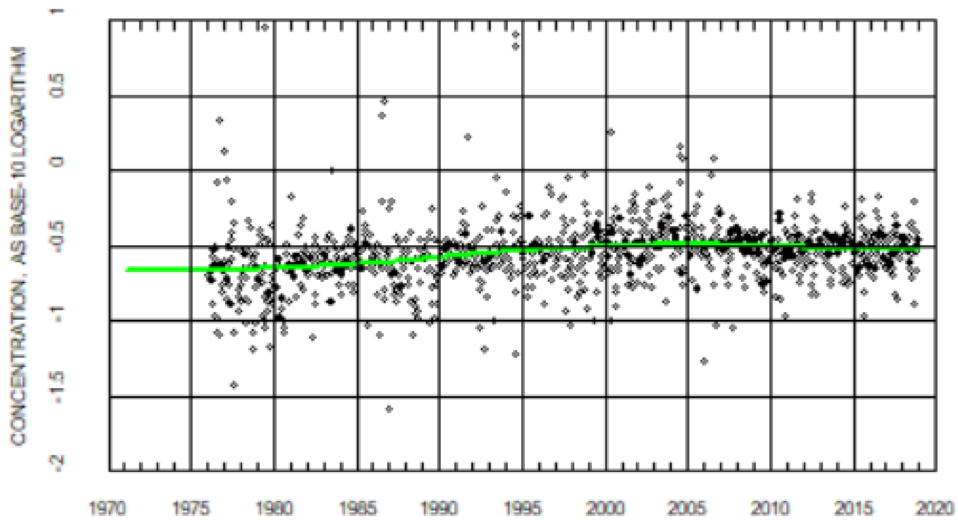

Figure 45. Statistical Trends for NOx Concentration in the St. Croix River at Stillwater.

No statistically significant trends were observed for 20- and 40-year non flow-adjusted nitrate loads in the St. Croix Stillwater (Table 27). This is not surprising, given the lack of either a flow trend or a concentration trend in the St. Croix Stillwater site during the past 20 and 40 years.

Table 27. Statistical Trends for Non Flow-Adjusted Nitrate (NOx) Loads in the St. Croix River at Stillwater.

Trend Period	Change Rate (kg/yr)	Change Rate (%)	*p*	Trend
20 years (1999 – 2018)	–	–	0.63	No trend
40 years (1979 – 2018)	–	–	0.97	No trend

3.2.7 Crow River, Rockford – Nitrate

Based on the Met Council QWTREND analysis, flow-adjusted nitrate concentration changes in the Crow River at Rockford can be best represented by a three-period trend model (p = 0.0003) over the assessment period from 1999 to 2018. Nitrate concentrations increased between 1999 and 2005, decreased from 2006 to 2012, then increased again from 2013 to 2018 (Table 28).

Overall, nitrate concentrations increased by 55% from 1999 to 2018, indicating a decline in water quality as it relates to NO_x during the recent 20 years.

Table 28. Statistical Trends for Nitrate Concentration in Crow River at Rockford.

Trend Period	Concentration (mg/L)	Change in Concentration (%)	Change Rate (mg/L/yr)	*p*	Trend
1999 – 2005	1.02 – 1.81	78%	0.11	0.002	↑
2006 – 2012	1.81 – 1.00	-45%	-0.12	< 0.0001	↓
2013 – 2018	1.00 – 1.58	58%	0.096	0.014	↑
Overall Trends					
20 years (1999 – 2018)	1.02 – 1.58	55%	0.028	–	↑

3.3 Red River of the North

Red River of the North flow-adjusted nitrate concentrations increased by 21-50% since 2000 at the Harwood, Halstad, and Grand Forks sites. However, concentrations decreased at the Fargo site, upstream from these other locations, and were not significant at the most downstream location at Emerson (Table 29 and Figure 31). The Emerson site is located just downstream from where the Pembina River flows in from Manitoba and North Dakota (Figure 46). The Pembina River has had decreasing nitrate trends and may be one reason that the Red River trend changes from an increase at Grand Forks to a non-significant trend further downstream near the Canadian border at Emerson.

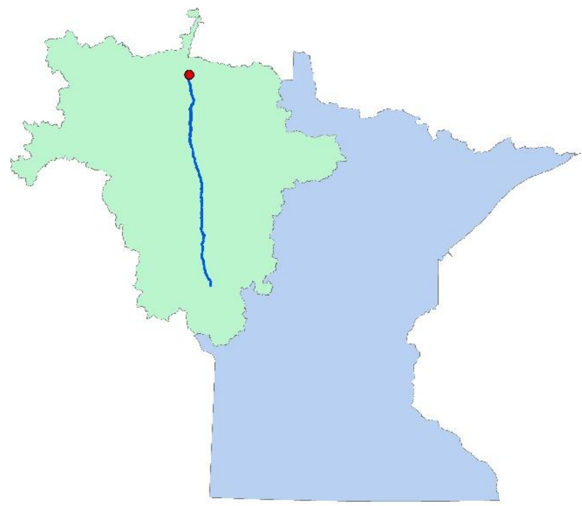

Figure 46. Watershed draining to Red River at Emerson monitoring site.

The Minnesota tributaries of the Red River evaluated by the USGS show four rivers with increasing nitrate concentration trends (48-181%), one river with a decrease (39%), and one non-significant trend (p>0.1). The predominantly increasing trends in these tributaries is generally consistent with the predominantly increasing trends in the Red River.

The USGS also assessed flow-adjusted total nitrogen concentration trends. The total nitrogen trends generally parallel the direction of nitrate trends. One difference was found at Emerson where total nitrogen increased by 8% (p=0.06), compared to non-significant nitrate trends.

More information about the nutrient trends in the Red River Basin can be found in Nustad and Vecchia (2020) found at www.[USGS report link – Pending Final web site placement]

Table 29. Overview of Red River Basin nitrate trend results at long-term Red River and Minnesota tributary monitoring sites. An increasing trend is denoted by "+" and a decreasing trend is "-." Non-significant trends at a p<0.1 is denoted by "NS."

Red River and HUC-8 Tributaries	Parameter and Method	Mid-range (2000-15)
Red River Emerson	Concentration and load (R-QWTREND flow-adjusted)	**NS**
Red River Grand Forks	Concentration and load (R-QWTREND flow-adjusted)	**+21%**
Red River Halstad	Concentration and load (R-QWTREND flow-adjusted)	**+28%**
Red River Harwood	Concentration and load (R-QWTREND flow-adjusted)	**+50%**
Red River Fargo	Concentration and load (R-QWTREND flow-adjusted)	**-39%**
Tributaries (MN)		
Wild Rice River Hendrum	Concentration and load (R-QWTREND flow-adjusted)	**+181%**
Sand Hill River Climax	Concentration and load (R-QWTREND flow-adjusted)	**-39%**
Ottertail River Breckenridge	Concentration and load (R-QWTREND flow-adjusted)	**+159%**
Clearwater River Red Lake Falls	Concentration and load (R-QWTREND flow-adjusted)	**NS**
Boix de Sioux River Doran	Concentration and load (R-QWTREND flow-adjusted)	**+134%**
Buffalo River Georgetown	Concentration and load (R-QWTREND flow-adjusted)	**+48%**

3.4 Lake Superior Basin

The St. Louis River at Scanlon site represents trends in the Lake Superior Basin for this analysis (Figure 47). Using the QWTREND model, the MPCA found flow-adjusted nitrate concentrations increased by 54% over the 43-year record from 1976 to 2018 (Table 30). This 54% increase during the long-term record represents a very small magnitude of change (0.042 mg/l). Analysis of the past 10 years (2009-2018) shows nitrate concentrations decreased by 11%.

The flow-adjusted nitrate load trends evaluated using EGRETci WRTDS show non-significant (p>0.1) trends for recent, medium-range and long-term periods (2008-2018, 1998-2018, and 1977-2018). The non flow-adjusted load five-year moving average shows an increasing trend since about 2004, which is likely driven by increasing precipitation and flows in the northeastern part of the state (Figure 48).

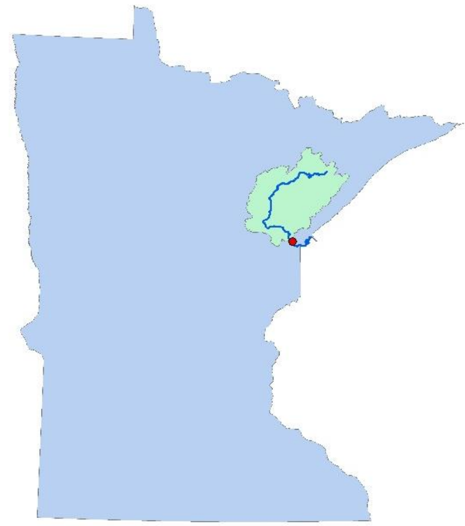

Figure 47. St. Louis River drainage area.

Table 30. Overview of St. Louis River nitrate trend results at long-term monitoring sites.
An increasing trend is denoted by "+" and a decreasing trend is "-." Non-significant trends at a p<0.1 is denoted by "NS."

Tributary	Parameter and Method (nitrate)	Recent (2009-18)	Mid-range (1997-2018)	Long-Term (1976-2018)
St. Louis River	Concentration (QWTREND flow-adjusted)	**-11%**	**NS**	**+54%**
	Load flow-adjusted (EGRETci WRTDS)	**NS**	**NS**	**NS**

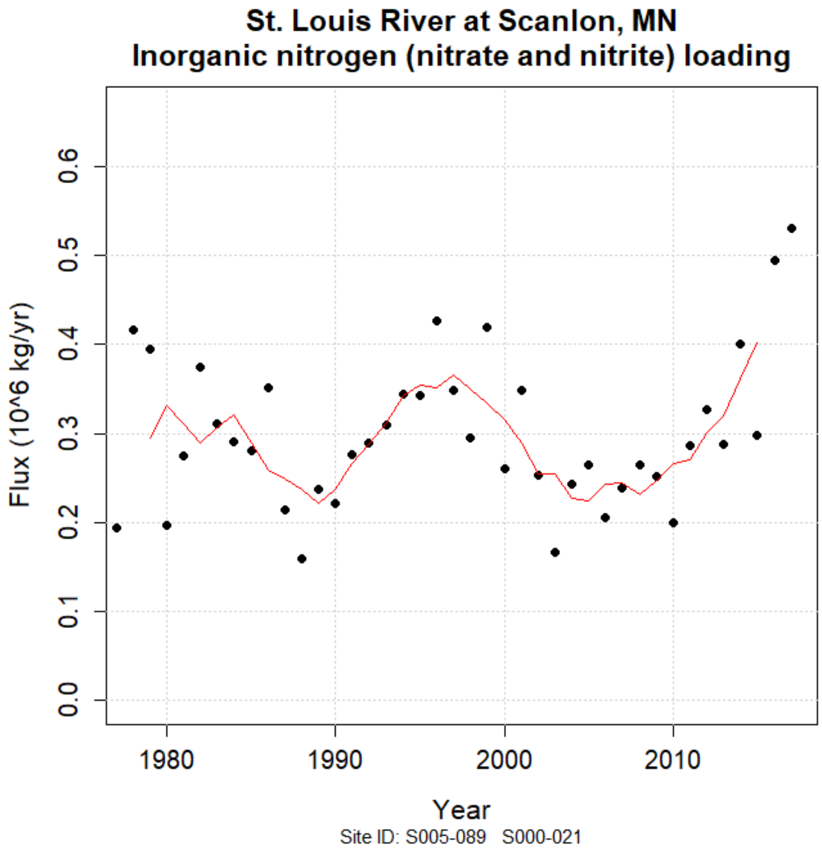

Figure 48. Non flow-adjusted nitrate load at the St. Louis River Scanlon site from 1978 through 2018, with the five-year moving average (red line).

4. Findings Overview

Because relatively long periods of time are needed to evaluate trends, definitive statements about the magnitude of river nutrient changes during 2014 to 2018 (since finalizing the 2014 NRS) are limited. Ten and 20-year trends, however, were determined, reflecting changes occurring since the NRS baselines in the late 1990's and the passing of the Clean Water Land and Legacy Amendment in 2008.

Based on intensive river monitoring efforts across the state, phosphorus concentrations have generally decreased and nitrate-nitrogen and total nitrogen concentrations have generally increased over the past 10 and 20 years. However, regional differences exist and high year-to-year variability makes it difficult to confidently show trend directions at many of the monitoring locations.

The findings indicate that our efforts to reduce river phosphorus concentrations have been working; whereas our efforts to reduce nitrate have not been as effective thus far.

Both flow-adjusted and non-flow adjusted evaluation methods were used to create a more complete picture of how nutrients are changing in Minnesota rivers. Flow-adjusted methods are intended to separate the water quality effects caused by human changes on the land and cities from those caused by variability in precipitation and river flow.

When river flow variability is not accounted for (non flow-adjusted) phosphorus concentration decreases are being at least partially offset by increased flow, such that phosphorus load reductions are not statistically significant at the primary Mississippi River monitoring sites. Nitrate loads show increasing trends at some sites, since both concentration and flow are increasing.

Flow-adjusted concentration trends

When using the flow-adjusted techniques for the past decade (2008 to 2017), 24 of 50 (48%) river sites showed *decreasing* phosphorus trends, with all other sites showing no significant trend ($p>0.1$). This indicates that efforts to reduce phosphorus in recent years have been making a difference. For nitrate-nitrogen, the dominant form of nitrogen in polluted rivers, 14 of 38 sites (37%) had *increases* with the rest having no trend. This suggests that efforts to reduce nitrate thus far are either insufficient and/or not enough time has elapsed for the full effects of our efforts to be seen in rivers.

Similar patterns were found when looking at flow-adjusted concentration trends over the past two decades. The Mississippi River monitoring sites near the Twin Cities had phosphorus concentration *decreases* of 21 to 26%, whereas nitrate had 20-year *increases* in the range of 25 to 34%. Further downstream near the Iowa border, the Mississippi River phosphorus concentrations have dropped by 50%, and nitrate was too variable to provide a high confidence in trends.

The Minnesota River, a high nutrient-loading tributary to the Mississippi River, has had flow-adjusted phosphorus concentration decreases of about 17% during the past 20 years. However, at Jordan Minnesota, this decrease has been shifting to increasing concentrations since 2009. The Minnesota River has had mixed 20-year nitrate trends, but has been showing an increase since 2012. Downstream from Jordan, the Minnesota River at Fort Snelling has had decreasing nitrate concentrations since 2005. Additional years of monitoring at the Minnesota River is needed to better understand recent flow-adjusted nitrate concentration trends.

In the Red River of the North, flow-adjusted phosphorus concentrations over the past two decades have decreased in the upstream reaches but increased at the state border, just downstream of the Pembina River. With a few exceptions, nitrate concentrations increased across the Red River Basin. At the state border with Canada, the Red River flow-adjusted nitrate concentration trend was not considered statistically significant.

In the St. Louis River, flow-adjusted phosphorus concentrations decreased significantly during the past 10 and 43-year time periods. A data gap in the middle of the record prevented analysis of 20-year trends. Nitrate concentrations have increased since the mid-1970’s, but have decreased within the past decade.

Load trends

Whereas reducing nutrient *concentrations* is important for local water quality and drinking water, reducing nutrient *loads* is important for downstream waters such as the Gulf of Mexico and Lake Winnipeg. Nutrient loads are affected by both nutrient concentrations and river flow.

The flow-adjusted loads show similar trends as the flow-adjusted concentrations. For example, when using flow-adjusted methods, data from the Mississippi River at Red Wing and Winona show phosphorus load decreases of 27 to 54%, respectively, varying with the assessed site and timeframe examined.

However, the non flow-adjusted loads show different results because precipitation and associated river flow has markedly increased during the past two decades in Southern and Eastern Minnesota. Decreasing phosphorus *concentrations* in these areas are not translating into statistically significant decreasing phosphorus *loads*. Phosphorus loads in the Mississippi River Basin have non-significant trends.

In the St. Louis River at Scanlon, flow-adjusted phosphorus loads decreased by 44% over 43 years. Decreasing phosphorus loads during the past 10 and 20-years were not statistically significant. The five-year rolling average of actual loads (non flow-adjusted) appear to be increasing since 2003, along with increasing precipitation during this same timeframe.

In the Red River, load results were only conducted using flow-adjusted approaches and the results parallel the concentration trend findings.

For nitrate, the combination of increasing concentrations and increasing flow has led to load increases of 62% on the Mississippi River near Red Wing. The non flow-adjusted nitrate loads at Red Wing increased by 62% with a combination of increasing river flow and increasing concentrations. Further downstream at Winona, there is too much variability for the flow-adjusted 20-year concentration or load trends to be statistically significant.

In the St. Louis River, the flow-adjusted nitrate load trends were not significant for short, medium and long-term loads. The five-year rolling average actual loads (non flow-adjusted loads) appear to be increasing since 2004.

References cited in Appendix C

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Attachment A – MPCA Trend Analysis Methods

Methods written by James Jahnz (MPCA)

Trend Methods: Bootstrapped Seasonal Kendall Test

Simple directional trends were determined by applying a block bootstrap procedure to water quality samples collected at MPCA Watershed Pollutant Load Monitoring (WPLMN) sites. Subsamples were weighted to better represent the underlying flow regime, a flow correction was applied to each subsample, and the seasonal Kendall test was applied. A confidence interval for Kendall's Tau was created after 1,000 bootstrap replicates were created. This confidence interval was then used to determine significance of Kendall's Tau to a 90% degree of confidence. Nitrate+nitrite nitrogen and total phosphorus were analyzed in this way and reported for 10- and 20-year time periods. Below is a more comprehensive description of the above methodology.

All WPLMN monitoring locations designated as 'basin' or 'major watershed' sites were considered for analysis. The water quality record for each of these sites was then examined to meet the minimum data requirements for this study. Minimum data requirements are as follows.

1. Sample location must be currently active and monitored year-round under the WPLMN program.
2. Greater than 50% of water quality samples must show concentrations above the minimumreporting limit for each dataset analyzed.
3. Water quality record must not display any major gaps in water quality sampling or daily flow measurements.
4. The length of time from the first to last sample must be approximately 8 or more years for the 10-year analysis, 15 or more years for the 20-year analysis, and 35 or more years for the 40-year analysis.

Results were not reported for any site where the water quality record did not satisfy requirements for analysis. In cases where results met data requirements for at least one parameter, but not for all parameters at a given site, results were reported for the parameters with sufficient data only. Datasets in which long gaps occur were evaluated on a case-by-case basis, and sites determined to have greater than approximately two years of sparse or missing data were removed. In cases where water quality sampling had previously occurred at the same location, but under a different site ID, or a nearby location in which no major confluence occurs between sites, datasets were combined in order to create a continuous water quality record of sufficient length to satisfy minimum data requirements for 20-year and 40-year trend analysis. For the purpose of consistency, the same datasets were used for 10-year trend analysis.

The highest reporting limit (RL) among water quality samples censored due to low concentration was identified for each individual dataset prior to analysis. All water quality samples with reported concentrations below that value were then censored as though they were also reported below the highest reporting limit, and the reporting limit was treated as though it were the maximum reporting limit found in the dataset. This was done because multiple reporting limits can create a false signal that may result in detection of a trend where a trend does not exist, or failure to detect a trend where a trend exists.

Periods of 10, 20, and 40 years were analyzed and results are reported. The 40-year period begins January 1, 1978, the 20-year period begins on January 1, 1998 and the 10-year period begins on January 1, 2008. All time periods end on January 1, 2018.

Trend analysis was performed according to the following procedure:

1) Subsample the population of water quality samples by season.
2) Correct for flow.
3) Perform seasonal Kendall test and record Kendall's tau.
4) Repeat steps 1-3 1,000 times and build confidence interval of Kendall's tau.
5) Use confidence interval of Kendall's tau to determine significance.

Water quality records analyzed in this study were subsampled prior to analysis such that one sample per season was chosen for analysis and the rest were discarded. Seasons were designated as follows; Season 1 (January-March), Season 2 (April-June), Season 3 (July-September), and Season 4 (October-December).

WPLMN sampling collection protocol requires water samplers to collect three or more samples for each flow event (rising limb, peak flow, and falling limb samples). This results in a dataset that is optimized for load calculation, but not for trend analysis. Specifically, samples are not randomly collected and water quality sample datasets are at risk of over-representing high flow events, especially on the peak and rising limb of high flow events.

Subsampling was performed in an effort to transform subsampled datasets such that they more closely approximate a random sampling regime. For each season-year combination, a random day was chosen. The two water quality samples immediately preceding and immediately following the randomly chosen day were identified. Of those two water quality samples, the sample collected on the day with a flow value closest to the flow value observed on the randomly chosen day was selected for analysis, and the rest of the samples taken during that season were not included in the subsampled dataset. Using flow as a selecting factor instead of time alone takes advantage of the sampling regime described above along with general principles of concentration-flow relationships to select the water quality sample most similar to the randomly selected day with respect to timing and hydrology. This subsampling procedure effectively prevents event samples from being over-represented in the subsampled datasets that are analyzed for trend. This subsampling procedure also results in a subsampled dataset with homogenous sample frequency such that the final analysis weighs periods of high observation frequency and periods of low observation frequency equally. Samples reported as below RL or censored previously for being below the maximum RL were then assigned a random value between zero and the maximum RL.

Flow correction was performed by calculating the residuals of a moving average (LOWESS) line with a smoothing value of 2/3 (f=2/3) for the concentration flow relationship. This method was selected as a non-parametric alternative to calculating residuals of a linear regression, a common method used to correct for a third variable. Base R was used to calculate the LOWESS line.

The seasonal Kendall test was performed on the flow corrected dataset using the 'rkt' package in R and results were recorded. Seasons were defined as above. No covariable was defined; a flow correction was applied prior to performing the Kendall test.

The above steps were then repeated 1,000 times, and a confidence interval for Kendall's tau was built for each site. Sites for which a 90% confidence interval for Kendall's tau does not overlap with zero were determined to show a significant trend. The direction of significant trends were determined by the sign of the Kendall's tau in the confidence interval, a 90% confidence interval comprised of only positive values displays a positive trend, and a 90% confidence interval displaying only negative values displays a negative trend.

Trend Methods – WRTDS, EGRET, and EGRETci

MPCA pollutant load trends for major rivers and certain major watershed outlet sites were calculated using the EGRET and EGRETci packages available for R. Both packages were created by the USGS and are capable of producing an array of products, including annual loads and yearly average concentration estimates.

EGRET and EGRETci use a model called Weighted Regression on Time, Discharge, and Season (WRTDS). WRTDS uses pollutant concentration data and a complete daily flow record to create daily concentration and flux estimates, as well as yearly average concentration and load estimates and long-term trend estimates. It does this by applying a moving window approach such that water quality samples collected in close temporal proximity to a given day have a high degree of influence on the resulting pollutant concentration estimate, and water quality samples collected at a greater time step are weighted proportionally less until they are no longer within the moving window. Samples that fall outside of the moving window are given a weight of zero and do not influence the daily estimate in question. The same basic approach is applied to flow (water quality samples collected on days where flow was similar are heavily weighted and those collected on days where flows fall outside the moving window do not influence the daily estimate), and season (water quality samples collected on days around the same time of year are heavily weighted and those collected during a completely different time of year fall outside the moving window do not influence the daily estimate). WRTDS is designed to perform well with different water sampling regimes and changing water sampling regimes. See Hirsch et al (2010) for a comprehensive description of the WRTDS model.

EGRETci is an add-on package for EGRET that builds on the base package by applying a block bootstrap type approach in which the population of sample observations are resampled and the WRTDS model is applied many times until a confidence interval is built. This technique allows users to understand the range of uncertainty associated with yearly concentration and load estimates and calculate *p* values from which significance is determined. See Hirsch et al (2015) for a comprehensive description of the bootstrap technique used in EGRETci.

EGRET and EGRETci were originally made to work with at least 10 years of water sample concentration and daily flow data. The original workflow uses methodology designed to eliminate the influence of year-to-year variations in flow. Recent updates increase the minimum data requirements to 15 years and allow for the estimation of the influence of changing flow on changing pollutant concentrations and loads. The original workflow was used for this study.

Large river and outlet sites included in this study that were monitored by the MPCA were analyzed for nitrate+nitrite-nitrogen and total phosphorus using the original workflow for WRTDS and EGRETci. Periods of 10, 20, and 40 years were modeled individually using EGRETci and results are reported. The 40-year period begins January 1, 1978, the 20-year period begins on January 1, 1998 and the 10- year period begins on January 1, 2008. All time periods end on January 1, 2018. In cases where the period of record began during a dataset, the period of analysis was shortened such that the start date began immediately following the gap in the water quality sample record. Gaps in sample data consisting of two or more years of no samples or sparse samples were entered into EGRET and EGRETci prior to running WRTDS so that the model does not make estimates for periods that lack sufficient information to make realistic estimates. Confidence intervals were set to include 500 individual model runs from which confidence intervals were built, and confidence levels for trends were set at 90%.

References cited in Attachment A – MPCA Trend Analysis Methods

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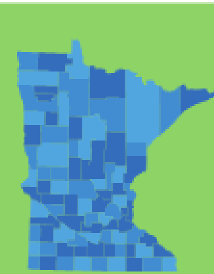
Nutrient Reduction Strategy

August 2020

Appendix D: Maximum Return to Nitrogen (MRTN) Values for Fertilizer

5-year Progress Report on Minnesota's Nutrient Reduction Strategy

MINNESOTA



Appendix D. Maximum Return to Nitrogen (MRTN) Values for Fertilizer

Written by Jeppe Kjaersgaard, Minnesota Department of Agriculture, in association with Minnesota's Nutrient Reduction Strategy 5-year Progress Report (2020)

Nitrogen (N) fertilizer rates for corn in Minnesota are established based on nitrogen fertilizer rate trials conducted by the University of Minnesota during the last 20 years. The rates are expressed in terms of Maximum Return to Nitrogen (MRTN) values. The MRTN is based on an index of the nitrogen price ($/lb) divided by the crop value ($/bu). While there are several factors influencing these values, which will vary over time and individual farm operations, the prices of grain and fertilizers are normally linked within the marketplace and for most situations, a 0.10 ratio is appropriate for corn production when manure is not used. In the guidelines there is a range of +/- $1 around the MRTN to allow flexibility relative to risk management. See University of Minnesota guidelines at https://extension.umn.edu/crop-specific-needs/fertilizing-corn-minnesota. When manure crediting is involved, a 0.05 ratio is commonly used. This allows a margin of uncertainty associated with the heterogeneous nature of nutrient release from certain manures. For more information about University of Minnesota Extension Service recommendations for manure, go to https://extension.umn.edu/manure-land-application/manure-application-rates.

MRTN values were first published by the University of Minnesota in 2006. MRTN values for irrigated corn was broken out separately by the 2015 growing season. Updated MRTN values for rain-fed (non-irrigated) corn were updated prior to the 2016 growing season and again prior to the 2019 growing season. Each update has incorporated the most recent results from ongoing nitrogen rate trials conducted by the University of Minnesota and include impacts of new hybrids, improved tools for nutrient management and climate conditions.

The MRTN values for rain-fed corn after corn and corn after soybean are shown in the tables below for 2006, 2016 and 2019. Also shown are acceptable rate ranges around the MRTN. For the 0.10 ratio the recommended rates have increased 25 lb N/ac for corn following corn and 20 lb N/ac for corn following soybean from 2006 to 2019.

A comparison between the MRTN for corn following corn for Minnesota and surrounding states are shown in the figure below. The MRTN rates for Minnesota are similar to those of Wisconsin and Michigan, but lower than those from Iowa, South Dakota and Illinois.

University of Minnesota guidelines for nitrogen fertilizer rates for non-irrigated corn following corn from 2006, 2016 and 2019.

MRTN is Maximum Return to Nitrogen.

N price/Crop value ratio	2006 MRTN	2016 MRTN	2019 MRTN	2006 Range	2016 Range	2019 Range
	lb N/acre					
0.05	155	180	195	130-180	160-200	175-215
0.10	140	155	165	120-165	145-170	152-180
0.15	130	150	150	110-150	140-155	140-160
0.20	120	140	145	100-140	130-150	135-155

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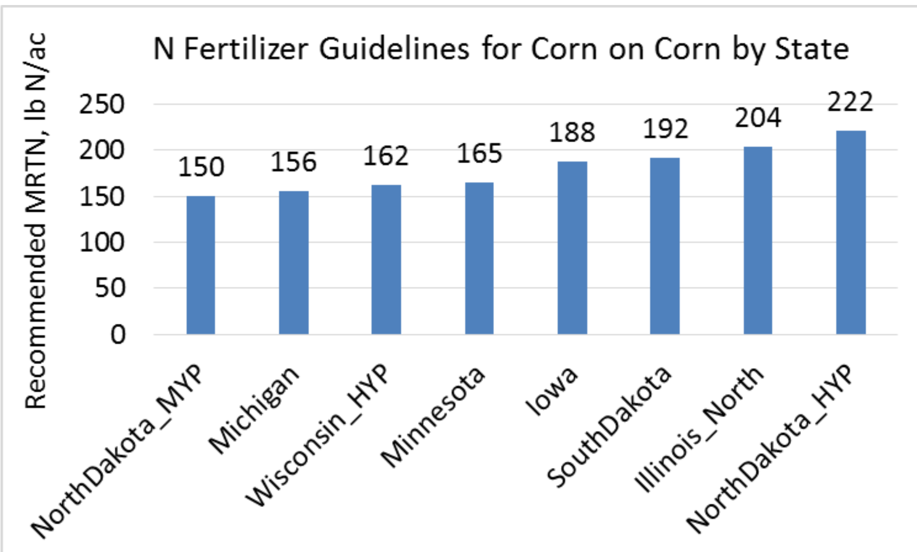
University of Minnesota guidelines for nitrogen fertilizer rates for non-irrigated corn following soybean from 2006, 2016 and 2019.

MRTN is Maximum Return to Nitrogen.

N price/Crop value ratio	2006 MRTN	2016 MRTN	2019 MRTN	2006 Range	2016 Range	2019 Range
	lb N/ac					
0.05	120	140	150	100-140	125-160	135-165
0.10	110	120	130	90-125	105-130	120-145
0.15	100	105	115	80-115	95-115	105-125
0.20	85	95	105	70-100	85-105	95-115



MRTN for the 0.10 nitrogen price/crop value ratio for corn following corn in Minnesota and surrounding states.

Data collected on March 25, 2019. MYP=Medium Yield Potential, HYP=High Yield Potential. Data for Minnesota is for High Yield Potential. South Dakota recommends using a yield goal approach, all other states uses the MRTN concept.